THE SOCIAL STRUCTURE OF

LARGE SCALE BLACKOUTS

CHANGING ENVIRONMENT, INSTITUTIONAL IMBALANCE,

AND UNRESPONSIVE ORGANIZATIONS

BY

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Abstract of the Dissertation

THE SOCIAL STRUCTURE OF LARGE SCALE BLACKOUTS:

Changing Environment, Institutional Imbalance, and Unresponsive Organizations

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This dissertation analyzes and explores the social structure of large scale blackouts from organizational and institutional perspectives and in consideration of power relations. Between 1965 and 2003, large scale blackouts or *cascading outages* have happened continually in the West, Midwestern, and Northeastern regions in the United States. Because technology is not separate from society, it is helpful to examine large scale blackouts as a case of the collapse of socio-technical systems. From this perspective, the dissertation first tests hypotheses regarding the characteristics of vulnerable power systems. Then it explores four representative, large scale blackouts: the 1965 Northeast blackout, the 1977 New York City blackout, the 1996 Western blackout, and the 2003 Northeast blackout. In particular, it examines the creation of institutions for electricity reliability, the characteristics of the institutions for electricity reliability in each historical period, and the interactions between electric utilities and those institutions.

The hypothesis test identifies as vulnerable those power systems having large size utility companies, weak institutional conditions (no strict standards, lack of complex human management, and weak regulatory relationships), high summer peaks, greater

electric power losses than others, and (or) less investment in facilities and technologies. These characteristics are outcomes of the historical development and organization of power systems that created tightly interconnected power systems with individualized systems control. Large scale blackouts usually happen in the regions where vulnerable control areas are located.

The four case studies show that cascading outages happen continually due to the repeated failure to create “a culture of reliability” among organizations by means of a strong institution. Such an institution would centralize basic premises and assumptions corresponding to the interconnected grid systems and decentralize system operators’ decisions at the local level. Power relations obstruct the development of strong institutions for creating a culture of reliability that is necessary in inter-organizational relationships, resulting in an imbalance between efficiency and reliability. Powerful groups, usually private utilities whose interests are different from those of legislators and regulators, impede the centralization of values and goals in the inter-organizational relationships, and determine the degree of centralization.

Acknowledgments

It is a long way to come here with this dissertation. In thinking about my first motivation to study urban planning and finally energy policy, I was interested in exploring intellectual traditions in the West as well as studying environmental problems. Therefore, many themes are within my sight. Starting from environmental planning, I studied urban and planning theories, environmental ethics & policy, and finally energy policy. After experiencing the 2003 Northeast Blackout, I was curious about social origins of low-probability, high-risk technological failure. Therefore I studied disaster, organization, and network theories. As an outcome of my study, I completed this dissertation, "The Social Structure of Large Scale Blackouts: Changing Environment, Institutional Imbalance, and Unresponsive Organizations."

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Lee Clarke who is one of the prominent organization and disaster theorists. I could not forget his critical advice on my proposal. He suggested how I would organize my thoughts and integrate each sentence, paragraph, and chapter into the final dissertation. Additionally, Frank Felder gave me frank and helpful critiques, and John Randolph at Virginia Tech introduced me to the world of energy. I thank them, too.

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Chapter 1. Introduction

On August 14, 2003, a major electrical power failure occurred in the Northeast United States and Ontario, Canada, with a loss of 61,800 megawatts (MW)[1] of load affecting 50 million people. The initial system disturbance started with the shutdown of a coal-fired power plant and tree contact on one transmission line in Northern Ohio as a local event. The loss of the transmission line made for heavy loads on other transmission lines, forcing them to trip one by one. Then the local event spread over the Northeast region. The affected areas covered 80,000 square miles including the states of Ohio, Michigan, Pennsylvania, New York, Vermont, Massachusetts, Connecticut, and New Jersey and the Canadian province of Ontario. The blackout started a few minutes after 4:00 p.m. Eastern Daylight Time, and continued for 2 days in some parts of the United States. City systems were paralyzed and some people experienced panic. Tens of thousands of people were stranded in New York subways and many of them were forced to walk home across the Brooklyn Bridge. Most traffic signals went out and streets were clogged with traffic. Some people could not get water, particularly in Cleveland, OH, and Detroit, MI, because the pumping stations were down. All transit systems except bus lines and airports were out of service. Restaurants and supermarkets were forced to throw

[1] Megawatts: one million watts; a watt is a unit of power per unit time produced as electricity; approximately the energy (on the surface of Earth) to lift up a one kilogram object by a height of 10 centimeters. Serway, R. A. and R. J. Beichner (2000). *Physics for Scientists and Engineers with Modern Physics. Fifth edition*. Orlando, FL, Hartcourt College Publishers.

away spoiled food, fresh meat and dairy products. People could only sporadically use cell phones, and depended on battery-operated radios to get news. In Canada there were rumors of a fire in New York City, terrorism, and even computer viruses. According to the Electric Power Research Institute (EPRI), the total estimated economic loss resulting from the 2003 blackout was 4.6 billion dollars. Because a power failure in a small area spread over the Northeast region through transmission lines, this kind of blackout has been called a "cascading outage."[2]

The 2003 blackout reminded people of the 1965 blackout which affected 30 million people and 80,000 square miles in the Northeastern states and two provinces of southeastern Canada. That blackout occurred on December 6, 1965, at 5:28 p.m. Eastern Time, during the evening rush hour. The initial system failure occurred on a back-up relay of the system at the Sir Adam Beck Hydropower plant on the Canadian site. The incident made four other back-up relays of the system disconnect and thus reversed the power flow from U.S.-Canada to Canada-U.S., affecting other systems in the Northeast region. City systems were also paralyzed by the electric failure at the time. Tens of thousands of New York City commuters walked home across the Brooklyn and Queensboro Bridges. About 800,000 passengers were stuck in the subway system. Thousands of people were trapped in elevators in the city's skyscrapers. Railroad lines at Grand Central Terminal and Pennsylvania Station were out of service. Kennedy International and LaGuardia Airports were shut down for 3 hours. Not one of nine-television channels in the NYC metropolitan area was able to broadcast. The initial

[2] According to the NERC definition, cascading outages refer to the uncontrolled successive loss of Bulk Electric System Facilities triggered by an incident (or condition) at any location resulting in the interruption of electric service that cannot be restrained from spreading beyond a predetermined area. NERC (2008). *Glossary of Terms Used in Reliability Standards*. NERC. Princeton, NJ, NERC.

blackout silenced radio stations, but some of them were able to come back on their own auxiliary power after 15 minutes. People could only get access to news from transistor radios.

Highly unlikely but catastrophic technological failures have taken place repeatedly and become recognizable technological incidents; the Mid-Atlantic power failure of June 5, 1967 affected 11 million people; the New York City blackout in 1977, 9 million people; and the Western power failure in August, 1996, 7.5 million people. In recent years large scale blackouts have occurred globally. During the summer of 2003, unusually wide spread blackouts happened in such places as Chile, Italy, Sweden, and Greece as well as North America. In November 2006, an initial power failure in Germany spread over other countries, affecting more than 1.5 million households, particularly in France.

People experience helplessness without electricity in city systems. As described above, people recognize their dependence on electricity which was once a luxury good a hundred years ago. After large scale blackouts,[3] people realize how deeply electricity penetrates into everyday life, and begin to appreciate that the electricity they use comes from a distant area through transmission lines. As they experience these events, people want to understand why they happen. Why does a large scale blackout such as the one that happened in 1965 in the Northeast region occur again 38 years later in the same region?

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[3] The Department of Energy defines a large scale blackout as an interruption of at least 100 megawatts load, a power outage affecting 50,000 customers, or mechanical failure of 200 or 300 megawatts of load interruption. (Cited from Feinstein, J. (2006). Managing Reliability in Electric Power Companies. *Seeds of Disaster, Roots of Response: How Private Action Can Reduce Public Vulnerability*. P. E. Auerswald, L. M. Branscomb, T. M. LaPorte and E. O. Michel-Kerjan. New York, Cambridge University Press. Basically I use this definition for the event history analysis and case studies in this dissertation. But for the case study, I define a large scale blackout as the one developed into a cascading stage that spreads over significantly large areas through transmission lines, shutting down a variety of power systems and leading to inter-organizational failures. I also perceive a blackout as a large scale one, if it happens in a metropolitan area, such as, New York, Chicago, Dallas, or Los Angeles.

1.1. Questions

This dissertation pursues an answer to the above question by exploring the social aspects – especially the structural relationship between utility organizations and reliability institutions in consideration of power relations – of four representative blackouts that are defined as large scale technological failures – the 1965 Northeast blackout, the 1977 New York City blackout, the 1996 Western blackout, and the 2003 Northeast blackout. By and large, members of the public have perceived causes of large scale blackouts as technological issues, not social ones, and think that technical recommendations will solve the problems. Provided that technological problems are solved, blackouts should not occur again, at least not in the same place.

Many experts in electrical utilities and related organizations explain the causes of failures within their professional languages. That is, an initial failure, as they describe it, starts from a back-up relay[4] in the system, malfunction of a state estimator,[5] lack of reactive power,[6] tree contact of sagging 345 kilovolt[7] transmission lines, etc. The public

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[4] Relay: a device that controls the opening and subsequent reclosing of circuit breakers. Relays take measurements from local current and voltage transformers, and from communication channels connected to the remote end of the lines. A relay output trip signal is sent to circuit breakers when needed. U&CTF (2004). Final Report on the August 14, 2003 Blackout in the United States and Canada: Causes and Recommendations. Washington D.C., U.S.-Canada Power System Outage Task Force.

[5] State estimator: a standard power system operations tool (a computer program) using a mathematical model to estimate current conditions – voltage at each bus, and real and reactive power flow on each line – on an extensive area of the transmission system. Ibid.

[6] Reactive power: The portion of electricity that establishes and sustains the electric and magnetic fields of alternating-current equipment. This is used to explain the loss of power due to the product of electric and magnetic fields, that is, heat and electromagnetic emissions on transmission lines. Actually reactive load such as inductors and capacitors do not dissipate power, and thus is called ‘imaginary power’ or ‘phantom

therefore perceives electric power systems to be complex and not easily understood. After electrical power is restored, the blackout is invisible, and thus no longer a social issue that is discussed publicly. Then the causes of large scale blackouts are intensely discussed in the community of electricity-related professional organizations and utilities using their particular technical languages. These organizations recommend remedial actions to improve the reliability of electricity and create institutions or organizations to implement their recommendations.

In the case of the 1965 Northeast blackout, the Federal Power Commission (FPC; previous incarnation of the Federal Energy Regulatory Commission) investigated the causes of it and made 34 substantial recommendations including institutional solutions. Because there were neither institutions nor unified reliability standards to integrate and manage transmission systems owned by individual utilities, the National Electric Reliability Council (later the North American Electric Reliability Council (NERC)), which consists of regional reliability councils organized by private and public utilities, was formed in 1968. From that date forward, uniform reliability standards have been shared among NERC members. The coordination among NERC members, and load-

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power.' Reactive power must be supplied to most types of magnetic equipment, such as motors and transformers. It also must supply the reactive losses on transmission facilities. Reactive power is provided by generators, synchronous condensers, or electrostatic equipment such as capacitors, and directly influences electric system voltage. It is usually expressed in kilovars (kVAr: kilo-voltage-ampere-reactive) or megavars (MVAr: mega-voltage-ampere reactive), and is the mathematical product of voltage and current consumed by reactive loads. Reactive loads, when connected to an ac voltage source, will draw current, but if the current is 90 degrees out of phase with the applied voltage, they actually consume no real power. Reactive power is important to maintain normal flow of current and stable voltage on the transmission grids. Ibid., p26.

[7] Kilovolt: 1,000 volts; voltage: the electrical force, or "pressure," that causes current to flow in a circuit, measured in volts. Ibid.

shedding[8] as well as protective equipment, became important concepts for reliability improvement.

From these remedial actions, one can see that the electricity industry provides multi-dimensional solutions. These include institutional improvements which have supported technical solutions by strengthening interconnected transmission systems and installing appropriate equipment at the right places. Cascading outages nevertheless happen repeatedly. We still need additional explanations for why they happen even though multi-faceted solutions have been implemented by electrical utilities and the FPC. Hence, I have come to think that there might be other constraints that impede the proper operation of electrical systems.

Large scale technological failures, as Turner puts it, ‘are not created overnight’; some small failures within or between organizations accumulate for a long time, which results in catastrophic disasters (Turner 1976). Large scale blackouts are the malfunction of complex grid systems which have historically developed through agreements between utilities for the purpose of efficient and reliable supply of electricity. With the development of the physical structure of interconnected transmission systems in the electricity industry, two basic questions arise; how to understand this big machine that is becoming one complex system by continuously interconnecting together; and how to manage them in a more integrated manner. While the former needs a physical understanding of electricity depending on engineering performance, the latter needs a structural understanding of how the electricity industry relates to its surrounding environment in providing efficient and reliable electricity. A utility may interconnect its

[8] Load shedding: the process of deliberately removing pre-selected customer demand from a power system in response to an abnormal condition, to maintain the integrity of the system and minimize overall customer outages. Ibid.

transmission lines with neighboring utilities. This is an individual activity at the local level, and gives benefits to the area in which the utilities are located. If there are a lot of contracts among utilities in and beyond a region, however, the control of bulk power systems cannot be achievable through individualized system operation. As grid systems become interconnected and complicated, they need a level of coordination among utilities that is beyond any individual organization's authority. A more active role for institutions to oversee individual organizations' performance systematically is necessary for maintaining reliability.

More specifically, one can think of decision-making by system operators who use control systems as their tools in specific institutional and organizational settings. Operators at dispatch control centers are positioned in the system to handle 'non-design' emergencies because the system designers can neither predict all possible contingencies nor install all safety devices (Reason 1990). Even with advanced technologies, human beings are still in front of computer monitors to monitor these complex systems. Considering the light speed of electricity delivery, however, it is a difficult task for those operators of dispatch control centers to respond immediately and correctly to unexpected system disturbances. Once a sequential tripping of numerous transmission lines starts, the interconnected grid systems can go out of control due to the dynamics of cascading outages (U&CTF 2004). Therefore, although system operators monitor the transmission systems every second, correcting human errors or system malfunction is impossible at the cascade stage of blackouts.

Before the cascading outages, however, there are mixed incidents of equipment failure and ordinary human errors which set the conditions for cascading outages. These incidents are closely related to operators' behavior or decision making processes as delineated in their manuals. That is, one of the focuses of analyzing large scale blackouts should be on the human behavior, particularly decision-making, before the cascading stages. And yet we should also consider that system operators are just on the front line of the large, complex systems which are historically formed by a variety of factors – system design, maintenance, organization of tasks, economic conditions, regulations, culture, and political environment. Operators' behavior including their errors is not independent of these factors. They work as constraints, affecting and regulating their actions. Under what institutional conditions are those mixtures of human errors and technical failure developed into large scale blackouts?

In this perception, the following questions come up. *1) How has the electricity industry created and developed institutions to improve reliability of electricity among control centers? 2) What are the characteristics of the institutions the electricity industry has developed to improve reliability? 3) How have the electrical utilities responded to large scale blackouts under given their institutional settings?* In other words, how have they responded if their interests, such as preserving autonomy in controlling their systems, conflicted with the integrated control of the whole system? To develop a more structural understanding of the current technological failures, we need to see how the electricity industry has historically interacted with its environment to shape current organizational performance in the context of its institutional setting. Analyzing the social process and structural framework that organize their actions – the way of creating institutions for electricity reliability, the characteristics of the institutions for electricity reliability in each historical period, and the interactions between utilities and the institutions – will give a complementary explanation of the causes of large scale blackouts that existing explanations may overlook.

1.2. Explanations of Large Scale Blackouts

How can one explain a technological failure from a social perspective so as to answer the above three questions? I want to distinguish first between theorizing from social phenomena and using existing social theories to explain disasters. First, social theorists may gain insights from the event that is the object of their research and theorize what they have found from the event. Then, they try to generalize their theories by applying them to other social phenomena. The Normal Accidents Theory (NAT) is generated from the Three Mile Island accident in which the research object is the complicated design of nuclear power reactors. Charles Perrow (1993) gained some insight for explaining the TMI accident as he was reading secondary data and understanding various designs of nuclear power plants. The explanation of *normalization of deviance* by Diane Vaughan comes from analyzing the organizational culture of NASA related to the Challenger disaster. At first she focused on the autonomy of organizational behavior in explaining the disaster (Vaughan 1990), and then identified a NASA culture that was taken for granted by insiders of the organization, as she was reading historical governments documents (Vaughan 1996). In this way, identification of critical factors that cause a technological accident happens during the review of materials that are specific to that accident. Many materials produced after large scale blackouts show some common patterns. In particular, I want to emphasize that system operators' behavior usually is not separate from their institutional environments and dominant groups' interests.

Second, this dissertation may test social theories of disasters, giving an explanation of social aspects of large scale blackouts and demonstrating that one theory is more relevant than another. However, generalization or application of a social theory from one social event to another is a difficult task, because it cannot explain all parts of the event whose conditions are different from those of the event for which the theory was developed. Each theory explains just some part of any social event. In this sense, a theory may encourage the research to narrow down the scope of observation by explaining only some observations. But employing different levels of theories without losing consistency may broaden the researcher's scope of observation, so that people can see additional aspects. Allison and Zelikow (1999), for instance, attempt to explain the Cuban Missile Crisis using the three models – the rational actor, organizational behavior, and government politics models. This attempt helps us understand the crisis more broadly and deeply. Hence, it is necessary to explain large scale blackouts by borrowing concepts from social theories whose traditions are different, and then by applying them to this particular phenomenon.

To explain the social process and structure of large scale blackouts, therefore, three theories are introduced to guide the analysis– Normal Accident Theory (NAT), High Reliability Organizations (HROs) theory, and New Institutional approaches including organizational ecology.[9] I apply these theories to the analysis at three different phases –

[9] New Institutionalists try to distance themselves from the Organizational Ecology theory in terms of the concepts – Adaptation vs. Selection – in discussing the relationship between an organization and its

describing system failures, observing inter-organizational relationships, and exploring a political process of creating institutions and institutionalization.

First, Normal Accident Theory argues that as technological systems become more complex and tightly coupled, unpredictable interactions of small failures in the system lead to inevitable, large-scale technological failures which are called Normal Accidents (Perrow 1999). The NAT can explain unintended interactions among a series of human errors and technological failures in interconnected power systems. The NAT is a realistic approach to the explanation of technological failure, but underestimates the fact that human behavior can be improved by institutional and organizational changes. The High Reliability Organizations theory focuses on this aspect. Thus the HROs theory can be complementary to the NAT. It provides evidence of why some potentially hazardous organizations do not fail. La Porte and his colleagues identify such properties of these organizations as good organizational design and management, safety as the organization's primary goal, redundancy, decentralized decision-making, a culture of reliability, continuous training of their employees, and trail-and-error learning (Sagan 1993). Particularly, I concentrate on the two concepts – a culture of reliability and decentralized decision-making – to observe insufficient, but improvable organizational performance. System operators in different locations may not reach similar, correct decisions during emergencies if they do not share the same premises and assumptions: that is, a lack of a culture of reliability between and within organizations. Thus those

institutional environments. But both of them emphasize "links between organizations and macro-sociological processes." See Hannan, M. T. and J. Freeman (1989). *Organizational Ecology*. Cambridge, Massachusetts, Harvard University Press. p35. And see DiMaggio, P. J. and W. W. Powell (1983). "The Iron Cage Revisited: Institutional Isomorphism and Collective Rationality in Organizational Fields." *American Sociological Review* **48**(2): 147-160.

system operators need to socialize themselves with the same premises and assumptions to prevent cascading outages.

Both NAT and HROs theories can provide a framework for analyzing a large scale blackout in terms of its social context. However, they do not fully consider the characteristics of the inter-organizational relationships which are one of the critical points in the electricity industry. Separated power systems are interconnected through transmission lines and efficiently work like one machine, even though system operations are organized at the individual utility level. As mentioned previously, the inter-organizational relationship is beyond the authority of one organization and needs to be managed at the institutional level.

Second, therefore, institutional approaches to an organizational analysis of inter-organizational coordination are helpful in the case of the electricity industry. System operators' decisions and utilities' decision-making process at the inter-organizational level are constrained by institutional environments. The new institutionalism provides useful concepts for explaining organizational responses to technological failures and institutional environments – rationalized myths and the cultural persistence of high institutionalization. One perspective is that the degree of institutionalization is a factor that explains how quickly organizations respond to a changing environment. According to Zucker (1991), formal structures of organizations often respond relatively slowly to threats and opportunities in their changing environments due to their interests and the high degree of their institutionalization. In the electricity industry, organizational or inter-organizational control of technological systems also responds slowly to a changing environment. Utilities tend to stick to socio-technical systems of electricity established in the early period which becomes a conservative force (Hughes 1983). They have improved efficiency continually through technological development and rationalization of their system operations. However, the utilities have not been able to make a clear attempt to improve reliability at the inter-organizational level due to the complexity of system ownership and the autonomy of system operation, even though they have made much effort to improve reliability technologically. As a result, the interorganizational relationships are, in Weick's terms (Weick 1976; Orton and Weick 1990), *loosely coupled*, while electric power systems are tightly interconnected with one another.

Another insight from the new institutionalism is that institutional environments may exist as rationalized myths, and therefore do not meet real demands of the organization's work (Meyer and Rowan 1977). Electricity reliability institutions are established, and have developed reliability standards. Because reliability institutions are loosely coupled with utilities, however, certain symbolic aspects of these institutions cannot be ignored in some critical moments when utilities urgently need coordinated decision processes directed by the reliability standards.

Third, these symbolic aspects are outcomes of the role of powerful groups[10] whose interests are reflected in institutional settings and systems control. Federal or state governments may get involved in administering power system organizations including reliability. But powerful groups in the electricity industry ultimately design and construct reliability institutions on the basis of their interests. Because reliability institutions are based on the resources from major utilities, they may inevitably reflect powerful utilities'

[10] In the electricity industry, these groups generally refer to high level managers of private utilities. Before the 1980s, they usually had electrical engineering backgrounds. As an elite group, they started their career usually in the private utilities rather than government organizations. Interviewee1 (2008). Blackout Interview. H. Park. Washington D.C. These groups were placed in a position of authority to decide basic structures of the electricity industry in the mid 1960s.

interests. The role of powerful groups is discussed by the NAT theorist, Perrow (1986). The dissertation adopts the NAT's perspective on the role of powerful groups in designing systems and setting reliability institutions.

Consequently, I argue that *the electricity industry shows a lack of balanced management between reliability and efficiency objectives: so that the industry gives relatively less attention to reliability in inter-organizational system operation, and thus has failed to establish strong inter-organizational relationships for reliability*. This statement is supported in detail in this dissertation with the examination of the three questions: the way of creating institutions for electricity reliability, the characteristics of the institutions for electricity reliability in each historical period, and interactions between utilities and these institutions.

1.3. Methods and Structure of the Dissertation

In my investigation of major factors that cause large scale blackouts, I review existing theories, two successful cases of social control of large scale technology, and secondary data of representative blackouts. Then I attempt to identify social factors that are critical in controlling interconnected transmission systems. To provide evidence about social factors with respect to the argument that there is an *institutional imbalance between reliability and efficiency*, I conduct quantitative and qualitative analyses of major power system disturbances and cascading outages, respectively. Quantitative (event history analysis or EHA) and qualitative (case studies) approaches are interdependent.

The event history analysis describes general, structural characteristics of major power system disturbances, while the case studies conduct in-depth analysis of large scale blackouts. EHA can support a claim that those disturbances are correlated with internal and external conditions of major utilities having critical infrastructures whose failure can develop into large scale blackouts including global cascades. EHA is complementary to case studies, and vice versa; case studies examine some issues (i.e. training) EHA cannot capture, and EHA can provide a comprehensive picture that case studies cannot present. Comparison of these conditions with the structural issues affecting large scale blackouts will strengthen my claim.

The dissertation consists of three parts – exploring current theories of large scale blackouts, analyzing general patterns of power system disturbance, and examining cases of the 1965, 1977, 1996, and 2003 blackouts. First, Chapter 2 briefly describes the history of power systems interconnection in the Northeast region in the North American electricity industry. This historical background provides us with basic information on the industry and can help with understanding the structural origins of the four large scale blackouts.

Chapter 3 completes the theory review begun in the current chapter. It starts by introducing a social-constructionist perspective to state that technological failure is to some extent socially determined within its organizational and institutional contexts. In order to explain organizational and institutional conditions and the structural processes that lead to large scale blackouts, I introduce the disaster theories – NAT and HROs theory – and then new institutional approaches based in organization theories. To support the analytic framework of HROs, I also briefly introduce two successful cases in controlling large scale technological systems: one is air traffic control systems in the United States, and another is the centralized grid control systems of Russia. On the basis of the three relevant theories and two cases, I construct an analytical framework to interpret large scale blackouts.[11]

In addition, Appendix 1 describes other extant theories explaining large scale blackouts, and discusses their pros and cons. These theories are categorized as ‘techno-economic theory approaches’ and ‘complexity-network theories.’ Although they are not the direct framework of the analysis in this dissertation, I include them in Appendix 1 to review the main currents in explaining large scale blackouts.

Chapter 4 analyzes general patterns of power system disturbances. Using data from the North American Electricity Reliability Council and Energy Information Administration, I conduct an event history analysis. This analysis provides general, structural characteristics and probabilities of major power outages in the United States. The characteristics of these outages can be compared to and guide our thinking about those of large scale blackouts.

Chapters 5, 6, and 7 examine the cases of the 1965 Northeast blackout, the 1977 New York City blackout, the 1996 West blackout, and the 2003 Northeast blackout. I selected these cases, first of all, considering the size of the affected population, with each affecting more than 5 million customers. Because of the size, the decision-making processes before, during and after these blackouts cannot be confined within an organization, but should be coordinated with other organizations. These cases show that

[11] My dissertation is an interpretation of existing explanations of large scale blackouts rather than direct explanation of them, because existing literature and documents already explain many of their technical and institutional causes. The dissertation attempts to reinterpret large scale blackouts by examining the evidence regarding social structure that emerges from these documents.

the causes of the blackouts cannot be interpreted simply as technical failure. According to the NERC reports of power system disturbances, evidently, there are additional large scale blackouts other than the above-mentioned ones. In-depth analysis of them can also reveal structural problems lying behind technological failure. Unlike the four selected cases, however, there has been no significant institutional or organizational change after these large scale blackouts. Additionally, their structural problems are by and large discussed through the analysis of the four cases.

Taking into account the coordinating mechanism of interconnected power system operation, these chapters look at organizations' reactions to the events in their institutional settings rather than conduct in-depth analysis of the inside structure of organizations. Each chapter examines institutional and physical conditions prior to each blackout, describes occurrence of blackouts, and analyzes remedial actions. In the comparison of the four blackouts, I will try to find common structural origins of large scale blackouts, particularly focusing on the relationship between organizational performance and institutional settings. Above all, I will discuss the interactions between private utilities and the federal government in establishing reliability institutions. State governments will not be a main focus of this dissertation, although they participate in establishing reliability institutions to some extent.

In the conclusion chapter, I summarize the findings supporting my argument – institutional imbalance and unresponsive organizations. Then I discuss two issues with the current large-scale-blackout discourse, that is, professionalism of electrical engineers and system operators, and NERC *the Electric Reliability Organization* as a self-regulatory organization. Because the research observes a dark side of organizations[12] and historical events that happened more 40 years ago, I have had difficulties in getting access to some specific data sources. Therefore, I often depend on secondary data about the events. Nevertheless, this research reveals the basic structural limitations of the electricity industry in coordinating system operations beyond individual utilities with respect to interconnected power systems.

[12] Vaughan uses this term, *the dark side of organizations*, to explain mistake, misconduct, and disaster caused by organizations. See Vaughan, D. (1999). "The Dark Side of Organizations: Mistake, Misconduct, and Disaster." *Annual Review of Sociology* **25**: 271-305.

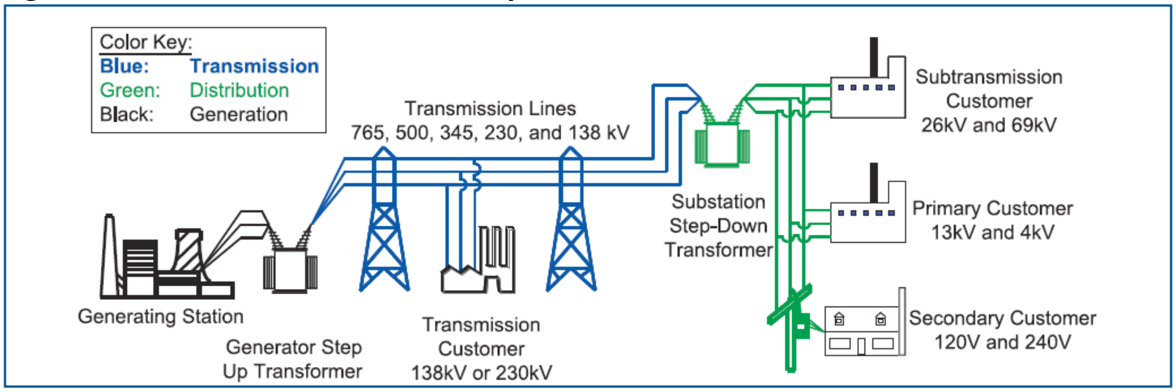
Chapter 2. Historical Formation of Transmission Systems[13]

The electricity industry traditionally has been vertically integrated: combining generation, transmission, and distribution within one organization. An electric utility usually serves as a territorial monopoly franchise. A power plant which is located near fuel sources – hydro, nuclear, coal, oil, natural gas, etc. – usually produces 25,000-volt electricity. Electricity is transformed into high voltage (up to 765k volts) at a transmission substation and travels to consumers through transmission lines. High voltage transmission lines can deliver electricity to end users without large power loss. However, it is more common to transform electricity to low voltages again at distribution substations. Low voltage electricity is then distributed to consumers at 120 volts or 240 volts (figure 2.1). In the United States, most power systems use alternating current (AC) with 60 cycles per second rather than direct current (DC). Transmission lines are connected together at substations, which makes a transmission grid and power pools. The regional power pools are divided into 13 market module regions: East Central Area Reliability Coordination Agreement (ECAR), Electric Reliability Council of Texas (ERCOT), Mid-Atlantic Area Council (MAAC, usually PJM), Mid-America Interconnected Network (MAIN), Mid-Continent Area Power Pool (MAPP), New York (NYISO), New England (ISO-NE), Florida Reliability Coordinating Council (FRCC),

[13] The chapter is based on the paper presented at the 2007 IEEE Conference on the History of Electric Power, August 3~5, 2007.

Southeastern Electric Reliability Council (SERC), Southwest Power Pool (SPP), Northwest Power Pool (NWP), Rocky Mountain Power Area, Arizona, New, Mexico, and Southern Nevada (RA), and California (CISO) (EIA 2008). Then they are grouped into three interconnections – the Eastern Interconnection, Western Interconnection, and the ERCOT Interconnection – as described in Chapter 4 (See figure 4.1).

Figure 2.1. Basic Structure of Electric System



Source: U.S.-Canada Power System Outage Task Force (2004)

Constructing and interconnecting the entire U.S. power system through transmission lines was an evolving process. This reflected American values; that is, in this country there existed individual rights, freedom of opportunity, material progress, and individual ownership over the concern for social or natural good (Barbour, Brooks et al. 1982). These values encouraged technological innovation and the development of the industry. With them, when the U.S. people had a need, they could invent an organization that would support the innovation and industrial development (Interviewee1 2008). In 1882, as Edison first displayed his electrical lamps on Pearl Street in New York City, he invented an electricity system which consisted of incandescent lamps, meters, dynamos, and distribution mains (Hughes 1979). Because Edison's direct current electricity could not travel long distances, his distribution systems were limited to 1 mile in length. Then electrical engineering pioneers developed alteration-current transmission systems through which electric power could travel longer distances, and thus established the current horizontally-connected, vertically integrated system. In these interconnected systems, system operators in each control center take a responsibility for operating the components within their control area.

System operators, who are positioned in the loop of power systems to monitor and control their systems, are supposed to keep their systems stable based on their knowledge, experience, and technology. There has been continuous technological research and improvement to help system operators control power flows and AC frequency on the transmission lines. However, there is little information and research, in social science, about the conditions which affect operators' decision making process. Since the Three Mile Island accident, some scholars have begun to consider the organizational contexts of human factors engineering in power systems (Sugarman 1979; Perrow 1983; Parsons, O'Hara et al. 2001). They have argued that organizational, institutional and educational systems tend to marginalize human and organizational issues for fast and proper decision-making at the human-machine interface (Badham 2001), and that specifically senior managers may not have urgent incentives to consider these issues (Perrow 1983).

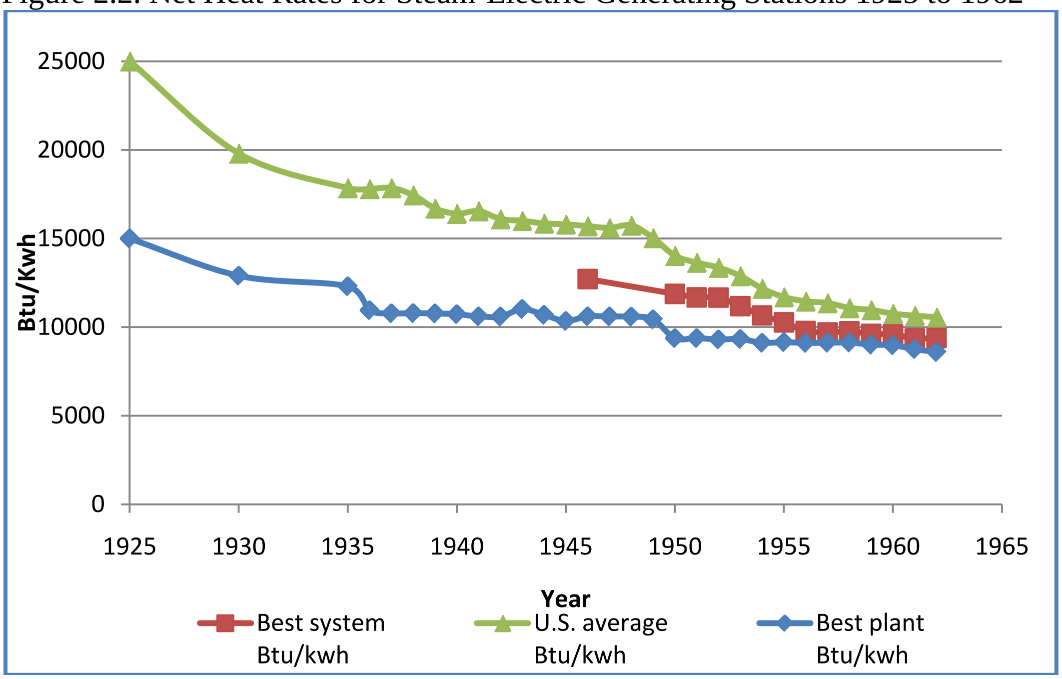
In general, two conflicting values – finding the most efficient ways of operating their systems while maintaining reliability – direct the decision making process of system operations. Taking into account these values, under certain operating criteria, system operators may manage their systems safely, but near at the critical point of the system's limit. Behind the system operation, there are the mixed interests of utilities, the federal government, state governments, labor unions, and others. Reliability regulations and institutions, which are products of these interests, are not likely to provide the operators with the best criteria and circumstances of their system operation. Considering those aspects, it seems that, historically, dispatch center operators have not been located in very good circumstances to achieve best practices. Based on the existing research and information, the rest of this chapter tries to briefly describe the historical formation of transmission lines and dispatch control centers from the early 1900s to the mid 1960s. This can help us better understand the place of dispatch control centers in the context of large scale blackouts.

2.1. Technical Development of Electricity Generation

Prior to the 1965 Northeast blackout, electricity became a universal carrier of energy which was widely used by all segments of society. Electric utilities promoted the use of electricity in the residential, commercial, industrial and transportation sectors by encouraging customers to use electrical equipment and home appliances, thereby improving the standard of citizens' lives. Hence, the demand for electricity continuously increased.

On the physical side, electric utilities took it for granted that they would improve their productivity through technological development, and the growth of the electricity industry promised a similar dynamic in the future. They improved thermal efficiency and exploited economies of scale by increasing the output of steam turbine generators to meet the growth of electricity demand while reducing the unit price (Hirsh 1989). Turbine steam generators increased their output through improved design: a horizontal position – single-shaft and later cross-compound units – of the turbine and generator to increase speed and size, enhanced cooling techniques for generators to increase the rotor's speed, improvement of turbine blades and nozzle shape design, use of stronger metals, and water-cooled furnace walls and new firebricks for boilers (Hirsh 1989). Therefore, one unit of a power plant was able to produce electricity from 3.5 MW in 1901 to more than 650 MW in 1963 (FPC 1964), and efficiency was greatly improved between 1925 and 1962 (figure 2.2).

Figure 2.2. Net Heat Rates for Steam-Electric Generating Stations 1925 to 1962



Source: Federal Power Commission (1964)

2.2. Emerging Market Institutions – Natural Monopoly

On the institutional side, electric utilities have created an institutional environment that is beneficial to them; electricity regulations have been created to support the perceived natural monopoly of utilities. A basic belief that the electricity industry should be viewed as a natural monopoly was that constructing two sets of duplicated power plants and lines in a same service area was inefficient. On the basis of Thomas Edison's model of the electricity system – vertical integration of generating and delivering power – Samuel Insull, who once was an employee of Edison laboratory and became president of the Chicago Edison Company (later Commonwealth Edison Company) in 1892, considered how to efficiently generate and manage electricity by maximizing the output of a generation unit. He knew that isolated power plants were not economically sound because of different and various habits of customers, and thus maintained that power plants had to be interconnected to reduce fixed costs and improve reliability (McDonald 1962). Developing and configuring the ideas of load factor,[14] load diversity and rate systems or metering,[15] he tried to include as many customers as possible by incorporating adjacent power stations through transmission lines and thus expanding his company's service territory. That is, on the basis of these principles, power plants in a large area were interconnected through transmission lines. Once the electric system – vertical integration of generation, transmission, and distribution – was established in the early

[14] "the ratio of the average to the maximum load of a customer, group of customers, or the entire system during a specified period" Hughes, T. P. (1979). "The Electrification of America." *Technology and Culture* **21**(1): 124-161., p.150.

[15] Metering refers to the methods of applying devices that measure and register the amount and direction of electrical quantities with respect to time. Ibid.

twentieth century, it dominated for almost nine decades in the form of a natural monopoly in the United States.

Insull and his colleagues sought to have themselves regulated by state commissions and established regulatory boundaries at the state level (McDonald 1962). They understood that it was tedious to be regulated at the municipal level because they had to negotiate with every municipal government. At the beginning of constructing the structure of the large scale electricity industry, the corruption of municipal governments was a barrier to the expansion of the electricity industry, and there would have been too many contracts for constructing power plants and transmission lines if utilities had to negotiate with municipal governments (Anderson 1981; Munson 2005). Deciding electricity prices[16] at the state level was a tool to secure utilities' production of electricity. Therefore, it was more favorable to enact regulations at the state level to set electricity prices. As a result, more advantaged utilities could remove competitors in developing their monopolized markets and ensure the rights of eminent domain. This also sometimes met the goal of state governments which had to secure public interests. Furthermore, technological development made the continuous growth of the electricity industry possible by providing consumers with low-priced electricity. From this historical fact, the electricity industry in its development has used its regulatory environment and has had a distinctively close relationship with state regulators.

Consequently, one utility could monopolize the electricity market in and beyond one state. Private utilities created an environment that would promise the growth of their

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[16] Yakobovich et al. discuss that the earliest electricity price systems such as the "Wright system" were shaped by the technological, economic, institutional, and political factors. The Wright system refers to revenue maximization and monopoly building without penalizing usage at peak times. Yakubovich, V., M. Granovetter, et al. (2005). "Electric charges: The social construction of rate systems." *Theory and Society* **34**: 579-612.

companies without competition in their service area. In monopolizing power systems, private utilities usually grew in densely populated areas where maximization of profits were guaranteed, while municipal and rural electric cooperative power systems were developed in sparsely populated, agricultural areas under the regulatory support of the federal government (Church 1960).

2.3. Development of Transmission Systems

The technological development of transmission lines accelerated Insull's idea of large, interconnected, centralized power systems to maximize output of electricity and profits while reducing construction and management costs. In addition, part of the initial goals of transmission systems was to improve reliability through interconnected power systems. Transmission systems were possible with the development of alternate current systems, transformers, and Nikola Tesla's invention of a three-phase induction motor (Weber and Nebeker 1994). Starting with the initiation of these AC transmission lines between Niagara Falls and Buffalo – 16 miles – AC transmission systems became a dominant technology to deliver power to end users from a long-distant power plant. To avoid power shortages in their service area, utilities began to interconnect their power plants, which also allowed the reduction of high reserve margins for generating capacity (Hirsh 1989). Insull, a fast mover in adopting innovative technologies, applied AC power systems; he changed most local power plants into substations, concentrated generating units into a few large power stations, and interconnected them. Electrical engineers and managers of utilities thought that they could maintain more reliable power service even if one power plant was shut down and, as a rule of thumb, if one power plant did not exceed 10% of the whole capacity of their system. By enlarging the scale of an industry unit, electricity became as big a business as the rail industry or the steel industry did.

The interconnection between utilities began in the Northeast region in the early 1910s. After the first interconnection between the two companies – the Turners Falls and the New England Power Co., located in the western part of Massachusetts in 1914 (FPC 1967c) –utilities interconnected their facilities to each other through transmission lines. Then these interconnected systems grew to power pools in which several utilities were tightly interconnected, thereby developing organizations to manage the pools. The Canada-United States Eastern interconnection (CANUSE Group) was formed in 1930, The Electric Coordinating Council of New England in 1947, and the Southeastern New York Power Pool in 1960 (FPC 1967c). These power pools were interconnected. The following are brief sketches of the evolution of the grid interconnection in the Northeast region.

2.3.1. Transmission System in New England

At the turn of the century, many municipal governments in the New England region [17] constructed small power plants that could supply electricity within their territories. As their power plants became obsolescent and because they could not afford additional construction costs, they sold them to private utilities and purchased electricity from the private utilities (Church 1960). Technical development of generators and

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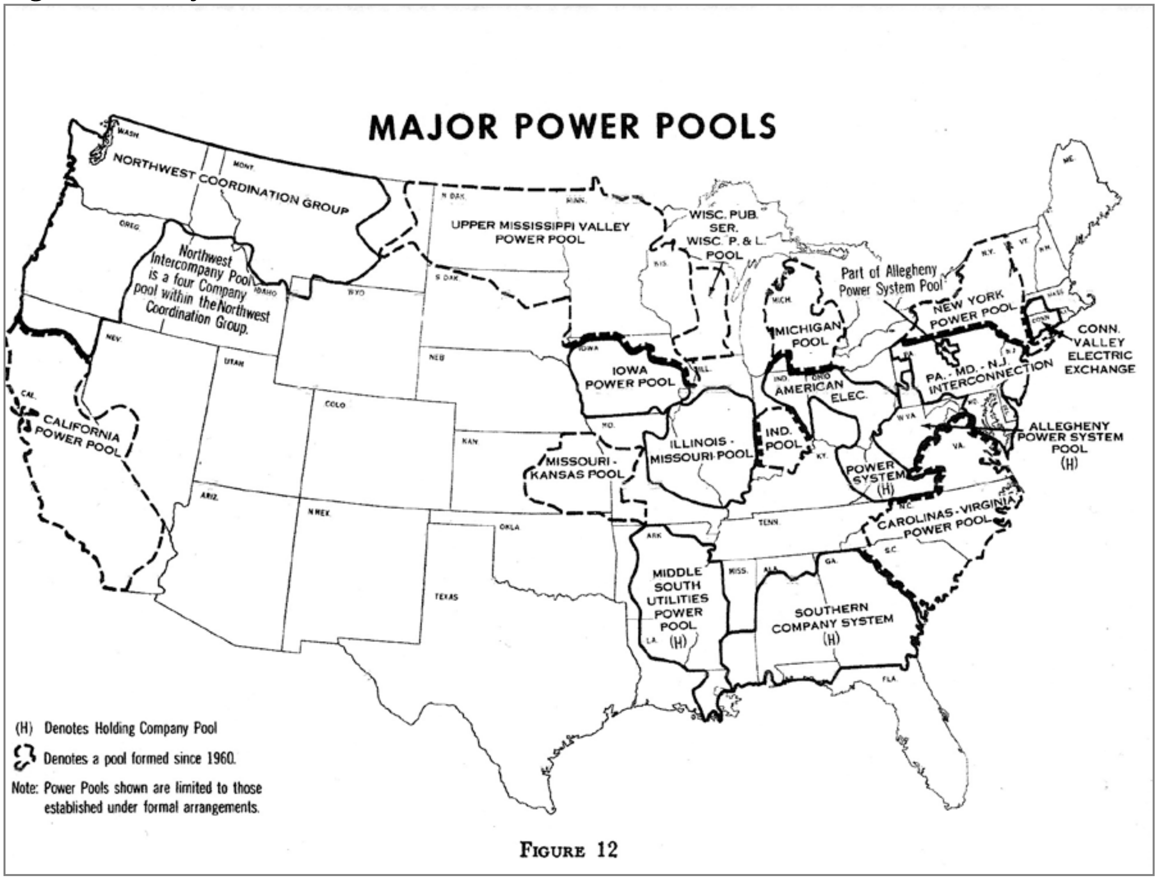
[17] The New England Region includes Maine, New Hampshire, Vermont, Massachusetts, Rhode Island, and Connecticut.

transmission lines made it possible to integrate individual power systems into larger interconnected systems. The Connecticut Valley Power Exchange (CONVEX) pioneered the interconnection between utilities in 1922 (EIA 2000). At the beginning of the interstate interconnection, however, some state power commissions and legislatures – New Hampshire and Maine – prohibited interconnections to protect their consumers and industries (Elsbree 1931). Because of the uneven distribution of potential resources such as hydropower, power-short states such as Massachusetts, Rhode Island and Connecticut were compelled to obtain power from Canada (Elsbree 1931), which meant that power supply systems became complicated.

In the mid 1960s, the major utilities in the region were Central Maine Power Company, Green Mountain Power Corporation, Central Vermont Public Service Corporation, Boston Edison Company, New England Gas and Electric Association, Eastern Utility Associates, New England Electric System, Public Service Company of New Hampshire, Holyoke Water Power Company and Holyoke Power & Electric Company, Western Massachusetts Company, The Connecticut Light and Power Company,[18] The Hartford Electric Light Company, and The United Illuminating Company (FPC 1967a). They had interconnected their system with New York and other regional power systems since 1924 and evolved nearly into a power pool around 1947. They still operated their systems separately and were not centralized (see figure 2.3).

[18] Later in 1966, the Northeast Utilities, the first multistate holding company since the passage of the Public Utility Holding Company Act of 1935, was formed when Western Massachusetts Company, the Hartford Electric Light Company, and the Connecticut Light and Power Company were affiliated to the larger integrated system. Holyoke Water Power Company became a member of the affiliation in 1967. The Hartford Electric Company ceased to exist when it was merged into the Connecticut Light and Power Company in 1982. The Public Service Company of New Hampshire went bankrupt and was merged into the Northeast Utilities in 1992. NU. "NU's History: The Formation of Northeast Utilities." Retrieved March 31, 2007, from http://www.nu.com/aboutnu/formation.asp.

Figure 2.3. Major Power Pools in the Mid 1960s



Source: (FPC 1967a)

2.3.2. Transmission System in New York

In New York State, system builders first developed power systems in urban areas. Starting with the Niagara-Buffalo transmission lines in 1896 and using abundant hydropower, they interconnected New York power systems from generating sites to consumer sites. Particularly, hydropower systems at Niagara Falls were interconnected with Central Hudson Gas & Electric Corporation and the Consolidated Edison System where metropolitan markets did not have sufficient electricity power resources. Before 1937, about 59 utility companies existed along the Mohawk Valley from Buffalo to Albany. Because their systems were interconnected through transmission lines, their separate operation was meaningless. Therefore, they consolidated their systems together since 1937, and finally established Niagara Mohawk Power Corporation in 1950 (Corporation 1951). In this way, many small companies merged together along transmission lines, which resulted in the establishment of major power utilities; they were Niagara Mohawk Power Corporation, Rochester Gas & Electric Corporation and New York State Electric & Gas Corporation in upstate New York; and Central Hudson Gas & Electric Corporation, Orange and Rockland Utilities, Inc., Consolidated Edison System, and Long Island Lighting Company along with the Hudson Valley. The hydropower on the St. Lawrence River, which was under the Power Authority of the State of New York (PASNY), was interconnected with other power systems in 1958. Subsequently those New York systems were interconnected with Hydro-Electric Power Commission of Ontario, Canada, New England systems, and the Pennsylvania-New Jersey-Maryland (PJM) power system.

2.3.3. Pennsylvania-New Jersey-Maryland (PJM) Power System

The development of the PJM power system started near the abundant power resources – the Susquehanna River at Conowingo, Maryland – with a master plan unlike other integrated systems which evolved from small systems (Hughes 1983). This project was initiated by private utilities at the time when the state government of Pennsylvania lost an opportunity to realize the publicly owned Giant Power plan because of the opposition from private utilities (Hughes 1983). As the PJM system tried to find its market, it planned to interconnect three power systems: Philadelphia Electric Company (PECO), The Public Service Electric & Gas Company of New Jersey (PSE&G), and

Pennsylvania Power & Light Company (PPL). Later, Maryland joined the system, and thus the Pennsylvania-New Jersey (PNJ) system was renamed into the PJM interconnection (Hughes 1983).

Originally there were different interests between private utilities, state governments and the federal government in developing electricity systems, and PJM was an outcome of this conflict. Some state governments wanted to use advanced technology, large-scale power plants, and wide-area grids of transmission lines for the public interest in a more revolutionary way. They saw the power systems controlled by public agencies of governments in Ontario, Canada and Great Britain (Hughes 1983). In 1925 Governor Gillford Pinchot of Pennsylvania and his technical assistant Morris Llewellyn proposed a plan to construct a large scale power plant which was called Giant Power and wanted to provide electricity in rural areas. Pinchot's intention was also to underscore state power against the federal regarding the construction of large scale power systems and interstate transmission lines (Hughes 1979). He basically believed that the growth of a holding company would make people "the helpless servant of the most widespread, far-reaching, and penetrating monopoly ever known" (Hughes 1979 p1363).

However, private utilities did not want power plants under state control which tried to regulate interconnected systems crossing state boundaries. Engineers and managers from the private utility side labeled the Pinchot's idea communistic (Hughes 1979). This situation gave an opportunity to the federal government to engage in the electricity industry, particularly hydropower across the country. In this context, the Federal Power Commission, which was established in 1920 to issue licenses for dam construction, authorized the Philadelphia Electric Company to build a hydroelectric plant on the

Susquehanna River in February, 1926 (Hughes 1983). Then the above three companies – PECO, PSE&G, and PPL – agreed on the establishment of the PNJ interconnection in 1927. This entity became the PJM interconnection in 1956 after the Baltimore Gas & Electric Company in Maryland joined it (Hughes 1983; PJM 2009). PJM gave member utilities high effective reserve margins,[19] so that they could meet electric demand during peak times. PJM was created by this friendly relationship between private utilities and the federal government at the time. Because the PJM system did not directly deliver electricity to end users, it was not under the control of state governments (Hughes 1983).

A unique feature of PJM was the centralized control of the interconnected power systems with a diverse fuel mix courtesy of its member utilities (Hughes 1983; Calabro 2003). This was different from other interconnected power systems which were developed through mergers, but controlled by individual utilities. From the planned construction of the PJM Interconnection, we can recognize that the idea of centralized control of interconnected power systems was emerging in the private sector at the regional level.

2.3.4. Power System in Ontario, Canada

Niagara Falls was also an opportunity for Canada to provide its people with low-priced electricity. Unlike the U.S. cases, Canadian power systems developed under the authority of the Ontario provincial government as publicly owned power systems. For their successful industrialization, Ontario's capitalists, whose steam-driven plants had

[19] Reserve margins (operating) refer to the amount of unused available capability of an electric power system (at peak load for a utility system) as a percentage of total capability.EIA. (2009). "Energy Terms and Definitions as Used in EIA Data, Reports, Presentations, and Survey Forms." Retrieved December 28, 2009, from http://www.eia.doe.gov/glossary/index.html.

depended on coal mines of Pennsylvania, needed sustainable power to run their factories, and thus turned their attention to hydropower at Niagara Falls. But Adam Beck, mayor of London, and his colleagues thought that the hydropower had to be used primarily for the public, and thus followed the initiative of the public power movement in constructing hydropower plants at Niagara Falls (Swift and Stewart 2004). The provincial government of Ontario created the Hydro-Electric Power Commission in 1905 which developed integrated electric systems, delivering electricity to rural areas as well as urban industrial sites in the province. The Ontario Hydro system, starting at Niagara Falls, expanded its territory by purchasing private units and constructing new power plants, and interconnected them reaching from Ottawa and Cornwall on the east border facing Quebec and New York borders respectively to Windsor on the west border facing Detroit during the 1930s (Denison 1960).

In 1947, Ontario Hydro divided the province into nine regions with regional offices (Denison 1960). Each regional office consisted of a regional manager, operations engineer, consumer service engineer, accountant, personnel officer, and staff (Denison 1960). Ontario Hydro continuously expanded its systems in the postwar period, and system operating engineers with a limited picture of planning and management of their system were to catch up with the expansion through standardizing frequency from 25 to 60 cycles, installing the latest equipment, and introducing helicopters for the inspection of transmission lines. But they could not reach the level where they maintained the balance of supply and demand, particularly during the winter season, which led to the import of electric power from the United States through interconnected transmission lines.

Figure 2.4. Sir Adam Beck Hydro Power Plant at the Niagara Falls

In the post postwar period, Ontario Hydro also launched the “Live Better Electrically” campaign in 1955 to promote consumption of electricity. After completing the construction of hydraulic power units at the Sir Adam Beck No.2 unit at Niagara Falls (figure 2.4) and the Robert H. Saunders-St. Lawrence generating station on the St. Lawrence River in the late 1950s, however, it ran out of viable hydro-electric sites. In addition, Hydro could not improve its reserve margin by more than 10 percent due to the constantly increasing demand in residential and commercial areas. Therefore, it moved on to the construction of thermal generating systems and the development of nuclear power plants to meet the demand. Interconnected transmission lines had been added continually and strengthened with improved technology until the 1960s: the length was

17,700 miles (Denison 1960). Ontario Hydro became a giant enterprise no other utilities could rival in the province.

The power systems interconnection between the United States and Canada led to the creation of CANUSE to coordinate among utilities as mentioned above. In 1962, PJM, CANUSE and the Interconnected Systems Group (ISG), which grew separately, were interconnected (Brand 1966). As the systems were integrated, however, their operation became complicated. They established the North American Power Systems Interconnection Committee (NAPSIC) through which representatives from all sections of the United States and Canada met twice a year to solve operation problems of interconnected systems and to agree on operational control standards (FPC 1964). The committee was to informally instruct the operation of interconnected systems, not to strictly unify their operations.

2.4. Development of Dispatch Control Centers

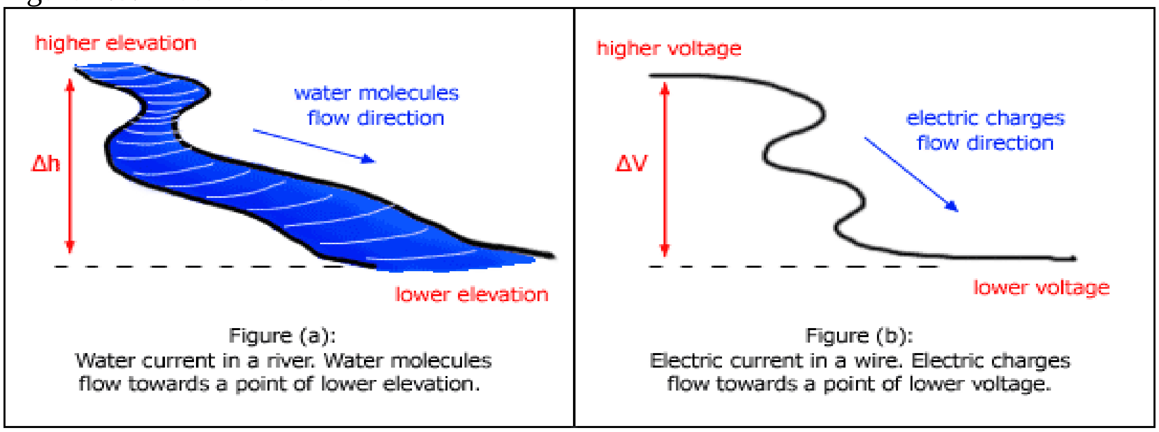
Current dispatch control centers are also a product of the system builders' need to manage the large scale power systems they had designed. System interconnection was also possible with the development of real-time control technology. Technological development and expansion of large scale systems has usually been followed by technological progress in controlling electricity. When system builders interconnected two local power systems through transmission lines, they needed the capability for a stable transfer of electricity and thus developed monitoring systems, particularly to measure and control tie power flow[20] and frequency stability. At first, system builders separated the control room from the generators room to make an appropriate environment for system operators in monitoring and controlling their power stations (Hughes 1983). Starting with the development of measurement equipment in 1909, the control systems evolved from unit control to multiunit control to interconnected systems control (Cohn 1984). Before 1930, system engineers and operators were able to control multiple units within one station, economically distributing power loads to each unit (Cohn 1984). They could also control frequency automatically as of that time.

In the early 1930s, however, controlling or coordinating interconnected systems was another dimension because power exchange depended on stable operation of large interconnected systems with diverse power plants in a region. If several utilities wanted to exchange AC power one another, they had to make electricity flow constantly, as scheduled, on the tie lines with the same frequency (60 Hz with scheduled deviation). However, "when the load changes were in a remote area, it was absorbed by the local frequency regulating station, resulting in undesirable changes in tie line flow" (Cohn 1984 p151) Electrical engineers had to avoid this problem. By trial and error during the 1930s, utilities developed a way to control 'frequency' and 'tie line flow' simultaneously in their interconnected power systems. Independently controlling frequency and net exchange by individual power systems became a standardized method for multiple-tie areas.[21] The input and output of each system were almost automatically controlled in

[20] Tie power flow is the power flowing through tie lines. Tie lines refer to a circuit connecting two Balancing Authority Areas. NERC (2008). *Glossary of Terms Used in Reliability Standards*. NERC. Princeton, NJ, NERC.
[21] Cohn recollects that "a preferred technique for each area would be to net all its own boundary ties and set its own bias independently of the bias settings of its neighbors. With this practice, each area would follow its own load swings." This technique is net interchange control: the fully distributed frequency biased net interchange control technique in all areas without a central frequency regulating area. Cohn, N. (1984).

coordination and cooperation by such newly developed equipment, and thus few tasks remained to be done directly by system operators.

Figure 2.5. Electric Current

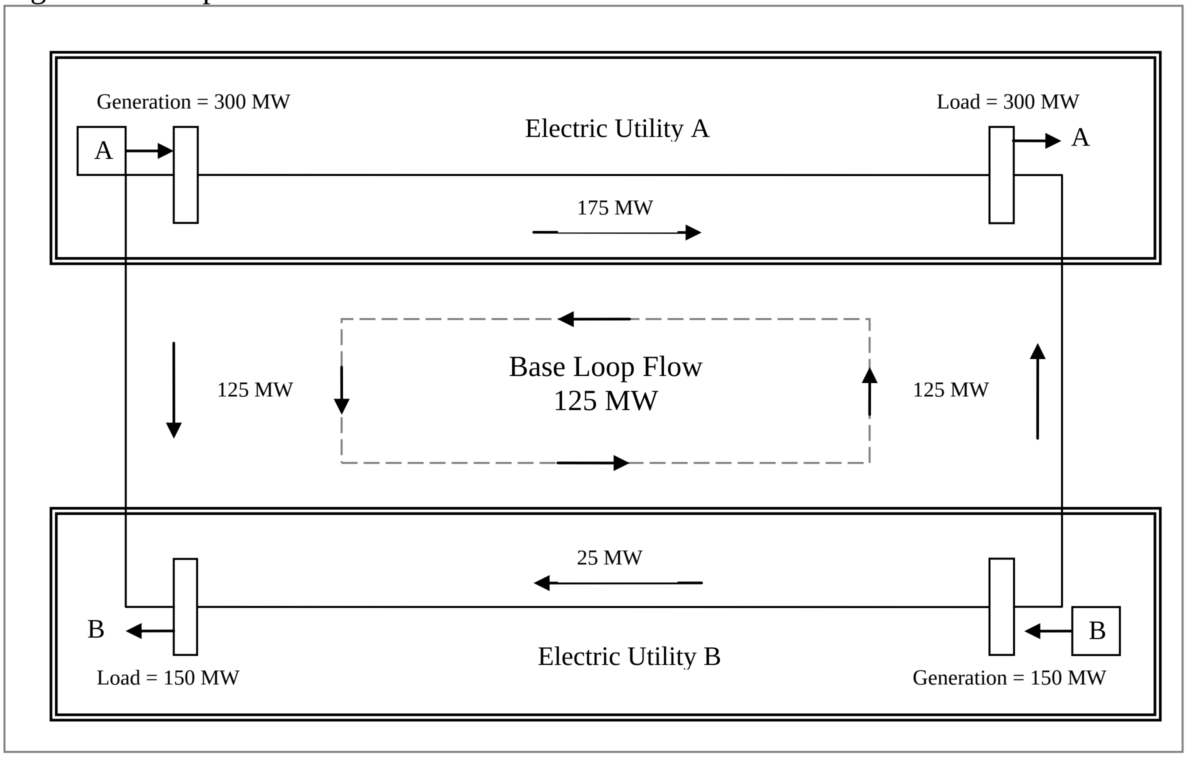


Source: (Physics_UC_Urvine 2008)

As power systems were interconnected and became complex, some problems arose. System engineers discovered unintended physical features of the interconnected grid systems: that is, circulating power – loop flow and parallel path flow (Casazza 1993). Basically electric power flows from a point of higher voltage to a point of lower voltage. As illustrated in figure 2.5, voltage like water pressure makes electricity flow from generators to end users through transmission lines.

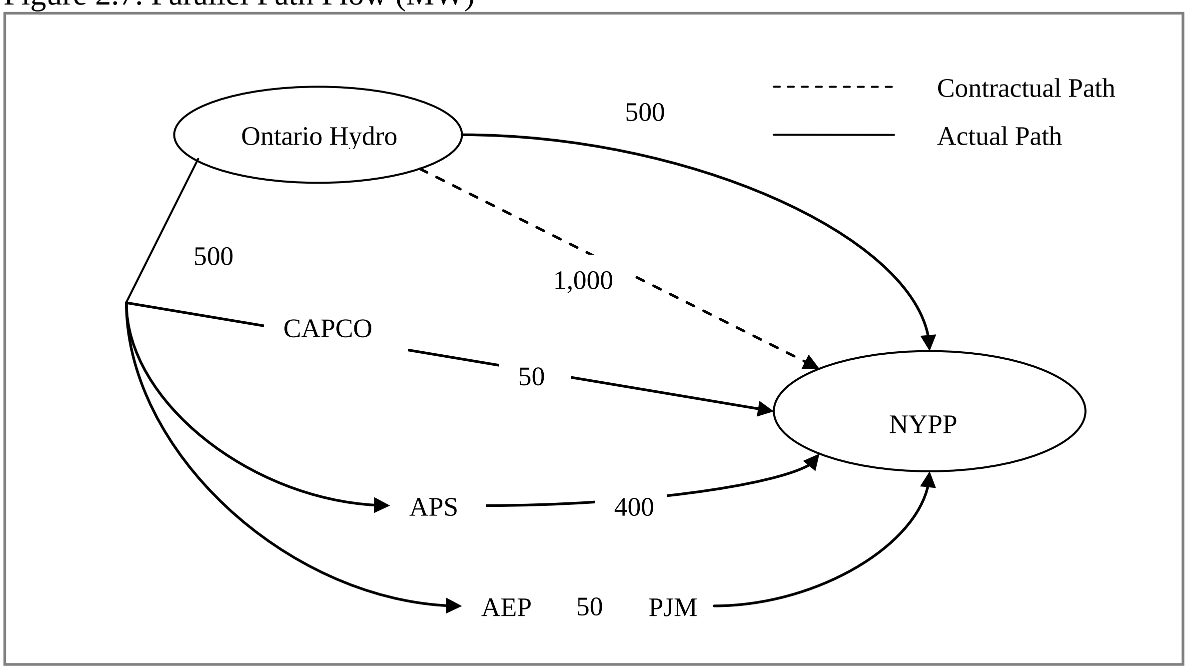
"Recollections of the Evolution of Realtime Control Applications to Power Systems." *IFAC Automatica* **20**(2): 145-162., pp154~155.

