Power System Analysis

SECOND EDITION

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Preface to the Second Edition

Our title *Power System Analysis* was published in 2007 and since then it has been readily accepted as a standard textbook both at the graduate and postgraduate levels. This second edition is a gradational revision of the power systems analysis course. Without disturbing the simple and mellifluous flow of the language, the second edition aims to fulfil the following objectives:

- Reflect the overall changes in the energy sector scenario which have come about during the past five years or so
- Further fortify the understanding of principles of power system analysis
- Expose readers to current topics such as *voltage stability* which have acquired significance in the context of large integrated power systems operating close to their maximum capacity

New to the Second Edition

The purpose of revising the already accepted title *Power System Analysis* was to see it as an opportunity to bring about improvements. Therefore, the changes which have been incorporated in the second edition are largely based on the following:

- Suggestions from students and faculty members in various institutions
- Our continual references to look for 'chinks in the armour' in our work
- Periodic comments from the publisher's reviewers

Common Features

The most important change in the second edition is the inclusion of the following in each of the chapters:

- *Learning Outcomes* at the beginning of each chapter defines the results a reader will be able to achieve following a study of the chapter.
- End chapter *Summary*, along with *Significant Formulae*, provides a recapitulation of the chapter.
- Descriptive questions have been included in the chapter end *Exercises*.
- *Multiple Choice Objective Questions*, with one correct answer, have been added to enable a reader to quickly gauge his/her understanding and retentivity of the principles and laws of power system analysis.
- Existing terminology, principles, laws, symbology, etc., wherever required have been further clarified.

Extended Chapter Material

Chapter 1 (*Power Sector Outlook*) Data related to the energy sector has been updated along with a brief description of Vision 2020. Additionally, solar power and magneto-hydro-dynamic (MHD) power generation have been included.

Chapter 2 (*Basic Concepts*) Comparison of single- and three-phase power transmission, along with typical solved examples, have been included.

Chapter 3 (*Transmission Line Parameters*) Overview has been re-drafted to highlight the importance of transmission lines in power transmission and the electrical properties of commonly used conductor materials are shown in tabular form. A separate section is included to explain at length skin, proximity, and spirality effects which lead to non-uniform distribution of alternating current in a conductor.

Chapter 4 (*Transmission Line Model and Performance*) Overview has been re-written to bring out the effect of distributed line parameters. Significance of ultra-fast transients leading to overvoltages has also been stated. Significance of propagation constant and Ferranti effect have been explained at length along with the inclusion of several typical solved examples.

Chapter 6 (*Formulation of Network Matrices*) Overview has been expanded to emphasize the formulation of network matrices based on graph theory.

Chapter 7 (*Power Flow Studies*) A new section to explain the simulation of DC power flow solution has been added. Similarly, a detailed comparison of the various power flow solution methods has been provided in tabular form.

Chapter 10 (*Symmetrical Components and Unsymmetrical Fault Analyses*) A table summarizing the phase shift between primary and secondary voltages of three-phase transformers, according to different vector groups, has been added for easy simulation for fault analysis.

Chapter 12 (*Voltage Stability*) Keeping in mind the several collapses of major power networks worldwide due to voltage instability, this new chapter has been included. After explaining and defining voltage stability and voltage collapse, the former is classified as large disturbance and small disturbance voltage stabilities. Formulation of transient voltage stability problem, due to a small disturbance, has been discussed along with techniques for performing transient voltage stability studies. Appropriate typical solved examples explain the application of the techniques.

Chapter 13 (*Contingency Analysis Techniques*) A typical solved example has been included to further explain the method of performing contingency analysis.

Chapter 14 (*State Estimation Techniques*) Variations in Examples 14.1 and 14.2 have been introduced to further explain the method of weighted least squares and the application of line power flow estimator for computing the system variables respectively.

Chapter 15 (*An Introduction to HVDC Power Transmission*) A whole new section explaining the operation of HVDC converter, in detail, has been included. Additionally, typical solved examples have been added. These examples further clarify the principles of HVDC operation.

Academic Capacity Test (ACT) has been provided as an online resource for students. It consists of 100 multiple choice objective questions, randomly selected from all the chapters in the textbook. ACT has been designed to enable a reader to identify chapter-wise strengths and weaknesses.

Acknowledgements

Words may not be enough to express our sense of gratefulness to our innumerable readers who took time out to provide priceless inputs. In particular we would like to acknowledge our gratitude to our colleagues, reviewers, and the staff of OUP who provided invaluable constructive criticism. Finally, last but not the least, we are indebted to the countless faculty members and young readers for their eager acceptance of our work.

T.K. Nagsarkar
M.S. Sukhija

Preface to the First Edition

The enjoyable experience of writing our first book *Basic Electrical Engineering* and its ready acceptance by the engineering faculty has inspired us to author our second book *Power System Analysis*. Written with the objective of assisting students to acquire the concepts and tools of analyses, it will also equip them in finding solutions to power system engineering problems in practice. In view of this objective, the language and style of writing this book is completely student oriented.

The growth of modern-day integrated power systems has fortunately been accompanied by the development of fast interactive personal computers. The latter has necessitated the integration of personal computers into the curricula of power system engineering programmes and has enabled the teachers to augment the learning process through the simulation and designing of more practice-oriented problems and taking up more complex topics for analyses.

Matrix laboratory (MATLAB) is a very powerful matrix oriented software package for numerical computations. It is a handy tool for solving numerical problems requiring numerous matrix operations, and therefore, a boon for analysing power system problems. Keeping in mind the current developments and future requirements, the book has an intentional bias towards computer simulation of power systems and the application of MATLAB for analyses and solutions of complex problems. The text integrates, through examples, several executable MATLAB functions and scripts. This will help the readers to comprehend not only the translation of a simulation into an executable MATLAB solution but will also encourage them to modify and even develop their own programmes. The MATLAB commands and their effects have been explained wherever they have been used in the text. Each chapter includes several such examples and unsolved problems with answers.

About the Book

Power System Analysis aims at providing a comprehensive coverage of the curricula and will serve as a very useful textbook for electrical engineering students at the undergraduate level. The book provides a thorough understanding of the basic principles and techniques of power system analysis. Beginning with basic concepts, the book gives an exhaustive coverage of transmission line parameters, symmetrical and unsymmetrical fault analyses, power flow studies, power system control, and stability analysis. With the inclusion of some advanced topics such as state estimation, stability analysis, contingency analysis, and an introduction to HVDC and FACTS, it would also serve the requirements of teachers and students alike at the postgraduate level.

Content and Coverage

The book comprises 15 chapters and three appendices. Each chapter in this book commences with an overview, which briefly outlines the topics covered in the chapter, and ends with numerous unsolved problems which help the readers to assess their comprehension of the subject matter studied in the chapter.

Chapter 1 in addition to tracing the history of the growth of the power sector outlines its structure and its present state. Statistical data is included to provide a perspective of the Indian power sector and its future plans for meeting the load demand and making it more energy efficient. The concept of deregulation of the power industry is also covered.

Chapter 2 covers the representation of power system elements suitable for circuit analysis. A review of phasor notation, phase shift operator for three-phase systems, and the power in single-phase and three-phase circuits is presented. It describes per unit representation of power systems and its advantages in power system analysis.

Chapters 3 and 4 deal with the parameters of transmission lines and steady-state performance and analysis of transmission lines, respectively. Chapter 3 outlines the computation of the parameters of transmission lines. Chapter 4 covers their simulation as short, medium, and long lines. Power handling capability and reactive line compensation of lines are discussed. The phenomenon of travelling waves on transmission lines is also included in the chapter.

Chapter 5 covers the representation of synchronous machines, transformers, and loads in the steady state and transient analysis.

Chapter 6 introduces graph theory along with the commonly employed terminology in the formulation of network matrices. Since network matrices form the basis of power system analyses, the chapter comprehensively covers the formulation of bus admittance and bus impedance matrices of a power system network. The chapter also includes the formulation of nodal equations, both in the admittance and impedance frames of reference, and their solutions by direct and indirect methods. Sparsity techniques for storing non-zero elements, network reduction, and optimal numbering schemes are also covered in the chapter.

Chapter 7 on power flow studies of integrated power systems, under normal operating conditions, provides a detailed description of the formulation of power flow equations. Solutions of these power flow equations by the well-accepted Gauss, Gauss–Seidel, and Newton–Raphson methods have been presented in detail in this chapter. Fast decoupled method for solution of power flow problems suitable for online studies has also been presented.

Chapter 8 deals with the maintenance of active power balance and control of voltage magnitude and power frequency, within specified limits, when a system is operating in the steady state. Beginning with the basic control loop in a generator, the automatic voltage control (AVC) and load frequency control (LFC) loops are described and their steady-state and dynamic performances are outlined in detail. The LFC of a single control area is first discussed and then extended to a two-area control system. Tie-line bias control and its application to a two-area control system are also presented in detail.

Chapter 9 deals with the methodical computation of bus voltages and line currents under balanced three-phase fault conditions. Impedance matrix for three-phase faults and computations of three-phase fault currents are also included.

Chapter 10 covers the analysis of power systems under unsymmetrical fault conditions. Symmetrical components which transform unbalanced currents and voltages into sets of three balanced components are employed as a tool for transforming an unbalanced circuit into a balanced circuit. The latter transformation makes it feasible to analyse the faulted network on per phase basis. The application of symmetrical components to various types of unbalanced faults, along with computational algorithms, has been detailed. Series faults such as one-conductor or two-conductors open are discussed. Generalized formulation for unbalanced short circuit computation using bus impedance matrix is also given at the end.

Chapter 11 commences with the assumptions commonly made in stability studies, followed by the derivation of the swing equation based on an analogy with the laws of rotational mechanics. The chapter includes an analysis of the single machine transient stability problem based on the equal area criterion. The solution of swing equation by conventional step-by-step method as well as modified Euler method has been presented. An algorithm for studying the multi-machine transient stability of a power system is also included. Numerical solutions of the non-linear algebraic equations are explained. MATLAB functions and scripts have been included to demonstrate their utility in obtaining numerical solutions and plotting the swing equation. Linearization of the swing equation and its solution for performing steady-state stability analyses are explained in detail. Some methods for improving stability are discussed.

Chapter 12 covers the contingency analysis of a power system and it deals with the determination of line currents following a line outage or a switching operation. The concepts of compensating currents, distribution factors, and their computation by employing the ***Z***-bus matrix are explained in detail. Contingency analysis of interconnected power systems by network equivalents is also presented.

Chapter 13 provides techniques to estimate the state of a power system using measured quantities such as P, Q, and line flows. Quantitative techniques to test the goodness of the state estimates from measurements and the elimination of bad data are also comprehensively described.

High voltage direct current (HVDC) systems operate in conjunction with ac systems to transmit bulk power in present day power systems.

Chapter 14 provides a historical perspective on the HVDC transmission, followed by a comparison of the ac and dc transmission systems. Typical configurations of HVDC converter stations and various types of dc links are also described.

Chapter 15 outlines the use of flexible ac transmission systems (FACTS) technology for enhancing transmission capability and improving grid reliability. The chapter highlights the restrictions in ac power flow in existing transmission systems due to parametric limitations and then explains how

FACTS technology can be employed to change the power flows by varying the parameters such as line reactance and voltage magnitudes. The various types of FACTS controllers employed for parametric variation have been described.

Three appendices are given at the end of the book. Appendix A defines the various types of matrices encountered in the modelling of complex engineering problems and outlines the matrix algebra involved in finding their solutions. Creation of matrices and the use of MATLAB commands have been demonstrated through examples. Numerous unsolved problems are provided at the end of the appendix. Appendix B comprises test data for power flow and the results for standard IEEE test systems. Solutions to end chapter exercises are provided in Appendix C.

We are confident that this book will enable students to achieve a better understanding of complex power system problems and help them solve these problems by utilizing the existing MATLAB functions and scripts. Students will become adept at developing their own functions and scripts independently, essentially after solving the problems at the end of each chapter. The faculty teaching the power systems engineering programme, on the other hand, will be able to enhance the teaching process by taking up modelling and analyses of problems which are encountered in the operation and control of power systems in practice.

We have developed this book over the past many years while teaching this subject to the students of electrical engineering at the postgraduate and undergraduate levels. The text has been written to match the evolving curriculum of the subject taught in universities in India and abroad. We acknowledge that the book is greatly influenced by earlier texts and literature written on diverse aspects of power systems by many outstanding professors and engineers. The details of the sources have been compiled in the bibliography at the end of the book. We wish to thank these individuals who have been instrumental in the development of this book. We are also grateful to our colleagues and friends who have provided valuable suggestions and criticism in formulating the contents of this book.

