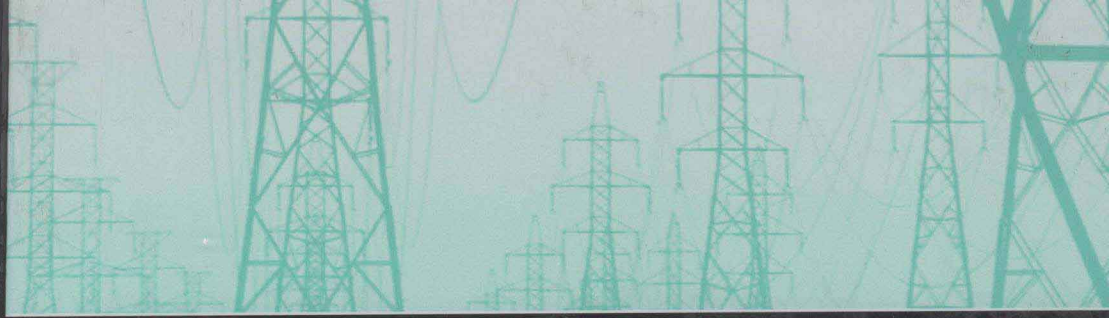

Electricity Power Generation

The Changing Dimensions

DIGAMBER M. TAGARE

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FOREWORD

It is with pleasure that I write this foreword to *Electricity Power Generation: The Changing Dimensions,* written by my esteemed friend, Mr. D. M. Tagare. Mr. Tagare and I have worked in the field of power generation and power management over the last 50 years. Mr. Tagare is known in India for his outstanding work in the field of power capacitors and filters. He was the chairman of capacitor division of Indian Electrical and Electronics Manufacturers Association and piloted growth and development of the industry for a number of years. He has published books on capacitors and reactive management that have received worldwide acclaim. This book is the result of decades of experience. It will enhance the knowledge of persons working in the power sector, both young and old. The book provides the latest knowledge on issues of electricity generation.

The electricity sector structure has changed rapidly, especially during the last 20 years. From a monopoly line-function structure, power generation and power trading have been transformed into a competitive industry. This has attracted the attention of planners, economists, managers, industrial engineers, and civil servants. Thus, there is a migration of other sector experts to the electricity sector. These experts require education and knowledge of electricity generation, not only basic, but most up-to-date, covering the latest and upcoming technologies, such as fuel cells and hydrogen. All these areas together with new and renewable energy generation are well covered in the book. Besides meeting the needs of working engineers in the sector, this book will also meet the needs of students working in the field of energy management, energy consultants, auditors, civil servants, industrial managers, economists, and planners. The book will serve as handbook and will be a useful addition to technical libraries.

Every technology over the years seeks to improve efficiencies; electricity power generation is no exception. Constant endeavor is made to achieve higher efficiencies through higher pressures and temperatures and so on. The development of power electronics, computer engineering, and information technology (IT) has added new dimensions to the electricity generation sector. Complete automation in working is achieved. Thus, the electricity engineer is required to acquire knowledge in these fields as applicable to his or her sector. The book includes updates on these subjects associated with electrical engineering. This enhances the value of the book by directly covering these

areas but also by giving generous references to IEEE publications. Thus, for obtaining further detailed/intimate knowledge of the subject, an engineer has at hand relevant literature. Together with the references, this book will serve the needs of research scholars.

The most prevalent and commercial services of power generation via hydroelectricity generation, thermal power generation, and nuclear power generation are covered in Chapters 2 to 8 of the book. The significant points to be noted are:

1. Hydroelectricity generation covers pumped storage systems and oceanic-energy-based electricity systems.
2. Thermal power generation covers the requirements of rigid frequency and voltage controls, a must in modern systems. Two chapters are assigned to environmental concerns, acid rain, and carbon emissions. Rarely are such details found in a book on electricity generation.
3. In the chapter on nuclear power generation, mention is made of smaller marketable nuclear power plants developed by Japan and Russia. These plants are used to power nuclear submarines.

After extensive coverage of conventional generation plants, the author covers in Chapters 9 to 11 cover wind power generation, solar power systems, and fuel cells. Wind power generation is now an accepted method, whereas other technologies are fast developing. Persons working in the field of power generation will often be confronted with these applications, as governments in various countries are making it mandatory to get such generation up to a certain percentage of the total. Chapter 12 on hybrid systems covers the combination of the renewable systems. Chapter 17 on the hydrogen era describes a technology of future that is in the nascent stage. However, basic knowledge of the process is necessary for a practicing electrical engineer.

