Risk Management vs. Risk Avoidance in Power Systems Planning and Operation

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I. Introduction

Civil and critical infrastructure systems such as transportation, communication, power, and financial systems have provided the foundation for modern society. Not surprisingly, much of the research work in many areas of engineering was directed over the years at the advancement and application of scientific principles to the design, maintenance and improvement of the critical infrastructures in our society. Risk assessment and systematic consideration of risk in the design and operation of infrastructure is a relatively new phenomenon that emerged within the last fifty years. While many engineering disciplines still do not consider probability and statistics as essential basic knowledge for engineers, like physics for instance, consideration of risk has penetrated all engineering disciplines. In most cases, however, such considerations take the form of setting thresholds and safety margins so as to avoid "unacceptable" risk, where acceptability levels are typically determined by experts. In power systems for instance, the common wisdom has traditionaly been to build sufficient capacity so that the system will fail to meet demand no more than one day in ten years. Similarly, power system operation is governed to a large extent by the "N-1 security criterion" which requires that the system as a whole can sustain failure of any one element (e.g. generator, transmission line, transformer etc.).

The last two decades brought about two revolutionary changes in critical infrastructures that will have a lasting impact on infrastructure related research and development. These changes present new challenges for academic research and training of professionals in infrastructure related fields. In particular, the way we think about risk and risk mitigation in the context of critical infrastructure is at the verge of a revolutionary transformation that will empower more personal choice and accountability.

The first change is the IT revolution. Electronic sensing, telecommunication, controllers and computation have proliferated into every infrastructure system and revolutionized their operational paradigms. The new information technologies also led to new critical infrastructures, such as the Internet, and to interdependencies and complexities that create new vulnerabilities and risks.

The second change is the massive deregulation of infrastructure industries such as the airline industry, natural gas industry, trucking, telecommunications and most recently, electric power. The deregulation of these industries in the US, and around the world, has challenged traditional beliefs that infrastructure industries should be publicly owned or be run by vertically integrated regulated monopolies, and that consumers should have little or no say in choices that concern tradeoffs between physical and financial risks vs. cost. Deregulation of infrastructure industries has brought about decentralization of the decision-making, and creation of markets that enable and incentivizes customer choice. By empowering consumers to make informed choices, the deregulation movement has triggered a process that is revolutionizing the concepts of reliability and risk. For example in an infrastructure industry governed by an "obligation to serve", service curtailment (e.g. being bumped off a flight due to overbooking) is considered a failure that counts toward reliability metrics. By contrast, in a deregulated environment governed by "obligation to serve at a price" service curtailment becomes voluntary (in exchange for compensation or a cheaper fare) and no longer counts as a failure. Airline passengers would probably feel more tolerant to schedule delays as well given the proper financial compensation.

II. Risk Mitigation Paradigms

We can identify three basic approaches to risk mitigation:

A. Risk avoidance

This has been the traditional approach adopted by engineering design and regulatory bodies. Typically it consist of screening alternative courses of action by performing a risk assessment, and enforcing a threshold criterion for acceptable risk. Such criteria are set on the basis of expert opinion and policy consideration including political compromise. Alternatives that fail to meet the set criterion are rejected. Typical applications of this approach include for instance FDA approval of drugs, EPA approval of emission levels or toxic waste levels, OSHA safety standards, and NERC [North American Electric Reliability Council] operating guidelines for the electricity grid.

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B. Decision-making under uncertainty

This approach, knoiwn as Decision Analysis, evaluates alternative courses of action by modeling the uncertain outcomes of each alternative, and taking into consideration subjective and objective information including assignment of values to potential outcomes and consideration of the decision maker's risk preference. The approach aims to identify the "best alternative" among the choices under consideration (including the alternative to seek more information), given current information and the decision maker's preferences. It also provides a variety of sensitivity analyses. Decision Analysis is a well-established discipline rooted in statistical decision theory and system analysis. This approach has been applied successfully to many decision problems in the private and public sector, in the context of decisions such as whether to seed hurricanes, decisions concerning earthquake reinforcement, product development decisions, investment decisions etc. Often decision problems under uncertainty have specific structures that can be exploited by specialized solution approaches. For example, Stochastic Programming methods address decision problems under uncertainty for which the objective function and constraints can be represented in functional form. Stochastic Dynamic Programming is applicable when the state variables and uncertainties have an underlying dynamic structure.

