Third Edition

Eastern Economy Edition

Wind Power Technology

Joshua Earnest
Sthuthi Rachel

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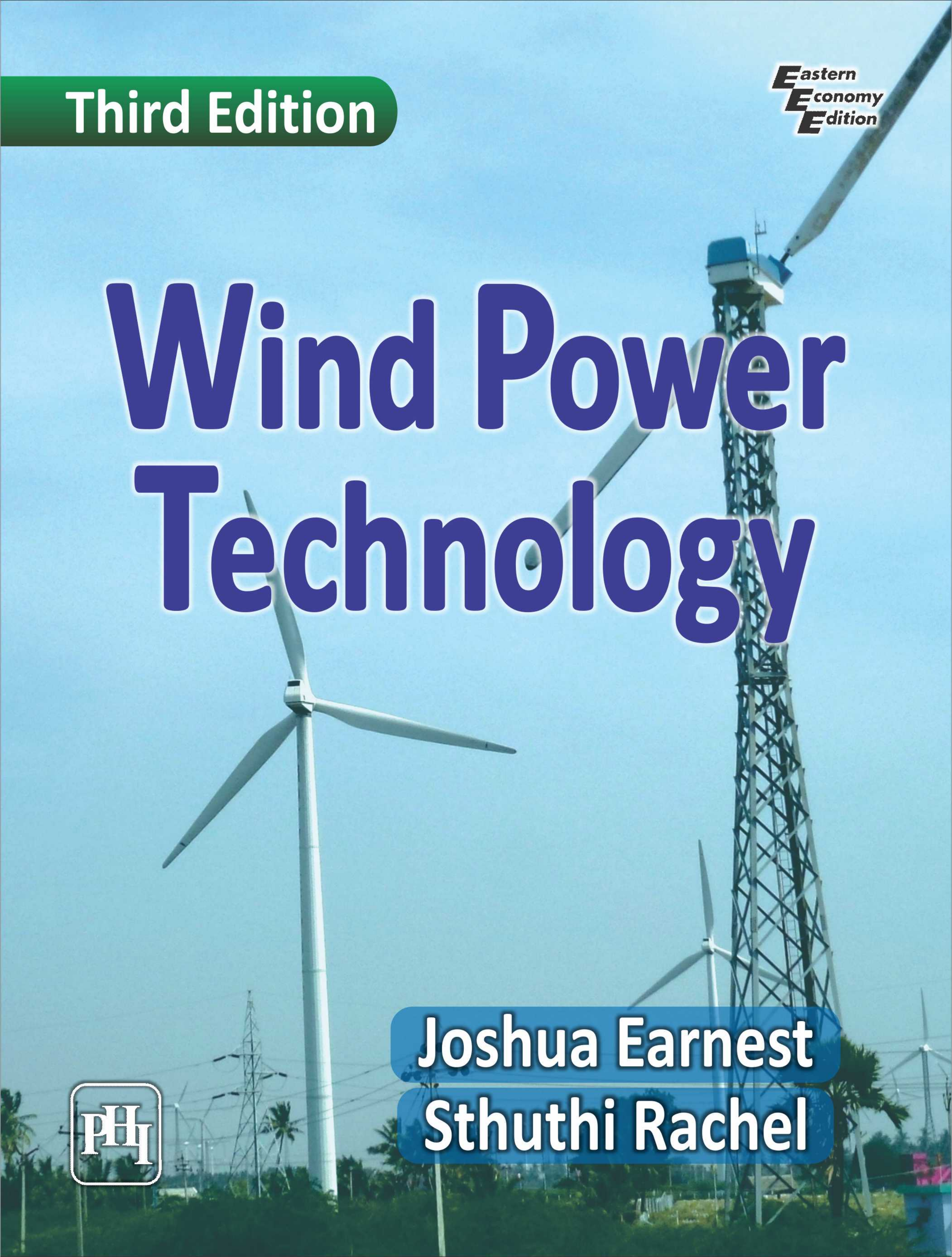

Wind Power Technology

THIRD EDITION

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WIND POWER TECHNOLOGY, Third Edition
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To