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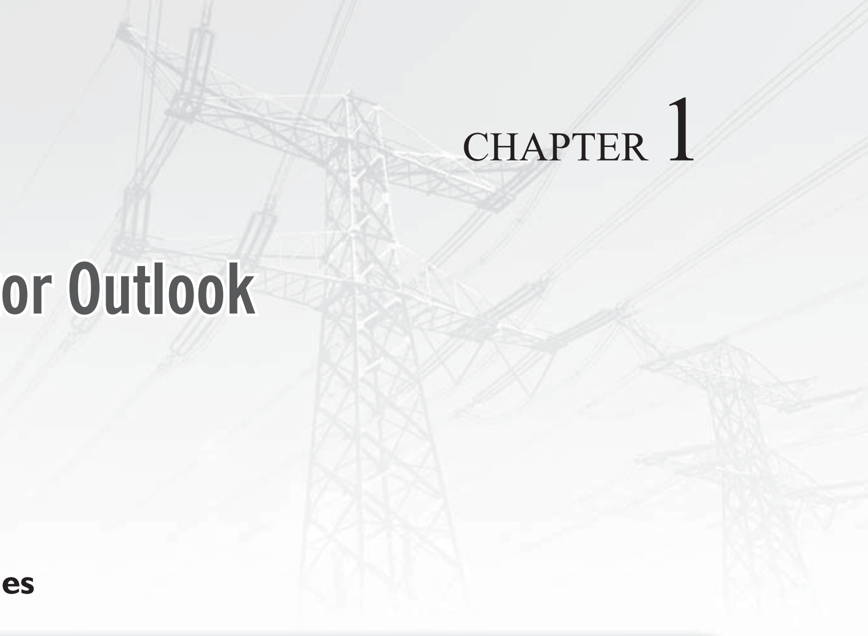

CHAPTER 1

Power Sector Outlook

Learning Outcomes

A focussed study of this chapter will enable the reader to:
- Learn the history and the growth of the power sector in India
- Obtain an overview of the existing situation of power generation, transmission, distribution, and consumption patterns
- Acquaint with Electricity Act 2003 and Electricity Act 2007 and their objectives
- Understand restructuring of the power sector and its importance in the Indian context
- Identify various systems and sub-systems of a power network, including categorization of various types of conventional (hydro, thermal, nuclear) and non-conventional (solar, wind, tidal, magnetohydrodynamic) primary sources of energy
- Know the significance of computers in online control for the efficient management of power systems and reliable supply of electrical energy

OVERVIEW

Electrical power is the most convenient form of energy since it is available to the consumer at the very instant it is switched on. The other benefits of electrical energy are the ease with which it can be generated in bulk and transmitted efficiently and economically over long distances.

1.1 HISTORY OF POWER SECTOR GROWTH

The first electric supply system was introduced by Thomas Edison in 1882 at the Pearl Street Station in New York, USA. Power was generated in a steam engine driven dc dynamo (generator), and dc power was distributed through underground cables for lighting purposes only. The scope of distribution was limited to short distances because of the low voltage of the distribution circuits.

In pre-independent India, the generation of electric power was mainly undertaken by the private sector and was limited to urban areas. The development of the power sector commenced with the commissioning of a 130-kW generator, in 1897, at Sidrapong in Darjeeling. In 1899, The Calcutta Electric Supply Company (CESC) established the first 1000-kW steam engine driven plant in Calcutta.

Post-Independence, the Government of India (GOI) took upon itself the task of developing the power sector in a rationalized manner so as to expand the electric supply industry for the benefit of the entire country. The early 1950s, therefore, saw the setting up of state electricity boards for the systematic growth of the power sector. Side by side a number of multi-purpose hydroelectric schemes were also commenced. In due course of time, work was started on building hydro, thermal, and nuclear power generating stations. In 1975, the GOI set up the National Hydroelectric Power Corporation (NHPC) and the National Thermal Power Corporation (NTPC) to signal their participation in the generation programmes and provide a stimulus to the growth of the power industry. Subsequently, Nuclear Power Corporation of India Limited (NPCIL) and Power Grid Corporation of India Limited (PGCIL) were established to provide an additional fillip to the power sector.

1.1.1 Installed Generation Capacity

Starting with an installed capacity of 1,713 MW at the end of 1950, installed capacity is being continually enhanced to meet the growing demand for power. As per the Central Electricity Authority (CEA) Monthly Power Sector Report (December 2012), the total installed generation capacity, constituting of hydro, thermal (including steam, gas, diesel), nuclear, and renewable energy sources (RES), as on 31 December 2012, stood at 210951.72 MW. The breakdown of installed capacity of different types of plants is given in Table 1.1. By the end of the 12 th Five Year Plan (2012–17), an additional total generation capacity of 79,790 MW (out of which hydro [9,204 MW], nuclear [2,800 MW], and thermal [67,786 MW]) is envisaged.

Table 1.1 Installed generation capacity (as on 31 December 2012)

Type of generation	Capacity in MW	% of installed capacity
Coal	120873.38	57.3
Thermal Gas	18903.05	9.0
Diesel	1199.75	0.6
Nuclear	4780.00	2.3
Hydro	39339.40	18.6
RES*	25856.14	12.3
Grand total	210951.72	100.0

* Renewable energy sources (RES) include small hydro projects, biomass gas, biomass power, urban and industrial waste power, and wind energy.

1.1.2 Gross Electricity Generation

The gross electricity generation at the national level, not considering the generation from the captive plants, grew from 5107 GWh in 1950 to 5,65,102 GWh during the second year of the tenth plan (fiscal year 2003–04). The electric energy generation target for the year 2011–12 was 8,55,000 GWh. Actual electric energy generation during the year was 8,76,400 GWh, and the growth in generation during 2011–12 was 8.05%. The details of generation and growth rates are given in Table 1.2.

Table 1.2 Annual electric energy generation targets and achievement

Category	Target 2011–12 (GWh)	Actual 2011–12* (GWh)	% of Target	Actual 2010-11 (GWh)	Growth (%)
Thermal	7,12,200	7,08,500	99.47	6,65,000	6.53
Nuclear	25,100	32,300	128.41	26,300	22.86
Hydro	1,12,100	1,30,400	116.40	1,14,300	14.15
Bhutan Import	5,600	5,300	94.60	5,600	–5.82
Total	8,55,000	8,76,500	102.51	8,11,200	8.05

* Generation excludes generation from plants up to 25 MW capacity.

The Central Electricity Authority Load Generation Balance Report 2012–13 predicted the anticipated power supply position in the country during the year 2012–13, taking into consideration the power availability from various stations in operation, fuel availability, and anticipated water availability at hydroelectric stations. A capacity addition of 17,956 MW during the year 2012–13 (comprising 15,154 MW of thermal, 802 MW of hydro, and 2,000 MW nuclear power stations) was envisaged. The gross energy generation in the country was assessed to be 9,30,000 GWh from the power plants in operation and those expected to be commissioned during the year.

1.1.3 Consumption of Electric Power

As is expected for a nation on the move, the consumption of electricity increased from year to year. The electricity consumption stood at 4,157 GWh by the end of 1950; it had increased to 3,22,459 GWh during the last year of the ninth five-year plan; and by the end of the second year (2003–04) of the tenth year plan, the electricity consumption registered was 3,60,937 GWh; an increase of 12% over the last two years. In 2009, the electricity consumption figure stood at 6,00,000 GWh which is expected to double by the next decade. The major consumers of electricity are: industrial sector (34.51%), domestic sector (24.86%), and agriculture sector (24.13%).

1.1.4 Rural Electrification

As a first step towards improving the quality of life in rural India, it was essential to undertake electrification of the villages. As per the report on the Status of Rural Electrification as on 31 March 2011, brought out by the Ministry of Power, Government of India, the number of villages electrified stood at 4,39,502, which represents a coverage of 74.02% of the villages, as against the 3061 villages electrified as on 31 March 1951. Based on the 1991 census data, 17 states/Union Territories have achieved 100% electrification of the villages. The details of rural electrification as on 31 March 2011 are presented in Table 1.3.

Table 1.3 Status of rural electrification as on 31 December 2011

Total number of villages	5,93,732
Villages electrified	4,39,502 (74.02%)
Villages to be electrified	1,54,320 (25.98%)
Total number of households	13,82,71,559
Electrified households	6,01,80,685 (43.5%)
Non-electrified households	7,80,90,874 (56.5 %)

1.1.5 Transmission and Distribution Lines

At the end of the second year of the tenth five-year plan, that is, 31 March 2004, the total length of the transmission and distribution lines stood at 63,44,858 circuit kilometres (ckm) as against 29,271 ckm on 31 March 1950. Table 1.4 provides the details of operating voltages and line lengths of transmission lines during the development of Indian transmission and distribution system through the five year plans.

Table 1.4 Transmission lines (all figures in ckm*) as on 31 December 2010

	6th plan	7th plan	8th plan	9th plan	10th plan	11th plan upto Dec 2010
± 500 kV HVDC						
Central	0	0	1,634	3,234	4,368	5,948
State	0	0	0	1,504	1,504	1,504
JV/Private	0	0	0	0	0	782
Total	0	0	1,634	4,738	5,872	8,234
765 kV						
Central	0	0	0	751	1,775	3,573
State	0	0	0	409	409	409
Total	0	0	0	1,160	2,184	3,982
400 kV						
Central	1,831	13,068	23,001	29,345	48,708	68,423
State	4,198	6,756	13,141	20,033	24,730	29,931
JV/Private					2,284	4,558
Total	6,029	19,824	36,142	49,378	75,722	1,02,912
220 kV						
Central	1,641	4,560	6,564	8,687	9,444	10,360
State	44,364	55,071	73,036	88,306	1,05,185	1,21,630
JV/Private						423
Total	46,005	59,631	79,600	96,993	1,14,629	1,32,413
Grand Total	52,034	79,455	1,17,376	1,52,269	1,98,457	2,47,541

*ckm is equal to 2 × route km.

The Government of India plans to quadruple the distribution network by adding 3.2 million ckm of distribution lines in the eleventh plan. Another 4.2 million ckm is planned to be added in the twelfth plan. Thus, by the end of the twelfth plan, the total distribution network in the country would have doubled, thereby greatly facilitating delivery of power to the expanding base of end-use customers. Table 1.5 indicates the details of future requirements of distribution network in the 11th and 12th plan periods as envisaged by the Working Group on Power for the 11th plan.

Table 1.5 System augmentation of distribution lines (all figures in ckm)

Particular	11th Plan	12th Plan
66 kV overhead	23,335	30,546
33 kV overhead	1,13,936	1,49,142
6.6/11/22 kV overhead	10,36,396	13,56,638
LT lines	20,80,106	27,22,857
Total	32,53,773	42,59,183

1.1.6 Per Capita Electricity Consumption

The per capita electricity consumption, which is an indicator of the development of a country, has been steadily increasing since 1950. For example, in 1950 this figure stood at 15.6 kWh, which increased to 559 kWh during the last year of the ninth five-year plan 2001–02. During the year 2003–04, the second year of the tenth plan, the per capita electricity consumption rose to 592 kWh. As per the highlights reported by the Central Electricity Authority, annual per capita consumption of electricity in the country during the years 2004–05 to 2010–11 is provided in Table 1.6.

Table 1.6 Annual per capita consumption of electricity

Year	Per capita consumption (kWh)
2004–05	612.5
2005–06	631.4
2006–07	671.9
2007–08	717.1
2008–09	733.5
2009–10	778.6
2010–11	818.8

1.2 VISION 2012 FOR THE POWER SECTOR

In order to develop the power sector and to alleviate the losses in the power sector, the GOI has prepared a scheme entitled ‘Mission 2012: Power for All’.The all-inclusive blueprint lays down an integrated strategy for the development of the power sector. The objectives defined to achieve the vision 2012 are as follows:

- Sufficient power to achieve GDP growth rate of 8%
- Reliability of power
- Quality power

- Optimum power cost
- Commercial viability of power industry
- Power for all

Achieving the objective of electrifying all households by the target year requires an addition of a massive 1,00,000 MW generation capacity and amalgamation of the regional grids into a national grid, with the latter having an inter-regional transfer capacity of 30,000 MW. Therefore, in order to achieve the above objective, additional generating capacity should be created and the transmission and distributions networks should be enhanced.

Consequently, the programmes of GOI focus on the following:

- Access to electricity to be made available for all households in the next five years
- Availability of power on demand to be fully met by 2012
- Energy shortage and peaking shortage to be overcome by providing adequate spinning reserves
- Reliability and quality of power to be supplied in an efficient manner
- Electricity sector to achieve financial turnaround and commercial viability
- Consumers' interests to be accorded top priority

1.2.1 Strategies to Achieve Power for All

The following strategies to achieve 'Power for All' have been outlined for developing the power sector:

Power generation strategy will focus on an integrated approach including low cost generation, optimization of capacity utilization, controlling the input cost, optimization of fuel mix, technology upgradation, capacity addition through nuclear and non-conventional energy sources, high priority for development of hydro power, and a comprehensive project monitoring and control system.

Transmission strategy focuses on development of a National Grid including interstate connections, technology upgradation and optimization of transmission cost.

Distribution strategy is to concentrate on distribution reforms by focussing on system upgradation, loss reduction, theft control, consumer service orientation, quality power supply commercialization, decentralized distributed generation, and supply for rural areas.

Regulation strategy aims at protecting consumer interests and making the sector commercially viable.

Financial strategy aims at generating resources required for the growth of the power sector.

Conservation strategy is to optimize electricity utilization with focus on demand side management and load management and technology upgradation to provide energyefficient equipment/gadgets.

Communication strategy focuses on achieving political consensus, with media support, to enhance general public awareness.

1.2.2 Vision 2020 for the Power Sector

The Vision 2020 committee set up by the Planning Commission in June 2000 envisages efficient and environment-friendly energy resources which would become the growth engines to provide speedy and sustainable future economic development. In order to power the country's industries, transport vehicles, homes, and offices, the demand for power is estimated to grow by another 3.5 times or more in the next two decades. This, in turn, will require that the installed generation capacity be compulsorily tripled from 101,000 MW to 292,000 MW. Such an overall growth in power demand will need a matching supply of all forms of fuels leading to a doubling of the coal demand and tripling of the demand for both oil and gas. Such swelling demands for the nation's growing requirements of energy will further strain the social and physical environments, in addition to increasing vulnerability due to fluctuating international market prices.