Figure 2.6. Loop Flow



Source: (Casazza 1993)

Figure 2.7. Parallel Path Flow (MW)



Source: (Casazza 1993)

Because of the complex interconnection and obstacles such as the Great Lakes and the Rocky Mountains, however, electric power flows into unanticipated directions or through different path ways. When two systems are interconnected each other, the generated power in one system flows to another system to reach its own load in the system, which is called ‘loop flow’ (figure 2.6). This kind of uncontrolled power flow frequently happens around Lake Erie where electric power flows from Ohio to Ontario to Michigan, causing undesirably heavy loads on transmission lines (Lerner 2003). Another is ‘parallel path flow’ when the power at one system flows over transmission paths of diverse systems to arrive at another system (figure 2.7). Electric power flows not only over the shortest path but also through other parallel paths of the system in the Northeastern region. These facts mean that those interconnected systems become a single huge machine, influencing one another. Power loss in part of a system can affect the whole interconnected system. The loop flow was one of the factors that caused the 1965 blackout (Interviewee1 2008).

Because of the complex interconnection of power systems, electric utilities needed well trained, experienced power system operators with standardized operation criteria to control the complicated power system and decide which power plants should be operated first on the basis of production costs and availability of each power plant in the pool. However, the system operation of interconnected grid systems was a fragmented rather than integrated activity in the early 1960s. System operators were recruited and trained by individual utilities. Guidelines for system operation were also defined by individual utilities. One example of individualized operating criteria was the grid systems in Michigan. On the west side of Ontario Hydro where Detroit Edison and Consumer Power were located, when they were integrated into one power system in 1962, they did not have the experience of operating a power pool. Thus, their option was to control their power pool based on previous methods of controlling individual systems (Miller 1971). But utilities lost momentum towards seeing the big picture in controlling interconnected systems. Although the length of transmission lines were more than doubled between the 1950s and 1965 (Table 2.1), there was no choice other than using the previous organizational practice for system management. Although system operators were well trained and experienced, and even knew the problem of the circulating power, their operation activity and criteria remained within their individual companies.

Table 2.1. High Voltage Transmission Lines 1950-70 (circuit miles)

years	110kv ≤	345kv ≤
1950	70,471	–
1955	104,875	1450
1960	130,718	2570
1965	165,417	6516
1970 (planned)	227,006	26,000

Source: Federal Power Commission (1967a)

2.5. Federal Power Commission and 1964 National Power Survey

The Federal Power Commission, as mentioned previously, was created to license hydroelectric power construction in accordance with *the Federal Water Power Act of 1920*. *The Federal Power Act of 1935* gave the FPC the power of regulating the interstate sale and transportation of electricity, but was not put into effect until the early 1960s. The Act did not have provisions regarding reliability.

One aspect of FPC's limited administration was that there was no engineer who could deal with physical features of electrical systems until Joseph Swidler, a lawyer and former general counsel of TVA, became the chairman of the FPC in 1962. He transformed the FPC from one of the most inept agencies to the most attractive organization for government officials (Henderson 2002). He recruited engineers and economists, and reorganized the FPC so that it could really become a regulatory agency. The staff inside the FPC newly recognized that the primary goal of the FPC was to become a guardian of the public interest, not merely an adjudicator of disputes. He wanted to make balanced decisions between managers and investors, and between investor-owned and publicly-owned systems.

One of the major initiatives of the FPC during the Swidler's term was the National Power Survey to encourage all power systems to expedite their system coordination efforts (FPC 1964). As the demand for electricity increased, the FPC recognized the necessity to put all of the sector's efforts together, to incorporate new advanced technology into electrical systems, and to provide possible patterns for future expansion in efficient ways. Through the report, it emphasized the benefits of coordinated growth which would significantly reduce capital and operating costs. For better coordination, the report suggested interconnection of power systems through transmission lines, including detailed recommendations for 16 study areas.[22] Although the FPC did not regard the report as a blueprint, it showed its significant and comprehensive role at the federal level through the report. Some power companies, such as Detroit Edison Company, which did

[22] The 16 areas are New England, New York, Pennsylvania-New Jersey-Maryland, Ohio Valley, Lower Michigan, Carolinas-Virginia, Tennessee Valley, Southeastern, Texas Area, Middle South area, New Mexico and Panhandle, North Central, Upper Missouri Basin, Colorado-Wyoming Area, Southwest, and Northwest.

not want federal government intervention, however, considered the report a means to expand governmental responsibility (Miller 1971). This showed a tension between the federal government and utilities in the mid-west region.

Even though the FPC had some tension with private utilities, it was able to attain, at least, the jurisdiction over interstate wholesale rates and services of investor-owned utilities in 1964.[23] But unlike the many roles given to the Federal Aviation Administration with respect to reliability and safety,[24] it did not have extensive authority over the coordination of interconnected transmission systems at the national level; that is, setting operation standards, licensing system operators, providing up-to-date equipment standards, planning and maintaining systems, and improving communication methods.

2.6. Integrated Systems and Local Operation before the 1965 Blackout

From the above sketch regarding the construction of the Northeast interconnected power systems, the electricity industry showed a social organization of their systems – tightly interconnected, but locally operated grid systems – which became preconditions of the 1965 Northeast blackout and other following large scale blackouts.

First, the Northeast interconnected system was not originally planned but was an evolved entity that emerged with the help of advancing technology in the early twentieth

[23] City of Colton v. Southern California Edison Case: the city of Colton petitioned the FPC to declare legal authority over intra-state sales of power that came from other states through transmission lines Henderson, S. (2002). *Power and the Public Interest: The Memoirs of Joseph C. Swidler*. Knoxville, The University of Tennessee Press.

[24] For more detailed description of the role of the Federal Aviation Administration, see Section 3.3.1 in Chapter 3.

century, and serving the objective of maximizing efficiency. This resulted from interaction between various interests. When early system builders gave the electricity industry significant momentum for growth (Hughes 1983), they expanded their individual systems with the strategy of design-by-experience (Hirsh 1989); that is, on the basis of their previous experience, they developed new power systems conservatively, giving generous margins for error (Hirsh 1989). From the 1950s, however, in order to exploit economies of scale, utilities and manufacturers extrapolated the scale of power systems without sufficient experiment (Hirsh 1989). Additionally, although engineers had tested some characteristics of high voltage transmission lines (Hughes 1983), these large technological systems could not be tested in lab conditions (Vaughan 1996). In this evolving process, no one could anticipate the whole interconnection of systems in the Northeast region, particularly the interconnection of those systems in Michigan and New York through the systems in Ontario and around the Lakes Erie and Ontario. The reliability of the whole system was not their primary concern.

Second, after World War Two, the growth of the electricity industry accelerated the growth of demand for electricity through such campaigns as “Live Better Electrically” by General Electric Company in the United States (EIA 2000) and by Ontario Hydro in Canada (Denison 1960). In particular, the rapid increase of electricity consumption did not allow enough of a reserve margin at peak time in Ontario, Canada. One economic consideration for the large, interconnected regional systems was that this would improve a systems’ load factor (Hughes 1983). But this also forced the Northeast interconnected system to be operated near the critical point with small reserve margins.

Third, the political tension between private and public ownership made IOUs and the federal and state governments pursue the large-scale regional power systems. They revealed different perspectives regarding the ownership of hydropower resources in such regions as the Columbia Basin in Northwest, Tennessee Valley, the St. Lawrence River hydropower, the Susquehanna River of PJM, and the Ontario Hydro in Canada. Private, federal or state ownership was decided according to power relations among them and public's relationship with them.[25] In dominating other parties, the parties made themselves large enough enterprises to absorb neighboring power systems. Although the industry might have had a chance to be reorganized into smaller companies after the collapse of holding companies during the Great Depression, the U.S. Congress opted to retain utilities' size at least within state boundaries through the passage of the Public Utility Holding Company Act (PUHCA) of 1935 (Hirsh 1999).

Fourth, these guaranteed state boundaries for utilities allowed them to maintain big organizations which led to creating local knowledge between utilities and interconnected systems (Vaughan 1996; Geertz 2000). In this situation, dispatch control centers, although coordinated technically through automated systems, were loosely coordinated between their organizations, which made them unaware of the status of neighboring systems under a changing environment. Vaughan describes this:

> Local knowledge develops from a process of learning that has at its base tacit understandings about how to go about the work and about the product itself that are difficult to convey. Tacit understandings are knowledge that has not been formulated explicitly and, therefore, cannot be stored, copied, or transferred effectively by impersonal means, such as written

[25] The dominant power has usually been big power companies. Weil argues that "no matter what government might do, the business would be dominated by large, private corporations with enormous power to set the conditions under which they operate."Weil, G. L. (2006). *Blackout: How the Electricity Industry Exploits America*. New York, NY, Nation Books. p xix. See also Chapter 9: The Survivor and Other Friends of the Consumers.

> documents or computer files … the production of technical knowledge also depends on more ephemeral, intuitive skills that enhance discovery, interpretation, and learning from experience (Vaughan 1996 pp201-202).

Early technological developments in system control were able to spread to dispatch control centers through communication among engineers or by means of their journals, conferences and meetings; some examples of the media are the journal *Electrical World*, the Association of Edison Illuminating Companies, and the National Electric Light Association. Although electrical engineers coordinated with one another for planning and constructing power plants and transmission lines (Interviewee1 2008), however, the organizational experience and practice of each dispatch control center often remained within the individual centers rather than being exchanged. System operators would understand the characteristics of their own systems, but might not know those of their neighboring systems in detail because they neither directly operated nor monitored the others. Each system had its unique characteristics; in technical terms, for instance, they could be expressed as the system bias or the power number[26] of the system which varied from system to system due to different mixtures of various power resources in the system (Mariani and Murthy 1997). For reliable and economic dispatch of electricity, system operators may evaluate the best mix of steam, hydro, and peaking units several times a day. That is, New England Power Pool, New York Power Pool and the PJM interconnection have different mixes of power resources (Table 2.2), and thus may have different regulating bands[27] to maintain stable frequency (60 Hertz). If they face a

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[26] The power number of a system refers to frequency or system bias defined as the ratio $\Delta P/\Delta f$, where ΔP is the variation in generated power and Δf is the variation in frequency, expressed in MW per Hertz. Mariani, E. and S. S. Murthy (1997). *Control of Modern Integrated Power Systems*. New York, Springer.

[27] The regulating band is "an amount of power which does not cover a corresponding amount of power demand but is available for development, in a manual or automatic manner to face contingencies." For

demand increase or a contingency, they distribute the additional generation among power plants to meet the demand in accordance with the mix of their power resources. From the exclusive characteristics of their systems, operators acquire tacit knowledge that would be shared by those within the same dispatch center, but different from neighboring systems.

Table 2.2. Percent Distribution of Power Resources in the Northeast Region (1980)*

Resource / System	Gas & Oil	Hydro	Pump-storage	Coal	Nuclear
New England Power Pool	3.1	8.0	4.9	61.3	22.7
New York Power Pool	1.6	12.7	8.2	54.3	23.2
PJM Interconnection	1.5	2.9	10.4	69.5	15.7

This is the projected data from 1964 National Power Survey. Source: (FPC 1964)

System operators, therefore, did not have a holistic view point on integrated systems. Within a large, bureaucratized organization, engineers were positioned in one of several departments. They inevitably had to have a limited picture of management regarding the entire, interconnected systems. Vaughan mentions:

> Workers' control over their craft was altered when planning responsibilities were taken from the individual craft worker and shifted to managers, leaving the worker to follow orders, implementing plans without access to the full picture (Vaughan 1996 p204).

In fact, dispatch control centers are not a place to produce knowledge, but one where knowledge that is created and tested by engineers or scientists in the lab conditions is applied to operate technical systems. By the mid 1960s, electrical engineers usually planned and designed power systems, and system operators daily controlled them

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example, the regulating band of hydro power can range usually from zero to the maximum output, while that of a thermal unit is 20~30% of its total capacity. Ibid., p66.

(Interviewee1 2008). Operators controlled these systems with the knowledge obtained through education and person-to-person training within individual utilities. With the large interconnected transmission systems which were untested, however, system operators had to manage them without knowing much about their neighboring systems as well as the entire system.

In addition, even though engineers and system operators knew the physical features of interconnected grid systems – loop flow and parallel path flow – their corresponding management strategies did not seem to be developed due to the localized management of their systems. Casazza argues that “business decisions, government legislation and regulation, and other institutional processes must be compatible with the technical characteristics” (Casazza 1993 p24). However, because of the different goals and interests among IOUs, and state and federal governments, it was difficult to achieve a consensus on managing reliability and setting standards.

Lastly, an irony of organizing the electricity industry is that individualism and decentralized power as fundamental values in the United States have helped to establish the current large scale centralized electricity industry by reducing the power of federal government engagement. At the same time, however, development of integrated management for interconnected systems was interrupted by those values. As in the case of the Tennessee Valley Authority which is a federally owned entity with large scale power systems, there has been tension between investor-owned utilities and the federal government.[28] Utilities, by means of their natural monopoly, have developed an institutional environment that is beneficial to them. The roles of most utility lobbyists

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[28] For more discussion , see the Selznick’s book - Selznick, P. (1966). *TVA and The Grass Roots: A Study in the Sociology of Formal Organization*. New York, Harper & Row.

have been to protect existing systems from changes in the regulatory environment rather than to innovate their systems (Munson 2005). When Senator George Norris tried to make grid monopoly flexible in the 1920s, the utilities blocked the senator's effort (Munson 1985; Munson 2005). To reduce production cost, utilities wanted to alleviate strict environmental and other regulations, and simultaneously were in more favor of large centralized systems to increase supply. However, at the same time they confronted problems controlling systems due to interconnected, complex transmission lines and centralized power systems. As a result, it appears that they did not develop appropriate institutional conditions for the integrated management of the whole systems as in the cases of the air transportation system in the United States and the electric transmission systems in Russia.[29]

In sum, by the mid 1960s the electricity industry had created large scale technical systems at the regional level. They were so large that a simulation, although well designed in a laboratory, could not test them. Their primary goal was to maximize efficiency, and reliability was a secondary consideration which would be achieved additionally. While the physical systems were tightly interconnected, institutions were not sufficiently integrated to support them. Because of their localized practices, utility organizations could not evolve effective strategies for controlling systems larger than power pools. That is, the electricity industry, from its early beginnings to the post-war golden age (1945~1965) of its efficiency improvements and generalization of electricity, created and developed latent problems that affected the management of entire systems. This ultimately resulted in large scale blackouts. Considering this brief history of

[29] The two cases are discussed in Section 3.3.1 and 3.3.2 in Chapter 3.

transmission systems interconnection, I construct an analytic framework for large scale blackouts in the following chapter.

Chapter 3. Explanations of Large Scale Blackouts

Large scale blackouts are not a common research subject in the field of social science. Most of the analyses of blackouts are conducted by engineers, economists and physicists. Engineers identify problems due to technical deficiencies, physicists in physical phenomena of transmission systems, and economists in the institutional arrangement of the electricity market. By and large, a few representative explanations about causes of large scale blackouts can be grouped into techno-economic approaches and complexity & network theory approaches

The term, *techno-economic approach*, comes from a predominant mode of thought that seeks to explain large scale power failure from an economic viewpoint. Techno-economic approaches consist of three arguments: centralized power systems (expanding systems), decentralizing system design, and market design and revising rules. Many experts explain that strong and centralized transmission lines can prevent large scale blackouts (Friedlander 1966; Cook 1967; Metz 1977; Chang 2003; Gellings and Yeager 2004). It seems that the role of engineers in investigating large scale blackouts was clear in the 1960s when the electricity industry greatly improved its efficiency and productivity within each utility by applying advanced technology[30] and grew with the development of

[30] Alfred Chandler (1977, p8), explaining the railroad construction in the United States, argues that economic activities of an enterprise increased its volume, until reaching the level where administrative coordination with new technology and expanding markets was still more efficient than market coordination. Alfred D. Chandler, J. (1977). *The Visible Hand: The Managerial Revolution in American Business*. Cambridge, MA, The Belknap Press of Harvard University Press.; Thomas Hughes discusses how large

a unique economic concept – natural monopoly. In this context, many engineers thought that large scale blackouts were the result of insufficient interconnection of transmission lines. Therefore, they believed that integration of local power plants into regional bulk power systems would prevent future large scale blackouts. After the 2003 blackouts, this view is maintained by energy economists as well as engineers. The analysis by economists has gained sway in this field since the early 1990s when market liberalization began. Economists point out that current transmission networks are inconsistent with the market design for the deregulation (Joskow 2003). Because the current transmission systems are not designed for the competitive market, but for a natural monopoly, they are being stressed by the recent increasing usage of transmission lines. Then a general conclusion by both engineers and economists is to strengthen transmission systems with appropriate institutional settings – a more sophisticated market design. In contrast to centralized power systems, however, a group of people criticize unpredictable interactions within centralized, complex power systems (Lovins and Lovins 1982; Lovins, Datta et al. 2003). Thus, they argue that decentralizing power systems by giving more diverse and redundant options ultimately prevents large scale blackouts.

A group of scholars usually from physics have tried to explain cascading outages with the framework of the power-law distribution and network theories since the 1990s. They focus on the natural characteristics of the system itself, and call attention to the inevitability of cascading outages in networked transmission systems. These approaches

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systems such as the electricity industry has evolved with advanced technologies Bijker, W. E., T. P. Hughes, et al., Eds. (1987). *The Social Construction of Technological Systems: New Directions in the Sociology and History of Technology*. Massachusetts, The MIT Press.; and Richard Hirsh discusses how electricity industry has improved its efficiency with the development of technology (Hirsh, R. F. (1989). *Technology and Transformation in the American Electric Utility Industry*. New York, Cambridge University Press.

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are categorized into self-organized criticality, highly optimized tolerance (HOT), and network theories. Concerning self-organized criticality, Bak et al.(1988; 1991) find that all natural systems with interdependent subsystems having degrees of freedom evolve to a self-organized critical point at which they sustain their stability. As a result, a small variation can cause the collapse of a large interactive system until it finds a lower-level equilibrium. Carreras, Lynch, and Dobson (Carreras, Lynch et al. 2002) also find that the same phenomena occur in a designed system – transmission networks. The theory of highly optimized tolerance also explains the “robustness, yet fragility” of complex systems focusing on heterogeneous configurations of their internal features (Carlson and Doyle 1999; Carlson and Doyle 2002). Because of their complexity, these systems amplify small perturbations, and thus show cascading failure (Carlson and Doyle 2002). Based on the concept of HOT, the network theory pays attention to the internal features of network systems, such as grid systems (Watts and Strogatz 1998; Strogatz 2003). Watts explains that an initial failure of the most vulnerable, interconnected system can make neighboring systems vulnerable, and thus ultimately generate a global cascade (Watts 2002). These three theories, therefore, argue that large scale blackouts are inevitable because of the complexity of in transmission systems. (For a more detailed explanation, see Appendix 1).

These explanations, however, do not take account of social processes and the industry’s structure that have constructed conditions for large scale blackouts. They do not explain processes of how institutional settings have affected organizational performance or system operators’ decisions which provide initial states of technological failure. Engineers may make substantial recommendations, but cannot fully implement them without structural support which is considered and analyzed in the fields of social science and public policy. Physicists can provide a good explanation of physical phenomena. However, their analyses may be useless if they are not integrated into the policy formation for electricity reliability. It is necessary to consider interaction between technological systems and social structure. As Thomas Hughes argues, development of electricity cannot be separated from the social contexts in which it is located (Hughes 1983). A technological failure, such as a large scale blackout, is a collapse of a socio-technical system, neither exclusively attributable to purely technical nor purely human factors (Reason 1990).

In consideration of the historical formation of interconnected power systems briefly described in chapter 2, system operators' decisions are inevitably constrained by their political and institutional environments. Thus this chapter starts with discussions about the ways in which technological failures are socially constructed, and that as existing disaster studies point out, man-made disasters originated in latent problems. And I argue that these problems are constructed and masked by irrelevant rules and power relations.

On the basis of these perceptions, I try to construct a framework that is a combination of the three different theories in analyzing internal and external conditions of technological failure. I briefly describe key concepts of Normal Accidents Theory and High Reliability Organizations Theory which will guide the initial analysis of large scale blackouts: inevitable features of technological failure in high-risk systems, and a culture of reliability within and between organizations. In the view of the organizational and institutional failure behind technological failure, the chapter brings in new institutionalist approaches. The new institutionalism emphasizes high institutionalization as a factor explaining organizations' cultural persistence to change. The lack of a culture of reliability or loosely coupled interorganizational relationships can reveal some symbolic aspects (or rationalized myths) of reliability institutions in managing large scale technology. The insufficient role of the reliability institutions is related to the role of powerful groups who shape institutional settings and the degree of institutionalization. After that, I introduce two relevant examples through which to find factors to explain large scale blackouts. Lastly I develop a framework that accounts for the social process and structure of the electricity industry lying behind cascading outages.

3.1. Theories of Technological Disaster

3.1.1. Studies on Unintended Disasters in Social Science

A starting point for explaining the causes of cascading outages is that they are social phenomena constructed by society. Bijker et al. (1987) state that the construction of scientific knowledge is a social rather than epistemological task (Pinch and Bijker 1984 p401). Scientific findings and technological artifacts are not free from the social conditions of those who research natural phenomena and invent artifacts. Generally, private organizations and the government decide whether to adopt particular technologies (Perrow 2002). In the electricity industry, Hughes (1983 p2) argues that "electric power systems embody the physical, intellectual, and symbolic resources of the society that constructs them." As a core group which decides what kind of technologies are selected under certain social conditions, electrical engineers invented, developed, consolidated, and economically rationalized grid systems. Although it is true that the engineers control interconnected power systems according to the law of physics, it is also true that decisions on particular technologies and management of grid systems are affected by the interaction of private organizations and governmental institutions.[31] In the process of socially constructing technological artifacts or interconnected power systems, design problems or inappropriate operation of them are not free from the conditions of the society which has influenced the construction of them. In this view, we can think of technological failure as products of how society manages technological artifacts.

Some examples of how social conditions influence scientific uncertainties and technological failures are found in the works of Clarke (1989) and Vaughan (1996). They discuss the social construction of uncertainty, which results in technological failure, between and within organizations, and how the uncertainty is accepted in society. Clarke explains how risk assessment is constructed in organizational contexts, as he explores the organizational response to an accident at the Binghamton State Office Building, the inside of which was contaminated by toxic chemicals – dibenzofurans and naphthalenes – as a result of high heat and fire (Clarke 1989). He concludes that *relative power* between organizations decides the acceptable risk rather than scientific judgment. In contrast to the relative power, Vaughan (1996) pays more attention to *cultural factors* in socially accepting uncertainties, using other scholars' analytical tools – core-set[32] (Collins 1981),

[31] The configuration of power systems as a result of various social conditions, however, does not overlook the effect of electric power systems on social change. David Nye explores how electrification has shaped American society and landscapes. Nye, D. E. (1990). *Electrifying America: Social Meanings of a New Technology, 1880-1940*. Cambridge, MA, The MIT Press.

[32] Core-set refers to a few scientists who are actively involved in experimentation or observation, or contribute to the theory of the phenomenon. Here 'set' means a group of people who share similar interests. And these scientists, whether proponents or opponents, when involved in the controversy over a scientific

trading zones[33] (Galison 1997; Vaughan 1999), the experimenters' regress[34] (Collins 1985), epistemic culture[35] (Cetina 1999), and flexible interpretation (Pinch and Bijker 1984) – to explain the production of techno-scientific knowledge at the organizational level. She starts her discussion with the fact that organizational mechanisms to reduce uncertainty paradoxically produce disordered knowledge (Vaughan 1999). She describes how the uncertain and unruly complex technologies brought about by an unprecedented design are transformed into acceptable artifacts with certainty in intra- and inter-organizational processes. Although organizations multiply and institutionalize uncertainties due to the conflicting meanings of their distinctive local knowledge (Geertz 2000), they convert them into official certainty through organizational procedures in which people produce and use administrative texts[36] and change the conditions for

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finding, tend to resolve the controversy not by way of 'the outcome of experiments', but through 'outcomes of the argument over definition of success', on the basis of social contingency, in other words, their "world view." See Collins, H. M. (1981). "The Place of the 'Core-Set' in Modern Science: Social Contingency with Methodological Propriety in Science." *History of Science* **xix**: 6-19.

[33] Structural differentiation of organizational forms leads to the development of local knowledge, creating conflicts among sub-cultures. Then these subcultures engage in exchanges in "trading zones," an intermediate domain to coordinate action and belief. See Vaughan, D. (1999). "The Role of the Organization in the Production of Techno-Scientific Knowledge." *Social Studies of Science* **29**(6): 913-943.

[34] Experimenter's regress happens in the situation in which "it is hard for a test to have an unambiguous outcome because one can never be sure whether the test has been properly conducted until one knows what the correct outcome ought to be" (p2) and so on. See Collins, H. and T. Pinch (1998). *The Golem at Large: what you should know about technology*. Cambridge, UK, Cambridge University Press.

[35] Epistemic culture refers to the cultures – aggregate patterns – of knowledge settings or machineries of knowing processes; particularly, these settings for obtaining knowledge are possible by separating "objects from their natural environment and their installation in a new phenomenal field defined by social agents" (p27), which means that knowledge is inseparable from its social contexts – external regulators, publishers, funders, suppliers or customers. See Cetina, K.-K. (1999). *Epistemic Cultures: How the Sciences Make Knowledge*. Cambridge, MA, Harvard University Press.

[36] According to Smith, textually mediated forms of ruling organize contemporary industrialized societies; that is, documents, which objectify knowledge, organization, and decision-processes, reproduce social relations. And the documentary reality is created by the social organization of production of account. Particularly, "our relation to others in our society and beyond it is mediated by the social organization of its ruling. Our knowledge is thus ideological in the sense that this social organization preserves conception and means of description which represent the world as it is for those who rule it, rather than as it is for those who are ruled." See Dorothy Smith, (1974) The Social Construction of Documentary Reality, *Sociological Inquiry*, Vol. 44, No. 4 (257-268); Smith (1984) Textually mediated social organization, *International Social Science Journal*, Vol. 36 (59-75).

techno-scientific knowledge production so as to reach a consensus on acceptable risks (Vaughan 1999).

Instead of clearing uncertainties, they become embedded in organizations and may be masked by power relations, irrelevant rules and administrative procedures that do not offer real solutions. More generally, in this situation the knowledge produced in organizations becomes a reality which exists as taken for granted and as socially approved even though it does not reflect real situations. Individuals in an organization accept this reality as they absorb knowledge constructed within their organization; “this is the knowledge that is learned in the course of socialization and that mediates the internalization within individual consciousness of the objectivated structures of the social world” (Berger and Luckmann 1967 p66). Objective realities in social relations prevail through knowledge that is absorbed and constructed by individuals in society, as the knowledge mediates human actions. Latent uncertainties, which are masked by irrelevant rules or power relations between and within organizations, can lead to technological failure. As briefly sketched and summarized in chapter 2, the electricity industry developed, interacting with its societal environment. At the same time, however, it also retained latent structural problems, especially balkanized operation of interconnected transmission lines, because private utilities as a dominant power decided to manage grid systems in this way. Thus the individualized operations could not provide system operators with the full picture of the interconnected power systems that was necessary for integrated control.

Studies of large-scale technological failure in social science are only beginning to deal with these latent uncertainties or problems in social structure. Excepting some studies of natural disasters which started after World War II (Quarantelli, Lagadec et al. 2006), not much research on technological failure was systemically conducted before the mid 1970s. Technological failure was a topic that was usually analyzed by scientists and engineers. In the early 1970s, Roberto Vacca (1973 p4) mentioned that “our great technological systems of human organization and association are continuously outgrowing ordered control: they are now reaching critical dimensions of instability.” He pointed out that, however, we did not have the basic theory or terminology for dealing with technological failure in social science (Vacca 1973).

In the mid 1970s, social scientists began to pay attention to the development of a systematic understanding of the disasters originated by human forces – “man-made” (Perry 2006). These man-made disasters or technological failures began to be understood as unintended disasters, which are different from natural or deliberate disasters (Perrow 2006). Some representative cases of technological failures to which social scientists have paid attention as the social events are such accidents as asbestos-related illnesses since the 1970s, DC-10 crashes in 1972, 1974, 1979 and 1989, the Tenerife runway collision in 1977, the Ford Pinto rear-end collisions in 1978, the nuclear power radiation leak in Three Mile Island in 1979, Hyatt-Regency walkway collapse in 1981, Tylenol poisoning in 1982 and 1986, Bhopal poison gas release in 1984, space shuttle Challenger catastrophe in 1986, and the Chernobyl nuclear catastrophe in 1986 (Weick 1990; Shrivastava 1992; Vaughan 1996; Perrow 1999; Manion and Evan 2002). Starting with Turner’s research on man-made disasters in 1976 (Turner 1976; Turner and Pidgeon 1997), the study of technological disaster has become an organized field of social science research. After analyzing 84 large scale accident and disaster reports published by the

British Government during the period from 1965 to 1975, Turner, whose background was chemical engineering, identified common patterns of those disasters and constructed a theory of ‘the incubation model’; that is, man-made disasters have preconditions whose warning signs are ignored or misinterpreted because they are indistinguishable in the incubation period, and therefore Turner’s focus is on the failures of foresight (Turner and Pidgeon 1997). At the time, social scientists did not give much attention to his theory, particularly in the United States.

After the nuclear power accident at Three Mile Island in 1979, social scientists, particularly in sociology, recognized problems of social systems with respect to large scale technological failure, and showed interest in theorizing about technological accidents and disasters. Among those who analyze social aspects of technological failure, Charles Perrow takes the central position in theorizing them and opens a new field of studies on technological failure in social science. Before Perrow’s analysis of the Three Mile Island accident, there were discussions about the structural problems behind human errors related to large scale technological failures. Since Perrow, this new academic field has been extended and deepened by Rasmussen et al. (1987), Weick (1987; 1990), La Porte (1991), LaPorte and Consolini (1991) Clarke (1989; 1999), Westrum (1991), Shrivastava (1992), Reason (1990; 1997), Vaughan (1990; 1996; 1999; 1999; 2004), Sagan (1993; 1994), Rudolph and Repenning (2002), Manion and Evan (2002), and others. And this field has become a major part of organization theory (Scott 1998). Although there are many controversial issues – arguments over difference between natural and technological hazards, contribution of social constructionism to theories of risk, fairness and trust related to risk perception, human errors or organizational, institutional & cultural factors, and organizational response to accidents (Clarke and Short 1993) – the main thrust of the argument is on the two representative theories – Normal Accidents Theory proposed by Charles Perrow and High Reliability Organizations Theory by Todd La Porte and his colleagues – which are repeatedly tested by others as main frameworks for observing failures in large scale technical systems.

3.1.2. Normal Accident Theory

After the Three Mile Island accident, Charles Perrow (1999) asked whether better organizations would help, or more money and resources for better people and equipment? As an organization theorist, he agrees with Simon's position on individual decision makers who have bounded rationality; 'administrative men' pursue their self-interests, but have limited knowledge about their condition and alternatives (Perrow 1986; Perrow 1999). In bureaucratic organizations, operators with bounded or limited rationality cannot have complete knowledge of the systems although they have several alternative responses to the systems failure. Hence, Perrow starts with an assumption that there is no perfect solution to technological failure. In addition, he is not sanguine about governments' and industries' efforts. He enumerates major factors that cause technological failures in terms of DEPOSE – *d*esign, *e*quipment, *p*rocedures, *o*perators, *s*upplies and materials, and *e*nvironment (Perrow 1986). Instead of discussing these individual sources of failure for explaining each accident, he pays more attention to the ramifications of how these factors produce system disasters: interactions of small failures, small beginnings resulting in a large accident (transformation), and the role of organizations and management –

organizational contradictions caused by decentralization and centralization at the same time.

From the above promises, Perrow argues that we can neither avoid accidents nor eliminate risk from high-risk systems in modern society, and that "no matter how effective conventional safety devices are, there is a form of accident that is inevitable" (Perrow 1999 p3). "Complexly (or linearly) interactive" [37] and "tightly (or loosely) coupled,"[38] which are properties of high-risk systems, are his key words for explaining and categorizing technological accidents. Because of these properties of high-risk technological systems, an unexpected interaction between parts, between units, and between subsystems is normal. He says that, historically, better organization and technological fixes have reduced interactive complexity and tight coupling, but cannot remove accidents. Adding more safety devices means more inexplicable interaction among unavoidable failures, thereby resulting in catastrophic accidents. From this perception, he coins the odd term "normal accident" (or system accident)[39] in the sense that, considering the characteristics of high-risk systems which are complexly interactive and tightly coupled, we inevitably confront multiple and unexpected interactions of small failures resulting in catastrophic system accidents although they are rare (Perrow 1999). Perrow applies the concepts of *interactive complex* and *tight coupling* to both human

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[37] To explain *complex interactions*, he introduces the three essential indications of interactiveness: 'common-mode' (components in a machine serve multiple functions), 'proximity' (close proximity causes an unanticipated interaction between two independent, unrelated subsystems), and 'indirect information.' Then he specifies that "*complex interactions* are those of unfamiliar sequences, or unplanned and unexpected sequences, and either not visible or not immediately comprehensible." And the opposite condition is the presence of linear interactions which are visible and comprehensible. See Perrow, C. (1999). *Normal Accidents: Living with High-Risk Technologies*. Princeton, Princeton University Press., p78.

[38] If two parts are quite dependent each other, this dependence is known as tight coupling; and if two events occur independently, these are loosely coupled events because although they are involved in the same accident in the same time, one was not caused by the other. Ibid.

[39] By Perrow's definition, "an *accident* is a failure in a subsystem, or the system as a whole, that damages more than one unit and in doing so disrupts the ongoing or future output of the system. An *incident* involves damage that is limited to parts of a unit, whether the failure disrupts the system or not." Ibid., 66.

organizations and technological systems, which leads to different starting points in supporting or criticizing his theory. [40]

Regarding organizational performance, Perrow discusses a dilemma of operating high-risk systems that are interactively complex and tightly coupled. To deal with tightly coupled systems, operators need centralized systems to check everything within a limited period, but to reduce the unexpected interaction of small failures in interactively complex systems, operators need decentralized systems (Perrow 1999). However, he argues that it is incompatible to both centralize and decentralize system operation – “both local autonomy and centralized control” – at the same time under tightly coupled, interactively complex systems (Perrow 1986 p150). To overcome this problem “somewhat,” he argues that it is necessary for an organization to continuously rotate personnel from bottom to top, so as to spread the skills and the accumulated experience, balancing between on-line experience of the operator and system-wide comprehension of the top management. But this process imposes expensive labor costs (Perrow 1986). Therefore, there is no real solution regarding the dilemma of a centralized-and-decentralized system design under tightly coupled, interactively complex systems. In his early article of The *Bureaucratic Paradox: The Efficient Organization Centralizes in Order to Decentralize*, however, Perrow argues that both a centralization and a decentralization in decision-making processes of an organization should exist simultaneously by controlling “the cognitive

[40] Lee Clarke regards the two concepts as properties of organizational configurations, while Karlene H. Roberts understands them as properties of technological systems, and argues that Perrow takes an engineering perspective. See Clarke, L. and J. F. Short (1993). "Social Organization and Risk: Some Current Controversies." *Annual Review of Sociology* **19**: 375-399., p388. and Roberts, K. H. (1990). "Some Characteristics of One Type of High Reliability Organization." *Organization Science* **1**(2): 160-176., p163. In addition, La Porte points out that “in characterizing air traffic control, grid management and even flight operations as basically linear, Perrow confuses technical complexity with social and operational complexity.” See LaPorte, T. R. and G. Rochlin (1994). "A Rejoinder to Perrow." *Journal of Contingencies and Crisis Management* **2**(4): 221-227., p223.

premises underlying action" (Perrow 1977; Perrow 1986 p129). Although he does not classify the properties of organizations, at the time, for both centralization and decentralization simultaneously, he discusses the necessity and possibility to centralize and decentralize decision making in complex, bureaucratic organizations by "indoctrination into the values of the larger systems that sustain the particular organization" (Perrow 1977 p13). He argues that the simultaneous process of centralization and the decentralization is necessary for efficient organizations which are emerging (Perrow 1977). I argue that this is true for organizational reliability or safety which I discuss as a proposition later in this chapter.

Considering the bounded rationality of each individual and current features of high-risk systems, his solution is that to reduce the possibility of large scale technological accidents, we need to reorganize decision-making systems which support social rationality – social bonds or social cooperation – and to redesign high-risk systems. As he points out the limitations of the centralized decision-making process on the basis of absolute rationality in a high risk society, he recommends the combined roles of various groups – social rationality – to reduce the possibility of normal accidents. As a final point he argues that power in and of organizations plays a certain role in systems failure.

Perrow extends his argument to the role of powerful groups and individuals who give more attention to efficiency for profit maximization than safety and reliability, which are regarded as production costs. The problem of organizational failure is not the culture of the organizations, but the power of decision makers both inside and outside the organization. Perrow defines organizations as tools to achieve group goals and interests within and between organizations. There are various groups who utilize organizations for their own ends which are not consistent with official goals or the public interest (Perrow 1999). As a result, the interests of influential decision makers may manipulate the primary goal of safety or reliability in organizations (Sagan 1993). Perrow insists that powerful individuals within and without the organization may influence the construction of reliability, making system failure more probable. This perspective can be extended at the institutional level; the exercise of power in establishing institutions affects organizational performance for reliability.

The power relations in Perrow's disaster theory are more explicitly explained by Sagan's discussion of bounded rationality and group interests. In his book of *The Limits of Safety*, Scott D. Sagan (1993; 1994) applies two models – the NAT and the HROs Theory [41] – to three cases so as to compare which theories explain the cases more explicitly. He identifies that 'redundancy' to improve reliability in a system or an organization simultaneously has a possibility to inadvertently reduce its reliability, and that 'organizational learning' usually reflects the narrow interests of influential organizations as the record or collective memory is filtered by powerful past members. His emphasis on the role of powerful groups with respect to the reliability of organizations or systems gives some insights in analyzing a real, structural situation of system.

In the case studies in Chapter 5, 6 and 7, through the framework of NAT, I initially observe the sequence of system failures that led to the four large scale blackouts. The dissertation also uses his concepts of centralization-and-decentralization and the role of

[41] While Perrow and Sagan insist on the inevitability of technological failure, La Porte and his group want to examine why some organizations successfully operate their technological systems – high reliability organizations. See LaPorte, T. R. and P. Consolini (1991). "Working In Practice but Not in Theory: Theoretical Challenges of High Reliability Organizations." *Journal of Public Administration Research and Theory* **1**(1): 19-47.

power groups in analyzing their structural aspects. According to NAT, large scale blackouts are a kind of normal accident,[42] when considering that transmission networks are too tightly coupled with a complex organization made up of a variety of utilities and power pools in the market. Hence, cascading outages are an inevitable system failure. To the extent that his theory explains static snapshots of technological systems, however, it misses processes by which operators act to trigger a small failure or fail to recover from small failures in grid systems. Operators are not a static entity in the chain of systems, and could maximize or minimize system failures in accordance with their given conditions. Thus, to get a more integrated perspective of large scale blackouts, we need an analysis that includes the explanations of how human errors linked to surrounding conditions amplify the outcomes of systems failure. In contrast to the normal accident theory which deals with properties of technological systems, another group of scholars with High Reliability Organizations Theory pays attention to organizational performance to improve reliability.

3.1.3. High Reliability Organizations Theory

A group of scholars – led by a group at Berkeley and Karl Weick – have studied complex organizations and have reacted to the normal accidents theory by proposing the HROs theory. Todd La Porte and his colleagues start with a set of components – interactive complexity and tight coupling – that Perrow has identified as “risks” that may

[42] In fact, Perrow assumes that electric grids are tightly coupled and linear systems with predictable interactions, not interactively complex ones. Thus, he excludes large scale blackouts from his analysis. See Perrow, C. (1999). *Normal Accidents: Living with High-Risk Technologies*. Princeton, Princeton University Press. But the grid systems consist of a variety of components with various organizations involved, which makes the system complexly interactive. In later work he categorizes large scale blackouts as normal accidents. See Perrow, C. (2007). *The Next Catastrophe: Reducing Our Vulnerabilities to Natural, Industrial, and Terrorist Disasters*. Princeton, New Jersey, Princeton University Press.

cause disasters. They argue that some potentially hazardous organizations – aircraft carriers, U.S. air traffic control systems, some power distribution grids and international banking – deal with these components successfully without any accidents (Rochlin, Porte et al. 1987; Roberts 1990). The properties of these high reliability organizations include good organizational design and management, safety as the organization's primary goal, redundancy, decentralized decision-making, a culture of reliability, continuous training of their employees and trial-and-error learning. In table 3.1, Sagan compares the two theories.[43]

Table 3.1. Competing Perspectives on Safety with Hazardous Technologies

High Reliability Organizations theory	Normal Accident theory
Accidents can be prevented through good organizational design and management	Accidents are inevitable in complex and tightly coupled systems
Safety is the priority organizational objective	Safety is one of a number competing objectives
Redundancy enhances safety: duplication and overlap can make 'a reliable system out of unreliable parts'	Redundancy often reduces safety: it increases interactive complexity and opaqueness and encourages risk-taking
Decentralized decision-making needed to permit prompt and flexible field-level responses to surprises	Organizational contradiction: decentralization for complexity but centralization for tightly coupled systems
A 'culture of reliability' will enhance safety by encouraging uniform and appropriate responses by field-level operators	A military model of intense discipline, socialization and isolation is incompatible with democratic values
Continuous operations, training, and simulations can create and maintain high reliability operations	Organizations cannot train for unimagined, highly dangerous, or politically unpalatable operations
Trial and error learning from accidents can be effective and can be supplemented by anticipation and simulations	Denial of responsibility, faulty reporting, and reconstruction of history cripple learning efforts

Source: Sagan (1993 p46)

[43] Perrow also discusses that Sagan identifies four critical features regarding high reliable organizations: "1) political elites and organization leaders put safety and reliability first as a goal; 2) high levels of redundancy in personnel and technical safety measures; 3) the development of a 'high reliability culture' in decentralized and continually practiced operations; and 4) sophisticated forms of trial and error organizational learning." See Perrow, C. (1994). "The Limits of Safety: The Enhancement of a Theory of Accidents." *Journal of Contingencies and Crisis Management* **2**(4): 212-220., p214.

The high reliability organization theory suggests some constructive solutions to improve organizational reliability, while the normal accidents theory is pessimistic about technological systems. The HROs approach focuses on the conditions of organizational performance for high reliability, while NAT identifies specific properties of high-risk systems. In this sense, La Porte argues that he and his colleagues are interested in properties of high reliability organizations, not the causes of technological accidents (LaPorte and Rochlin 1994). Therefore, the HROs theory selects those cases of error-avoiding or failure-free "organizations," while NAT usually analyzes error-inducing or already failure-experiencing "systems." Karlene H. Roberts argues that the normal accident theory deals with the characteristics of technical systems, not the properties for high reliability organizations, and proposes that the high reliability of hazardous organizations can be enhanced by adding the above properties to their performance (Roberts 1990). Accordingly, La Porte explains that their HROs can be complementary to the normal accidents perspectives (LaPorte 1994). And he wants to reveal more practical, abundant properties of high reliability organizations, challenging current theoretical limits in analyzing large scale technical systems (LaPorte and Consolini 1991).

One of the issues La Porte raises is that he and his colleagues' analyses concentrate on a set of common organizational and structural factors within high reliability organizations, and try to identify the organizational and socio-cultural conditions that make organizations relatively safe and technological management productive (LaPorte and Rochlin 1994). NAT also generally gives attention to the inside properties of high-risk systems. However, neither theory considers the conditions of inter-organizational relationships and the properties of the networked systems that are organizational features of interconnected transmission systems in the electricity industry. An analysis of inter-organizational relationships is an important aspect of interconnected transmission systems, because individual electricity systems, which are interconnected through transmission lines, are controlled by each electric utility. Therefore, it is necessary to extend the HROs theory by including a relevant framework of explaining the inter-organizational relationships in which large scale blackouts occur. The inter-organizational relationship is beyond the authority of one organization and should be managed and regulated at the institutional level. Hence, an institutional approach can be a relevant framework to improve our understanding of the conditions of inter-organizational relationships which bring about large scale blackouts.[44] In this perspective, the two successful cases – the air transportation system in the United States and the interconnected power systems in Russia – are illustrated in Section 3.3.

Another issue is that the HROs group does not consider the role of power in their explanation of constructing a culture of reliability, while NAT significantly discusses it in regard to the process of decision-making and technological system design. In the electricity industry, different interests conflict with one another in the process of constructing institutions, which should be considered in explaining inter-organizational relationships. A culture of reliability between organizations may not be created without cooperation between utilities and regulatory bodies. This is discussed in Section 3.2.2

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[44] Studies on inter-organizational relationship have been dealt with by various approaches and theories. They are "industrial economics, organizational economics, industrial marketing and purchasing, organizational sociology, game theory, resource dependence theory, population ecology, institutional theory, and social network approaches." Ebers, M. (1997). Explaining Inter-Organizational Network Formation. *The Formation of Inter-Organizational Networks*. M. Ebers. New York, Oxford University Press., pp 5-15. Their research mostly focuses on the motives for cooperation among organizations at the actor level, and socio-economic conditions for the formation of inter-organizational networks at the institutional level. However, they rarely pay attention to how an inter-organizational network produces flip side of itself.

3.2. Institutional Imbalance and Organizational Inertia

3.2.1. Culture and Organizational Failure

The HROs theory extends the scope of analyzing potentially high risk organizations to consider socio-cultural factors. I emphasize the importance of culture, because a culture of reliability will guide timely and appropriate decision-making during emergencies. Organizational safety culture after the accident at Chernobyl becomes an important factor to be considered in technological failure (Pidgeon 1997). A culture is generally defined as a system of symbols or meanings through which a group of people understand the world (Pidgeon 1997), and also a set of solutions which is institutionalized and passed on as the rules, rituals, and values of the group[45] (Vaughan 1996). In the combined explanation of human actions, socio-cultural factors, and environmental preconditions of technological failure, such scholars as Karl Weick and Diane Vaughan discuss cultural aspects of organizations. While Perrow does not deal with the changing process of inside actors in systems, Weick gives more attention to those actors who can change loosely coupled components into a tightly coupled interactive system. He points out that technological accidents occur because human beings are not sufficiently complex to discern and predict problems generated by the complex systems they operate and manage (Weick 1987). As he searches for some features of high reliability organizations,

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[45] A representative example of culture is language. A language as a symbol is a medium for communication. Understanding the language is based on its cultural background or meaning systems. Without understanding the cultural background, the language is merely a series of sounds.

Weick (1987; 1990) examines the process of how small events are linked together and amplified, resulting in large, disastrous consequences. In his macro-micro analysis of the Tenerife air disaster, Weick (1990) as a psychologist points out the role of individuals who are affected by a stressful environment; as a result, operators' small errors lead to the breakdown of coordination among organizations. He discovers that communication among and within groups is critical in improving high-reliability performance, and insists on developing a "collective mind" in an organization through social skills (Weick 1993). Thus, the organizational culture, in which people share "similar decision premises and assumptions" through socialization, becomes an important factor for high reliability organizations (Weick 1987 p124).

As mentioned earlier, Vaughan (1996), investigating and describing the *Challenger* launch disaster through a historical ethnography and macro-micro analysis, identifies broad socio-cultural causes of the disaster. She revisits and reinterprets existing documents and discovers how technological deviations in an organization have been normalized to the extent that the organization accepts risks as taken for granted in the culture of the NASA organization. In the analysis of *Challenger* launch decision, she explores that "historically, economic conditions, social relations, and politics have shaped technological products, undermining their quality" (MacKenzie and Wajcman 1985, cited by Vaughan 1996 p20). But a more important thing she wants to discuss is, in her term, the theory of *the normalization of deviance* – the production of culture, the culture of production and structural secrecy – rather than the historically accepted interpretation of the *Challenger* disaster – production pressure and managerial wrongdoing. She argues that mistake, misconduct, and disaster are, as previously discussed, "socially organized and systematically produced," and that the social cause of disaster comes from mistakes entrenched in the banality of organizational life (Vaughan 2004 p342). The simple replacement of personnel neither addresses social causes of disaster nor changes the organizational culture which produces disaster; her premise is that an individual's choice is not free from their organizational and environmental context. She mentions those environmental factors that facilitate a disaster: "scarcity and competition, elite bargaining, uncertain technology, incrementalism, patterns of information, routinization, organizational and inter-organizational structures, and a complex culture" (Vaughan 1996 p xiv).

Human actions, when they meet with external factors such as production pressure and a changing environment, can increase the possibility to bring about errors, thereafter triggering and magnifying the failure along with the structural problems – sloppy management,[46] conflicting goals, poor design and defective organizational settings – in the organization. Although highly complex systems themselves have an inevitable potential of technological failure due to the unforeseen interaction of small component failures as stated by Perrow, they are also controlled by operators who are affected by a variety of internal and external variables. In this sense, Weick's analysis with the internalizing process of external stress in human mentality, and Vaughan's view of the *Challenger* launch disaster through an explanation of normalization of deviation give us more room to analyze and consider the operators' tasks to improve reliability. It is the

[46] A simple meaning of sloppy management is the disregard of safety rules and instructions, ignoring warnings, lack of adequate communication. From the sloppy management perspective, Turner has developed an incubation model of disaster according to which there are six phases of disaster development: "[1]a notionally normal starting point; [2]an incubation period; [3]terminated by a precipitating event; [4]which leads to the onset of the disaster; [5]rescue and salvage dealing with the immediate problems after the disaster; and [6]a final stage of full cultural readjustment to the surprise associated with the precipitating event." See Turner, B. A. and N. F. Pidgeon (1997). *Man-Made Disasters (2nd ed.)*. Boston, Butterworth-Heinemann., p83.

organizational culture that should be considered in technological failure, as Weick and Vaughan emphasize. Cultures in an organization, which are influenced by its environment, are more broadly discussed in the New Institutional approach.

Just focusing on socio-cultural factors in analyzing technological accidents, however, might miss another aspect of how institutions to support a culture of reliability are created and maintained in an arena with conflicting interests. Perrow argues that “a cultural approach is necessary, but it must be informed by an awareness of political and organizational power” (Perrow 1986 p265). Powerful groups or decision makers are located in the position to set organizational goals and create organizational cultures that may not be sufficient for organizational reliability. Thus, power relations are another factor that should be considered in the analysis of technological failure with respect to networked systems. The two concepts – power and culture – should be treated equally in examining large scale blackouts. These are further discussed in relation with an institutional approach in the next section.

3.2.2. Power, Institutional Imbalance, and Organizational Inertia

In this section, I discuss the following concepts: centralization-and-decentralization in an organizational culture, organizational inertia, symbolism (rationalized myths) of institutions, and the role of powerful groups. These concepts are used to construct the analytic framework to support my arguments. That is, as I repeatedly state, system operators’ decision-making is not independent of their institutional environments, and powerful groups exert influence on the creation and development of reliability institutions. The section introduces the New Institutionalism.

A (new) institutional approach in the social sciences has revived in recent decades.[47] Since the mid-1970s, a group of organizational theorists have recognized organizations as more than production systems; they do not think that organizations are simply “a product of increasing technical sophistication from within” (Scott 2001 p43). As Scott (1998) defines, organizations are seen as socio-cultural and open systems which interact with their institutional environment. A group of organizational theorists pay attention to institutions in order to observe cultural aspects of organizations (Scott 2001) and examine inter-organizational relationships (Meyer and Scott 1992). At first, taking Berger and Luckmann’s perspective, Scott (2001) defines facts in the real world as agreement by human beings, and cultures as common meaning or belief systems constructed in social interaction. Social institutions refer to types of social reality carried out through regulative rules which are emphasized by scholars embracing a regulative view of institutions, and constitutive rules[48] which are stressed by cultural-cognitive scholars (Scott 2001). In this view, organizational behavior is affected by the socially embedded logic of institutions. Organizations, as collective actors, “result from the increasing rationalization of cultural rules that provide an independent basis for their construction” (Scott 2001 p43).

Institutional environments bound the behavior of actors and organizations through regulative, normative, and cultural-cognitive elements[49] (Scott 2001). Institutions as a

[47] New institutional approaches are discussed usually in political science, economics, and sociology. The dissertation focuses on new institutional approaches in sociology.

[48] Constitutive rules refer to deeper level mechanisms devising categories and constructing typifications through which human experiences become an ongoing reality, objectively and subjectively, under general orders of meaning. See Scott, W. R. (2001). *Institutions and Organizations*. California, Sage Publications, Inc., p64, and Berger, P. L. and T. Luckmann (1967). *The Social Construction of Reality: A Treatise in The Sociology of Knowledge*. New York, Anchor Books., p39.

[49] Cultural-cognitive elements refers to “the shared conceptions that constitute the nature of social reality and the frames through which meaning is made” including symbols – words, signs, and gestures; normative

form of external pressure have an influence on the internal formation of organizational behavior. Institutions provide individuals and organizations with meaning and stability so that social life can continue (Scott 2001). Individuals in organizations attain routine behavior as they reify social relations which are at first unfamiliar to them. They get acquainted with the routines through mechanisms – cultural-cognitive, normative, and regulative elements – behind the social practice. With an extension of this view by Giddens's term of *structuration*,[50] the individual actions, whether or not relevant to their jobs, are institutionalized through time and across space.

From these insights, we can say that electrical engineers and managers in the early period of the electricity industry created institutions that were necessary for controlling electric power systems. At the same time, they were influenced by the established institutions. The dominant institutions from the 1890s to World War I were individual public and private utilities, and their managers decided the configuration of the power systems rather than inventors and engineers (Hughes 1983). Then regional coordinators in interconnected systems, reliability standards, and state level regulatory agencies developed.

In this institutional environment, creating a culture of reliability as well as efficiency in utilities is a major process involving the establishment of institutions; first with

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elements refers to prescriptive, evaluative, and obligatory dimensions of institutions – that is, how things should be done; and regulative elements, such as rules, laws and sanctions, are to constrain and regularize behaviors. Scott, W. R. (2001). *Institutions and Organizations*. California, Sage Publications, Inc., pp51-58.

[50] Giddens (1986) coins the term *structuration* to define social structure which cannot be just visual imagery such as the girders of buildings, external to human actions. The social structure does not explain social relations in society. He pays attention to the reproduction of similar social practices across varying spans of time and space. According to him, while "the most important aspects of structure are rules and resources recursively involved in institutions," structuration refers to "conditions governing the continuity or transmutation of structures, and therefore the reproduction of social system." A social system means "reproduced relations between actors or collectivities, organized as regular social practices." Giddens, A. (1986). *The Constitution of Society: Outline of the theory of Structuration*. Berkeley, University of California Press., pp24-25.

development of regulative institutions and then with institutionalization, including cultural-cognitive factors. Institutions and institutional settings, here, refer to regulative and normative aspects – rules, laws, values and expectations – and regulatory agencies – Federal Power Commission (FPC, later Federal Energy Regulatory Commission), state public utility commissions, NERC, regional reliability councils, and regional power pools. As for the cultural-cognitive aspects, concerning the unique conditions of the electricity industry – with interconnected transmission lines and tightly networked systems – the industry should be expected to need holistic management of its systems.

This could be achieved by drawing upon two perspectives from the HROs theory so as to create reliability management of the interconnected systems (see table 3.1). One is a ‘strong organizational culture’ of centralizing similar premises and assumptions - recruiting, socialization, incentives for organizational mission (LaPorte 1991) – and another is ‘decentralized decision making’ for flexible field-level responses to emergency situations. Weick clearly describes this process of centralization-decentralization. That is;

> Before you can decentralize, you first have to centralize so that people are socialized to use similar decision premises and assumptions so that when they operate their own units, those decentralized operations are equivalent and coordinated. This is precisely what culture does. It creates a homogeneous set of assumptions and decision premises which, when they are invoked on a local and decentralized basis, preserve coordination and centralization (Weick 1987 p117).

Therefore, I believe that the electricity industry must develop a culture of reliability by centralizing basic premises and assumptions and at the same time by decentralizing decision making at each utility level. In particular, a centralization-and-decentralization is necessary during emergency situations. If one of utilities experiences a system failure, then it must share the information with other neighboring utilities, so that they can prevent the spread of the initial failure to other systems. According to the reliability standards of NERC, the operational decisions among utilities should be made usually within 15 minutes during an emergency. This would be possible if they make decisions using shared premises among the control centers of each utility.

The industry, however, appears not to really have a strong culture of reliability – reliable inter-organizational relationships – when the causes of the four large scale blackouts are considered. Because utilities retain the autonomy of controlling their own facilities, they can make decisions independent of other systems, reliability coordinators and reliability institutions. In Weick’s terms (1976 p4), there is no strong coupling mechanism – benefits, responsibilities, or sanctions – between utilities, between utilities and their reliability coordinators, and between utilities and reliability institutions. Although they coordinate interconnected power systems, they control their interconnected systems in a loosely coupled way, without much sharing of premises and assumptions.

Of course, the industry has developed impressive and somewhat reliable electric systems through the efforts of private and public utilities. The bottom-up approach in creating reliability institutions allowed control of interconnected power systems. Nevertheless, it seems that the industry has not developed appropriate institutions nor institutionalized common premises and related decision-making processes within and between utilities, as it has developed systems interconnection to improve the efficient supply of electricity.

Regarding this institutional imbalance, one basic interpretation by the new institutionalist approach is to see institutions as rationalized myths. Formal organizations are constructed under the domain of rationalized institutions. And these institutions are merely cultural symbols and rationalized myths,[51] because they do not reflect real demands of the organization's work (Meyer and Rowan 1977). Organizations usually adapt to their institutional environments which are created by the force of powerful organizations (Meyer and Rowan 1977), and assume that the institutions rationalize their structural forms and activities. As a result, organizations' structural forms and practices become isomorphic (DiMaggio and Powell 1983). Indeed organizational structures and practices of the electric utilities are very similar in terms of professionalization.[52] Reliability institutions have developed a formal structure in dealing with reliability standards: planning and system operation tasks. Then major utilities have corresponding sub-organizations which conduct common functions for reliability – usually construction planning, finance, reliability coordination, transmission operating centers, emergency planning, training, and so on. Because the interorganizational relationships are loosely coupled, however, the electricity industry has not practically developed necessary contents of reliability related institutions, although it has tried to develop them. Meyer and Rowan (1977) argue that because the rationalized institutions are merely rationalized myths, actually they do not secure the survival or success of organizations which pursue

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[51] The conceptualization of institutions as myths comes from the study of education systems and hospitals conducted by John W. Meyer, Brian Rowan and W. Richard Scott in the early 1970s. And they generalize what they have found. See Perrow, C. (1985). "Review: Overboard with Myth and Symbols." *The American Journal of Sociology* **91**(1): 151-155., and Meyer, J. W. and B. Rowan (1992). The Structure of Educational Organizations. *Organizational Environments: Ritual and Rationality (Updated Edition)*. J. W. Meyer and W. R. Scott. Newbury Park, California, Sage Publications.

[52] DiMaggio and Powell provide three types of institutional isomorphic change: coercive isomorphism, mimetic isomorphism, and normative isomorphism. According to coercive isomorphism, some organizations exert formal and informal influence on other organizations. Government regulations can change organizations' practice. Mimetic processes means that organizations imitate other organizations' features and practice due to uncertainty. By normative pressure, professional workers define the conditions and methods of their work, "to control the production of producers and to establish a cognitive base and legitimation for their occupational autonomy." DiMaggio, P. J. and W. W. Powell (1983). "The Iron Cage Revisited: Institutional Isomorphism and Collective Rationality in Organizational Fields." *American Sociological Review* **48**(2): 147-160., p152.

productive efficiency in their specific situations. In this sense, the reliability institutions exist, to some extent, as rationalized myths masking real situations.

In addition to the above explanation which focuses mostly on the contents of institutions, another account of organizational failure leading to technological failure is the process of institutionalization and cultural resistance to change. Zucker (1991) argues that high institutionalization increases the cultural persistence of organizational action. As mentioned above, actors or organizations create and follow rules simultaneously in a process of structuration. Actors and organizations can transform things – transformative capacity (Baert 1998). However, "the very factors that make a system reproducible make it resistant to change" (Hannan and Freeman 1984 p154). Because of the resilience of the internalized institutions in which an actor's behavior is embedded, actors or organizations may fail to adapt to changed institutional environments, thereby resulting in organizational and thus technological failure. Hannan and Freeman (1984 p151), who are organizational ecologists, also argue that because of the high level of reproducibility, "organizations respond relatively slowly to the occurrence of threats and opportunities in their environments." In the early 1990s after the enactment of *the Energy Policy Act of 1992*, there was a critic regarding utilities' reluctance to adopting new innovative systems under a changing environment (Griffith 1993). In organizational practice, resilience to these changes can be noticed from some negative signals when large scale blackouts occur. In fact the 1965 blackouts started from the backup relays whose capacity settings had not changed since 1963 although there was a constant increase of power trading between Canada and the United States. The 2003 blackout occurred due to the obsolete monitoring systems in utilities, negligence of tree trimming, and inadequate training hours (Munson 2005). Before and after the 2003 blackout, reliability institutions raised a question of outdated reliability standards in the changing institutional environment – deregulation – under which the traffic of electricity on transmission lines became heavier. Major utilities, which once administered their transmission systems, lost their incentives to construct and maintain them, as the control of transmission systems was separated from that of generating systems. As a result, actors in organizations are often neither aware of nor seriously accept those negative signals. Actors' conventional practices do not change easily in response to changing physical or institutional environments. Old organizational behavior which has developed from old institutional arrangements is inconsistent with new institutional arrangements.

Two questions are raised. Why are organizations culturally resistant to change? Why do reliability institutions exist to a certain extent as rationalized myths? The question can be considered in the conditions under which the goals and interests of utilities conflict with those of federal government regarding inter-organizational relationships. As the story of the public power movement called Giant Power in Pennsylvania and the creation of PJM tells us, utilities may want more autonomy for their system management, while federal or state governments want to have control over interconnected transmission systems. Then power relations will govern those interests, and therefore, those who dominate the industry will decide the structure of inter-organizational relationships that affect the culture of reliability. In organization theory, power is defined as the capability of one social actor or group to overcome resistance and thus to extract a desired objective or outcome from a given system where each interest conflicts with another (Pfeffer 1981; Perrow 1986). The new institutionalists generally focus on the cultural aspects, that is, “the taken-for-granted nature of organizational forms and practices” which are not affected by the interests of politically influential actors (DiMaggio 1988 p4). Nevertheless, they also insist on the power relations which affect institutional properties. “The success of an attempt at institutional change depends not simply on the resources controlled by its proponents, but on the nature of power and the institutionally specific rules by which resources are produced, allocated, and controlled” (Friedland and Alford 1991 p254). Scott cites Selznick’s (1966) and Stinchcombe’s (1968) perspectives who stand for the old institutionalism. They argue:

> power was employed not only to design structures that advantaged some groups over others but also to construct rules and norms that justified and legitimated these advantages (Scott 1998 p170).

Organizations are capable of responding to institutional influences creatively and strategically. Not only do they shape their structure and culture according to their institutional settings, but also can they create or modify their institutional environments. Scott perceives that even if institutional environments are endogenously created by social actors, they act as an external force, regulating the social actors (Scott, Ruef et al. 2000). Organizations internalize their institutional environments – the external forces – through the process of institutionalization, which, in DiMaggio’s terms, “is profoundly political and reflects the relative power of organized interests” (DiMaggio 1988 p9). With the power relations perspective, the new institutionalism articulates the relationships between private firms and the state; “private-sector firms use the state to organize their [organizational] fields in a fashion that supports the interests of the already existing organizations” (Fligstein 1991 p314).

The perspective of power relations can explain much about the construction of institutions in the field of the electricity industry. Powerful groups – or leading utilities – construct organizational forms and institutional settings, and stabilize a certain structure of inter-organizational relationships. As other large scale industries do, the electricity industry has grown with its technological development. With a certain scale of expansion, the unregulated electricity industry takes on the form of a regulated business, creating an institutional environment on the industry's behalf. Electricity organizations, especially investor owned utilities (IOUs), take the initiative to form institutions to reduce uncertainty. Then, this institutional environment influences the form of electricity utilities. In this process, utilities fight any coercive regulations if they think the regulations threaten their autonomy. In the process of negotiating each interest, the electricity industry has developed a concept of voluntary 'coordination' among utilities in controlling interconnected transmission systems.

It seems that the voluntary coordination among operators of each system does not work as properly as the industry expects at the critical moment of cascading outages. Sublevel decision makers will give priority to the interests of their organizations rather than the whole interest of the interorganizational level, even though the organizations coordinate with one another consequently to maintain the whole interest. And their decisions are affected by a context that reflects the interests of leading utilities.