GOD

Who is Omniscient, Omnipresent and Omnipotent

and

Bindhu Joshua
Koshy Earnest
Mariamma Thomas
Late John A. Earnest
Late Achamma Earnest
Late Saramma Earnest
Late M.T. Thomas

Preface

HE let loose the East wind from the heavens and by HIS power made the South wind blow
—Psalms 78:26 (Bible)

The enthusiastic response to the earlier editions motivated us to bring forth the new edition with improved and significant changes. The speciality of this edition is that apart from the significant updation of the 1st chapter of this book, a new Chapter 15 has been added which will be of great interest as it deals with the Electronics in Renewable Energy Systems. We are thankful to all those who encouraged us by giving tremendous responses about the book. At the same time, the readers' feedback and suggestions have been incorporated in several chapters and at the same time retaining the systematic flow of contents, visuals and pagination of the 1st edition for the readers' convenience. However, the readers can also note all the other significant improvements made in the book while reading through the book. One of the key features of this book is the lucidity of the diagrams and images, which have been carefully chosen in order to develop a clear understanding of the various concepts of wind power technology.

Today, wind energy is the world's fastest growing source of renewable energy. To abate the global climate change, commercialisation of the renewable energy technologies and wind power in particular, are growing quite fast across the world. More and more windy areas are being discovered and every year, grid connected wind power is growing in leaps and bounds and India is one such happening place, where the world is watching. Among the renewable energy sources, the cost of producing one kilowatt hour (kWh) of electrical energy from the wind power is the cheapest. It is competing almost at par with the other fossil fuel power plants. All this has become possible because of the recent advancements in electrical, mechanical, power electronics, digital electronics, materials and other branches of engineering, which are used in renewable energy technologies.

Although the earlier jointly authored book *Wind Power Plants and Project Development* along with Tore Wizelius was written to cater to industrial need, it was also well received by the academia and training organisations, as such information was not available in other Indian books. Therefore, it dawned on the author that there was a niche for an additional book on "wind" to fulfil the needs of the Indian universities. It is in this backdrop that this book *Wind Power Technology* got evolved and now revised to the third edition. Along with the former, this book has been proved as a good additional resource material to satisfy the needs of various curricula of different universities and also for those who are interested in developing a deeper understanding of modern wind power plants.

With the race hotting up, China overtook the USA to occupy the top slot with the largest capacity of installed wind power plants in the world, a position long held by the USA for the last several decades. India is also not far behind and is in the fourth position. In this changed industrial scenario of renewable energy, a number of universities across India have revised their curricula to give a greater focus to wind power and renewable energy courses and also to include exclusive wind power courses in various short and long term engineering and training programmes.

As a result of research and development, the capacities of the large wind turbines are continuously increasing, the largest one today being the 7.58 MW Enercon wind turbine, they behave almost similar to the conventional power plants and therefore, the term wind power plant (WPP) is more relevant. Since the modern WPP integrates the technologies from various branches of engineering, all the chapters of this book focus on the various technological principles of these branches that govern the functioning of a typical modern wind turbine. The concepts and principles have been written in such a manner that most of the students of the various branches of engineering would be able to acquire the requisite knowledge to understand the broad-based technology of the wind turbine.

A unique feature of this book is that along with every figure title, a brief explanation that follows helps the reader to understand without referring to the relevant paragraphs again and again. Another salient feature is that the learning outcome expected to be developed in the student is provided on the title page of every chapter, thereby helping the reader to focus better on how to learn. Moreover, worked-out examples are given at relevant places and exercises are given at the end of the chapters to cement the learning further.

To address some specific curricular needs, Chapter 1 of this book begins by explaining the basic working principles of the various types of electricity generating renewable energy technologies and the tremendous potential that they have in India including the significance of wind power. Chapter 2 discusses the wind characteristics that are necessary to be understood in the context of electricity generating WPPs.

The WPP being a classic example of a mechatronic machine, Chapter 3 describes the functions of various components of this state-of-the-art electricity producing WPP. Chapter 4 explains the working principles on the basis of which the WPPs are designed to convert most efficiently the wind energy into useful electrical energy.