In today's energy scenario, it would be prudent to take a focussed visionary approach to place greater dependence on renewable energy sources, which not only offer immense economic benefits but also offer social and environmental benefits. With India already being the fifth largest wind power generating country in the world, use of other renewable energy technologies such as solar power, solar thermal, biomass, and small hydro power is being explored.

1.3 POWER SECTOR REFORMS

Development of the power sector continues to be one of the greatest challenges in maintaining economic growth and further reducing poverty in India. About 45% of the households remain unconnected to the public power system, and those who are connected often receive infrequent and unreliable service.

The State Electricity Boards (SEBs) have been incurring losses and are unable to even make payments to the Central Power Sector Units (CPSUs) such as NTPC and PGCIL for the purchase of power. The accumulation of outstanding amounts to the CPSUs grew to over ₹ 40,000 crore, seriously hampering their capacity addition programme. The reform of the power sector is crucial, as financial losses amount to 1.5% of the GDP. To strengthen the financial health of the power sector, the GOI has taken up reforms for gradual elimination of losses. In India, the power sector reform process was initiated in 1991 and since then the Indian power sector has been witnessing major structural changes.

1.4 PERFORMANCE/POLICY INITIATIVES/DECISIONS

During the year 2003–04, the following decisions were taken for achieving the objectives of 'Power for All'.

- Electricity Act 2003 was enacted in July 2003.
- Accelerated electrification programme for 1,00,000 villages and one crore rural households launched. The scheme outlay of ₹ 6,000 crore comprised a grant component of ₹ 2,400 crore.
- 50,000 MW hydro initiative launched.
- Improvement in power supply position: Since the beginning of the ninth five-year plan (1996–97), the peak shortfall had reduced from 18% to about 11%. Supply shortfall had also reduced from 11.5% to 7.1%.
- Generation performance: During 2003–04, the generation, compared to the previous year, improved from 531 billion units (BU) to 558 BU (1 billion = 10^9). Overall plant load factor (PLF) of generating stations improved from 72.2% to 72.7% while in the central sector it improved from 77.1% to 78.7%.

Capacity addition target and achievement Uninterrupted and reliable supply of electricity for 24 hours a day needs to become a reality for the whole country including rural areas. In order to fully meet the energy and peak demand by 2012, enough generating capacity has to be created with some spare generating capacity so that the system is also reliable. The sector is to be made financially healthy so that the state government finances are not burdened by the losses in this sector. The sector should be able to attract funds from the capital markets without government support. The consumer is paramount and he/she should be served well with good quality electricity at reasonable rates.

To ensure grid security, quality, and reliability of power supply, a reasonable spinning reserve at the national level has to be created in addition to enhancing the overall availability of installed capacity to 85%.

A capacity of about 1,00,000 MW is planned to be set up during the tenth and eleventh five-year plans, that is, between 2002 and 2012. This implies doubling the installed capacity which works out to adding about 430 MW every fortnight! Capacity addition plan for addition of 41,110 MW has been finalized for the tenth plan period. The central, state, and private sector's share of the capacity addition is expected to be 51%, 16%, and 25% respectively. About 7% is expected to come from renewable sources and 2% from the Tala project in Bhutan.

A hydro power initiative has also been launched by the Prime Minister in 2003, under which a capacity of 50,000 MW is to be added in the same period, that is, 2002 to 2012. Outlay for power sector for the tenth plan period has been enhanced to ₹ 1,43,399 crore, an increase of approximately 214% over the ninth plan outlay of ₹ 45,591 crore. Advance action plan has also been initiated to identify the capacity addition required in the eleventh plan. In the last two plan periods, barely half of the planned capacity addition was achieved. The optimistic expectations from the Investments in Power Projects (IPPs) have not been fulfilled and, in retrospect, it appears that the approach of inviting investments on the basis of government guarantees was perhaps not the best way.

1.5 ELECTRICITY ACT 2003

The Electricity Act 2003 envisages bringing in a market-oriented management in the power sector by introducing in it a spirit of competition which hitherto was non-existent. The major focus of the Act is to amend existing laws and enact new laws in the areas of generation, transmission, distribution, buying and selling, and utilization of power. The objectives of the Act are as follows:

- Generating a market-responsive competitive power industry
- Guaranteeing reliable and quality power supply to all areas
- Rationalizing tariff regime
- Bringing down the levels of cross-subsidization
- Safeguarding consumer interests

The salient provisions in the Act are as follows:

- No licences for setting up generating stations, except hydro stations, subject to their meeting specified technical standards
- No permission is necessary for establishing captive power plants

- ‘Open access’ permitted for transmission
- Multiple licences are permissible for transmission and distribution (T&D) in the same geographical area
- Establishing a spot market (stock market) for bulk power
- Function (generation, transmission, and distribution) based unbundling of state electricity boards
- Accountability through mandatory metering of electrical energy supplied to consumers

The Act, however, permits the state electricity boards to operate, for a limited period, with their integrated structure and allows them to select the order and segments of restructuring. The Electricity Bill 2003 passed by the Parliament in May 2003 is a unified central legislation and replaces the earlier three electricity Acts of 1910, 1948, and 1998 along with their amendments.

1.5.1 Electricity Act 2007

The Electricity (Amendment) Act was passed by the Parliament in June 2007. It would be out of the scope of this text to discuss the Electricity (Amendment) Act 2007 in its entirety. In Section 6 of the Electricity Act 2003, the following section shall be substituted:

“6. The concerned State Government and the Central Government shall jointly endeavour to provide access to electricity to all areas including villages and hamlets through rural electricity infrastructure and electrification of households.”

Other important amendments to the Electricity Act 2003 are as follows:

- The term ‘elimination’ has been omitted in relation to cross-subsidies.
- Captive units will not require a licence to supply power to any user.
- Strict action against unauthorized usage of power.
- Power theft has been recognized as a criminal offence, punishable under Section 173 of the Code of Criminal Procedure, 1973.

1.6 RESTRUCTURING THE POWER SECTOR

It would be appropriate to develop the concepts associated with regulation and deregulation, in respect of the power sector in India, before describing the concepts of restructuring.

Regulation of the power sector implies that it must function within the laws and regulations which have been specified by the government.

Deregulation of the power sector implies that the government has specified rules and economic enticements for restructuring, controlling, and driving the electrical power sector.

Clearly, a regulated power sector means that it functions in a monopolistic and risk-free environment. On the other hand, in a deregulated scenario, the power sector operates in a competitive environment and is subject to market risks. Thus, regulation and deregulation symbolize opposite concepts without any one of them being absolutely black or white.

1.6.1 Features of a Regulated Power Sector

Monopolistic There is only a single authority to generate, transmit, distribute, and sell electrical energy.

Responsibility to supply The authority is obliged to supply energy to all areas irrespective of viability and profitability.

Government as a supervisor The government acts as a regulator by legislating laws and rules within which the authority should operate and do business. This implies that

(a) the operating principle of the authority must be based on least-cost operation, that is, it must function such that it minimizes its overall revenue needs, and
(b) the government decides the rates to be charged by the authority.

The authority is expected to function within the government's specified regulatory guidelines and practices and it is assured a reasonable return on its investments.

1.6.2 Structure of a Regulated Power Sector

The electrical power sector in India, until recently, has been vertically integrated, with all the functions of power generation, transmission, and distribution being performed by a single entity, which complicated the separation of costs attributed to the three activities. Therefore, the electricity tariff rate charged to consumers is based on cumulative costs.

From the foregoing, the structure of a regulated authority may be conceptualized as one in which (i) information flow is present between the generating and transmission systems only, and (ii) the direction of flow of money is from bottom to top only, that is, from consumers to the authority.

1.6.3 Structure of a Deregulated Power Sector

Unlike the regulated power sector, a deregulated power sector is characterized by a competitive structure in which the various job functions, in a traditional set-up, are identified and segregated so that these job functions, whenever practical, can be thrown open to competition for improving efficiency and profitability. The procedure of restructuring is called unbundling.

Generally, the objective of the government in deregulating the power sector is to induce competition, by allowing several new players, in the production of electrical energy (generation) and retail marketing (distribution) of electricity, while maintaining a single transmission and distribution system in an area. Figure 1.1 presents a conceptual perspective of a deregulated power sector.

As can be observed from the figure, an unbundled power sector permits the entry of various players to undertake different tasks. In order to ensure smooth and uninterrupted functioning, a central operating authority, designated as Self-governing System Administrator (SSA) or Independent System Operator (ISO), is appointed for the entire system. The SSA is an independent authority. It does not possess its own generation facilities for business or indulge itself in market competition. The SSA ensures that there is a balance between generation and imports on one hand and consumption and exports on the other, at all times.

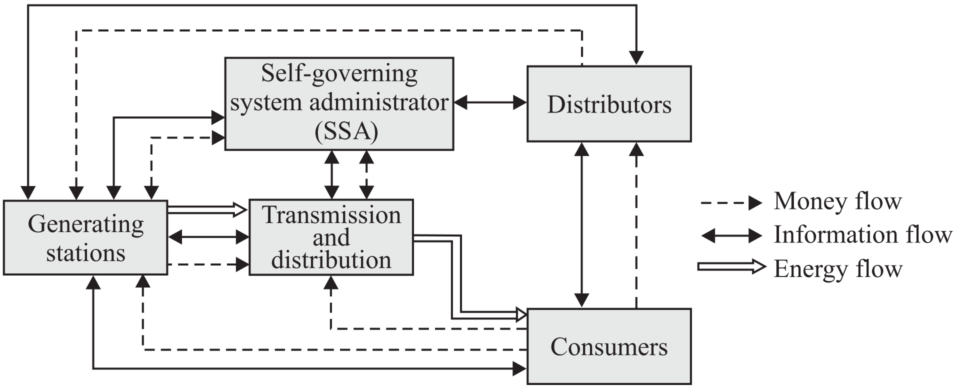

Fig. 1.1 Conceptualized perspective of a deregulated power sector

In the deregulated model, the flow of energy is from the generating stations to the consumers, via the transmission and distribution system as in the regulated power sector. In terms of the functioning of the deregulated power sector, one model is that various generating companies will sell and deliver power via the transmission and distribution (T&D) system to the distributors. The consumer transacts with the distributors. Another practice is that the consumer transacts directly with the generating company. The T&D system is operated by the SSA.

From the perspective of information flow, the consumer generally communicates with the distributor and the generating companies while T&D authorities and the distributors communicate with the SSA. In the model shown in Fig. 1.1, money flow is from the consumer to the distributor, generating companies, and T&D companies. Money is also exchanged between the SSA and the generating and T&D companies. The generating companies pay to the T&D authority for using their facility for supplying energy to the consumer. There is, however, no money flow between the distributor and the SSA.

Functionally, the consumer places a demand for energy with the distributor who in turn buys power from the generating company and transfers it to the customer via the regulated T&D system which is operated by the independent SSA. The SSA is accountable for maintaining a liaison with the various players and keeping track of the transactions being enacted.

Owing to the various players in the deregulated structure, the energy bill gets segregated into various amounts to be paid towards generation, transmission, and other costs. This is in contrast to the single energy bill in the regulated power sector. The different heads under which an energy bill gets segregated into, in the deregulated scenario, are as follows.

- Price of energy supplied.
- Price of energy delivered: This is analogous to the price of transportation of goods from one station to another.
- Price of quality of energy supplied: The quality of energy supplied is determined by the extent to which frequency is regulated and the voltage magnitude is controlled at the consumers' end. These services are individually priced and charged. The price for these services, however, may or may not be indicated in the energy bill separately.

1.6.4 Various Participants in a Deregulated Power Sector

It is clear from the foregoing that a deregulated power sector comprises various participants. Although the designation of the various participants and the role played by each in a market-driven deregulated power sector cannot be clearly specified, yet the next section broadly delineates the various players. Figure 1.2 provides an example of an indicative segregation of participants in a market-driven power sector.

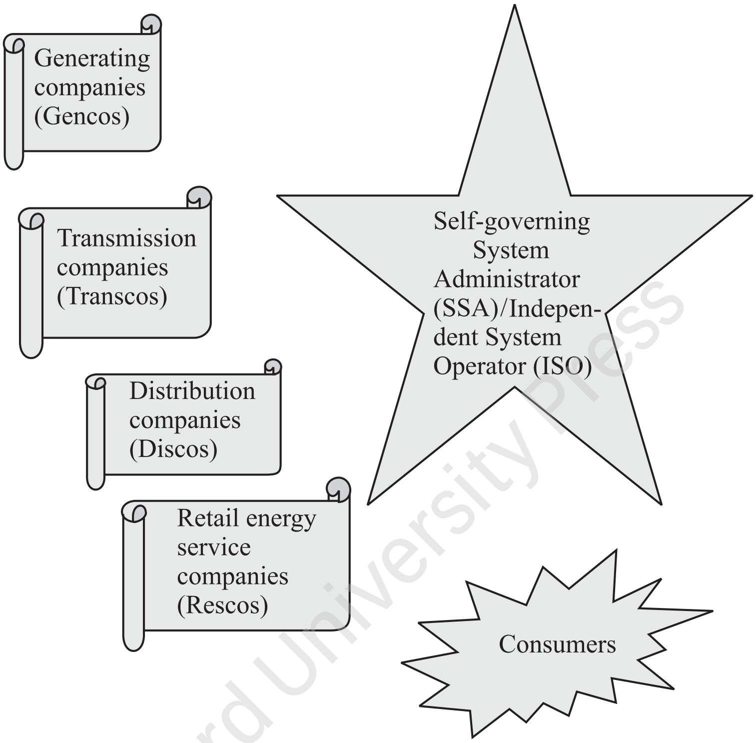

Fig. 1.2 Various components of a deregulated power sector

1.6.5 Role Description of Various Participants

Generating company (Genco) Genco is a company which owns and operates generating stations to produce electrical power. The bulk energy produced by a Genco is sold at its site which is similar to a petroleum company selling bulk crude at its site.