In sum, we can interpret some rationalized institutions (or imbalanced institutions), which affect preference of decision-makers in organizations and the shapes of organizations, as myths which do not reflect real demand of the society. They are culturally persistent to changes due in part to power relations among organizational actors.

Considering specific features of the electricity industry – tightly coupled or interconnected transmission systems but loosely coupled interorganizational coordination efforts, and the light speed of cascading outages of the systems –the explanation of social aspects of large scale blackouts must draw on several elements of the above theories of technological failure.

3.2.3. Disaster Theories and Interorganizational Reliability

As discussed above, large scale blackouts can be seen as an outcome of organizational and institutional interaction as well as technological failure or inappropriate rules of market design. Organizational theorists who have developed social theories on technological failure, however, do not place the large scale blackouts in the scope of their analysis. After the 2003 blackout, some scholars and electrical engineers discussed organizational and institutional issues regarding large scale blackouts. A group of scholars at Carnegie Melon University pointed out system problems of the electricity industry and organizational issues (Apt, Lave et al. 2004; Apt, Lave et al. 2006). Concerning the interrelationships in the electricity industry, some engineers in this field have raised institutional issues of electrical blackouts, particularly focusing on deregulation and restructuring (Casazza, Delea et al. 2005; Casazza, Delea et al. 2005). The organizational issues are explained in detail by Mark de Bruijne (2006) in a more organized manner, applying Normal Accident Theory and High Reliability Organizations Theory to the case of the California energy crisis. He argues that in the process of deregulation, institutional settings for reliable operation of electricity systems as a whole have become fragmented, and thus organizational performance does not work well before (Bruijne 2006).

In fact, I argue that the fragmented institutional settings – or in my term *institutional imbalance* – are historically and socially constructed. As mentioned earlier, Hughes (1983 p465) observes that the sociotechnical systems of electricity, long since established, have become "a conservative force[53] reacting against abrupt change in the line of development." The operation of electricity systems just before the 1965 and 1977 blackouts shows the individualized (or fragmented) practices of utilities in historical contexts in which utilities, states and federal agencies have interacted with one another to create institutions for a culture of reliability. These unforgettable blackouts have occurred periodically, and human errors in organizations have continually been involved in large scale blackouts. It can be assumed that one of the reasons why large scale blackouts occur repeatedly is related to the conservative force of the historically constructed sociotechnical systems, as they affect interorganizational practices. The conservative force is still working in the current interorganizational settings of each utility which were established in the early period of electricity, particularly before the 1930s. However, how these socio-technical systems, especially organizations of interconnected transmission systems, are linked to large scale blackouts are not discussed and still in a black box.

Some elements of NAT, the HROs theory, and the new institutional approach deliver insights in analyzing large scale blackouts. These insights are; 1) institutional settings for reliability are decided by powerful groups; 2) reliability institutions exist as rationalized

[53] As conservative forces, Hughes identifies such ideas as load factor, economic mix, and pricing based on cost, heavy capital investment, supportive legislation, and the commitment of know-how and experience on the basis of which utilities have their current organizations: generation, transmission, and distribution (Hughes 1983).

myths or symbolism due to cultural persistence to change and loosely coupled relationships among utilities, reliability coordinators and reliability institutions; and 3) there are unintended interactions of human errors and equipment failure and a lack of an effective culture of reliability in interorganizational relationships. Even though the electricity industry has had great technological achievements in improving the quality of life, at the interorganizational level it has not possessed an attentive ability to avoid spreading blackouts from local power disturbances. Exploring the historical cases of the 1965, 1977, 1996, and 2003 blackouts shows the social origins of these large scale blackouts. Before exploring the four cases, a brief account of the U.S. air transportation system, and electrical systems in Russia, which better satisfy the conditions of the HROs theory, will enhance the possible future direction of the electricity industry to prevent large scale blackouts.

3.3. Lessons from Other Network Industries

In this section, I introduce two comparable cases in which networked industries achieved reliability. Air transportation is a high risk system, leading to fatalities if it fails. But it has continuously improved its systems at the federal level and it has achieved high reliability in air traffic control by reducing accidents significantly. The electricity industries in other countries show how each country socially organizes its systems to manage reliability. One example is the emergency control systems of the Russian electricity industry. The electricity systems of Russia have developed at the continental level which is comparable to those of the United States. The Russian emergency control systems, which are centralized and managed at the national level, will provide us with some insight regarding the management method – centralized or decentralized management. In a brief examination of these systems, this section tries to identify common factors for successful control over a networked industry.

3.3.1. Air Transportation System in the United States

Interconnected electric transmission systems are sometimes compared with the air traffic control system. Both of them are highly complex socio-technical systems. They are networked systems, connecting each node through transmission lines or airways. Each node means transmission control centers or air traffic control towers. They also depend on highly complex technologies including monitoring and communication systems to control electric power and airplanes. However, their institutions have evolved along different paths. The institutions of the air traffic system have developed at the national level, while those of electric transmission systems have been formed at the state or regional level. One result is that the air traffic system has constantly reduced its accident rate from 29.43 accidents per 100,000 hours in 1930 to 0.24 in 1985 (LaPorte 1988). The constant improvement of safety and reliability of the air traffic control system is related to the way the aviation industry has socially organized its system and institutions as well as its technological development.

The air traffic control system unified and mandated its regulations at the federal level at an early stage of its development. The aviation industry, the public and legislators all knew how fatal aviation accidents are, and aviation accidents are directly visible to everyone. Thus, there was a consensus; that is, the federal government should support the technical advance and coordination of aircraft aloft. The industry asked for a federal role in establishing navigable air routes and related air traffic service, and the federal government accepted its role of licensing pilots, inspecting aircraft and supervising the use of airfields and navigation safety. The public demanded that the system should be always safe. The Congressional legislators, who needed safe air travel for their work in both Washington D.C. and their home constituencies, were interested in the quality of air traffic management and supported the Federal Aviation Administration (FAA) which was created in 1958. They enacted the Civil Aeronautics Act in 1938, and later incorporated military and civil air control systems through the passage of a new Federal Aviation Act (FAAct) in 1958 (Gilbert 1973; LaPorte 1988). In particular, the FAAct played many roles in improving the reliability of Air Traffic Control (ATC) – the operator/controller of the U.S. Air Traffic System.

The industry was able to improve safety through the constant upgrading of radar, communication and computer systems under the U.S. ATC direction, although there was rapid growth in the numbers of passengers and commercial carriers between the mid 1960s and the early 1980s. In 1961, the national ATC system divided airway altitude into three tiers: lower level, intermediate airways, and high altitude jet ways to prevent collisions. Under ATC direction, air traffic control towers shared data between control systems and made center/pilot communication possible (Gilbert 1973).

In the early period of the FAA, it became a full-fledged bureaucracy, increasing employment to 30,000 to provide various programs such as the Air Traffic Services, Flight Standards Service, System Maintenance Service and Airports Service. Because of the density and complexity of airways, tighter coordination was necessary, and thus the FAA gave more emphasis on ATC controller training and retention and expanded the national ATC training facility (LaPorte 1988). Currently the Air Traffic Organization (ATO), a performance-based organization that is an operational arm of the FAA, is composed of more than 35,000 employees, including air traffic controllers, operation supervisors, air traffic managers, professional aviation safety specialists for research and planning, engineers, and maintenance technicians (ATO 2007). They are working at 314 air traffic control facilities.

Deregulation[54] after passage of *the Airline Deregulation Act of 1978* changed the institutional environment of air traffic systems to a free market environment. One public perception was that the aviation industry would reduce expenditure on safety-related items under the competitive market. As a result, there were concerns about safety after the deregulation. But empirically there is no evidence that deregulation has impaired the safety of air traffic systems (Cunningham, Slovin et al. 1988; Morrison and Winston 1988; Moses and Savage 1990; Clinton V. Oster, Strong et al. 1992). Rather, the accident rates for commuter airlines and jet carriers have decreased since deregulation (Clinton V. Oster, Strong et al. 1992). Because air traffic control systems managed by FAA are separated from the air traffic market, the deregulation in the market does not directly affect the organization of the air traffic control systems. A concern is that systematic risk in the aviation industry is high during the period of transition (Cunningham, Slovin et al. 1988). Therefore, it is better for commercial airlines to reduce the transition to as short a timeframe as possible, responding to the institutional change as quickly as possible. One

[54] Here deregulation of the air traffic system refers to removing barriers for new companies' entering the air traffic market, deciding air fares in the market, and opening new routes and services to scores of cities.

major conclusion is that safety is directly related to measures other than deregulation (Morrison and Winston 1988). Additionally, there was an air traffic controller's strike in 1981 which led to firing more than 10,000 air traffic controllers. But this event did not reduce the safety of ATC system. In 2004 the U.S. air traffic system recorded the lowest accident rates by world region (table 3.2).

Table 3.2. 2004 Accident Rates by World Region

	Accidents per 100,000 Flight Hours	Accidents per 100,000 Departures
United States & Canada	0.181	0.243
Central & South America	0.541	0.672
Europe & Russian Federation	0.167	0.341
Africa & Middle East	0.854	1.902
Asia & Pacific	0.171	0.394

Source: National Transportation Safety Board (2007)

In sum, on the basis of social and political consensus, the aviation industry has centralized the FAA programs so that they are managed at the national level, and then decentralized some critical functions necessary at the regional level, such as the designation of airways within the territory of control towers. The aviation industry has separated the ATC system from air carriers, centralizing the control of air traffic networks. This is one example of the centralization-and-decentralization process, and in Perrow's term, linearization of complex, tightly coupled systems by providing separate tiers of airways (Perrow 1999). There was a consensus that in managing safety, centralization of some key programs was necessary and the role of the federal government was imperative. With demand from the public and the elites (especially Congressional legislators) the aviation industry has created almost failure-free systems and high-reliability interorganizational relationships. Despite deregulation, safety systems are working independently under the auspices of the federal government. The ATC system shows a well balanced social organization between safety (reliability) and efficiency. The social organization of the ATC system can be a good model to guide critical thinking about the social structure of the electricity industry.

3.3.2. Electric Transmission Systems in Russia

Electrification in the Soviet Union (1917-1991) was symbolized as the success of constructing a socialist state against capitalist ones. Lenin believed that electrification as a base of industrialization would be a great facilitator for the conquest of capitalism, and thus decreed that “Communism [should be] soviet power plus the electrification of the whole country” (Lawton 1932 p176). Lenin reported that through the GOELRO plan, the first imperative economic plan for electrification, proposed by an electrical engineer, 221 power stations were opened (Barnett 2004). This shows Lenin’s belief in electrification of the Soviet Union in the beginning of the Bolshevik Revolution. The Soviet leaders thought that electrification was not a state agenda of economic reconstruction, but the revolutionary government’s vision for the social and economic transformation of Russia (Heywood 1999). With strong political support, therefore, electrical engineers took the initiative to electrify Russia, replacing the railroad as the state technology (Heywood 1999).

Table 3.3.Growth of Power Stations' Installed Capacity and Length of 220-1150kv Networks of the USSR

	1960	*1965*	*1970*	*1975*	*1980*	*1985*	*1990*
Installed capacity (M kW)	29.1	53.9	104.9	153.1	223.4	265.3	288.6
Highest voltage (kv)	500	500	750	750	750	750	1150
Length of HVL (1000km)	14.74	27.75	52.83	79.69	122.87	154.04	185.73
220kv	9.68	17.27	30.11	44.55	72.63	90.29	107.03
330kv	0.66	4.58	12.86	18.79	23.63	27.66	31.10
500kv	4.40	5.90	9.77	14.67	23.75	30.85	38.42
750kv	-	-	0.09	1.68	2.86	4.35	7.27
1150kv	-	-	-	-	-	0.89	1.91

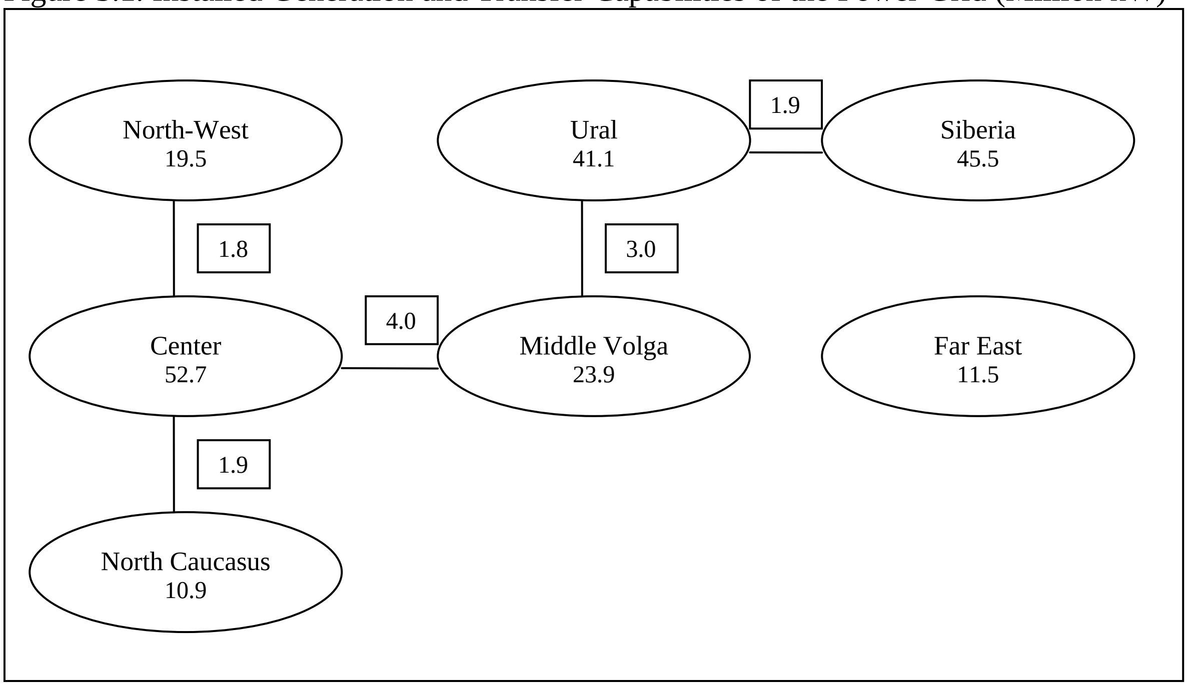
Source: (Diyakov and Barinov 1998)

The First Five-Year [centralized] Plan for economic development started in 1929, accelerating the construction of power plants. By 1935 after the First Five-Year Plan, the capacity of installed electricity generation of the Soviet Union became the third largest in the world after the United States and Germany (Xu 2004). Installed capacity increased from 37.2 million kW in 1955 to 344 million kW in 1990, which was the second largest in the world, before the collapse of the Soviet Union (Diyakov and Barinov 1998). Table 3.3 shows the installed capacity and the length of transmission lines. During this time, the Soviet Union created the Unified Power System (UPS) of the USSR which became "the biggest centrally dispatched power system in the world," and by 1990 the installed capacity of the UPS system became 288.6 million kW (table 3.3), 83.9% of the total installed capacity of USSR (Diyakov and Barinov 1998).

Before the collapse of the Soviet Union, the UPS consisted of 9 interconnected power systems (IPSs): Center, Middle Volga, Urals, North-West, North Caucasus, Siberia, Ukraine, Trans-Caucasian, and Kazakhstan. Two other Soviet IPSs – Central Asia and the Far East – operated separately. After the disintegration of the Soviet Union, the IPSs of Ukraine, Trans-Caucasian, and Kazakhstan were excluded from the UPS.

Currently seven regional power systems are included in the Russian territory (figure 3.1). Power resources and plants vary from region to region and are unevenly allocated. In Siberia, a majority of generation capacity comes from hydro power plants and rest of it from coal-fired ones. Most nuclear power plants are located in the North-West, the Central and Volga region, while gas-fired power plants are concentrated in Central, Urals, and North-West region (Diyakov and Barinov 1998; Xu 2004).

Figure 3.1. Installed Generation and Transfer Capabilities of the Power Grid (Million kW)



Source: (Palamarchuk, Podkovalnikov et al. 2001)

The conventional wisdom is that Russia inherited the well-interconnected transmission systems from the Soviet Union (Grudinin and Roytelman 1997; Morozov, Semenov et al. 1998; Xu 2004). Although the Soviet economic system collapsed due, by and large, to a parasitic party bureaucracy and multi-layered complexity of the socialist system, the interconnected power systems have worked reliably in the western part of the country.[55] As described above, all systems except for the Far East system are interconnected through transmission lines. The state owns all facilities, and thus the interconnected systems are under the control of the hierarchically centralized operating centers: the Central Dispatching Board – dispatching boards of the IPSs (7 regions) – centralized dispatching services of the power systems – operational controls of the power stations (Diyakov and Barinov 1998). Control centers include one central control center in Moscow and seven regional control centers. Two of the regional control centers are backup control centers for the central power center.

One of the reasons why the Soviet Union had centralized control systems was due to limited transmission capabilities resulting from lack of steel available for construction of transmission lines. Therefore, it operated its grid systems with small reserve margins. Other problems were poor network observability, the limited performance of available computers, and limited means of control. To overcome these conditions, the Soviet Union developed a control system which was called centralized emergency preventive automated control (Cepac) - (Grudinin and Roytelman 1997 p44). The Cepac systems operated at the regional control centers as well as the central control center. The primary goal of the Cepac systems was to prevent local level system disturbances from developing into cascading outages.

The key concept of Cepac is the cut-set – breaking up an interconnected system into two subsystems during emergencies — ensuring power flow stability (Grudinin and Roytelman 1997). There are four levels of sequences for controlling emergencies. First,

[55] In the 1980s, the West Siberian region suffered from power shortages and unreliable electricity supplies because of mistaken forecasts of power demand growth by customers, lack of railway access to power plant construction sites, and delayed construction of power plants. To address this problem, electricity is delivered to Siberia from the Ural region. Wood, A. (1987). *Siberia: Problems and Prospects for Regional Development*. New York, Croom Helm.

the voltage, power flow and relay systems of individual lines are controlled at the local level. Then two or more systems are coordinated and system operators consider the integrated effect of preventive control systems on power systems at the second level – stability control schemes. At the IPS level, the Cepac systems oversee interregional emergencies, adjusting local level devices – out-of-step protection. At the level of the UPS of Russia, a preventive control system watches for loss of stability and cascading outages on the whole system, sometimes using load shedding schemes (Grudinin and Roytelman 1997; Morozov, Semenov et al. 1998).

The Cepac system demonstrates that the emergency control systems of Russia prevent system disturbances with a view of the whole system of UPS, while those of North America, Japan, and Europe, in general, are designed to address the overloading of individual transmission lines or individual events in a power system (Grudinin and Roytelman 1997). With the Cepac system, Russia achieved a highly reliable grid; power losses for average customers per year do not exceed 5~6 minutes, the grid systems have not collapsed for many years, and the last blackout in Moscow occurred on December 18, 1948 (Morozov, Semenov et al. 1998).

Currently the UPS of Russia has such problems as primitive data acquisition and state estimation systems, poor computer systems, and obsolete facilities. As a result, Russia is privatizing and restructuring its power systems, and is deregulating its institutions to attract domestic and foreign investment in modernizing the systems. Therefore, ultimately transmission systems will be disintegrated from the vertically integrated power systems. Transmission and distribution networks will be transferred to a Transmission System Operator (SO) and the Federal Electricity Transmission Grid, and the Russian government will be a major owner of the asset (Engoian 2006). System control will be centralized at the SO level, and thus the Cepac systems will still be a main measure of controlling the whole grid systems.

The Russian case affirms that the interconnected transmission systems work well and show high reliability when they are operated with centralized control systems. There was the central government's support for the electrification that positively affected the reliability of the Russian electric systems. The institutions of the Russian electricity industry developed at the central government level. The emergency control systems of Russia are designed to consider whole system dynamics. System operators in the central control center in Russia, therefore, can make decisions based on the whole picture of the Unified Power System. Deregulation may change the institutional conditions of operating emergency control systems. Nonetheless, the emergency control systems of the Soviet Union, the former Russian entity, illustrate the importance of centralized emergency control for interconnected transmission systems.

3.4. Propositions, Research Strategy, and Data Collection

3.4.1. Propositions

Concerning large scale blackouts, my questions are about institutionalization and institutional conditions that affect system operators' decisions within their organizational boundaries. My questions address 1) the way of creating institutions for electricity reliability, 2) the characteristics of the institutions for the electricity reliability during each historical event, and 3) interactions between utilities and the institutions in improving reliability. These questions come from observation of the physical conditions of the electricity industry, especially the features of the interconnected individual power systems. As I mentioned earlier, current social theories on disasters do not provide an appropriate explanation of the social aspects of large scale blackouts. In order to construct a more relevant explanation, in Section 3.1 and 3.2 I briefly explored and discussed social theories – the NAT and HROs theories – on large scale technological failure, and the new institutional approach in the consideration of socio-cultural factors and power relations which are also important in explaining large scale blackouts. Then, in Section 3.3 I introduced the two comparable cases – air traffic systems and the Russian electricity system – with respect to the reliability of inter-organizational relationships. From these discussions, as already stated in Chapter 1, the propositions are as follows:

The electricity industry shows a lack of balanced management between its reliability and efficiency objectives: so that the industry gives relatively less attention to reliability than efficiency, and thus has failed to establish strong inter-organizational relationships for reliability.

I-1. The electricity industry should create "a culture of reliability" among organizations by means of a strong institution: centralizing basic premises and practices corresponding to the interconnected grid systems and decentralizing system operators' decisions at the local level. But it does not presently have strong institutions for creating a culture of reliability.

Under the condition in which power systems are interconnected, but operated by individual utilities, strong inter-organizational reliability relationships or well-organized coordination among control centers must inevitably be established and managed at the institutional level. NERC identifies the basic mission of the transmission control centers: generation control and performance, transmission, interchange, system coordination, emergency operations, operations planning, telecommunication, operating personnel and training, and reliability coordinator procedures. To perform these functions in coordination with other utilities, individual utilities need to centralize basic premises, assumptions and practices. In this system, however, I do not mean a strong, centralized hierarchical bureaucracy through which a command-and-control decision is made.

In evaluating the proposition, some institutional conditions – or characteristics – merit consideration. These conditions for reliability are derived from the cases of the U.S. air traffic system (the Air Traffic Services, Flight Standards Service, System Maintenance Service and Airports Service, ATC controller training & retention, and expanded national ATC training facility) and the Russian electric system (holistic approach, and integrated planning & management standards at each level). These cases suggest a need explicitly at the central level, for *1) setting operation [planning] standards, 2) licensing system operators, 3) providing up-to-date equipment standards, and 4) improving communication methods*. These are measures the U.S. air traffic system and the Russian electric system have developed so as to reduce catastrophic technological failures.

I-2. Power relations obstruct the development of strong institutions for creating a culture of reliability that is necessary in inter-organizational relationships, resulting in an imbalance between efficiency and reliability.

Creating the above institutional conditions in the electricity industry is examined in connection with the role of powerful groups. As discussed above, institutional approaches generally deal with interest-free, taken-for-granted factors in organizations (DiMaggio 1988). Mary Douglas (1982, p12) also argues that "we should treat cultural categories as the cognitive containers in which social interests are defined and classified, argued, negotiated, and fought out." In this sense, powerful group interests can also be defined by cultural categories. But institutional approaches also acknowledge power of elites. Professionals, in pursuing their own interests, can exert their influence on the structure of organizational systems, thereby inducing institutionalization (DiMaggio 1988), and capitalist elites can also make critical decisions in setting the direction of institutional development (DiMaggio and Powell 1983). At the early stages of institutionalization, power relations can be an important factor. Once institutions are created and developed, organizations under the institutions are culturally resistant to change due to the interest of powerful groups affiliated with the organizations. Under the reliability institutions utilities created, they maintain loosely coupled coordination, while protecting the autonomy of their own system operations and efficient power production rather than reliability of the entire grid. Because of conflicts in power relations, an imbalance between efficiency and reliability exists. The fact that utilities were unresponsive to the physical interconnection of whole power systems resulted in the 1965 Northeast blackout; they were unresponsive to the recommendations after the 1965 blackout, which led to the

1977 Blackout in New York City; and they were also unresponsive to institutional change – deregulation – thereby contributing to the 2003 Northeast Blackout.

The above propositions will be verified through the case studies and compared to and supported by the hypotheses tested by the event history analysis (EHA). The data on major power system disturbances used in EHA are considered events that occurred at the local and regional level, not the global level. But according to the NERC's reporting criteria, they have the potential to develop into the cascading outages. Thus this analysis is important to identify general conditions under which local events increase the probability of large scale blackouts. The utilities are the unit of analysis. Through the event history analysis, I examine institutional, physical, and organizational conditions that exist behind major power system disturbances. Generally, I expect that utilities are more likely to be exposed to system disturbances in accordance with their physical complexity, properties of reliability institutions, and poor organizational performance. Specifically, they are as follows:

Physical Complexity

II-1. The more complex power systems are, the more likely are they to experience power system disturbances.

Institutional Changes

II-2. Institutional changes – introducing competition in wholesale or retail markets– will increase the likelihood of experiencing disturbances.

Institutional Settings (Conditions)

II-3. Penalty: In resource adequacy planning, utilities which face contractual penalties set by their regional reliability councils are less likely to experience disturbances.

II-4. Planning: If a reliability council considers more factors for resource adequacy assessment, utilities under the council will be less likely to experience disturbances.

II-5. Emergency operation: If a reliability council considers more factors for emergency operation, utilities under the council will be less likely to experience disturbances.

II-6. Operation: If a reliability council adopts central dispatch, utilities under the council will be less likely to experience disturbances.

II-7. Regulatory relationship: If a reliability council has a strong regulatory relationship with FERC or State Commissions, utilities under the council will be less likely to experience disturbances.

Organizational Performance

II-8. The higher summer and winter peaks in kilowatts per customer are, the more likely are power system operators to fail in managing their systems during these peaks.

II-9. If utilities have more power losses in percentages of total power sources between generation and end users, they are more likely to experience power system disturbances.

II-10. Utilities are more likely to experience system failure when focusing on profit maximization while subsequently paying less attention to investment in facilities and technologies.

These hypotheses are further discussed in Chapter 4. Above all, utilities may be constrained by the characteristics of institutions, and confront the challenge of physical complexity and severe organizational conditions that should be overcome by good organizational performance. It is these conditions that major utilities and control centers that are involved in the four large scale blackouts also faced. That is, if the above hypotheses are correct, those utilities that support the hypotheses may have a greater potential of triggering cascading outages. Therefore, the organizational performance of utilities having major control centers, and achieving strong coordination among them, becomes important, which means that establishing reliability between those critical control centers should be a priority. In this sense, the hypotheses tested by the event history analysis will support proposition 1; *the electricity industry should create "a culture of reliability" among critical control centers by means of a strong institution*. Figure 3.2 illustrates the position of the analytic framework in the space of social theories about technological failures, and figure 3.3 shows a schematic model of the propositions and the hypotheses in relation to large scale blackouts.

Figure 3.2. Location of the Analytic Framework in Theories

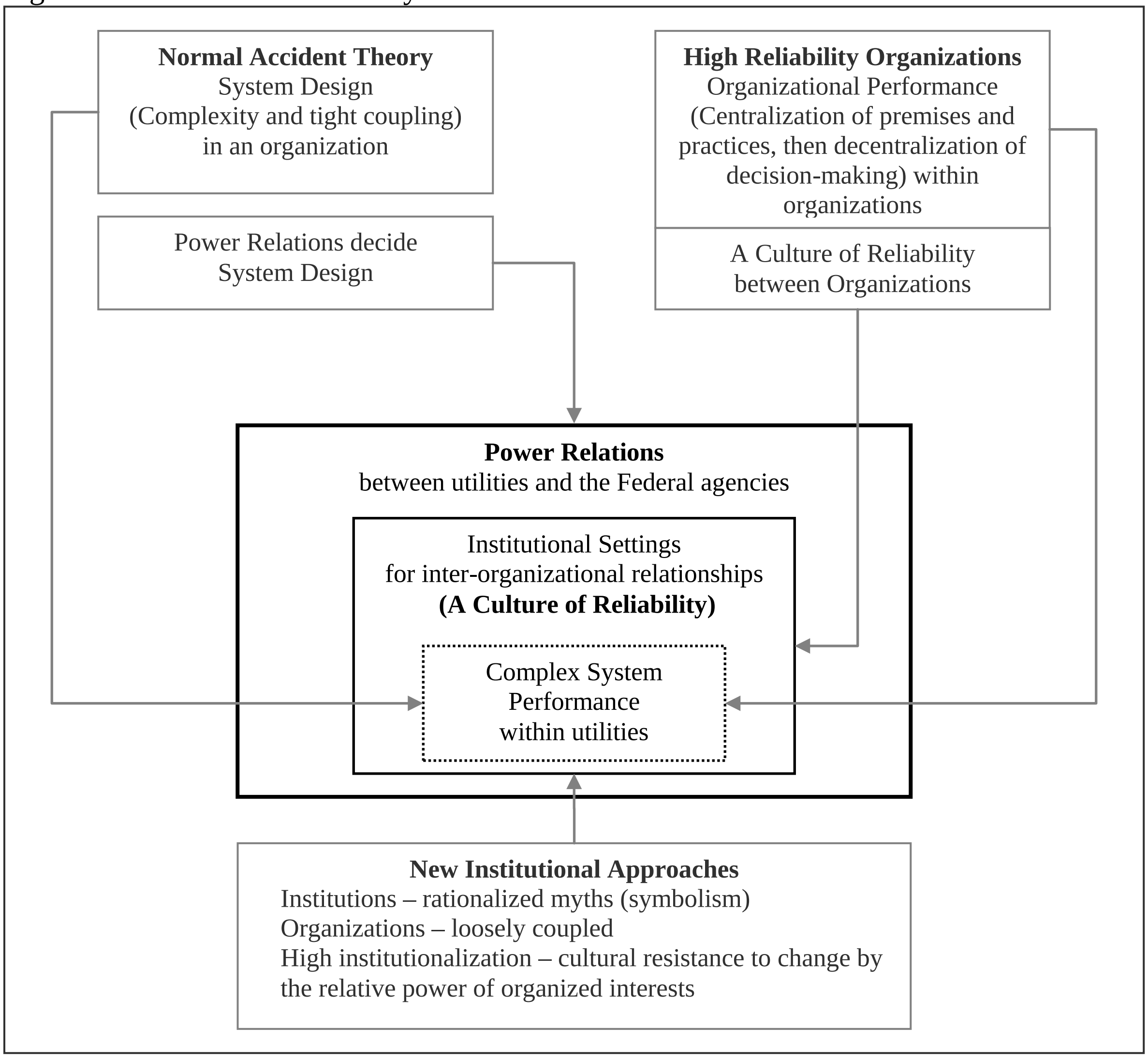
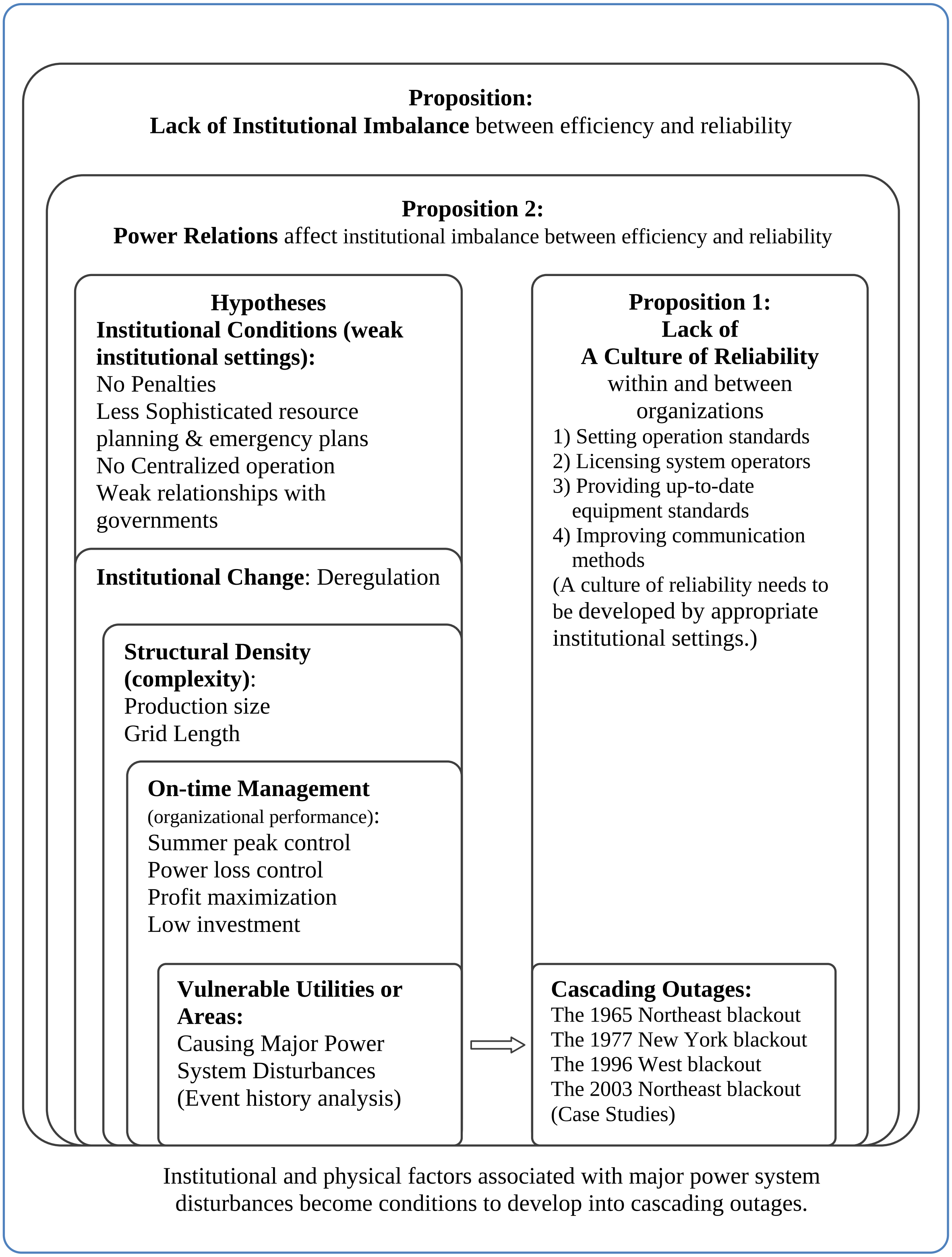


Figure 3.3. Schematic Model of the Framework for Large Scale Blackouts



3.4.2. Research Strategy and Data Collection

This dissertation seeks to interpret large scale technological failures in terms of a social-science framework, so as to grasp and emphasize how organizational performance can be enhanced by way of appropriate reliability institutions. The challenges are to explain how social structure is linked to technological failure, how technological failure can be observed by the lens of social science, and how we can claim that certain types of organizational and institutional settings are, whether directly or indirectly, related to the technological failure. To answer these questions, I have stepped through several relevant social explanations – social construction of technological failure, Normal Accident theory, High Reliability Organization theory, New Institutional approaches, and culture vs. power relations.

On the basis of these theories, I set two propositions and ten hypotheses. I conduct case studies for the evidence of the former, and an event history analysis for the latter. Four large scale blackouts are selected for case studies, because, as mentioned in Chapter 1, their impact is not confined in a territory of just one power system except for the case of New York City and because each affected more than 5 million customers (Table 3.4). The selected blackouts occurred in different times and in different institutional and physical contexts. Comparing them across these differences will strengthen the above claim of dominant groups' influence on institutionalization which has resulted in a recurring imbalance between efficiency and reliability. Focusing on the performance of control centers and utilities, I look at the institutional and physical contexts around them, relying in part on a macro-micro approach. For each case study, I use secondary data from Congressional hearings, blackout reports published by utilities and city, state and the federal governments, utilities' history books, electricity related laws, and other documents. I also use the data from interviews conducted with engineers involved in those blackouts or related to power system reliability, so as to complement the evidence found in the secondary data.

Table 3.4. Major Blackouts[1]

Blackouts	Customers (1,000)	Power Loss (MW)	Affected Area
1965	30,000	20,000	8 states in Northeast
1977	9,000	6,000	New York City
1996	7,500	28,000	14 states in West Coast
2003	50,000	61,800	9 states in Midwest and Northeast

1. Other major blackouts occurred in 1967, December 1982, July 1996, and June 1998 affecting millions of customers.

Chapter 4 presents an event history analysis to identify general patterns of power system disturbances, and thus to test ten hypotheses related to the external and internal conditions of utilities. I use data on power system disturbances from NERC, data regarding characteristic of utilities – wholesale and retail sale deregulation, characteristics of reliability institutions, power generation, sale, trade and loss – from the Energy Information Administration (EIA), and data for profitability and investment in facilities and technology from Moody's. The data on transmission lines are derived from each utility's websites. Particularly, the analysis examines the relationship between major power system disturbances and reliability standards which are one of the four items in a successful culture of reliability identified in section 3.4.1. The detailed research design of the event history analysis is discussed in Chapter 4.

Table 3.5. Research Methods and Data Collection

Chapter	Methods	Data
Chapter 4	Event history analysis	Power System Disturbance Data by Disturbance Analysis Working Group: NERC (1984~2006) Data of EIA-861 and 412 forms (1990~2006) Utility Websites Moody's manuals and website
Chapter 5	Case study The 1965 Northeast Blackout	Congressional hearings of 1965, 1966, 1967 and 1968 FPC reports of 1965 and 1967 Interviews Newspapers and Magazines Utility history books and others
Chapter 6	Case study The 1977 New York City Blackout	Congressional hearings of 1977 and 1978 FERC report of 1978 New York State report of 1977 New York City report of 1977 Con Edison reports of 1977 Interviews Newspapers and Magazines Other books and articles
Chapter 7	Case study The 1996 Western Blackout The 2003 Northeast Blackout	Congressional hearings of 1989, 1991, 1996, and 2003 WECC report of 1996 U.S.-Canada Power System Outage Task Force reports of 2003 and 2004 NERC report of 2004 ECAR report of 2003 ISO-NE report of 2004 New York ISO report of 2004 Interviews Other books and articles

In the next four chapters, structural issues which have historical roots will be addressed through case studies and event history analysis (Table 3.5). The identification of these structural issues provides a basis for improving the inter-organizational relationships in the electricity industry to emphasize better reliability, and to develop a holistic view for anticipating and preventing cascading outages.

Chapter 4. General Patterns of Blackouts

This chapter observes general patterns of major electric system disturbances, using NERC data on power system disturbances: historic and geographical trends of blackouts, and influential internal and external conditions. Simple observation shows that power system disturbances are usually affected by external factors such as natural disaster and severe weather conditions. In this chapter, however, I argue that structural – institutional, physical and organizational – conditions of power systems are also major factors in accelerating power system outages. From the viewpoint of organizational performance, therefore, I test whether there are vulnerable power systems and locations where structural conditions are not managed in an integrated-enough, sophisticated-enough manner at the institutional level.

4.1. Trends in Power System Disturbances

NERC has publicly provided data on power system disturbances since 1984. According to the NERC definition, power system disturbances refer to “electric service interruptions, voltage reductions, acts of sabotage, unusual occurrences that can affect the reliability of the bulk electric systems, and fuel problems” (NERC 2008). Because the reporting of major power system disturbances is mandatory under Public Law 93-275, *the Federal Energy Administration Act of 1974*, utilities must report their system outages (Form OE-417) within a certain time after a power system disturbance occurs that meets a certain criteria[56] (DAWG 2001; U.S.DOE 2008). The data have been used by physicists for developing nonlinear dynamics models in complexity theory,[57] and by engineers and policy makers for constructing reliability policy models that will help improve the decision-making process and prevent power outages (Carreras, Newman et al. 2000; Chen, Thorp et al. 2001; Dobson, Newman et al. 2002; Felder 2004; Hines, Apt et al. 2008).

NERC collects system outage data with the help of the regional reliability councils (Figure 4.1), and provides such information as the time and date of events, restoration time, causes focusing on technical issues, affected utilities and NERC regions, size of power loss, and the number of affected customers. In fact, all power system disturbances do not affect customers. Nor do they always cause a loss of electric power. Sometimes system disturbances occur accidentally, but operators control them successfully so that there is neither power loss nor loss of service. One of the important reporting criteria is "the loss of a bulk power transmission component that significantly affects the integrity of the interconnection system operation" (DAWG 2001 p35). That is, these events have the potential to develop into large scale power system disturbances if other events happen and interact with them. Hence, NERC counts and includes such system disturbances in their annual data, although they are negligible in terms of physical damage. Hereafter, system disturbances or disturbances mean major power system disturbances.

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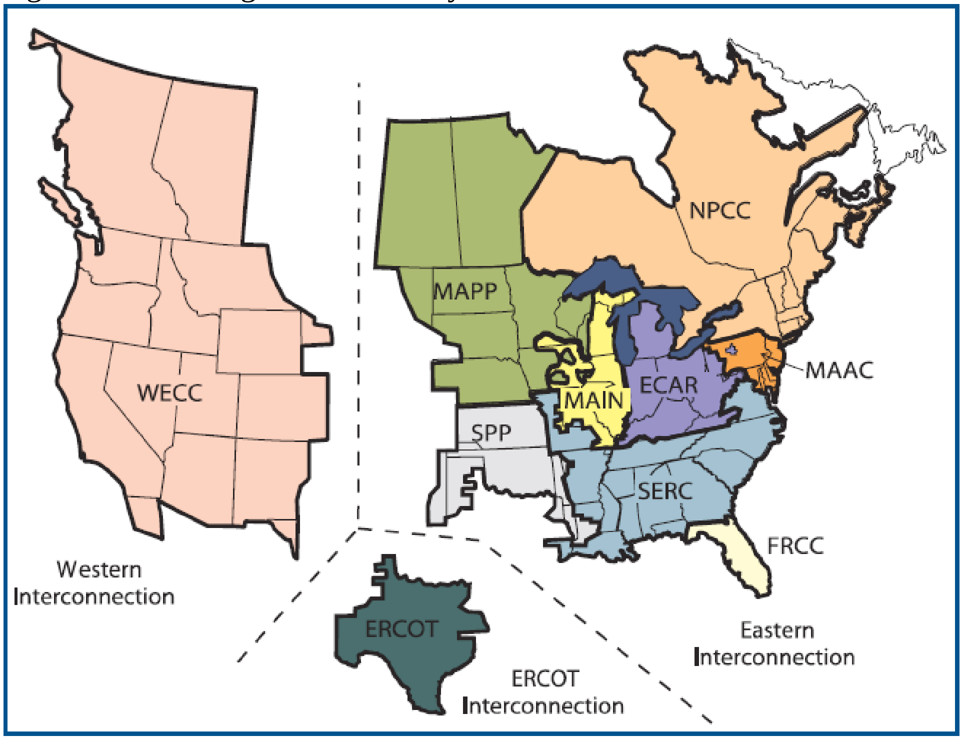
[56] For more details, see Appendix 2: Disturbance Reporting Requirements.
[57] A nonlinear dynamic model is briefly explained and discussed in Appendix1: Other Explanations on Large Scale Blackouts.

Figure 4.1. Ten Regional Reliability Councils in 2003

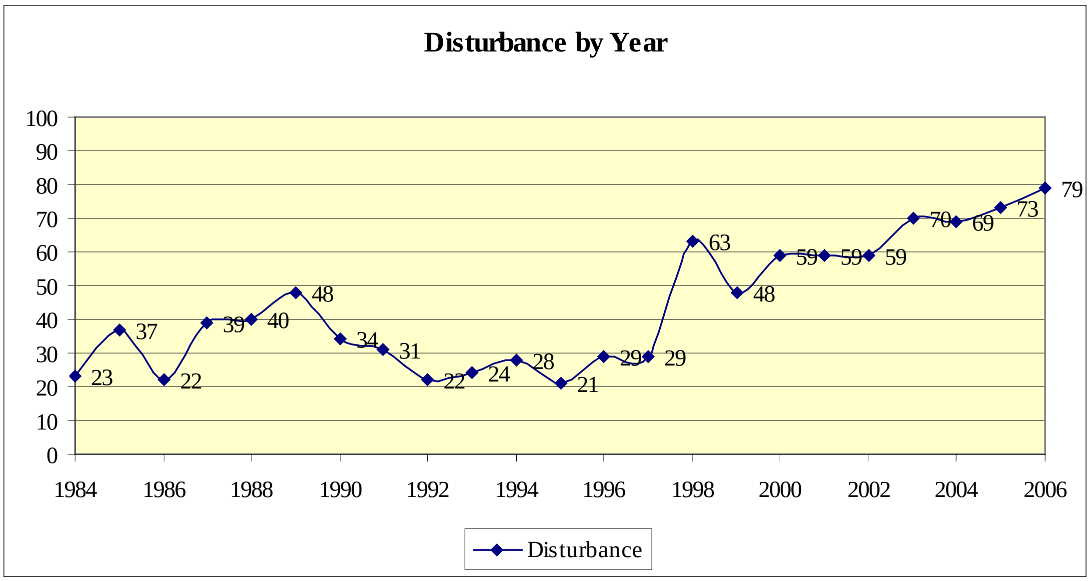


ECAR: East Central Area Reliability Coordination Agreement
ERCOT: Electric Reliability Council of Texas, Inc.
FRCC: Florida Reliability Coordinating Council
MAAC: Mid-Atlantic Area Council
MAIN: Mid-America Interconnected Network, Inc.
MAPP: Mid-Continent Area Power Pool
NPCC: Northeast Power Coordinating Council
SERC: Southeastern Electric Reliability Council
SPP: Southwest Power Pool, Inc.
WECC: Western Electricity Coordinating Council

Source: U.S.-Canada Power System Outage Task Force (2004)

The data show basic trends in power system disturbances by year across the nation. The total cases are 1,006 from 1984 to 2006. Some disturbances occurred in several NERC regions and utilities, and thus I count them separately when I analyze causes of system disturbance according to NERC regions; their total cases are 1,031. The annual data on system disturbances show the general patterns of blackouts. Overall the data show that weather and equipment failure are the primary causes of power outages which have increased slightly in recent years. They usually occur in the summer and winter rather than spring and fall. Capacity shortages and human errors are the next most frequently cited reasons for power outages. Capacity shortage is most common in the summer and winter, and human errors happen regularly over the years and seasons. The Eastern Interconnection is more affected by weather than the Western Interconnection. Capacity shortages and human errors are important problems in the northeastern region while weather is an important factor in the southeastern region. The following figures illustrate these characteristics of power system disturbances.

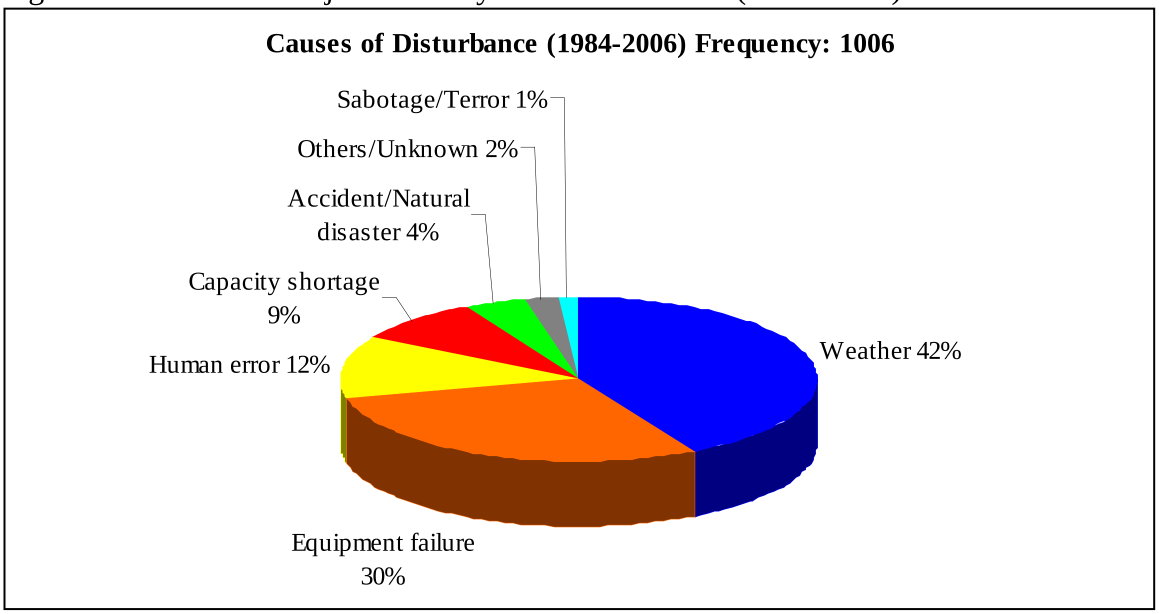
Figure 4.2. Power System Disturbances by Year



Source: NERC

Figure 4.2 shows annual occurrence of major power system disturbances. The number of power system disturbances per year fluctuates between 20 and 40 occurrences before 1998. Then the events have increased since 1998. There might be several reasons for the rapid increase. One thing is that after the enactment of the Energy Policy Act in 1992, both wholesale and retail sale markets introduced competition, which reached full implementation in the late 1990s leading to increased power trading in the wholesale markets. The heavy electric loads on the transmission lines may contribute to power line capacity shortages, resulting in the occurrence of power system disturbances. Another reason could be a change in the utilities' attitude in reporting system disturbances; that is, they may report their disturbances more correctly than before. Additionally, we can conjecture that the rapid increase of power system disturbances is related to unusual and severe weather conditions in recent years which amplify the magnitude of system disturbances. Therefore, the scale and significance of many events are above the reporting criteria defined by NERC.[58]

Figure 4.3. Causes of Major Power System Disturbances (1984~2006)



Source: NERC

Figure 4.3 illustrates the direct causes of power system disturbances. I categorize causes into seven groups: weather, equipment failure, human error, capacity shortage,

[58] For the reporting criteria, see Appendix 2: Disturbance Reporting Requirements.

natural disaster, unknown, and sabotage or terrorist act.[59] If there are multiple causes in an event, I classify it according to its initial cause. For example, high temperature increases electricity demand, leading to capacity shortage of generation or transmission lines. In this case, weather becomes the main cause. If I count these causes in this way, weather (42%) is the major reason for blackouts. The second is equipment failure (30%) which includes a variety of faults in the bulk power system: generation, transmission, and distribution. It is argued that 70% of the major disturbances are associated with the failure of relay systems which, although they are not the initial causes, can contribute to the cascading nature of the event (Chen, Thorp et al. 2005). Human error (12%) and capacity shortage (9%) are the other major reasons for system disturbance. And others are natural disaster & accidents by human activities (4%) and Sabotage/terrorist acts (1%).

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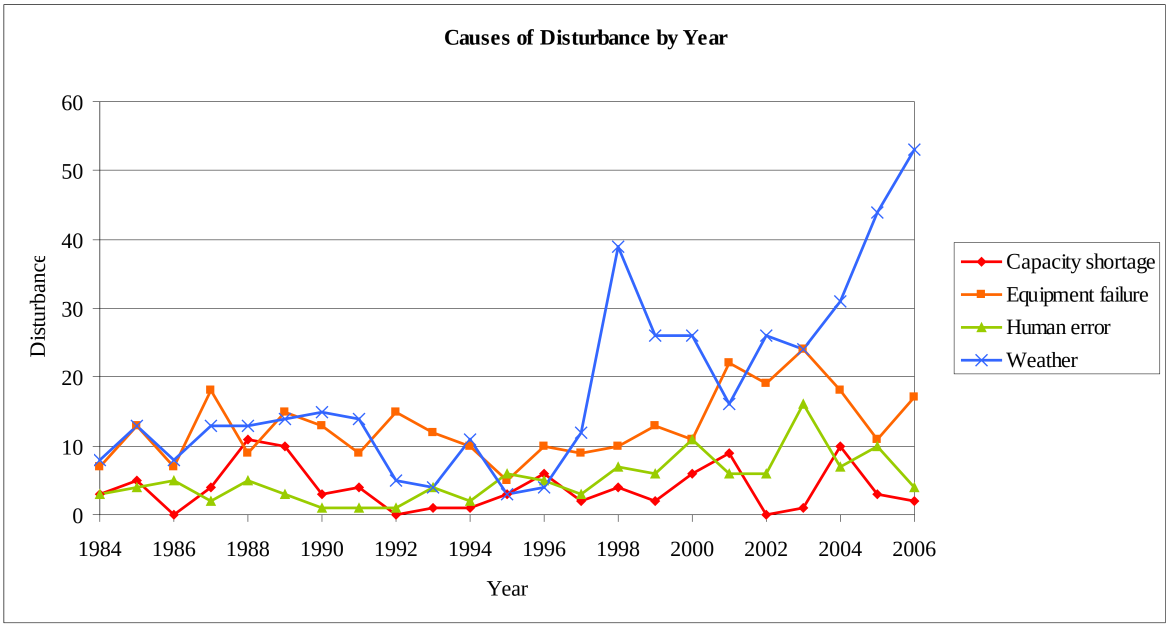
[59] I categorize causes as follows. 1) 'Weather' refers to hot temperature, severe ice storm, lightning, hurricanes, tornados, strong winds, heavy snows, etc. 2) 'Equipment failure' includes insulator failure, loss of distribution network, special protection system, loss of distribution feeder, line fault, ground fault, transmission line fault, fire, special protection system failure, etc. 3) 'Human error' includes operators' error, misinterpretation of data, contractor accident, switching error, maintenance error, tree contact, etc. 4) 'Capacity shortage' means insufficient generation, insufficient reserve, insufficient transmission lines, voltage reduction, etc. 5) 'Accident/Natural disaster' indicates wild fire, solar magnetic storm, geomagnetic activity, earthquake, tree fall, animal contact, and other accidents caused by unintentional human activity. 6) 'Sabotage or terrorist act' refers to dynamite blast, removal of tower bolts, etc. Others categorize them with more resolution. Felder categorizes them into *internal event, generation outage/high demand, transmission outage, external event, severe weather/lightning, earthquake, external fire, other, human error, maintenance, operations, sabotage/vandalism, and other (insufficient information)*. Felder, F. A. (2004). "Incorporating Resource Dynamics to Determine Generation Adequacy Levels in Restructured Bulk Power Systems." *KIEE International Transaction on PE* **4**(2): 100-105. Another categorization ranges from technical failure (internal causes) to natural disasters (external causes): volunteer reduction, voltage reduction, operator error, equipment failure, other external causes supply shortage, intentional attack, fire, other cold weather, wind/rain, lightning, ice storm, hurricane/tropical storm, tornado, and earthquake. Hines, P., J. Apt, et al. (2008). "Trends in the History of Large Blackouts in the United States." *Carnegie Mellon Electricity Industry Center Working Paper CEIC-08-01*: 1-8.

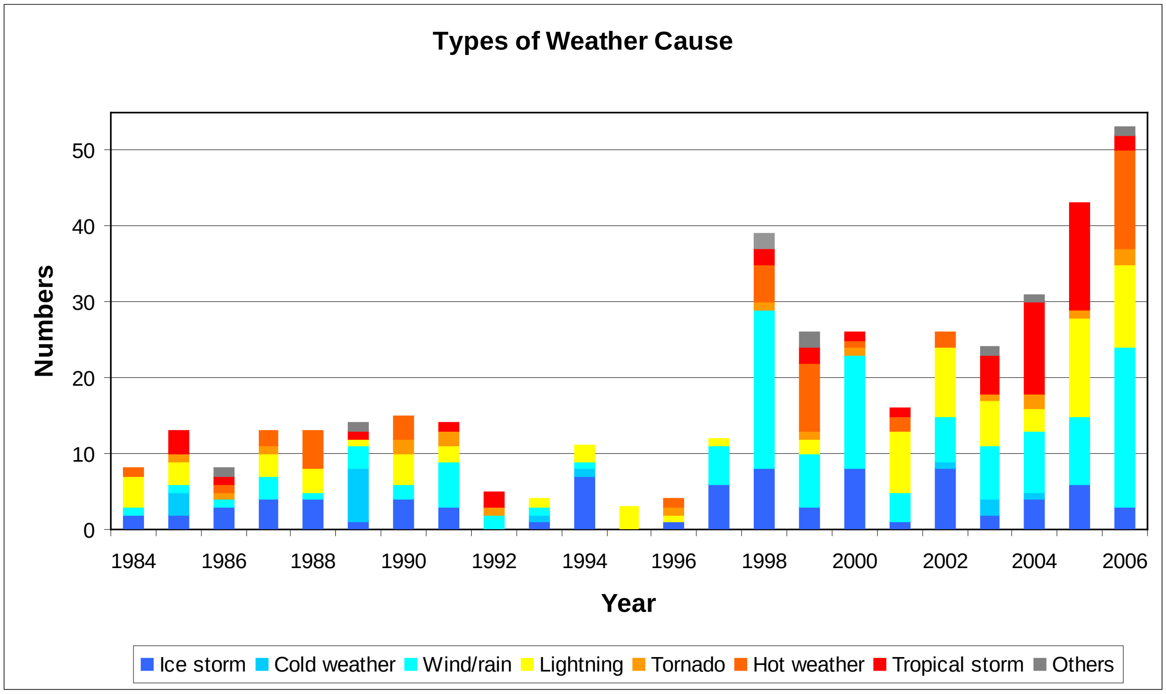
Figure 4.4. Four Major Causes of Power System Disturbances by Year



Source: NERC

Figure 4.4 shows how the annual variation in four of the repeated causes of system disturbances. The graph does not show any specific relationships between the four factors. But it illustrates some facts regarding causes of blackouts over the years. Weather is not the only major factor for disturbances every year. Equipment failures also occasionally become the primary cause of events. Both equipment failure and severe weather related outages increase after 1998. From figure 4.4 and 4.5, we can understand that the increase of disturbances in recent years is due to the factors of equipment failure and weather. In particular, weather has become a major cause since 1998. Human errors are almost evenly distributed over the years although they increase slightly after 1998. That is, human errors routinely happen every year, constituting a certain portion of all disturbances. As a result, people may take it for granted that human errors cannot be avoided but could be ignored when compared to other factors. Therefore, it might be appropriate to focus on factors such as equipment failure and severe weather conditions, which make up the largest portion of the events.

Figure 4.5. Types of Weather Causes



Source: NERC

More specifically, severe weather conditions can be divided into 7 categories: ice storm, cold weather, wind/rain, lightning, tornadoes, hot weather, and tropical storms including hurricanes. In figure 4.5, there had been no specific features until 1997, but some weather patterns leading to power disturbances have remarkably increased since 1998. While there were on average 9.8 power disturbances per year due to severe weather conditions between 1984 and 1997, there were 31.6 events between 1998 and 2006 which are three times as many as the previous period. Severe thunder storms (wind/rain), lightning, hot weather, and tropical storms caused disturbances more than before. Recently, power disturbances caused by ice storms are also happening frequently. In particular, tropical storms became the largest cause between 2003 and 2005. From these trends, we could perceive that severe weather conditions have become important factors of disturbances, and thus suspect El Niño. At the same time, however, we cannot attribute the rapid shift of power outages only to the severe weather conditions. It is not reasonable to think that weather conditions suddenly changed in 1998 compared to those in 1997.[60] Considering that 1998 is the beginning year of wholesale market competition, we can also reasonably suspect that institutional conditions and other factors may have contributed to the rapid shift.[61]

If the frequency of each cause is grouped into seasons as in figure 4.6, power system disturbances are especially frequent in the summer. The number of equipment failures and capacity shortages as well as severe weather conditions is higher than other seasons. Human errors in the summer also happen more than other seasons. These patterns tell us that the causes are interrelated with one another in the summer when power demand is peaking. Hence, controlling power systems during the summer season is an important task for power system operators.

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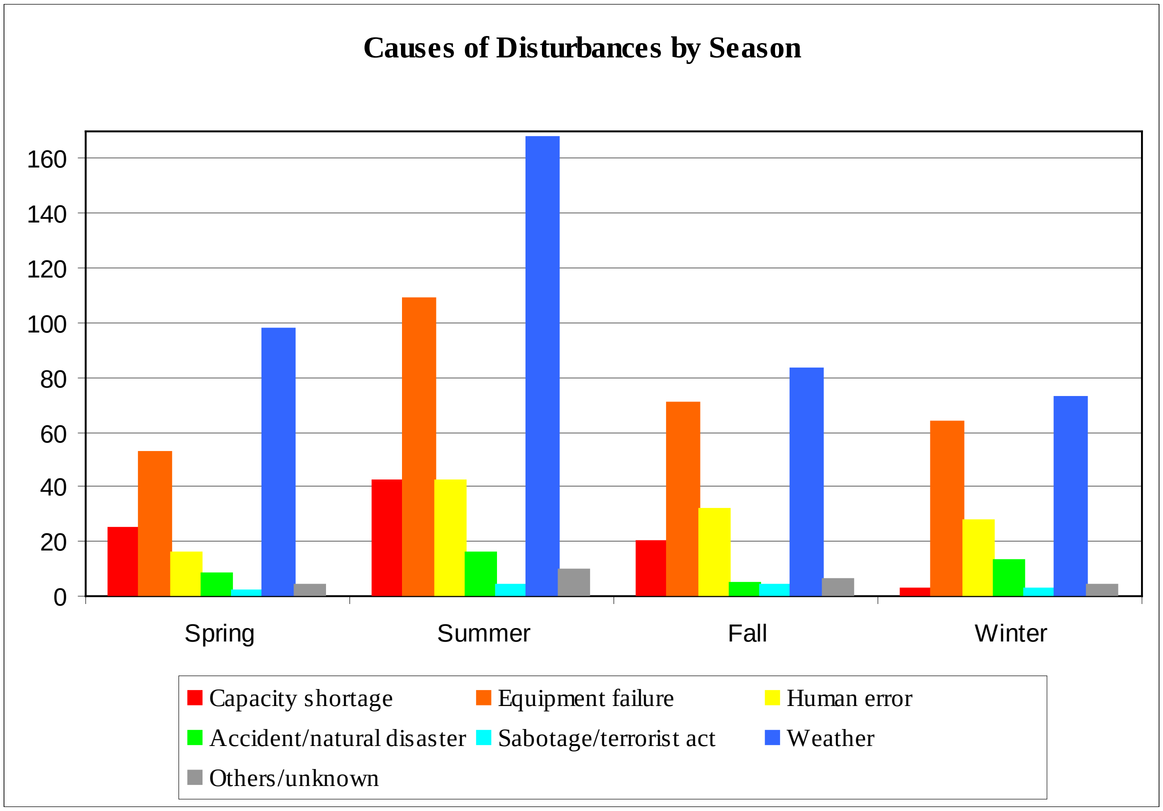
[60] According to the data of the National Oceanic and Atmospheric Administration (NOAA), there is no radical shift in the number of tropical storms, average temperature in July and August, and annual precipitation in the trends between 1990 and 2006. See Appendix 3.

[61] There is a question of why NERC include disturbance data caused by severe weather conditions which cannot be the objects of analysis. On the NERC website, they explain, "Events initiated by natural phenomena such as earthquakes, tornadoes, hurricanes, ice storms, etc., will not be analyzed although the resulting outages are encompassed by the EA (Event Analysis) categories. However, those events will be triaged to determine if there are any abnormal system behaviors or performance exhibited that warrant further analysis." That is, there will be possibilities in NERC. (2009). *Event Analysis: Classification Scale*, January 18, 2010, from http://www.nerc.com/page.php?cid=5|252.

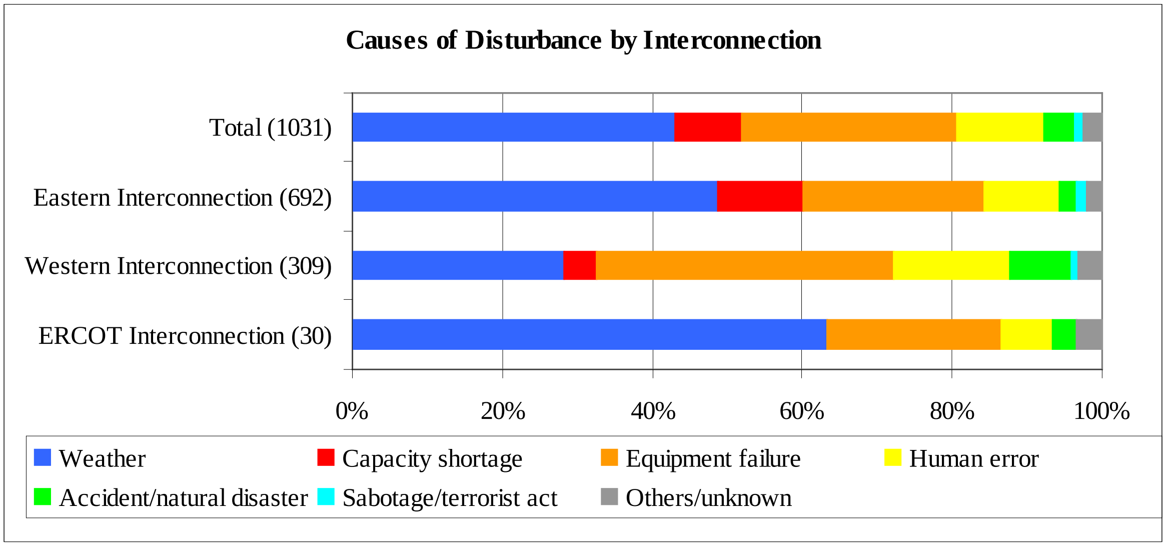
Figure 4.6. Causes of Power System Disturbances by Season



Spring: March, April, and May
Summer: June, July, and August
Fall: September, October, and November
Winter: December, January, and February
Source: NERC

Considering geographical differences, we cannot say that severe weather conditions are the only major reason for power outages. If we count causes of power system disturbances by interconnection, each interconnection has different major factors of power outages. From figure 4.7, the primary cause in the Eastern Interconnection is weather conditions while the Western Interconnection's major factor is equipment failure. Geographically weather conditions in the region of the Eastern Interconnection have various sources that cause power outages, such as thunderstorms, tornadoes, tropical storms, and severe ice storms. The share of natural disaster in the Western Interconnection is higher than that in the Eastern Interconnection due to more frequent occurrences of forest fire or earthquakes. In addition, all interconnections suffer from human errors.

