Preface

Electric power networks are, in general, among the most complex yet most reliable systems engineered by man. However, these large interconnected systems often operate under high stresses because of the increasing demand for electric energy and the difficulty of improving the infrastructure due to economic and environmental constraints. The major challenges facing the electric power industry today include the need for balancing resource adequacy, safety, network reliability, stability, economics, environmental and other public objectives to optimize resources while satisfying the growing demand. This optimization must be performed with due consideration of such constraints as having to meet reliability criteria and stability margins.

Armed with such a vision, this book covers a wide spectrum of issues ranging from methods for balancing the resources to various reliability and security aspects of the electrical grid. These topics are presented by a number of prominent researchers, scientists and practitioners from many countries. While the book focuses on the technological breakthroughs and roadmaps for implementing new technologies, it also presents a much needed forum for sharing of the best practices.

Chapter 1 describes some strategies for meeting challenges to the grid's ability to provide reliable power delivery. Solutions are offered through applications of modern technologies, such as advanced feedback control schemes using wide area measurements, wide-area visualization techniques, and intelligent operational tools applying Standard IEC-61850 and information semantics. The goal is to provide a vision for a comprehensive and systematic approach to meet the criteria for grid safety and reliability through new information services. Some of the concepts suggested in this chapter, such as advanced information services combined with the new computational paradigms for maintenance and on-line power equipment diagnostic, and integrating data from a myriad of sensors, will be instrumental in achieving the reliability, efficiency, and financial soundness of future power grids.

In the present business environment of competition and re-regulation, the determination of asset values and methods of reaching the best investment decisions are of increasing interest. Traditional approaches to establishing maintenance and replacement expenditures can no longer satisfy regulators or bottom-line-driven decision-makers. Chapter 2 addresses the subject of optimal maintenance policies for power equipment. In the emerging operating environment of deregulation and market-based competition, every management decision involves a certain amount of risk. These risks need to be evaluated and courses of actions selected so that the risks are minimized. Quantitative methods are needed that combine technical aspects with financial and business risk factors. For quantitative risk evaluations, analytical tools are necessary.

For the maintenance (or asset sustainment) function at an electric utility, the following question is of particular interest: Faced with multiple options for re-investment in equipment maintenance, what is the best course of action to take in order to maximize reliability at minimum cost? The decision-maker can use several criteria for selecting the best reinvestment policy. In the past, engineers operating an electric power system were mainly concerned about equipment reliability, with the financial aspect playing a secondary role. However, in the new economic environment, the reliability and financial aspects of system operation will be equally important. Hence, both reliability and cost should be considered in the selection of maintenance alternatives. With this in mind, a substantial effort has been made to develop suitable mathematical models and decision support tools to address the issue of maintenance/refurbishment/investment option selection.

Mathematical models can be deterministic or probabilistic. Because maintenance models are used for predicting the effects of maintenance in the future, probabilistic methods are more appropriate than deterministic ones, even if the price for their use is increased complexity and a consequent loss in transparency. For these reasons, the use of such methods is spreading only slowly. Examples of simpler mathematical models, still based on fixed maintenance intervals (scheduled maintenance) are compared with more complex ones that incorporate the idea of condition monitoring, where decisions about the timing and amount of maintenance are dependent on the actual condition of the device (predictive maintenance). Such policies can be optimized with respect to any of the model parameters, such as the frequency of inspections or the life-cycle costs. This chapter also discusses model optimization, both through a sensitivity analysis and through a mathematical formalism.

The development of theoretical and practical aids for selecting reliability models for power system equipment represents a very active area of research. This topic is addressed in Chap. 3. The main purpose of this chapter is to present an up-to-date review of the basic theoretical and practical aspects of the major reliability models. The presentation also includes a review of some models that are rarely discussed in the literature, but that, in the authors' opinion, can be very useful. Some new models or new ways of justifying the usefulness of the older models are also presented. These aspects are illustrated with practical examples that show how to perform rational model selection. The authors stress that the analyst should spend a sufficient amount of time in performing the preliminary analysis to fully understand the consequences of adopting—sometimes without sufficient information—a given model.