Transmission company (Transco) The role of a Transco is to transfer bulk power generated at the site of a Genco to where it is to be delivered. In respect of ownership, management, and maintenance of transmission lines, one of the following methodologies may be adopted in a deregulated power sector. Normally, Transco owns and maintains the transmission lines under monopoly contract. The operation of the transmission lines is undertaken by the SSA/ISO. Since Transco is the sole franchisee of the transmission lines, it is paid for by the SSA/ISO for the use of the facility. Transco may also be assigned the administrative responsibility of carrying out the engineering functions to ensure that the transmission lines perform the task of transmitting power adequately.

Distribution company (Disco) Disco performs the function of power delivery to individual consumers consisting of business houses, commercial organizations, and domestic customers. Disco is also an owner-operated organization under monopolistic contract. There are two models in which a Disco can function. In the first model, Disco owns and controls the distribution network and it earns its income by renting out the same or by billing for delivery of electric energy. In the second model, a Disco buys power in bulk either directly from a Genco or from the spot (stock) market and delivers it to the consumers.

Retail energy service company (Resco) Rescos can be carved out of the several retail departments of the earlier vertically integrated utilities or these could be new entrants in the electrical power industry who believe that they are competent in the art of selling. The job of a Resco is to vend electrical power, that is, buy power from Gencos and sell it directly to the consumers.

Self-governing System Administrator (SSA)/Independent System Operator (ISO) An SSA/ISO is an independent authority whose role is to ensure reliable and secure electrical power system. It does not involve itself in the electricity market trade. However, in order to ensure security and reliability of the electrical power supply, an SSA/ISO obtains various services such as reactive power and supply of emergency reserves from different players in the system. Normally, an SSA/ISO does not possess any generation capacity, apart from reserve capacity, in some cases.

Consumers In the deregulated environment, consumers are categorized as a single entity and are perceived as the buyers. A consumer has the option to purchase electrical energy from a local Disco, or directly from a Genco, or from the spot (stock) market by bidding.

1.6.6 Mechanism of Competition

One of the basic objectives of deregulation is to promote competition within the electrical power industry. Figure 1.3 symbolically explains how the mechanism of competition is created in the electrical power industry.

In a deregulated electric power industry, competition is at the generation level and at the retail market level. Companies (Gencos) generate bulk power and put it on the market for sale at the wholesale level. Typically, customers who buy power in bulk from Gencos are large industrial consumers or other companies. For maximizing their profits, Gencos offer their power in the marketplace.

At the retail market level, distribution companies (Discos) buy power in bulk from Gencos and sell the same to individual customers, in small quantities, as per the requirement of the latter. Rescos and Discos compete for increasing their consumer base by offering competitive prices, good services, and other attractive service features.

A deregulated electrical power sector, therefore, is competitive at the wholesale and retail levels and in between is the monopolistic transmission and delivery system.

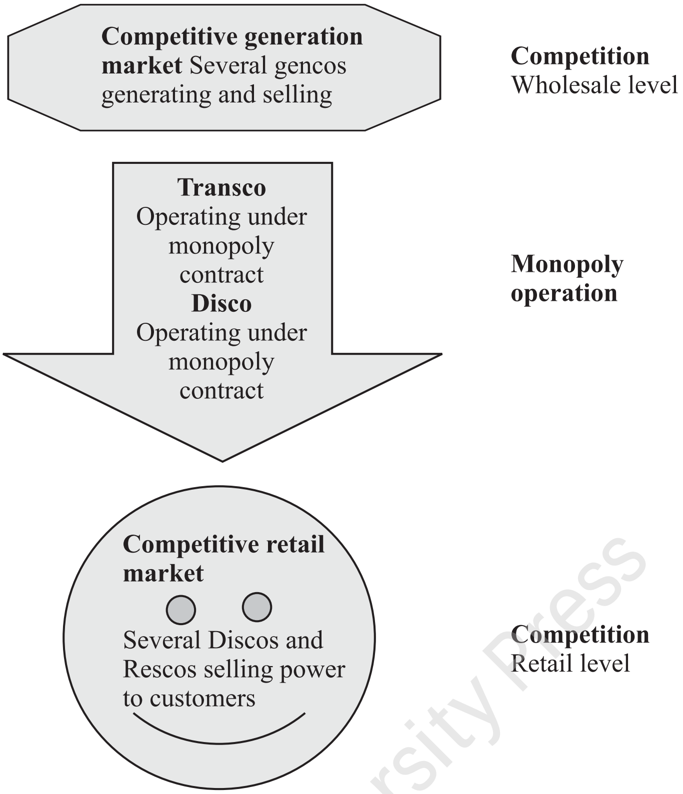

Fig. 1.3 Symbolic representation of the mechanism of competition in a deregulated environment

1.7 WHOLESALE POWER MARKET

It is logical to expect that there exists (i) a marketplace for the sellers and buyers to trade, and (ii) an adequate system for transportation and distribution. Similarly, in the context of a deregulated power industry, the following two additional systems are essential.

Power market A methodology for the bulk power producers (Gencos) to sell and Rescos and Discos to buy power.

System operation A viable transmission system, on real-time basis, which will transport power from the sellers' (Genco) site to the consumers' site.

The cornerstone of a deregulated power industry is a level playing field to all the entities. System operation is satisfactorily achieved by Transcos and Discos, which are regulated by an independent mechanism. The concept of a power market was both novel and alien to the power industry and required the introduction of new players.

1.7.1 Instruments of Sales Transactions

A market mechanism through which Gencos can sell their product (power) at competitive prices and transact business with buyers (Rescos and Discos) is an essential feature of a deregulated power industry. There are three fundamental models for transacting business and they are described as follows:

Poolco It is the single government or semi-government buyer which also functions as the system operator. Its job is to buy power for all consumers. It operates by inviting bids from all Gencos and buying power, at the lowest quoted price, to meet the total demand.

Bilateral exchange It functions on a multi-seller and multi-buyer approach. In this, bilateral agreements are reached confidentially, between a seller and a buyer, to exchange power at a mutually agreed price.

Power exchange (PX) It is a trading exchange for electrical power, very similar to the monetary stock exchange, and is established by the government. In this mechanism, business is transacted through the PX. Similar to a monetary stock exchange, the PX constantly revises and declares the current price, called the market clearing price (MCP), at which transactions are done. A feature of the PX is that both the sellers and the buyers are really 'conversing' with the PX (marketplace) instead of individual sellers and buyers and thus are not aware of whom they are dealing with.

It may be mentioned that none of the three market instruments are mutually exclusive. It is not impossible to have several combinations of all three market devices to be operative at the same time. In practice, however, it is prudent for two of the three devices to be in operation concurrently.

1.8 RESPONSIBILITIES OF THE SSA/ISO

The SSA/ISO is the key to the successful operation of a deregulated power industry. It must function transparently to ensure a secure and reliable system, justifiable and impartial transmission tariffs, and provide other services. The SSA/ISO is expected to perform the following basic functions:

- Deliver power on request to the sellers and buyers, and to transmission services for the transportation of power.
- Determine and post prices for transmission usage, offer to reserve or sell track usage, invoice users and settle the same with the users, and promptly pass on revenues to owners of T&D system owners.
- Operate the system in a stable and economical mode.
- Assure and provide high quality of service.
- Provide ancillary services such as generation/load balance control area, respond quickly to correct generation/load imbalances by utilizing spinning reserve, maintain system voltages within specified limits by injecting or absorbing reactive power, and operate the system so as to minimize the transmission losses.
- The SSA/ISO should itself operate in a manner to reflect optimum economic efficiency and should deal fairly, equitably, and transparently with all the entities in the industry.

1.9 STATUS OF DEREGULATION OF THE POWER SECTOR IN INDIA

The physical infrastructure in the power sector in India has witnessed incredible growth since Independence. This expansion is attributed to

(a) government budgetary support,

(b) cross-subsidy,
(c) emphasis on utilizing indigenous resources for expansion, and
(d) centralized supply and grid expansion.

Until 1991, the power sector was vertically integrated with over 98% generation and over 95% distribution being undertaken by the state-or central government-owned utilities, like the electricity boards. Therefore, the power industry imbibed the inherent shortcomings such as operational inefficiencies, high T&D losses, and over-staffing of a vertically integrated system.

The government of Orissa was the first state to initiate the process of restructuring, in the mid-1990s, with the help of a loan from the World Bank (WB). The model of unbundling envisaged: (i) restructuring the state-owned electricity board (SEB) into three separate entities consisting of generation, transmission, and distribution, (ii) generation and distribution to be privatized, and (iii) setting up an independent regulatory authority to monitor and control these players.

Following in the footsteps of the Orissa state, various other states, such as Andhra Pradesh, Haryana, Rajasthan, and Uttar Pradesh, have obtained loans from international funding agencies, such as the WB and the Asian Development Bank (ADB), for unbundling their respective SEBs.

1.10 CONSTITUENTS OF A PRESENT-DAY POWER SYSTEM

An electrical power system is a complex network of several subsystems, which convert some form of latent energy into electrical energy and transform, transmit, and distribute it for consumption at the customers' terminals. Figure 1.4 is a single-line representation of a three-phase ac power system.

The various subsystems of an electrical power system may be classified as follows:

(a) Generation
(b) Transmission and distribution
(c) Loads
(d) Protection and control

It may be noted that transformers are used in all the subsystems. A transformer transfers power with very high efficiency from one voltage level to another voltage level. The insulation requirements limit the generated voltage to low values up to 30 kV. Thus step-up transformers are used for transmission of power at the sending end of the transmission lines. At the receiving end of the transmission lines, step-down transformers are used to reduce the voltage to suitable values for distribution to consumers of electric energy. Furthermore, depending on power handling capacity, two types of transformers, namely power transformers and distribution transformers, are shown in Fig. 1.4. Power transformers are usually rated from 250 kVA up to 1000 MVA, and distribution transformers are rated between 20 kVA and 250 kVA.

In Fig. 1.4, voltage levels at various subsystems are indicated. EHV designates extra-high voltage, usually above 220 kV and up to 800 kV. HV denotes high voltage, usually from above 66 kV to no more than 220 kV. MV means medium voltage, usually from above 1 kV but less than 66 kV. LV stands for low voltages, which are 1 kV or less.

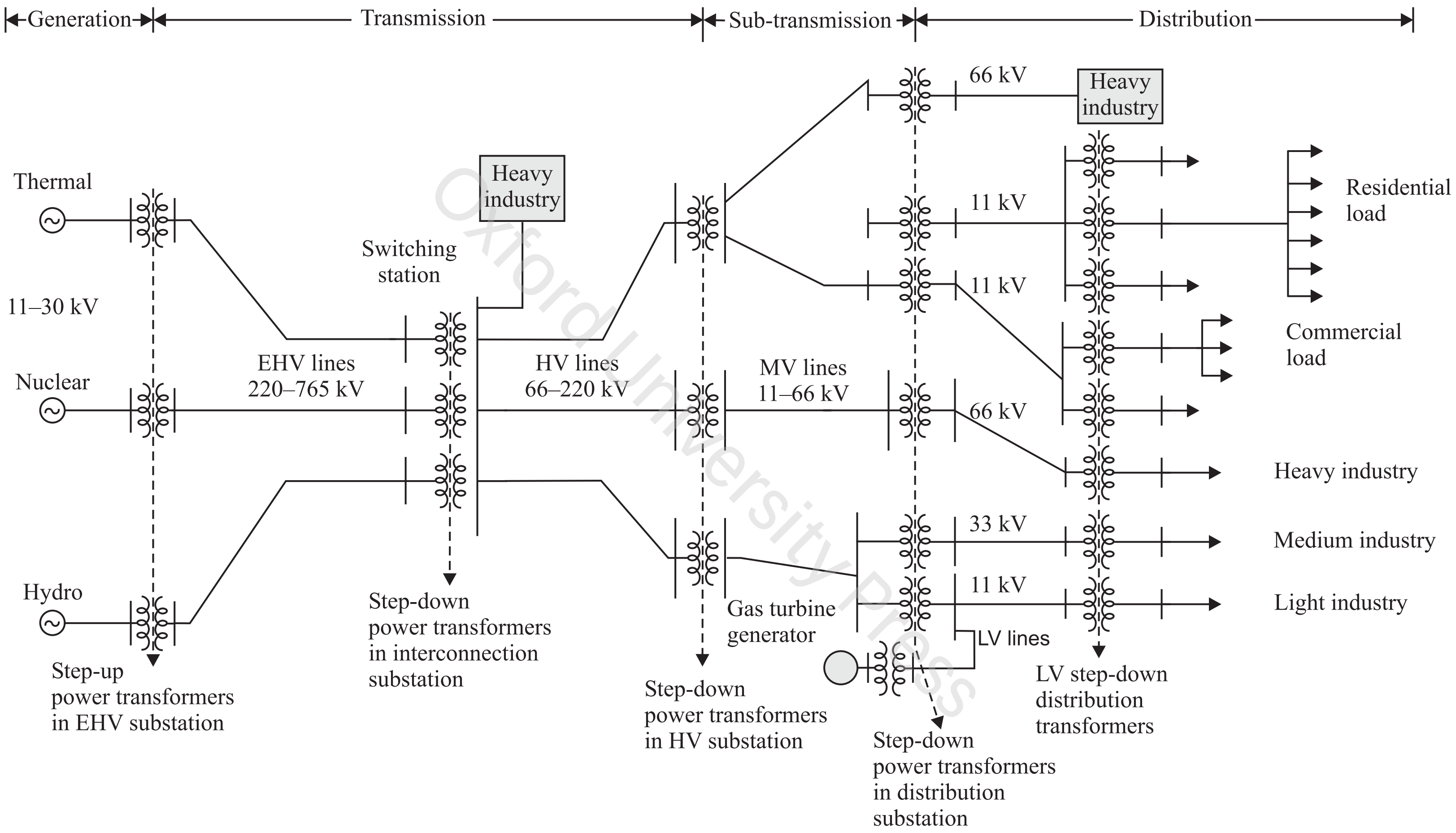

Fig. 1.4 Single line representation of an ac network

1.10.1 Generation Subsystem

Generation of electric energy commenced with the setting up of individual power stations at the pitheads to supply electric power to individual consumers. As the demand for electric energy increased, power systems came into existence. Thus, the generation subsystem is constituted of groups of generating stations, which convert some form of primary energy into electrical energy.