Figure 4.7. Causes of Power System Disturbances by Interconnection



Source: NERC

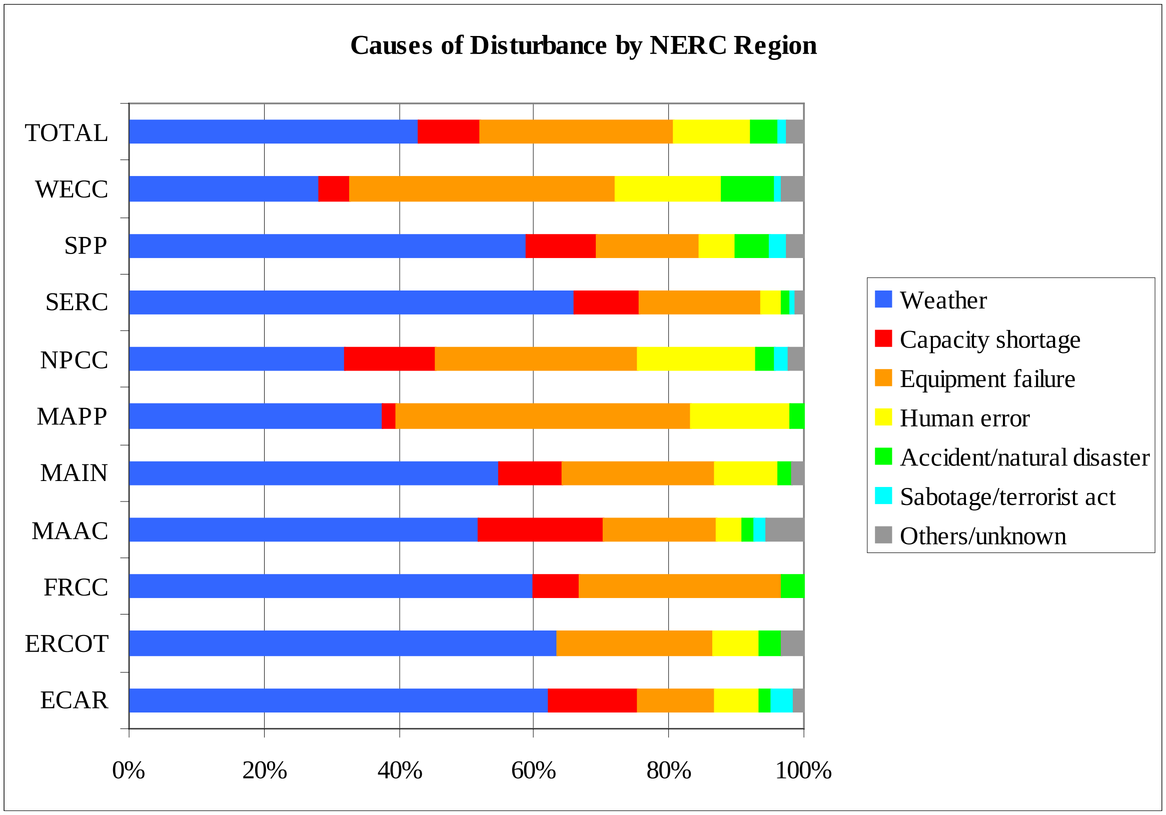
Specifically, if the Eastern Interconnection is divided into 8 NERC regions, the factors that cause power outages vary from region to region. Table 4.1 and figure 4.8 illustrate causes of system disturbance by the NERC regions. Severe weather conditions cause more power outages in the southern regions – FRCC (60%), SERC (66%), SPP (59%), and ERCOT (63.3%) in the cells with a blue shaded color – when they are compared to other regions. ECAR (62.3%), which is located in the Mideast region, is frequently affected by severe weather conditions, too. Severe ice storm, tornadoes, thunderstorm usually cause power outages in these regions; hurricane is another reason in the region of FRCC and SERC. Human errors are relatively small in these Southeastern regions, but are not a negligible part in the northern and western regions: MAPP (14.6%), MAIN (9.4%), NPCC (17.5%), and WECC (15.5%) in the cells with a yellow shaded color. Capacity shortage is a fairly essential factor of power outages in ECAR (13.1%), MAAC (18.5%) and NPCC (13.5%) – the cells with a red shaded color – where cascading outages happen repeatedly. The capacity shortage also means that there is more likelihood of power trade in these regions than others, so as to meet power demand in their regions. This situation could make the systems in those regions vulnerable. Additionally, another cause of power system disturbances in the WECC region is natural disasters, as described previously.

Table 4.1. Causes of Power System Disturbance by NERC Region (%)

Region	Weather	Capacity shortage	Equipment failure	Human error	Accident/ natural disaster	Sabotage/ Terror	Others/ Unknown	Total
ECAR	38 **(62.3)**	8 **(13.1)**	7 **(11.5)**	4 **(6.6)**	1 **(1.6)**	2 **(3.3)**	1 **(1.6)**	61 **(100)**
ERCOT	19 **(63.3)**	0 **(0.0)**	7 **(23.3)**	2 **(6.7)**	1 **(3.3)**	0 **(0.0)**	1 **(3.3)**	30 **(100)**
FRCC	18 **(60.0)**	2 **(6.7)**	9 **(30.0)**	0 **(0.0)**	1 **(3.3)**	0 **(0.0)**	0 **(0.0)**	30 **(100)**
MAAC	28 **(51.9)**	10 **(18.5)**	9 **(16.7)**	2 **(3.7)**	1 **(1.9)**	1 **(1.9)**	3 **(5.6)**	54 **(100)**
MAIN	29 **(54.7)**	5 **(9.4)**	12 **(22.6)**	5 **(9.4)**	1 **(1.9)**	0 **(0.0)**	1 **(1.9)**	53 **(100)**
MAPP	18 **(37.5)**	1 **(2.1)**	21 **(43.8)**	7 **(14.6)**	1 **(2.1)**	0 **(0.0)**	0 **(0.0)**	48 **(100)**
NPCC	80 **(31.9)**	34 **(13.5)**	75 **(29.9)**	44 **(17.5)**	7 **(2.8)**	5 **(2.0)**	6 **(2.4)**	251 **(100)**
SERC	103 **(66.0)**	15 **(9.6)**	28 **(17.9)**	5 **(3.2)**	2 **(1.3)**	1 **(0.6)**	2 **(1.3)**	156 **(100)**
SPP	23 **(59.0)**	4 **(10.3)**	6 **(15.4)**	2 **(5.1)**	2 **(5.1)**	1 **(2.6)**	1 **(2.6)**	39 **(100)**
WECC	87 **(28.2)**	14 **(4.5)**	122 **(39.5)**	48 **(15.5)**	25 **(8.1)**	3 **(1.0)**	10 **(3.2)**	309 **(100)**
Total	443 **(43.0)**	93 **(9.0)**	296 **(28.7)**	119 **(11.5)**	42 **(4.1)**	13 **(1.3)**	25 **(2.4)**	1,031 **(100)**

Source: NERC

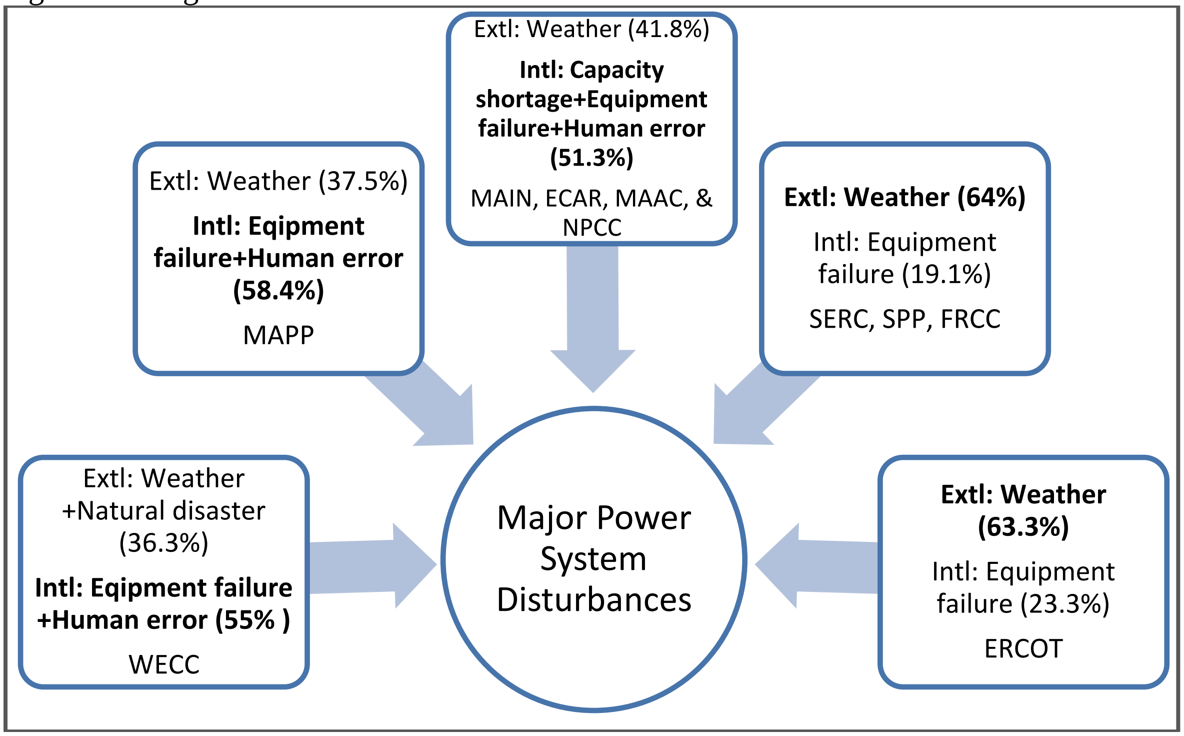
Figure 4.8. Causes of Power System Disturbance by NERC Region



Source: NERC

Human errors are not the major factor when they are compared to severe weather conditions and equipment failure. But they happen regularly over the years and seasons. They are usually operators' mistakes, switching errors, maintenance error, mismanagement of tree trimming, contractors' accidents, etc. In particular, they are, to some extent, important causes of power system disturbances in the Northeastern region (NPCC: 17.5%) and Western region (WECC: 15.5%) where cascading outages have happened a few times – the cells with a yellow shaded color (table 4.1). This gives us a reason for exploring human errors from the institutional and organizational view points.

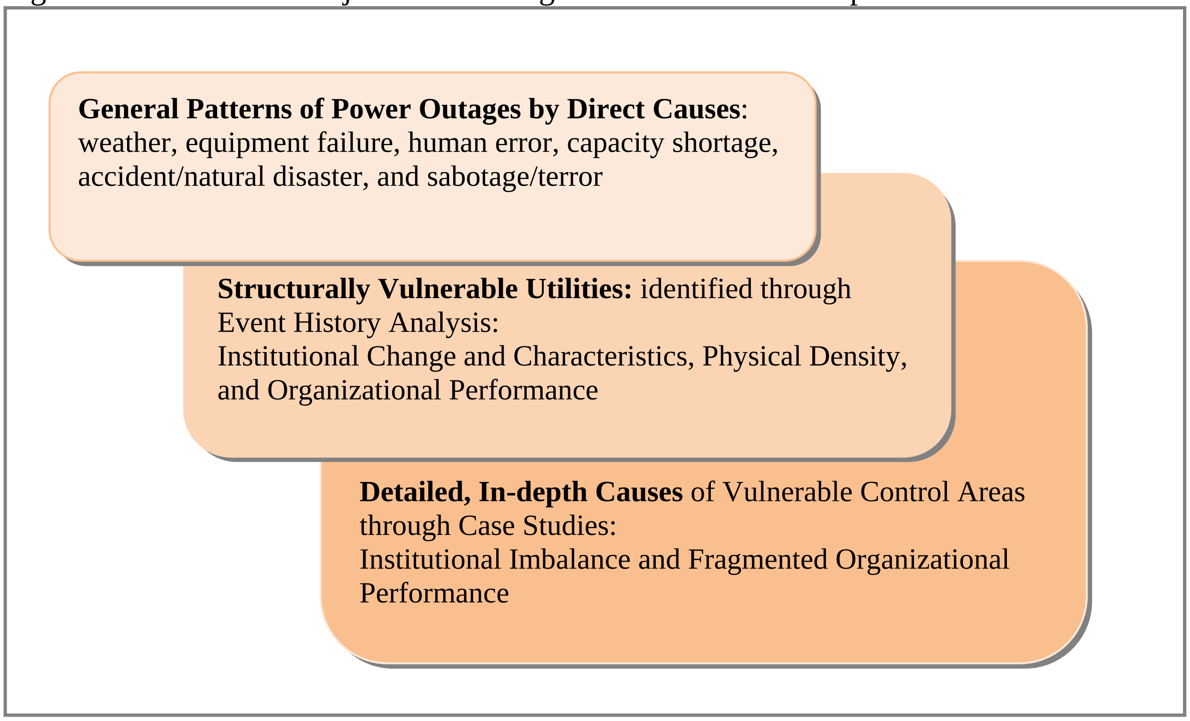
Figure 4.9. Organizational Performance vs. Weather/Natural disaster



External factors: Weather and Natural disaster
Internal factors (Organizational performance): Capacity shortage, Equipment failure, and Human error

Overall, it is apparent that severe weather conditions are a major factor of power system disturbances. The patterns also suggest that the rapid increase of blackouts since 1998 is related to such weather conditions as thunderstorm, hot weather, and tropical storms, or El Niño. But I suspect that weather conditions have not suddenly changed since 1998, causing disturbances more frequently. These data need more scrutiny. In addition, as illustrated in figure 4.9, geographical differences exist; weather is the major cause of power outages in the southeastern NERC regions – ERCOT, FRCC, SERC, and SPP; equipment failure is the main reason for blackout in the WECC and MAPP regions; and capacity shortage is another main cause in the northeastern regions – ECAR, MAAC, and NPCC. That is to say, these geographical differences in cause demonstrate that the radical shift of the number of power outages since 1998 cannot be attributable only to weather conditions.

Figure 4.10. Causes of Major Power Outages from Surface to Deep Structure



Until this point, the analysis of the general trend has been based on the direct causes: weather, equipment failure, human error, capacity shortage, accident/natural disaster, and sabotage/terror. Because these direct causes depict outside features of power system disturbances, they do not expose any underlying structural, organizational causes (Figure 4.10). In fact, each system disturbance includes a series of failures following the initial failure. As James Reason points out, we need to observe the collapse of the socio-technical system underneath the direct causes (Reason 1990). Considering a new institutionalist perspective on links between organizations and institutional environments, we should take account of institutional characteristics and change in analyzing the structural causes of major power system disturbances. From the fact that capacity shortage and human errors are higher in the summer and that equipment failure is higher in the WECC region from the preceding analysis, we can be aware of that organizational performance is an important factor in power system management and maintenance. That is, organizational performance for reliability is affected by other internal and external conditions. It is necessary to identify certain power systems or utilities that are exposed to vulnerable situations through the examination of institutional, physical and organizational conditions.

4.2. Repeated Event History Analysis: 1990 – 2006

Electrical engineers and experts began to discuss the structural issues of large scale blackouts after the 2003 blackout. Apt et al. (2006 p51) argue that since such factors as equipment failure, ineffective vegetation management, and human mistakes lead to large scale blackouts, “the causes of outages in the United States show there is considerable room for improvement.” Then, they point out a need to examine human and organizational factors, so that the electricity industry can prevent large scale blackouts (Apt, Lave et al. 2006 p57). The U.S.-Canada Power System Outage Task Force (2004 p103) states that “system-wide disturbances that affect many customers across a broad geographic area are rare, but they occur more frequently than a normal distribution of probabilities would predict.” Then the Task Force argues that if the electricity industry had responded in a timely way to changing conditions, cascading events, in retrospect, would have been preventable. The events of major power system disturbances analyzed in Section 4.1 are related to the integrity of the interconnected system operation. To prevent large scale blackouts, therefore, it is necessary that the electricity industry reduce the frequency of "major power system disturbances" by improving the internal and external conditions of electric utilities. As discussed above, there are structural reasons for power system disturbances beyond the direct causes of weather or environmental conditions.

We can say that good performance for more improved reliability is achievable with a prudent combination of physical, organizational and institutional settings. In achieving good performance, a first step is to identify vulnerable features of organizational and institutional settings in interconnected grid systems. It is necessary to uncover latent structural reasons why major power system disturbances occur by looking at external and internal conditions of utilities. In this analysis, especially paying attention to the frequencies of major power system disturbances in Section 4.1, I have attempted to determine what kinds of structural properties accelerate power system outages, and what structural properties reduce the system survival intervals between major power outages.

4.2.1. Institutions, technology, and organizational performance

A basic perspective on the social structure of the electricity industry is that as discussed in Chapter 3, organizational behavior is constrained by the external – physical and institutional – environment as well as by its own activities. Identifying and explaining the structural properties of power system outages is based on four sources of theory: Giddens's structural theory, Vaughan's concept of autonomy, Weick's perspective on high reliability organizations and concept of loosely coupled systems, and Scott's organizational performance. First of all, defining the structure of the electricity industry is a difficult task owing to the diverse dimensions of the electricity industry. Anthony Giddens (1979; 1986, p25, pp185~186), generally but precisely, regards structure – structural properties in his terms – as rules and resources or as institutionalized features to reproduce social systems which refer to regular social practices or situated activities organized by human agents.[62] On the basis of this perspective, as I reviewed the historical development of the electricity industry in Chapter 2, I perceived several specific structural properties which organize power systems: structural density (or complexity), autonomy (with coordination), and on-time management (for electric power balance). The electricity industry has evolved to encompass current physical, organizational features with these structural properties.

Structural Density (Complexity): Physical conditions

According to Lovins and Lovins (1982), the physical structures of electricity systems have these characteristics: centralized supplies, long haul distances, limited substitutability, and continuity & synchronism in grids. Originally power systems were located near densely populated urban areas. With the development of alternating current (AC) and other power delivery technologies, large-size and centralized power plants could be constructed near the resource-abundant areas. Those distant areas were

[62] Adopting Garfinkel's notion of ethnomethodology, Giddens defines rules as methodical procedures of how social actors interact with each other in everyday routines, and resources as the media whereby transformative relations are used to produce and reproduce social practices. Giddens, A. (1986). *The Constitution of Society: Outline of the theory of Structuration*. Berkeley, University of California Press. The concept of *rules* includes broad meanings; that is, rules are procedural in social practices as well as constitutive and regulative such as codified or formulated rules. Regulations or institutions in this sense are specific types of formulated rules. Also see footnote 47, constitutive rules.

subsequently linked together through transmission lines. As large power systems were constructed and interconnected with one another, the integrated systems became a huge, complex entity at the regional level. The growth of power system interconnections generated densely interconnected areas or clusters along with which power systems management of a cluster developed and was separated from other clusters.

Weick (1987 p112) argues "organizational culture as a source of high reliability," and points out that "accidents [or system failure] occur because the humans who operate and manage complex systems are themselves not sufficiently complex to sense and anticipate the problems generated by those systems." The operation of complex power systems in each utility becomes a difficult task, because grid system engineers and operators should consider and solve as many contingencies as they can, thereby requiring more sophisticated procedures. Generally utilities controlling large scale power systems may have more variables to be controlled, and therefore have more chances of system failure. Therefore;

Hypothesis II-1: *The more complex power systems are, the more likely are they to experience power system disturbances*.

Autonomy

Although power systems are interconnected through transmission lines, individual electric utilities construct and organize their own systems and exist as separate and independent entities. They are also self-regulating entities in discovering, monitoring, investigating and sanctioning flaws within their systems (Vaughan 1990). Because of autonomy, regulators do not have enough authority to get access to information on individual power systems, nor do they have the capability to interpret the information that is necessary for management of the entire power system (Vaughan 1990). In this situation, an institutional change in just one aspect of power systems without structural consideration of the entire power system may make system reliability unstable. In addition, utilities want to protect their operational autonomy of strict regulation, and therefore do not want to be constrained by their institutional environment. As a result, power system operators working under condition of loose coupling with reliability institutions may not share similar premises and assumptions. This situation may lead to inappropriate responses to emergencies.

Autonomy: Institutional changes

According to Giddens (1986), social structures have a dualistic character: constraining and enabling. Institutional change is an enabling aspect of social structures. There are two classes of explanation of institutional transformation; one is the reflection of a fundamental transformation, i.e. restructuring or liberalization; and another is a long-term adaptation in response to major technological and economic change (Schneider 1991). The latter may mitigate future system failures during the period of institutionalization by incorporating information produced by trial and error. The former might create a radical shift that leaves utilities unprepared for unanticipated system failures. Deregulation[63] of the electricity market is an enabling aspect of the electricity industry, and an example of this reflection is that it can produce an unanticipated problem

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[63] Deregulation in the electricity industry generally refers to independent power producers' open access to power grids to promote wholesale competition. In this dissertation, deregulation means that wholesale electricity prices are determined in the free market, and that at the distribution level, retail customers can have retail choices.

with respect to reliability due to the fundamental transformation of the market structure – from monopoly to competition in the wholesale and retail markets. Regulators, usually the Federal Energy Regulatory Commission (FERC) or state governments, might not consider all features of the grid system, especially reliability, when they introduce competition in electricity wholesale and retail sale markets.[64] Although they consider reliability, they may not get access to specific information on each utility or region that is critical for reliability.[65] NERC, which deals with reliability standards, knows how critical the deregulation is to electricity reliability, but its action and authority to enact a reliability law is neither fast nor strong enough to catch up with the institutionalization of deregulation.[66] In the wholesale market, investor owned utilities, which have controlled their own integrated power systems, may lose the autonomy to control their transmission systems although they want it for their own facilities.[67] Because deregulation allows open

[64] 1) Weil points out that "…[regulators] had no experience in establishing commodity markets…Not knowing to construct markets, FERC was also ignorant of how to protect consumers from unscrupulous market operators." Weil, G. L. (2006). *Blackout: How the Electricity Industry Exploits America*. New York, NY, Nation Books. pp64-65. 2) After extensively allowing IPPs' open access to transmission lines, no one knew who were connected to transmission lines and how power flew on the lines. NERC said that transmission lines were almost out of control as of the 2003 blackout. Interviewee5 (2008). Blackout Interview. H. Park. Princeton, NJ. FERC did not anticipate this situation. NERC introduced NERC tags to capture the whole transactions on transmission lines. 3) Another aspect of unanticipated outcomes is that as discussed in Chapter 2, increased power transactions cannot control the laws of physics – paralleled flow and loop-flow which cause unintended heavy loads on neighboring transmission lines rather than the contracted line.

[65] Through the Open Access Same-time Information System (OASIS), market participants can know, on the Internet, the information about the short-term and long-term use of transmission systems managed by ISOs and RTOs. However, Casazza et al. points that "…companies began to withhold information of commercial use to competitors, but important from a reliability coordination viewpoint." Casazza, J., F. Delea, et al. (2005). Blackouts and Blunders: the Failure of Electric Power Policies in the United States. Springfield, Virginia, Power Engineers Supporting Truth., p4. An example was opportunities for power marketers, Enron and others, which exercised market power, when demand was high and supply was inelastic. By withholding power supplies, they sent the wholesale market a wrong price signal – making wholesale prices volatile at the spot market – which caused the reliability problem in California in 2001.

[66] Since the 1996 West blackout, the community of reliability related organizations began to discuss the state of electricity reliability: the existing principles of voluntary participation in reliability standards and peer review in violation of them. But it is not until the passage of the Energy Policy Act of 2005 that reliability standards became mandatory. NERC's authority is further discussed in Chapter 7.

[67] To provide all power producers in the wholesale market with equally open access to transmission systems, FERC wanted transmission lines to be operated independently. FERC Order 888, therefore,

access to transmission lines, it increases unusually the amount of power trading through transmission lines. At the retail level, because utilities desire to keep their retail customers from switching to competitive retail suppliers, they may need additional retail supply costs, such as customer service, and advertising and promotion costs. Thus they might reduce long-term investment in their facilities including distribution systems so as to cover the retail supply costs,[68] which affects the reliability of electricity distribution. Under these situations, therefore;

Hypothesis II-2: *Institutional changes – introducing competition in wholesale or retail markets– will increase the likelihood of experiencing disturbances*.

Autonomy: Institutional settings (Conditions)

There were 10 regional reliability councils[69] whose work is generally twofold: evaluating regional reliability (resource adequacy planning) and setting reliability standards (operation and emergency criteria). Thus these reliability councils function as

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encouraged power pools to organize Independent System Operators (ISO) – approval by FERC after negotiations – in order to separate utilities' operation of transmission lines from generators. Furthermore, FERC Order 2000 guided minimum characteristics and functions for establishing Regional Transmission Organizations (RTO) to promote efficiency in the wholesale markets and to ensure that electricity consumers pay the lowest price possible for reliable service. As a result, utilities, which own transmission systems, turned their grid operation rights over to ISOs or RTOs.

[68] Because of little information about retail choices, Joskow states that it is too early to evaluate the performance of retail choice programs in states which introduced retail competition to their retail markets. So far, at least, retail prices have been lowered. Joskow, P. L. (2005). The Difficult Transition to Competitive Electricity Markets in the United States. *Electricity Deregulation: Choices and Challenges*. J. M. Griffin and S. L. Puller. Chicago, The University of Chicago Press. The fact that lower retail prices reflect market efficiency might be examined. Retail price mechanisms vary from state to state. But one possibility is that incumbent utilities will lower their retail prices to keep their customers in the service. As a result, the utilities might not recover their stranded costs. In addition, they may cut budgets for system maintenance to allocate them for customer services – advertising and promotion costs.

[69] After the 2003 blackout the three regional reliability councils – ECAR, MAAC, and MAIN – merged together, becoming ReliabilityFirst Corporation (RFC). Now there are eight reliability councils – NPCC, RFC, SERC, FRCC, SPP, ERCOT, MRO, and WECC. In this dissertation, 10 regional reliability institutions are used for data analysis.

institutions. Utilities are expected to make plans and operate their systems according to the planning and operating criteria of the regional reliability councils. These criteria vary from region to region, since there are differences in the mixture of power resources, geographical locations of power systems, different types of ownership (federal, state, municipal, rural cooperatives, and private utilities), and organizations of systems control. Because of utilities' tendency to operate their systems in a more self-regulated manner, their system planning criteria may vary from utility to utility within the region. However, a few regional councils manage things more strictly, forcing utilities to pay contractual penalties for any violations. This policy can improve reliability. Therefore,

Hypothesis II-3 (Penalty): *In resource adequacy planning, utilities which face contractual penalties set by their regional reliability councils are less likely to experience disturbances*.

As mentioned earlier, Weick emphasizes the need for human sophistication in managing complex systems based on a concept of *requisite variety*[70]; "when people have less variety than is requisite to cope with the system, they miss important information, their diagnoses are incomplete, and their remedies are short-sighted and can magnify rather than reduce a problem" (Weick 1987 p112). If utilities consider as many factors as possible in resource adequacy planning and emergency plans, they can prepare for more potential contingencies, and they can reduce likelihood of major power failure. Therefore,

[70] "The law of requisite variety… the variety within a system must be at least as great as the environmental variety against which it is attempting to regulate itself. Put more succinctly, only variety can regulate variety." See Buckley, W. (1968). Society as a Complex Adaptive System. *Modern System Research for the Behavioral Scientist*. W. Buckley. Chicago, Aldine Publishing Company., p495.

Hypothesis II-4 (Planning): *If a reliability council considers more factors for resource adequacy assessment, utilities under the council will be less likely to experience disturbances*.

Hypothesis II-5 (Emergency operation): *If a reliability council considers more factors for emergency operation, utilities under the council will be less likely to experience disturbances*.

As discussed in Section 3.2.2, to create a stronger organizational culture of reliability, utilities in a reliability region could centralize similar premises and assumption before decentralizing their decision making. One technical way to do this is to put a central dispatch center in the region, so that utilities' system operations are coordinated through the center. This would make coordinating power systems tightly coupled, and thus improve reliability. Therefore,

Hypothesis II-6 (Operation): *If a reliability council adopts central dispatch, utilities under the council will be less likely to experience disturbances*.

Another way of creating a strong culture of reliability in interorganizational relationships is to make use of government regulatory power, so that regional reliability institutions can effectively coordinate utilities' individualized system operations. This also makes interorganizational relationships tightly coupled. I predict, therefore, that strong actions by federal agencies and state public services can mediate interests among utilities and provide the necessary regulation for coordination. For example, the federal government has been involved in power system management in the New England region

(FERC 1981), and the Public Service Commission in Florida has supported utilities' power systems management to keep the lights on in the face of natural disasters (FRCC 2008).

Hypothesis II-7 (Regulatory relationship): *If a reliability council has a strong regulatory relationship with FERC or State Commissions, utilities under the council will be less likely to experience disturbances*.

On-time management (Balance): Organizational performance for reliability

Electricity is consumed by end users as soon as it is produced by power plants. Thus, utilities need continuous, on-time management of their interconnected power systems. For this on-time management, a large work force at the supply side is involved from the planning stage to the power transmitting stage: predicting long and short term demand, siting and constructing power plants and transmission lines, and operating and maintaining those systems. Among these tasks, balancing power demand and supply by power system operators is critical during the summer and winter seasons when the power demand is very high. Utility system operators are normally very busy during this period, and their performance is important for the reliable supply of electricity.

To manage peak time demand, some utilities implement demand side management (DSM) programs by encouraging consumers to install and use energy efficient technologies, such as energy efficient lighting, high efficiency heating, cooling, and ventilation equipment (HVAC), and energy efficient appliances. By using these technologies, utilities can provide consumers with such DSM programs as peak-load reduction, load shifting, or load building. Thus, how they deal with peak hours with DSM programs during the summer and winter seasons can be an important indicator of organizational performance. If utilities can manage peak time control successfully, they can make an accurate prediction of electric demands and proper use of DSM programs as well as the appropriate level of power supply. Nevertheless, if they cannot handle peak demands, a heavy load on their system to meet high demand will increase the chance of system failure during the peak hours in these seasons. Therefore,

Hypothesis II-8: *The higher the summer and winter peaks in kilowatts per customer are, the more likely are power system operators to fail in managing their systems during these peaks*

Organizational performance is generally expressed in terms of *effectiveness* and *efficiency* (Flood and Scott 1987). *Effectiveness* refers to the extent to which the preferred outputs are obtained, while *efficiency* refers to how resources are minimized to get the same result, measured by the ratio of inputs to outputs.

Concerning effectiveness, reliable supply of electricity denotes one of the effective outputs. An indicator for measuring organizational effectiveness is power loss on transmission lines. Physically, power loss is inevitable when power produced by generators at power plants travels to end users. As electric power is pushed along transmission lines, electrical friction (known as resistance) causes losses in the form of heat. Because of the transmission losses, therefore, the power that is used by end users through space heaters and incandescent lights is less than the power that is sent from the generator. The amount of power losses on transmission lines may be similar in all companies.

Particularly during the summer peaks, more power loss occurs by end users and transmission lines.[71] When we use induction motors such as air-conditioners and fan motors which have coil structures inside similar to power generators, we use both real power and reactive power. The use of induction motors causes reduced consumption of real power due to the consumption of reactive power. The relative magnitudes of real power and reactive power are measured in terms of *load power factor*.[72] In the United States as a whole, load power factor is 0.92 during the winter peak, and is 0.88 at the summer peak (U&CTF 2004). Because the induction motors still need certain amount of real power, power flow increases on transmission lines. That is, the low power factor causes heavy loads (high current) on the transmission lines which need additional reactive power to push electricity to end users; this also increases power loss due to the high current on the power lines (Interviewee2 2009). Power losses are higher with low load power factor than high load power factor. Considering these facts, power system operators[73] in most regions need more careful prediction of demand and system management – good planning, sufficient voltage control resources, and adequate maintenance – during the summer peak hours than the winter peak hours. Therefore,

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[71] Power loss also happens through power thieves. Interviewee2 (2009). Blackout Interview. H. Park. Englishtown, NJ. Utilities need good organizational performance – monitoring their systems effectively – to prevent power thieves from stealing power.

[72] Power factor is measure in terms of the ratio of real power to apparent power. S^2 (apparent power) = P^2 (real power) + Q^2 (reactive power). Load power factors of space heaters and incandescent lights are 1.0 since they use only real power and no reactive power. Because induction motors use both real power and reactive power, however, load power factors range from 0.7 to 0.9 generally. U&CTF (2004). Final Report on the August 14, 2003 Blackout in the United States and Canada: Causes and Recommendations. Washington D.C., U.S.-Canada Power System Outage Task Force., p26.

[73] "It is the responsibility of system planners and operators to plan reactive power requirements and make any short-term arrangements needed to ensure that adequate reactive power resources will be available." Ibid., p38.

Hypothesis II-9: *If utilities have more power losses in percentages of total power sources between generation and end users, they are more likely to experience power system disturbances*.

Efficiency is related to the economic side of organizational performance in the electricity industry. Profit maximization is a primary goal of electric utilities, particularly investor owned utilities. Every moment, therefore, utilities must consider the economic allocation of power resources and the dispatch of electric power when they generate and transmit electricity. Through these considerations, utilities try to maximize return on assets (ROA) and return on equity (ROE). ROA usually measures efficiency of organizational management, while ROE evaluates profitability of a company.

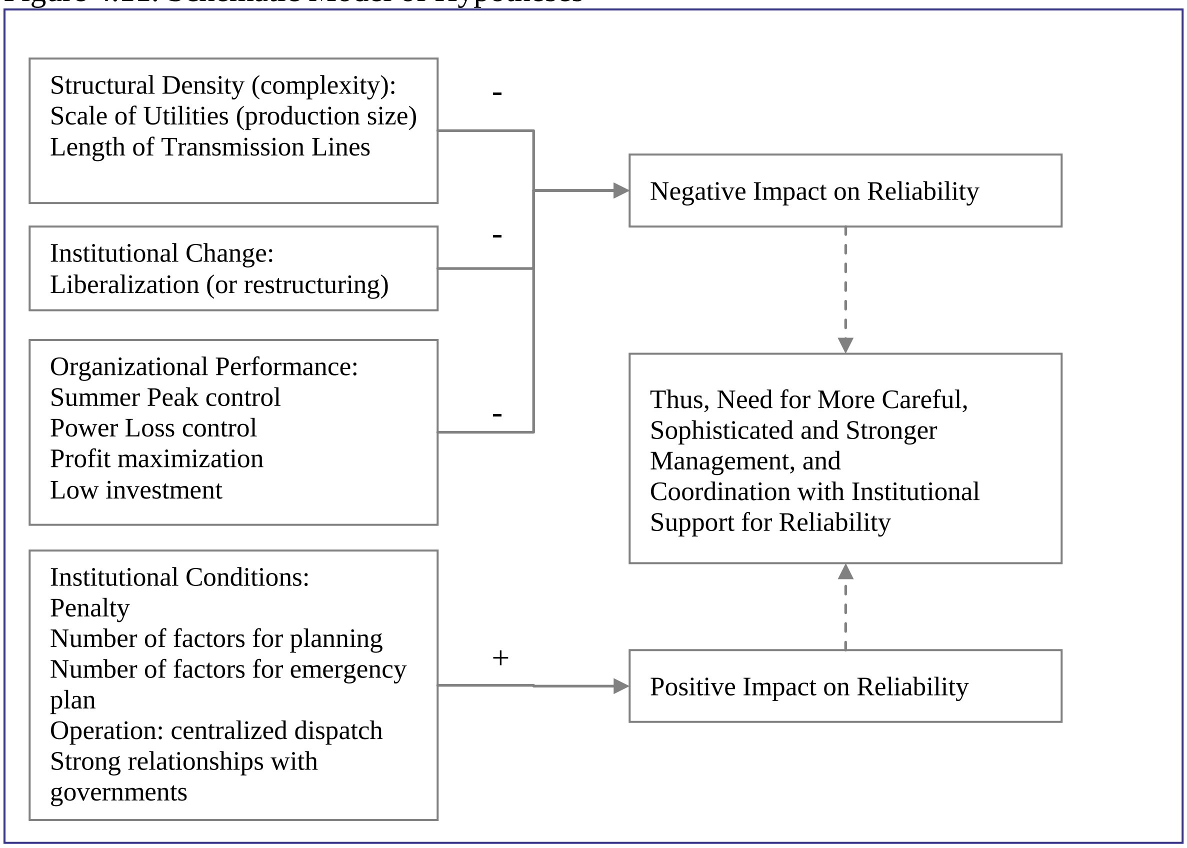
However, the current emphasis on ROA and ROE may conflict with the reliability of electricity, which ultimately incurs higher costs by investment in technologies and facilities for reliability.[74] Because the electricity industry is capital intensive, utilities issue bonds to invest in facilities that are also important for the reliable supply of electricity. Therefore, utilities must maintain the high bond ratings assessed by financial service companies such as Moody's and Standard & Poor's. Plausibly, utilities with high

[74] According to Quanta Services Inc., the world's largest builder of transmission lines, utilities cut spending on maintenance by as much as by 50% because of the uncertainty in recovering maintenance costs through rate increases. John R. Colson, Chief Executive Officer of Quanta Services Inc., says, "Because they haven't been doing maintenance for a few years, we will see longer outages and we will see more frequent outages as storm season approaches. In addition, "FPL Group Inc., which was fined a record $25 million for a Florida power failure, halted some projects targeting improvements in reliability in the state after it got a lower- than-requested rate increase on Jan. 13." Klimasinska, K. (2010). U.S. Faces Extended Power Outages, Largest Grid Builder Says. . *Bloomberg*. New York. Utilities may try to make their profits by cutting their costs, such as maintenance, if they cannot increase rates approved by their state commission in recovering the costs.

ranking bonds may have stable investment in their facilities and technologies, thereby improving reliability. Therefore,

Hypothesis II-10: *Utilities are more likely to experience system failure when focusing on profit maximization while subsequently paying less attention to investment in facilities and technologies.*

Figure 4.11. Schematic Model of Hypotheses



Summarizing these hypotheses, I assume that institutional, physical, and organizational conditions negatively or positively affect the reliability of electricity as shown in figure 4.11. There will be vulnerable utilities with the above characteristics in the interconnected transmission system. I will return to these characteristics during the case studies in chapter 5, 6, and 7. In testing the above hypotheses, I will use the data and methods described in the next section.

4.2.2. Data and Methods

Data

The analysis in this chapter focuses on the structural factors which are associated with major power system disturbances. As discussed in Section 4.1, NERC's power system disturbance data only include events meeting NERC's reporting guidelines. The primary guideline is "the loss of a bulk power transmission component that significantly affects the integrity of interconnected system operations" (NERC 2001 p35; NERC 2009). That is, NERC collects and analyzes disturbances which had the potential to develop into a large-scale system failure, or which already caused large-scale power failures – loss of firm system loads affecting customers' services. The disturbances include the events that happen at the generation, transmission, or distribution level.

Minor power system disturbances, however, are excluded in the NERC data, because they are local events which do not significantly affect the integrity of interconnected system operations. There are more than 3,000 utilities in the United States.[75] They include small-scale municipal utilities and rural cooperatives. Some of them have their own generating systems to supply electricity within their territory. Others do not possess generating units and transmission lines, and must buy electricity from IOUs or public utilities owned by federal or state governments. These small-scale utilities also

[75] According to Form EIA-861 Database (Annual Electric Power Industry Database), there are 3,244 and 3,270 utilities in 1990 and 2006, respectively. EIA. (2009). *Form EIA-861 Database* Retrieved December 23, 2009, from http://www.eia.doe.gov/cneaf/electricity/page/eia861.html.

experience system failures interrupting customer services. Because their system failures are small-scale and limited within their territory, they are excluded in the NERC data. These small-scale power failures are not the subjects of the analysis in this chapter.

The scope of analysis here is to see the associations between these major power system disturbances and structural factors including physical, institutional and organizational conditions. Since the NERC data meet the scope of analysis, therefore, I have used power system disturbance data from NERC (1990 – 2006)[76] and EIA annual disturbance events data from 1999 to 2006.[77] These data include time and date of events, region, utilities, disturbance types,[78] size of power loss (mega watts), the number of affected customers, restoration time, and causes categorized by NERC. Table 4.2 shows descriptive statistics using the NERC data, after subtracting events which occurred in several utility areas. As the table shows, many events are large scale as determined by power loss and affected customers. There are 277 events of power loss more than 300 MW, and 320 events related to more than 50,000 affected customers.[79] In addition to these direct effects of power loss and subsequent consumer impact, other events are also reported to NERC if they are the failures of critical components included in the first column.

[76] Before 2007, NERC data collection was based on utilities' voluntary participation.
[77] EIA data also have the similar reporting criteria to those of NERC about power system disturbances. See Appendix 2 Disturbance Reporting Requirements.
[78] NERC defines disturbance types as customer interruption (INT), unusual occurrences (UO), demand reduction (DR), voltage reduction (VR), public appeal (PA), and not available (N/A).
[79] Customers include industrial and commercial as well as residential customers. As a rule of thumb, therefore, the number of affected people is four times as many as affected customers, which means that if 50,000 customers lose power, approximately 200,000 people may lose power.

Table 4.2. Descriptive Statistics for the NERC DAWG data, 1984-2006

	All	≥ 300 MW	≥ 50k Customers
Total # of events	861	277	320
Mean size in MW	584	1,706	1,111
Median size in MW	90	637	274
Std. dev. MW	3,272	5,610	5,163
Mean size in customers	62,640	288,720	429,180
Median size in customers	1,000	71,000	149,750
Std. dev. in customers	87,150	1,020,200	1,076,700

Source: (Hines, Apt et al. 2008)

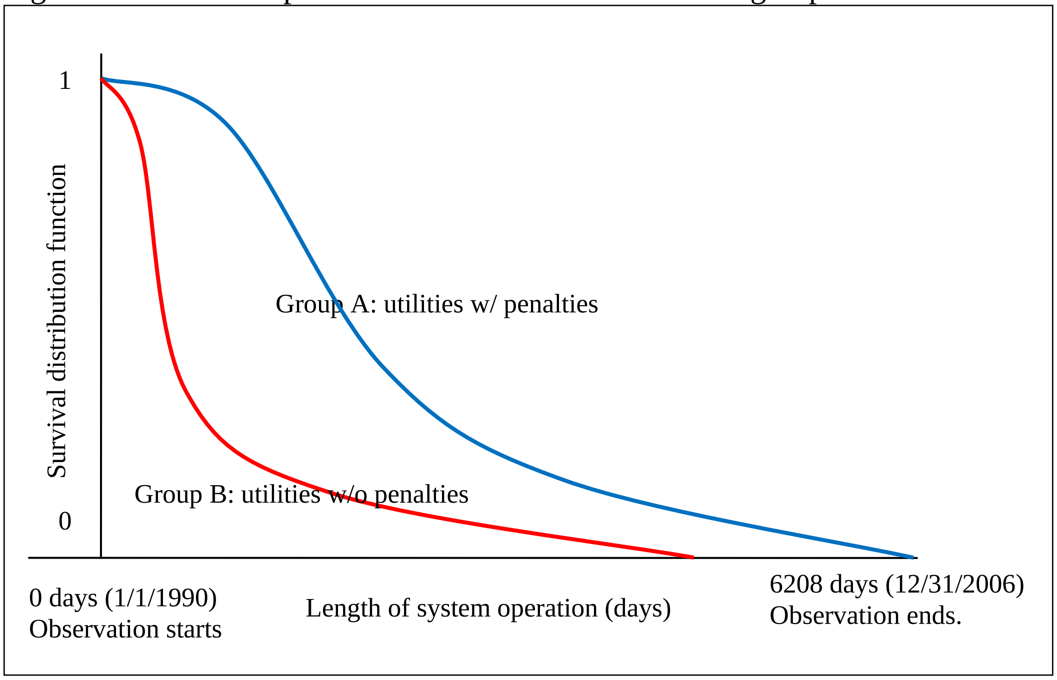
One issue about the data is that they do not represent the whole population of power system disturbances including small-scale ones. A large scale utility may have the same reliability as a small one, or even better. However, the focus in this analysis is on the major power system disturbances, not the reliability for each customer. The research is about the characteristics of utilities which are exposed to major power system disturbances, whether they are small or large scale utilities. Therefore, an important point is the NERC's reporting guidelines as mentioned previously. The reporting guidelines are those critical components' failures of grid and generating systems which have potential to develop into cascading outages if they interact with other events. Again, the analysis focuses on the structural factors lying behind the utilities that experience major power system disturbances, and therefore the NERC data are appropriate for the analysis.

Because the NERC and EIA interruption data have limited information on the characteristics of utilities, I have collected data from various sources for independent variables. I draw data from EIA form-861 for the explanatory variables of scale of utilities in terms of structural density (total power delivered a year), locations of utilities in reliability institutions (characteristics of regional reliability councils), summer & winter peaks, and power losses (organizational performance: effectiveness). To observe the structural density (complexity) represented in terms of miles of transmission lines I have searched the data from each utility's website. Regarding institutional change, I utilize the data on the effective years of deregulation by state from Andrews's article (2000) – *Diffusion Pathways for Electricity Deregulation*. More specifically, implementation of deregulation (institutional change) is based on the information from the websites of Independent System Operators (ISO) and Regional Transmission Organizations (RTO) – ERCOT ISO, PJM Interconnection, New York ISO, New England RTO, MISO RTO, California ISO, and SPP RTO – and EIA's Status of State Electric Industry Restructuring Activity. To measure the characteristics of reliability institutions, I have reviewed and quantified the contents of reliability standards from the survey of FERC's Power Pooling and each reliability council's planning and operating manuals. To analyze the effects of organizational performance (organizational performance: efficiency and investment through ROA, ROE, and bond ratings) – on power system disturbances, I have used data on EIA form-412 (Public Electric Utilities Database), Moody's Public Utility Manual from 1991 to 2001, and the Moody's website.

Methods

In examining general patterns of blackouts, I use 'Event History Analysis' which is a useful method for explaining general characteristics of utilities regarding system failure. Time is a concern in event history analysis. It measures the duration of time units spent until an event occurs, and describes distribution of time to a given event. Using event history analysis, I can analyze how long a utility operates its systems successfully until an event – a major power system disturbance – occurs and what kind of factors affect the duration of the system. That is, a long duration time of a system operation between major events means that the utility shows good performance under the appropriate institutional environments, which will reduce the frequency of the events. The duration of system operation (in days), as the dependent variable, can be estimated by explanatory variables (or covariates) – institutional, physical, and organizational conditions.

Figure 4.12. An example of survival curves for utilities in group A and B



Basically, if utility A were to experience a major power system disturbance on May 1st, 2003, and experience another on April 1st, 2004, the duration of successful system operation would be 11 months or 335 days. The length of time may vary from utility to utility according to their institutional or physical conditions. Thus, we can measure how the length of time is associated with an explanatory variable. For example, let us assume that utilities in group A have to pay penalties for not complying with regulations, but utilities in group B do not have to do. Then, as the survival curves of figure 4.12 illustrate, there would be different survival distributions between the two. That is, utilities in Group A have a higher probability of system operation more successfully than those in Group B.

Instead of using the survival function with the length of time, we can employ a hazard function to estimate the conditional failure rate (hazard rate) at a specific time interval as a dependent variable.[80] For example, if there are 75 power system disturbances among 100 utilities per year, the hazard rate is 75/100 = 0.75 in a given time interval. In other words, utility's hazard for an event is 1.3 years from 1/0.75 = 1.33 (years). Because hazards are inversely related to event times, the hazard rate of Group A is lower than that of Group B in figure 4.12. In this way, by tracking utilities over time, I can trace the dependent variable, the duration of successful system operation or hazard rates, and the length of successful operation time affected by covariates.

Utilities, as the unit of analysis, own and operate transmission systems in their territories. A utility can experience major power system disturbances repeatedly. In his book *Survival Analysis Using SAS – a Practical Guide*, Paul Allison (1995) treats them as independent observations. I will use his method. Each event can be a starting point of observation until the next event. One difficulty is that there is no data on disturbances since the establishment of each utility. There are the only observations from 1984.

[80] Hazard is the instantaneous risk that an event will happen at time t. The hazard function *h(t)* is

$$h(t) = \lim_{\Delta t \to 0} \frac{\Pr\{t \le T < t + \Delta t \mid T \ge t\}}{\Delta t} = \frac{f(t)}{S(t)},$$
$$S(t) = 1 - F(t),$$
$$f(t) = \lim_{\Delta t \to 0} \frac{\Pr\{t \le T < t + \Delta t\}}{\Delta t}, \text{ and}$$
$$f(t) = \frac{dF(t)}{dt} = \frac{d}{dt}\{1 - S(t)\} = -\frac{dS(t)}{dt} = -S'(t)$$

, where *t* is time, *T* is a non-negative random variable of the event time for some individuals, *f(t)* is probability density function, *F(t)* is cumulative distribution function, and *S(t)* is survival (survivor) function. As we can see in the above functions, the hazard function *h(t)* is inversely related to the survival function *S(t)*.

Furthermore, the DAWG data of NERC have limited information about utilities. In analyzing characteristics of utilities, the data from EIA form 861 and 412 are useful, but EIA's posted data on the website range from 1990 to present. That is, DAWG data from 1984 to 1989 are useless. Therefore, the observation period is from 1/1/1990 to 12/31/2006 after combining the DAWG and EIA data. This period is meaningful. First, the wholesale and retail sale market competitions started during this period after the legislation of the Energy Policy Act of 1992. Then, most states decided their policy for introducing competition in their retail sale markets during this period. Second, after the 2003 blackout, mandatory and enforceable reliability standards have been effective since June 18, 2007. This means that the analysis primarily focuses on utilities' performance based on voluntary participation in reliability standards.

Independent Variables

First, physical density increases the probability of system failure. This is measured by annual power sources[81] in million megawatt hours (MMwh). According to ownership types – private, Federal, State, Cooperatives, Municipal, and Political Subdivision utilities – power sources available per year vary from utility to utility. Table 4.3 shows the annual power sources by ownership type only including the utilities experiencing power system disturbances observed between 1990 and 2006. Private utilities (Investor Owned Utilities) usually provide electricity in urban areas. Federal utilities, in

[81] Power sources here refer to primarily generation from utility-owned generators, wholesale purchases, and exchanges. (defined as a trade, or barter, of electric energy for electric energy in return). EIA (2000). F861 Datafile - Final-YR2000. Washington D.C. Power sources are different from energy sources. The energy sources refer to coal, petroleum, natural gas & other gases, nuclear, hydroelectric conventional, and renewables (wind, solar, solar thermal, photovoltaic, geothermal, and biomass). Both of them are measured in giga-, mega-, or thousand-watt hours.

accordance with their founding laws, were founded to implement regional hydraulic power projects, such as Bonneville Power Administration, Tennessee Valley Authority, Southeastern Power Administration, Southwestern Power Administration, and Western Area Power Administration. These private and federal utilities have large sized power systems. Political subdivisions as publicly owned utilities include many municipalities and counties, while cooperatives serve mostly rural areas. Both of them are developed usually in the sparsely populated areas. They have medium sized power systems, although they cover large areas through long transmission lines. And most municipal power systems provide local areas with relatively small scale power. That is, power systems owned by IOUs and the federal government have more physical density or complexity than those of cooperative, municipal, and political subdivision. Because they should consider more factors in controlling their power systems, utilities with large scale power systems have more likelihood of failure than those with medium and small scale ones.

Table 4.3. The Annual Power Sources and the Average Number of Customers of Utilities Observed 1990 to 2006
(above, Gwhrs/year; below, customers)

ISO_RTO	State	Federal	Private	Pol. Sub.	Cooperative	Municipal
186,723	123,877	78,002	43,871	15,626	10,377	7,911
7,770,818	6,395,114	6,011,008	1,426,129	391,427	402,122	330,380

Source: EIA Form-861 (1990~2006)
ISO_RTO, Federal, cooperative and some of Private utilities are an aggregation of utilities' annual power sources within its jurisdiction.

Another way to measure the complexity of interconnected power systems is miles of transmission lines. As transmission lines become longer, system operators might consider more factors to be controlled which make power systems management more complicated. The length of transmission lines are normalized by the number of customers in each utility – miles of transmission lines per each utility customer in miles/customer. Therefore, the longer the transmission lines a control center manages, the more likely are the system operators to fail.

Second, concerning institutional change, I treat restructuring as a dummy variable. Deregulation is divided into two levels: wholesale deregulation and retail sale deregulation. The wholesale deregulation is implemented by Independent System Operators and Regional Transmission Organizations at the regional level under the orders of FERC, while retail sale deregulation is managed by retail utilities under the approvals of the state governments. The analysis observes the impact of deregulation in both wholesale and retail sale markets. If deregulation is implemented after the approval or the passage of legislation or regulatory order, it is recorded as 1, otherwise 0. Determining the effective day of deregulation is based on the EIA information, Status of State Electric Industry Restructuring Activity (EIA 2008) and ISO and RTO’s websites.

Third, institutional conditions include the characteristics of each regional reliability council. EIA form-861 provides information about what utilities belong to which regional reliability councils. As mentioned previously, the councils evaluate and guide resource adequacy planning and system operations to maintain reliability. Because the data do not provide specific information on the councils, it is necessary to convert the data into detailed characteristics of them. Usually the councils can be characterized by such institutional conditions: 1) existence of contractual penalties for failing to meet regional criteria, 2) the range of planning factors considered for resource adequacy and transmission planning, 3) the range of emergency factors considered in making emergency operation planning, 4) operation utilizing central dispatch, and 5) strength of the regulatory relationship with federal and state governments.

Table 4.4. Characteristics of Reliability Institutions (Yes:1; No:0)

Regional Reliability Councils	ECAR	ERCOT	FRCC	MAAC	MAIN
Penalty (yes=1, no=0)	0	0	0	1	0
# of factors considered for planning	12	12	18	18	16
# of factors considered for emergency	15	19	19	23	17
Central dispatch (yes=1, no=0)	0	1*	0	1	0
Regional Reliability Councils	MAPP	NPCC	SERC	SPP	WECC
Penalty	1	0	0	0	0
# of factors considered for planning	17	17	9	17	12
# of factors considered for emergency	18	17	12	19	13
Central dispatch	0	1	0	0	0

Source: NERC (1994); factors for emergency plan in various sources. See Appendix 3.
*since July, 2001

Some regional reliability councils strictly apply reliability standards of planning to their region. They impose contractual penalties when utilities violate resource adequacy planning criteria. Utilities under these regional reliability councils try to obey reliability standards of planning, and thus improve their reliability. The regional reliability councils of MAAC and MAPP apply this program (table 4.4). The contractual penalties will have a positive effect on reliability. This is treated as a dummy variable.

As discussed earlier, system operators' management should be fully sophisticated enough to manage complex power systems. First, this means the sophistication of the planning reliability standards, which consist of three parts – resource adequacy, transmission system reliability, and interregional reliability coordination agreements, criteria and procedures (NERC 1994). Regional reliability councils consider specific factors[82] related to resource adequacy and transmission system reliability. The number of factors each council considers is different and the standardization of the factors is difficult because of the differences in “rate of demand growth, demand shape, sensitivity of demands to weather, emergency assistance from others, potential slippage of in-service dates, fuel and generating unit availability, … and the relationship between the Regions and their member systems” (NERC 1994 p7). Nevertheless, as system operators consider as many factors as possible, they can predict and prepare for more contingencies than others, thereby improving reliability. As table 4.4 shows, the number of factors considered in the planning stage vary from region to region. If utilities are under Regions with more sophisticated planning criteria, they might reduce the frequency of major disturbances between 1990 and 2006.

Regional reliability councils also differ in their emergency plans and procedures. More detailed factors considered during emergencies are in table A4.2 in Appendix 4. These factors are historically developed in accordance with their geographical locations, natural environments, and the relationship between the regions and their member systems. For instance, the Florida Reliability Coordinating Council (FRCC) has developed more sophisticated emergency plans to manage Hurricanes. The Mid-Atlantic Area Council has upgraded emergency operations plans continually under the relatively unified system management in the PJM region. Table 4.4 presents differences in the number of factors considered emergency operating plans. Utilities with more detailed emergency plans in the Region may reduce the number of major disturbances they experience.

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[82] For the detailed information, see table A4.1. Planning Factors Considered for Resource Adequacy and Transmission Planning in Appendix 4: Characteristics of Regional Reliability Institutions.

Some regional reliability councils have coordinated power system controls among utilities through a central dispatch center (table 4.4). This is a way of centralizing systems control which helps utilities share similar premises and assumptions. They may decide their system operations in concert with other utilities through a coordination of the central dispatch center. A representative case is the PJM Interconnection and MAAC is its reliability council. The region is a tight pool with joint planning and operation on a single system basis, and it may show good performance, reducing major outages. This is a dummy variable.

The regulatory relationship with governments is also related to the development of regional power pools.[83] Although utilities typically do not want government intervention in their system operations, historically all regional pools have developed their pool agreements and coordination with involvement of federal or state governments to promote good reliability (FPC 1964; FERC 1981). Because federal or state governments were in a position to see a bigger picture than utilities, they could consider more factors than utilities in developing pool agreements. As discussed in Section 4.2.1, therefore, government intervention and its regulatory support could create tight management within a power pool, and prevent member utilities in the pool from experiencing major power system disturbances. There are different levels of the involvement of federal and state governments in developing pool agreements. Specifically, there was no regulatory influence on the development of interstate coordination in ECAR, because most coordination agreements were based on the utilities' own initiatives (FERC 1981). The influence of FERC on the PJM coordination agreement in MAAC was insignificant

[83] The area of a regional reliability council generally matches that of the regional power pool, because it is organized on the basis of regional power pools. Regional power pools have developed as a utility interconnect its system with neighboring utilities on the basis of agreements between them.

because PJM was organized before the full operation of FERC functions. By contrast, FERC was deeply involved in the development of the New England Power Pool in NPCC and the power pools in FRCC, Florida (FERC 1981). Particularly in FRCC, the state government as well as the federal agency was actively involved in the development of coordination agreements, resource adequacy planning, and emergency plans in order to respond to severe tropical storms. Because the New York Power Pool in NPCC and power pools in SPP and ERCOT developed within the state boundary, the state commissions were significantly involved in developing the coordination agreements (FERC 1981). In WECC, FERC exerted regulatory influence on the development of a power pool in the Northwest Power Area, whereas state commissions were critically involved in the formation of the other three pools – the Rocky Mountain Power Area, the Arizona-New Mexico Power Area, and California-Nevada Power Area (FERC 1981). If power pools developed crossing state boundaries, however, state governments had little room to engage in the development of coordination agreements, as in the cases of PJM, NEPOOL and SERC.

Table 4.5. Regulatory influence (Categorical variable)

Regional Reliability Councils	ECAR	ERCOT	FRCC	MAAC	MAIN
Regulatory influence: strong	0	0	1	0	0
Regulatory influence: moderate	0	1	0	0	1
Regulatory influence: weak	1	0	0	1	0
Regional Reliability Councils	MAPP	NPCC	SERC	SPP	WECC
Regulatory influence: strong	0	0	0	0	0
Regulatory influence: moderate	1	1	1	1	1
Regulatory influence: weak	0	0	0	0	0

Source: FERC reports on power pooling (FERC 1980; FERC 1981; FERC 1981; FERC 1981c; FERC 1981d)

We may assume that if there is little government involvement, the region and its utilities have a weak regulatory relationship with their government leading to loose coupling among utilities. If federal or a state government is significantly involved in developing a regional power pool, the region and its utilities have a moderate relationship with their government. If both federal and state governments are heavily involved in the regional power pools, the region and its utilities have a strong regulatory relationship with their government. Because one of the purposes of government's involvement is to improve reliability, a strong regulatory relationship will increase the duration of time between major power system disturbances and reduce hazard of system disturbances. This is a categorical variable. Table 4.5 defines regulatory relationships between utilities and governments: strong, moderate, and weak.

Third, concerning organizational performance, summer and winter peaks per customer in kW/customer can measure the challenge of maintaining system performance during the most difficult hours of the year. If the summer and winter peaks per customer increase, system operators face heavier peak loads on their systems, and thus may have more likelihood of power system failure.

During the summer period system operators should deal with end-users' induction motors which consume both real and reactive power. These end-user facilities inevitably augment power losses. If system operators are not mindful of the prediction of losses associated with end-users' induction motors, they may face more chances of system failure. That is, the magnitude of annual power loss (MWh) in total power resources (MWh) in percent can affect the length of time between power system disturbances. Thus, it serves as an effective output measure of electric utilities' performance.

Economic efficiency can be measured in terms of ROA (percent of net income in total assets) and ROE (percent of net income in shareholder's equity). The higher ROA or ROE is, the higher the hazard of power system failure is. Because investment in facilities and technologies may improve reliability, high ranking bond ratings may indicate good performance of utilities. As shown in table 4.6, I have assigned a numerical value to each Moody's bond rating. I expect that the higher the bond ratings, the less likely it is that the utility's control centers experience system failure. I assume that the distance between bond ratings is same (See Appendix 5 for the definitions of each bond rating by Moody's).

Table 4.6. Values Given to Moody's Bond Ratings

Bond rating	Aaa	Aa1	Aa2	Aa3	A1	A2	A3	Baa1	Baa2
Value	18	17	16	15	14	13	12	11	10
Baa3	Ba1	Ba2	Ba3	B1	B2	B3	Caa	Ca	C
9	8	7	6	5	4	3	2	1	0

With these independent variables (or covariates), the Cox Proportional Hazard Model with Breslow method for ties (unordered same type model) is used to observe the duration (the length of time between events) of each utility. First, the Cox Proportional Hazard Model is widely used for large numbers of observations because it does not need to choose some particular probability distribution[84] – base hazard rate (Allison 1995). Second, since I include only those utilities which experience at least one system disturbance, there is no censored data in this model. Third, because all events are treated equally (major power system disturbances), an unordered same-type model is appropriately applied in this repeated event history analysis. Fourth, some utilities may

[84] Parametric models include Exponential, Weibull, Log-Logistic, Log-Normal, and Gompertz. They show different hazard rates distribution according to duration time. Box-Steffensmeier, J. M. and B. S. Jones (2004). *Event History Modeling: A Guide for Social Scientists*. New York, Cambridge University Press.

have the same duration (same days) from one to the next event time. For this condition, the Breslow method[85] for ties is used which simplifies the calculation. Fifth, a utility experiences events repeatedly with time-varying covariates. Thus the analysis uses *robust standard errors* by grouping repeated events within each utility. It is reasonable to assume that there is "positive serial dependency" among recurrence times within each utility (Box-Steffensmeier and Jones 2004 p115). In this case, to account for a cluster of repeated events within a utility, it is necessary to make statistical estimates "robust" to violations of the common assumption: that is, each event is independent of one another (Box-Steffensmeier and Jones 2004). Because this method is grouping the repeated observations within each utility, and thus because it may lose information about individual observations, its estimates of standard errors are larger than those of assuming independence. But the coefficient estimates are unchanged. The function is as follows;

$$h_i(t|X) = h_0(t)\exp(\beta_1 x_{i1} + \beta_2 x_{i2} + \cdots + \beta_{15} x_{i15}) = h_0(t)\exp(\sum_{j=1}^{15}\beta_j x_{ij})$$

, where $\log h_i(t)$ is the hazard rate of utility i

$h_0(t)$ is the base hazard rate.

x_{i1} is the annual power sources of utility i.

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[85] The Cox partial likelihood function is

$$L(\beta) = \prod_{j=1}^{k}\left(\frac{\exp(X_j\beta_x)}{\sum_{i\in R_j}\exp(X_i\beta_x)}\right)$$

, where X_i is a covariate, β_x is an estimate of X_i, and R_j is the risk set (those subjects at risk of experiencing an event) at time t_j.