The second purpose of this chapter, closely related to the first, is to highlight the rationale behind a selection of the models that are based on the phenomenological and physical characteristics of the aging of the power system equipment. These models consider the probabilistic laws governing the stresses acting on the devices and the degradation (deterioration) processes that the equipment or its components are often subjected to. The authors argue that this "technological" approach, which is also referred to in the recent literature as an "indirect reliability assessment", might be in practice the only feasible tactic available to the researcher in the presence of a limited amount of data, as is typically the case in the field of modern power systems. The chapter also addresses the relationship between purely mathematical models and those exploiting the physical characteristics of the devices.

Equipment reliability models also constitute a basic building block in the analysis of the entire electric power network. As a matter of fact, the development of mathematical models representing the reliability characteristics of the electrical devices went hand-in-hand with the development of power system reliability evaluation techniques. New technological developments in power system generation and transmission warrant a new look at the well-established reliability assessment methods. In particular, renewable energy resources are receiving considerable attention in the continued deployment, growth and development of bulk electric power systems. At the present time, the most promising new source of electrical energy is wind power and the governments around the world are making commitments to add considerable amount of this new generation resource to the existing power grids. This is discussed in Chap. 4. The increasing use of wind power clearly indicates the importance of reassessing the traditional models for the reliability evaluation of the composite power systems containing significant amounts of wind energy.

To address this issue, Chap. 4 proposes advanced methodologies for adequacy assessment of integrated composite generation and transmission systems containing wind generators. Adequacy evaluation of composite generation and transmission systems is a complex task that includes detailed modelling of the generation and transmission facilities. The emergence of wind generation as an important electrical energy source creates some challenging complications in evaluating the adequacy of composite systems, because wind power behaves quite differently from the conventional electric power generating facilities. This chapter discusses the general area of composite system adequacy evaluation and some of the new techniques that can be utilized to incorporate wind power in a system assessment. Wind power modelling in both generation and composite system adequacy evaluation is discussed and illustrated by application of the proposed method to the two well-known reliability test systems. The studies presented utilize sequential and non-sequential Monte Carlo simulation and illustrate the effects of addition of independent and correlated wind generation to the two test systems.

One of the goals of a bulk electric system reliability evaluation is the determination of a need for new investments in the grid infrastructure. This is discussed in Chap. 5. Utilities may be asked by regulators (such as the North American Electric Reliability Corporation [NERC] in the United States) to identify their transmission line and substation facilities that are critical for operation of the power network. Generators, transmission lines, and power transformers represent the major portion of bulk transmission systems, and these assets should perform well in order to achieve a high level of reliability for the bulk power system. Such high performance can be achieved if there are no restrictions on budgets. In many cases, budget constraints have been imposed, and the owner of the system has to set priorities with regard to the work that needs to be done on those transmission components. Such work may involve large or small projects, depending on the objective and the importance of each project. Depending on the network configuration, and on how loads and generators are connected to the network, the consequences of generation and transmission component outages could be more or less significant. One of the goals of a bulk electric system reliability evaluation is the determination of a need for new investments in the grid infrastructure. This is discussed in Chap. 5. Utilities may be asked by regulators (such as the North American Electric Reliability Corporation [NERC] in the United States) to identify their transmission line and substation facilities that are critical for operation of the power network. Generators, transmission lines, and power transformers represent the major portion of bulk transmission systems, and these assets should perform well in order to achieve a high level of reliability for the bulk power system. Such high performance can be achieved if there are no restrictions on budgets. In many cases, budget constraints have been imposed, and the owner of the system has to set priorities with regard to the work that needs to be done on those transmission components. Such work may involve large or small tasks depending on the objective and the importance of each project. Depending on the network configuration, and on how loads and generators are connected to the network, the consequences of generation and transmission component outages could be more or less significant.