The simplest form of a generating station is constituted of a prime mover coupled to an electric generator. A primary source of energy is employed as the input to the prime mover, which in turn rotates the generator to produce electric energy.

Primary Sources of Energy

The important primary sources of energy employed for generation of electric energy can be broadly classified into three categories:

(i) fossil fuels, for example, coal (including lignite and peat), oil, and natural gas
(ii) renewable energy from hydro, wind, and solar
(iii) nuclear energy from uranium or plutonium

In modern-day electric power systems, majority of the generating stations employ these three types of primary energy sources. The amount of electric power contributed by each type of generating station is governed primarily by the market costs of primary energy sources. For example, water stored in dams and wind as primary input sources of energy have zero cost compared to the cost of fuel such as coal, oil, gas, and uranium used in thermal and nuclear generating stations. In nuclear generating stations, energy costs are low compared to thermal generating stations. The economics of generating stations employing fossil fuels as source of energy are dependent on market prices of the fuels.

Types and Characteristics of Generating Stations

Generating stations, based on the type of primary source of energy employed, can be classified into the following four categories:

(i) thermal,
(ii) hydro,
(iii) nuclear, and
(iv) non-conventional.

In thermal generating stations, coal, oil, natural gas, etc. are employed as a source of primary energy, while the head and volume of water is employed as the primary source of energy in hydro generating stations. Controlled nuclear fission is the source of energy in a nuclear power station. In non-conventional generating stations, wind, geothermal (heat deep inside the earth) energy, tidal energy, etc. are used as sources of energy to generate electric power.

Thermal Generating Stations

Coal fired A simple schematic diagram of a thermal generating station is shown in Fig. 1.5. The chemical energy in coal is utilized to generate electrical energy. Pulverized coal is burnt to produce steam, at high temperature and pressure, in a boiler. The steam so produced is passed through an axial flow steam turbine, where the internal heat energy of the steam is partially converted into mechanical energy.

The steam turbine, which is the prime mover, is coupled to an electric generator. Thus, mechanical energy produced by the rotating turbine is converted into electric energy.

The efficiency of the process of conversion of chemical energy into thermal energy and then into mechanical energy is poor. Due to heat losses in the combustion process, rejection of large quantity of heat in the condenser and rotational losses, the maximum efficiency of the conversion process is limited to about 40%. In order to increase the thermal efficiency of conversion of heat into mechanical energy, steam is generated at the highest possible temperature and pressure. To further increase the thermal efficiency, steam is reheated after it has been partially expanded by an external heater. This reheated steam is returned to the turbine where it is expanded in the final stages of bleeding.

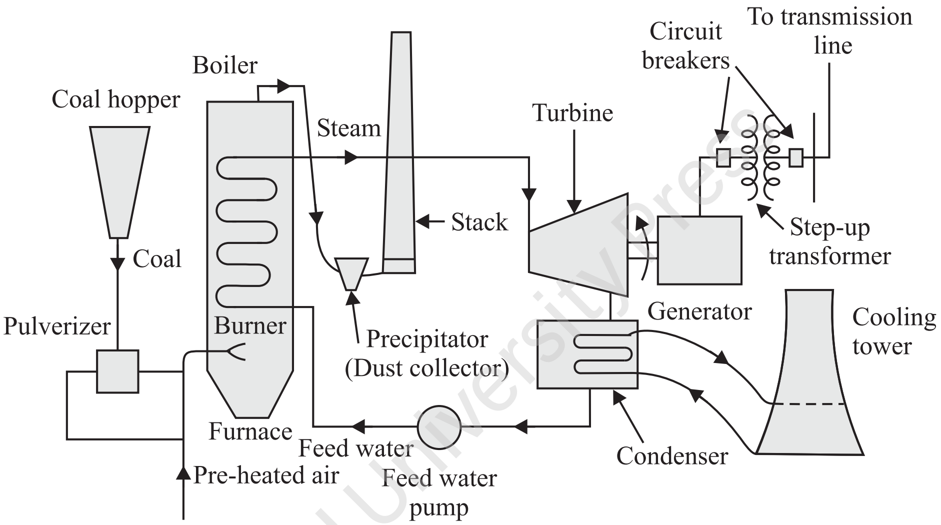

Fig. 1.5 Schematic diagram of a thermal generating station

Modern practice is to design and build generating units having large megawatt generating capacity, since their capital cost per kilowatt decreases as the megawatt capacity is increased. Increasing the unit capacity from 100 MW to 250 MW results in a saving of about 15% in the capital cost per kilowatt. It is also established that units of this magnitude result in fuel saving of the order of 8% per kilowatt-hour. Additionally the cost of installation per kilowatt is considerably lower for large units. Currently, the maximum capacity of turbo-generator sets being produced is nearly 1200 MW. In India, super thermal units of capacity 500 MW are being commissioned by BHEL.

Thermal generating stations also employ cogeneration in order to utilize the large amount of waste heat. In cogeneration, electricity and steam or hot water are simultaneously made available for industrial use or space heating. It is claimed that cogeneration results in an overall increase in efficiency of up to 65%. Cogeneration has been found to be particularly advantageous for industries such as paper, chemicals, textiles, fertilizers, food, and petroleum refining.

The waste gases produced by coal fired generating stations contain particles and gases such as oxides of sulphur and NO_x. These gases are released to the atmosphere resulting in pollution of air. Thermal pollution also results due to the large amount of heat released via the condenser to the cooling water.

Oil fired In the oil fired steam station, oil is employed to produce steam, which is used to run the steam turbine. In the oil fired stations, the oil used is of two types: crude oil, which is the oil pumped from oil-wells, and residual oil, which is the oil left behind after the more valuable fractions have been extracted from the crude oil. Cost of transporting oil through pipelines is less than shipping coal by rail. However, residual oil fired stations have to be located close to the oil refinery because it is uneconomical to transport residual oil by pipelines because of its high viscosity.

Gas fired The primary source of energy in such types of generating stations is natural gas. A gas turbine engine, which is similar to a turbo-prop engine used in an aircraft, is employed as a prime mover to run the generator. In order to achieve higher thermal efficiency, combined-cycle method is used to generate electricity. In the first stage, gas turbine engines coupled to electric generators produce power. In the second stage, the hot gases exhausted from the gas turbines are passed through a heat exchanger to generate steam, which is used to run a conventional steam generator to produce electric energy. Alternatively, the hot gases exhausted from the gas turbine can be used for producing steam for an industrial process. Figure 1.6 shows a schematic layout of a combined-cycle gas fired power station.

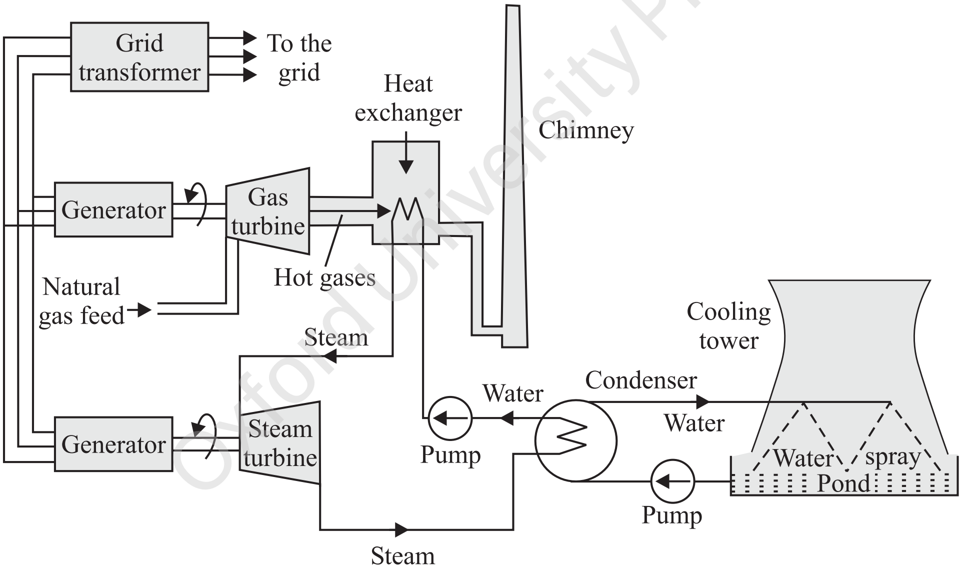

Fig. 1.6 Schematic layout of a combined-cycle gas fired power station

For the same amount of power generated, combined-cycle gas fired stations are more environment friendly. The flue gases emitted by these stations contain almost zero sulphur dioxide, 50% carbon dioxide, and 25% NO_x as compared to those produced in a coal fired power station. Compared with coal fired steam power stations, the installation cost of gas fired stations is lower and they can be quickly started. The operational cost of gas fired stations is high due to the high fuel cost when employed to supply power on their own. As such, they are used to supply peak load demand and for short periods.

The world over, gas turbines in conjunction with 100 MW generators are being used to generate electrical power. In India, a gas power station with an installed capacity of 180 MW (6 × 30 MW) is operational in Delhi.

Diesel oil fired Diesel oil is used to run large internal combustion engines of the type employed in ships. The diesel oil fired stations exhibit characteristics similar to those of a gas fired station. However, the speed of a diesel oil fired station is considerably low and its fuel efficiency is higher than that of a steam power station. Since diesel is more expensive than oil, in an oil fired steam station, the use of diesel oil fired stations is limited to supplying stand-by power.

Hydro Generating Stations

In a hydroelectric generating station, the potential energy and quantum of water are utilized to generate electrical power. In other words, hydroelectric schemes function on flow of water and difference in level of water known as head. Due to the difference in head, considerable velocity is imparted to the water, which is used to drive a hydro turbine. This hydro turbine acts as a prime mover and is coupled to an electric generator to produce electrical energy.

Hydroelectric stations depend on the availability of a head of water. As such they are often sited in mountainous terrain and require long transmission lines to deliver power to the load centres. Hydroelectric schemes are classified on the basis of the head utilized to generate power: high head storage type, medium head pondage type, and run-of-river. In low head type of hydro generators, both the velocity of water and difference in levels are used to rotate the turbine. In high head generators, the difference in levels is used to impart high velocity to the water to run the turbine. As the name suggests, in the run-of-river hydro generators, the natural flow of river water is used to drive the turbines. Figure 1.7 shows a schematic diagram of the high head storage type hydroelectric scheme.

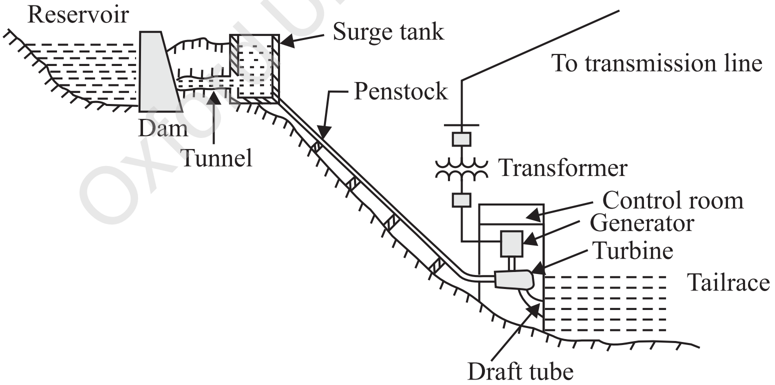

Fig. 1.7 Schematic diagram of a high head storage type of a hydroelectric scheme

The power P generated in a hydroelectric station is given as

$$P = 9.81\rho Q h \eta \times 10^{-3} \text{ kW} \tag{1.1}$$

where Q is the discharge of water in m^3/s through the turbine, ρ is the specific weight of water in 1000 kg/m^3, h is the head of water in metres, and η is the generation efficiency.