Then, the Breslow approximated partial likelihood function is

$$\mathcal{L}_{Breslow} = \prod_{j=1}^{k}\frac{\exp(\boldsymbol{s}_j\beta_x)}{\left[\sum_{i\in R_j}\exp(X_i\beta_x)\right]^{d_j}}$$

, where $\boldsymbol{s}_j$ is the sum of the covariates X for the tied failures, and d_j is the number of tied failures at time t_j. See Box-Steffensmeier, J. M. and B. S. Jones (2004). *Event HIstory Modeling: A Guide for Social Scientists*. New York, NU, Cambridge University Press., pp48-55, and Cleves, M. A., W. W. gould, et al. (2004). *An Introduction to Survival Analysis Using Stata (Revised Edition)*. College Station, Texas, A Stata Press Publication., pp136-143.

x_{i2} is the miles of transmission lines per customer of utility *i*.

x_{i3} is institutional change *wholesale deregulation* with utility *i*.

x_{i4} is institutional change *retail sale deregulation* with utility *i*.

x_{i5} is contractual penalty applied to utility *i*.

x_{i6} is the number of factors considered for adequacy planning applied to utility *i*.

x_{i7} is the number of factors considered for emergency planning applied to utility *i*.

x_{i8} is operation of central dispatch applied to utility *i*.

x_{i9} is the regulatory relationship of utility *i* with federal and state governments.

x_{i10} is summer winter peaks per customer of utility *i*.

x_{i11} is winter peaks per customer of utility *i*.

x_{i12} is annual power loss from total power resources in utility *i*.

x_{i13} is ROA of utility *i*.

x_{i14} is ROE of utility *i*.

x_{i15} is a bond rating of utility *i*.

, and $\beta_1, \beta_2 \cdots \beta_{15}$ are coefficients of each covariate.

The coefficients are converted into hazard ratios[86] when e^{β_j} is calculated. Table 4.7 illustrates units and variable types of independent variables or covariates which affect the duration times of power system operations.

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[86] As shown below, if one unit increase of x_2 is divided by the original x_2, the hazard is expressed as the ratio between the two,

$$\frac{h(t|x_1, x_2+1, \ldots, x_k) = h_0(t)\exp\{\beta_1 x_1 + \beta_2(x_2+1) + \cdots + \beta_k x_k\}}{h(t|x_1, x_2, \ldots, x_k) = h_0(t)\exp\{\beta_1 x_1 + \beta_2 x_2 + \cdots + \beta_k x_k\}} = \exp(\beta_2) =$$

Table 4.7. Units and Variable Types of Each Independent Variable

Independent Variables	Units	Variable type
Physical Density (Complexity)		
Power System Scale	Million Megawatt Hours	Interval
Miles of transmission lines	Miles/customer	Proportional to total customers of utilities
Institutional Change		
Wholesale Deregulation	1 if wholesale competition, otherwise 0	Dummy
Retail Sale Deregulation	1 if retail choices, otherwise 0	Dummy
Penalty	1 if contractual penalty, otherwise 0	Dummy
Factors for planning	The number of factors considered	Interval
Factors for emergency	The number of factors considered	Interval
Operation: central dispatch	1 if central dispatch, otherwise 0	Dummy
Regulatory relationship	Strong, moderate, and weak	Categorical
Organizational Performance		
Summer and winter peaks per customer	kW/customer	Proportional to customers of utilities
Power loss in total sources	KWh/KWh*100	Percent
ROA and ROE	ROA=(Net Income/total Assets)*100 ROE=(Net Income/shareholder's equity)*100	Percent
Bond ratings	0 to 18 (C to Aaa)	Interval

Strengths and weaknesses of the model

The Cox model can demonstrate the relationship between survival and its covariates without specifying a base line hazard distribution, but reduces the efficiency of the covariates. Therefore, its estimation is called *maximum partial likelihood*.

The model shows robustness in terms of the robust estimates of variance. As described above, robust variance estimation makes standard errors larger than those of the non-robust Cox model. But it solves a problem of the possible correlation between repeated events within a utility, so that the model is robust to violations of assumptions, especially independence of each event.

The model can indicate how strongly institutional conditions – reliability standards – are associated with major power system disturbances, and show how structural density and organizational performance affect them. Because of data limitations, however, the covariates cannot reflect more specific information, such as inside and outside decision-making structure of utilities for communication methods, preparedness for up-to-date equipment, quality of system operators measured by certificates and years of experience which are considerations in the case studies. In spite of these limitations, the measurements for these structural properties can shed light on a direction for reliability improvement by revealing vulnerable features of the industry.

Additionally, the original data on covariates need to be transformed in order to analyze the general characteristics of utilities. In normalizing summer and winter peaks and miles of transmission lines, I use the number of customers served by a utility. However, EIA form-861 does not provide exact data for customer numbers of the utility in concern: i.e. federal or cooperative utilities. In these cases, the number of the customers is counted by aggregating customer numbers of sub-utilities which are under the territory of the upper level utility. Thus there might be some difference between the aggregated and real numbers.

4.2.3. Results and Discussion

The observation period is from January 1st 1990 to December 31st 2006. In the NERC's report, there are 167 utilities in the U.S. that have experienced major system failure at least once since 1990. Including all repeated events, which are regarded as independent events, the total observations are 925 (table 4.8, unordered same type model). Total analysis time at risk is 716,937 days. The exit time ranges from 1 to 5,914 days (16.2 years).[87] The mean value of exit time is 775.1 days (2.1 years), and median is 268 days (0.73 years). Considering the 167 utilities that experience at least one major event,

[87] Year = 365.25

they experience system failure every 2 year and 1.5 months on average, but the median value is only 8.8 months.

Table 4.8. Data Summary (Unordered same type event)

Category	Total	Mean	Minimum	Median	Maximum
Number of subjects	925				
Number of records	925	1	1	1	1
(first) entry time		0	0	0	0
(final) exit time (days)		775.067	1	268	5,914
Time at risk (days)	716,937	775.067	1	268	5,914
Failures	925	1	1	1	1

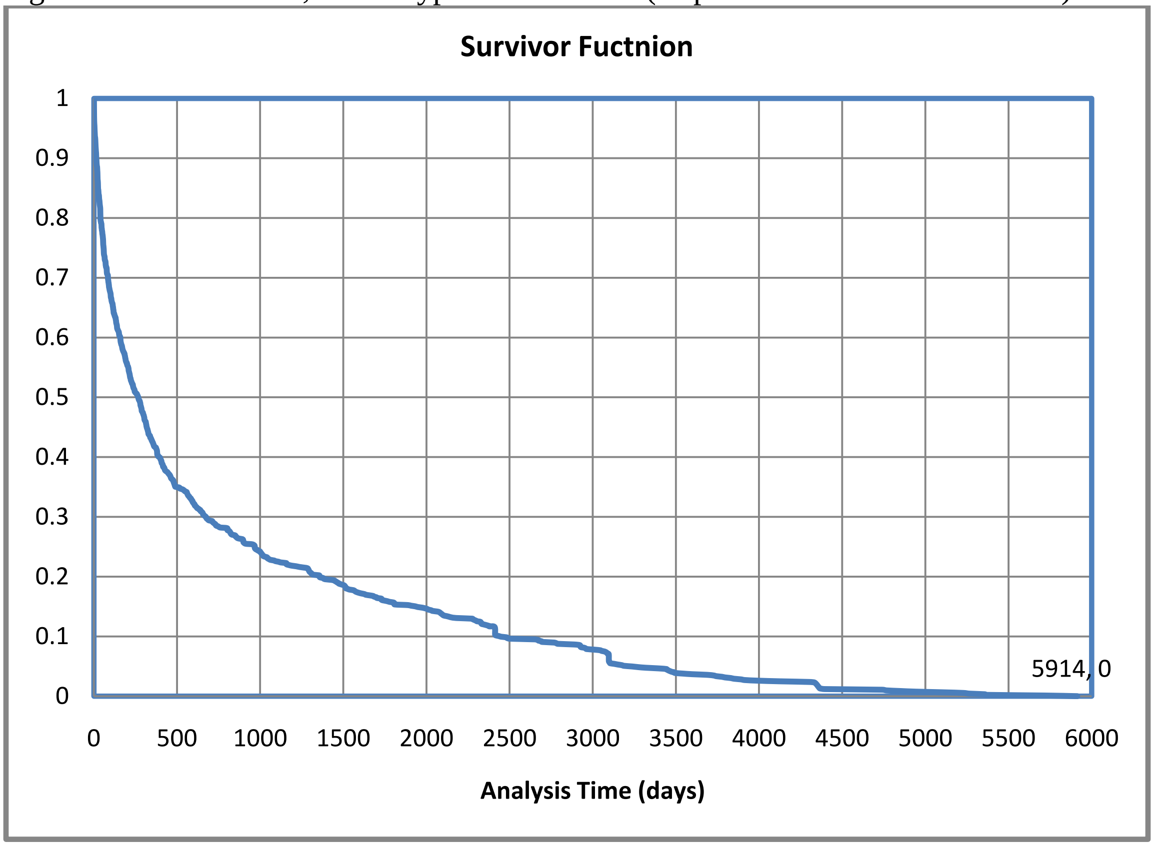
Figure 4.13 illustrates the Kaplan-Meier survival estimate with the unordered, same type of an event model.[88] In this analysis, 50 percent of observations occur before 268 days (0.73 years), and 25 percent of observations remain after 966 days (2.64 years). Before 1,933 days (5.3 years) 85 percent of events are observed, and almost 90 percent of events happen before 2,374 days (6.5 years). 15 percent of the utilities do not experience major system disturbances after almost 5 years, and at least 10 percent of the utilities in concern survive more than 6.5 years without major power system disturbances.

[88] Survivor function is the probability of survival past time *t*. The division of time intervals is arbitrary: 1 year, 150 days, or 10 days. Kaplan-Meier survival model avoids the arbitrariness by using the smallest time units; in this analysis measured in days. Survivor function is

$$\hat{S}(t) = \prod_{j|t_j \le t} \left(\frac{n_j - d_j}{n_j}\right) = \left(1 - \frac{d_1}{n_1}\right) \times \left(1 - \frac{d_2}{n_2}\right) \times \cdots \times \left(1 - \frac{d_j}{n_j}\right)$$

, where *S(t)* is survivor function, n_j is the number of individuals at risk at time t_j, and d_j is the number of failures at time t_j.

Figure 4.13. Unordered, Same Type Event Model (Kaplan-Meier survival estimate)



The result of the Cox Proportional Hazard regression (unordered same type model) is in table 4.9. Because of the 159 missing values in covariates of ROE, ROA, and Bond ratings, only 766 of 925 observations from the survival function are used for the analysis. The dependent variable is the hazard for the events expressed as hazard ratios. The model shows both the hazard ratios and coefficients of covariates. The negative values of coefficients are expressed as from 0 to less than 1, and the positive values of coefficients as more than 1 in hazard ratios. Hazard ratios change in accordance with a one-unit change in a corresponding covariate. Hazard ratios less than 1 imply less likelihood of major system failure and increased length of time between major events. Hazard ratios more than 1 indicate more likelihood of system disturbances, and thus reduce the length of time between major events.

Table 4.9. A proportional hazard (Cox) regression model for system operation times With Breslow Method for Ties (Unordered same type model)
Dependent variable: the hazard for the event
(Standard Error adjusted for 133 clusters in utilities)

Covariates	Coefficient	Hazard Ratio ($e^{coefficient}$)	z	P>z
Size of Power Systems (Utilities)				
Total Source (1,000Gwh)	0.007***	1.007***	6.88	0.000
Miles of trans/customer	-1.266**	0.282**	-2.48	0.013
Institutional Change				
Wholesale Deregulation	0.072	1.074	0.58	0.561
Retail Sale Deregulation	0.014	1.014	0.11	0.912
Institutions (Regional Reliability Councils)				
Penalty	-0.269*	0.764*	-1.76	0.078
Factors Considered for Adequacy Plan	0.080**	1.084**	2.04	0.041
Factors Considered for Emergency Plan	-0.116***	0.890***	-2.79	0.005
Centralized Operation	0.104	1.109	0.56	0.575
Regulatory relationship: Moderate	0.318	1.375	1.54	0.123
Regulatory relationship: Weak	0.538**	1.712**	2.21	0.027
Organizational Performance				
Summer Peak/customer (kW)	0.043***	1.043***	4.08	0.000
Winter Peak/customer (kW)	-0.036**	0.965***	-3.22	0.001
Power loss/total source (%)	0.051***	1.052***	3.27	0.001
ROA (%)	0.001	1.001	0.04	0.972
ROE (%)	0.002**	1.002**	2.53	0.011
Bond Ratings	-0.039**	0.962**	-1.90	0.057
Log pseudolikelihood	-4,245.94			
Wald chi2(16)	199.53			
No. of subjects	766			
No. of observations	766			
No. of failures	766			
Time at risk	583,886			

*** <0.01, **<0.05, *<0.1
Regulatory relationship (strong) dropped due to collinearity.

First, concerning the structural density (complexity) in terms of the scale of utilities, adding one million megawatt hours in power sources slightly increases the likelihood of system failure by 0.7 percent. Accordingly, large utilities – usually private and federal utilities – are more likely to experience system failure than medium size utilities – cooperatives consisting of several interconnected cooperatives in rural areas. Small size utilities owned by municipal governments are also less likely experience system failure than federal, private, or cooperative ones. Consequently large scale power systems are more likely to experience disturbances although the likelihood increases slightly.

Adding transmission lines per customer, however, might reduce the hazard of system failure; adding 1 mile per customer will reduce system failure by 72%. That is, simply expanding transmission lines could improve reliability. This is true in rural areas where long transmission lines are necessary without dense interconnections with one another. Based on these hypotheses, there are weak points in the interconnected power systems by utility size, but expanding transmission lines in rural areas improves reliability.

Second, the model shows that the institutional change, especially *deregulation*, does not have any statistical significance in both wholesale and retail sale markets. According to the hypotheses, the increases power trades in the wholesale markets lead to heavy loads on transmission lines giving more possibility of system disturbances. Retail choices may also cause reliability problems due to the less investment in utilities' facilities including distribution systems. But the result does not confirm what the hypotheses expected. That is, the institutional change of deregulation is not associated with major power system disturbances although we suspect that increasing power trades due to deregulation may affect reliability. This can be interpreted into two ways. First of all, utilities' shrinking investment in power delivery facilities as a result of deregulation could be captured in the variables of ROE and bond ratings, because ROE and bond ratings also measure the level of investment in utility's facilities. As discussed below, a higher percentage of ROE increases hazard ratios, while higher bond ratings decrease them. Second, we might not generalize an assumption that deregulation increases hazard ratios during this observation period. The investment in facilities takes long time. Therefore, we may need more observation periods to examine long term effect of deregulation. In this perception, the case of the California electricity crisis may not be generalized into other major power system disturbances.[89] From the corollary evidence that deregulation in the air traffic market did not directly affect the safety of the U.S. air traffic system, it may be necessary to separate structural issues of major power system disturbances from deregulation. We should deal with the relationship between reliability and deregulation case by case rather than as a general phenomenon at this time.[90] Because deregulation is not a major factor in these power system disturbances, it may be more helpful to pay attention to the characteristics of reliability institutions – regional reliability councils – which have developed historically.

Third, the result demonstrates that some characteristics of the reliability institutions are associated with major power system disturbances. If utilities are subject to the

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[89] There are different views on the cause of the California electricity crisis. Some experts view it as "fundamentally a regulatory crisis rather than an economic crisis." Wolak, F. A. (2005). Lessons from the California Electricity Crisis. *Electricity Deregulation: Choices and Challenges*. J. M. Griffin and S. L. Puller. Chicago, The University of Chicago Press. By contrast, others, some of electrical engineers, see it as a result of restructuring.Interviewee1 (2008). Blackout Interview. H. Park. Washington D.C. Although there are different views about the California electricity crisis, a commonly recognized issue is that the crisis took place in the transition period of restructuring the electricity markets.

[90] Wholesale market models vary from market to market. Different market designs may affect reliability of electricity. For example, the wholesale market in California was more dependent on the real-time spot market than that in the PJM region. Therefore, market participants in California had room for exerting their market power on the wholesale market. This was one of the reasons for the 2001 California energy crisis.

reliability institutions which impose contractual penalties on violations of planning standards, they are likely to experience 24 percent fewer power system disturbances than those without penalties. Strict application of planning standards is important to maintain a culture of reliability, and to prevent major power system disturbances.

Fourth, concerning planning and emergency plans with respect to complex power systems, I assumed that consideration of more factors for resource adequacy planning and emergency plans would bring a lower likelihood of system failure. The results are statistically significant but mixed. Regarding hypothesis II-5 of emergency plans, the hazard ratio is 0.89. Utilities are less likely to experience major system disturbances by 11 percent, if they are under a regional reliability council which provides them with more sophisticated emergency standards (every one unit increase). This supports the notion that human management should have as much variety as complex systems.

Concerning resource adequacy planning, unexpectedly the result is the reverse of hypothesis II-4. As a regional reliability council considers more factors for resource adequacy planning, utilities within the region have more likelihood of system failure. The hazard ratio is 1.084. Nevertheless, it is necessary to think about the result still sticking to Weick's viewpoint. There is a regional reliability council which manages complexly interconnected power systems with more complex planning standards, but which experiences more major system disturbances than others. The Northeast region is in this situation. In order to deliver electricity from resource abundant areas to densely populated urban areas, utilities in this region highly interconnect their power systems through transmission lines. To manage the complex grid systems, the regional reliability council of NPCC also develops resource adequacy planning standards as complexly as other well organized regional councils do. And yet its resource adequacy planning standards might not be as complex as the interconnected power systems. As a result, utilities in the region experience more major power system disturbances than those in other regions even though they have more sophisticated human management. This situation is reflected in the above result, conversely; complex human management still has more likelihood of system failure. I think that hypotheses II-4 is still relevant. An important thing is that NPCC should need much more elaborated resource adequacy planning than its current one to reduce major power system disturbances.

Fifth, the hypothesis that system operation by way of a central dispatch center at the regional level will improve reliability is not statistically significant. This may imply that centralization of system operation in a region is not sufficient. To make a central dispatch center work reliably, the region also needs centralized reliability standards in planning, system operation, emergency plans, and training system operators.

Sixth, if utilities are under a region which has a weak regulatory relationship with state and federal governments, they are more likely to experience major power system disturbances than those under a region with a strong regulatory relationship. Weak regulatory relationships with governments will increase more major system failure by 71 percent than strong ones. The result is what hypothesis II-7 expected. Federal and state governments can function as a coordinator to develop pool agreements and deal with utilities' interests in a region by using their regulatory power. Therefore, if a region has complex power systems with a variety of utilities' interests, it should consider government regulatory power to tightly coordinate power systems operation for reliability.[91]

Seventh, regarding organizational performance during peak periods, although utilities do their best, they still need greater efforts during the summer peaks. From table 4.9, utilities are more likely to experience system failure when summer peaks are highly pronounced (increasing about by 4.3 percent of the hazard every 1 kW per customer increase), while they are less likely to do so when winter peaks are sharp (decreasing about 3.5 percent of the hazard every 1 kW per customer increase). Power losses usually happen when power is transmitted on the transmission lines because of resistance. Additionally, power losses are high during the summer season when residential and commercial customers use inductive motors. That is, load power factors are low and less predictable during the summer peaks. Thus, utilities should be able to produce more power than expected due to reactive power consumed by air-conditioners and fans, as they consider the capacity of transmission lines. As mentioned previously, therefore, utilities should predict power demands accurately during the summer season, and their performance including demand side management is important.

Eighth, high power loss implies higher likelihood of system failure due to poor performance. Particularly, the above finding that utilities are less likely to experience major system failure in winter peaks is understandable, because people generally do not use air-conditioners and fans in the winter, reducing reactive power losses, and thus yielding higher load-power-factors which are predictable.

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[91] Now reliability standards are mandatory after the passage of the Energy Policy Act of 2005. This is discussed in Chapter 7.

Ninth, profitability increases hazards of major system failure, while investment in facilities and technologies decreases hazards of it. If a utility increases one percent of ROE, it will slightly increase the hazard by 0.02%. This is statistically significant although the hazard rate change is small. Bond ratings, which represent an investment in facilities and technologies, would reduce the hazard by 3.8%, as they go up one higher rank. As assumed in hypothesis II-10, the idea of profit maximization forces senior managers to reduce budgets for investment in their transmission and reliability equipment, leading to an increase in the hazard.

In summary, the vulnerability of utilities increases as the size of power systems becomes larger. Vulnerable utilities are located in the reliability regions where strict contractual penalties are not applied, where resource adequacy planning and emergency plans are not as complex as their complex systems, or where regulatory relationships with federal and state governments are weak. Internally these utilities have higher summer peaks per person, facing more electric power losses than others, or have less investment in facilities and technologies.

In particular, the strength of institutional settings – penalty, sophisticated resource adequacy planning & emergency plans, and strong regulatory relationships – is also associated with geographical locations. When regional reliability councils are included as dummy variables in the model in place of institutional variables, the councils of ECAR and WECC show high hazard ratios. First, ECAR and WECC have no penalties for any violation of reliability standards. They also have less sophisticated resource adequacy and emergency plans than others (table 4.4). FRCC, which has more sophisticated planning and emergency standards with good regulatory relationships with government, shows a low hazard ratio, however. As mentioned earlier, Florida experiences more severe tropical storms than other regions, and thus should prepare for them. As a result, it seems that it has more reliable power systems than others. Additionally, MAAC and NPCC, which have relatively more sophisticated reliability standards, exhibit high hazard ratios. These regions are related to densely interconnected power systems and must supply large amounts of power in response to high demand.

There is no statistical relationship between vulnerability of electricity systems and deregulation in the electricity wholesale and retail sale markets. We may not generalize an assumption that deregulation affects the reliability of electricity at this time. Instead, we should address the relationship between deregulation and electricity reliability case by case. Considering that the safety of air traffic systems is robust to deregulation, it seems that managing reliability is another dimension of the power system organization, which is different from managing efficiency including market efficiency. Reliability could be maintained through a more holistic approach that looks at the big picture and focuses on the entire system as in the case of the air traffic systems.

From the results of the hypothesis test on physical density, we can also perceive that there are some utilities which are vulnerable and cause major power system disturbances because they have large power systems. However, strict planning standards, appropriately complex human management, and strong regulatory relationships can reduce major power system disturbances. This tells us that evidently a holistic approach to monitor the entire system within a certain boundary is necessary.

On-time management – meeting demands with just-in-time production of electricity – by system operators is critical during the summer season when predicting the demand for electric power is uncertain due to large power losses. This also implies the necessity of a more engaged management as well as watchful routines at the local level if the power systems are interconnected densely and complexly. The test also provides evidence of the benefits of investing in facilities and technologies for reliability rather than profit maximization.

Vulnerable utilities related to major power system disturbances are one of the outcomes of the historic formation of bulk power systems and their management. As described in chapter 2, individual utilities ultimately decide to construct their own grid systems, although they discuss the impact of it on the entire grid system with neighboring utilities. Utilities construct transmission lines to deliver electric power from resource-abundant areas to densely populated areas and to reduce costs incurred by sharing the cost of constructing additional power plants among utilities. In the process, a cluster of utilities with centralized, densely interconnected and complex power systems has come to exist. Utilities need to develop additional procedures or a more integrated approach to system management which corresponds to complexity. Because they operate individually owned grid systems, however, they may not share local experience and information that are necessary for the management of the entire system. Without integrated system management and operation, they have different system operation criteria, and thus the quality of organizational performance can vary from utility to utility. These situations become preconditions for the existence of physically and managerially vulnerable areas, especially ECAR and WECC regions.

The case studies in the next three chapters show that the general characteristics of vulnerable utilities identified by the hypotheses test also become the conditions of large scale blackouts. In particular, the case studies will demonstrate that the structural causes of cascading outages already exist in some regions related to institutional characteristics – lax reliability standards, simplistic planning and emergency criteria, and weak regulatory relationships – which are associated with major power system disturbances. Inversely, through the description of performance within and between utilities connected with the large scale blackouts, we can identify detailed reasons why some areas become vulnerable.

Chapter 5. The 1965 Northeast Blackout[92]

5.1. Institutional and Physical Conditions Prior to the 1965 Blackout

Prior to the 1965 Northeast blackout, few Americans ever thought about the occurrence of such a highly unlikely yet catastrophic event. In the mindset of the early 1960s, as Vassell mentions, the reliability of electric bulk power supply was not a major issue within the electric utility industry nor within its various "publics" (Vassell 1990). After the large scale blackout in the Northeast region, however, people began to think seriously about the reliability of electricity.

Among participants in the electricity industry, there was certainly no movement toward a consensus on the need for holistic management of interconnected grid systems. Traditionally, the electricity industry was dominated by IOUs and although some hydroelectric power and rural electrification efforts were under the control of the Federal, state and municipal governments and rural electric cooperatives; 76.4 percent of electricity was generated by private utilities in 1962 (FPC 1964). IOUs sought a reliable supply of electricity in terms of interconnecting power systems through transmission lines, but did not want the federal government's involvement in interconnecting power systems. The private utilities guarded their autonomy and claimed that the federal

[92] The Chapter is based on the paper presented at the 2007 IEEE Conference on the History of Electric Power, August 3rd~5th.

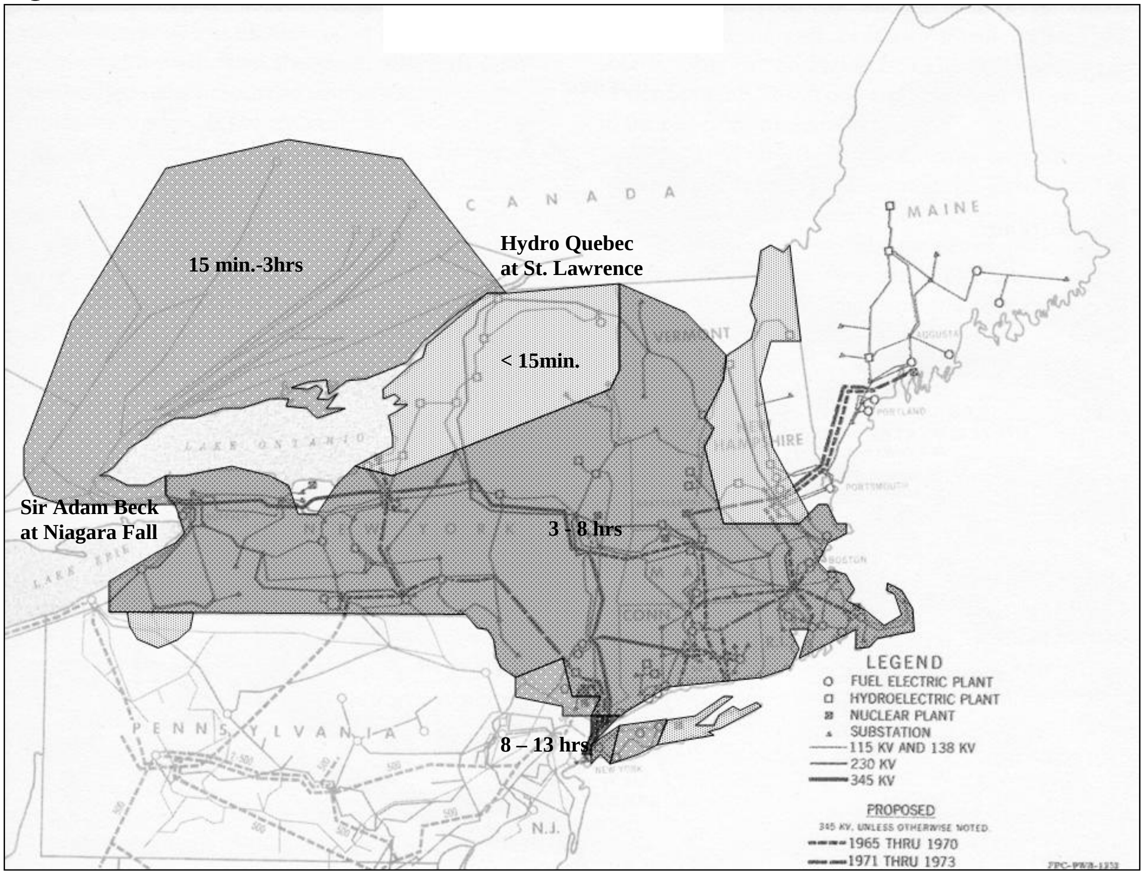
government's intervention seriously hurt the American values of democracy and freedom. Therefore, development of integrated institutions for electricity reliability was delayed, generating an apparent institutional imbalance between efficiency and reliability.

In the mid 1960s, the Federal Power Commission held limited jurisdiction over licensing hydropower plants, the construction and management of interstate transmission services, and wholesale rates. Additionally, power projects were constructed, operated, and maintained by several federal agencies, including the Bureau of Reclamation, the Army Corps of Engineers, and Tennessee Valley Authority (TVA). Although some leaders, such as Joseph Swidler, chairman of the FPC, exerted considerable influence on public and private relationships within the industry, the collective efforts of those involved were insufficient to alter the given regulatory environment. The industry's technical achievements were sufficient to operate interconnected power systems successfully without any large scale failure – at least until the 1965 blackout.

5.2. The Blackout of 1965

The blackout on November 9th, 1965, affected Northeastern America and parts of Canada, trapping 30 million people in darkness. It started on a backup relay in the system – the Sir Adam Beck plant – of Hydro Electric Power of Ontario, and quickly spread over New York, Connecticut, Massachusetts, Rhode Island, and small segments of Pennsylvania and New Jersey in the United States and the province of Ontario in Canada.

Figure 5.1. Transmission Lines and Power Failure in 1965



Adapted from Federal Power Commission (1965; 1967a)

At the time, the Beck plant had to produce more power than usual because the Lakeview power station near Toronto was having trouble with its generating machinery, significantly increasing the load on Beck's transmission lines. The backup relay was set to trip at about 375 megawatts (MW) of load and at a bus voltage of 248 kilovolts (kv) was coordinated with other relays in the system in 1963, although its line had higher load-carrying capacity. When the load became heavier in 1965, operators should have modified the relay settings. However, they were not aware that the settings were insufficient (FPC 1965). On that day, just before the blackout, in addition to 1175 MW of power generated from Beck, Canada had imported 500 MW from the U.S. through the

Niagara Mohawk power system which had a load-carrying capacity of 864MW. One of the five relays tripped at 5:16 p.m. Eastern Time when the load was too heavy on the relay at the Sir Adam Beck plant.[93] The other four relays also tripped one by one owing to the additional loads from the initial relay's trip. Because the power of 1675 MW (500 + 1175MW) could not find a path from Ontario and Quebec, via Canadian lines, it surged at Niagara and went to New England and the southeast New York. By way of the New York lines, some of the power went to Hydro Quebec at St. Lawrence where the United States had been importing Canadian power.

System operators at the various transmission control centers in the affected areas knew that the frequency and voltage on their system was fluctuating and that the power flow was reversing in some areas. But they were unable to take timely emergency action owing to the lack of clear decision criteria. With the big surge at Niagara and New York, the Northeastern automatically system broke into several parts and isolated. After the separation, system operators at the Consolidated Edison Company, New York City, had two options: load shedding or increasing generation by the spinning reserves.[94] They selected spinning reserves, but were not able to respond to the load quickly enough in the Manhattan area. Other areas in New England and up-state New York were in the same situation. All electricity in the Northeastern region went out of service at 5:28 p.m., some 12 minutes after the initial trigger in Canada. Figure 5.1 shows duration of outages and affected areas.

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[93] It is not known why the first relay tripped although the power load was near the limit. FPC (1967c). Prevention of Power Failures: Volume III – Studies of the Task Group on the Northeast Power Interruption. Washington D.C., Federal Power Commission., Interviewee3 (2008). Blackout (Telephone) Interview. H. Park. Piscataway, NJ.

[94] Spinning reserve: reserve capability which is required in order to enable an area to restore its tie-lines to the pre-contingency state within 10 minutes of a contingency which causes an imbalance between load and generation. PJM (2004). PJM Manual 35: Definitions and Acronyms, PJM.

A cascading outage occurs when several component failures interact with human errors (Interviewee1 2008). There was a series of component failures and human errors in the Northeast region – unawareness of insufficient relay settings, lack of power generation in the Toronto area owing to a shutdown of a power station, heavy loads on transmission lines to import power from the United States, tripping the first backup relay, tripping other relays which were tightly coupled with one another, and lack of unambiguous emergency plans in the region. As Perrow points out, power systems are tightly coupled with one another, and there are unexpected, complex interactions between component failures and human errors. These interactions develop a local blackout into a cascading stage which leaves human controls. Before developing into the cascade, however, there is room in which system operators can make timely decisions to prevent a local blackout from spreading over other areas.

Two causal factors in managing systems appeared before and during the cascading outage. First, system operators at Niagara Falls were unaware of increased power flow over transmission lines. Therefore, they were not responsive to growing power demand. Second, system operators in affected dispatch control centers could not take immediate action although they had detected an unusual sudden increase of power load over their systems and a drop in frequency. NAPSIC had generally specified actions that were to be taken when a system disturbance occurred, but did not provide explicit or precise guidelines for emergencies. As a result, system operators in most dispatch control centers could not make quick, clear-cut decisions when faced with genuine emergencies. The FPC's report states that:

> There were no outstanding instructions by CANUSE or Consolidated Edison specifying, in terms of frequency loss or otherwise, under what particular circumstances particular interconnections should be served or particular load segments of Consolidated Edison's system temporarily disconnected in order to save the remainder (FPC 1965 p16).

Because of the lack of specific criteria and practices that should be shared among system operators, they did not take appropriate action within context of the whole Northeast system, although they might have full authority over and responsibility for load shedding and disconnecting ties with other systems. These two causal factors underscore how the localized or fragmented practices of each system contribute to the deficiency of centralized institutional settings that are otherwise necessary for insuring the reliability of the integrated systems. To redress these problems, the private and public utilities, and the federal government took different approaches with different perspectives.

5.3. Remedial Actions

The remedial actions following the blackout ranged from technical analysis to institutionalization of recommendations. A month later, the FPC published a report which announced the detailed sequence of the blackout. Electricity related journals, such as *IEEE Spectrum*, *Electrical World* and *Public Utilities Fortnightly*, began to analyze the event three months later focusing on technical aspects, and then, six months later, provided a more in-depth analysis of the industry's political and economic structure. The U.S. Congress organized two hearings in December 1965 and February 1966. In July 1967, the FPC published a three-volume report to address and improve the physical and institutional deficiencies in the power industry. To enact the Electric Reliability Act, Senate hearings were held in August 1967, December 1967, and April 1968. The representative outcomes are regional reliability councils and the North American Electric Reliability Council (NERC) established in 1968.

5.3.1. FPC's Hope for Authority over Reliability

A movement to legislate a reliability act existed before the 1965 blackout, but even within the commission, there were two different positions regarding the FPC's authority over reliability. The FPC sent two draft bills – H.R. 7788 and H.R. 7791 – to Congress (Radin 2003). Two commissioners, David Black and Charles Ross, supported FPC certification and licensing of interstate transmission lines. Two others, Lawrence O'Conner and Swidler who tried to balance the power between public and private sectors, favored the less stringent bill, H.R.7788, requiring the FPC's consultant role with private utilities in transmission planning, and provided the opportunity for further public hearings. Carl Bagge, who newly joined the commission, was against the mandatory licensing bill (Radin 2003). Right after the 1965 blackout, the discussion of reliability legislation was accelerated in the direction of Swidler's plan of voluntary participation in implementing reliability standards. In this context, the FPC's report on the Northeast Power Failure was published in December 1965.

The report was the first systematic analysis of this event. In the report, the FPC and the utilities began to pay attention to the concept of reliability. In improving reliability, the report emphasized the concept of a "fully coordinated" or "integrated" power pool to prevent recurrence of large scale blackouts. The report defined full coordination as follows:

> By "fully coordinated" or "integrated" we mean that the interconnected system, whether of a single company or a pool of many companies, is designed, planned and operated as a unit, so that each part will fully reflect the duty which might be imposed upon it as a part of the system (FPC 1965 p23).

The FPC perceived interconnected systems as a single unit. At first, the report addressed physical aspects of the coordination, particularly strengthening transmission lines and improving reserve margins through spinning reserve and a more diverse fuel mix. Next, the FPC perceived that creating a culture of reliability – shared premises, assumptions, and practices – in utilities' inter-organizational relationship through centralization is an essential way to improve electricity reliability. Making 19 specific recommendations, the FPC ultimately requested Congress to consider "[FPC's] jurisdiction over the reliability of service for bulk power supply from interstate grids" (FPC 1965 p45). The FPC thought that the centralization of authority was a necessary step for improving reliability. But the report did not clearly state whether the FPC would have the authority of licensing transmission planning or be a consultant with private utilities or whether the FPC would add an organization to deal with reliability at the federal level.

During the Congressional hearing in December 1965, one of the main issues was who should control the interstate power systems with respect to reliability. At the time, both private utilities and FPC recognized the necessity of reliability standards at the national and regional level. Swidler, chairman of the FPC at the time, criticized the structure of power system operation. He said, "We needed greater uniformity of criteria and we needed an overall view of the possible impact of one system upon another. As long as each company runs its own show, the other members of the pool, although they have a stake in what happens, are not in position to control it and have no real voice in it" (U.S.Senate 1967a p27). Thus, the FPC began to discuss creating a coordinating organization in 1966. Brand, a staff attorney of the FPC, argued that the absence of a single agency to mediate the coordination of planning interconnected systems would lead to a scanty exchange of information between planning groups (Brand 1966). In this debate, the FPC did not consider a more aggressive path: the centralized and stratified dispatch control of interconnection systems in each power pool as in the cases of the PJM, the air traffic control, and the former USSR. Regarding the role of the FPC, Swidler testified that it should be "an overseeing agency," setting standards and forcing private utilities to implement standards rather than a mandatory design and planning organization (U.S.House 1966 p21).

However, private utilities regarded even this attempt to be an overseeing agency as a political rather than industrial action. Nevertheless, centralization followed by decentralization was recognized as a necessary process by both private utilities and the FPC. The question was who would control this process and to what extent centralization would be established before decentralization. According to the degree of the centralization – planning systems, setting operation standards, licensing system operators, providing up-to-date equipment standards, and improving communication methods – the level of inter-organizational reliability would be decided.

5.3.2. Continuing Local Practice in Spite of FPC's Effort

In the mean time, many experts discussed the direction of interconnecting power systems at the technical level: firm vs. weak interconnection. Most were in favor of strengthening interconnection (Friedlander 1966). Although the FPC obtained jurisdiction over interstate wholesale rates and services of IOUs, the jurisdiction did not mean that reliability, which should be realized by a tangible entity of interstate coordination, was being managed. The nature of the desired entity became clear through the 1967 report issued by the FPC.

In 1966, Joseph Swidler was replaced by Lee White who favored a more comprehensive plan expanding the FPC's authority over regulating extra-high-voltage transmission facilities for reliability (Radin 2003). In July 1967, the FPC issued the three-volume report which detailed institutional as well as the technical aspects of preventing large scale blackouts and made 34 recommendations. At the same time, the FPC also proposed the Electric Power Reliability Act to carry out some of the recommendations.

The 1967 report pointed out the control rooms' inability to "exchange information in time to take such emergency actions as were open to them" (FPC 1967a p1). This implies that there were a variety of associated structural problems. To address the problems, the report considered (1) formation of coordinating organizations, (2) interconnected system planning, (3) interconnected system operating practices, (4) interconnected system maintenance, (5) criteria and standards, defense and emergency preparedness, (6) manufacturing and testing responsibilities, (7) increased need for technical proficiency, and (8) power system practices in other countries (FPC 1967a). Above all, the FPC proposed creating a council which would coordinate planning, construction and operation of power systems, and exchange information between utilities. It suggested that the council would consist of regional organizations which were funded by member utilities. The 1967 report recommended:

> A council on power coordination be established, made up of representatives from each of the nation's regional coordinating organizations to exchange and disseminate information on regional coordinating practices to all of the regional organizations, and to review, discuss and assist in resolving matters affecting interregional coordination (FPC 1967a pp4-5).

In addition to the creation of a coordinating organization, the 1967 report reaffirmed the voice of the FPC with respect to its authority over reliability as stated by the FPC during the Congressional hearing in December 1965. That is, the authority of setting reliability standards and assuring compliance should be within the FPC's jurisdiction. Under White's leadership, the commission thought that the FPC should expand its jurisdiction over the reliability of power service including the regulation of extra-high-voltage transmission facilities.

On June 5, 1967 another large scale power failure in the PJM region affected 11 million people. This provided an opportunity to demonstrate the FPC's jurisdiction over reliability. On June 8, 1967 right after the second largest power failure, the FPC proposed the bill in which the FPC would be empowered to accomplish part of its recommendations. The bill included (1) authority to secure the establishment of regional planning organizations, (2) setting planning and operating standards, (3) approval authority over extra-high-voltage transmission lines, and (4) compulsory interconnections between bulk power generating utilities. It was the product of a year and a half of deliberations (U.S.Senate 1967b). The key to the bill was the regional planning organizations whose future plans had to be subject to the FPC's approval. Although there was an effort by private utilities to establish similar regional planning organizations, however, the FPC thought that the effort was not enough.

This bill brought about strong opposition from private utilities, while it was generally supported by such organizations as the National Rural Electric Cooperative Association[95] and the American Public Power Association (PUF 1967). Herbert B. Cohn, executive vice-president of the American Electric Power Service Corporation, argued that the proposed bill should not be law. The reasons were as follows; "(1) The very reliability sought by the FPC can be achieved without legislation; (2) A great many matters which are not relevant to reliability, and sometimes even conflict with it, are included in the bill; (3) Most important, even where the FPC desires to speed things along, the bill's provisions have substantial delays written in at every stage; [and] (4) The bill would divide responsibility and authority" (PUF 1968 p36). Private utilities and other related organizations including Edison Electric Institute did not agree with the trend toward centralized decision making (PUF 1969); that is, John F. Bonner, senior vice president of Pacific Gas & Electric Company, said, "Basically, it is a bill that provides for centralized federal management of the entire electric power industry in this country, both public and investor owned" (U.S.Senate 1968 p607). Their perception was that "the bills attempt to treat reliability as a regulatory matter, instead of an engineering matter" (PUF 1969 p40).

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[95] In 91st Congressional Hearing, Charles A. Robinson, Jr., staff counsel to the general manager of the National Rural Electric Cooperative Association, stated that "the avowed purpose of NERC and its constituent regional coordinating councils is the improvement of bulk power supply planning and reliability. An obviously implied secondary purpose is to avoid passage of the type of legislation which is the subject of these hearings and which would impose additional federal controls on the electric utility industry." Committee:I&F_Commerce (1971). Electric Power Reliability - 1969-1970; Electric Power Coordination Act of 1969, Part1: Hearing. *The Committee on Interstateand Foreign Commerce*. Washington D.C., U.S. Government Printing Office., U.S.House (1971). Electric Power Reliability - 1969-1970; Electric Power Coordination Act of 1969, Part1: Hearings before the Committee on Interstate and Foreign Commerce, 91st Congress, First and Second Sessions on H.R.7186, H.R. 12585, H.R. 489, H.R. 9429, and H.R. 2506. *The Committee on Interstate and Foreign Commerce*. Washington D.C., U.S. Government Printing Office.

This perception revealed private utilities' distrust of the FPC's ability to deal with large scale technological systems. Private utilities did not want any type of federal intervention in their business of power system planning, construction, and operations, and regarded the bill as such an action. They were reluctant to cooperate with government initiation of centralized management regarding reliability.

Worrying about their future business being regulated by the strong authority of the FPC, private utilities took the initiative to create regional organizations and their own reliability council such as proposed in the 1967 report and the subsequent legislative bills. As a result, they established the National Electric Reliability Council (NERC) in June 1968 when the bill was in the U.S. Congress. At first, the NERC started with five regional groups: Northeast Power Coordinating Council (NPCC), East Central Area Reliability Coordination Agreement (ECAR), Electric Reliability Council of Texas (ERCOT), Western Systems Coordinating Council (WSCC), and Mid-Atlantic Area Council in the exact PJM territory (MAAC). Later, four groups joined NERC; they are Mid-America Interpool Network (MAIN), Mid-Continent Area Reliability Coordination Agreement (MARCA), Southeastern Electric Reliability Council (SERC), and Southwest Power Pool (SWPP). Many of the proposed plans in the bill were adopted by the NERC and regional coordinating organizations. And private utilities voluntarily participated in the regional groups and fulfill reliability criteria. Table 5.1 compares the two different perspectives of the FPC and IOUs on institutionalization of reliability.

Table 5.1. Comparison of Reliability Institutionalization between the FPC and Private Utilities

Federal Power Commission’s Plan	Private Utilities’ Initiative
Reliability Standards - Mandatory standards	Reliability Standards - Voluntary participation
Federal Power Commission - setting reliability standards - regulating EHV transmission lines - compulsory interconnection - review and approval of regional coordinating plans - nonvoting participation in the council and regional organizations A interregional coordinating council - representatives of regional organizations - exchanging and disseminating information	National Electric Reliability Council (NERC) - setting reliability standards and developing interregional agreement - data collection - exchanging and disseminating information - assessment of reliability - providing information to FPC
Regional coordinating organizations - procedures for effective coordinating actions: planning, construction, operation and maintenance - funded by member utilities	Regional Reliability Councils - coordinating planning, construction, operation, and maintenance - assessment of reliability within regions - data collection

Losing the initiative in creating a reliability institution sponsored by the federal government, the FPC requested that its staff and state regulatory agencies participate in the regional council deliberations as nonvoting members (U.S.House 1971). This request was ignored. Congress did not pass the modest bill named *the Electric Power Coordination Act of 1969*, which proposed a data collecting and reporting system.

Consequently, the proposed bill – the Electric Power Reliability Act – stimulated utilities to participate in setting and implementing reliability standards voluntarily, but utilities did not have any legal responsibility to abide by the forthcoming reliability standards. They did not have to report information that would be secret, but critical to reliability. This situation implied that although utilities agreed with the formation of a centralized agency in setting unified reliability standards, the credible exchange of their information for reliability, including tacit knowledge, would depend on private utilities’ voluntary participation. In fact, the 1965 blackout report shows how scantily utilities at the Niagara Falls, prior to the 1965 blackout, had exchanged local performance information due to the absence of a centralized reliability institution. It describes:

> [During the investigation after the 1965 blackout,] FPC *was informed* by the Ontario Hydro officials that following the occurrence of a fault on one of these lines in ***1956*** in which the breaker failed to open, all of Beck's generation was lost causing a power outage in Ontario and northwestern New York during which load shifted from Beck to PASNY (the Power Authority of the State of New York) and Niagara plants (FPC 1965 p6).

Before November 1965, the FPC did not know that the power outage of 1956 was structurally similar to the 1965 blackout. This region already experienced the power sway from Beck to PASNY, and thus the industry could have anticipated the possibility of load shifts like the 1965 blackout. Utilities both in Canada and the United States did not have any means to share their local experience. The experience was merely local knowledge of the area, not of the entire region.

The case of the Nation Power Survey of 1964, as mentioned in Chapter 2, also reveals the loose coordination of information among related parties. Before the 1965 blackout, the survey proposed a extension of government responsibility for growing interstate interconnection of power systems (Miller 1971). Utilities, however, were reluctant to be under the control of the FPC, and considered reporting information on their facilities and performance as evidence of their being subject to the FPC (Miller 1971). Although utilities shared information, such as planning, construction or operation of their systems, they were unwilling to communicate with federal agencies except for data related to interstate wholesale trade. This situation meant that they did not have a medium to share information among themselves.[96] Before the separation of each affected area during the 1965 blackout as illustrated in figure 5.1, their local information and organizational performance was already isolated from one another.

In sum, electric utilities did not develop system management criteria at the institutional level before the 1965 blackout. Unexpected interactions between component failures and human errors were inevitable due in part to the absence of reliability institutions and the lack of unified reliability standards. Utilities had different levels of criteria for operation, training, system equipment, and communication (Table 5.2). These issues were raised during the investigation, and the FPC made recommendations for improving them. After the 1965 blackout, utilities considered more coordination with one another, but without hurting the autonomy of operating their own systems. Thus the level and functions of reliability institutions were determined by utilities' interests. Only member utilities voluntarily complied with reliability standards, and reliability institutions basically carried out a function of evaluating resource adequacy plans in their region. NAPSIC still provided utilities with operating criteria. As a result, even though the power systems became a huge, tightly interconnected machine that needed intensive organizational coordination among dispatch control centers, private utilities chose loosely coordinated organizational performance under the voluntary participation in the NERC.

The NERC's and regional councils' roles in successfully improving electricity reliability should not be denied. But their symbolic aspects should also be pointed out. On the basis of voluntarism, utilities implemented reliability standards provided by regional

[96] In fact, IOUs established the Edison Electricity Institute (EEI) for information dissemination regarding promotion of electricity use or berating the growth of federally assisted rural electrification cooperatives, TVA and Bonneville Power Association. EEI reflected the interests of IOUs. Richard F. Hirsh, *Power Loss: The Origins of Deregulation and Restructuring in the American Electric Utility system*. Cambridge, Massachusetts: The MIT Press, 1999.

reliability councils, not by the NERC. Utilities could exchange information about their systems for coordination, but did so in a scanty manner. They took a variety of remedial actions to solve such problems as communication between the Ontario Hydro and PASNY after the 1965 blackout. Given their loose connection of organizational performance, however, the remedial actions did not mean that they created a strong culture of reliability which would activate a feedback mechanism to check new emerging problems within and between their organizations, and thus which would prevent future blackouts. Twelve years later, the delayed remedial action after the 1965 blackout contributed to the 1977 New York City blackout.

Table 5.2. Status of Institutional Conditions before the 1965 Blackout

Evaluation Items	Institutional Status
Setting operation standards	No institutionalized standards
	NAPSIC did not provide strong standards
Licensing system operators	No institutionalized training and licensing programs
	Most system operators did not have a college degree, which means that unlike engineers they could not have properly system design and planning (Interviewee1 2008). Individual utilities provide their own training programs: for instance, the PSE&G was operating a training program – the Cadet Program – after World War II (Calabro 2003).
Up-to-date equipment standards	No institutionalized criteria
	Individual utilities decided on the installation of state-of-the-art equipment; for instance, PJM and Consolidated Edison put into service computerized control devices in 1962 (Luce 1979; PJM 2009).
Improving communication methods	No institutionalized criteria
	Each utility had different levels of communication methods, and communication with neighboring utilities was based on their contracts (FPC 1967a). Engineers' meeting as the planning stage to study the impact of new facilities on each utility (Interviewee1 2008).

Chapter 6. The 1977 New York City Blackout[97]

6.1. Institutional and Physical Conditions Prior to the Blackout

The blackout in New York City occurred on the evening of July 13th, 1977. As a result, not only were city systems paralyzed, but the City also experienced the turmoil of looting and arson. The blackout raises a question of what went wrong with the institutional and physical conditions that were established after the 1965 blackout. After the Arab oil embargo in 1973, the federal government and legislators thought about transforming the configuration of generating resources from oil and natural gas to other alternative resources, such as coal gasification, geothermal energy, wind power, solar energy, and small hydroelectric power. In addition to the transformation of power resources, the federal government also considered a variety of energy conservation measures. In this context, efficient use of electricity through power system interconnection and wheeling were ways of reducing consumption of power resources without constructing power plants. Therefore, electricity reliability for interconnected power systems became one section in national energy bills in each congressional session. However, this section brought about controversies between the federal government and

[97] The Chapter is based on the paper presented at the 2007 IEEE Conference on the History of Electric Power, August 3rd ~ 5th.

the NERC and its regional councils which typically represented utilities' interests. In the meantime, the 1977 blackout happened. This case suggests that the industry achieved some symbolic improvements at the institutional level, but these at the organizational level seem less tangible.

6.1.1. Continual Debates on Strong Reliability Criteria

A regional coordinating organization was created as recommended in the 1967 report of the FPC. The Northeast Power Coordinating Council was formed on a voluntary basis as a regional reliability council in January, 1966. The region included New York, New England, Ontario, Quebec, and the Maritime Provinces of Canada. The purpose of the NPCC was to assess periodically the reliability performance in the region. The work that the NPCC carried out was that of the recommendations made in the 1965 and 1967 reports of the FPC. Utilities, however, did not have an obligation to comply with the criteria. In fact, the NPCC was not a planning entity, nor did it have power to order changes (Clapp, Charles P. Almon et al. 1978). The Council developed its operating criteria over several years. They are:

> Minimum maintenance guide – protective relaying and associated device – July 1971 (superseded minimum maintenance practices, April 1969);
> Basic criteria for design and operation of interconnected power systems – September 1967, revised July 1970, revised June 1975;
> Operating reserve policy – March 1972;
> Procedure in a major emergency – May 1967; revised March 1972;
> Bulk power system philosophy – August 1970; and
> Uniform method for rating generating capability – August 1972 (U.S.House 1976b p2007).

Prior to the blackout, the NPCC did not provide guidelines for training system operators.

At the state level, the New York Power Pool (NYPP) was also organized in 1966 to operate interconnected power systems and provide detailed coordinating planning in New York. It actually began its work of coordinating power flow in 1970. Its control center was owned by the Niagara-Mohawk Power Corporation, one of the companies in New York State. The NYPP had neither employees nor assets, although there were 100 people at the Pool's control center. Those system operators at the NYPP were paid by the companies to which they belonged, and some of them – those who came from small-scale utilities – did not have experience with operating large scale power systems (Interviewee2 2009). This means that the NYPP was not fully able to coordinate the power systems in New York. Although the NYPP had a superior overview of the interconnected systems in New York, actual control over transmission lines rested with individual control centers (Clapp, Charles P. Almon et al. 1978). Because of this fact, it was doubtful whether the NYPP was an independent entity which was able to coordinate power flow and exchange information, including training system operators of utilities in New York (U.S.House 1977b).

As mentioned earlier, there were continual efforts to legislate electricity reliability at the federal level in the process of enacting national energy plans through which the federal agencies would force the industry to use power resources efficiently in response to the 1973 oil crisis. Because power transmission networks evolved from a variety of interconnections among individual utilities, significant regional differences exist that might restrict the efficient use of power resources with load diversity in different time zones. In this context, Senator Lee Metcalf and others introduced a bill, *the National Electric Energy Conservation Act of 1975* (S.1208 and H.R. 5048), and sought a feasibility study of a national power grid system to economically manage the interconnected power grids (U.S.Senate 1976). The bill did not directly mention electricity reliability, but implied a possibility to improve the reliability of interconnected transmission systems by directly managing some critical grid systems in a more integrated manner. Because the intent of the the bill was to strengthen the FPC's authority over planning, wheeling, and ownership of some power facilities, it was opposed by almost the entire electricity industry (Greber 1977).

The direct efforts for regulating reliability standards were included in a few national energy bills proposed in 1976 and 1977. A bill, *the Electric Utility Rate Reform and Regulatory Improvement Act of 1976* (H.R. 12461), was introduced by Congressman John D. Dingell and others in 1976. In the bill, Section 309 proposed regulating utility reliability standards by giving the FPC the legal authority to prescribe minimum reliability rules. Accordingly, the FPC, pursuant to Section 501, was supposed to establish *regional planning councils* (U.S.House 1976a p44 and p54). The NERC and regional reliability councils, however, strongly opposed these sections. Walter Matthews, president of the NERC at the time, argued that reliability was to be achieved in the process of planning and constructing a fully coordinated power system by preserving the flexibility of each utility, not in regulating reliability standards. Matthews also stated that an area planning council would destroy the current successful work of individual utilities and their regional councils (U.S.House 1976b p1336). However, Richard L. Dunham, chairman of the FPC, was moderately in favor of regulating reliability standards, while being aware of the strong opposition from private utilities represented by the NERC and regional reliability councils (U.S.House 1976b p1417). A similar bill, t*he Electric Utility*

Act of 1977, was introduced by the same Congressmen in April, 1977. The bill also proposed the same reliability rules and regional planning councils. But the NERC and regional councils repeatedly criticized these regulations for the same reasons; that is, reliability could be achieved only by experienced and knowledgeable engineers, not by regulations. They believe that the proposed planning councils would destroy the increasingly effective coordination among regional councils (U.S.House 1977a). Until the 1977 blackout, these efforts to institutionalize reliability standards at the federal level were frustrated by utilities and their related institutions. Utility leadership regarded the federal government's efforts as interventions in the field of their traditional and professional work. Rather than taking advantage of the government's regulatory initiatives, the utilities did not work systematically to improve electricity reliability. In this situation, system operation for reliability at Con Edison was still loosely coordinated with the NYPP and other neighboring utilities.

6.1.2. Consolidated Edison

Consolidated Edison, which has a long history for electricity supply, and is a member company of the NYPP, was providing electricity for New York City, but did not have a good managerial record in the late 1960s. The company grew by merging with and acquiring other utility companies serving New York City and Westchester County. Con Edison's questionable managerial expertise can be demonstrated in the following examples: in the mid 1960s, in an attempt to reestablish its management reputation, Con Edison installed a large size generating unit at Ravenswood on the West Queens site in New York without considering its impact on neighboring power systems. Later, in 1967

Con Edison found itself in a difficult relationship with New York City. At that time, Con Edison needed to renew its permit for the maintenance and expansion of aqueduct transmission lines in New York City. John Lindsay, NYC Mayor at that time, had not made peace with Con Edison and was using the company’s unpopularity for his own political interests, and therefore rejected the renewal of the permit by demanding nine times more than the original fee. This situation tempted Con Edison to offer a bribe for renewing the permit, but Charles Luce, the chairman and CEO of Con Edison at the time, uncovered this scandal, thereby attempting to enhance the company’s reputation (Goodman 1971; Henderson 2002).

Managerial difficulties also existed in other areas such as recruiting qualified employees, meeting the growing electricity demand in New York City, and updating their facilities. In this period, system operators did not receive regular training, and thus did not have a systematic view of their systems (Interviewee2 2009). Con Edison did not have sufficient space in the City to build power plants. To meet the rapidly growing demand, the company had to obtain power from Orange & Rockland utilities and Central Hudson Power & Light, and negotiate with the City for the construction of a power plant at the Astoria site (Henderson 2002). Con Edison also experienced a credit crunch in early 1974 due to quadrupled oil prices (Luce 1979). In this context, Con Edison could not invest in modernizing their operating systems nor in maintaining their facilities in good operating condition. Rather, the utility tried to reduce management costs.

Con Edison’s physical infrastructure was vulnerable because of the geographical location of New York City. Since the company could not supply cheap electricity in the densely populated area with its existing power generating facilities, it had to import a large portion of its electric power from the Niagara area where electricity generation was cheap. In particular, the company had to import power only through the North corridor lines. If the lines were out of service, few paths to import electricity to New York City remained. Prior to the 1965 blackout, the interconnection between PJM and New York City was weak. Therefore, the 1967 report recommended, "The 500-kilovolt interconnection between southeastern New York and the Pennsylvania-New Jersey-Maryland (PJM) network, which has required rescheduling from 1968 to 1969 because of right-of-way delays, is urgently needed" (FPC 1967a p89). Engineers knew the necessity of strengthening the existing 345kv Linden-Goethals line between PSE&G in New Jersey and Con Edison in New York City. After a long discussion with PSE&G, both companies decided to construct the second line, but in 1977 Con Edison was still in negotiation with PSE&G due to construction costs (Millstein 1977; U.S.House 1977b).

From the above description, it is evident that the institutional and physical settings at the time were not well organized, and therefore that the system operators at the Con Edison control center were limited in their ability to respond to emergencies. Hackman (2002) depicts compelling direction and enabling structure among five enabling conditions for creating effective work teams. A compelling direction, which means clear but challenging goals, should balance between standardization and autonomy in managing power systems (Hackman 2002). To enhance reliability, system operators need increased standardization of work procedures, sophisticated management of technology and sufficient autonomy. The properties of enabling structure in a control room include the design of team tasks, core norms of conduct and good composition of system operators – with a balance between homogeneity and heterogeneity (Hackman 2002).

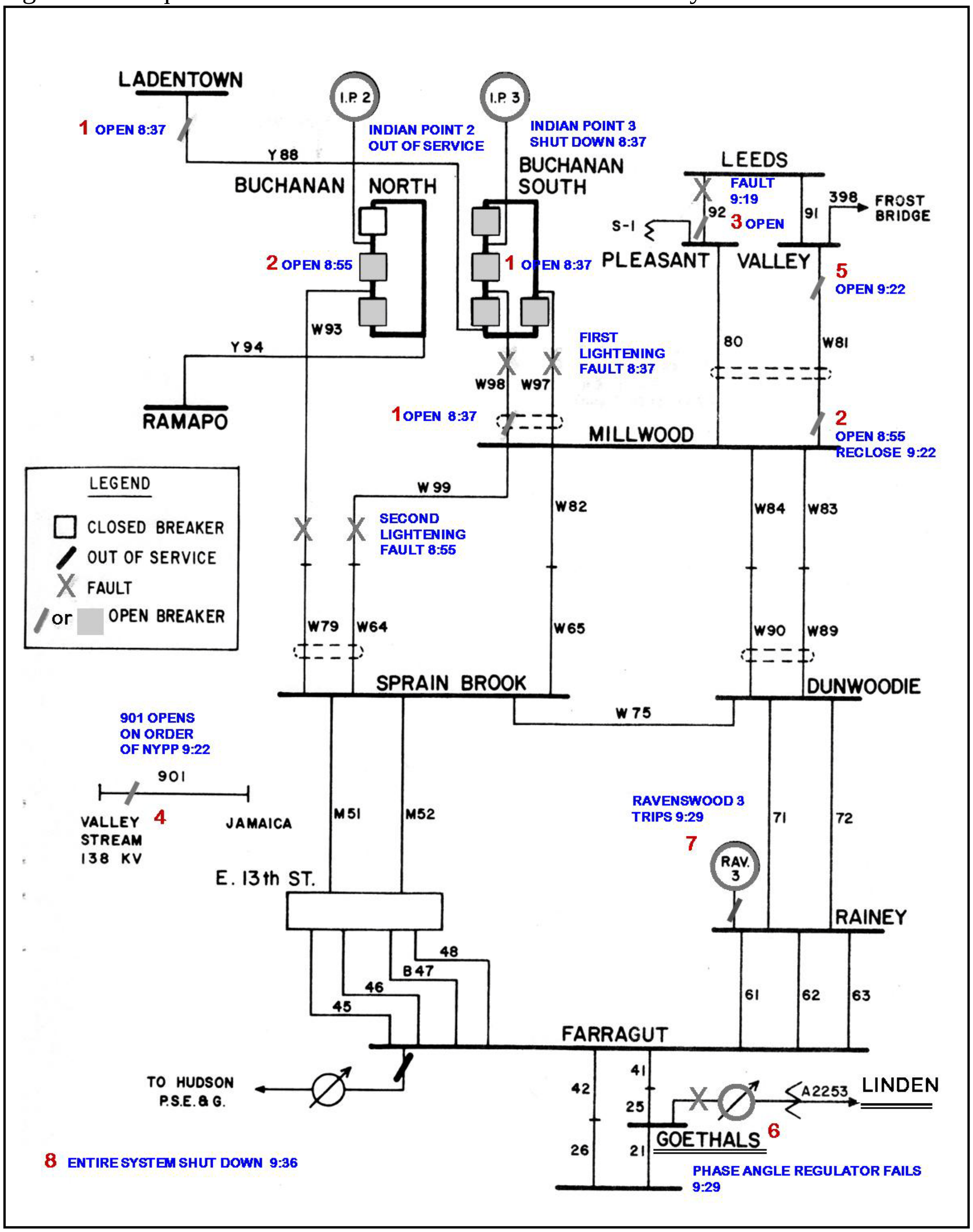
The institutional and physical conditions just before the 1977 blackout, however, did not show authentic indications of supporting organizational performance. Although the region took remedial actions after the 1965 blackout by creating coordinating organizations and by strengthening part of the physical structure in this region, the New York region was still leaving many decisions to individual utilities. As described above, electric utilities and voluntarily organized regional reliability councils did not want any federal government intervention in setting reliability standards. The various utilities were responsible for providing organizational support for system operators, but their managerial decisions were based on cost reduction, minimal operator training and deferred facilities maintenance rather than reliability. Then the blackout happened.

6.2. The Blackout of 1977

At 8:30 on the evening of July 13 before the initial trigger happened, New York City and Westchester County in the Con Edison's service territory imported 2,860 MW of electricity, almost 50 percent of the demand, from outside of the city through the four 345kv transmission lines located in the northern boundary of Con Edison. The import was a result of economic dispatch control coordinated by NYPP. Con Edison had 1,998 MW of operating reserves with 1,208 MW of spinning reserve and 790MW of quick-start gas turbines. Additionally, the Con Edison system was connected with the Long Island Lighting Company (LILCO) through an underground cable known as the 138kv Jamaica tie and with New Jersey through the 230kv Linden tie and the 345kv Hudson (PSE&G)-

Farragut (Con Ed: Brooklyn) tie. Because of a problem of phase angle regulators, the Hudson-Farragut tie had been out of service since September, 1976 – almost nine months.

