INTRODUCTION

Motto: The “millennial” generation have also been called the Net generation because they are the first generation that has not known life without the Internet.

Power systems are the most complex systems ever devised by man. This is primarily for several reasons. The electrical transmission networks can consist of hundred or even thousands of substations to which power plants, lines, transformers, and/or consumers are connected. These substations are typically distributed across wide geographical areas, which can be separated by tens, hundreds, or even thousands of kilometers. Finally, generation sources that exist within these networks can at times be located at great distances from each other, yet must operate synchronously to continuously balance the load.

In order to achieve operation security and economical benefits, the electrical power systems have been expanded at all levels and interconnections have been developed linking neighbor electrical networks from local to national level and from national to continental and even to planetary dimension.

Expanding the power system interconnections is critical to allow transfer of the electrical energy over long distances from locations where the primary energy resources are available to the large consumers that include cities and industries. The actual trend is to exploit the clean energy sources, for example, wind and solar, which causes changing of the usual generation pattern. The strong wind and high-rated power wind turbines suitable for the offshore locations in North Sea, the U.S. coast Mid-Atlantic, and so
on are attractive “ingredients” for designing large generation projects. Similar attention
is paid to the sunny land in North Africa or Australia to construct large photovoltaic
power plants.

However, changing the generation pattern may require strengthening parts of
the electrical network by increasing the transmission capacity or even by developing
new transmission corridors when the new clean resources-based power plants are
located very far from the consumption areas. Engineers think thereby to design
supergrids that allow transferring large amount of electrical energy over large distances.
In most cases, superhighways consisting of high-voltage direct current (HVDC)
links are required. The power electronic-based technologies become vital for the
power system operation. In the AC transmission systems, the FACTS devices may
significantly contribute to controlling the state parameters and deal with transient
processes.

Furthermore, advanced digital technologies have been implemented for protection and
control functions, able to anticipate, detect, and correct the changes occurring in the power
system parameters.

Most important is to realize that, although there are significant benefits provided by all
upgrades in the power systems, the amount of information has increased significantly. This
is in fact the biggest challenge for the power system operators that are responsible to safely
operate the power system. Furthermore, in the planning and operation activity, the system
operators need accurate modeling of the power system components and phenomena as well
as robust tools for both steady-state and dynamic analyses.

Although there are a large number of benefits of the power system inter-
connections, adverse effects are also recorded, which include increased risk of system
instability, especially related to voltage, generators’ angles, and low-frequency interarea
oscillations.

On the other hand, the transition toward open access electrical networks and
development of the electricity market lead to increased stressing conditions for the power
system operation and current congestions. In interconnected power systems, the physical
paths do not match the commercial contracts and “parasite” flow may create additional
problems. These may also explain the major grid blackouts that have occurred recently
even in highly developed regions from United States, Japan, and European countries, and
so on. For these reasons, the power system stability problem is one of the most important
carets of the power systems engineers.

However, the electrical energy is one of the humankind’s development “pylons.”
Stable and economical operation of power systems, subjected to environment protection,
is the main concern for power system engineers, who are continuously looking for
solutions to improve the power quality to the final consumer. This may include
the upgrade toward more “intelligent-smart” networks following the advancements
in telecommunications, hardware and software computation technologies, power
electronics, sensors, metering systems, wide area coordination systems, new electro-
technical materials, new generation technologies, and so on. Smart grids might be our
wish to create opportunities for better technologies able to coexist in harmony with the
nature.

Sir Isaac Newton once said about himself “If I have seen further than others it is
because I have stood on the shoulders of giants.” It is therefore our duty to acknowledge
prior work of great specialists, as mentioned also in the large number of references. In the
field of power system stability, it is worth mentioning some of the most important books
that were published over the years:
The idea of this book was born 7–8 years ago, encouraged by Professor Prabha Kundur after the visit to Romania as Distinguished Lecturer of IEEE. This is also the result of a strong relationship between coauthors after collaboration in a large number of activities organized under IEEE-PES and CIGRE, projects developed at European level or various educational programs. Several schools from seven countries have therefore joined to share their knowledge with other engineers. Each chapter reflects mainly the tradition and experience in topic of power system dynamics, stability, and control of the contributors’ schools.