For safety and to maximise electricity production, Chapter 5 elaborates the various strategies that can be adapted to aerodynamically control the WPP. Apart from the aerodynamic control, there are electrical and electronic control strategies for additional control of the WPP that are explained in Chapter 6.

WPPs are broadly classified as constant speed and variable speed WPPs. With considerable amount of research and development being undertaken across the world, state-of-the-art wind power technologies are adapted for these different categories of WPPs and explained lucidly using relevant visuals and diagrams in Chapter 7 and Chapter 8.

Chapter 9 discusses about the electrical power quality produced by the different types of WPPs, while Chapter 10 explains how the different issues are resolved to integrate this green power into the electrical grid network supported by worked-out examples and some software simulations as well.

The rest of the chapters will also be of special interest to the students. Chapter 11 on *Wind Resource Assessment Technologies* describes the different types of wind related sensors necessary to determine the wind potential at a particular site. Chapter 12 discusses some of the major *Design Considerations of WPPs* supported by some worked-out examples as well.

All those enthusiasts of small wind turbines will be very happy to read Chapter 13. It explains in detail the essentials related to various types of small wind turbine technologies hardly found in a single book. *Wind Project Life Cycle* a concept in the curricula of some Indian universities is discussed in Chapter 14.

Chapter 15 on *Electronics in Renewable Energy Systems* is a new chapter in this edition and will help all students interested in the electronics related to this area.

Finally, to solve the energy crisis, the authors wish that this book may serve to advance in the greater use of renewable energy and wind power technology in particular.

Best wishes for a smooth sailing through this book.

Joshua Earnest
Sthuthi Rachel

Acknowledgements

First and foremost, the authors would like to thank Jesus GOD and LORD, who empowered them and taught them wind power technology, and spurred them to write this, much needed book for the university students, a unique book of its kind.

The first author thanks to one of his mentors and friend Tore Wizelius, the 'Guru of Swedish Wind Power' and co-author of his first book *Wind Power Plants and Project Development* for the encouragement to write this book to cater to the needs of the university system and for some unique ideas that are reflected in different sections of this book.

The authors are grateful to all those wind power plant manufacturers, individuals and other websites who have extended their cooperation directly or indirectly in permitting them to use the pictures duly acknowledged under each visual and thus, help in the cause of spreading the knowledge of this green and clean energy. The authors also thank the National Renewable Energy Laboratory (NREL) and DOE—Subcontract Report NREL/SR-500-35524, entitled *Northern Power Systems WindPACT Drive Train Alternative Design Study Report; Period of Performance: April 12, 2001 to January 31, 2005,* by G. Bywaters, V. John, J. Lynch, P. Mattila, G. Norton, J. Stowell, M. Salata, O. Labath, A. Chertok, and D. Hablanian for use of their pictures.

The first author extends his thanks to the feedback of his students spread over different continents of the globe who have attended his wind power training programmes over the past several years, whom he taught in the face-to-face sessions, conference rooms during the wind farm visits and also in the e-classroom of the distance mode training programmes offered by National Institute of Technical Teachers' Training and Research (NITTTR) Bhopal.

Here, the authors would like to admit that the concepts, ideas and discussions contained in this book are also the result of the interactions with various wind power plant manufacturers, their brochures, Websites, wind farm developers and authors of wind related books. They are also thankful to the authors of various journal papers, research reports, conference proceedings, and monographs which they have referred to extensively and duly acknowledged them in the bibliography.

The first author is also grateful to Thomas Ackerman, author of *Wind Electric Systems* and founder, Energynautics GmbH, Germany as well as to his close friend Sven Ruin, CEO of Teroc, Sweden, who has given him valuable feedback regarding the earlier wind power book. He also owes his sincere thanks to his friend Henk Polinder of Delft University, The Netherlands, whose numerous papers, articles and discussions have considerably educated him about wind power. His thanks also go to his close friends Lars Hallen, Founder & Chairman, LIFE Academy, Sweden and Bo Gillgren for their encouragement. Special thanks are due to his friends of the Union of Evangelical students of India, whose encouragement and prayers spurred him on in this endeavour. He would also like to thank his colleagues Ms. Susan S. Mathew, A.S. Walkey, Shashikant Gupta, N.P. Patidar and other friends and well-wishers who have directly or indirectly supported him in this book writing project. He also grateful to Aditya Patil, PRDC, Bangalore, and Dr. Vinod Kumar of Maharana Pratap Univesity, Udaipur, Rajasthan for their valuable academic inputs.