The merits of a hydroelectric station are as follows:

- Minimal operational costs (since there is no fuel cost involved)
- No air pollution

- No waste products
- Minimal maintenance
- Quick start-up time (within five minutes)
- Long life (minimum fifty years)

The demerits of a hydroelectric station are as follows:

- High capital costs
- Long gestation period
- Ecological damage to the region

Nuclear Power Stations

The fuel in a nuclear power station is uranium. Of the two isotopes of uranium, uranium-235 and uranium-238, found in natural uranium, only uranium-235 is capable of undergoing fission. Fission in uranium-235 is brought about by bombarding it with neutrons. Due to the fission reaction, heat energy and neutrons are released. The released neutrons further react with fresh uranium-235 atoms to generate more heat and produce more neutrons. Thus the fission reaction is a chain reaction and is required to be conducted under controlled conditions in a nuclear reactor.

In a nuclear power station, the nuclear reactor constitutes the heart of the station and replaces the boiler in coal or oil fired stations. Figure 1.8 shows a schematic layout of a nuclear power station.

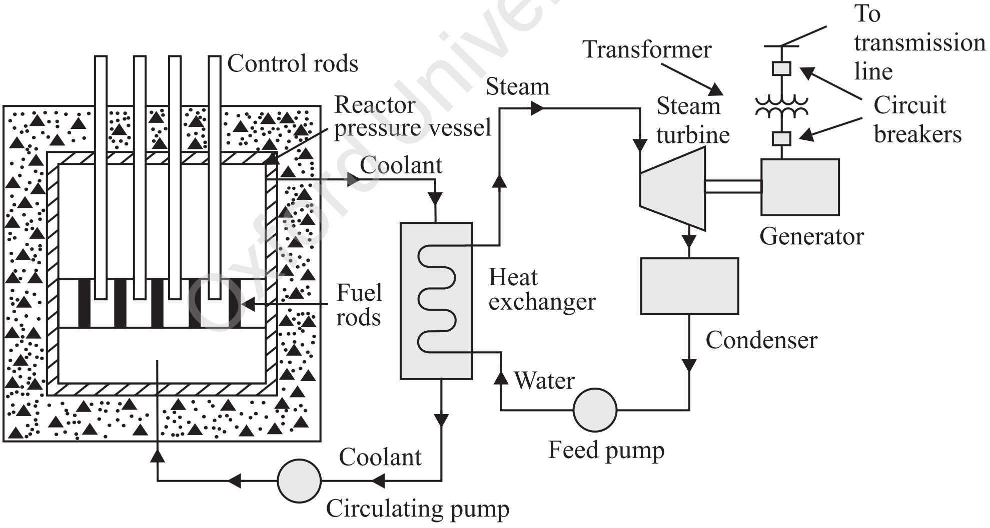

Fig. 1.8 Schematic layout of a nuclear power station

In the reactor pressure vessel, nuclear fuel rods are embedded in neutron speed reducing agents such as heavy water and graphite called moderators. These moderators reduce the speed of neutrons to a critical value. The nuclear reaction is controlled by inserting boron steel rods, which have the property to absorb neutrons. Thus, the rate of nuclear fission is controlled by controlling the neutron flux.

A primary coolant such as heavy water or carbon dioxide is used to transfer the heat generated due to the fission reaction to the heat exchanger. Steam is produced in the heat exchanger, which is used to run a conventional steam turbine.

The fuel requirements of a nuclear generating station are minimal compared to a coal fired generating station. In addition, the cost of transporting nuclear fuel is negligible. Another advantage of nuclear power stations is that they do not produce any air pollution. Nuclear stations, therefore, can be sited close to load centres. However, since radioactive fuel waste is produced in the nuclear reactor, safety considerations demand that nuclear stations be sited away from the populated areas. Nuclear stations require a high capital investment. The operational cost of such stations, however, is low.

Non-conventional/Alternative Generating Stations

Wind power stations Wind as a source of energy has been used for centuries to grind grain and pump water. It is particularly attractive since it is non-polluting. However, it is unpredictable and unsteady. The expression for theoretical power generated, in watts, by wind of average velocity V metres per second is given by

$$P = 0.5\rho AV^3 \text{ W} \tag{1.2}$$

where ρ is the air density (1201 g/m^2 at normal temperature and pressure) and A is the swept area in square metres.

The success of wind power generating stations is governed by the initial capital cost, maintenance cost, useful life, and power output. Wind power generating stations are useful for meeting low power requirements in small isolated areas. In India, the gross potential of wind power has been assessed at approximately 45,000 MW, and the technical potential is estimated at 13,000 MW. Wind power stations have been set up in the states of Gujarat, Maharashtra, Orissa, Andhra Pradesh, and Tamil Nadu. The largest installation of wind turbines in the country so far is in the Muppandal–Perungudi area near Kanyakumari in Tamil Nadu with an aggregate installed capacity of about 500 MW. State-of-the-art technology is now available in India for manufacturing wind turbines of capacity up to 750 kW.

Geothermal power stations Geothermal power generation involves conversion of the heat energy contained in hot rocks inside the core of the earth into electricity through steam. Water is used to absorb heat from the rock and transport it to the earth's surface, where it is converted to electric energy through conventional steam-turbine generator. Geothermal energy has been employed to generate steam in a limited way in Italy, New Zealand, Mexico, USA, Japan, etc. In India, the use of geothermal energy is still at the developmental stage with feasibility studies for a 1-MW station in Ladakh being undertaken. Though the efficiency of a geothermal station is less than that of a conventional fossil fuel plant, geothermal stations have become attractive due to their low capital cost and zero fuel cost. The total available geothermal power globally has been estimated at 2000 MW of which only about 500 MW has been tapped. In India, despite a number of hot springs, the availability of exploitable geothermal energy potential appears to be unattractive.

Tidal power stations The gravitational effects of the sun and the moon and the centrifugal forces of the earth's rotation on its axis cause sea tides. In about 25 hours there are two high tides and two low tides. The minimum head required for generation is about 5 m. Tidal power stations use periods of high tides to fill reservoirs, through open sluice gates, behind embankments along the seashores.

During low-tide periods, when the tide is falling on the seaward side of the embankments, the sluice gates are closed and stored water is made to flow through turbines coupled to generators. This is known as *ebb generation*.

A tidal power station is usually sited at the mouth of an estuary or a bay. A barrage or an embankment is constructed at the site to store water. A two-way generation can be achieved in a tidal power station. As the tidal waves come in, water flows through the reversible turbines to generate power and fill the estuary/bay. As the tide falls, water flows out of the estuary/bay and the turbines. Since the turbines are reversible, power is again generated.

The disadvantage of tidal power stations is that, due to variation in high and low tide timings, they may be generating at peak demand on some days and idle for other days. Another disadvantage is the high cost of civil engineering works required.

With hundreds of kilometres of coastline, a vast potential source of tidal energy is available in India. It has been planned to set up a 600-MW tidal power station in India by constructing a dam at Kandala on the Gujarat coast. Other sites under exploration are at Bhavnagar, Navalakhi (Kutch), Diamond Harbour, and Ganga Sagar.

Solar power The earth receives radiation continually from the sun to the equivalent of 1.17×10^{17} W. This energy from the sun is utilized to generate electricity. A solar cell is a thin silicon wafer of thickness 0.25 mm and can have a round or square form. It has the property of converting light energy of the sun into current. Figure 1.9 shows the one-dimensional geometric view of a PN junction solar cell.

Light photons from the sun penetrate into the PN junction diode (cell) and impart enough energy to the valence electrons to make them jump into the conduction band. Due to the unaccounted number of photons penetrating the cell, an extremely large number of electrons enter the conduction band and are pushed out of the cell by the internal electric field which has already been produced during the manufacture of the PN junction diode. This flow of electrons leads to the flow of current. The process of direct conversion of solar light energy into electric current is called ‘photovoltaic’ (PV) effect.

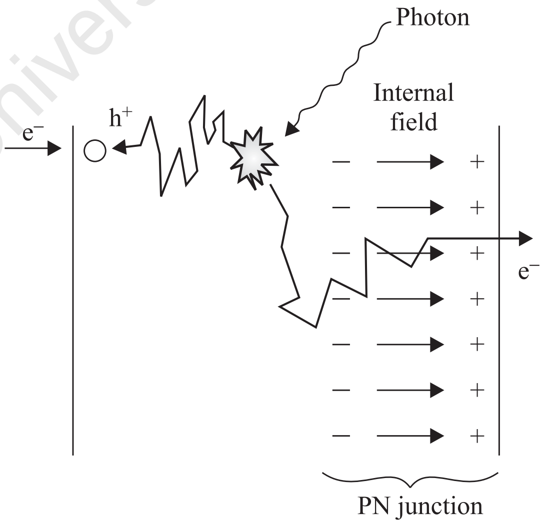

Fig. 1.9 Direct conversion of solar energy to electricity in a photovoltaic PN junction diode

The electrons will continue to flow out of the cell as long as light photons from the sun continue to penetrate the cell. As such, a cell never loses power, like a battery, since cells do not ‘consume’ electrons. Therefore, a cell may be viewed as a converter since it changes (sun) light energy into electric energy.

Figure 1.10 shows a view of a basic circular PV device. The metal contacts placed in front and at the back draw and deliver the electrons to the cell. In this manner, the same electrons continue to travel the same path and in the process deliver light energy to the load.

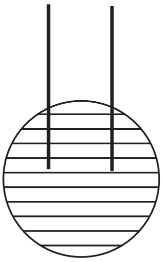

Fig. 1.10 Basic PV device

A typical silicon PV cell produces only 0.5 V DC. Therefore, a PV cell forms the basic device to form modules or panels to obtain higher voltages. Since a minimum of 12 V is required to charge a storage battery, a typical 65 × 140 cm panel will be made of 36 PV solar cells connected in series to produce 18 V. When loaded, the output voltage of the panel drops to 14 V which is the minimum voltage required to charge a storage battery. Thus, 36 solar cells panel has become the standard or basic module for the solar battery charger industry. Solar panels can be connected in series to obtain higher voltages of 24 V, 48 V, and more. Higher current capacity and therefore more power output can be obtained by connecting the basic modules of 36 cells each in parallel. Figure 1.11 provides a pictorial view of a basic module of 36 cells.

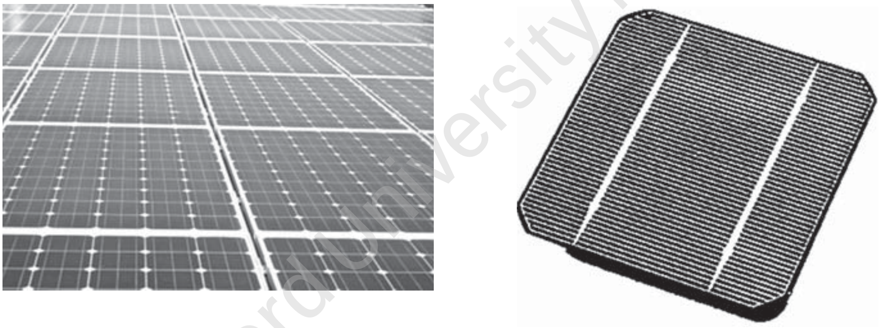

Fig. 1.11 Pictorial view of a basic solar PV module
(*Courtesy*: SunGift)

As on 31 March 2012, out of an installed capacity of about 200 GW in India, the share of renewable energy was 24,915 MW, which constitutes 12% of the total capacity. The share of solar energy in the installed renewable energy component stood at 905 MW (4%).

Under the National Action Plan on climate change, one of the eight missions that the GOI has set up in January 2010 is the Jawaharlal Nehru National Solar Mission (JNNSM). The aim of the Mission is to develop and promote the use of solar energy technology. The Mission aims to achieve, in three phases, a cumulative target of 20,000 MW and 2,000 MW, respectively, in grid and off-grid solar power generation by 2022.

MHD generation The magnetohydrodynamic power generation technology (MHD) is the production of electrical power utilizing a high-temperature conducting fluid (plasma) moving through an intense magnetic field. The conversion process in MHD was initially described by Michael Faraday in 1893. However, the actual utilization of this concept remained unthinkable. The first known attempt to develop an MHD generator was made at Westinghouse Research

Laboratory (USA) in around 1936. Since the 1960s, many different types of MHD power generators have been classified according to the type of cycle (open loop or closed loop) and the type of fluid used. Open loop MHD generators were first realized in 1965 in the USA. It was a 32 MW facility, fuelled with alcohol, which had a start-up time of three minutes. In 1971, an MHD pilot plant using natural gas fuel was commissioned at the Institute of High Temperatures, USSR. This pilot plant had 75 MW of power (25 MW of MHD and 50 MW from steam). In 1984, a coal-fired MHD pilot plant was constructed in USA. Closed loop MHD generators are usually associated with nuclear reactors as heat source, where the working fluid can be a noble gas or liquid metal. In India, BHEL Tiruchirappalli started work in MHD technology in 1978 in close cooperation with BARC and High Temperature Institute, Moscow, which was a pioneer in large-scale MHD activities, and a 5 MW pilot plant was commissioned in Tiruchirappalli in 1985. Later in 1993 there was a proposal for installing a 200 MW retrofit in an existing thermal station, but it was later shelved.

Working principle The MHD generator can be considered to be a fluid dynamo. This is similar to a mechanical dynamo in which the motion of a metal conductor through a magnetic field creates a current in the conductor, except that in the MHD generator the metal conductor is replaced by conducting gas plasma.

When a conductor moves through a magnetic field, it creates an electrical field perpendicular to the magnetic field and the direction of movement of the conductor. This is the principle, discovered by Michael Faraday, behind the conventional rotary electricity generator. Dutch physicist Hendrik Antoon Lorentz provided the mathematical theory to quantify its effects.