Part I of the book, comprising Chapters 2–7, is devoted to “Power system modeling and control.”

The theory and modeling of the synchronous generator in steady state, under dynamic behavior as well as when subjected to a short circuit, are presented in the first part of Chapter 2. Modeling of various excitation systems and power system stabilizers is also included in the first part, as they are vital components of the synchronous generator for its stable operation. The second section is devoted to the induction motor, which is the most important dynamic component of the load. Starting from the known form of the electric circuits equations, the fundamental equations in the $d$-$q$ reference frame are developed for steady-state and transient operation studies. Other theories of load modeling are provided in Chapter 11.

Chapter 3 presents the modeling of the main components of the classical power plants, which include steam, gas, or hydraulic turbines. The first part provides the steam systems configurations, the corresponding mathematical models, and the governing systems. The next part includes the basic configurations and the model block diagrams of combined cycle power plants. The last part of the chapter includes the modeling of hydraulic prime movers and the main auxiliary control systems used in power system studies.

The wind turbine generating systems have gained their place in the power systems because the share of electrical energy produced by wind sources reaches high percentages in some countries and is continuously growing. From the power system operation point of
view special attention must be dedicated to wind turbine systems due to their intermittency in power generation. Chapter 4 describes the theory of energy extraction from wind and transformation into electrical energy. The classification of wind turbine systems and types of electrical generators are then provided. The second part presents the modeling and the vector control of the doubly fed induction generator and the permanent magnet synchronous generator-based wind turbine systems. The fault ride-through capability of these generation systems are described in the final.

Appropriate design of power system components and their protection systems is very important in order to avoid the effects of undesired but inevitable disturbances, for example, short circuits. Chapter 5 focuses on “Short-circuit currents calculation” methods in meshed and nonmeshed networks, based on the newest recommendations of the IEC Standards 60900-1–4. Three applications are provided in the final where calculation of the single-phase and the symmetrical three-phase short-circuit currents is performed for three different network configurations. These help the reader to understand what steps are needed to perform such calculations.

The main electrical quantities of the power system that define the electrical energy are the frequency and the voltage. As the load is affected by variation of either quantity, appropriate control actions are of great importance. Keeping the frequency and the voltage in predefined limits is also important for the stability of the power system.

The basic theory of “Active power and frequency control” is shown in Chapter 6. After a short presentation on the situation in Europe and United States, the chapter continues with the fundamental characteristics of frequency control, that is, system dynamics, inertia, droop, regulation, and dynamic frequency response. In order to understand the power system frequency performances, it is important to adequately model the power plants governors. Special attention is paid here to the thermal governor and hydraulic governor, respectively. In the second part of the chapter, development of a new model of thermal governor is presented. Then, the theory of area generation control in isolated systems as well as in multiarea systems is shown.

A more exhaustive approach of the “Voltage and reactive power control” is observed in Chapter 7. The principles and technologies used for controlling the voltage either by directly focusing on voltage or by acting on the reactive power are discussed in this chapter. Equations for a simple radial network are first written; then more complex models are developed for voltage control at regional and national levels, where centralized and coordinated actions are usually performed. This latter approach, which assumes a hierarchization of the control actions, similar to frequency control, is developed in detail. Greater attention is paid to the secondary voltage regulation system based on the Italian experience. This chapter also includes examples of hierarchical grid voltage control systems already in operation in some power systems (Italy and France) and implementation studies in other systems.

The second part of the book, titled “Power system stability and protection,” comprising Chapters 8–12, is devoted to evaluation of different forms of power system stability as well as analysis of critical situation experienced in power systems together with possible preventive or remedial solutions.