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Joshua Earnest
Sthuthi Rachel

Contents

List of Symbols/Notations

Symbols/ Units	*Main use of the Symbols in this Book*	*Other Uses/Comments*
α	Angle of attack	—
β	Blade pitch angle	—
γ	Kinematic viscosity of fluid	—
δ	Load angle (angle between the rotating magnetic field of electrical machine)	Yaw angle of a WPP
λ	Tip speed ratio	—
σ	Solidity	Standard deviations (SD)
θ	Angle between voltage and current	—
φ	Flux density and power factor (cos φ)	Inflow angle (fabrication angle)
ω	Angular velocity (rad/s)	—
ψ	Flux	Could be stator/rotor flux
ρ	Density of air (kg/m^3)	—
ρ_a	Area density (kg/m^2)	—
η	Efficiency	—
η_g	Efficiency of gearbox	—
η_e	Efficiency of electrical generator	—
A	Swept area of WPP rotor (m^2)	—
a	Ampere–current	—
B	Flux density	—
c	Shape parameter of Weibull probability function	—
C	Capacitance (F)	—
C_D	Drag coefficient	Dimensionless number

Symbols/ Units	Main use of Symbols in this Book	Other Uses/Comments
C_L	Lift coefficient	Dimensionless number
C_M	Pitching moment	Dimensionless number
C_p	Power coefficient or aerodynamic efficiency	Dimensionless number
C_T	Torque coefficient	Dimensionless number
D	Diameter of wind turbine rotor	Diameter of electrical generator
Dg	Air gap diameter	—
E_A	Generate voltage	—
E	Lift-to-drag ratio	—
E_{year}	Energy content of the wind during a year	—
f	Frequency	—
f_s	Shear stress (Pa or N/m^2)	—
f_d	Tangential force	—
F_{circ}	Circumferential or driving force applied in the plane of rotation and helps the rotor to rotate and produce the useful power	—
F_d	Drag force	—
F_L	Lift force	—
F_{res}	Resultant force	—
F_{torque}	Torque producing force	—
F_{thrust}	Useless force, gets applied perpendicular to the plane of rotation which tries to bend the WPP tower	—
g	Gravity	—
G	Giga (10^9)	Shear modulus
H	Hub height or height of obstacle	—
I	Polar mass moment of inertia	—
J	Polar area moment of inertia	—
k_T	Torsional spring constant	—
K	kelvin (absolute temperature measurement)	—
L	Lift of the wind turbine blade	Inductance of a winding or coil
l	litre	
l_s	Axial length of generator stator	—
I	Current	—
I_F	Fault current	—
J	Polar moment of inertia of the wind turbine rotor	—
k	Shape parameter of Weibull probability function	kilo (10^3)
M	Mega (10^6)	—
m	Metre	Mass or milli (10^{-3})
mb	Milibar (ambient pressure measurement)	—
m/s	Metre per second	—

Symbols/ Units	Main use of Symbols in this Book	Other Uses/Comments
μ	Micro (10^{-6})	—
n	Number of wind turbine rotor blades	—
N	Revolutions per minute	—
Nm (N)	newton meter (unit of force in SI units)	—
N_s	Synchronous speed of generator	—
P	Active power (kW)	—
p	Number of poles of an electrical generator	Air pressure
p.u.	Per unit	—
P_e	Electrical power delivered by the generator	—
P_{kin}	Kinetic power in wind or energy/second (W or J/s)	—
P_m	Mechanical power produced by the wind turbine rotor	—
Q	Reactive power kVAr	—
R	Radius of rotor	Resistance
R_A	Armature resistance	—
R_k	Reactance of grid	—
R_e	Reynolds number	—
s	Second	Slip of induction generator
S_s	Speed of sound	
S_{sc}	Short circuit power	—
T	Torque	Time (s); period of rotation of rotor; tera (10^{12}), and tesla
T_{aero}	Aerodynamic torque of wind turbine rotor shaft	—
T_{gen}	Torque of electrical generator rotor shaft	—
U	Potential energy of wind turbine shaft	—
V	volt	—
V_G	Generating voltage	—
V_S	Transmission (or sending end) voltage	—
v	Wind velocity (m/s)	—
v_d	Downstream wind velocity after energy is extracted and passing through the blades of the rotor	—
v_h	Number of hourly wind speed values during the month	—
v_{mean}	Mean wind speed	—
v_o	Undisturbed wind velocity before impinging on wind turbine rotor	—
v_{tip}	Wind velocity at blade tip	—
W	watt	—
X	Reactance	—
X_k	Reactance of grid	—
X_s	Synchronous reactance	—
Z	Impedance	—