A facility-ranking procedure would help utilities perform critical facility assessment. A documented assessment procedure for identifying and ranking facilities will help utilities justify assessment results. Additionally, scarcity of resources, both financial and human, requires that the available funds are directed to the places that would benefit the network the most. For all these reasons, robust and accurate ranking procedures could be very helpful. This topic is addressed in Chap. 5. The proposed approach utilizes some concepts of the spectral graph theory to rank electric power substations in a high-voltage network. This approach is only one of the possible approaches to finding the most critical facilities in the network. Other approaches could include additional information related to the reliability of the system components. This extension of the ideas presented in Chap. 5 will undoubtedly be the subject of new research in the near future.

Continuing with the theme of identifying the critical infrastructure in an electric power grid, a logical extension of this topic is the question how to reinforce the grid so that the networks are adequately fulfilling their design tasks. This question is addressed by transmission system planners. The main objective of multistage transmission expansion planning (TEP) is to define where, when, and what reinforcements should be placed in the network to ensure an adequate quality level of energy supply to customers. In a competitive energy market, TEP is a complex optimization task to ensure that the power system will meet the predicted demand and the security criteria, along the planning horizon, while minimizing investment, operational, and interruption costs. This practice is the only rational response to conflicting customer and regulatory demands.

Several approaches for solving the TEP challenges can be found in the literature, however, only a few have considered the multi-stage nature of the TEP problem. The multi-stage nature of the TEP problem requires consideration of multiple time periods, determining possible sequences of transmission reinforcements. To deal with the multi-stage nature of the problem, simplified studies (also known as static analyses) can determine, for just one stage, where new transmission facilities should be installed. Different from most approaches to static planning, the ideas presented in this chapter solve the TEP problem considering the chronology of reinforcements. The goal of the suggested approach is not only to define what reinforcements should be placed in the electrical network and their corresponding locations, but also when they should be added within the planning horizon to ensure an adequate level of energy supply to the customers. In the end, the best expansion plans must be selected in order to minimize the present value costs defined in the objective function.

Whereas the transmission expansion planning is a purely system planning problem, modeling of the day-to-day operation of the power system is of interest also to researchers involved with issues of system operation. In the restructured environment, the improvement of the economic efficiency of the electricity markets has been the focus of several studies. Central to these efforts is a better understanding of the nature of the tight coupling between market and system operations. An important aspect of this coupling is the dependence of market outcomes on the way the system is operated. A key driver in system operations is the security criterion, with which compliance must be ensured. Chap. 7 focuses on the dependence of market performance on system security. In this chapter, the authors propose an approach to quantify market performance as a function of a specified security criterion for both single- and multi-settlement environments.

The chapter investigates the interactions between the system security criterion and the associated economics in terms of the marginal costing—used to determine the security prices—and the evaluation of expected system security costs. The problem is analyzed in various contexts by both empirical and analytical means. The empirical studies investigate the adverse impacts of market participants' behaviours on the performance of electricity markets. The analytical studies, on the other hand, focus on the impacts of constrained system operations on markets to determine the unavoidable losses in the economic efficiency of electricity markets.

The expected system security costs are evaluated, taking explicitly into account the random nature of the outages and the costs of the required security control actions to deal with them. The authors argue that there is a clear need, in the restructured environment, to quantify market performance as a function of system security in a way that appropriately reflects the regional transmission operations. This quantification further requires the consideration of different market and system conditions that may exist within a period in order to capture the range of impacts under such conditions. One approach to address this issue is a cost/benefit analysis, taking into account the expected costs of operating the system and the expected outage costs. Such an approach may be viewed as the application of the notion of "value of reliability", which obviously is a topic of great interest to the market participants.

It is a well-known fact that the increase in energy demand and the advent of the deregulated market mean that both the static and the dynamic system limits must be considered in a modern power systems reliability analysis. Chapter 8 discusses a general analytical method for the probabilistic evaluation of power system transient stability. The chapter also reviews some of the basic contributions available in the relevant literature and previous results obtained by the authors. The first part of the chapter introduces the basic concepts required for the calculation of the probability of system stability. The chapter characterizes the random variables that enter this analysis (e.g. system load, fault clearing time, and critical clearing time) and discusses the methods of analytical or numerical calculations. The values of these parameters are uncertain, and the discussion in this chapter shows that ignoring the uncertainty may lead to a serious underestimation of the probability of system instability.