The author's practical approach is exhibited through Chapter 13 on cogeneration, Chapter 14 on distributed generation (DG), Chapter 15 on interconnecting distributed resources, and Chapter 16 on energy storage. These chapters provide information for field engineers, consultants on the issues, and power system engineers who face these issues in daily life. These issues, once again, are rarely incorporated in books on electricity generation. Distributed generation is coming up in a large way to improve system reliability and reduce transmission and distribution losses. However, there are interconnection problems. I am happy that the issue is fully explained here. Demand-side management is an issue in power systems that cannot be sidetracked. Power storage provides a solution.

Chapter 18 gives a brief outline of power marketing and is a must for every engineer working in a generating company. Merely increasing and optimizing generation is not adequate. This power has to be sold. Thus, without an insight in power marketing, the knowledge base of a generation executive is not complete.

Electricity reforms are taking place all over the world. The executives in the power sectors are facing constant competition. In a competitive world without sound knowledge of the subject and knowledge of the latest technological developments, the com-

petition cannot be faced. The book will impart the necessary knowledge to senior as well as junior executives, and can be used as textbook and a reference handbook. I congratulate Mr. D. M. Tagare on this excellent publication and wish him all success. I am confident the book will receive worldwide acclaim.

P. L. NENE
Former Chairman, Madhya Pradesh Electricity Board
Bhopal, India

PREFACE

The historical growth of the electricity business has been the result of a continuously growing demand for electricity. It came about through careful nurturing under the monopolistic conditions under which it was born. This growth fell short of meeting a rising demand for electricity in quantity, quality, and price. There grew up buffeting forces, such as concerns on environmental damages associated with its production and open marketing of electricity as a commodity. The system, which had become stagnant and contented, could not attract innovative young engineers. It had to change.

These changes did come and are coming still. They came through structural changes in business, both in management and in sales. Revolutionary and possibly epoch-making changes are in the making in the outlook on sources of energy and its utilization through energy reserves. Smug reliance on buried but presently cheap fossil fuels is giving way to finding ways to utilize abundant amounts of energy in nature: water from the mountains and the seas, air, the sun's rays, and bioproducts. Research is concentrated on bottling up electricity in small or large reserves. In short, its dimensions are changing, demanding innovation. This book is about these changing dimensions and how existing producers are trying to adapt to the changes. It begins by outlining the structural changes which have and are taking place in the electricity business all over the world.

Hydroelectricity is our strongest ally during this transition. Its logical growth and renovation in operation are explained in Chapter 2. Apart from producing electricity as and when we want it, it has produced economic prosperity in the basins it serves. Pumped storage, minor electricity production based on irrigation canals, seasonal cascades, and seawater tides and waves were once experimented upon and shelved as being nonviable. They have rising dimensions now and offer scope for innovation and wealth production. Chapter 3 details these. Noncontinuous energy supply from the seas and its adoption in the existing electricity supply grids demands a look.

Thermal electricity power generation today is the backbone of electricity business. Universally available coal is the main fuel. A close look is being taken into the methods of its use. Emphasis is shifting from the size of generators to better efficiencies through higher temperatures and pressures, and, consequently, through combined cycle plant processes. With interconnections and rising transmission grid sizes, the old NERC norms meant for bringing uniformity in the rising electricity systems are giving

way to new norms such as dispersed reliability reserves in specified droop characteristics of generators, very stringent system frequency controls, and so on. Power marketing has brought renovations in maintenance systems of generators in general. Chapters 4 and 5 cover these aspects of thermal generation.

Acid rain resulting from oxidation of sulfur present in fossil fuels and of nitrogen in air have a limited product volume. These can be and are contained, at a cost. Past legislation and current costs for containing acid rain, along with its measurement and reporting systems, are given in Chapter 6.