Acronyms and Abbreviations

AC	Alternating Current
AD	Accelerated Depreciation
ADC	Analogue to Digital Converter
AEP	Annual Energy Production
AF-PMSG	Axial Flux Permanent Magnet Synchronous Generator
agl	Above ground level
ANSI	American National Standards Institute
ASC	Active-Stall Control
AWEA	American Wind Energy Association
BDIG	Brushless Doubly-fed Induction Generators
BJT	Bipolar Junction Transistor
BWEA	British Wind Energy Association
CCT	Critical fault Clearing Time
CDM	Clean Development Mechanism
CEA	Central Electricity Authority
CER	Certified Emission reduction Receipt
CFD	Computational Fluid Dynamics
CFRP	Carbon Fibre Reinforced Polyester
CHB	Cascaded H-Bridge
CMS	Condition Monitoring System
CoE	Cost of Energy
CRGO	Cold Rolled Grain Oriented
CSI	Current Source Inverter
CSP	Concentrating Solar Power
CTU	Central Transmission Utility
dB	Decibel (measure of sound levels)
DAC	Digital to Analog Converter

DC	Direct Current
DDT	Dichloro-Diphenyl-Trichloroethane (pesticide)
DFIG	Doubly-Fed Induction Generator
DG	Distributed Generation
DisCom	Distribution Company
DMPPT	Decentralised maximum power point tracker
DNES	Department of Non-conventional Energy Sources
DNO	Distribution Network Operator
DST	Department of Science and Technology
DVR	Dynamic Voltage Restorer
EIA	Environment Impact Assessment
EMI	Electro Magnetic Interference
EPF	Energy Pattern Factor
EU	European Union
EWEA	European Wind Energy Association
FACTS	Flexible AC Transmission System
FRT	Fault-Ride-Through (similar to LVRT)
GBI	Generation-Based Incentive
GEDA	Gujarat (and Goa) Energy Development Agency
GIS	Geographical Information Systems
GMT	Greenwich Mean Time
GPRS	General Packet Radio Service (used by GSM mobile phones)
GR	Gearbox Ratio
GRP or GFRP	Glass-fibre Reinforced Plastic
GSC	Grid-Side Converter
GTO	Gate Turn-On Thyristor
GWh	Gigawatt hours
HF	High Frequency
Hg	Mercury
HWRT	High Wind Ride Through
Hz	hertz [i.e., electric power frequency (in cycles per second)]
IC	Integrated Chips
IEA	International Energy Agency
IEA 2003	Indian Electricity Act 2003
IEC	International Electrotechnical Commission
IEEE	Institute of Electrical and Electronic Engineers
IG	Induction Generator
IGBT	Insulated Gate Bipolar Transistor
IGCT	Integrated Gate Commutated Thyristor
IREDA	Indian Renewable Energy Development Agency
JNNSM	Jawaharlal Nehru National Solar Mission
kVA	kilovolt ampere
kVArH	kilovolt ampere reactive hours
kW	kilowatt
kWh	kilowatt hours