The flow (motion) of the conducting plasma through a magnetic field causes a voltage to be generated (and an associated current to flow) across the plasma, perpendicular to both the plasma flow and the magnetic field according to Fleming's Right Hand Rule. This is illustrated in Fig. 1.12.

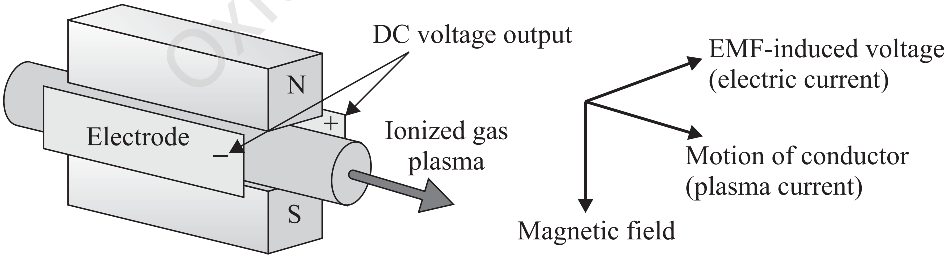

Fig. 1.12 Magnetohydrodynamic power generation (*Courtesy:* www.electropaedia.com)

The MHD system The MHD generator needs a high-temperature gas source, which could be the coolant from a nuclear reactor or more likely high-temperature combustion gases generated by burning fossil fuels, including coal, in a combustion chamber. Figure 1.13 shows the possible system components.

The expansion nozzle reduces the gas pressure and consequently increases the plasma speed through the generator duct to increase the power output. Unfortunately, at the same time, the pressure drop causes the plasma temperature to fall which also increases the plasma resistance.

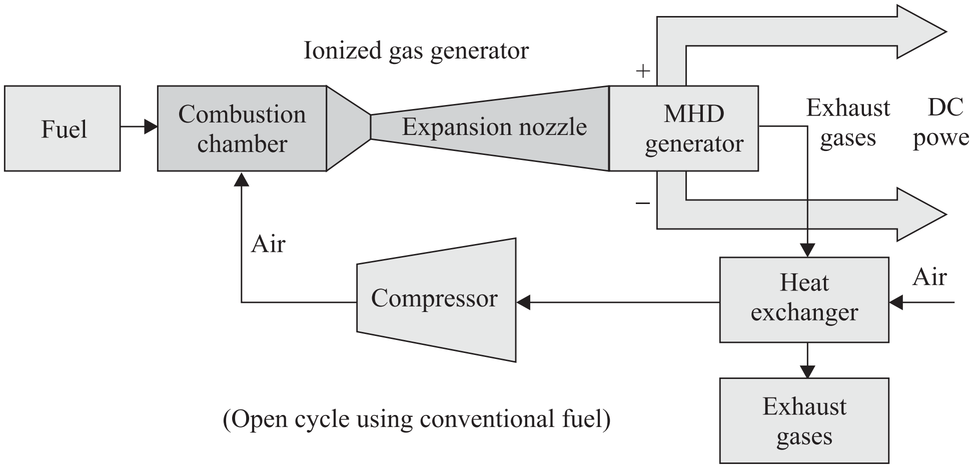

Fig. 1.13 Magnetohydrodynamic electricity generation
(*Courtesy*: www.electropedia.com)

The following are some of the merits of MHD power generation:

- Simple structure
- Works at high temperatures
- High Carnot-cycle efficiency
- Easy to realize combined cycle with other systems

The following are the disadvantages of MHD power generation:

- Simultaneous presence of high temperature and a highly corrosive and abrasive environment
- MHD channel operation under extreme conditions of electric and magnetic fields
- Expensive initial instalments

1.10.2 Transmission and Distribution Subsystem

The transformer and transmission line subsystems are designed to transmit bulk electric power for consumption at the load centres. In the generating stations, power is generated at voltage levels, which vary between 11 to 30 kV. The transformers at the generating station end step up the voltage to the level of transmission voltage suitable for transmission of bulk power. Since these transformers step up the voltage, they are also known as step-up transformers.

The power transmitted over a transmission line is proportional to the square of the transmission voltage. Therefore, ideally it is desirable to have the highest transmission voltages. As such, continuous efforts are undertaken to increase the transmission voltages. In the western countries, transmission of power is undertaken at transmission voltages of 765 kV. In India, the transmission voltage levels vary between 66 to 400 kV.

High voltage direct current (HVDC) transmission of bulk power over long distances is more economical than high voltage alternating current (HVAC) transmission when bulk power is to be transmitted over distances greater than 600 km. The dc voltages at which transmission takes place are 400 kV and above. At the generator end the ac voltage generated is stepped up to the transmission voltage level by a step-up transformer, which is converted to high voltage dc by a converter circuit. A converter is a three-phase full wave bridge circuit consisting of silicon-controlled rectifiers that can operate as a rectifier converting ac voltage to dc voltage and can also operate as an inverter converting dc voltage to ac voltage. At the receiving end or the load end of HVDC transmission, a converter operating as an inverter is used to change high voltage dc to high voltage ac, and then the ac voltage is stepped down by a step-down transformer to lower voltage level for distribution to consumers of electric energy.

The level of voltage at which distribution of power is undertaken depends on the type of industry in the region. The first step down in voltage may be from the transmission or grid level to the subtransmission level and may range between 132 kV to 33 kV.

For the purpose of supplying power to small industries and commercial and domestic consumers, the voltage is again stepped down at the distribution substation. The distribution of power is undertaken at two voltage levels; the primary or feeder voltage at 11 kV and the secondary or consumer voltage at 415 V for three-phase supply and 230 V for single-phase supply.

Subtransmission System

The portion of the transmission system that connects the high-voltage substations through step-down transformers to the distribution substations is called the subtransmission network. There is no clear demarcation between the transmission and subtransmission voltage levels. The voltage level of a subtransmission system ranges from 66 kV to 132 kV. Some heavy industrial consumers are connected to the subtransmission system.

A distribution subsystem constitutes the part of the electric power system between the step-down distribution substation and the consumers' service switches. A distributed system is designed to supply continuous and reliable power at the consumers' terminals at minimum cost. A typical distribution system is shown in Fig. 1.14.

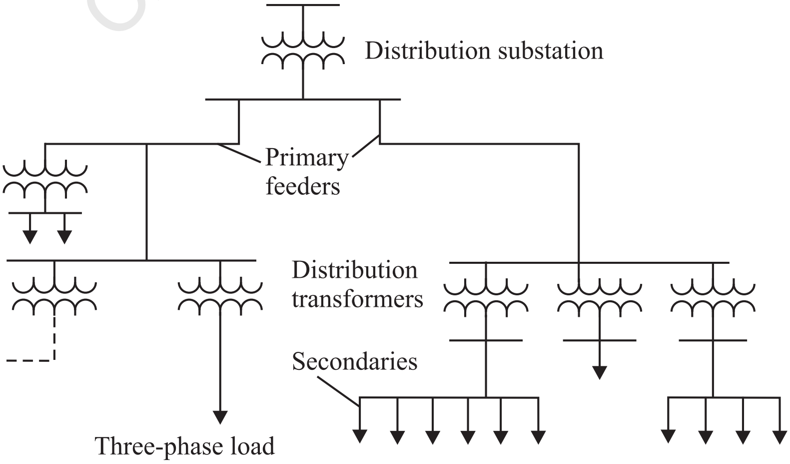

Fig. 1.14 Layout of a typical distribution system

At the distribution substation, the voltage level is brought down from 66 kV at the subtransmission level to 11 kV at the distribution level. Each distribution substation normally serves its own area, which is a subdivision of the area served by the distribution system. Distribution transformers are ordinarily connected to each primary feeder and its sub-feeders and laterals. Each transformer or banks of transformers serve to step down the voltage to utilize voltage of three-phase 415 V or single-phase 230 V and supply a consumer or a group of consumers over its secondary circuit. Each consumer is connected to the secondary circuit through service leads and a meter.

The subtransmission and distribution systems remained neglected for a long time and it was only in the mid 1990s when the development of their infrastructure was recognized as a core issue in the power sector. The reason for lack of initiative to update the subtransmission and distribution infrastructure was attributed to a generation-centric focus by both the central and state governments. The bias towards generation is obvious when it is observed that till 1993 the ratio of plan outlay for the development of the generation subsystem to the transmission and distribution subsystem was 3:1 as against the desired 1:1. However, during the period 1997–2002 (ninth plan period) this ratio improved to 1.3:1, which is mainly due to a reduction in investment by the government in the generation subsystem.

The shortcomings in the distribution infrastructure, on the other hand, have been identified as follows:

(a) Insufficient transformation capabilities
(b) High technical losses
(c) High non-technical losses, such as pilferage and commercial losses
(d) Inadequacy in addressing consumer concerns including poor service
(e) Absence of redundancies

Another very pressing issue related to the subsystem is that of unbearably high T&D losses. The collective T&D losses in the power industry in India increased from 17.5% to an astonishing 21.7% during the period 1970–85. On an all-India basis, the average T&D losses are estimated at 40%, which is very high when compared to the international average of approximately 6–7%. Table 1.7 provides the year-wise T&D losses in the power industry in India.

Table 1.7 Year-wise T&D losses in the Indian power industry

Year	T&D losses in % (All India)
2007–08	27.20
2008–09	25.47
2009–10	25.39
2010–11	23.97

Due to concerted efforts, the transmission and distribution (T&D) losses have come down but have stagnated at 23.97%.

The aggregate technical and commercial losses (AT&C) are of the order of 50% power generation. Billing for generated power is approximately 55% of the total power generated while the realization is only about 41%.

National Grid

Hitherto transmission networks were developed with a focus on self-sufficiency on regional basis. As such the period from the mid 1970s to the early 1990s saw the building up of strong state grids and the emergence of regional grids. Presently, the regional grid networks are adequately strong to meet the inter-state transmission requirements while the state grids can focus on meeting the intra-state needs of their respective states.

The spotlight is now on building a national grid for better utilization of hydro resources, saving the transportation cost of coal (since it is economical to transmit electrical energy), sharing of reserves, etc.

1.10.3 Load Subsystem

From the perspective of a power supplier, an item (component) consuming electrical energy is a load. Therefore, loads on a power system can be broadly categorized as follows: (a) industrial, (b) commercial, and (c) domestic.

Industrial loads, which are voltage and frequency dependent, are a combination of motor loads, lighting loads, etc. Induction motors comprise a high percentage of the industrial load and consume considerable reactive power. Both commercial and domestic loads are voltage dependent and are mainly constituted of lighting, heating, and cooling. A few terms related to load subsystems are described here.

Load curve of a utility is a plot of variation of composite load against time. If the variation of load is on a 24-hour basis it is called a *daily load curve*.

Peak or maximum demand is defined as the maximum load occurring in a 24-hour cycle.

Load factor (*LF*) is defined as the ratio of average load during a period to maximum load during the same period. Thus,

$$\text{LF} = \frac{\text{Average load in kW/MW}}{\text{Maximum load in kW/MW}} \text{ for a specified period} \tag{1.3}$$

If the specified period is a 24-hour cycle, the LF is called a daily LF. Multiplying Eq. (1.3) by 24 yields

$$\begin{aligned}\text{Daily LF} &= \frac{\text{Average load in kW/MW} \times 24}{\text{Maximum load in kW/MW} \times 24} \\ &= \frac{\text{Energy consumed in 24 h in kWh/MWh}}{\text{Maximum load} \times 24 \text{ in kWh/MWh}}\end{aligned} \tag{1.4}$$

If the specified period is one year (24 × 365 = 8760 h), the LF is called an annual LF. The annual LF is used to assess the performance of a generating station. Thus,

$$\text{Annual LF} = \frac{\text{Energy consumed in 8760 h in kWh}}{\text{Maximum load} \times 8760 \text{ in kWh/MWh}} \tag{1.5}$$

Higher the annual load factor, more economical is the plant operation. The desirable range of annual load factor of a system is between 55% to 70%.

Diversity factor is defined as the ratio of the sum of maximum demands of individual category of consumers, such as industrial, commercial, and domestic, to the maximum load on the system. Thus,

$$\text{Diversity factor} = \frac{\sum \text{Max. demand of individual category of consumers}}{\text{Max. demand on system}} \tag{1.6}$$

It is a parameter which provides the diversification in load and is used to decide the installed capacity of a generating station. It is greater than unity, and therefore the installed capacity will be less than the sum of the maximum demands of individual category of consumers.

Utilization factor is defined as the ratio of maximum demand to installed capacity, that is,

$$\text{Utilization factor} = \frac{\text{Max. demand in MW}}{\text{Installed capacity in MW}} \tag{1.7}$$

Plant factor is defined as the ratio of annual energy generated to the possible annual energy that can be generated based on installed capacity. Thus,

$$\text{Plant factor} = \frac{\text{Annual energy generated in MWh}}{\text{Installed capacity in MW} \times 24 \times 365} \tag{1.8}$$

Example 1.1 Compute the (i) average load, (ii) maximum load, and (iii) daily average load factor, if the daily variation of load on a power company is as follows:

Interval number	Clock time in hours		Load in MW
1	00	06	4
2	06	09	8
3	09	11	12
4	11	14	18
5	14	18	15
6	18	20	12
7	20	22	8
8	22	24	4

Solution The MATLAB function `lodata` is used to draw the daily load curve. The input to the program consists of the following:

`nintrvl`	The number of intervals which is 8 in this case
`load`	It is a matrix whose order is equal to (number of intervals) × 3. The first two columns of the matrix represent the duration in clock hours and the third column represents the load in MW.