Figure 6.1. Sequence of Power Failure in 1977 New York City Blackout



Adapted from the Con Edison first phase report (1977)

At 8:37:17p.m., lightning first struck the two transmission lines located in the northern part of Westchester County (line W97 and W98 at the Millwood Substation in Westchester County, see figure 6.1). In order to protect the system, protective relays separated the line from the rest of the system. The relays had to reclose the lines as they were designed. Because of faulty design, however, one of the two lines – line W99-W98 at the Millwood Substation in Westchester county – remained out of service and the outage problem spread further. The power flow on the lost transmission line went to other lines, increasing their loads. The Con Edison system operator decreased power flow on the Linden tie to New Jersey, which subsequently increased the flow in the northern corridor lines.

Additionally, the nuclear power plant at Indian Point 3 in Westchester County, which produced 900MW of electricity, shut down owing to malfunction of the circuit breakers on the struck line. This power loss was able to be replaced by a statewide generation increase. At 8:45 the NYPP asked whether Con Edison could raise its power, and the Con Edison system operator subsequently increased power within the system by 397 MW between 8:45 and 8:55.

At 8:55:53 p.m., a second lightning bolt struck a transmission tower which carried two 345kv lines. One line reclosed successfully, but another line (W93) at the Buchanan North Substation in Westchester County remained open as a result of the relay operation designed to protect the nuclear power plant at the Indian Point 2 which was already out of service at the time. The system operators at Con Edison did not know that line-W93 at the Buchanan North Substation in Westchester County was open. The opening of a second line sent a fault signal to other lines, which resulted in the opening of a third line (W81) at the Pleasant Valley Substation in Dutchess County.

The loss of line W81 led to a heavy load on line W80 at the Pleasant Valley Substation in Dutchess County which delivered power from the Niagara-Mohawk power system. The line exceeded its short time emergency rating.[98] Because the senior operator at the NYPP did not have any means to reduce power flow on line W80, he asked the Con Edison system operator to raise its own power. However, Con Edison could not do this, because the gas turbine power plants for a quick-start were unmanned at 9:02. The only option open to the Con Edison system operator was to disconnect customer loads in New York City. During the telephone conversation that ensued from 8:56 and 9:27, the senior operator advised the Con Edison system operator to shed load nine times.

Instead of load shedding, however, the Con Edison system operator attempted to bring gas turbines in service between 8:55 and 9:19 in order to initiate voltage reduction. He then tried to shed load manually at 9:24. But, by then, the load shedding did not work as intended, and it seemed too late to disconnect customer loads elsewhere. The heavily loaded line (W80-W92 at the Pleasant Valley in Dutchess County) of the north corridor tripped. As a result, the load on the ties with LILCO and PSE&G also became heavier. Nevertheless, the senior operator at the NYPP requested the LILCO system operator to help Con Edison by maintaining the connected tie. But later, the NYPP and LILCO decided to disconnect the tie with Con Ed in order to prevent the spread of the blackout. Subsequently, the Linden-Goethals tie between PSE&G and Con Edison tripped due to

[98] Short time emergency rating refers to the limits the equipment can withstand for a limited time, such as a transmission line with 650 MW two-hour rating, 700 MW one-hour rating, and an 800 MW 30-minute rating. NERC (2006). Reliability Concepts (Version 1.0.0). Princeton, NJ, The North American Electric Reliability Corporation.

the heavy load, exceeding their relay settings. Then the Con Edison system was separated from outside systems, thereafter shutting down its generating units automatically, especially the Ravenswood power plant, and New York City blacked out at 9:36 p.m. (See figure 6.1 for the sequence of power failures).

The blackout occurred after unexpected interactions among component failures, human misjudgment, and lightning. It took 59 minutes from the first disturbance to the entire shutdown of the Con Edison system. Considering the almost one-hour period from the initial trigger, however, Con Edison could have maintained most of the system in service if the system operator had made the right load shedding decisions in the service area. A review of the system operator’s actions reveals structural and institutional issues that directly relate to the delayed remedial actions after the 1965 blackout. These technical, operational and institutional issues were discussed among Con Edison, New York City, the Public Service Commission of New York (NYSPC), and the FERC during the process of taking remedial actions – investigating, reporting, public hearings, institutionalizing, and implementing recommendations.

6.3. Remedial Actions

The 1977 New York City blackout brought about the second debate on reliability, and engineers, regulators and legislators repeatedly discussed the same issues as those after the 1965 blackout. Con Edison published its first and second phase reports on July 26 and August 24, 1977, respectively. Both reports described the sequence of the power failure in the service territory of Con Edison, and analyzed the operation of automatic protective equipment and system operators' actions. Then, on the basis of these reports, hearings were held at City, state, and federal levels between August and November 1977. After these hearings, the Special Commission of New York City issued a report of its power failure investigation which critically reviewed Con Edison and the roles of regulatory institutions – NYPSC and FPC (Federal Energy Regulatory Commission (FERC) after 1977). Concerning these hearings and NYC's report, when publishing the third phase report in December 1977, Con Edison refuted NYC's conclusion, especially the "lack of incentive for the Company's management to provide reliable service" (ConEd 1977). The Public Service Commission of New York State, in its report on the New York City power failure released in January 1978, insisted on a state role in establishing enforceable reliability criteria applicable to all utilities in the NYPP. Yet again, the FERC, in its report published in June 1978, primarily indicated the problem of Con Edison's "insufficient management attention to reliability matters" (FERC 1978 p3). The two Congressional hearings offered opportunities to listen to the different stories of each party: New York Power Pool, New York City, New York State Public Service Commission, Federal Energy Regulatory Commission, and Con Edison. In particular, Con Edison refuted many of the views of New York City. The newly established federal Department of Energy also participated in the discussion with impact assessment of the 1977 blackout.

Table 6.1. A Series of Investigation Actions after the 1977 Blackout

	Con Edison	New York City	New York Sate	Federal Government
July 13 & 14, 1977	New York City Blackout			
July 26	First phase report			
August 24	Second phase report		New York Public Service Commission first report	
August 30 & 31		City hearings in New York City		
September 20 & 21			State hearings in New York City	
September			New York Public Service Commission second report	
October 12				First session hearing in D.C.
October 25 & 26			State hearings in New York City	
November 15 & 16			State Hearings in Albany	
December 1		Special commission report		
December 28	Third phase report			
January, 1978			Special commission report	
June				FERC's report
July 10				Second session hearing in D.C.
July				DOE's report

Table 6.1 illustrates the sequence of actions taken by each party. The outcomes were *the Public Utility Regulatory Policies Act of 1978* (PURPA) which allowed small power systems to participate in the electricity market, and the strengthening of the NERC which defined the concept of reliability and expanded its role from reliability assessment to reliability planning in response to the FERC's efforts to obtain an authority over reliability. At the organizational level, in order to prevent future blackouts, Con Edison built a learning center to share values and the experience of senior employees (Feinstein 2006).

6.3.1. Operation in Need of Reliability Standards for Grid Systems

The sequence of actions during the cascading events and the debates after the 1977 blackout showed that the framework of reliability based on voluntary coordination between utilities and power pools established after the 1965 blackout was not stable, and that the discussion after the 1965 blackout was not finished yet. The debates were, by and large, about technical problems, emergency planning, operational and managerial aspects, and institutional settings (see table 6.2, a summary of different views on causes of the New York City blackout). Overall, the debates were concerned with: establishing reliability in the inter-organizational relationship, the degree of centralized institutional settings for controlling interconnected systems, and the characteristics – voluntary or mandatory – of reliability standards.

First, concerning system status, design and planning, New York City and NYPSC pointed out the design deficiencies of systems in the North corridor paths. They also picked up the problem of outdated display equipment at the control center and the malfunction of automatic load shedding equipment (Millstein 1977; Clapp, Charles P. Almon et al. 1978). As a result, they argued that the system operator at Con Edison did not have a complete understanding of the emergency in the Con Edison system. In fact, he did not recognize one of the transmission line trips. According to the published reports, however, Con Edison and the FERC did not agree with these alleged deficiencies of system design and planning. Con Edison argued that "the present system meets all applicable regional and New York Power Pool design criteria and standards" (ConEd 1977 p25) and that the company invested enough capital in the control center equipment. The FERC also stated that "criteria for system planning and design employed by Con

Edison are generally consistent with those established by the Northeast Power Coordinating Council (NPCC) and NYPP" (FERC 1978 p4).

Table 6.2. Different Views on the Causes of the New York City Blackout

	Con Edison	New York City	New York Sate & NYPP	FERC
System design and planning	**Meet all regional and NYPP criteria** Critical: Lightning Malfunction and incorrect design of protective relays – but a minor issue	Inadequate protective equipment design and arrangement Inadequate control procedures of relays Malfunctioned automatic load shedding	Incorrect relay operations Question of Buchanan ring-bus arrangement Compromise due to financial limits	Not real problems Lightning strike
Generation	**State support for constructing plants**	Not necessary		Not necessary
Vulnerability of transmission lines	CL&P and LILCO's disconnection w/o notice	No operational adjustment for the out-of-service Hudson-Farragut tie	**Unavailability of Hudson-Farragut tie** Relying on a narrow north path	Not critical: operational modification possible Not a narrow north path
Control center equipment	**Enough investment since 1963**	**Obsolescent display equipment**	**Poorly displayed information**	Not old, adequate for experienced operators
Emergency planning		Exceeding import limits set by NYPP Violating contingency criteria	Within the transfer limits set by NYPP Critical: interpretation of double line trips as a single contingency	No violation **Lack of personnel readiness** Need of higher reliability criteria for New York City
Spinning reserve and quick-start	Unavailability (unmanned)	Unavailability (unmanned)	**Unavailability (unmanned)**	Misinformation of availability of quick-start
Maintenance		Inadequate maintenance of protective equipment for emergencies	**Maintenance by individual utilities**	Further improvement for maintenance of equipment
Operation	Enough experience and training **Fast developing emergency** Late quick-start, voltage reduction, and load shedding	Deficiency of adequate operating directives, training and display equipment	Relying on past experience **(Organizational inertia)** **No safety margin** Late load shedding Lack of operator training and experience Lack of unified command and action	**Inadequate programs for selection, training, and supervision of system operators** **Insufficient attention to existing procedures** **Clear definition of contingencies**
Management	**Strong motivation for higher reliability** Capital investment	**Profit-oriented attitudes of top management** No mechanism to stimulate reliability	**Financial constraints** Public pressures **Judgmental compromises**	No evidence of profit-orientation; instead, **Inadequate attention to reliability**
Communication	Ineffective with NYPP and other utilities Load shedding = voltage reduction	Failure to notify PSC of status of Con Ed system	Poor communication Load shedding ≠ voltage reduction	**Imprecise terminology and jargon**
NY PSC/ NYPP	No use of hot line with NYPP	Failure to exercise authority given by State Legislature Closing investigation of 1965 w/o sufficient remedy **PSC and NYPP: no performance standards and sanctions**	NYPP: not exercise control of the factors **NYPP: no authority over design, planning and control criteria** **Lack of team discipline** No design for grid losses No attention to islanded operation	No evidence to support NYPP authority over design and control No use of hot line with NYPP
NERC		Inadequate criteria for Con Ed **Lack of authority to mandate reliability**		
FERC		**Limited authority over reliability**		
Recommendations by FPC after 1965	**Adequate Compliance with recommendations**	**Never implemented recommendations**		**Compliance with recommendations**

Note: emphasis and different views are in **bold**.

In addition, New York City and NYPSC indicated the vulnerability of the physical infrastructure: specifically the narrowly designed north corridors of transmission lines and the out-of-service Hudson-Farragut tie. Instead of addressing these problems, Con Edison pointed to the disconnection of the tie between Con Edison and LILCO without any reference to the Con Edison control center. The FERC argued that the Hudson-Farragut tie was not critical to the blackout because system operators had already modified system operations to conform to the reliability criteria. Rather, the FERC emphasized that a more important factor was the incorrect information on the availability of the gas turbines.

Another design issue associated with the physical infrastructure was the siting of transmission towers. The struck tower should have delivered the lightning current to the ground where it would dissipate. But the ground did not work as designed. Because of the resistance of the ground, the tower kept the potential, which caused a short circuit between the tower and the transmission lines. As a result, the power flow on the line was disrupted, which led to line disconnection. Later it was discovered that the struck tower was not properly grounded nor was it tested when it was constructed. Engineers found many transmission towers nation-wide to have the same problem (Interviewee2 2009).

In general, deficiencies of system design and planning were not significant causes of the blackout according to the viewpoints of Con Edison and the FERC. Instead, Con Edison focused on the combination of two lightning strikes, minor design deficiencies, and the operator’s misjudgment. With respect to the combination of these factors, the FERC gave more weight to the management and operator’s decisions. In fact, New York City pointed out the management problems of Con Edison that lay behind the system deficiencies. NYPSC also perceived the system deficiencies, although critical, as “the product of financial constraints, public pressures, divided responsibilities, organizational inertia, and judgmental compromises” (Clapp, Charles P. Almon et al. 1978).

Second, emergency planning principally includes such procedures as the quick-start of gas turbines, load shedding, and voltage reductions. Con Edison was not able to raise output of electricity generation in time to keep the system in service, because the quick-start gas turbines were unmanned, which was a result of financial constraints in 1974. Con Edison’s system operators did not rapidly take load shedding actions even though they had enough time after the first system disturbance. Thus, New York City and NYPSC concluded that Con Edison violated contingency criteria and lacked the specific planning for contingencies. The FERC’s conclusion, however, was that Con Edison followed all contingency criteria. The problem was the less stringent interpretation of the NYPP criteria; that is, Con Edison interpreted double line trips on the same tower as one contingency, which resulted in incorrect actions by the Con Edison system operator. Therefore, the FERC’s conclusion was that there was a lack of higher reliability standards in such sensitive areas of New York City – heavy loads in the small area – in addition to the need of clear definition of contingency criteria.

Third, regarding operational and managerial aspects, Con Edison, insisting that the experience and training of its system operators was adequate, argued that the blackout was inevitable because of the fast development of the emergency. However, New York City, NYPSC and FERC pointed out the inadequate programs for selection, training, and supervision of system operators. NYPSC stated that Con Edison had merely depended on the past experience of its system operation rather than new programs in the changing environment. NYPSC further maintained that organizational inertia was strong in the Con Edison system operation. The system operators of Con Edison relied on outdated instructions for load shedding. In fact, one critical mistake was that there was no manual for the procedures of load shedding. The engineers who designed the control systems at Con Edison told system operators how to shed loads during emergencies. They did as they were taught – to turn on the load shedding switch on the control console, select a substation, open the capsule, push the button, and check the load shedding lights on the console. But it did not work as was designed. One year later, as the chief system operator was reading a newly written manual of system operation, he found that the engineers did not tell the system operators to wait at least 5 seconds after pushing a load shedding button (Interviewee2 2009).

New York City, NYPSC, and FERC considered these operational problems a result of managers' inattention to reliability in the Con Edison management system. Particularly, New York City criticized the profit-oriented attitudes of the Con Edison top management, and NYPSC judged that the deficiencies of current equipment were due to financial compromises made by management. Con Edison, however, maintained that the board of trustees had a strong motivation for high reliability in its management and had adequately invested in their systems.

After the blackout, Con Edison began to think about human factors in the design and engineering (ergonomics) of display equipment and control consoles. In addition to a study in 1975 conducted by Lockheed Martin and Boeing Companies which had know-how in cockpit designs, the Con Edison Board of Review requested Lockheed to study the procurement specifications for a new control system called the System Operations

Computer Control System (ConEd 1977; Feinstein and Durkin 2000). Con Edison subsequently improved their monitoring equipment by installing indicators of transmission line status on the existing mimic board.

Fourth, during the cascading failure, there was not good communication between NYPP and Con Edison in exchanging information about the Con Edison system. Even though a formal training program had been established at the NYPP level after the 1965 blackout (Interviewee3 2008), it seems that system operators did not share the same premises, assumptions and practices. Con Edison, according to the NYPP agreement, was supposed to notify the NYPP of its policy change concerning required operating reserve, but subsequently failed to inform the NYPP (U.S.House 1977b). Because the NYPP did not know how many gas turbines were available for the quick start, the senior operator of the NYPP just asked Con Edison to raise its own power without considering the status. There was also a different understanding of ‘load shedding’ between Con Edison and NYPP; the senior system operator at NYPP regarded load shedding as disconnecting customer service, while the Con Edison system operator considered it to be voltage reduction (U.S.House 1977b; U.S.House 1978).

Excluding the Con Edison viewpoints which generally defend its position throughout congressional hearings, a series of operational and managerial problems disclosed during the blackout demanded more explicit reliability standards in such areas as system maintenance, specific procedures for emergencies, precise definitions of criteria for good communication, and qualification of system operators. Although individual utilities could specifically treat these issues, they also needed coordination by a centralized entity. The New York Power Pool took the initiative of coordinating power flows during the system failure, but with weak authority. These operational and managerial problems with respect to reliability standards are linked to the institutional settings that guide system operators' decisions during emergencies.

6.3.2. Institutional Centralization and Authority

Concerning the power pools' authority and centralization, the senior operator at NYPP was not in a position to give orders to the system operators of member utilities in the pool under the voluntary participation in the NYPP agreement. Right after the first system disturbance, the senior operator of NYPP was in direct contact with the Con Edison system operator and other pools and utilities; he recommended nine times that Con Edison shed load (Millstein 1977; FERC 1978). But he could not compel Con Edison to accept the decision he thought best. The Con Edison system operator applied the voltage reduction method rather than load shedding. This shows that frequent telephone communication insured neither good communication nor coordination. In the following conversation between the NYPP senior pool dispatcher and the Con Edison system operator, the senior pool dispatcher requested load shedding at 9:05, 31minutes before the complete shutdown of the system:

CE SO	It should be able to help me if he [Ramapo power systems] back off on their Rosetone machines [to reduce the load on line W80].
NYPP SPD	Yeah, but you got nothing to pick up. See what I'm saying? You need something in the south to ease it off, and there's nothing you can do but shed load down there. You can't get your turbines on.
CE SO	It's just the idea. I was figuring ongoing ahead of the game and letting them go naturally. I'm getting the Narrows [power plant] put on and the Astoria [power plant] machines put on (FERC 1978 p96).

Each had different assumptions about the understanding of the emergencies, and different approaches to taking actions. Con Edison wanted to maintain the whole system in service while the NYPP wanted to disconnect some part of the system in order to keep most of the system in service. The Con Edison system operator thought that he had another alternative to the emergency, while the NYPP senior operator thought that there was nothing except for the load shedding. Therefore, the Con Edison system operator was thinking about bringing gas turbines into service and thereby mitigating heavy loads on the last remaining line in the north path, while the senior operator at NYPP advised Con Edison to shed loads immediately. This shows that utilities and centralized organizations such as power pools did not share similar decision premises, assumptions and practices. Although the electricity industry developed a centralized management entity in institutional settings after the 1965 Northeast blackout, it had not yet created a culture of reliability in the inter-organizational relationship.

The creation of a culture of reliability is a process of centralizing premises and assumptions that are necessary for clear communication and expected actions. A push to centralize system operation can be found in the recommendations for voluntary action made after the 1965 blackout. The 1967 report made nine recommendations for interconnected system operating practices – display and recording equipment, communication systems for checking system condition, spinning reserves' quick response to emergency, automatic load shedding, and thorough programs of operator training and retaining (FPC 1967a) – and detailed digital technology for power system operation (FPC 1967b). Although these recommendations were already proposed in the 1967 report, the electricity industry did not centralize system operating practices enough to control interconnected transmission systems. FERC talks about the centralization effort:

> The NYPP does not direct and control bulk-power-transmission system design and operation but rather provides only a coordinating function. Different degrees of centralization exist in various power pools, from simple planning coordination through centralized bulk power dispatch. As the degree of centralization of pool functions increases, the reliability of any given system becomes more dependent on that of the entire group of systems. In July 1977, NYPP was in its first few months of operation with central dispatch; previously, each member of the pool had been responsible for its own load dispatch. As the member systems acquire additional experience in coordinated planning and operation, further centralization of transmission design and operation functions can be anticipated. These functions may be centralized to a greater extent in the pool or in the NPCC (FERC 1978 pp72-73).

That is to say, centralization is a process of creating a culture through accumulation of experience in coordinated planning and operation. However, surrendering very little of utilities' sovereignty for their power pool was a tedious process, which made the creation of a culture of reliability difficult in the inter-organizational relationship. The NYPP was established in 1966 by seven investor owned utilities in New York right after the 1965 blackout, but the actual function started in March 1971. The 1977 blackout report of FERC states that "the reasons for the later agreement were principally to strengthen the organization and to establish, staff, and operate a power pool control center facility located near Albany, New York" (FERC 1978 p81). In other words, individual utilities did not want to yield their sovereignty, and thus it took time to strengthen the NYPP. This process of collecting a small portion of sovereignty delayed the proper functioning of the pool, and therefore deferred creating a culture of reliability among utilities. This organization process of NYPP shows that utilities were unresponsive to large scale power failure, although utilities, including Con Edison, argue that they voluntarily conformed to the Federal Power Commission recommendations made after the 1965 blackout.

At the time, the NPCC to which the NYPP belongs did not have much of a role in this matter except for collecting data and reviewing the generation and transmission expansion plans within its jurisdiction of Ontario and New Brunswick, Canada, and New York and New England in the United States. As described earlier, the NPCC developed regional reliability standards each year, but NAPSIC still had the major role in setting reliability standards. In this sense, the NPCC was still too weak "to promote maximum reliability and efficiency of electric service in the interconnected systems of the signatory parties by extending the coordination of their planning and operating procedures" (FERC 1978 p84).

Another weak aspect of the inter-organizational relationships was revealed in constructing transmission lines between utilities, and therefore the electricity industry reconsidered the role of FERC through the 1977 blackout. As mentioned above, a project to strengthen transmission lines from 345kv to 500kv on the interconnection between Con Edison and PSE&G was delayed. This fact reduced the choices system operators could select. Con Edison suggested paying for the construction cost of transmission lines crossing the Hudson River. PSE&G, which did not have sufficient generating power at the linked site, did not agree with that line construction, however. To deliver power from PSE&G to Con Edison through the proposed path, PSE&G had to construct additional transmission lines within its territory from the north to Hudson County where the line would be linked to Con Edison (Interviewee2 2009). Finally the line construction was completed by 1982 due to a lot of pressure after the 1977 blackout (Interviewee4 2009). Even though Con Edison and PSE&G had their own specific reasons for the construction delay, it essentially resulted from the institutional deficiency to mediate the negotiations between the two. The 1967 report made a recommendation of strengthening that interconnection. At the time of the blackout, the FPC did not have the authority to order interconnection, which the FPC requested in the proposed Electric Power Reliability Act in 1967. The reconsideration did not develop into FPC's regulatory power before the 1977 blackout. After the passage of PURPA in 1978, the FERC was able to order interconnection, wheeling, and pooling, except for immediate interconnection.

6.3.3. Creating a Culture of Reliability Within and Between Organizations

After the 1977 blackout, there was an attempt to create a culture of reliability at the organizational level. Senior managers at Con Edison understood "the need for becoming a learning organization" from failures, and opened the Con Edison Learning Center in 1993 (Feinstein 2006 p187). Generally the interpersonal climate – a lack of psychological safety – in an organization tends to inhibit employees from speaking up with questions, concerns and challenges, thereby discouraging root cause analysis and systematic problem solving (Edmondson 2004). In this situation, leadership is critical for providing a learning environment in which employees in each part are encouraged or motivated to speak up with difficult questions and participate in collaborative problem solving (Edmondson 2004; Cannon and Edmondson 2005). Recognizing that accumulation of minor errors led to catastrophic failure, Con Edison adopted a procedure through which the on-duty senior system operator recorded critiques of every abnormal event, and all system operators had to read the critiques so that they were able to learn from other operators' experience (Feinstein 2006). In the process of establishing the Learning Center, the company centralized all training programs including a business academy for the training of future managers, the Center recorded important lectures and seminars to capture and share these experiences, and trainers with 30~40 years of experience in system operation and maintenance transferred their knowledge to newly hired employees (Feinstein 2006).

However, centralizing core premises and assumptions for a culture of reliability was a difficult task at the institutional level. NERC, which had largely reflected private utilities' interests since its establishment, did not have a dominant role for investing the blackout and making recommendations before, during and after the 1977 blackout. NERC did not have any authority of oversight over utilities' system operation and maintenance at the time (Interviewee2 2009; Interviewee4 2009). It did not provide system operating and planning standards for reliability. Because NAPSIC and regional reliability councils provided utilities with those criteria, NERC's role was limited to reliability assessment for long term, winter and summer periods at the time (Interviewee5 2008). Instead, as described earlier, NERC usually represented utilities' interests, opposing any reliability regulations, when the federal legislative bodies considered enactment of reliability standards. Utilities wanted their autonomy in managing interconnected power systems. In response to the federal government's effort or regulating reliability standards, NERC's role was expanded. After NAPSIC merged with NERC in 1980, the NERC performed the task of setting reliability standards for system operation and maintenance, such as balancing power – frequency and power flow – between interconnected systems (Interviewee5 2008). NERC became a more organized entity after it elected a full time president in 1980. NERC was still in the process of organizing its roles in the late 1970s.

Although creating a culture of reliability was possible at the organizational level, it was nearly impossible at inter-organizational level without institutional support. Another example is that Con Edison made an attempt to distribute videotapes in which lessons learned from the 1977 blackout were recorded. It is pointed out that if the utility personnel involved in the 2003 blackout could have watched at least the videotape, they would not have repeated the same mistakes (Interviewee2 2009). NERC or the regional reliability councils might have had more active roles in disseminating lessons learned from large scale blackouts including the 1977 blackouts. This case shows that creating a culture of reliability was a difficult task without institutional support and in a situation with loosely interconnected inter-organizational relationships.

In summary, weak institutional settings for reliability and delayed implementation of the recommendations after the 1965 blackout are linked to the 1977 New York City blackout. During the Congressional hearings, each party – private utilities, regulators and legislators – repeated the discussion of whether the federal government had more authority with respect to reliability standards. The hearing also revealed that the authority of New York Power Pool which was created by the New York state utilities after the 1965 blackout was not enough to control reliability at the time. As described in table 6.3, just before the 1977 blackout, system operating criteria were still very weak. Although there was a formal training at the NYPP level, system operators did not share premises, assumptions and experience, which resulted in poor communication between NYPP and Con Edison during the emergency on July 13, 1977. Developing and installing more advanced equipment was a task initiated by individual utilities, not by reliability institutions. The attempt to share lessons learned from the 1977 blackout had a limited effect on other organizations in the absence of strong institutional support. Regulatory authorities such as NPCC, with the help of the federal agencies, needed to pre-engineer the system operators' roles and tasks, and predefine their composition in the control rooms of NYPP and utilities as the aviation industry did. Through the intensive relationship between regulatory agencies and utility control centers, they needed to create enabling structures – in other words, supportive organizational contexts – in which system operators could perform their tasks for reliability.

Table 6.3. Status of Institutional Conditions before the 1977 blackout

Evaluation Items	Institutional Status
Setting operation standards	Weak institutionalized standards at the regional level
	NAPSIC and NPCC providing operating standards No significant role of NERC
Licensing system operators	Weak institutionalized training and No licensing programs
	A formal training program at NYPP No formal training at the organizational level
Up-to-date equipment standards	No institutionalized criteria
	In the process of developing computerized operating system at the organizational level.
Improving communication methods	Weak institutionalized criteria
	Need for shared premises and criteria for emergencies in addition to physical equipment; concepts such as load shedding, emergency procedures, N-1 criteria, etc.

In 1978, the U.S. Congress passed PURPA under which a new class of small power producers – nonutilities – was permitted to interconnect with electric utilities. FERC was given the authority to propose voluntary standards of reliability which it never exercised. NERC defined the concept of reliability in two dimensions, adequacy and security,[99] in the early 1980s. To some extent, the institutional settings became stronger than before.

[99] According to NERC, reliability is defined as; 1) Adequacy — the ability of the electric system to supply the aggregate electrical demand and energy requirements of customers at all times, taking into account scheduled and reasonably expected unscheduled outages of system elements; and 2) Security — the ability of the electric system to withstand sudden disturbances such as electric short circuits or unanticipated failure of system elements. NERC (1985). Reliability Concepts in Bulk Power Electric Systems. Princeton, NERC.

But reliability standards had been based on utilities' voluntary participation before the 2003 Northeast blackout. The voluntary membership was an outcome of which parties, private utilities or the federal agency, really dominated the issue of electricity reliability. The dispute between the two is continued in Section 7.1.3, Chapter 7.

Chapter 7. The 1996 West Blackout and the 2003 Northeast Blackout[100]

7.1. Institutional and Physical Conditions Prior to the Events

7.1.1. Small Power Producers – a New Class in the Electricity Market

In his book, *Power Loss*, Richard Hirsh discusses three major reasons that led to the loss of political power that obtained among investor owned utilities and which, subsequently, led to deregulation and restructuring after the 1970s. Specifically, these reasons include the technological stasis of conventional power plants, the energy crisis, and the environmental movement (Hirsh 1999). These areas of concern became the forces that ultimately changed the institutional arrangements for managing the electricity industry.

The first outcome from the loss of political power, as mentioned in chapter 6, was the enactment of PURPA in 1978. This allowed small power producers, known as qualifying facilities (QFs), to access the transmission lines owned by IOUs. After the 1973 oil crisis, the federal government recognized the importance of energy independence. In 1977, to strengthen the topical focus of the federal government, Congress created the Department of Energy (DOE) which would ultimately carry out

[100] The chapter is based on the paper presented at the 2007 International Symposium on Technology and Society Program: Risk, Vulnerability, Uncertainty, Technology and Society, IEEE-Society on Social Implications of Technology, May 31st~June 2nd, 2007.

energy-related activities. Congress also changed the Federal Power Commission (FPC) into the Federal Energy Regulatory Commission (FERC) which was given more power than before.[101] In order to use energy resources efficiently by way of these federal agencies, the Carter Administration tried to reform the electricity rate structure from average cost-based rates to marginal-cost (or time-of-day) pricing, but the IOUs opposed this proposal (Hirsh 1999). Instead, Congress passed Section 210 of PURPA entitled, "Cogeneration and Small Power Production," which would significantly change the physical and market structures of the electricity industry in the coming decades.

PURPA partially adopted market-based principles, and therefore became the starting point of disintegrating vertically integrated power systems in the following areas: generation, transmission and distribution. The FERC encouraged the QFs to participate in the electricity market through the generous interpretation of Section 210 of PURPA,[102] and some state governments subsequently set guidelines for implementing QFs. Physical and market structures changed gradually, as the FERC exercised its regulatory power over physical interconnection for small power producers, wheeling for resale of

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[101] FPC's function was transferred to FERC. Its jurisdiction included major natural gas and wholesale electric pricing and licensing matters, the issuance and renewal of hydroelectric licenses, abandonment of gas facilities or service, determinations on construction work in progress, regulation of merger and securities acquisitions, natural gas curtailments, and electrical interconnections under §202(b) of the Federal Power Act. Nassikas, J. N. (1977). A Regulatory Official's Assessment of the New Department of Energy. *Public Utilities Fortnightly*. **100:** 65-72., p68. But it did not include such functions as imports and exports of natural gas and electric power, the establishment of natural gas curtailment priorities, approval of state compacts, assessment of electric power reliability, and electric power emergency interconnection requirements which was exercised by the Secretary of the Department of Energy or his designee. PUF (1978). Fedral Energy Regulatory Commission's Fiscal 1979 budget Explained. *Public Utilities Fortnightly*. **101:** 27-28., p28. FERC exists as an agency under DOE, but is a quasi-independent entity, making decisions without approval of DOE.

[102] Section 210. Cogeneration and Small Power Production (a) …the Commission shall prescribe, and from time to time thereafter revise, such rules as it determines necessary to encourage cogeneration and small power production which rules require electric utilities to offer to (1) sell electric energy qualifying generation facilities and qualifying small power production facilities and (2) purchase electric energy from such facilities.U.S.Congress (1978). Public Utility Regulatory Policies Act of 1978. T. t. U. S. Congress, U.S. Government Printing Office. **Public Law 95-617 (H.R.4018)**.

purchased electricity from other utilities, and pooling for the voluntary coordination among utilities. Small power producers collectively responded to this condition by organizing statewide industry associations for the QFs to represent their interests and strengthened their fields (Russo 2001). Hence, PURPA opened a way to shift the use of power resources from traditional fossil fuels to renewable resources. More efficient generators such as cogeneration, gas turbines and wind power could produce cheap electric power through improved energy efficiency.

As a result, PURPA incrementally weakened the justification of the natural monopoly that existed in the electricity industry, and moved the private utility dominant market structure toward that of greater competition among power producers (Hirsh 1999). In a broad sense, PURPA, which introduced unregulated power producers for the purpose of energy conservation, had also enabled an unintended consequence, the deregulation of the electricity market.

7.1.2. NERC's Expanded Role after PURPA

Before and after the passage of PURPA, NERC pursued its roles more extensively even as DOE and FERC were looking for more authority in setting reliability standards. In 1978, Congress finally passed the new *National Energy Act.*[103] Under PURPA, as mentioned earlier, the FERC had authority over interconnections, wheeling, and pooling for the purpose of efficient utilization of power resources and the improvement of

[103] The National Energy Act was composed of the five bills which were passed by Congress October 15, 1978: the Public Utility Regulatory Policies Act of 1978, the Power plant and Industrial Fuel Use Act of 1978, the National Energy Conservation Policy Act of 1978, the National Gas Policy Act of 1978, and the Energy Tax Act of 1978. PUF (1978). An Overview of the National Energy Act. *Public Utilities Fortnightly*. **102:** 28-32.

reliability (U.S.Congress 1978). While the former bills - *the Electric Utility Rate Reform and Regulatory Improvement Act of 1976* and *the Electric Utility Act of 1977*- tried to regulate minimum requirements of reliability standards, the final version in PURPA gave the FERC only the authority to study the reliability of electric utility systems, request regional reliability councils to examine specific reliability issues, and recommend standards and practices for resolving reliability problems (Matthew Holden 1978). This section never changed until the 2003 blackout. As a newly established government department, the DOE explored the technical and economic feasibility of a national power grid system with the creation of a *National Power Grid Corporation* (PUF 1978; Falcone 1979). But the idea of a national power grid was not realized owing to opposition from private utilities which perceived the NPGC as a socialistic project. Despite their efforts, the federal government, without technical or professional knowledge about electricity, was not able to persuade the electric utilities to adopt federally regulated reliability standards.

NERC, after reviewing its roles and merging with NAPSIC in 1980, expanded its activities from data gathering and reliability assessment functions to planning guide functions[104] (Swidler 1979). NERC subsequently clarified the concept of reliability – adequacy and security – in the early 1980s (NERC 1985). Yet the implementation of reliability standards was left to the utilities' voluntary participation and the use of peer pressure. In his recommendations after the passage of PURPA, Joseph Swidler suggested

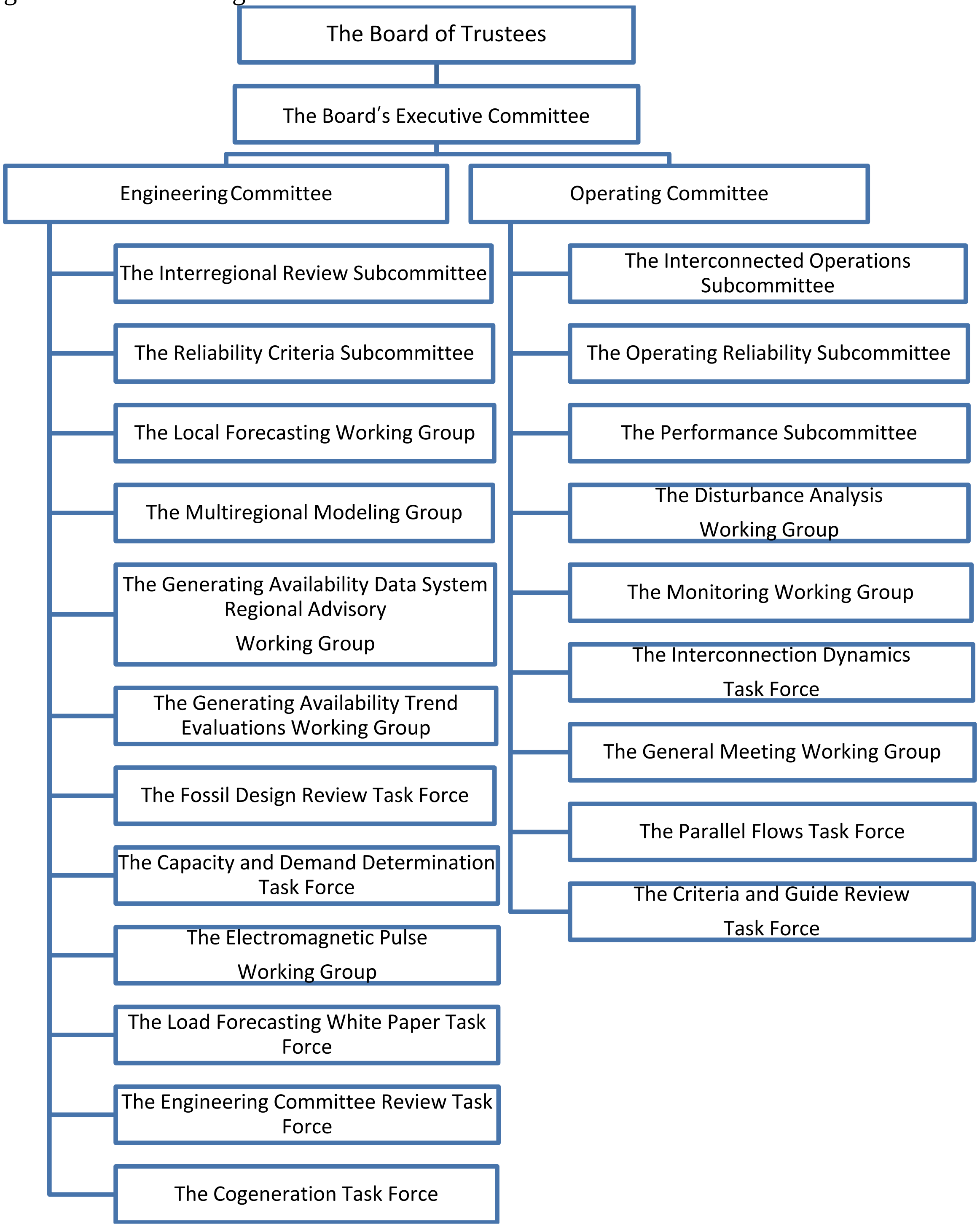
[104] The NERC's Operating Committee included such activities as "development of operating guidelines, recommendations, and standards for: 1. Operating reliability, 2. Frequency regulation, 3. Time control, 4. Tie line frequency bias, 5. Operating reserves, 6. Time error correction procedures, 7. Emergency operating procedures – a. load shedding and restoration, b. tie separation and restoration, c. generating-unit security – 8.Scheduled maintenance outages of major facilities, 9. Interchange scheduling procedures, 10. Procedures for handling inadvertent interchange, and 11. Any other operating matters that require coordination to effect reliable interconnected operation." FERC (1981). Power Pooling in the United States. FERC, Office of Electric Power Regulation., p32.

that NERC conduct periodic visits to all control centers and monitor operating practices to prevent power failures arising from inadequate organizational performance (Swidler 1979). NERC, however, did not successfully include these activities. Instead, it added technical staff – the Disturbance Analysis Working Group (DAWG) – to investigate power failures and disseminate lessons learned since 1979 (NERC 1996).

After expanding its activities, NERC appeared to take a dominant role in the reliability issue, and continued in this capacity until the enactment of *the Energy Policy Act of 1992* (EPAct 1992). NERC produced sophisticated guidelines that eventually led to greater reliability standards. To create these guidelines, NERC organized various subcommittees, task forces, and working groups which were under the supervision of the two committees – the Engineering Committee and the Operating Committee. The Board's Executive Committee [105] oversaw the two committees, and ultimately the Board of Trustees exercised control over the Executive Committee (See figure 7.1). The Board of Trustees consisted of 25 utility executives who were from nine regional councils, a Canadian utility and each utility ownership segment (federal, investor-owned, rural electric cooperative and state/municipal systems).

[105] The Board's Executive Committee consisted of chair, past chair, president, secretary-treasurer, and one member selected by the Board of Trustees. OTA (1988). Electric Power Wheeling and Dealing: Technological Considerations of Increasing Competition. Office_of_Technology_Assessment, U.S. Government Printing Office. **Volume II**.

Figure 7.1. NERC's Organization in 1986



Source: Office of Technology Assessment, the U.S. Congress (1988)

Because NERC was controlled by the 25 utility executives, however, it could not be free from utilities' perspectives and interests. NERC was still funded by member utilities. Even though NERC advocated for more unified practices for system control in addition to sophisticated guidelines, it could not effectively recommend these practices due to the limitations of its decision making structure. Member utilities did not want NERC to be able to take control of utilities' transmission system operation. They preferred to adopt reliability standards to the extent that the reliability standards did not hurt the autonomy of their system operation.

Therefore, NERC did not have the authority to reorganize loosely coordinated practices among utilities and their dispatch control centers. In fact, because of the diversity of over 150 control centers, utilities had to operate with technically different control systems at various levels that were often the product of local conditions (S.E.A.B. 1998). NERC simply provided these different levels of control centers with minimal guidelines for reliability, which neither tightened the looseness between NERC's standards and control centers' performance, nor the coordination among control centers. This resulted in different normal and emergency ratings for 345kv transmission lines among the control centers in ECAR and MAAC reliability regions, which came to light after the 2003 blackout.

7.1.3. IOU's Agreement with Deregulation

In addition to the passage of PURPA in 1978, a long controversy between market-based and regulatory approaches to energy conservation became grounds for opening the electric wholesale and retail markets to local, distant and small power producers in an era of economic decentralization (Hirsh 1999). Because the basic philosophy of PURPA was the efficient use of energy resources, PURPA, to some extent, intended to reduce the power of private utilities – specifically, their authority of planning power supply – which typically emphasized the construction of expensive power plants in order to meet future electric demands. In the late 1970s and 1980s, the concern about energy conservation evolved into such strategies as demand-side management, least-cost planning (LCP)[106] and integrated resource planning (IRP). State governments actively adopted these strategies to manage electric demand and respond to the environmental movement. Because some IOU senior managers believed that they could make profits only by selling more kilowatt-hours, they criticized these programs as central planning and untested ideas (Hirsh 1999). The senior managers argued that consumers should choose energy efficient technologies, appliances, and machines in the market. The criticism of DSM and IRP was linked to the adoption of free-market principles to prevent the government intervention in the market.

The Gulf War in 1990 provided the momentum to enact a law for increasing the use of renewable resources and the adoption of energy efficiency practices (Hirsh 1999). The senior Bush Administration sought to achieve its goals through free-market principles because the prevailing thought at that time was that power suppliers would seek the most efficient ways by cutting costs and improving services in the market (Hirsh 1999). The passage of EPAct 1992 encouraged these free-market principles, thereafter allowing local, distant, and independent power producers' open access to transmission lines.

[106] Least-cost planning or integrated resource planning refers to provision of electric services at the lowest cost with the combination of "market forces, energy efficient technologies, fuel substitution, renewable energy, and conventional equipment." Hirsh, R. F. (1999). *Power Loss: The Origins of Deregulation and Restructuring in the American Electric Utility system*. Cambridge, Massachusetts, The MIT Press., p194.

EPAct 1992 expanded FERC's authority – claimed in FERC Order 888 in 1996 – that "requires transmission-owned utilities to provide transmission service at FERC-defined 'just and reasonable' rates" (E.I.A. 2000 p33). FERC issued Order 889 in 1996 requiring that all IOUs participate in the Open Access Same-Time Information System (OASIS) (E.I.A. 2000). OASIS included available transmission capacity, capacity reservation, ancillary services, and transmission prices. The FERC also issued Order 2000 to promote regional wholesale markets, and regional transmission organizations (RTOs)[107] which have since been organized in such regions as New England, New York, PJM, the Midwest area and California.

Congress, however, unlike in PURPA and other proposed bills in the past, avoided including specific reliability sections in EPAct 1992 although implementing regulations of open access to transmission lines would impact on transmission capacity that was critical for reliability. EPAct 1992 just contained the regulations about what, how, and to whom free-market principles should be applied. One paragraph about reliability appeared in Section 721(b) Reliability of Electric Service, EPAct 1992 – "No order may be issued under this section or Section 210 if, after giving consideration to consistently applied regional or national reliability standards, guidelines, or criteria, the Commission finds that such order would unreasonably impair the continued reliability of electric systems affected by the order" (1992 106 STAT. 2915).

[107] RTOs are also called power pool, regional transmission groups (RTGs), and independent system operators (ISO). For the open access to transmission lines in each relevant power market, FERC wanted to form RTGs based on the territory of regional reliability council. NERC (1993). NERC 2000: The Future Role of the North American Electric Reliability Council. Princeton, NERC. The formation of ISO is a voluntary process; according to Order 888, transmission owners transfer the operating control of their facilities to the ISO, while the owners maintain the ownership of their facilities. E.I.A. (2000). The Changing Structure of the Electric Power Industry 2000: An Update. DOE, Energy Information Administration.

Prior to the passage of EPAct 1992, Congress continually considered enacting legislation that would introduce more competition in both wholesale and retail electric markets in the late 1980s – *the Competitive Wholesale Electric Generation Act* of 1989 (U.S.Senate 1989). In 1986 NERC had already pointed out that the wholesale competition with open access to transmission lines would adversely affect reliability because of the possibility of overload on the network (OTA 1988). But NERC was not invited to testify during the Congressional hearings related to the proposed energy bills – *the Competitive Wholesale Electric Generation Act* of 1989, *the Electric Power Fair Access Act of 1991* and *the National Energy Security Act* of 1991 (U.S.Senate 1989; U.S.House 1991; U.S.Senate 1991). Instead, a group of executives from major investor owned utilities – temporarily named *the Electric Reliability Coalition* (ERC) – testified before the Senate, opposing mandatory transmission access because it might reduce electric reliability and increase consumer costs (Hirsh 1999 p245). In addition to the concern about reliability, however, the speakers sought ERC to protect their utilities from competition by removal of a barrier to independent power producers' market entrance. IOUs argued that because of the independent power producers' participation in the market, they would lose economic advantages and be unable to recover their investment costs (stranded investment) and preserve autonomy in managing their power facilities (U.S.Senate 1989). Therefore, the IOUs temporarily organized ERC and directly appealed to Congress rather than requesting NERC to raise the genuine concern about reliability in a more objective manner. If the ERC had truly wanted to maintain the existing level of reliability, it would have proposed some alternative ways of dealing with reliability. As a result, even though ERC's perspective on the reliability problems was right, it was not persuasive, so that ERC sometimes was called the “Just Say No” crowd (Hirsh 1999). The result was deregulation without preparations for upcoming reliability problems.

Concerning reliability coordinators such as ISOs and RTOs, FERC made an attempt to control transmission systems independently, separating their operation from generating systems and giving ISOs and RTOs this grid-system-control authority. This can be compared to the operation of air traffic systems although there is a structural difference between the two. The power flow on transmission lines is controlled by individual control areas; the ownership of both power generation and transmission is not separated. But the ownership of an air traffic system is separated from the air carriers, and thus the air traffic controller can be more focused on safety. Like the air traffic system, ISOs and RTOs can control power flows with the ideas of optimizing market efficiency and maintaining reliability. However, their practices for reliability may be insufficient as long as utilities possess transmission lines and operate their own control centers under the supervision of ISOs and RTOs. Without strong reliability institutions compatible with free-market principles, utilities, non-utilities, and power marketers have nonetheless participated in their regional power pools. One result is increasing power trade transactions – from 100 Megakilowatt-hours in 1996 to 4500 Megakilowatt-hours in 2000 (Munson 2005) – and transmission congestion in some areas. The congestion increased reliability problems as ERC pointed out.

7.1.4. NERC's Unstable Role under Deregulation

EPAct 1992 demanded more in-depth review of reliability. Most parties, however, seemed to pay more attention to the efficient operation of the competitive electricity market than the reliability of electricity. Under these conditions, the reliability issue was been raised regularly by DOE and NERC. They were concerned about the structurally limited reliability authority which included only self-regulated reliability standards and peer pressure to encourage implementation.

Although NERC did not attend the Congressional hearings for the above proposed bills in 1989 and 1991, by letter it requested that the U.S. Congress urge FERC to follow NERC's reliability standards, guidelines, and criteria before the passage of the EPAct 1992. The U.S. Congress included what NERC requested, as written in Section 721(b) Reliability of Electric Service (NERC 1993). NERC sensitively recognized the institutional change toward the competitive market and sought a new role under these new circumstances. Concerning the policies for interconnected systems operation and planning, NERC sought the authority to ensure that all control areas would comply with NERC's reliability criteria. When NERC assessed the current reliability of interconnected systems (NERC 1996) and reviewed different regional criteria in 1996 (NERC 1994), it was aware that utilities could neglect reliability of their systems. This is because, in the future, utilities' transmission operations and reliability functions would be independent of their wholesale electricity business functions according to FERC Order 889 (NERC 1996). NERC perceived that utilities were increasingly in violation of reliability criteria each year. Since many utilities were able to get access to transmission lines under the deregulation, no one knew which utilities were connected to transmission lines, therefore making grid systems almost out of control (Interviewee5 2008). NERC began to recognize the need for strict compliance with network security standards and additional activities – measuring performance – to monitor member utilities' routine works related to reliability standards under the changing institutional environment (NERC 1996).

The 1996 Pacific Northwest blackout made NERC reconsider the current voluntary systems in a stricter way. In 1997, the report of NERC's Electric Reliability Panel suggested a new organization which would have *oversight authority* while maintaining the flexibility of a self-regulating organization; the Panel called the organization the North American Electricity Reliability Organization (NAERO) which would be independent of government and also separate from the ten regional reliability councils' in governance and funding (NERC 1997). The Panel suggested that the activities of government entities be limited to review and approve the standards and procedures of the NAERO. At the same time, the Panel pointed out that "the challenge that will be faced in accommodating this need is to create review and approval procedures that are appropriate to the responsibilities of government entities while not imposing excessive constraints on NAERO" (NERC 1997 p26). The Panel members' recommendations showed that the NERC was also aware of the current loosely coordinated performance among control centers which, under the competitive market, would lead market participants to abuse transmission systems and data according to their interests. However, NERC was aware of the federal government's concerns about intervention in the future NERC's self-regulating authority. Here we see that NERC was still very sensitive to government's active involvement in reliability. And yet NERC did not specifically mention what government entities should review and approve NERC's reliability standards, leaving the decision uncertain regarding FERC's role and relation to NAERO.

7.1.5. Federal Government's Call for a Role in Reliability

In this period, the federal government raised concerns about electricity reliability to be addressed along with deregulation. In its interim report in July 1997 after the 1996 Pacific Northwest blackout, the Secretary of Energy Advisory Board (SEAB) Task Force of DOE initiated a discussion regarding the current governance of regional reliability councils. The Task Force characterized its recommendations as consistent with those of the Electric Reliability Panel. It thought that system operators should be independent of commercial interests in electricity markets (S.E.A.B. 1997). In 1998, the Task Force suggested a more rigorous level of organizational settings in dealing with reliability, stating that:

> The Task Force is especially interested in seeing the reliability institutions [NAERO and Regional Reliability Councils] becoming truly independent of commercial interests so that their reliability plans and actions are – and are seen to be – unbiased and untainted by the economic interests of any set of bulk power market participants… The Task Force believes that the U.S. Congress should explicitly assign *oversight* of bulk-power reliability to the FERC, including the authority to coordinate North American reliability with the appropriate regulatory agencies in Canada and Mexico (S.E.A.B. 1998 p xv).

The Task Force was in strong support of FERC's more active participation in managing reliability by assigning oversight authority to FERC, about which the position of the NERC's Electric Reliability Panel was uncertain. In addition, the Power Outage Study Team (POST) of DOE underscored the fundamental responsibility of the federal government and recommended modified (or new) institutions to implement reliability standards in a stricter manner – mandatory reliability standards (DOE 2000). They indicated the lack of real-time power system and market information for best practices under current conditions in managing reliability, particularly concerning low-probability, high-consequence events, and thus wanted to enhance federal activities (DOE 2000). DOE in concert with FERC went further from oversight authority to reliability rulemakings, as it had sought after the 1965 blackout.

7.1.6. Seeking a New Institution for Reliability

Since the federal government began to consider intervening in mandatory reliability standards by rulemaking, NERC and regional reliability councils have sought to maintain their leading position over the reliability issue. Thus, they requested DOE to support their transition from encouraging voluntary application of reliability standards to mandatory and enforceable ones while keeping their basic philosophy: that is, an independent, industry self-regulated reliability organization (NERC 2001). This controversy between private utilities and the federal government was reflected in the debate over enacting an energy policy bill on the Senate floor: the Daschle-Bingaman Bill and their amendment (2002a) vs. Thomas amendment (2002b) supported by NERC and the Western Governors' Association in 2002. In the Daschle/Bingaman bill, FERC would have the authority over establishment of "one or more systems of mandatory electric reliability standards to ensure the reliable operation of the interstate transmission system" (2002a p21). According to this bill, FERC would be able to "create mandatory and enforceable reliability rules," by giving authority and responsibility to FERC (2002b p22). But Senator Craig L. Thomas of Wyoming argued that FERC had neither the technical ability nor the manpower to set and enforce reliability standards, and that because of the international nature of connection of the U.S. transmission grid with Canada and Mexico, FERC would not be able to regulate systems in those countries. Instead, he suggested that his amendment would establish "a participant-run, FERC-overseen electric reliability organization," combining a federal oversight function and industry's professionalism (2002b pS1873).

In sum, NERC and the federal government knew about the serious deficiency of the existing system in maintaining electricity reliability in a substantially changing environment due to deregulation, but did not show concerted efforts to reorganize institutional settings and organizational performance for reliability. As a result, it was more difficult to find a way to tighten already loosened performance exercised by utilities as well as new players; as ISOs, RTOs, independent power producers and power marketers entered the deregulated market. Although some IOUs restructured themselves by merging together, they maintained existing organizational performance in their dispatch control centers because of their structural inertia (Hannan and Freeman 1984). Even though there were some warning signs of impending large scale blackouts – the 1996 Pacific Northwest outage and the 2001 California crisis – reliability was under discussion. The slack between institutions and organizational performance was getting broader.

7.2. The 1996 Blackout

The 1996 Pacific Northwest blackout was not directly related to deregulation. Instead, it showed again that the absence of integrated coordination among individual control centers with proper institutional settings could bring about a large scale blackout. Power systems in the Pacific Northwest region are also loosely coordinated due to various power pool agreements.[108] Following the tradition of the public power movement in the Northwest region in the 1930s, the federal government created the Bonneville Power Administration (BPA) in 1937. The region, however, had experienced a long period of tension between public and private power utilities with respect to the dominance over the Northwest electricity resources, resulting in informal operation of power pools by private utilities in the early 1940s (Miller 2001). In the early 1980s, the region had the Northwest Power Pool (NWPP) classified as an informal pool in which the pool members adopted standard operating practices, but without a pooling contract (FERC 1981). While the Tennessee Valley Authority developed a more integrated power system and managerial skills to compete with an investor-owned utility, BPA did not have to do that. It already had markets: municipal utilities, public utility districts in rural areas, IOUs, and large users such as aluminum corporations (Salsbury 1991). BPA receives power from its own power plants and the hydro generators of the U.S. Army Corps of Engineers, and transmits power to the above wholesale customers through

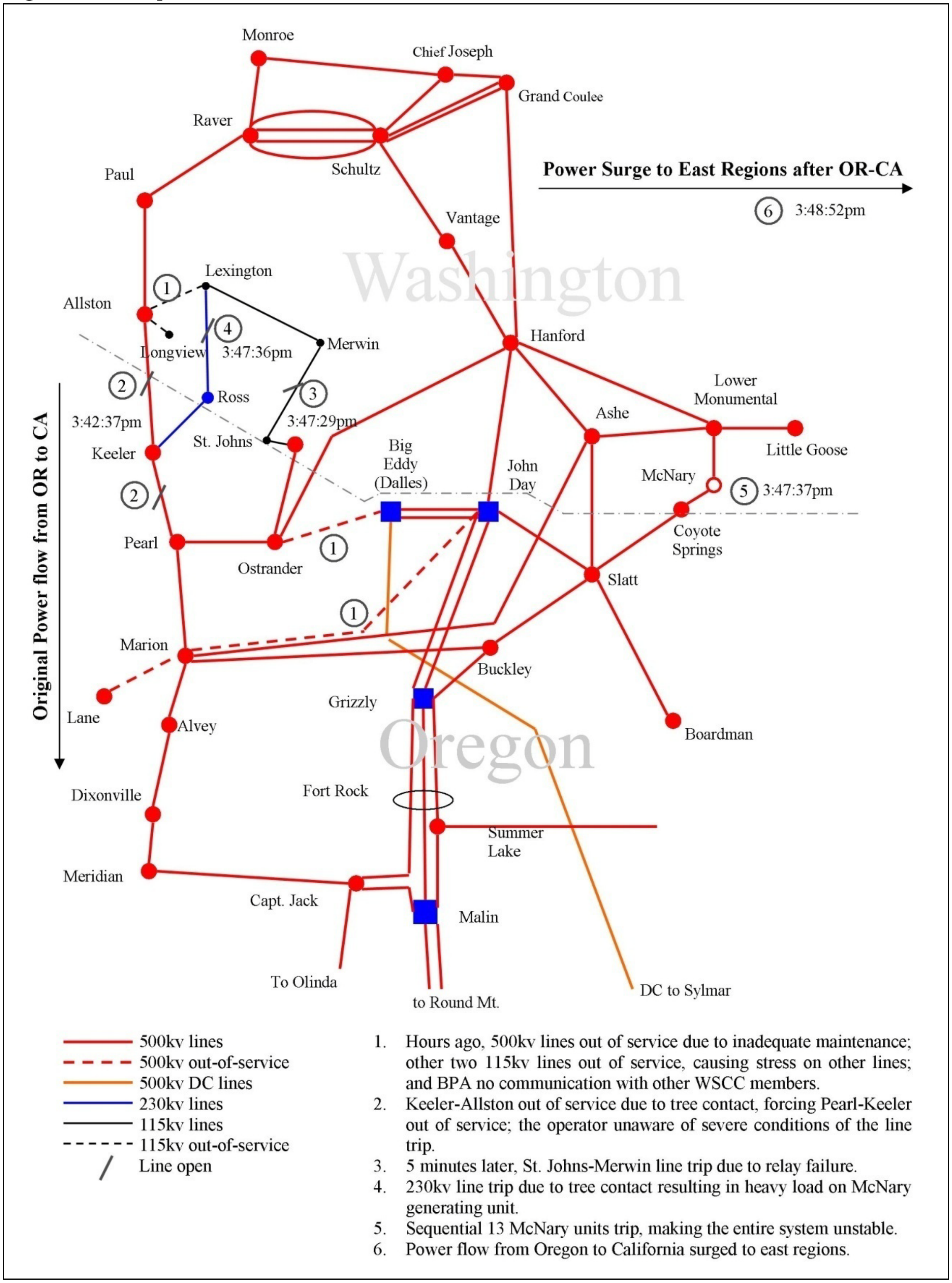
[108] In the early 1980s, there were 7 power pool agreements in the region: the Northwest Power Pool (NWPP, 1942), Pacific Northwest Coordination Agreement (PNCA, 1964), Mid-Columbia Hourly Coordination Agreement (MCHA), Intercompany Pool (ICP), the Pacific Northwest Utilities Conference Committee (PNUCC, the mid 1940s), the Public Power Council (PPC, 1966), and the Public Generating Power Pool (PGPP).

transmission lines. Because of BPA's weak link to other parts of the Northwest, BPA did not have a variety and depth of management skills that TVA had (Salsbury 1991).

After the 1965 blackout, the region joined the Western System Coordinating Council of NERC. But the region did not develop integrated institutional arrangements to operate and manage its large scale power system. In this structural context, the region had already suffered from the collapse of the Washington Public Power Supply System due mainly to incorrect forecasts of demand in the 1980s (Salsbury 1991; Miller 2001). Without having an agency to oversee the power flows along transmission lines, the region was preparing for the separation of transmission operation and the power supply function according to FERC Order 888 in 1996. While preparing for this separation process, the region experienced the Northwest power outage.

At 3:48 p.m. Pacific Advanced Standard Time (PAST) on August 10, 1996, the largest blackout in the history of the Pacific Northwest occurred, affecting approximately 7.5 million people in the entire Western region. Electric power in the Pacific Northwest is usually transferred from Canada south through Washington and Oregon to California during summer seasons when power demands in California are high. Because of excellent hydroelectric conditions in Canada and the Northwest in 1996, power flow was heavy on the transmission lines (WSCC 1996). According to the WSCC Report (1996), it started on the tie line between Oregon and California on the west coast area. In the hours before the outage, two 500kv lines (John Day-Marion-Lane and Big Eddy-Ostrander) in the Portland area were forced out of service due to inadequate maintenance leading to tree contact. Two other 115kv lines were also out of service, escalating stress on the system with the major disturbance – the loss of the Keeler (south)-Allston (north) 500kv line.

Figure 7.2. Sequence of the 1996 Western Blackout



Adapted from Kosterev et al. (1999 p967)

The Saturday afternoon was hot, creating heavy load on the transmission lines, and BPA was transmitting about 7,400 MW of electricity to California, equivalent to the demand of 7 million homes. Because of the heavy load, the Keeler-Allston line sagged close to a filbert tree and flashed over. The Pearl (south)-Keeler (north) 500kv line was also opened. Then the system in the Portland area became depressed, and five minutes later the system began to lose other lines consecutively. The power surged to the east then south through Idaho, Utah, Colorado, Arizona, New Mexico, Nevada, and southern California, separating the system into four islands. As a result, 15 large thermal and nuclear generating units shut down in California and the Southwest. Figure 7.2 illustrates the sequence of the blackout.

BPA operators had previously experienced the loss of the same Keeler-Pearl line due to tree contact on July 13, 1996. But they operated the line without any hesitancy about triggering cascading outages. Nor did they send warning signs to other WSCC operators at dispatch centers for one and half hours after the two major lines (John Day-Marion-Lane and Big Eddy-Ostrander) went out of service. The report of the Northwest outage pointed out that:

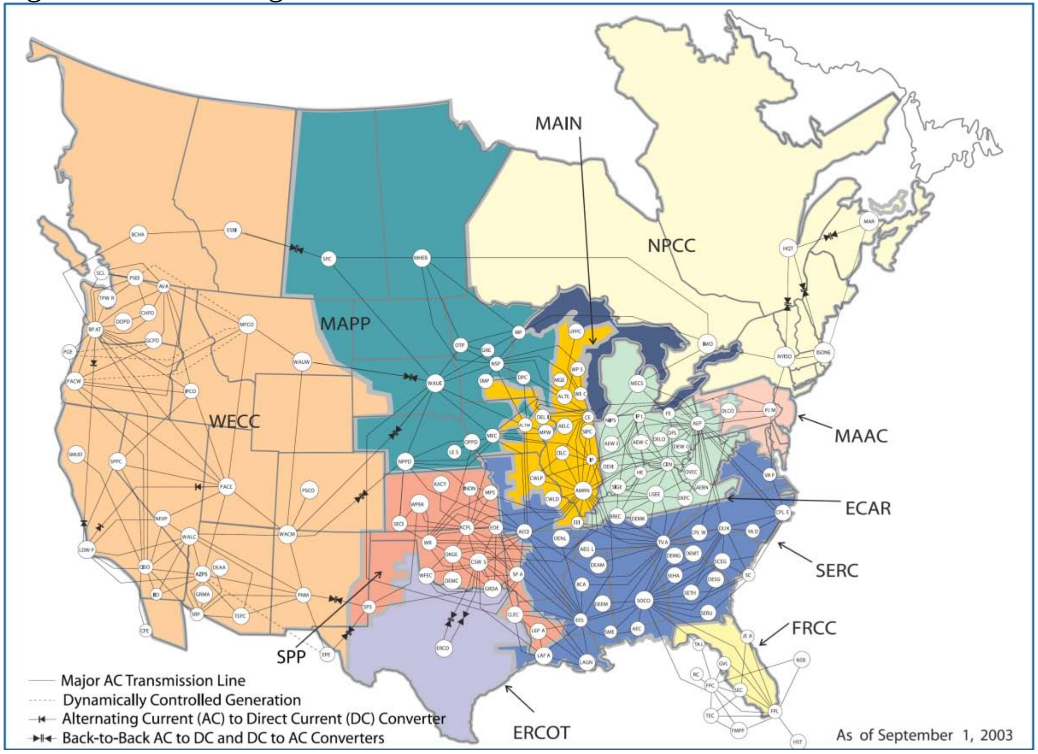
> While none of these lines were individually judged to be crucial by BPA dispatchers, the cumulative impact resulted in a weaker system. BPA did not widely communicate these outages to other WSCC members nor did they reduce loadings on lines or adjust local generation as precautionary measures to protect against the weakened state of the system (WSCC 1996 p4).