C. Risk management

This approach aims to mitigate adverse financial or operational consequences of uncertain outcomes through economic or operational hedging. Such mitigation often takes the form of trading contingent claims whose financial settlement depends on realizations of uncertain state variables or by building into the system operational flexibility. Contractual arrangements such as insurance contracts are examples of such contingent claims. Risk sharing agreements and syndication is another form of economic risk mitigation. Interruptible loads, under-frequency relays for load shedding and various forms of reserves in power systems are examples of operational hedging. These are mechanisms for absorbing or diversifying the risk or spreading the financial consequences of the risk. Selling shares in a company through a public offering is an example of a risk sharing arrangement. Financial hedging is a form of economic risk mitigation in which a risk bearer reduces its exposure by creating a portfolio of ventures whose outcomes happen to be correlated so as to reduce total variability. A farmer for instance can hedge the price risk of its crop by purchasing a financial contract that pays the difference between some set price and the market price of the crop. If the price of the crop goes down the payoff from the contract goes up so the gains from the financial contract offsets the losses due to the decline in crop prices. It may not be possible or economical to remove all the risk through mitigation strategies described above. One popular criteria used in risk mitigation are maximization of expected utility which reflects risk aversion or a tradeoff between expected outcome and the variance over that outcome. Another popular criterion is the "value at risk" (VAR) which limits the probability that losses will exceed a specified amount.

Financial and physical (operational) hedging can be substitutes or compliments. For instance, a PC manufacturer can hedge the risk associated with a long term supply contract due to fluctuating prices of some critical input (e.g. memory chips) by merging its operation with the company producing that critical input, by accumulating large inventories of that input or by buying stock in the company that supplies that input.

The applicability of the various approaches in a specific context largely depends on the type of risk we are facing and the perception of that risk. In particular, it is useful to classify types of risks based on the following categories:

- Voluntary vs. Involuntary
- Private vs. Public
- Diversification options (risk sharing, portfolio approaches)
- Tradability (insurance, hedging)
- Interdependency (ability to provide differential protection)

It is important to note, however, that in some instances these categories depend on the framing of a situation. For instance, it is well known that individuals' risk tolerance is higher for voluntary risk then for involuntary risk. But the distinction between what is voluntary and what is involuntary is vague and can shift depending on framing and incentives. Similarly, it is often possible to localize risk or convert public risk to private risk through the use of technology and information that can localize the consequences of risky actions.

III. Implications for Electric Reliability

The electric power system is undoubtedly one of the most important and complex critical infrastructures, which is currently undergoing massive restructuring in the US and around the world from a vertically integrated regulated monopoly structure to a deregulated market based industry. The reliability standards for the power industry, however, continue to be regulated and the 2005 Energy Policy Act (EPACT2005) has empowered the Federal Energy Regulatory Commission (FERC) to enforce mandatory reliability standards.

The electric power industry serves as an excellent example of how technological and regulatory changes in a critical infrastructure can affect the risk mitigation paradigm. The North American Electric Reliability Council (NERC) which now operates under a FERC mandate, defines *reliability* as: "the degree to which the performance of the elements of the electrical system results in power being delivered to consumers within accepted standards and in the amount desired" This definition of Reliability encompasses two concepts:

Security (Operational Reliability): "the ability of the system to withstand sudden disturbances." This aspect concerns short-term operations and is addressed by ancillary services, which include: Voltage support, Congestion relief, Regulation (AGC) capacity, Spinning reserves, Non-spinning reserves, Replacement reserves.