The output variables are `energy`, `Pavg` (average power), `LF` (load factor), and `Pmax` (maximum power demand).

```
% Program for plotting the load curve and computing avearge load and load factor
% Program developed by the authors
function [energy,Pavg,LF,Pmax]=lodata(nintrvl,load);
% Initialization
time = zeros(1,nintrvl);P=zeros(1,nintrvl);
Pmax = 0;X = 0;
hold on
% Plotting the load curve
for I =1:nintrvl;
 time(1,I) =load(I,2)-load(I,1);
 x=linspace(X,load(I,2),500);
 Y =load(I,3);
 plot(x,Y)
 X=X+time(1,I);
 if I < nintrvl;
 y=linspace(load(I,3),load(I+1,3),500);
 x=load(I,2);
```

```
 plot(x,y)
% Computing the average load and load factor
 energy=0;
 for I =1:nintrvl;
 energy=energy+(load(I,2)–load(I,1))*load(I,3);
 if load(I,3) > Pmax;
    Pmax=load(I,3);
 else
 end
 end
else
end
end
% Setting the axes and labelling the plot
axis([0 24 0 25]);
xlabel (‘Time in hours’);
ylabel (‘Load in MW’);
title (‘DAILY LOAD CURVE’);
hold off
% Output
energy
Pavg=energy/24
LF=Pavg/Pmax
Pmax
≫ nintrvl=8;load=[00 06 4;06 09 8;09 11 12;11 14 18;14 18 15;18 20 12;20 22
8;22 24 4];
% Input data
≫ [energy,Pavg,LF,Pmax]=lodata(nintrvl,load);    % Statement to call function
                                                 lodata for execution.

energy =
 234
Pavg =
 9.7500
LF =
 0.5417
Pmax =
 18
≫
```

The daily load curve is shown in Fig. 1.15.

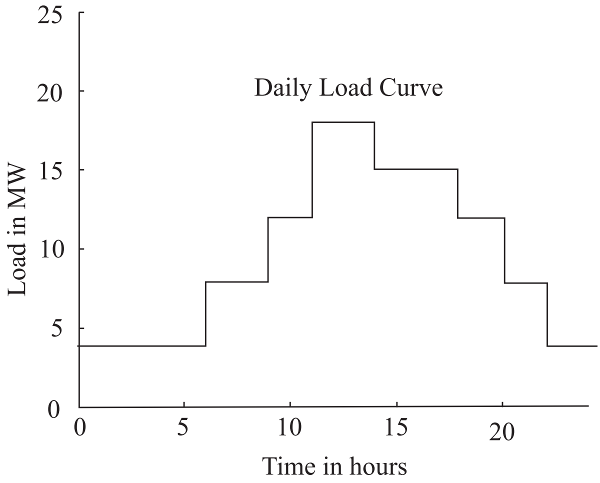

Fig. 1.15 Load curve of Example 1.1

1.10.4 Protection and Control Subsystem

Protection and control subsystem is constituted of relays, switchgear, and other control devices, which protect the various subsystems against faults and overloads, and ensure efficient, reliable, and economic operation of the electric power system.

1.11 ENERGY CONSERVATION

A unit of energy saved is a unit of energy generated at no extra cost. One of the objectives of the GOI under its Mission 2012: 'Power for All' is to evolve a conservation strategy to optimize the utilization of electrical energy. The focus will be on (i) demand management, (ii) load management, and (iii) technology upgradation to provide energy-efficient equipment and gadgets. It is possible to bring about an energy saving of the order of 20% in various sectors without sacrificing any of the end-use benefits of energy.

Keeping in mind the need and importance of energy conservation, the GOI has enacted the Energy Conservation Act (2001) under which a Bureau of Energy Efficiency has been established for the promotion of conservation and efficient use of energy.

1.12 COMPUTERS IN POWER SYSTEM ANALYSIS

Historically, digital computers were first employed for analysing power system problems, in a restricted manner, in the late 40s of the last century. With the advent of computers having capabilities to handle large volumes of data with adequately fast processing speeds, in the mid 1950s, their usage in analysing varied and more intricate problems related to larger and complex power system networks was a natural outcome.

The operation and control of present-day interconnected power networks, each constituting of substations, transmission lines, and transformers, has become so complex that from the perspective of economy and reliability of supply it is essential that these be monitored through a central point called an Energy Control Centre (ECC). An ECC is an online computer which undertakes signal processing based on remote data acquisition system and performs in both normal and emergency situations. The constituents of an ECC are as follows.

(a) An operator who acts as a human–machine interface

(b) A visual display unit (VDU) which enables the selection of presentation of the desired portion of the network, along with the data summaries and performance indices, through paging buttons

(c) Editing and special function keyboards to change operating conditions, system parameters, transformer taps, switch-in-out line capacitors, etc.

(d) Light pen cursor for operating circuit breakers, switches, etc. and for changing displays directly on the VDU

SUMMARY

- After Independence, the GOI, amongst other development plans, took upon itself to develop the power sector.

- Vision 2012 for the power sector, in addition to providing 'Power for all', also envisioned reliable and quality power at optimum cost along with the development of a competitive power industry in addition to providing sufficient power to achieve a GDP growth of 8%.
- Vision 2020 envisages efficient and environment-friendly energy resources which would become the growth engines to provide speedy and sustainable future economic development.
- In order to achieve the objectives of Vision 2012 for the power sector, Electricity Act 2003 was amended and enacted to bring about a market-oriented management, through restructuring and deregulation of the power sector, so as to introduce a spirit of competition. Electricity Act 2007 further amended Electricity Act 2003 to allow setting up of captive power units without obtaining licences and making power theft a criminal offence.
- A power sector is a complex network constituted of (a) generation, (b) transmission and distribution, (c) loads, and (d) protection and control subsystems.
- Primary sources of energy are (a) fossil fuels such as coal, oil, and natural gas, (b) renewable energy sources like hydro, wind, solar, and (c) nuclear energy.
- Based on the type of primary source employed, generation stations are categorized into (a) thermal, (b) hydro, (c) nuclear, and (d) non-conventional. In 2009–10, the total all-India generation was 771,173 GWh. Generation voltages range between 11 kV and 30 kV.
- DC transmission voltage is 500 kV while the AC voltages range between 66 and 400 kV. By 2017, it is planned to add transmission lines operating at 765 kV, along with HVDC Bipole lines. Distribution of power is undertaken at AC voltages up to 500 V.
- The load subsystem consists of (a) industrial, (b) commercial, and (c) domestic loads. The important terms used to define a load subsystem are: (a) load curve, (b) daily and annual load factor, (c) diversity factor, (d) utilization factor, and (e) plant factor.

EXERCISES

Review Questions

1.1 Trace the history of the growth of the power sector after Independence.

1.2 Write a short essay on 'Vision 2020' for the power sector.

1.3 Describe the models of regulation and deregulation associated with the power sector. Discuss the features of a regulated power sector and explain the structure of a regulated authority.

1.4 With the help of block diagrams, illustrate and explain the structure of a deregulated power sector.

1.5 Explain the mechanism of competition.

1.6 Write short notes on: (i) wholesale power market, (ii) instruments of sale transaction, and (iii) responsibilities of the SSA/ISO.

1.7 Draw a neatly labelled diagram of a power network and indicate the various subsystems along with their operation voltages.

1.8 Enumerate the various sources of energy and categorize generating stations based on primary source of energy employed.

1.9 Draw a block diagram of a thermal station and describe its main features. Explain cogeneration.

1.10 Write short notes on: (i) oil-fired, (ii) gas-fired, and (iii) diesel oil-fired generating stations.

1.11 Describe with the help of a diagram the salient features of a hydro generating station and itemize its merits and demerits.

1.12 Describe the working of a nuclear generating station.

1.13 List the various types of non-conventional generating stations and describe any two of them.

1.14 (a) Briefly describe the transmission and distribution subsystems.
(b) Highlight the concerns of the T&D subsystem in the Indian power sector.

1.15 (a) Describe the components of the load subsystem.
(b) Discuss the utility of load curve and define peak demand.

1.16 Define and write notes on: (i) load factor, (ii) diversity factor, (iii) utilization factor, and (iv) plant factor.

1.17 Write a note on the importance of computers in power system analysis.

Numerical Problems

1.1 A power utility with an installed capacity of 100 MW is supplying a composite load whose details are as follows:

Type of load	Average load in MW	Load factor
Industrial	48	0.8
Commercial	12.5	0.5
Domestic	24.5	0.7

Calculate the diversity factor.

1.2 A generating station has a plant factor of 50% and a maximum demand of 450 MW. If the annual load factor is 60%, determine the additional load the station can supply. Assume that the generating station can be fully loaded.

1.3 The demand for power on a 100-MW generating station is as follows: 80 MW for 4 h, 50 MW for 8 h and 20 MW for 6 h. For the remaining part of the day it is switched off. Determine the annual load factor of the station. Assume that the station is under maintenance and repair for 45 days in a year.

1.4 The demand for energy on a utility is growing exponentially and can be expressed as $P = P_0 e^{at}$ where a and t are the growth rate and time respectively. Determine the growth rate if the energy consumption is expected to increase 1.5 times in 10 years.

1.5 Mathematically the demand on a utility is estimated to be $P = P_0 e^{a(t-t_0)}$, where P is the demand in the year t, P_0 is the demand in the base year t_0, and a is the per annum growth rate. If the maximum power demand in the base year was 250 GW, write a MATLAB function to plot the growth of demand for the next 15 years. What is the demand after 10 years?

1.6 The month-wise load on a generating station is as follows:

Month	Jan.	Feb.	Mar.	Apr.	May	Jun.	Jul.	Aug.	Sep.	Oct.	Nov.	Dec.
Load in MW	6	6	4	3	6	10	12	14	13	4	5	6

Write a MATLAB function to plot the annual load curve for the generating station and determine the average load and load factor.

Multiple Choice Objective Questions

1.1 Who introduced the first electric supply system?
(a) Edison (b) Faraday
(c) Tesla (d) Marconi

1.2 Which of the following was set up for the development of nuclear power?
(a) NHPC (b) NTPC
(c) NPCIL (d) None of these

1.3 Which of the following is not an objective of 'Vision 2012' for the power sector?
(a) Reliability of power
(b) Quality power
(c) Sufficient power to achieve 8% GDP growth rate
(d) None of these

1.4 The process of reforming the power sector was started in
(a) 1981 (b) 1991
(c) 2001 (d) 2011

1.5 Electricity Act 2003 was enacted in the month of
(a) April (b) May
(c) June (d) July

1.6 Loss reduction and theft control was which part of the strategy to achieve 'Power for All'?
(a) Power generation (b) Transmission
(c) Distribution (d) Conservation

1.7 As per 'Electricity Act 2003' which of the following type of generating stations requires a licence?
(a) Oil fired (b) Hydro
(c) Gas fired (d) Solar

1.8 Which of the following industries employs cogeneration?
(a) Fertilizer (b) Petroleum refining
(c) Paper (d) All of these

1.9 Which of the following is not true of a hydroelectric station?
(a) No ecological imbalance (b) Long life
(c) No air pollution (d) None of these

1.10 Which of the following contains nearly zero sulphur dioxide?
(a) Oil fired (b) Coal fired
(c) Gas fired (d) Diesel fired

1.11 Which of the following is a reason to locate nuclear stations away from populated areas?
(a) Primary coolant is heavy water.
(b) High capital investment is required.
(c) Radioactive waste is generated.
(d) All of these.

1.12 The success of wind power stations is based on
(a) initial capital cost (b) power output
(c) useful life (d) all of these

1.13 Which of the following states has not set up wind power stations?
(a) Orissa (b) Punjab
(c) Tamil Nadu (d) Maharashtra

1.14 The voltage produced by a typical silicon PV solar cell is
(a) 0.25 V DC (b) 0.25 V AC
(c) 0.5 V DC (d) 0.5 V AC

1.15 Which of the following is not required for the flow of electrons in a PV cell?
(a) External field
(b) Internal field
(c) Penetration of a photon of light
(d) None of these

1.16 The minimum voltage required to charge a 12 V storage battery is
(a) 18 V (b) 16 V
(c) 14 V (d) 12 V

1.17 Which of the following will become a part of the transmission system by 2017?
(a) 765 kV (b) HVDC Bipole
(c) 400 kV (d) All of these

1.18 Currently the level of T&D losses stands at
(a) 17.5% (b) 21.7%
(c) 25% (d) 40%

1.19 A higher annual load factor indicates
(a) economical plant operation
(b) uneconomical plant operation
(c) no effect on economics of plant operation
(d) none of these

1.20 Which of the following is employed to determine the installed capacity of a generating station?
(a) Maximum demand (b) Annual load factor
(c) Diversity factor (d) Plant factor

Answers

1.1 (a)	**1.2** (c)	**1.3** (d)	**1.4** (b)	**1.5** (d)	**1.6** (c)
1.7 (b)	**1.8** (d)	**1.9** (a)	**1.10** (c)	**1.11** (c)	**1.12** (d)
1.13 (b)	**1.14** (c)	**1.15** (a)	**1.16** (c)	**1.17** (d)	**1.18** (c)
1.19 (a)	**1.20** (c)				