The 1996 blackout shows that the historically constructed institutional settings for reliability created flaws in organizational performance. BPA system operators did not have effective ways to minimize the power loss without appropriate agencies to oversee the entire interconnected system and judge the situation. They depended on systems' information communicated by isolated, local dispatch centers. As a result, the BPA operators could not get the big picture of the system. Dispatch control centers need to work closely and intensively with the higher level control center and neighboring centers given their complex systems. Without a holistic approach to control of the entire system, the deregulated environment in which many players participate can make already difficult situations worse. The 1996 Pacific Northwest blackout was a precursor of another massive power outage because the industry was not appropriately responding its changing environment.

7.3. The 2003 Blackout

The Midwest region where the initial trigger happened was engaged in wholesale electricity trade, which means that there were many transactions a day from hundreds of utilities and marketers in 2003. In addition, the region is the crossroads for east-west and south-north power flows (Figure 7.3). The Northeast, especially New York City, is also an area that consumes electricity heavily, importing power from the neighboring regions. Those regional power pools are controlled by an RTO or ISO, the reliability coordinators: Midwest ISO (MISO), the PJM Interconnection, Inc., New York ISO, ISO New England, and the Independent Market Operator of Ontario. Then the region’s control centers operated by IOUs are in coordination with them.

Figure7.3. NERC Regions and Control Areas

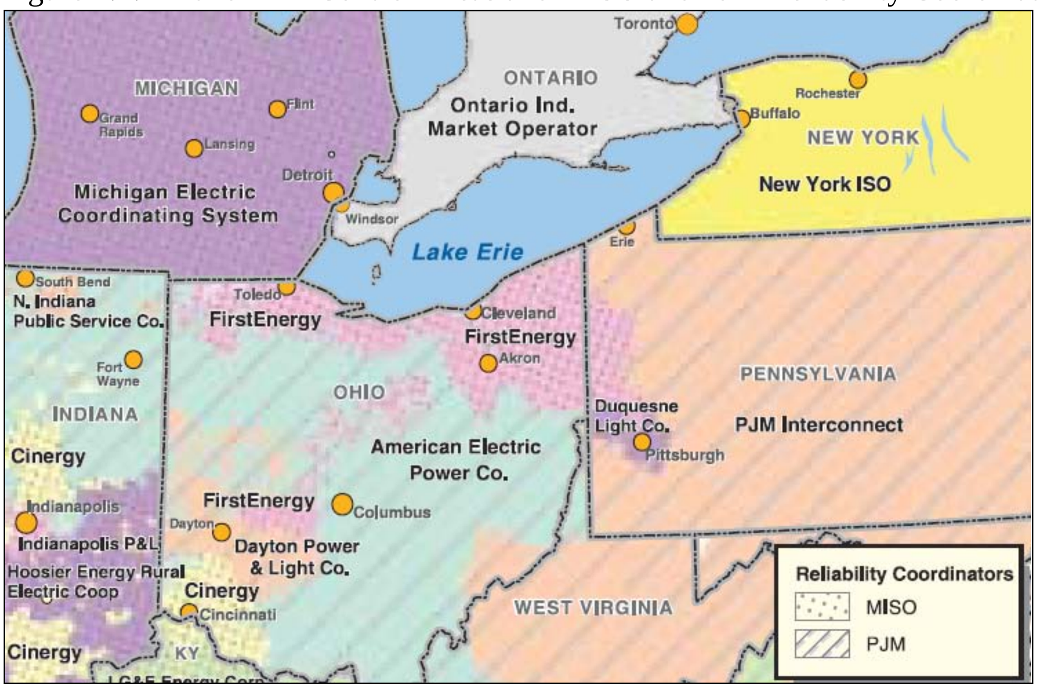


Source: U.S.-Canada Power System Outage Task Force (2004)

On August 14, 2003, the largest electrical power failure in the U.S. history occurred in the Northeastern region, with a loss of more than 60,000 MW of load affecting 50 million people. This blackout is recorded as the worst outage in North American history. The mixture of several small contingencies resulted in a massive power failure. In accordance with the three reports published by U.S.-Canada Power System Outage Task Force and the NERC Steering Group, a brief sequence of power system disturbances is as follows (U&CTF 2003; NERC 2004; U&CTF 2004).

In the morning on that eventful day, considering weather conditions – temperature and humidity – and from their experience, system operators of the affected area expected that August 14 would be an ordinary day with peak load conditions that were less than peak load day. The blackout started in Northern Ohio (the Cleveland-Akron Area) as a local event after 12:15 p.m. Eastern Daylight Time (EDT, hereafter all times means EDT) when the state estimator (SE)[109] and a software program performing real time contingency analysis (RTCA)[110] of MISO failed to monitor generation and line losses within its reliability zone. This resulted in a cascading stage right after 4:00 p.m., and continued for 2 days in some parts of the United States.

Figure 7.4. FE and AEP Control Areas and MISO and PJM Reliability Coordinators



Source: U.S.-Canada Power system Outage Task Force (2004 p13)

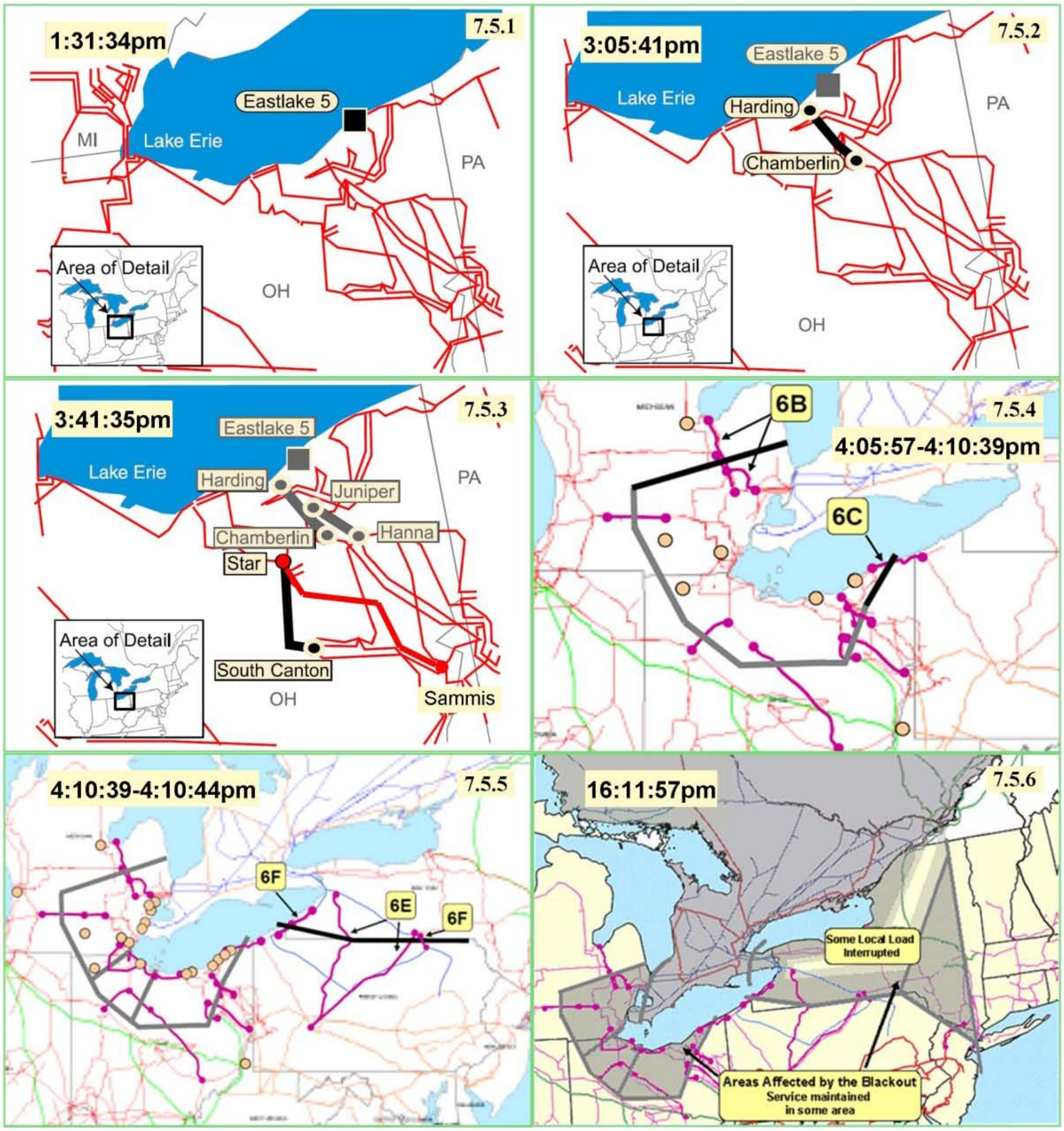
At the time, MISO was the reliability coordinator for 37 control areas including FirstEnergy (FE), and the PJM Interconnection coordinated reliability for 10 utilities and

[109] A standard power system operations tool (a computer program). It uses a mathematical model to estimate current conditions – voltage at each bus, and real and reactive power flow on each line – on an extensive area of the transmission system. U&CTF (2004). Final Report on the August 14, 2003 Blackout in the United States and Canada: Causes and Recommendations. Washington D.C., U.S.-Canada Power System Outage Task Force.

[110] "Given the state estimator's representation of current system conditions, a system operator or planner uses contingency analysis to analyze the impact of specific outages (lines, generators, or other equipment) or higher load, flow, or generation levels on the security of the system. The contingency analysis should identify problems such as line overloads or voltage violations that will occur if a new event (contingency) happens on the system." Ibid., p47.

5 control areas including American Electric Power (AEP) located in Ohio south of the FE system (Figure 7.3 and 7.4). The FE and AEP systems complied with the reliability criteria of ECAR, while PJM with those of MAAC. In addition to the breakdown of MISO's SE and RTCA, one of FE's critical coal-fired units (Eastlake 5) in this area tripped at 1:31 p.m., which resulted in sparse spinning reserves, thereafter making power supply unstable (See figure 7.5.1). Hence, the Cleveland-Akron area, where FE was located, imported power from Southern Ohio, thereby increasing power load on the four 345kv lines – Harding-Chamberlin, Hanna-Juniper, Star-South Canton, and Sammis-Star lines. The power flow on the Harding-Chamberlin line was only 44% of its normal and emergency rating (U&CTF 2004). Because of the insufficient criteria of vegetation management and poor vegetation, the trees in the rights-of-way of the line were not fully trimmed. They grew up enough to contact the line as it sagged lower under increased leading, and the line tripped due to tree contact at 3:05 p.m. (Figure 7.5.2). As a result, the remaining three southern 345kv lines had to deliver more power than before. The second line, Hanna-Juniper, also tripped due to tree contact at 3:32p.m., and thus the third line, Star-South Canton, opened because of the resulting overload at 3:41p.m. – jumping from 82% to 120% of normal and emergency rating after the Hanna-Juniper line trip (Figure 7.5.3).

Figure 7.5. Sequence of 2003 Power System Disturbances



Local Events

7.5.1 Eastlake Unit 5 (coal-fired) tripped in northern Ohio; FE imported more energy into the Cleveland-Akron area; and FE operators had fail to detect computer malfunction from 2:14 to 3:59pm. These created the vulnerability of the system.

7.5.2 Because of the heavy loads and tree contact, critical 345kv lines began to trip from 3:05 to 3:57pm. FE did not detect line trips.

7.5.3 AEP lost a major line (Star-South Canton) part of which is in their territory. After the major 345kv lines' trip, underlying 138kv systems collapsed from 3:39 to 16:08pm.

Cascading Stage

7.5.4 After Sammis-Star line loss, several local events developed into the cascading stage affecting line losses in Ohio and Michigan.

7.5.5 Power surged at Western Pennsylvania and New York resulting in separation between the two.

7.5.6 New York and New England were separated, multiple islands formed, and most islands out of service except for a few of them.

Source: U.S.-Canada Power System Outage Task Force (2004)

During this time, FE's computer system had lost its alarm function – Emergency Management System Servers[111] – since 2:14 p.m., and thus the FE operators did not recognize that there was a series of the transmission line trips which started rapidly after 3:00 p.m. Because MISO turned off the state estimator and RCTA by mistake, it could not recognize FE's evolving contingency situations, and therefore could not tell member utilities including FE about the correct situation. At 3:45 p.m. FE operators began to recognize the outages of their 345kv lines after they received several telephone calls from MISO, AEP, PJM, and FE's power plant operators. At that time, the FE's control center did not have a schematic map board which could show the locations of major lines and plants in the FE's control area.

Beginning at 3:35p.m., after the Hanna-Jupiter line trip (the second line), the nearby utility, AEP, whose reliability coordinator is PJM, discussed the heavy load of their lines – linked to FE's lines (Star-South Canton) – in their control area with PJM without knowing that another line trip had occurred in the FE and MISO's control area. As the Star-South Canton line tripped at 3:41p.m., underlying 138kv transmission systems began to collapse due to the heavy loads on them, causing an overload on the Sammis-Star line, the last 345kv line, that had been delivering electricity to the Cleveland area (Figure 7.5.3). During a phone call between AEP and PJM operators, they did not fully grasp the emergency due to poor operator training and lack of information. The following is a part of a conversation between the two operators:

AEP Operator: "What do you have on the Sammis-Star, do you know?"

[111] An energy management system is a computer control system used by electric utility dispatchers to monitor the real time performance of various elements of an electric system and to control generation and transmission. Ibid.

PJM Operator: I'm sorry? Sammis-Star, okay, I'm showing 960 on it and it's highlighted in blue. Tell me what that means on your machine.”

AEP Operator: “Blue? Normal. Well, it's going to be in blue, I mean - that's what's on it?”

PJM Operator: “960, that's what it says.”

AEP Operator: “That circuit just tripped. South Canton-Star.”

PJM Operator: “Did it?”

AEP Operator: “It tripped and re-closed…”

AEP Operator: “We need to get down there now so they can cut the top of the hour. Is there anything on it? What's the flowgate, do you know?”

PJM Operator: “Yeah, I got it in front of me. It is-it is 2935.”

AEP Operator: “Yeah…2935. I need 350 cut on that.”

PJM Operator: “Whew, man.”

AEP Operator: “Well, I don't know why. It popped up all of a sudden like that…that thing just popped up so fast.”

PJM Operator: “And… 1,196 on South Canton. Can you verify these? And 960 on – South Canton-Star 1,196, Sammis-Star 960?”

AEP Operator: “They might be right, I'm…”

PJM Operator: “They were highlighted in blue, I guess I thought maybe that was supposed to be telling me something.” (NERC 2004 p49)

In this conversation, the PJM operator did not fully understand the monitoring systems, which suggested that the operator was not adequately trained. The AEP operator did not know the 345kv line outages – Harding-Chamberlin and Hanna-Juniper lines – in the FE’s control area, and therefore could not understand why the two 345kv lines – Star-South Canton and Sammis-Star – were heavily loaded in their control area. The following conversation shows that they saw the 138kv lines tripping on their system display boards after the loss of the major 345kv line – Star-South Canton line:

> AEP Operator: "Probably."
>
> PJM Operator: "Yeah, it's behind, okay. You're able to see raw data?"
>
> AEP Operator: "Yeah; it's open. South Canton-Star is open."
>
> PJM Operator: "South Canton-Star is open. Torrey-Cloverdale?"
>
> AEP Operator: "Oh, my God, look at all these open..."
>
> AEP Operator: "We have more trouble… more things are tripping. East Lima and New Liberty tripped out. Look at that."
>
> AEP Operator: "Oh, my gosh, I'm in deep…"
>
> PJM Operator: "You and me both, brother. What are we going to do? …."
>
> AEP Operator: "Now something else just opened up. A lot of things are happening." (NERC 2004 p50)

They were watching underlying 138kv lines being opened. It seems, however, that they did not have any contingency plans. Or they did not bear in mind the plans at the time. Again, without knowing that the two 345kv lines had tripped in FE's control area, they did not know reasons why their 138kv lines were tripping out after the loss of the 345kv line – Star-South Canton line. They had a monitoring system that only showed the status of their system, not neighboring systems. After the phone call with AEP, PJM called MISO to report the Star-South Canton line and 138kv line trips at 3:55 p.m.

PJM Operator: "…AEP, it looks like they lost South Canton-Star 345 line… Since they lost that line, I was wondering if you could verify flows on the Sammis-Star line for me at this time."

MISO Operator: "Well, let's see what I've got. I know that First Energy lost their Juniper line, too." ………

PJM Operator: "Yes. And we were showing an overload for Sammis to Star for the South Canton to Star. So I was concerned, and right now I am seeing AEP systems saying Sammis to Star is at 1378."

MISO Operator: "All right. Let me see. I have got to try and find it here, if it is possible and I can go from here to Juniper Star. How about 1109?"

PJM Operator: "1,109?"

MISO Operator: "I see South Canton Star is open, but now we are getting data of 1199, and I am wondering if it just came after."

PJM Operator: "Maybe it did. It was in and out, and it had gone out and back in a couple of times."

MISO Operator: "Well, yeah, it would be no good losing things all over the place here."

PJM Operator: "All right. I just wanted to verify that with you, and I will let you tend to your stuff."

MISO Operator: "Okay."

PJM Operator: "Thank you, sir. Bye." (NERC 2004 p51)

Without knowing about FE's Harding-Chamberlin line trip, MISO informed PJM of FE's Hanna-Juniper line trip. Then the PJM and MISO operators were confused with different measures regarding the power load on Sammis-Star line which was the last line delivering power to Cleveland; 1378MW at the PJM side and 1199MW at MISO. The

PJM operator should have reported to MISO the cascade of both 345kv and 138kv line trips. However, the operator finished the phone call without telling MISO about a series of 138kv line outages. Even in the cascade of transmission line outages at the local level, they did not have situational awareness. With a concern about the impact of Star-South Canton line trip, PJM called FE to report the line trip and resultant overload on the Sammis-Star line – the last 345kv line. However, FE was not able to confirm this overload, because unlike PJM, MISO, and AEP, FE was using a different normal rating for the Sammis-Star line; the rating of FE was higher than that of others (NERC 2004). This illustrates that reliability standards are interpreted differently and the coordination between control centers is not sufficient.

Close to 4:00 p.m., the depressed Midwest and Northeast systems left human control. The loss of the Sammis-Star line was critical. After the line trip, the local events developed in a global cascading stage. Because the power flows from Southern Ohio lost paths to the Cleveland-Akron area, Northern Ohio, they had to find other routes to the area: that is, through Michigan and New York-Ontario lines. A huge surge at Michigan, New York, and Ontario brought about heavy loads on transmission lines in these regions, and their lines and power plants tripped off one by one and were separated into several parts to protect themselves. First, the transmission lines in Michigan and Ohio were open (Figure 7.5.4), and then the lines in New York and Ontario (Figure 7.5.5 and 7.5.6). Losing balance of power demand and supply, the regions were blacked out in a few minutes only except for some local areas.

In Perrow's terms, both 1996 and 2003 blackouts occurred due to a series of unexpected interactions of small failures in tightly and complexly interconnected grid systems. In the case of the 1996 blackout, there were interactions of equipment failures and human errors: major transmission lines' tripping as a result of tree contact, increasing stress on other grid systems, another line's tree contact, situational unawareness, poor communication with other system operators, fragmented control of interconnected grid systems, etc. The 2003 blackout was also a result of unexpected interactions of small failures: simultaneous malfunctions of software programs at MISO and FE, software operators' mistakes during rebooting the program, shutdown of coal-fired units, poor vegetation management, a series of tree contacts with major transmission lines, collapse of underlying transmission lines, situational unawareness, poor communication between reliability coordinators and utilities' system operators, different criteria in setting grid ratings, and poor display equipment.

As discussed in Section 3.1.2, however, there are expected failures in these unexpected interactions of small failures. Human errors amplify the outcomes of system failure. System operators are able to recover their grid systems from initial failure if they make timely decisions. In 2003 the system operators of the New England ISO detected the unusual fluctuations in voltage and power flow, immediately disconnected transmission lines linked to the New York power pool, and prevented the cascading outage from spreading over their region (Interviewee3 2008). In both 1996 and 2003 blackouts, system operators did not take appropriate action in the early stages. Their behavior was constrained by the lack of training and information, and by institutional deficiencies. Ultimately power relations between utilities and governments delayed the best formation of reliability standards. In this situation, therefore, their errors are expected.

7.4. Remedial Actions

7.4.1. Complicated Decision-Making Process in the Pacific Northwest

After the 1996 Pacific Northwest blackout, WSCC published a report on the event in October 1996, which addressed technical aspects of the outage. The technical task force conducted an in-depth analysis of the voltage collapse so as to improve system security. The Subcommittee on Water and Power Resources of the Committee on Resources of the House of Representatives held a Congressional hearing in November 1996 which dealt with human judgment and institutional conditions. They discussed the need for mandatory membership and compliance with reliability standards.

At the hearing, an administrator of BPA testified about the existing complicated, bureaucratic decision-making processes during the emergency situation because of dispersed responsibilities between generating units and transmission system operators (U.S.House 1996). Additionally, in this region where power was usually from hydro resources, environmental concern about preserving fish migration regulated by the National Marine Fisheries Service was another issue related to power output during the emergency. Most parties – BPA, WSCC, Southern California Edison, Los Angeles Department of Water and Power, Pacific Gas & Electric Company, and Arizona Corporation Commission – involved in the outage did not share information about the transmission line trips in advance, even though they had enough time to exchange the information (U.S.House 1996). This resulted in isolation of performance in each control center.

Therefore, those utilities in the Pacific Northwest region recognized the importance of a comprehensive operation mediated by a single control center such as an ISO. They also agreed with mandatory membership and reliability standards to prevent future large scale power outages. At the hearing, however, private utilities subtly took a different position regarding NERC’s role. As mentioned above, they argued that FERC should support NERC’s transition by giving more authority to NERC with respect to mandatory reliability standards and oversight power rather than having FERC directly exercise its influence on reliability.

One outcome of the 1996 blackout was the creation of regional security coordinators. Concerned by the absence of coordinators to monitor the whole power flow in each regional council, NERC with its ten regional reliability councils created the regional security coordinators. NERC expected these coordinators to monitor regional power flows, concentrating on the big picture that individual control areas cannot easily perceive (S.E.A.B. 1998). Recognizing strong reliability standards and the necessity of more integrated practices among system operators, NERC established certificate programs for different levels of system reliability coordinators in 1998 (Interviewee5 2008). The programs tested basic understandings and minimum requirements of system operation, but the certificates were not enforceable (Interviewee5 2008).

Between the 1996 and the 2003 blackouts, however, mandatory reliability standards and enforceable integrated organizations for coordinated performance of individual control centers were still on the table for discussion, but not at the stage of implementation across the country, whereas free-market principles had been applied to the whole industry. The related federal and private agencies were still seeking a balance of power between the two in establishing new reliability criteria and an agency. After the 2003 blackout, more practical action materialized.

7.4.2. Loose Coordination between the Northeast and Midwest region

The 2003 Northeast blackout brought about discussions about reasons why it happened again in the same region. The main focus was on the technical issues. Several reports were published by the related organizations. These include the U.S-Canada Power System Outage Task Force (U&CTF 2003; U&CTF 2004), NERC (NERC 2004), East Central Area Reliability Coordination Agreement (ECAR 2004), New York ISO (NYISO 2004; NYISO 2005), and ISO New England (ISONE 2004). These reports clearly elaborated the sequence of the events in technical terms, and illustrated the technical problems in their systems; addressing whether the blackout happened due to aged equipment, less investment in transmission systems, or poor maintenance. The next step would be to improve their systems with strong transmission lines and up-to-date protective equipment. However, how to operate those equipments was another issue yet to be addressed.

The blackout of 2003 showed how the localized performance of each organization worked poorly as regional complexity increased. At the Congressional hearing which was held prior to the publication of the interim report by the U.S-Canada Task Force, those parties of operating transmission systems in the New York, New England and Ontario regions uniformly testified that they noticed their systems' problem – frequency fluctuation and voltage collapse – right after 4:00 p.m. (U.S.House 2003). They would have had enough time to act correctly before the cascading stage if they had been informed by those control centers in the Midwest region. This reveals poor coordination among control centers of the reliability coordinators.

The 2003 blackout reveals that there was only loose coordination between the Midwest where FE and MISO were located and the Northeast where AEP and PJM resided. The system operators' situational unawareness at FE, MISO, and PJM demonstrates the importance of system operator training.. At the hearing, those parties – FE, MISO, and PJM – involved directly in controlling emergency situations testified that they had the best qualified operators with best equipment (U.S.House 2003). Even though FE and MISO's system operators had the NERC certificates for basic system operation, they were not trained to respond to emergencies. In fact, as shown in the above transcription, system operators lacked familiarity with their systems let alone neighboring systems, and did not know how to handle the emergency – a series of line tripping.

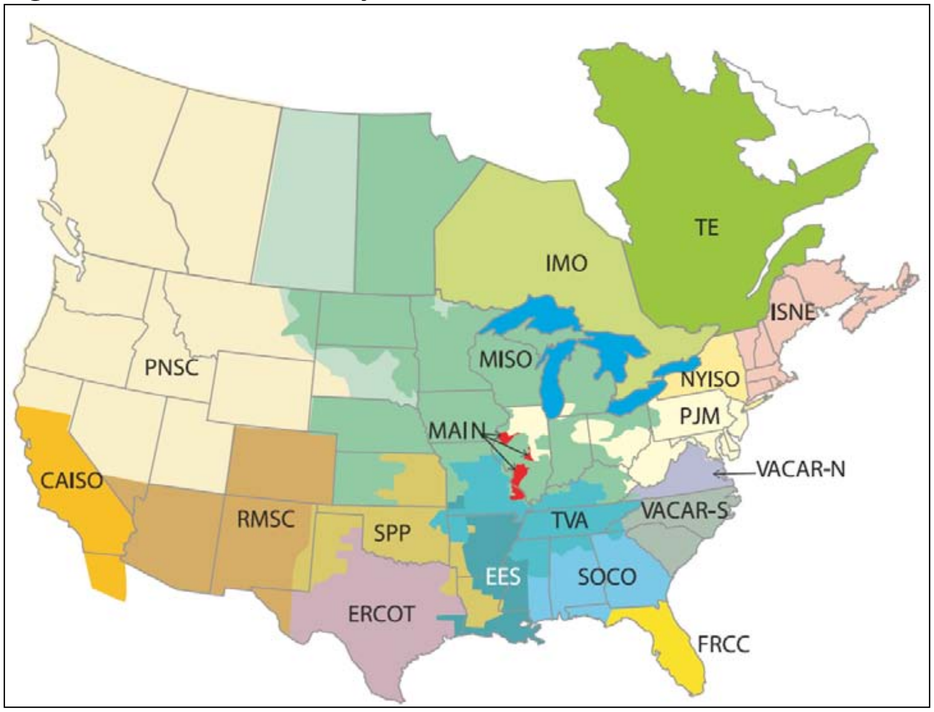
The control centers and reliability coordinators – FE, MISO, AEP, and PJM – involved in the blackout did not have facilities to get the whole picture of the system. FE system operators did not have a display board to show the system's current status. These control centers and reliability coordinators did not have a display board to explain the status of neighboring systems (NERC 2004). Because they did not have the monitoring systems to check neighboring systems, they were not aware of the emergency clearly. As in the case of FE's ratings of transmission lines, they did not share reliability criteria – normal and emergency ratings of transmission lines – that should be coordinated at the local level. It was not until the catastrophic cascade that the deficiencies leading to weak coordination between the Midwest and the Northeast were recognized.

7.4.3. Structural Complexity in the Midwest Region

Although there were reliability coordinators at MISO and PJM to monitor FE and AEP's performance respectively, they did not work as well as expected. This is related to the structural complexity of the MISO region and MISO's inadequate authority (Figure 7.6); "MISO provided reliability coordination for 35 control areas in the ECAR, Mid-America Interconnected Network (MAIN) and Mid-Continent Area Power Pool (MAPP) regions and 2 others in the Southwest Power Pool (SPP) region, and PJM provides reliability coordination for 8 control areas in the ECAR and MAIN region… MISO has less reliability-related authority over its control area members than PJM has over its members. Arguably, this lack of authority makes day-to-day reliability operations more challenging" (U&CTF 2004 p14).

Historically, many power pools in ECAR, MAIN, and MAPP were created and disappeared according to economic benefits and utility autonomy. Tight coordination was impeded because of different evolving processes of transmission network management among utilities, degrees of retaining decision making authority of individual systems, the responsibility and authority for jointly owned power units, financing arrangements, economic feasibility of power pools, and effects of State regulatory actions (FERC 1981). This structural complexity of the MISO region resulted from FERC's limited authority to require greater MISO's authority than approved by its members, and only to request that NERC assess the reliability plan proposed by MISO and PJM (U&CTF 2004). As mentioned previously, the region was a crossroad of power flows and consisted of a variety of control centers, but did not have an adequate coordinator for its competitive market before 2001. Establishing MISO brought about controversy over whether its authority and tasks overlapped with other regional reliability councils. Therefore a weak MISO was a likely outcome of the process of balancing existing interests in the region. In this context, MISO was conditionally approved by FERC in 1998, and started its work as a reliability coordinator in 2001. FE has been under the MISO coordination since February, 2003. Systems' control in MISO was dispersed among control centers before centralization.

Figure 7.6. NERC Reliability Coordinators



Source: U.S.-Canada Power System Outage Task Force (2004)

In summary, NERC and regional reliability councils have developed and elaborated, voluntary-based reliability criteria with respect to operation standards, certificate programs for system operators, up-to-date equipment standards, integrated system maintenance, and communication methods, but they still have deficiencies which were uncovered during the 1996 and 2003 blackout (Table 7.1). Moreover, the same failures happened repeatedly; namely, inadequate coordination of relays and other protective devices or systems, and failure to ensure operation within secure limits as in the case of the 1965 blackout; inadequate regional-scale visibility over the power system as in the case of Con Edison; failure to identify emergency conditions and communicate that status to neighboring systems, and inadequate vegetation management as in the case of the 1996 blackout; and inadequate operator training in all previous events (U&CTF 2004).

Table 7.1. Status of Institutional Conditions Related to the 1996 and 200 Blackouts

Evaluation Items	Institutional Status
Setting operation standards	Institutionalized standards, but with shortcomings
	NERC has general standards. Regional reliability councils have specific standards applicable to their regions.
Licensing system operators	Institutionalized training, but some shortcomings Certificate programs since 1998
	Formal training in each regional council Certificates for improving basic understandings of system operation, but not for emergency operation
Up-to-date equipment standards	No criteria
	Each control area has system operating facilities and computer programs but at different levels
Improving communication methods	Direct lines to neighboring control areas
	Need for shared goals and criteria for emergencies Need for visibility of entire systems including neighboring systems

One reason for repeating the same types of failures over and over again is that utilities do not widely share lessons learned from previous failures among organizations in the industry. In the case of Con Edison, although the company recorded its experience on video tapes and distributed these to other companies, it is not easy to share them widely with only one company’s effort. Without strong institutional support, organizations may not be actively involved in learning lessons from previous failure at the inter-organizational level. NERC posts the cases of major power system disturbances on the website, but it is unclear how many utilities among the more than 3000 utilities are really interested in these cases.

7.4.4. Creation of the Electricity Reliability Organization (ERO)

The U.S-Canada Task Force concluded that the causes were related to human decisions rather than technical problems such as insufficient reactive power; those human errors are inadequate system understanding, inadequate situational awareness, inadequate tree trimming, and inadequate reliability coordinator diagnostic support (U&CTF 2004). Thirty-four recommendations were made. The first three include:

1. Make reliability standards mandatory and enforceable, with penalties for noncompliance.
2. Develop a regulator-approved funding mechanism for NERC and the regional reliability councils, to ensure their independence from the parties they oversee.
3. Strengthen the institutional framework for reliability management in North America (U&CTF 2004 p3).

During the Congressional hearing in 2003, most participants from the electricity industry agreed with the need for mandatory reliability standards and a new entity with more authority than that of the current NERC. The above three recommendations about new institutional settings were already in a proposed bill, the *Energy Policy Act of 2005* (EPAct 2005), which was waiting for Congress’s final decision at the time of the

Congressional hearing. After the passage of the bill, EPAct 2005 gave FERC more authority to have jurisdiction over an ERO certified by FERC and to approve mandatory reliability standards proposed by the ERO (2005). Therefore, NERC, which is the only organization to deal with reliability, submitted an application to FERC for certification as the ERO. Of the 102 mandatory reliability standards filed with FERC, ninety were approved by FERC as of May 15, 2006 (U.S.Senate 2006).

NERC restructured its organization, renewed reliability standards, and embraced new tasks. It changed from a stakeholder Board of Trustees into an Independent Board of Directors, so that it tried to make itself independent of any organizational influence. To be an independent organization, therefore, it is now funded by end users (U.S.Senate 2006). NERC launched “a new standard development process that is fair, open, balanced, and inclusive” in 2003 (U.S.House 2005 p38). After experiencing problems of tree trimming, different ratings of transmission lines, and lack of operators’ training for emergencies, NERC has developed “new standards for vegetation management, determining facility ratings and operating limits, system personnel training, system frequency response, and nuclear offsite supply reliability” (U.S.House 2005 p40). NERC initiated the readiness audit program to evaluate the qualifications of all control areas and reliability coordinators (U.S.House 2005). In fact, Swidler recommended this program in the early 1980s, but the utilities did not accept it. Now the industry supports a readiness audit program.

FERC gained the authority to approve reliability standards proposed by NERC and oversee an electric reliability organization. It seems that FERC has become a winner in a historical process of regulating reliability (See table 7.2). John Moot, the FERC General counsel, said that “Although the industry made great strides since the 1960’s and the blackouts of the 1960’s in creating a voluntary regime of reliability standards, Congress was correct to recognize that, over the long run, only an enforceable mandatory regime of reliability standards would protect the public and support a vibrant economy” (U.S.Senate 2006 p2). FERC created a new Division of Reliability for the development of policies, programs and strategies with respect to reliability, and recruited engineers to have the capability of reviewing NERC’s proposed reliability standards and reliability readiness for balancing authorities, transmission operators, and reliability coordinators (U.S.Senate 2006). As many engineers have stated many times, however, FERC has no experience in dealing with reliability. Therefore, FERC also worries about the lack of precedents for people to look at regarding this task.

In fact, the new reliability section of the Energy Policy Act of 2005 contains what NERC intended it to include, although FERC’s authority over reliability is now more strengthened than before. EPAct 2005 formed another balance between private utilities and the federal government. At least the act provides some bases for the centralization-decentralization process in creating reliable organizations or control centers, but leaves open the possibility of creating another bureaucracy in setting reliability standards. This form of organization – ERO – is an inevitable outcome because FERC, which has had the regulatory power only over interstate and wholesale transaction and transmission of electric power, has not developed the capability to deal with reliability since its inception. ERO proposed 102 reliability standards on the basis of the NERC’s historically developed ones. Only NERC had the ability to propose reliability standards.

Table 7.2. Chronology of Reliability Related Legislation by Congress

Year	Proposed Bills, Amendments or Passed Acts	Legislative Body
1965	The Federal Power Act, S. 2139 and H.R. 7788 (Amendment Section 202)	Senate House of Representative
1965	The Federal Power Act, H.R. 7791 (Amendment Section 202)	House of Representative
1967	Electric Power Reliability Act in the Federal Power Act, S.1934 (Amendment)	Senate
1969	The Electric Power Coordination Act, H.R.7186. H.R. 12585, H.R. 489, and H.R. 2506 (Bill)	House of Representative
1975	The National Electric Energy Conservation Act, S.1208 and H.R. 5048 (Bill)	Senate House of Representative
1976	The Electric Utility Rate Reform and Regulatory Improvement Act, H.R. 12461 (Bill)	House of Representative
1977	The Electric Utility Act in the National Energy Act, H.R. 6660 (Bill)	House of Representative
1978	The Public Utility Regulatory Policies Act in the national Energy Act (Passed Act)	Senate House of Representative
1989	The Competitive Wholesale Electric Generation Act, S. 406 (Bill)	Senate
1991	The Electric Power Fair Access Act, H.R. 2224 (Bill)	House of Representative
1991	The National Energy Security Act, S. 341 (Bill)	Senate
1992	The National Energy Policy Act (Passed Act)	Senate House of Representative
1999	The Energy Competition and Reliability Act, H.R. 2944 (Bill)	House of Representative
2002	The Energy Policy Act, S. 1766 (Daschle/Bingaman Bill Amendment)	Senate
2002	The Energy Policy Act (Thomas Bill Amendment)	Senate
2005	The Energy Policy Act (Passed Act)	Senate House of Representative

Concerning the future of ERO's performance, one question is whether new enforceable reliability standards will really address the coordination problem among control centers. Apt et al. argue that "NERC standards were regional industry-consensus standards, their stringency has been limited by the influence of members with substandard performance and that such influence could continue in the future"(Apt, Lave et al. 2006 p56). EPAct 2005 forces all users, owners, and operators of the bulk power system to be subject to the mandatory standards, and FERC executes and approves regional delegation agreements (U.S.Senate 2006). In reaching regional delegation agreements, there will be compromise rather than cooperation. Institutionalization brings a possibility of creating an institutional myth, so that people may regard compromised reliability standards as rationalized ones. There is still a possibility of utilities' influence on setting reliability standards reflecting their local interests at the expense of genuine reliability.

The possibility remains that utilities, which operate dispatch control centers, may not consider fully improving their organizational performance in concert with other control centers. Those who are in the centralized organizations such as ERO are likely to be more mindful, because they more clearly see the big picture of their transmission systems and try to manage them as a whole. But the regional control centers at the next level of the systems may focus more closely on the transmission lines within their territory, not the entire system, with diminished mindfulness, and local control centers below them see even less of the whole picture. At this level, organizational inertia or cultural persistence may hinder needed behavioral changes if local control centers do not know what harm is caused by the inadequate behavior such as a lack of situational awareness in the big picture of the entire system. By improving situational awareness in their routines, operators could better understand how their systems relate to the bigger picture. A new program of readiness audits for control centers is one way that ERO can link the local experiences of individual control centers to the core performance of the entire system.

Both the 1996 and 2003 blackouts point to the neglect of human factors in some control centers. One control center "did not have any large-scale visualization tool such as a dynamic map board" (NERC 2004 p32). As in the case of FE, because of the distance between the control room and the computer support room, system operators had a communication problem with their computer support staff. This shows how the managers of the utility viewed their organizational structure which was created to construct technical equipment affecting operators' behavior. After the Three Mile Accident in 1979, utilities began to incorporate human factors engineering in the control-room design practices of their nuclear power plants (Seminara and Parsons 1980). Perrow argues that the study of technology and structure of industries "failed to recognize how structure can affect technology and speculate about the large areas of choice involved in presumably narrow technological decisions, choices that are taken for granted because they are part of a large unquestioned social construction of reality" (Perrow 1983 p540). Considering the bulk-power systems which are working at the speed of light, ERO and utility managers again find themselves considering how to improve technological decisions in pursuit of high reliability, and under what organizational structures.

Chapter 8. Conclusion

This dissertation has explored the social structure of large scale blackouts. After city systems were paralyzed during the 2003 blackout, we saw a picture in which thousands of helpless people walked home across the Brooklyn Bridge. The scene tells us how critical urban infrastructure networks are and that they fundamentally mediate contemporary urban life (Graham and Marvin 2001). Electricity systems are invisible in our daily routines although we are completely dependent on electricity. After the lights go out, we begin to recognize this critical infrastructure. Electrical systems are socio-technical; technological development and social processes that influenced each other and have organized current systems. We know that the current transmission networks evolved by interconnecting independent power systems by way of utilities' contracts, and in this sense they are not planned but an unintended product. There have been continual tensions between the private sector and the federal government in controlling the interconnected transmission networks. In this process, weak links or vulnerable areas have come to exist, and regulatory processes have neglected to strengthen them. The results are that repeated human errors have led to large scale blackouts. In this concluding chapter, I summarize the results of the event history analysis and the four case studies which support my argument, and discuss professionalism and self-regulatory organizations which could be a direction for improving reliability.

8.1. Institutional Imbalance, Unresponsive Organizations, and Weak Links

In the event history analysis in chapter 4, I tested 10 hypotheses to determine what the characteristics of the electricity sector's reliability institutions are and to verify the proposition that it lacks strong institutions for creating a culture of reliability. I state that the basic structural properties of this industry in the United States are structural density (or complexity), autonomy (with coordination), and on-time management (for power balance). These structural properties produce unintended outcomes in the form of vulnerable utility organizations and weak links in some transmission networks. Vulnerable utilities are generally characterized as those having large-size power systems. They are governed by regional reliability institutions which neither apply reliability standards strictly nor have sophisticated planning criteria and emergency plans. Vulnerable utilities are more likely to experience major power system disturbances if their regulatory relationships with federal and state governments are not strong. They experience high summer peaks, face more electric power losses than others, or make less investment in facilities and technologies. Such utilities have more likelihood of major system failure, because the reliability standards of their reliability institutions, in Weick's terms, are not as complex as their complex systems. There is an institutional imbalance between human management capabilities and complexity of the systems utilities manage. The physical and institutional characteristics of these vulnerable utilities are also evident in the stories of the four cascading outages.

The blackouts in 1965, 1977 and 2003 happened in the Northeast region where the transmission systems are densely interconnected and summer peaks are sharp. In particular, ECAR has too many control areas, which makes coordination more difficult. The 1996 blackout happened in the Pacific Western region where a large amount of electricity is transferred from the Northwest – British Columbia in Canada, Washington and Oregon – to California during the summer peaks, thereby causing heavy loads on the transmission lines. These results imply that centralized, densely interconnected and complex power systems, which are located in the regions of high electric demand, need sophisticated procedures and more integrated system management which are compatible with the system complexity.

The boundary of each utility's system control is limited to its territory. Electric utilities historically constructed a unique structure based on service territories – natural monopoly and the vertical integration of generation, transmission and distribution – to rationalize their system operation. Power systems are connected to one another through transmission lines, but each of the segments of the interconnected systems is operated by a variety of individual utilities. System operators may have very good knowledge about their own systems, but do not know much about the state of neighboring systems. Each operator runs their system inevitably in loose coordination with neighboring systems, because one utility's contract with a neighboring utility may not fully consider the effect on another neighboring utility. Since system operators lack a big picture of the whole system, their system control becomes fragmented. Business decisions and government regulations are neither compatible with the technical characteristics nor supportive of inter-organizational management.

Much as Perrow argues, the four large scale blackouts show that there are unintended interactions of small component failures and human errors before cascading outages. Most human errors, however, are also related to institutional deficiencies. The utilities and control centers directly involved in the four large scale blackouts have revealed fragmented organizational performance rather than integrated system management in their interconnected transmission networks.

As of the 1965 blackout, the mindset of the electricity industry did not pay much attention to reliability compared to the competing value of efficiency. Utilities' control centers did not have the capability to exchange information in time to take emergency actions (FPC 1967a). The system operators at Ontario Hydro, Canada, did not detect the insufficient ratings of their protective relays. During the cascade, the system operators in the Northeast perceived the instability of their systems, but did not respond to it immediately due to the lack of precise contingency criteria. In the case of the 1977 blackout, both NYPP and Con Edison system operators did not communicate properly because of their different understandings of the situation. The system operators at Con Edison lacked situational awareness, and did not have a correct manual for load shedding. In 1996, system operators at BPA did not inform neighboring control centers of the outage of major lines, nor did they act immediately to reduce loadings on their system. The 2003 blackout, as the U.S.-Canada Task Force points out, reveals inadequate system understanding, inadequate situational awareness, inadequate system maintenance, and inadequate reliability coordinators' judgment. In a broad sense, the four cases demonstrate the failure of coordination among control centers in addition to the small failures in the individual control centers. System operators could not see the whole picture. There were no relevant criteria to prevent the small failures from developing into a cascading outage.

The fragmented organizational performance disclosed through the large scale blackouts indicates a structural problem with the interconnected power systems. Weak and imbalanced institutional structures make utilities pay little attention to the reliability of electricity service within their inter-organizational relationships. That is to say, the industry has failed to create *"a culture of reliability" among organizations by means of a strong institution: centralizing basic premises and practices corresponding to the interconnected grid systems and decentralizing system operators' decisions at the local level.* As the air traffic system has provided, the electricity industry should provide at least the following reliability guidelines at the institutional level: 1) setting sophisticated operation [and planning] standards, 2) licensing system operators, 3) providing up-to-date equipment standards, and 4) improving communication methods.

First, system operation standards were not institutionalized before the 1965 blackout. NAPSIC had some broad guidelines which were not enforceable. After the blackout, regional power pools to deal with reliability were organized, and NAPSIC and regional reliability councils provided utilities with system operation criteria. However, they were not strong enough to force utilities to conform to the criteria. Although NERC was in the position of integrating system operation criteria, it was rarely visible in the 1970s. It was not until the 1980s that the NERC developed and elaborated operation standards. In that decade, the NERC expanded its role more than before, but did not have strong authority to impose more strict standards. From the testimony before Congress in the 1970s and 80s, it is clear that the regional reliability councils had more power to guide system operation. The investigation of the 2003 blackout makes clear that system operation criteria still have deficiencies – i.e., no standard of normal and emergency ratings of transmission lines, no "clear definition of *normal*, *alert*, and *emergency* operational system conditions", and no vegetation management criteria (U&CTF 2004 p3). The results of the event history analysis verify that because some regional reliability councils do not provide sophisticated reliability standards, their member utilities have a higher probability of experiencing major system failure. NERC has revised and updated their reliability standards since the 2003 blackout. It re-examined the procedure of standards development – the *NERC Reliability Standards Process Manual* – through which it updates and develops reliability standards in existing and new areas (U&CTF 2006). It may be important for NERC to have the ability to grasp invisible institutional deficiencies from a small failure that would be critical for entire system management.

Second, in the 1960s and 1970s system operators, unlike the electrical engineers, did not have systematic training. Individual utilities developed their own training programs for their system operators. After the 1965 blackout, regional power pools initiated training programs for senior level operators. NERC began different levels of certificate programs for system operators in 1998. The 2003 blackout also showed that training programs for contingencies did not exist at the time. Unlike the air traffic controllers and airline pilots, training programs for system operators are not centrally organized, and therefore they are generally isolated in their practice. Overall the quality of system operators may vary from utility to utility, and is not standardized. After the 2003 blackout, the U.S.-Canada Task Force made recommendations for improving training and certification requirements including system operators at control areas (U&CTF 2006).

NERC now implements the recommendations. An important issue is the NERC's ability to screen the performance of system operators who are controlling power systems located in the periphery of the entire interconnected system.

Third, equipment modernization is dependent on the utilities' decisions. The four cases suggest that equipment modernization is a constant issue. First, if a more advanced technology is introduced in the industry, some utilities may actively adopt it and others may not. For instance, PJM and Con Edison were early adopters of computerized control devices. But other utilities put them into service later. As a result, some control centers, although they are located in critical areas, do not have necessary equipment for monitoring their systems. Second, because there is no equipment standard for monitoring neighboring systems, system operators often do not have adequate situational awareness. Third, as the event history analysis in chapter 4 shows, investment in facilities improves reliability. Considering these facts, there should be minimum standards for reliability facilities, even though installing new facilities and monitoring devices depends on each utility's financial situation. The U.S.-Canada Task Force recommended that control areas should "establish minimum functional requirements for control area operators and reliability coordinators" and be equipped with adequate EMS and SCADA systems (U&CTF 2004 p159; U&CTF 2006 p33). Through the reliability readiness audits, NERC evaluates whether control areas comply with those minimum functional requirements (U&CTF 2006). In particular, NERC may evaluate whether some vulnerable and critical control areas – especially in densely populated areas – have additional reliability requirements.

In addition to up-to-date equipment standards, utilities should maintain their systems in good condition. Utilities have developed their own maintenance methods, such as regularly monitoring transmission lines and tree trimming. Later these methods became generalized among utilities rather than standardized by reliability institutions. The blackouts of 1965, 1977, 1996 and 2003 were due to malfunctions of relay systems or other equipment due to poor system maintenance. Unfortunately when utility managers need to cut costs, they often cut the system maintenance budget. As a result, it has not been possible to achieve minimal guidelines for integrated system maintenance everywhere. Among reasons for the 1977 New York blackout were the unmanned quick-start generators and inadequate maintenance of protective equipment due to budget cuts for personnel and system maintenance at the time. The initial failure of the 1996 and 2003 blackouts started from tree contact as a result of the poor management of tree trimming in the rights-of-way. After the 2003 blackout, NERC created standards for vegetation management (U&CTF 2006). Because the malfunction of power system equipment is a chronic issue, regional reliability councils and NERC should always be aware of how they can provide the lower-bound requirements for system maintenance.

Fourth, improving communication methods includes not only communication devices but also shared premises, assumptions, and contingency procedures. The four blackouts suggest that system operators did not share similar premises and assumptions when they faced contingencies. Nor did they have appropriate procedures and criteria to inform neighboring control centers of emergency. The U.S-Canada Task Force recommended tightened communication protocols and the technical improvement (U&CTF 2006). In addition to the protocols, however, the important thing is that system operators must share premises and assumptions before they make local decisions. Engineers from each utility in a region may share basic understandings of the electric system design from the planning stage. All system operators in the region, as the engineers do, should also share the similar goals and understandings of the bulk power system operation, so that they can respond to contingencies properly at the control center level.

Concerning the two questions of how utilities created reliability institutions and how utilities interacted with the institutions, I have examined the process of establishing the NERC and regional reliability councils. I have also explored utilities' responses to efforts by the federal government to enact reliability laws. I have explained the process of creating the reliability institutions and the utilities' reaction in terms of institutional perspectives and power relations. After the 1965 blackout, the industry established reliability institutions of power pools, regional reliability councils, and the NERC. However, these institutions have sometimes seemed more like rationalized myths, even as the physical features of power systems became more complicated. Utilities were reluctant to centralize system planning and operations for reliability. In addition, the sociotechnical systems of electricity, since established, have become "a conservative force[112] reacting against abrupt change in the line of development" (Hughes 1983 p465). Because of the complex structure and conservative force of the electricity industry, utilities could not easily change their production process by giving up some portion of

[112] Regarding conservative force, Hughes indicates such ideas as load factor, economic mix, and pricing based on cost, heavy capital investment, supportive legislation, and the commitment of know-how and experience on the basis of which utilities have their current organizations: generation, transmission, and distribution[39] T. S. Hughes, *Networks of Power: Electrification in Western society, 1880-1930*. Baltimore, Maryland: The Johns Hopkins University Press, 1983.

their sovereignty or autonomy – that is, system planning and operation. Although there were several attempts to centralize system management at the federal level, utilities did not like the idea of centralization and yielding part of system management. In this way they are unlike the air transportation industry which requested Congress to enact a law of controlling air traffic systems. As a result, there are many barriers to establishment of a regional power pool, which shows the utilities' unresponsiveness, even to large scale blackouts. Loosely coordinated inter-organizational relationships inevitably create weak points in the transmission networks. Because of the lack of an intensive relationship with regulatory agencies, some utilities and their control centers did not have enabling structures – in other words, supportive organizational contexts – in performing their tasks for reliability during emergencies.

Under the current structure of loose coordination among control areas, therefore, deregulation of the wholesale market may exacerbate the weak links or control areas with respect to reliability. As power trading increases, many utilities' control centers experience difficulties such as complicated transactions, insufficient transmission capacity, and network congestion. These situations will lead to power system disturbances. Some experts argue that deregulation is a cause of the 2003 blackout. As shown in the event history analysis in Chapter 4, however, deregulation is not statistically related to major power system disturbances. We ought to be careful about whether to generalize the impact of deregulation on major power system disturbances. This result implies that a more fundamental issue is the loosely coupled inter-organizational relationships between utilities and reliability institutions, and among utilities.

This dissertation shows that creating a culture of reliability in inter-organizational relationships is a difficult task because of the different interests and goals of individual organizations. Considering the fact that large scale blackouts are, in part, consequences of the fragmented performance of the related organizations and their control centers, it is necessary, as the high reliability organizations theory argues, to centralize core premises and assumptions before decentralizing local practices. However, *power relations obstruct the development of strong institutions for creating the culture of reliability that is necessary in inter-organizational relationships, resulting in an imbalance between efficiency and reliability objectives*. Powerful groups – usually private utilities – whose interests are different from those of legislators and regulators pay more attention to their organizational values and goals rather than supporting a centralization of norms to strengthen inter-organizational relationships. Their interests determine the degree of centralization. The groups have continually insisted that reliability legislation at the federal level was not necessary because NERC and regional reliability councils were doing their jobs well. They considered that the federal agencies did not have any technical capability to manage reliability. To prevent small initial failures from becoming large scale blackouts, however, utilities should consider establishing basic and stringent guidelines to abide by the decisions made by coordinating institutions of power pools, regional reliability councils, NERC, and the FERC. These institutions, especially FERC, should have the independent ability to guide reliability with the support of utilities, so that the electricity industry can maintain a mechanism of checks and balances regarding reliability.

In conclusion, the electricity industry has created and developed, to an extent, a symbolic institution – or a set of rationalized myths – directed at the control of the large interconnected transmission system in order to respond to low-probability, high-consequence events. Therefore, a chronic issue is what the appropriate institutional settings are in order for the industry to create more realistic and highly reliable organizations for operating their interconnected systems. In resolving this issue, I consider two aspects. One is that we need to think of professional roles of system operators and engineers in managing reliability. Another is that if ERO is the preferred institutional alternative, the question is its capability to create a culture of reliability in the coordination of individual control centers with strengthened authority.

8.2. Electrical Engineers, System Operators, and Professionalism

The profession of electrical engineering includes the design of power systems and transmission interconnections as a major practice area. Electricity systems are not possible without them. Electrical engineering was established as a professional field in the late 19th Century.[113] Many inventors and organizers have developed and designed modern power systems and made electrical engineering a professional field. Among other founders of what became this field, Edison thought up the idea of power systems, Tesla

[113] Electrical engineering became a four-year independent course, being separated from physics at the Massachusetts Institute of Technology in 1882 and Cornell University in 1883. For more information, see Chapter 6. Hughes, T. P. (1983). *Networks of Power: Electrification in Western society, 1880-1930*. Baltimore, Maryland, The Johns Hopkins University Press.

designed three phase alternating-current generators to transmit electricity a long distance from power producers to end users, Insull developed interconnected bulk power systems and introduced corporate management ideas into the electricity industry, and Cohn formulated economic dispatch of electric power to end-users.

Electrical engineers have developed distinctive formal knowledge of a “science” and technical competencies recognized by the public and the electricity market, and they participate in corporate management (Roos 2000). They are educated systematically in universities in which engineering departments design courses to meet industrial needs. Their empirical as well as formal knowledge also composes their power as experts (Whalley 1991). Because they are one of the qualified elite groups in society, it is not necessary to certify them by way of federal agencies. Professional engineering licensure is performed by the states. Engineers carry out their tasks satisfying industrial needs. As interviewees have indicated, however, the quality of system operators preparation is relatively neglected in the industry (Interviewee1 2008; Interviewee2 2009). They operate the power systems designed by engineers. Conventionally they are trained in terms of apprenticeship with experienced workers. Later they are more systematically trained, which is accomplished not by standardized certain criteria, but by the need of individual utilities. As shown in the 1977 blackout, sometimes system operators could not perform their tasks very well, because of the poor communication with engineers who designed the control systems. The 2003 blackout also showed system operators’ inadequate understanding of systems and situations. As air traffic controllers and commercial airline pilots do, power system operators conduct complex tasks with computerized facilities. Therefore, there should be a strong perception of system operators as professionals, and more systematic education programs to meet current needs of the electricity industry.

Unlike physicians, lawyers, and the clergy who are usually self-employed with exclusive jurisdictions over their practice, electrical engineers are hired as utility employees and help senior managers make profits, and work with professionals in other fields' engineers, such as mechanical engineers, civil engineers, or physicists (Perrucci 1971; Whalley 1991). They consider their jobs to be managerial, supervising workers in their organizations, and are under the pressure to deliver cost-effective system designs, serving dominant corporate interests (Perrucci 1971; Whalley 1991). Because they are more focused on the corporate level of management, therefore, they may fail to see the management needs of interconnected power systems. In the process of influencing legislation on reliability at the federal level, they have usually defended their management behavior, preferring to leave reliability in the realm of their autonomy. Unlike the air traffic industry which used legislative power of the federal government to improve safety of its systems, electrical engineers did not use them. In this sense, they have failed to perceive reliability from the legal and economic perspective: that is, they must persuade the public with respect to why reliability is economically important and how it is regulated. Their professionalism, therefore, should be combined with legal and economic professionals in an interdisciplinary approach.

Concerning the interdisciplinary professionalism of electrical engineering, for example, George Loehr's opinion on the transformation of physical structure to improve reliability should be interpreted in economic and legal terms. He suggests that the interconnection between regional power pools should be DC lines to prevent cascading outages, because DC ties insulate one power system from others (Loehr 2003). This is a possible alternative to cascading outages. However, the question is how engineers can persuade the public regarding how the laws of physics link to economic and legal perspectives, especially the costs of constructing DC ties and the legal or social legitimacy of them.[114] Electrical engineers need a combined approach to this solution, and have to communicate with the public in economic and legal terms. The NERC and regional reliability councils could also actively include these kinds of analysis when they assess power system reliability. Fundamentally they may need to include new curricula related to power system economics and utility regulations even in an engineering department at the higher education level.

8.3. ERO and Self-Regulatory Organizations

The electricity industry has created and developed a reliability institution that sometimes has a tendency to reflect major utilities' interests rather than the need of the physical transmission networks. NERC as a reliability institution identifies itself as a self-regulatory organization whose aim is to regulate private utilities' performance without government regulators. The underpinnings of this kind of organization are the American traditions of protecting individual freedom from other external pressures and promoting "socially responsible self-governance of functional groups" through "political

[114] Concerning reliability and economics, Stoft internalizes reliability in his power system economics. See Part 2, Stoft, S. (2002). *Power System Economics: Designing Markets for Electricity*. New York, Wiley-Interscience.

reconstruction of community" (Streeck 1992 p513 & p517). In his book *Organizing America*, Charles Perrow describes a social atmosphere with respect to corporate capitalism in the U.S.

> Our particular history allowed less regulation of the pursuit of wealth and power, and the pursuit occurred over a socially and culturally unencumbered landscape…The [U.S.] citizen feared a large government but took few steps to limit the size and power of private organizations. In the United States, large private organizations were allowed to grow, in spite of considerable resistance, and this growth generated inequality. (Perrow 2002 p16)

In dealing with crises and challenges many industries confront, therefore, private organizations with the above perception have sought "a middle way between government regulation and laissez-faire prescriptions" (Rees 1997 p481). Because private utilities do not want federal or state government involvement in their entrepreneurial activities, they regard reliability regulations as government intervention. Therefore, self-regulation of reliability in the electricity market becomes a basic idea to be protected by market participants. In this atmosphere, NERC and the regional reliability councils have developed with the support of electrical utilities.

Consequently, the establishment of self-regulatory organizations was an industry's response to a crisis or external challenge. Self-regulation became an important goal that trade associations in many industries place among other organizational goals to promote their interests. Some examples of self-regulatory organizations are Chemical Manufacturers Association (CMA) in the chemical industry, Institute of Nuclear Power Operators (INPO) in the nuclear power industry, the National Association of Security Dealers (NASD) and later the Financial Industry Regulatory Authority (FINRA) in the financial industry, etc.

The CMA is a self-regulatory organization that protects chemical manufacturers' interests by improving member companies' organizational performance with respect to environmental issues. CMA was created in 1978 by reorganizing the old form of the trade association, *Manufacturing Chemists Association (MCA)*, because the chemical industry had to change its deteriorating image imposed by the criticism of environmental groups in the 1970s (Rees 1997). After the reorganization, the CMA became a much stronger industry advocate by inducing cooperation and coordination within the industry, so as to improve public perceptions of the chemical industry while pursuing member companies' economic interests (Rees 1997). After the Bhopal disaster in 1984, the chemical industry confronted another legitimacy crisis and needed to regulate their hazardous wastes by itself. Therefore, in 1989 the CMA expanded its mission by initiating the Responsible Care program to promote member companies' environmental, health, and safety performance. The program implementation is based on the member companies' voluntary participation and peer pressure, much as electrical utilities did for implementing the NERC reliability standards.

There are two different views on the achievement of the Responsible Care program. One is that it is too soon to evaluate the program, because institutionalization is a slow process and because Responsible Care is in the earliest stage of the development (Rees 1997). Another view point considers the threat of opportunism; a chemical firm may adopt the Responsible Care program on paper, but fail to truly change its behavior without any sanctioning mechanisms (King and Lenox 2000). According to an empirical analysis, there are "a disproportionate number of poor performers" in CMA member companies due to the lack of explicit sanctions (King and Lenox 2000 p713). Most firms may primarily think about the cost of hazardous waste disposal when they implement the program (Press and Mazmanian 2003). Additionally, there might be no urgency in member companies concerning, in Harding's terms, the tragedy of the commons: the negative impact of their activities on water, air and ecosystems (King and Lenox 2000). As a result, CMA member companies do not effectively implement the Responsible Care program under the principles of voluntary participation and peer pressure.

In contrast to the CMA, however, the Institute of Nuclear Power Operations as a self-regulatory organization has demonstrated significantly improved performance of nuclear power plants, thereby reducing the risk of nuclear plant accidents, since its establishment. The Three Mile Island accident forced the nuclear industry to establish the INPO. There was an urgent mindset in those who operate nuclear power plants, because they understood that another catastrophic accident like Chernobyl would mean the collapse of the entire industry (Rees 1994). They also feared excessive governmental intervention in the operation of their nuclear power plants (Rees 1994). As private utilities established NERC in 1968 to prevent the intrusion of government, nuclear utility officials created the INPO in 1979 to regulate their nuclear power plants by themselves, and thus "to promote the highest levels of safety and reliability – to promote excellence – in the operation of nuclear electric generating plants" (INPO 2009a). INPO reduces any recalcitrant sense among nuclear power operators, because its staff come from the same industry and share the same experience. It is a professional self-regulatory organization, but, as Rees puts it, "a very secretive regulatory bureaucracy" without describing its work in-detail publicly (Rees 1994; INPO 2009b). Nevertheless, it states that the main tasks of INPO are plant evaluations including system maintenance, training & accreditation, events analysis & information exchange, and assistance (INPO 2009a).[115] The INPO also has a peer pressure mechanism to improve poor performance of a nuclear power plant, but ultimately works with a federal agency of the Nuclear Regulatory Commission (NRC) (Rees 1994; Rees 1997). As INPO's achievement demonstrates, organizational change or performance improvement is not possible without a strong institutional arrangement. Therefore, self-regulatory organizations may take advantage of an industry's professionalism, but at the same time need to work together with related government agencies so as to practically improve organizational and inter-organizational performance.

After the 1965 blackout, NERC was created to orchestrate the performance of a number of control centers on the basis of utilities' voluntary participation in reliability standards. NERC was an outcome of the power balance between private utilities and the federal government. It did not have strong authority over electricity utilities to the extent that it was not able to create a culture of reliability in the coordination of fragmented control centers. As a result, the tightly interconnected systems with inadequately performing weakly linked control areas have brought about cascading outages in 1965, 1977, 1996 and 2003. As in the case of the 2003 blackout, a cascading outage occurred, partly because the industry substantially transformed its market design without strengthening reliability standards. This caused an institutional imbalance.

The ERO is the outcome of another power balance between private utilities and the federal government. In seeking independent governance of reliability in the industry, NERC proposed the creation of a self-regulating organization in 1997, and was finally

[115] These are the same items that I use to evaluate the institutional arrangement of inter-organizational reliability in the electricity industry.

transformed into the ERO in July, 2006 with stronger authority over the reliability performance of individual control centers. In fact, the NERC has carried out the role of a self-regulatory organization since its inception, at the time with weak institutional authority over loosely coordinated utilities. Now NERC has more power than before – the authority to make mandatory and enforceable reliability rules. In addition, the periodic site-visit assessment of performance is a key to the success of such an organization, along with the sharing of equipment failure, operational error and event data – centralizing basic premises and assumptions in the inter-organizational relationship, and decentralizing decision-making processes. When NERC's historical assets are considered, NERC as a self-regulatory organization has more advantages than the CMA and the INPO. It was established earlier than they were, and thus has developed reliability standards on the basis of its experience for a long time. In fact, most reliability standards proposed by ERO are based on criteria historically developed by NERC and Regional Councils. From its experience, NERC already knows that voluntary participation in reliability standards did not work well for all NERC members. Therefore, how effectively NERC takes advantage of the power of federal agencies and its strengthened authority with its historical accumulated know-how will be of importance in preventing future large scale blackouts.