A Bayesian statistical inference approach is then proposed for the probabilistic transient stability assessment; in particular, the chapter discusses both point and interval estimation of the transient instability probability of a given system. A Bayesian approach is particularly useful in this context, because the parameters affecting transient stability probability (e.g., mean values and variances of the above random variables) are not generally known and have to be estimated. The authors propose application of the well-established system models for the description of the load evolution in time.

The second part of the chapter investigates a new aspect of the on-line statistical estimation of the transient instability probability. The goal is to predict whether the system will become unstable with the help of advanced modelling tools, including a new Bayesian approach utilizing the Dynamic Linear Model for the stochastic evolution of the system load.

A major hurdle in the widespread application of the probabilistic transient stability analysis was the low computational efficiency of the classical models. In the numerical studies discussed in this chapter, the authors show that computations involving "tracking" of the transient stability versus time can be performed very fast.

The reported results could be very important in a modern, liberalized market in which fast and large variations of load and generation are expected to have a significant effect on the transient stability probability. To conclude the chapter, some results on the robustness of the estimation procedure are also briefly discussed. The discussion demonstrates that the assumptions regarding the system parameter distributions do not affect the efficiency of the proposed approach.

To perform efficient and accurate probabilistic analysis of the system transient stability, network parameters must be well defined. This conclusion became even more obvious after a number of reports analyzing the 2003 blackouts events pointed out that several national and transnational grids had been managed without sufficient real-time data, particularly in the presence of a large number of new uncertainties. Reliable real-time data, oriented to the monitoring of system dynamics, were not available, and the operators did not have enough time to take decisive and appropriate remedial actions. What has become clear is that, after the blackouts of 2003, despite the revolution driven by electric industry restructuring and energy market re-regulation, the general approach to power system security has not changed. A key feature is still the lack of dynamic data concerning key system parameters.

Chapter 9 discusses estimation of dynamic system parameters. In this chapter, the authors propose an optimization method, utilizing a nonlinear programming algorithm, to obtain such estimates. In the proposed procedure, time domain simulation trajectories are compared with on-line measurements in order to update or estimate dynamic parameters. The main advantage of this method is its flexibility because it can be adopted for estimating parameters such as synchronous machine constants, external network equivalents or the constants for frequency or voltage dependent loads. The authors show that the methodology can be applied during the on-line power system operation and provides a more reliable database for real-time dynamic security and control. In fact, a frequent update of the power system dynamic model can guarantee more reliable simulations and, consequently, more effective control.

Finally, Chap. 10 addresses advanced methodologies for reliable power flow analysis in the presence of data uncertainties. Power flow analysis is used to determine the steady state of the power system for a specified set of load and generation values. It is one of the most extensively used tools in various power engineering applications, including network optimization, voltage control, state estimation, and market studies.

The most common formulation of the power flow problem—the deterministic power flow—has all input data specified from the snapshot corresponding to a selected point in time. Alternatively, the analyst can construct data to reflect the required assumption about the expected generation/load profiles for a certain peak demand condition. The solution for the study is deemed representative for a limited set of system conditions. However, when the input conditions are uncertain, there is a need to analyze numerous scenarios to cover the range of uncertainty. Under such conditions, reliable solution algorithms, incorporating the effect of data uncertainty into the power flow analysis, are, therefore, required. Reliable power flow solution algorithms allow the analyst to estimate both the uncertainty in the input data and in the solution tolerance. In this way, the uncertainty propagation effect is explicitly represented, and the level of confidence of power flow studies can be assessed.

Acknowledgment We would like to thank Dr. Giosuè di Franco for his valuable support in editing the book.

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http://www.springer.com/978-0-85729-087-8

Innovations in Power Systems Reliability
Anders, G.; Vaccaro, A. (Eds.)
2011, XVI, 364 p., Hardcover
ISBN: 978-0-85729-087-8