Carbon emissions, on the other hand, spread out and have to be attacked at the generating source, only by cutting down on thermal generation. This is rather a tall order, considering that thermal generation is the main electricity producer today. Containing carbon emissions in times of rising electricity requirements is undertaken as a main task by the United Nations Framework Convention on Climate Change (UNFCCC). The efforts are backed up by no less than a former president of the United States, Nobel prize winners, and governments all over the world. Limitations agreed to upon, from time to time, such as the Kyoto Protocols, are voluntary. Inducements, both for developed countries and for developing countries, are continuously worked out by UNFCCC. At the time of this writing, there are as many as 57 different schemes on the Internet for earning these inducements. Chapter 7 gives basic details. There is a good scope for self-learning and helping out on these efforts for electrical engineers.

Nuclear power generation, promises to be one of the major tools in the struggle against carbon emissions. Its association with mass destruction, the possibility of misuse of its materials, and high costs and long implementation delays are the major deterrents. Safety considerations require special categorization of its in-plant cable and wiring layouts. Safety drills are a must in these plants. Safety is also important in disposal of the waste materials. Accidents at these plants could be catastrophic, as happened at Chernobyl in Russia. Chapter 8 details all these issues. Smaller marketable nuclear power plants have been developed by Japan and Russia. These represent small plants used for power in nuclear submarines with improvements that reduce the life of waste materials. Avenues for developments in nuclear power applications are listed.

Wind power generation is a leading contender for maximum share in electricity generation by renewable energy sources. Denmark, in association with hydroelectricity sources from Sweden, claims 100% wind energy for its total energy requirements. The fluctuating and unpredictable nature of wind power creates technical as well as managerial problems in its adoption in power grids. Low-voltage ride-through and modeling parameters required by grid managers are technical problems. Maximum penetration limits and capacity factor are the managerial problems. Accurate supply quantity and timing predictions are the marketer's problems. Chapter 10, with its long list of references, covers these aspects.

Photovoltaic energy is the most vied for energy source among the renewable sources. It has a basic regularity in magnitude and timing all over the world. However, atmospheric conditions, high costs of solar cells, and large surface areas required have deterred its wider application so far. Maximum power point trackers are a universal solution for utilizing PV energy. Interfacing with grids increases the costs due to the need for power conditioners. Interfacing also raises technical problems, such as high

ramping rates up or down, loss of load possibilities, and a limitation on its penetration into the grid. Presently, it is best suited as a low-volume dispersed energy generator, particularly for agricultural water pumps and residences. These aspects are covered in Chapter 11. The chapter also covers expanding application ranges for solar panels.

Fuel cells are the latest entrants on the electricity generation scene. Instead of generating thermal energy through chemical conversion like oxidation of H2 by burning, they draw out the energy electronically. Efficiencies claimed are high. Proton energy membranes (PEMs) for fuel cells operating at low temperatures (80°C) have come up fast. Present developments cast these fuel cells as low-volume dispersed electricity generators, with main applications in automobiles. They are making inroads in the electricity requirements of other customers, such as hotels, hospitals, and residential complexes, not in competition with grid supplies, but as supplementary suppliers, contributing to electricity cost reduction. Solid oxide fuel cells operating at higher temperatures have possible applications in the larger megawatt ratings. Fuel cells have scope for R&D both in basic membranes and customer-end applications. Chapter 12 deals with these issues.

Stand-alone hybrid systems are sprouting up all over the world. Chapter 12 gives detailed analytical study of six alternative hybrid stand-alone systems for a remote Mexican village. Support batteries for a PV cell array have low lives and are costly. Their use should be optimized. Fuel cells are fast replacing storage batteries in hybrids. Cases of unique midsea island-based wind energy hybrids are interesting for optimally using diesel oil. Limitations, interconnections, and controls between a hybrid and a grid become demanding as individual cases arise. Chapter 12 deals with these systems. Hybrid cars are an intermediate stage to fully electric cars. They are developing at a fast rate.

Combined generation has long been in operation and is reliably providing electricity. Equally important is its ability to utilize otherwise wasted thermal energy since their generating capacities are considerable. Existing thermal electricity generators formed strict rules for admitting this combined generation into their grids. Combined generation could influence grid parameters considerably. It was also under a sort of dual control. Its control system, vis-à-vis the grid parameters, had to be watched. It could and did operate in an islanded condition with or without a portion of the main grid. Its partnership with the grid, which was on an on-again/off- again basis, has now turned into a permanent basis, mainly due to relief it provides under environmental concerns as well as under open marketing system. To cite an example, a cooperative sugar factory in India earned revenue from sale of electricity to a state electricity board, compatible with the revenue it earned from the sale of its sugar. In another example cited, a refinery cut down its electricity bill from the grid supply. Combined generation has good scope for optimization. Chapter 13 covers combined generation.