Adequacy: "the ability of the system to supply the aggregate electric power and energy requirements of the consumers at all times". This aspect concerns planning and investment and is addressed by Planning reserves, Installed capacity, Operable capacity or Available capacity.

Security and Adequacy are clearly related since it is easier to keep a system secure when there is ample excess generation capacity. However, a system with limited adequacy can also be operated securely by simply maintaining sufficient reserves on hand even if that means curtailing customer loads (that approach has been used in California at the time of the energy crisis during Stage 3 alerts when reserves dropped below 2% and more recently in Texas on April 17, 2006 when online generation capacity could not meet unexpected high demand).

From an economic perspective, security and adequacy differ in the sense that security is a public good (like fire protection, national defense or clean air) while adequacy is (or can be) treated as a private good. With existing technology, it is not practical to offer differential security to customers, offering for instance exclusionary protection against system collapse. This creates externalities and potential "free rider" effects. Thus, while the resources that are needed to meet security needs can be procured through a competitive process the decisions concerning the amounts of ancillary services that are needed, how they should be dispatched and how should their cost be allocated to the various parties need to be centralized. By contrast, generation adequacy decisions can be decentralized and left to the market. Inadequate supply will result in high prices, which in turn encourage new capacity. Customers can be allowed to decide how much reserve capacity they want to pay for, whereas suppliers can decide how much to invest in new capacity. These are individual economic and risk management decisions that can be facilitated by developing the technological infrastructure for demand response and differential service provision.

Unfortunately, in most of the restructured systems the independent system operators (often influenced by political considerations) continue to operate under the old "obligation to serve" paradigm which leads to the treatment of generation adequacy as a public good, and to undermining the foundation of a market based system. Furthermore reliability criteria and the determination of planning and operating reserve quantities are not based on probabilistic analysis but rather on worst case scenarios that lead to costly and inefficient allocation of resources. In order to reap the potential benefits of electricity market restructuring it is essential to revisit the ways by which reliability standards are implemented. Whenever it is feasible risk should be diversified through market based mechanisms and metering and control technologies should be deployed that will convert involuntary outage risk to voluntary risk balanced by economic incentives for those who are willing to assume it. For non diversifiable operational risk, operational hedging mechanisms such as operating reserves should be procured and deployed based on decision analysis methods that balance the cost of outage and equipment damage against the mitigation cost and attempts to minimize the overall expected performance that reflects societal tradeoffs between reliability and cost as well as risk preferences.

IV. Research and Educational Challenges

Implementing planning and operation practices based on Probabilistic risk analysis and Economic-based risk mitigation, whenever appropriate, poses political challenges since it requires removal of regulatory and institutional impediments to the exercise of individual risk preferences. It also poses methodological and implementation challenges that require new research as well as curricular innovation and training of a new breed of engineers that are versed in technology, statistics, economics and finance. Such multidisciplinary training is essential for dealing with the complexities of the restructured electricity infrastructure. This infrastructure combines the physical aspects of the network and the economic behavior of the market participants who control the resources that are needed to ensure efficient and reliable operation of the electricity system. Of course a precondition

The research and development agenda needed to support personnel training and to facilitate implementation of the proposed paradigm shift includes:

- Development of market instruments, markets and institutions for risk trading and risk sharing. Such development should be viewed as "Market Engineering" which builds on the "physics" of markets explored by social sciences (including economics) but focuses on the harnessing of market forces and human behavior to achieve a desired outcome.
- Create mechanisms for transforming involuntary private risks to voluntary risk so as to empower individual choice. Without individual choice market based risk mitigation is not possible.
- Develop decision analytic methodologies that integrate expert risk assessment with market based pricing of risk (e.g. decision theory, real option theory, financial engineering methods)
- Develop pricing and portfolio analysis methods for valuation and optimization of risk mitigation options.