A “Background of power system stability” is provided in Chapter 8, as a preamble for the next chapters. Classification of the types of stability in a power system and a short description of each type are provided, based on reference publications of IEEE and CIGRE working groups. Before beginning to evaluate the stability of an electrical generator or the power system as a whole, it is very important to understand the nature of the problem that may cause instability and what quantity is most affected.
Small disturbances can occur at any moment in power systems as both the loads and
the power plants are characterized by a dynamic behavior. Safe operation of the
interconnected power systems assumes also that all generators are coherent to each other,
that is, they do not oscillate against each other. The theory of “Small-disturbance angle
stability and electromechanical oscillations damping” in power systems is presented in
Chapter 9, where all dynamic models are developed from an automatic system point of
view, appropriate for dynamic simulations. The causes of electromechanical oscillations
and the major factors affecting the damping of oscillations are first identified, and then
solutions for improvement of oscillations damping are proposed. One of these solutions
also includes the design of the power system stabilizer and tuning its parameters. To better
understand the theory, various applications are presented in the chapter.

Chapter 10, titled “Transient stability” covers the angle stability problem in the case of
large disturbances. The power system behavior, in general, and the synchronous generator,
in particular, are evaluated from simple to complex. The transient stability analysis begins
from the classical theory of the equal area criterion and integration methods and moves to
the more complex Lyapunov-based methods, emphasizing the Russian school in mathema-
tics and applications of Lyapunov theory in power systems. Dynamic equivalents are
also included in this chapter as a tool in transient stability assessment of large inter-
connected power systems. An educational exercise with equal area criterion and integration
of swing equation using both the trapeze method and the Runge–Kutta method on a simple
power system is presented at the end of chapter.

Small-disturbance and large-disturbance angular stabilities are related to the synchro-
nous generator. However, stability problems in power systems, as regards keeping the
voltage within secure operating limits, may appear due to the load. Chapter 11 relates
“Voltage stability” issues and explains the interaction between network, loads, and control
systems and the mechanisms leading to voltage instability. Voltage stability is assessed
here by methods and indices such as sensitivity analysis, modal analysis, the smallest
singular value, participation factors, or bifurcation theory. When a power system is
subjected to under-voltage problems, the means employed to bring the voltage within
security limits, for example, on-load tap changers or generators excitation systems, can
sometimes have opposite results worsening the voltage level. Based on such issues, some
countermeasures are discussed in the final.

Beyond any evaluation of the power system dynamic behavior, either seen as a whole
or decomposed in individual components, timely and correct actions are necessary through
dedicated protection systems in critical moments. Chapter 12, titled “Power system
protection,” presents a vision on the protection systems in the modern power systems,
which are based on digital devices, advanced telecommunication infrastructure, and wide
area coordination. Reliability, selectivity, speed of performance, recording for statistic
analysis, or adaptation to the power system conditions are the advantages of the new
protection systems, which are briefly discussed in this chapter.

The third part of the book approaches the problems of “Grid blackouts and restoration
processes.” The power systems are continuously subjected to critical events or stressed
operating conditions, which may push the system beyond the safety limit. The technology
has continuously advanced, but the major grid blackouts that happened around the
world in the last two decades shows that the power systems are still vulnerable. Maybe
the reason is that new causes of system security challenges have been added, such as:
still aged transmission infrastructure, increased number of natural disasters, higher
number of uncertainty factors caused by the electricity market, rapid changes in network
operation due to intermittent renewable energy sources, insufficient training of human
operators, or even military attack. However, many of these causes may reside in financial aspects.

On this line, Chapter 13, titled “Major grid blackouts: analysis, classification, and prevention,” discusses the most important partial or total blackouts that occurred in power systems over the years. The chain of power system conditions and events that have led to blackout, also including the resynchronization, are first explained. Learning from history is very important for the human in order to design better machinery or to better train the engineers assisting the machinery, since the blackouts have major economical and social implications.

On the other hand, Chapter 14, titled “Restoration processes after blackouts,” presents the way in which a power system can be reenergized after a blackout by contribution of individual power plants, through their black-start capability. The analysis is focusing on modeling the gas turbine and combined cycle power plants in the dynamic process of system restoration.

A deeper evaluation of the transient phenomena is presented in Chapter 15, based on “Computer simulation of scale-bridging transients in power systems.” The chapter shows how various scale-bridging phenomena ranging from electromagnetic to electromechanical transients are modeled efficiently. Simulation of a blackout based on this theory is also provided.

The book is written in a didactic fashion and addressed to a broad category of power system engineers, from master and Ph.D. students to practicing engineers involved in power system operation and design, equipment manufacturers, telecommunications, and so on.