A fairly large population of gas/oil-based piston/turbine-driven generators are dispersed across a sizeable distribution network of electric power systems. Their main purpose is to support distribution networks with active/reactive power at their weak points. They are put in by growing distribution systems as an economic alternative to other systems. They are also put in by private operators, preferably at load points. Chapter 14 shows that distributed generation (DG) power systems are not under area

control and are not allowed operations that will impact system parameters such as frequency and voltage. They do alter local short-circuit levels. DGs give support to problems such as ride-through during voltage dips, small-disturbance stability, fuse ratings and relay settings, load flows, and so on. Upon a system disturbance, they must disconnect instantly through special relays like voltage vector relays and rate of change of frequency relays. Location at load centers, selling energy under peak load periods, selling contingency reserves, and so on can make them lucrative for private operators. Large-sized stand-by generators in industries are not allowed to connect into a distribution system. The Pune system, developed to help a distribution company with these standby generators, allows industries to "sell" power without actually putting current into the distribution network. A concept of distributed marketing centers is being promoted in Britain. Under this concept, local distribution generation will be given incentives to compete in the electric supply, particularly under peak-load conditions as well as under emergency conditions. It will help in breaking the barriers on wind energy penetration as well as in improving the utilization of the existing electricity systems.

Chapter 15 deals with distributed resources (DR) with higher power capacities and compatible power control systems. They connect into the upper voltage end of distribution system and are under command of the main system operation. These DRs can participate directly in power market operations. Typical examples are wind turbine generators. Interconnection systems covered here relate to system controls, system protection, steady-state control on system parameters like voltages, frequency, power factor, and so on. The interconnections impose restraints on both sides at the point of common coupling (PCC). Power quality windows specify upper and lower limits on voltages, frequencies, and harmonics. Operations recommended under islanding conditions and reconnections are given. Safety aspects are also sketched out. For exact and accurate information, it is recommended to refer to IEEE standards mentioned at the end of the reference list.

Chapter 16 on energy stores begins with the advantages of various types which are available and their applications, particularly to electrical power systems. Distribution system parameters, load density, and short-circuit capacity influence their applications. Details of a storage design to support the fluctuating nature of a PV system are given. This is followed by a detailed storage design for wind energy. Energy output from this store and its revenue earning capacity under different control nodes of storage are given. Compressed air energy storage is gaining attention. Energy stores are important for utilizing nature's abundant energy supply. The subject is an evolving challenge.

Hydrogen is looked upon as a remedy against atmospheric pollution. First, atmospheric pollution sources, their lifetimes, and rates of increases are presented. Hydrogen properties are given next. Production processes of hydrogen, their costs, and performance characteristics are given. Roadblocks to development and spread in usage are discussed. Various governments have appointed special commissions for recommendations on tackling these issues. A proposal for producing hydrogen from nuclear power is outlined. Chapter 17 covers these aspects.

Chapter 18 covers the basic structure of power marketing of electricity. The first part covers market operators, their tools, and objectives. Objectives are also laid out for transmission, still a monopoly, and wholesale markets. The second part covers cap-

ital investment prospects under the revised circumstances. Attention is given to promoting investment in the transmission sector, which is now not a market player.

Chapter 19 looks into the future with transfer of the energy source for automobiles from fuels to electricity. Thermal electricity generation will increase rather than diminish. It will not stay contained. Can future energy stores come in packs on racks in a commodity store? Electricity power production is not constrained to its old ways. It is evolving and challenging. The book tries to open up these vistas.

Many thanks go to the IEEE for its permission to dig into and borrow from their publications, on which this book is almost wholly based. I thank the IEEE Press and John Wiley & Sons, Inc. for publishing the book. I have to thank Mr. P. L Nene, ex-chairman of Madhya Pradesh Electricity Board (MPEB), for his support and Foreword. Thanks are due to Mr. Dwarkanath, ex-chief engineer, thermal generation, of MPEB, for his help. Thanks are due to my staff, particularly to Mr. Abhijit Katepallewar for his untiring help in getting this in print.

Last but not the least, thanks are due to my wife, Mira, for her enduring patience with me and support.

DIGAMBAR M. TAGARE

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CONTENTS