In summary, to prevent large scale blackouts, there should be institutionally and organizationally supporting mechanisms. NERC has already developed stronger reliability standards and tools for enhancing reliability, such as mandatory operation, design, connections & maintenance standards, the NERC Reliability Standards

Development Procedure, the Compliance Monitoring and Enforcement Program, continuous integration of the Compliance Reporting, Analysis & Tracking Software program, expanding Certification programs (NERC 2010). NERC also improves methods for real-time communication and data collection to ensure timely awareness of emergencies. It seems that NERC is moving in the right direction for preventing cascading outages. Nevertheless, NERC should consider what this dissertation recommends in terms of four reliability guidelines in Section 8.1. First, minimum reliability standards are necessary for the control centers or power systems which seem weak links in bulk power systems. In its annual report, NERC states that "the bulk power system is only as strong as its weakest link" (NERC 2009, p1). As mentioned earlier in the Chapter, power system disturbances or large scale blackouts occur in the places where the less sophisticated standards are applied – usually in Mid and Western areas. These are weak links in the bulk power systems. NERC should have an authority to provide them with minimum acceptable reliability guidelines. Although an area has sophisticated standards, such as the New York region, it also experiences more system disturbances than others. Concerning high demand areas, NERC needs to consider more factors that are sometimes invisible. NERC, therefore, develops a structure, internally and externally, being capable of dealing with invisible institutional deficiencies from small failures that would be critical for entire system management. As mentioned earlier, NERC can also consider DC transmission lines between the weak links and other bulk power systems.

Second, to address the invisible institutional deficiencies, NERC should consider various training programs and encourage utilities to become learning organizations. NERC has developed certification programs to test system operators' knowledge and skill since 1998, and recently started audits by visiting each control center. Through the certification and audits, NERC needs to screen the performance of system operators who are controlling power systems, especially those located in the periphery of the entire interconnected system. NERC should consider a program of exchanging system operators among control centers, so that they can have a comprehensive and mutual understanding of neighboring power systems and different scales of system control. In addition to training system operators, NERC should develop a manual on how to make utilities learning organizations. One of NERC's visions for 2010 is to have a role as "a learning and teaching organization" (NERC 2010). NERC is an organization to support learning organizations rather than a learning organization itself. As in the case of Con Edison's Learning Center, NERC should recommend utilities to open a learning center, so that system operators can share lessons learned from human errors, system failures and successful stories. NERC should open regional learning centers for those from small scale utilities.

Third, as discussed in Section 8.1, NERC is to provide least guidelines for equipment modernization and maintenance. Although investment in reliability facilities depends on utilities' financial situation, NERC should have authority to evaluate whether some vulnerable and critical control areas – especially metropolitan areas – need additional requirements for reliability. NERC may also consider developing financial tools in supporting those requirements, if some small scale utilities cannot afford them.

Fourth, communication in this dissertation refers to shared goals and understandings of the bulk power system operation, so that system operators can respond to contingencies properly at the control area level. These can be achieved through training system operators and opening learning centers. During the training, NERC should perform various contingency scenarios, so that it can review how system operators reach similar and appropriate decisions under what conditions.

Additionally, NERC could consider a precautionary approach in responding to changing physical and institutional environments, so that it does not repeat the same mistake as the electricity market liberalization did without prescription of reliability. NERC can confront a situation to respond to a certain changing environments which affect the reliability of bulk power systems. If NERC wants to be a self-regulatory organization, it may have the authority and leadership to temporarily regulate bulk power systems to secure stability in the face of any changing environment. According to the Energy Policy Act of 2005, transmission organizations – RTOs, ISOs, and other transmission organizations – shall continue to comply with [any] function, rule, order, tariff, rate schedule or agreement accepted, approved, or ordered by the Commission until a conflict is resolved. NERC as a coordinator among stakeholders must show leadership to resolve conflict.

There are several future research questions suggested by this research. First, at the organizational level, it identifies the importance of loosely coordinated system operators' behavior with respect to inter-organizational relationships. However, it would be valuable to perform more detailed analysis on internal structures of utilities that support reliability performance: that is, their decision-making structures for emergencies, communication methods within and between control centers, system operators' training and work experience, and investments in reliability. Second, at the institutional level, it would be interesting to perform a study on self-regulatory organizations in various industries, discussing pros and cons in order to magnify its merits. NERC benchmarks its business model from FINRA (formerly NASD). The research on various self-regulatory organizations will help the NERC clarify its future progress toward becoming a self-regulatory organization. More specifically, it would be helpful to research the leadership of self-regulatory organizations in their industry. In fact, some reliability coordinators do not think that the NERC has all of the necessary information in dealing with reliability (Bruijne 2006). Because of the their ambiguous location between the private sector and the federal government, self-regulatory organizations may fail to perform their role as a coordinator among utilities, and between the federal government and private utilities. Thus, a study on the way of successfully establishing leadership is necessary – that is, reducing risks while improving reliability and safety in an industry. Third, it is necessary to research reliability costs. From the above event history analysis, investment in facilities increases reliability. Thus, a basic assessment of reliability costs and inclusion of them in the market price will help improve electricity reliability.

In organization theory, institutional theorists typically consider institutional analysis a cultural approach. As a result, they overlook power relations that drive the direction of institutionalization. In analyzing institutions, it is important to examine the role of powerful groups and organizations, because their interests could decide the characteristics of institutions which sometimes do not reflect the real demands on an industry. In addition to the analysis of the effects of power relations on the process of institutionalization, there are opportunities to develop better theories regarding the safety, security and reliability of networked industries in our network society.

Appendix 1. Other Explanations on Large Scale Blackouts

Appendix 1 briefly reviews a set of explanations about large scale blackouts other than the disaster theories and new-institutional approaches which are frameworks for the analysis in this dissertation. As mentioned earlier, these are grouped into techno-economic approaches and complexity and network theory approaches. Since they are leading explanations in the engineering literature, I introduce them here. However, they do not have a framework to look at the social and human factors that organize interconnected power systems and management, and to observe power relations that decide the level at which the sector institutionalizes reliability.

1.1. Techno-Economic Approach

1.1.1. Centralized Power Systems: Expanding Systems

Many experts try to explain blackouts in terms of an interaction of technological events with the market structure. Most reports on large scale blackouts largely deal with technical problems,[116] and discussions following large scale blackouts focus on what

[116] *Report to the President by the Federal Commission on the Power Failure in the Northeast United States and the Province of Ontario on November 9-10, 1965* (Federal Power Commission 1965); *Prevention of Power Failure volume I, II, and III* (Federal Power Commission 1967); *The Con Edison Power Failure of July 13 and 14, 1977* (U.S. Department of Energy (DOE) and Federal Energy Regulatory Commission (FERC) 1977); *Western System Coordinating Council Disturbance Report For the Power System Outage that Occurred on the Western Interconnection* (WECC 1996); *Interim Report: Causes of the August 14th Blackout in the United States and Canada* (U&C TF 2003); *Final Report on the August 14, 2003 Blackout in the United States and Canada: Causes and Recommendation* (U&C TF 2004); *Technical Analysis of the August 14, 2003, Blackout: What Happened, Why, and What Did We Learn?* (the NERC Steering Group 2004); *ECAR Investigation of August 14, 2003 Blackout* (ECAR Major System Disturbance Analysis Task

goes wrong technologically or how the system failure is related to the market structure. In particular, among many technological issues , experts have talked primarily about design issues related to insufficient transmission lines to absorb shocks in the system (Joskow 2003; Seppa 2003; Casazza, Delea et al. 2005). Therefore, one of the solutions is to strengthen the transmission network by expanding, modernizing, and centralizing it.[117]

After the 1965 blackout, the majority of experts were in favor of strengthening transmission lines (Friedlander 1966). Since World War II, high-voltage transmission lines had been linked each other so as to integrate local power plants into bulk power systems. In particular, the Mid and Northeast power pools – Maine (Northeast interconnection), the Michigan pool, Ontario, and PJM – were interconnected by 1962 (Brand 1966; Priest 1967). At the time, experts thought that the capacity of the transmission lines was not enough to prevent cascading outages because integration was underway and the transmission systems were not yet fully integrated (Friedlander 1966). They argued that even small systems should be fully integrated into the bulk power system to minimize the cost of generation (Cook 1967). Thus, they believed that to construct transmission infrastructure as planned would improve reliability.[118] As a result of the interconnection of transmission lines, some concepts were developed; the organization of the market – power pools – became a boundary within which to manage

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Force 2004); Blackout 2003 – *Performance of the New England and Maritimes Power Systems During the August 14, 2003 Blackout* (Independent System Operator New England (ISO NE) 2004); and *Interim Report on the August 14, 2003 Blackout* (New York ISO 2004).

[117] Strengthening transmission systems usually refers to upgrading existing grid systems or constructing new lines. This also includes other control equipment, such as protective relays, circuit breakers, capacitors, etc.

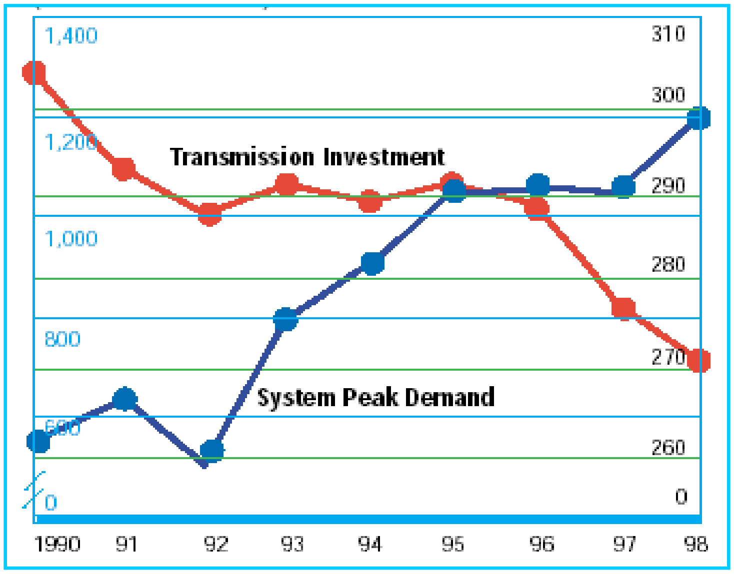
[118] A spokesman of AEP believed that "the industry can design power supply systems to prevent widespread blackout, if the various major system components, comprising generating plants, transmission lines, and interconnections with neighboring systems, are planned as an integrated whole, with proper consideration given to their interrelated effects." Friedlander, G. D. (1968). Prevention of Power Failure - The FPC Report of 1967. *IEEE Spectrum*. **February:** 53-61.

integrated transmission systems; and coordination among utilities or power pools was also a basic principle for improving reliability, which led to the establishment of NERC.

Regarding the 1977 blackout in New York City, many engineers also believed that the existing interconnections were insufficient to maintain the systems in the city (Metz 1977). In its interim report, FPC states that the Con Edison’s interconnections with the neighboring utilities, Public Service Electric & Gas Co and Long Island Lighting Co, were not strong enough to respond to the emergency (EW 1977; EW 1977). Boffey (1978), although he moved the focus toward the human errors, also pointed to the basic problems of physical constraints due to the weak interconnection between utilities which only had transmission lines from the north to Manhattan, and lacked connections to east and west.

Before and after the 2003 blackout, experts warned that transmission lines should be modernized because existing transmission lines, many of which were constructed more than 50 years ago, are too old to sustain high reliability (Chang 2003; Firestone and Revkin 2003; Gellings and Yeager 2004). They point out the fact that the investment in transmission lines has declined since the introduction of deregulation (figure A1.1), because it does not guarantee profits for transmission system owners (Firestone and Revkin 2003). Joskow (2003), who advocates deregulation, draws attention to the mismatch among organization, management, regulation, and physical infrastructure because of the poorly designed market. He argues that the federal government should be given primary regulatory jurisdiction over transmission lines to promote investment in them. Therefore, they support the expansion of transmission lines whose capacity is currently short due to low investment.

Figure A1.1. U.S. Net New Transmission Investment vs. System Peak Demand Growth
(Millions of 1990 Dollars) (Thousand Mw)



Source: National Energy Policy in 2001

After the 1965 and 1977 blackouts, as discussed above, experts said that interconnections were too scarce to support each power pool in times of emergency. After the 2003 blackout, experts argued that transmission lines are antiquated and weak in the era of deregulation. Their arguments are relevant in each time. Considering several large scale blackouts that happened between 1965 and 2003, however, we have witnessed that extending and integrating transmission systems are not fundamental solutions to those blackouts. Those cascades have occurred repeatedly although transmission systems have been strengthened continually. How large a capacity is enough to prevent cascades? Does the competitive market, in which efficiency is one of the main concerns, solve the problem? The following view point contrasts with the belief that transmission lines should be added and strengthened.

1.1.2. Decentralizing System Design

The expansion of transmission lines is viewed skeptically by those who raise questions about the current centralized architecture of the power system (NYT 1965; Lovins and Lovins 1982; Lovins, Datta et al. 2003). Amory Lovins advocates for decentralized power systems rather than centralized ones in the electricity industry. He points out some attributes of the structure of current energy systems: centralization of supplies, long haul distances, limited substitutability, continuity and synchronism in grids, specialized labor and control requirements, and potential for misuse of energy distribution systems (Lovins and Lovins 1982). “As the interconnected electric energy systems become more tightly interconnected over larger regions, systems problems are emerging which neither are presaged, predicted, or addressed by classical electrical engineering and which are no longer amenable to ad hoc solution” (Lovins and Lovins 1982 p138). Therefore, he argues that we cannot predict a large-scale power failure due to the complexity of the transmission network and unpredictable interactions within the system. Lovins indicates that the 1965 Northeast blackout and the 1977 New York blackout are representative consequences of the current energy structure. In addition, he points to problems of information transfer and decision making in the tied complex system in which an individual’s decision in one control center can affect other interconnected systems (Lovins and Lovins 1982). To avoid the brittleness of centralized systems, he seeks alternative ways; more dispersed, diverse, local, and redundant modules. He suggests a decentralized electricity supply with newly developed technologies and small-scale renewable sources, which, he argues, not only prevent large scale blackouts, but also improve energy efficiency.

They perceive cascading outages as a result of the highly interconnected transmission lines that connect current centralized power systems from Canada to Florida. Lovins's argument, however, does not discuss advantages of the current transmission systems which are based on such principles as economies of scale, universal systems, load diversity, and load factor. The electricity industry has grown with the fact that the integration of the transmission network is a way to improve reliability as well as efficiency. If one generator in an area is out of service due to its maintenance schedule, other generators in another area can supply power through transmission lines thereby keeping current. If the power systems in the area are interconnected to other systems, it does not have to construct surplus power plants to maintain electrical service. These advantages of centralized power supply systems are real and important. But Amory Lovins argues that district heating and industrial cogeneration have more economic advantages than a centralized power system, considering construction time, thermal efficiency, reserve margin, and the costs of construction, delivery and operation (Lovins and Lovins 1982). He also argues that a system that includes many small scale power plants is more reliable because they might not fail simultaneously compared to just a system with a few large nuclear power plants.

Admittedly, both arguments, centralized and decentralized power systems, have their own valid explanation about technological problems of a cascading outage although they have some deficiencies in suggesting more relevant solutions. As mentioned above, strengthening transmission systems in centralized systems remains a question of how many transmission lines are enough. Amory Lovins's argument for decentralizing power systems is a radical approach to the solution of cascades, leaving open the question of how to deal with current centralized power systems. While physical designs have been a recurrent factor in large scale blackouts since the 1965 blackout, revising current reliability standards and setting new ones are recent issues with the introduction of deregulation in the competitive electricity market.

1.1.3. Market Design and Revising Rules

Joskow (2003) and Hogan (2004), who actually designed competitive electricity markets, diagnose inconsistency of market design with transmission networks as a key cause of the 2003 Northeast blackout. As mentioned earlier, Joskow argues for strong transmission systems. He tries to find an answer from a well designed market with 'performance based regulatory mechanisms' to encourage utilities' investment in transmission systems (Joskow 2003). Joskow agrees with expanding transmission lines to a certain degree to meet the market demand, and insists on giving more power to the federal government. Although he mentions a variety of problems of mismatch among organization, management, regulation and physical infrastructure including monitoring, communication, and control capabilities, his discussion focuses on the market design (Joskow 2005). As a result, his argument is too simplified in explaining reasons for large scale blackouts.

Hogan perceives the problem to be that the centralized, vertically integrated power systems are designed for the market of natural monopoly, not for the competitive market. Hogan admits the inevitability of cascading outages under interconnected transmission systems. Hogan points out an issue with highly interconnected and interdependent transmission lines with too many control areas, which might result in more blackouts

(Hogan 2003). If the transmission lines are more interconnected, they can easily absorb lots of little shocks, but ultimately they will provide a better chance of a large power failure spreading over the network (Nadis 2004). Thus the only way, he says, is to mitigate the consequences of large scale power failure by implementing policies for nationwide power management. Hence he draws attention to FERC's role in providing good reliability standards and market design simultaneously (Hogan 2004). He insists on the additional role of the federal government to design efficient and consistent rules, because he believes such rules cannot be made by the market. His approach admits the real situation of inevitable consequences in current, complex grid systems. Because Joskow and Hogan focus on the market design, they overlook how institutions for reliability should be rearranged, how utilities, more specifically control centers of individual utilities, could reorganize their behavior in order to make electricity reliability work under deregulation, and how the federal government's regulatory power can be linked to the industry's reliability institutions.

Expanding transmission lines is criticized by Kirschen and Strbac (2003) who raise a question of improving the reliability in the existing rules, particularly the N-1 criterion.[119] Following the 2003 blackout, Kirschen and Strbac argue that upgrading the transmission network will improve the security of the system in the short run, but consequently confront another capacity problem due to the increased power transfers from regions with cheap energy resources to others under the competitive electricity market (Kirschen and Strbac 2003). The increased power transaction and stress on the transmission network may augment the probability of blackouts, especially under deregulation, and thus

[119] According to N-1 Criterion, an electrical system should work properly and maintain its stability although it loses any one component of its *N* components.

deterministic security rules, such as the N-1 criterion, may not be adequate any more (Kirschen and Strbac 2003). To reduce probability of blackouts, they suggest introducing new rules, such as probabilistic criteria, that reflect changed circumstances. Although Kirschen and Strbac discuss the problem of highly connected transmission lines, they do not explicitly mention how to reshape the physical structure of centralized and interconnected power systems. Instead they accept the current, centralized electric system as reality of the market. Thus, they try to find solutions in the market design and alternative policies, particularly reviewing the level of security rules – the N-1 criterion. But they do not elaborate those rules in detail.

Frank Felder reviews existing reliability standards in detail, arguing that existing reliability standards are outdated and should be changed to meet current demands for electric service under deregulation (Felder 2001). He critically reviews two prominent reports, *Reliable Power: Renewing the North American Electric Reliability Oversight System* published by the Electric Reliability Panel (ERP) of NERC and *Maintaining Reliability in a Competitive U.S. Electricity Industry: Final Report of the Electric System Reliability* by the Secretary of Energy Advisory Board (SEAB) of the U.S. Department of Energy. Then he points out that these reports do not provide an analytical framework to improve reliability under the changing market rules toward competition in wholesale and retail electricity markets. One of his questions is "what framework a publicly minded governance board of a reliability institution should use in deciding which reliability policies to adopt" (Felder 2001 p25). However, this question is not answered in the above reports. According to him, the existing framework – adequacy and security – used by NERC does not cover all possible power system disturbances that are reported by the

DAWG of NERC. In addition, the framework does not consider the current market dynamics in which reliability costs should be considered. He proposes the probabilistic risk approach and a cost-benefit criterion that should be included in a new analytic framework for reliability (Felder 2001).

In sum, the above viewpoints try to explain causes of recent large scale blackouts from the perspective of an incomplete market design in the process of deregulation. They are interested in setting the game rules – market design – including new policies for reliability. In addition to the rules, Joskow and Hogan emphasize the role of the federal government as an umpire to make electric utilities comply with rules for reliability without hurting market efficiency. Because their focus is on the economic behavior of utilities, as discussed above, they do not critically deal with other reliability-related issues, such as monitoring systems, communication, decision making processes for coordination among control centers, system operators' training, and the effects of institutional settings on system operators with respect to the role of the federal government and other reliability institutions. Felder broadens their arguments by relating reliability-related issues to the market design. Although he analyzes problems of current reliability standards through the sophisticated question of what is a new framework, however, he does not answer his first question of "how to formulate an independent and publicly minded reliability institution in a restructured electric power industry" (Felder 2001 p24). This question is related to my question of what kind of the institutions the electricity industry has developed to improve reliability. Overall, their arguments tell us what kinds of rules are necessary, but do not take into account the physical and institutional environment of rule-making processes and the behavior of key players – usually system operators and electrical engineers – who interact with reliability standards. How governments and utilities establish an institutional environment that affect setting reliability rules, and how players perform their roles in their given environment are also an important factor that should be reflected in the policies, the market design and technological development.

1.2. Complexity and Network Approach

The second popular explanation for blackouts is to observe the cascading outage itself as a physical phenomenon independent of the social organization of technological events. An initial small variation, like 'the butterfly effect,' becomes a large event due to the integration of local electrical systems into bulk power systems through high-voltage transmission lines. This explanation is derived from two dominant theories – self-organized criticality and highly optimized tolerance in explaining complexity – in physics (Bak, Tang et al. 1988; Carlson and Doyle 1999; Sachtjen, Carreras et al. 2000; Carlson and Doyle 2002; Carreras, Lynch et al. 2002; Dobson, Newman et al. 2002; Carreras, Newman et al. 2004; Dobson, Carreras et al. 2004; Nedic, Dobson et al. 2005), and from small world phenomena in Milgram's network theory (Watts and Strogatz 1998; Watts 1999; Newman, Strogatz et al. 2001; Strogatz 2001; Watts 2002).

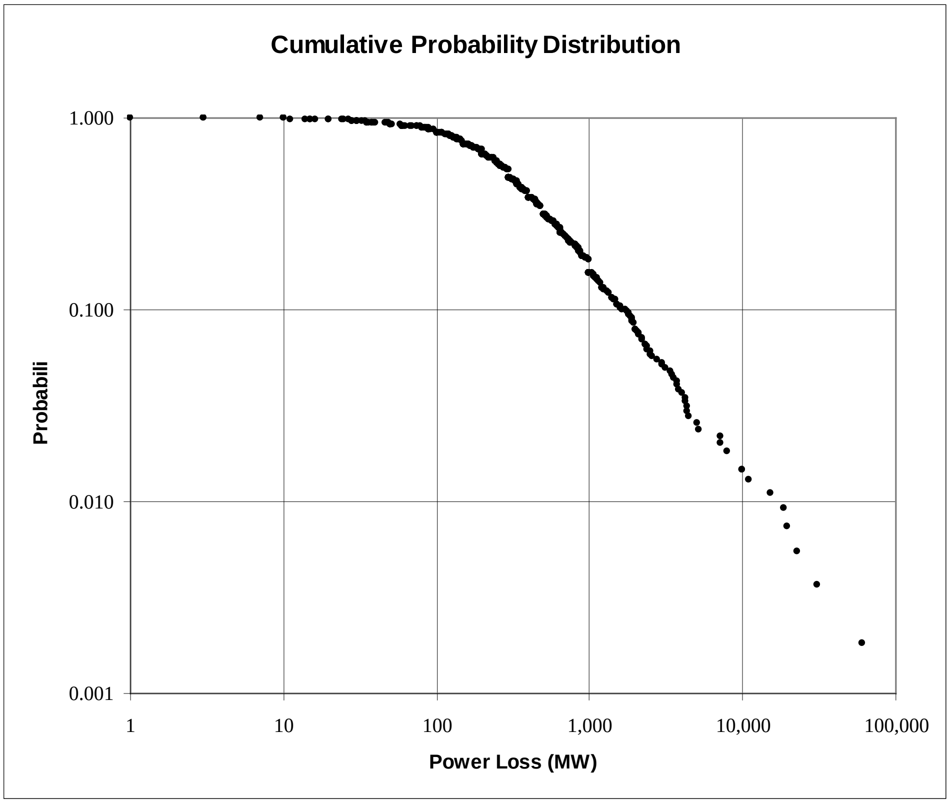
1.2.1. Complexity and Cascades

Bak et al. criticize those who try to predict the performance of large interactive systems by analyzing elements separately. Then they introduce a concept of self-organized criticality (SOC) which explains the behavior of spatially extended dynamic systems (Bak, Tang et al. 1988; Bak and Chen 1991). They pay attention to the generic properties of naturally occurring dynamical systems. Drawing on phenomena in natural ecosystems, they state that all systems with interdependent subsystems having degrees of freedom evolve to the self-organized critical point at which they sustain their stability. They depict it as follows;

> …Ecological systems are organized such that the different species "support" each other in a way which cannot be understood by studying the individual constituents in isolation. The same interdependence of species also makes the ecosystem very susceptible to small changes or "noise." However, the system cannot be too sensitive since then it could not have evolved into its present state in the first place. Owing to this balance we may say that such a system is "critical." (Bak, Tang et al. 1988 p364)

If there is a microscopic variation, a large interactive system has a higher than expected probability to collapse due to its self-organized criticality which is a function of its vulnerability to small changes. Then the impact spreads over the system in the form of chain reaction until it finds its equilibrium at another critical point at a lower level. These phenomena can be found in avalanches, forest fires, breakdown of stock exchange price indices, etc. To explain their model, Bak et al. use a pile of sand which collapses when the pile increases and reaches a critical point. They argue that "this self-organized criticality is the common underlying mechanism behind the [catastrophic] phenomena" (Bak, Tang et al. 1988 p365).

Figure A1.2. Cumulative Probability Distribution of North America Power Disturbance[120]



Data source: NERC 1984-2002; and DOE 2003-2005.11

Carreras, Lynch, and Dobson apply the above argument to a designed system – transmission networks. The Carreras-Lynch-Dobson group thinks that there are the same principles working as those in natural catastrophes behind the phenomena of chain reaction trips in power transmission systems due to the complex interconnection among substations and power plants. They display a graph of the probability distribution function of power grid failure which shows that the size of blackouts is randomly

[120] The probability distribution function by the size of power loss depends on the number of observations that researchers use: the probability distribution function in the Carreras-Lynch-Dobson group's graph is a little different from that of the Carnegie Mellon University group, but both of them show $p(x) = 1/x^{\alpha}$ and its cumulative probability distribution is $P(x) = \Phi[\Sigma(1/x^{\alpha})]$. The coefficient of α varies from researcher to researcher due to the different conditions of their experiments; the range by the Carreras-Lynch-Dobson group is from 0.6 to 1.9; and the Carnegie Mellon University group give the range of the coefficient between 1 and 2. What is important is that the distribution has a heavy tail.

distributed and that the graph has a power law scaling (Dobson, Newman et al. 2002). Figure A1.2 is a display of the cumulative probability distribution by size – loss of load. The probability of blackouts decreases as the size of blackouts increases, but does not disappear. Because of the power law tail,[121] large scale blackouts have more probability to happen than they might be expected (Dobson, Newman et al. 2002; Fairely 2004 cited again). They find that the North American electricity system is operating almost at a critical point where power failures are inevitable.

Doyle and Carlson have also studied the vulnerability of transmission systems (Carlson and Doyle 1999; Carlson and Doyle 2002). They introduce a concept of highly optimized tolerance (HOT) that contrasts with self-organized criticality in its depictions of the characteristics of complexity. HOT draws more attention to highly structured, heterogeneous, internal configurations of the systems, while SOC emphasizes internally generic, homogeneous configurations among the systems. They also describe features – "robust, yet fragile" – of high complex systems which are different from self-organized criticality. When confronting some emergencies, modern technological systems such as the central processing unit (CPU) and the Boeing 777, which are designed to respond to various predictable variations, usually work properly without losing their functions, and thus are robust to uncertainty in their environment; yet they are fragile because "this complexity can amplify small perturbations" (Carlson and Doyle 2002 p2539). Therefore, they also argue that there is a power law distribution in complex systems, which means that there are rare but unanticipated cascading failures even in highly structured systems.

[121] The power tail law refers to the probability on the right side tail in the probability distribution function which is thicker than expected. The power law tail is represented in terms of $p(x) = 1/x^{\alpha}$, where α is a positive number. According to this distribution, "the probability of a blackout is related to its magnitude by some constant exponent" Fairely, P. (2004). The Unruly Power Grid. *IEEE Spectrum*. **August:** 22-27.

Doyle argues that engineers may prevent small disturbances with given resource allocations according to a highly optimized tolerance model, but cannot avoid large scale blackouts due to the complexity of grid design. Hence, the can-do recommendations of U.S-Canada task force report cannot stop cascading failures of the grid; “I don’t think there are simple policy fixes”, Doyle says (Fairely 2004 p22). Further, Doyle’s curve predicts that a large power failure happens periodically – one event every 35 years, which, conveniently, almost equals to the interval of 38 years between the 1965 and 2003 blackouts in the Northeast (Fairely 2004).

Considering Carreras-Lynch-Dobson group’s theory, the Carnegie Mellon group turns their focus toward survival after cascading outages rather than prevention of them (Talukdar, Apt et al. 2003). Because of more than 100,000 devices in a grid system which “can be either ‘off’ or ‘on’”, their possible configuration is $2^{100,000}$ which is too large to be dealt with regarding the possibility of all contingencies (Talukdar, Apt et al. 2003 p27). It is not feasible to test all contingencies using current analytic and simulation methods (Talukdar, Apt et al. 2003). Thus, the focus of their solutions is on how to minimize the social costs of large scale blackouts; identifying socioeconomic missions fulfilled by electric power, determining the critical missions that should be protected even after blackouts, prioritizing the missions, checking weak links in city systems and infrastructures such as domestic but important airports – La Guardia near JFK –, requesting new hardware for protection, seeking cost-effective technologies, and making a system for the allocation of resources to achieve these missions (Talukdar, Apt et al. 2003).

In sum, on the basis of complexity theory, the above groups agree that large scale blackouts are inevitable although they have low possibility to occur, and that strengthening transmission lines are not an appropriate solution to them. They want to see the current grid systems in an entirely different way: a holistic approach to the nature of the system rather than viewing each component of the system separately, and think that engineers need to change fundamentally their way of operating grid systems (Fairely 2004).

1.2.2. Networks and Cascades

Another explanation of the cascades in complex systems comes from network theory focusing on small world phenomena. Strogatz discusses the problem of the 2003 blackouts (Strogatz 2003); the question is not how it started, but why it spread so fast and far. At first, Watts and Strogatz explain the 1996 Northwest blackout and the social network of film actors in terms of ‘small-world’ networks: analogy with Milgram’s small-world problem (Watts and Strogatz 1998 p440). Milgram finds that to link two randomly selected individuals, surprisingly there are only five intermediate acquaintances on average between the two (Milgram 1967); that is called a small world phenomenon. This notion became popular through the Broadway play and later movie *Six Degrees of Separation* (Guare 1994; Watts 1999). Strogatz and Watts, inspired by the idea of Milgram’s small-world problem, tried to find general principles in the typology of network systems, such as the diffusion of innovation, electric power grids, the World-Wide Web, food webs, social networks, coauthorship and citation networks of science, infectious disease, etc (Strogatz 2001; Watts 2003).

They describe a specific model of complex systems which is different from that of self-organized criticality – the systems are networked and located between completely regular and random in their network typology – and find that the structure of networks is highly clustered to some nodes locally, yet has small characteristic path lengths through which information or diseases spread more easily (Watts and Strogatz 1998; Watts 1999). In addition to the model, Watts introduces a *threshold* concept on each node to explain the degree of its changing state by its neighbors (Watts 2002). Each node has a different threshold fraction, keeps its state (either 0 or 1), and is connected to other nodes by edges. The lower a threshold fraction is and the more degrees of connectivity to neighbors there are, the more vulnerable it is to a shock. The threshold fraction and the number of connections are heterogeneous. In accordance with the *local dependencies* threshold rule, the nodes' state can be affected by their neighbors and then becomes 1, if enough of the node's neighbors change their state from 0 to 1. Watts assumes that the features – *local dependencies*, *fractional thresholds*, and *heterogeneity* – are necessary for the dynamics of cascades and that there is a finite fraction of vulnerable clusters in an infinite network (Watts 2002). Even with the finite fraction of vulnerable clusters, an initially small seed strikes neighbor nodes and forces them to change their stable state into susceptible state, extending the size of vulnerable clusters. The result is that a global cascade occurs when an initial shock affects the neighboring nodes which have the low thresholds and highly connected nodes, extending vulnerable clusters, which then spread over all networks through small characteristic path lengths. Even though a system may routinely display great stability for a long period of time, the presence of continual small failures and shocks ultimately generates a cascade that reveals, in Doyle and Carson's term, the *robust yet fragile* nature of many complex systems; "the most connected nodes are critical in triggering cascades" (Watts 2002). This model can be applied to power grids which are also network systems with nodes (generators, substations) and edges (transmission lines). According to this model, vast and complex grid systems itself have the possibility of cascading outages because of the topology of complex networks.

In sum, the above three ways of explanations – self-organized criticality, highly optimized tolerance, and small-world phenomena – accept the fact that cascading outages cannot be avoided because of the complexity in transmission systems. In addition, the Carreras-Lynch-Dobson group assumes that economic principles of maximization of return by reducing investment in transmission equipments force engineers to perform their tasks at the higher power levels (Fairely 2004), thereby making some bad situations worse. In this sense, those groups regard human errors as an initiation of triggering cascades. "Big blackouts are a natural product of the power grid. The culprits that get blamed of each blackout – lax tree trimming, operators who make bad decisions – are actors in a bigger drama, their failings mere triggers for disasters that in some strange ways are predestined" (Fairely 2004 p25). The only solution to cascading outages is to fundamentally change systems.

Although it is important to understand the physical features of complex, networked system, however, their arguments overlook the social construction of technological failure. I agree that all problems are not attributable to operators who are mere actors for triggering cascades as mentioned above. But I want to consider that they are standing on the front line not only of complex network systems, but also of the huge electricity industry and their institutional environment which constrain their behavior. If we only consider physical features of a complex network system, we could fall into the trap of technological determinism. The laws of physics do not explain how social actors perform their work according to rules and institutions. Social contexts constrain operators' behavior and provide the environment for cascading outages. In addition to social context, I want to think about human errors again because small but similar mistakes appear repeatedly at the initial stage of large scale power outages: sagging transmission lines and tree contact due to vegetation mismanagement, miscommunication, and operators' poor decision regarding load shedding. These mistakes, although similar in its appearance, play certain roles in different physical and institutional environments, causing cascading outages. Why do the same mistakes happen again and again? Why do these mistakes periodically – almost every 30 years, particularly in the Eastern interconnection – trigger cascading outages? Recently the frequency of cascading outages has been growing: blackouts in 1996 in the Northwest coast, 2001 in California, and 2003 in the Northeast region. Operators in the transmission control centers may already be aware of similar small problems if they have some experience and knowledge about previous outages, and thus they could predict and prevent them. But they show the same failings at the critical moments. Do we take it for granted that those errors are everyday routines? Human or organizational performance and its institutional environment are factors that should be considered to some extent.

Appendix 2. Disturbance Reporting Requirements

NERC Reporting Requirements for Major Electric System Emergencies[122]

These disturbance reporting requirements apply to all entities using the electric transmission systems in North America and provide a common basis for all NERC disturbance reporting. The utility or other electricity supply entity on whose system a disturbance that must be reported occurs shall notify NERC and its Regional Council of the disturbance using the NERC Preliminary Disturbance Report form. If a disturbance is to be reported to DOE also, the responding entity may use the DOE reporting form when reporting to NERC. The report is to be made as specified in Policy 5F for any of the following events:

1. The loss of a bulk power transmission component that significantly affects the integrity of the interconnection system operation.

2. The occurrence of an interconnected system separation or system islanding or both.

3. Loss of generation by a utility or generation supply entity — 2,000 MW or more in the Eastern Interconnection or Western Interconnection and 1,000 MW or more in the ERCOT Interconnection or Québec Interconnection. Reports can be sent to NERC via e-mail (info@nerc.com) or by facsimile (609-452-9550) using the NERC Preliminary Disturbance Report form.

4. Equipment failures/system operational actions, which result in the loss of firm system demands for more than 15 minutes, as described below.

    4.1. Entities with a previous year recorded peak demand of more than 3,000 MW are required to report all such losses of firm demands totaling more than 300 MW.

    4.2. All other entities are required to report all such losses of firm demands totaling more than 200 MW or 50% of the total customers being supplied immediately prior to the incident, whichever is less.

5. Firm load shedding of 100 MW or more to maintain the continuity of the bulk electric system.

6. Any system operation or operator action resulting in:

    6.1. sustained voltage excursions equal to or greater than ±10%, or

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[122] These are as they are in the NERC reporting requirements. Source: NERC (2001). 1998 System Disturbances: Review of Selected Electric System Disturbances in North America. NERC. Princeton, NJ., pp 35~37

6.2. major damage to power system components, or

6.3. an event other than those covered above that a system operator in another electric transmission system might encounter and should be aware of, or

6.4. failure, degradation, or a "near miss" of system protection, special protection schemes, remedial action schemes, or other operating systems that do not require system operator intervention.

7. An operating security limit violation as required in Policy 2A — Transmission Operations, Standard 2.2.

8. An actual or suspected act of physical or electronic (cyber) sabotage or terrorism directed at the bulk electric system or its components with intent to deny service or disrupt or degrade the reliability of the bulk electric system.

U.S. Department of Energy Disturbance Reporting Requirements[123]

Introduction

Every electric utility or other entity subject to the provisions of Section 311 of the Federal Power Act, engaged in the generation, transmission, or distribution of electric energy for delivery and/or sale to the public shall expeditiously report to the U.S. Department of Energy's (DOE) Emergency Operation Center (EOC) any of the events described below. Such report or a part of such report may be made jointly by two or more entities or by a Regional Reliability Council or power pool.

1. Loss of Firm System Loads

1.1. Any load shedding actions resulting in the reduction of over 100 megawatts (MW) of firm customer load for reasons of maintaining the continuity of the bulk electric power supply system.

1.2. Equipment failures and system operational actions associated with the loss of firm system loads for a period in excess of 15 minutes, as described below:

1.2.1. Reports from entities with a previous year recorded peak load of over 3,000 MW re required for all such losses of firm loads which total over 300 MW.

1.2.2. Reports from all other entities are required for all such losses of firm loads which total over 200 MW or 50% of the system load being supplied immediately prior to the incident, whichever is less.

[123] Source: Ibid., pp38~39.

1.3. Other events or occurrences which result in a continuous interruption for three hours or longer to over 50,000 customers, or more than 50% of the total customers being served immediately prior to the interruption, whichever is less.

When to Report: The DOE EOC (202-586-8100) shall be notified as soon as practicable without undue interference with service restoration and, in any event, within three hours after the beginning of the interruption.

2. **Voltage Reductions and Public Appeals**

2.1. A report is required for any anticipated or actual system voltage reduction of 3% or greater for purposes of maintaining the continuity of the bulk electric power supply system.

2.2. A report is required for any issuance of a public appeal to reduce the use of electricity for purposes of maintaining the continuity of the bulk electric power system. When to Report: The DOE EOC (202-586-8100) shall be notified as soon as practicable, but no later than 24 hours after initiation of the actions described in paragraph 2, above.

3. **Vulnerabilities That Could Impact Bulk Electric Power System Adequacy or Reliability**

3.1. Reports are required for any actual or suspected act(s) of physical sabotage (not vandalism) or terrorism directed at the bulk electric power supply system in an attempt to:

3.1.1. Disrupt or degrade the adequacy or service reliability of the bulk electric power system such that load reduction action(s) or special operating procedures may be needed.

3.1.2. Disrupt, degrade, or deny bulk electric power service on an extended basis to a specific: (1) facility (industrial, military, governmental, private), (2) service (transportation, communications, national security), or (3) locality (town, city, county). This requirement is intended to include any major event involving the supply of bulk power.

3.2. Reports are required for any other abnormal emergency system operating conditions or other events which, in the opinion of the reporting entity, could constitute a hazard to maintaining the continuity of the bulk electric power supply system. DOE has a special interest in actual or projected deterioration in bulk power supply adequacy and reliability due to any causes. Events which may result in such deterioration include, but are not necessarily limited to: natural disasters; failure of a large generator or transformer; extended outage of a major transmission line or cable; Federal or state actions with impacts on the bulk electric power system.

When to Report: The DOE EOC (202-586-8100) shall be promptly notified as soon as practicable after the detection of any actual or suspected acts(s) or event(s) directed at increasing the vulnerability of the bulk electric power system. A 24-hour maximum reporting period is specified in the regulations; however, expeditious reporting, especially of sabotage or suspected sabotage activities, is requested.

4. **Fuel Supply Emergencies**

4.1. Reports are required for any anticipated or existing fuel supply emergency situation, which would threaten the continuity of the bulk electric power supply system, such as:

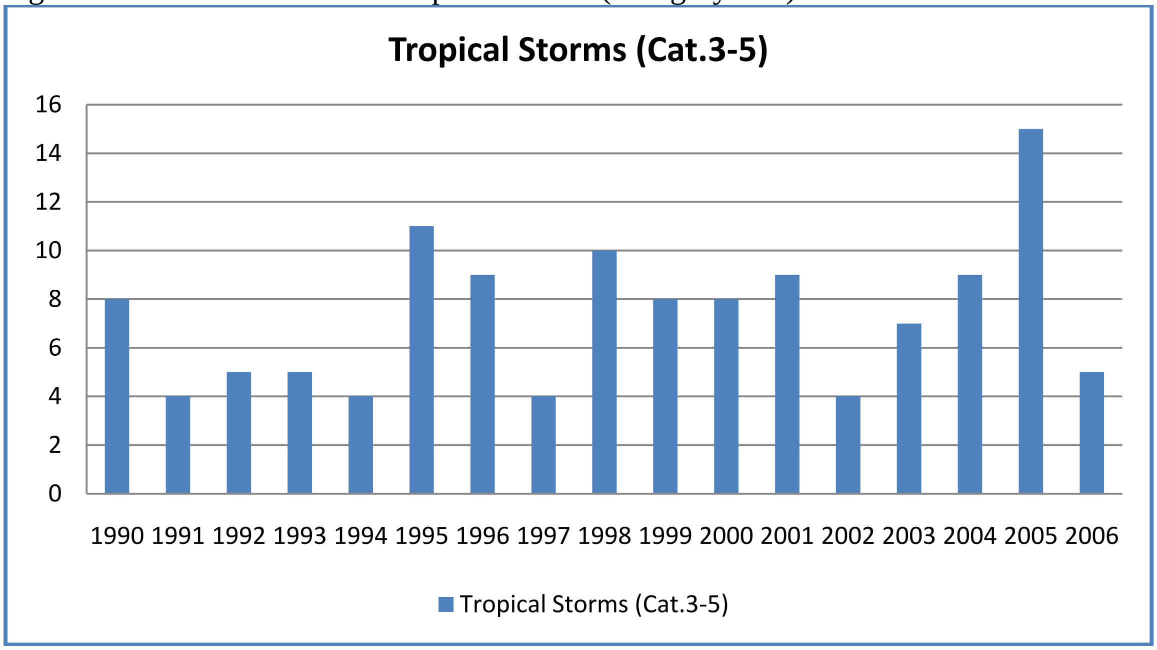
4.1.1. Fuel stocks or hydroelectric project water storage levels are at 50% or less of normal or that time of the year, and a continued downward trend is projected.

4.1.2. Unscheduled emergency generation is dispatched causing an abnormal use of a particular fuel type, such that the future supply or stocks of that fuel could reach a level, which threatens the reliability or adequacy of bulk electric power supply.

When to Report: The DOE EOC (202-586-8100) shall be notified as soon as practicable, or no later than three days after the determination is made.

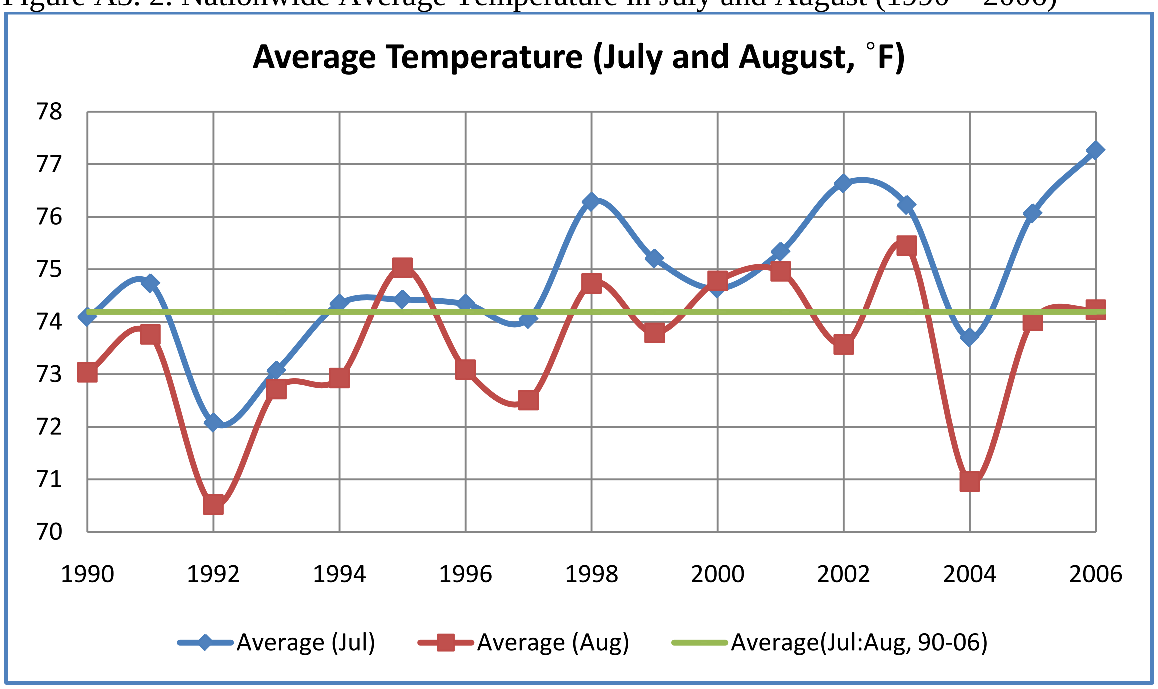
Appendix 3. Tropical Storms, Temperature, and Precipitation

Figure A3. 1. The Number of Tropical Storms (Category 3~5) between 1990 and 2006



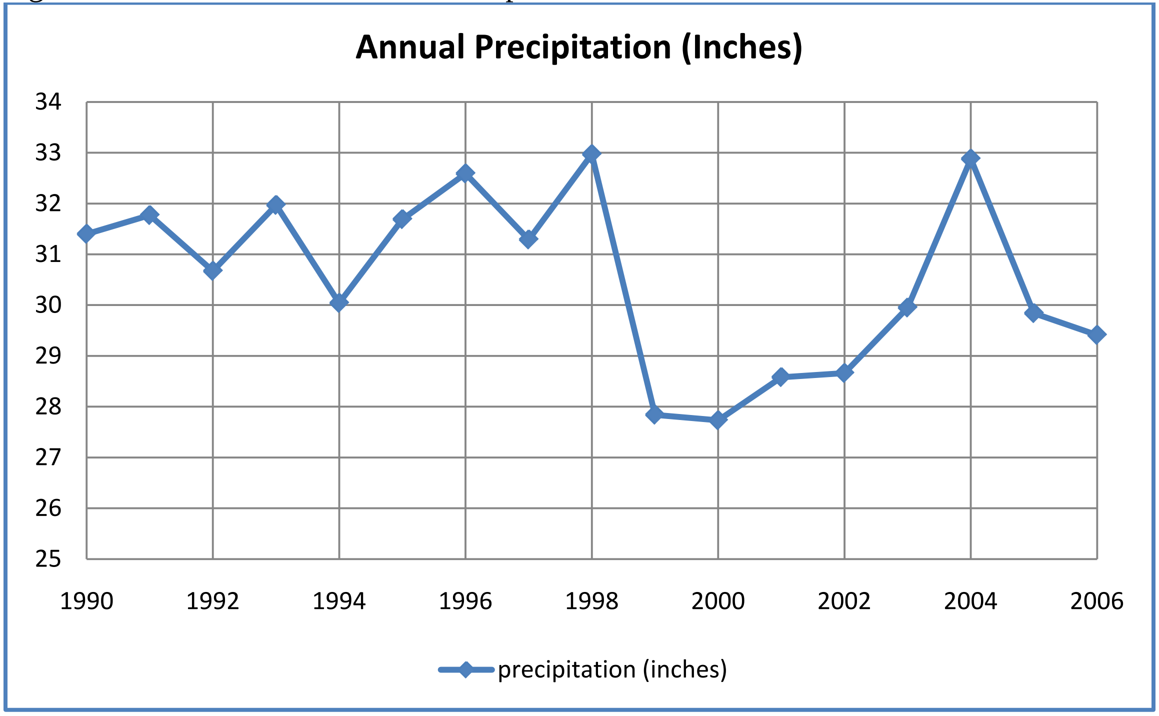
Source: NOAA (http://www.ncdc.noaa.gov/oa/climate/research/cag3/na.html)

Figure A3. 2. Nationwide Average Temperature in July and August (1990 ~ 2006)



Source: NOAA (http://www.ncdc.noaa.gov/oa/climate/research/cag3/na.html)

Figure A3. 3. Nationwide Annual Precipitation between 1990 and 2006



Source: NOAA (http://www.ncdc.noaa.gov/oa/climate/research/cag3/na.html)

In figure A3.1, severe tropical storms (Hurricanes, category between 3 and 5) constantly happen every year. In 2005 severe tropical storms including Katrina unusually happened 15 times more than other years. But the number of annual occurrences ranges from 4 to 10. That is, there is no radical shift in the annual number of tropical storms. Figure A3.2 also illustrates that there is no abrupt change in July and August temperature between 1990 and 2006.

Annual cumulated precipitation drops significantly in 1999. But as figure 4.5 in chapter 4 shows, major power system disturbances had constantly occurred due to rain and wind regardless of the radical shift of annual precipitation between 1998 and 1999.

Appendix 4. Characteristics of Regional Reliability Institutions

Table A4.1. Planning Factors Considered for Resource Adequacy and Transmission Planning

Inst. Characteristics	ECAR	ERCOT	FRCC	MAAC	MAIN	MAPP	NPCC	SERC	SPP	WECC
Factors for Resource Adequacy Planning										
forced full & partial outages	1	1	1	1	1	1	1	1	1	0
NERC GADS ten-year data	0	1	0	0	1	0	0	0	1	0
specified outage factors	1	0	1	1	0	1	1	0	0	0
load diversity	0	0	1	1	1	1	0	1	1	0
load forecast uncertainty	0	1	1	1	1	1	0	0	1	1
scheduled interregional transactions	1	0	1	1	1	1	1	1	1	0
capacity assistance via interregional ties	1	0	1	1	1	0	1	1	0	0
maintenance	1	1	1	1	1	1	1	1	1	1
voltage reduction	0	0	1	0	1	0	0	0	0	0
voluntary load curtailments	0	0	0	0	0	0	0	0	1	0
delay of new units	1	1	1	1	0	1	1	0	1	1
transmission outages	0	0	0	0	1	0	0	0	1	0
non-utility generation	1	1	1	1	1	1	1	1	1	1
DSM	0	1	1	1	1	1	1	0	1	0
fuel shortages	0	0	0	1	0	0	1	0	0	0
large scale capacity curtailments	0	0	0	1	0	0	0	0	0	0
Factors for Transmission Planning										
pre-disturbance conditions	1	0	1	1	1	1	1	0	1	1
initiating disturbance	1	1	1	1	1	1	1	1	1	1
adjustments between contingencies	0	0	1	1	0	1	1	0	1	1
delay fault clearing	1	1	1	1	1	1	1	1	1	1
special protection schemes	1	0	1	0	0	1	1	0	0	1
var/voltage criteria	0	1	0	0	0	1	1	0	0	1
Definition of Acceptable System Performance										
-more probable contingencies	0	1	1	1	1	1	1	0	1	1
-Extreme contingencies	1	1	1	1	1	1	1	1	1	1
Total	12	12	18	18	16	17	17	9	17	12

Source: (NERC 1994)

Table A4.2. Emergency Factors Considered in Making Emergency Operation Planning

Emergency factors	ECAR	ERCOT	FRCC	MAAC	MAIN	MAPP	NPCC	SERC	SPP	WECC
fuel supply and inventory	1	1	1	1	1	1	1	0	1	0
fuel switching	0	1	1	1	1	1	1	1	1	1
environmental constraints (weather)	0	1	1	1	1	1	1	0	0	1
system energy use (reduction)	1	0	1	1	0	1	0	0	1	0
public appeals	1	1	1	1	1	1	1	0	1	1
load management (voltage reduction)	1	1	1	1	1	1	1	1	1	1
optimize fuel supply	1	1	1	1	1	1	0	0	1	1
appeals to customers	1	0	1	1	0	1	0	1	1	0
interruptible and curtail loads	1	1	1	1	1	1	1	1	1	1
maximizing generator output and availability (Ancillary)	1	1	1	1	1	1	1	1	1	1
notifying IPPs	0	1	1	1	1	0	0	1	0	0
requests of government	1	1	1	1	0	1	0	0	0	0
load curtailment (load shedding)	1	1	1	1	1	1	1	1	1	1
Emergency Power Purchases	1	1	1	1	1	1	1	0	1	1
Internal Demand curtailment	0	0	1	1	0	0	1	0	1	0
Utilize Reserve Sharing	1	1	0	1	1	1	1	1	1	1
Selected Rotating Service Interruptions	1	0	1	1	0	1	0	1	0	0
Manual Mitigation of Frequency Decline	1	1	0	1	1	0	1	0	1	1
Exiting Emergency Procedures	0	1	1	1	1	1	1	0	1	1
Sequential Warning Levels	0	1	1	1	1	1	1	1	1	0
Conservative System Operation for Unusual and Infrequent System Conditions	0	1	0	1	0	1	1	1	1	0
emergency transfer capabilities (interregional)	1	1	0	1	1	0	1	0	1	0
securing startup power	0	1	1	1	1	0	1	1	1	1
Total	15	19	19	23	17	18	17	12	19	13

Source: NERC and 10 regional reliability councils' emergency operations standards: (NERC 1995; ECAR 1996; NPCC 2001; SERC 2001; WECC 2002; MAIN 2003; NPCC 2004; MAAC 2005; MAIN 2005; WECC 2005; NERC 2006; SPP 2006; FRCC 2008; ERCOT 2009; MISO 2009)

Appendix 5. Moody's Bond Ratings

Table A5.1. Definitions of Moody's Bond Rating

Bond Ratings	Definition	Numeric Modifiers
Aaa	Bonds which are rated **Aaa** are judged to be of the best quality. They carry the smallest degree of investment risk and are generally referred to as "gilt edge." Interest payments are protected by a large or by an exceptionally stable margin and principal is secure. While the various protective elements are likely to change, such changes as can be visualized are most unlikely to impair the fundamentally strong position of such issues.	
Aa	Bonds which are rated **Aa** are judged to be of high quality by all standards. Together with the **Aaa** group they comprise what are generally known as high grade bonds. They are rated lower than the best bonds because margins of protection may not be as large as in **Aaa** securities or fluctuation of protective elements may be of greater amplitude or there may be other elements present which make the long term risks appear somewhat larger than in **Aaa** securities.	1,2,3
A	Bonds which are rated **A** possess many favorable investment attributes and are to be considered as upper medium grade obligations. Factors giving security to principal and interest are considered adequate but elements may be present which suggest a susceptibility to impairment sometime in the future.	1,2,3
Baa	Bonds which are rated **Baa** are considered as medium grade obligations, i.e. they are neither highly protected nor poorly secured. Interest payment and principal security appear adequate for the present but certain protective elements may be lacking or may be characteristically unreliable over any great length of time. Such bonds lack outstanding investment characteristics and in fact have speculative characteristics as well.	1,2,3
Ba	Bonds which are rated **Ba** are judged to have speculative elements; their future cannot be considered as well assured. Often the protection of interest and principal payments may be very moderate and thereby not well safeguarded during both good and bad times over the future. Uncertainty of position characterizes bonds in this class.	1,2,3
B	Bonds which are rated **B** generally lack characteristics of the desirable investment. Assurance of interest and principal payments or of maintenance of other terms of the contract over any long period of time may be small.	1,2,3
Caa	Bonds which are rated **Caa** are of poor standing. Such issues may be in default or there may be present elements of danger with respect to principal or interest.	
Ca	Bonds which are rated **Ca** represent obligations which are speculative in a high degree. Such issues are often in default or have other marked shortcomings.	

C	Bonds which are rated **C** are the lowest rated class of bonds and issues so rated can be regarded as having extremely poor prospects of ever attaining any real investment standing.	
1	Moody's applies numerical modifiers, 1, 2, and 3 in each generic rating classification from **Aa** through **B** in its corporate bond rating system. The modifier 1 indicates that the security ranks in higher end of its generic rating category;	
2	the modifier 2 indicates a mid-range ranking;	
3	and the modifier 3 indicates that the issue ranks in the lower end of its generic rating category.	

Source: (Moody's 1990, p viii)

Acronym

AC: Alternating current

AEP: American Electric Power

APPA: American Public Power Association

ATC: Air Traffic Control

ATO: Air Traffic Organization

CANUSE: Canada-United States Eastern Interconnection

CISO: California Independent System Operator

Cepac: Centralized emergency preventive automated control

CMA: Chemical Manufacturers Association

CONVEX: Connecticut Valley Power Exchange

DAWG: Disturbance Analysis Working Group

DC: Direct current

DOE: Department of Energy

DSM: Demand Side Management

ECAR: East Central Area Reliability Coordination Agreement

EIA: Energy Information Administration

ERC: Electric Reliability Coalition

ERCOT: Electric Reliability Council of Texas, Inc.

ERO: Electric Reliability Organization since 2006

FAA: Federal Aviation Administration

FE: FirstEnergy

FERC: Federal Energy Regulatory Commission since 1977

FINRA: Financial Industry Regulatory Authority

FPC: Federal Power Commission, later FERC

FRCC: Florida Reliability Coordinating Council

HOT: Highly optimized tolerance

HROs: High Reliability Organizations

IEEE: Institute of Electric and Electronic Engineering

INPO: Institute of Nuclear Power Operators

IOUs: Investor owned utilities

IPSs: Interconnected Power Systems of the USSR

IRP: Integrated resource planning

ISG: Interconnected Systems Group

ISO-NE: New England Independent System Operator

LCP: Least cost planning

LILCO: Long Island Lighting Company

MAAC: Mid-Atlantic Area Council

MISO: Midwest Independent System Operator

NAERO: North American Electricity Reliability Organization

MAIN: Mid-America Interconnected Network, Inc.

MAPP: Mid-Continent Area Power Pool

NAPSIC: the North American Power Systems Interconnection Committee

NASD: National Association of Security Dealers, later FINRA

NAT: Normal Accidents Theory

NERC: the National Electricity Reliability Council since 1968, the North American Electricity Reliability Council since 1981, and now North American Reliability Corporation since 2007

NPCC: Northeast Power Coordinating Council

NRC: Nuclear Regulatory Commission

NYISO: New York Independent System Operator

NYPP: New York Power Pool since 1966, later changed into NYISO

NYSPC: Public Service Commission of New York

PASNY: Power Authority of the State of New York

PJM: Pennsylvania-New Jersey-Maryland Interconnection since 1956

PNJ: Pennsylvania-New Jersey Power System, later the PJM Interconnection

PSE&G: Public Service Electric & Gas Company of New Jersey

PURPA: Public Utility Regulatory Policies Act of 1978

RCTA: Real time contingency analysis

ROA: Return on assets

ROE: Return on equity

SEAB: Secretary of Energy Advisory Board

SERC: Southeastern electric reliability council

SO: Transmission System Operator

SOC: Self-organized criticality

SPP: Southwest power pool

TVA: Tennessee Valley Authority

UPS: Unified Power System of the USSR

WECC: Western Electricity Coordinating Council

WSCC: Western System Coordinating Council, later WECC

Glossary

Cascading Outages: refers to the uncontrolled successive loss of Bulk Electric System Facilities triggered by an incident (or condition) at any location resulting in the interruption of electric service that cannot be restrained from spreading beyond a predetermined area. (NERC 2008)

Energy Management System Servers (EMS): An energy management system is a computer control system used by electric utility dispatchers to monitor the real time performance of various elements of an electric system and to control generation and transmission. (U&C TF 2004)

Federal Energy Regulatory Commission (FERC: formerly Federal Power Commission, FPC): Independent federal agency that, among other responsibilities, regulates the transmission and wholesale sales of electricity in interstate commerce. (U&C TF 2004)

Frequency: the number of complete alternations or cycles per second of an alternating current, measured in Hertz. The standard frequency in the United States is 60 Hz per second. In some other countries such as those in Europe the standard frequency is 50 Hz. (U&C TF 2004)

Independent System Operator (ISO): An organization responsible for the reliable operation of the power grid under its purview and for providing open transmission access to all market participants on a nondiscriminatory basis. An ISO is usually not-for-profit and can advise utilities within its territory on transmission expansion and maintenance but does not have the responsibility to carry out functions. (U&C TF 2004)

Kilovolt: 1,000 volts; voltage: the electrical force, or “pressure,” that causes current to flow in a circuit, measured in volts. (U&C TF 2004)

Load factor: the ratio of the average load to the maximum load of a customer, group of customers, or the entire system during a specified period. (Hughes 1984 p218)

N-1 Criterion: An electrical system should work properly and maintain its stability, although it loses any one component of its *N* components.

Reactive Power: the portion of electricity that establishes and sustains the electric and magnetic fields of alternating-current equipment. This is used to explain the loss of power due to the product of electric and magnetic fields, that is, heat and electromagnetic emissions on transmission lines. Actually reactive load such as inductors and capacitor do not dissipate power, and thus is called ‘imaginary power’ or ‘phantom power.’ Reactive power must be supplied to most types of magnetic equipment, such as motors and transformers. It also must supply the reactive losses on transmission facilities. Reative power is provided by generators, synchronous condensers, or electrostatic equipment such as capacitors and directly influences electric system voltage. It is usually expressed in kilovars (kVAr: kilo-voltage-ampere-reactive) or megavars (MVAr: mega-voltage-ampere reactive), and is the mathematical product of voltage and current consumed by reactive loads. Reactive loads, when connected to an ac voltage source, will draw current, but because the current is 90 degrees out of phase with the applied voltage, they actually consume no real power. Reactive power is important to maintain normal flow of current and stable voltage on the transmission grids. (U&C TF 2004)

Real Power: Also known as "active power." The rate at which work is performed or that energy is transferred, usually expressed in kilowatts (kW) or megawatts (MW). The terms "active power" are often used in place of the term power alone to differentiate it from reactive power. (U&C TF 2004)

Real Time Contingency Analysis (RTCA): Given the state estimator's representation of current system conditions, a system operator or planner uses contingency analysis to analyze the impact of specific outages (lines, generators, or other equipment) or higher load, flow, or generation levels on the security of the system. The contingency analysis should identify problems such as line overloads or voltage violations that will occur if a new event (contingency) happens on the system. (U&C TF 2004)

Regional Transmission Operator (RTO): An organization that is independent from all generation and power marketing interests and has exclusive responsibility for electric transmission grid operations, short-term electric reliability, and transmission services within a multi-State region. To achieve those objectives, the RTO manages transmission facilities owned by different companies and encompassing one, large, contiguous geographic area. (U&C TF 2004)

Relay: a device that controls the opening and subsequent reclosing of circuit breakers. Relays take measurements from local current and voltage transformers, and from communication channels connected to the remote end of the lines. A relay output trip signal is sent to circuit breakers when needed. (U&C TF 2004)

Reliability: defined as; 1) Adequacy **—** the ability of the electric system to supply the aggregate electrical demand and energy requirements of customers at all times, taking into account scheduled and reasonably expected unscheduled outages of system elements; and 2) Security **—** the ability of the electric system to withstand sudden disturbances such as electric short circuits or unanticipated failure of system elements.

Reserve margins (operating): the amount of unused available capability of an electric power system (at peak load for a utility system) as a percentage of total capability. (EIA 2009)

SCADA (System Control and Data Acquisition): System operators use SCADA systems to acquire power system data and control power system equipment. SCADA systems have three types of elements: field remote terminal units (RTUs), communication to and between the RTUs, and one or more Master Stations. (U&C TF 2004)

State Estimator: a standard power system operations tool (a computer program). It uses a mathematical model to estimate current conditions – voltage at each bus, and real and reactive power flow on each line – on an extensive area of the transmission system. (U&C TF 2004)

Tie power flow: the power flowing through tie lines. Tie lines refer to a circuit connecting two Balancing Authority Areas. (NERC 2008)

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