LAN	Local Area Network
LIDAR	LIght Detection And Ranging
LV	Low Voltage
LVRT	Low Voltage Ride Through
MCS	Micro-generation Certification Scheme
MNRE	Ministry of New Renewable Energy
MOSFET	Metal Oxide Field Effect Transistor
MPPT	Maximum Power Point Tracking
msl	Mean sea level
MV	Medium Voltage
MW	Megawatt
MWh	Megawatt hour
NACA	National Advisory Committee for Aeronautics
Nd-Fe-B	Neodymium-iron-boron
NFYP	National Five Year Plan
NIWE	National Institute of Wind Energy, Chennai, India
NPC	Neutral Point Clamped
NPS	Negative Phase Sequence
O&M	Operation and Maintenance
OLTC	On load tap changing (for transformer)
OSIG	Opti-Slip Induction Generator
OTEC	Ocean Thermal Energy Conversion
PC	Personal Computer
PCC	Point of Common Connection (same as POI)
PEC	Power Electronic Converter (Circuits)
PFC	Power Factor Correction
PLC	Power Line Communication
PLC	Programmable Logic Controller
PM	Permanent Magnet(s)
PMSG	Permanent Magnet Synchronous Generator
POI	Point of Interconnection (same as PCC)
PPA	Power Purchase Agreement
PV	Photo Voltaic
PWM	Pulse Width Modulation
R&D	Research and Development
REC	Renewable Energy Certificates
RF-PMSG	Radial flux Permanent Magnet Synchronous Generator
RLDC	Regional Load Despatch Centres
RoCoF	Rate of Change of Frequency
RPM	Revolutions Per Minute
RPO	Renewable Purchase Obligation
RSC	Rotor-Side Converter
SAPS	Stand Alone Power Systems
SCADA	Supervisory Control And Data Acquisition
SCIG	Squirrel Cage Induction Generator

SCR	Silicon Controlled Rectifier
SERC	State Electricity Regulatory Commission
SODAR	SOnic Detection And Ranging
SPV	Solar Photo Voltaics
SR	Spinning Reserve
SSC	Static Series Compensator
STATCOM	STATic (Synchronous) COMpensator
SVC	Static VAr Compensators
SWCC	Small Wind Certification Council
T&D	Transmission and Distribution
TCR	Thyristor Controlled Reactors
TCS	Thyristor Switched Capacitors
TF-PMSG	Transverse Flux Permanent Magnet Synchronous Generators
THM	Top Head Mass
TSO	Transmission System Operator
TSR	Tip Speed Ratio (or Thyristor Switched Reactor)
TWh	Terawatt hours
Type-A	Constant speed WPP
Type-A0	Constant speed WPP with stall regulation
Type-A1	Constant speed WPP with pitch regulation
Type-A2	Constant speed WPP with active-stall regulation
Type-B	Narrow range speed WPP
Type-B0	Narrow range speed WPP with stall regulation
Type-B1	Narrow range speed WPP with pitch regulation
Type-B2	Narrow speed WPP with active-stall regulation
Type-C	Limited range speed WPP
Type-C0	Limited range speed WPP with stall regulation
Type-C1	Limited range speed WPP with pitch regulation
Type-C2	Limited range speed WPP with active-stall regulation
Type-D	Wide range speed WPP
Type-D0	Wide range WPP with stall regulation
Type-D1	Wide range WPP with pitch regulation
Type-D2	Wide range WPP with active-stall regulation
VAr	volt ampere reactive
VSC	Voltage Source Converter
VRLA	Valve Regulated Lead Acid (batteries)
VSI	Voltage Source Inverter
WEC	Wind Energy Converter
WEG	Wind Energy Generator
WFMS	Wind Farm Management System
WPP	Wind Power Plant
WRIG	Wound Rotor Induction Generator
WRSG	Wound Rotor Synchronous Generator

1

Renewable Energy Technologies

...HE makes the wind blow, and the waters flow
—Psalm 147:18

Learning Outcome

'On studying this chapter, you will be able to justify the need and potential of renewable energy technologies and even designing a simple domestic solar PV system'.

CHAPTER HIGHLIGHTS

1.1 INTRODUCTION

Renewable energy can be defined as the energy sources that are natural and continually replenished either at the same rate or faster than the rate at which they are being used up by humans more or less indefinitely such as the sun, wind, rain, tides, biomass and geothermal energy. *Green energy*, *alternative energy* and *sustainable energy* are the other synonyms sometimes used to describe the renewable energy that is converted into either electricity, heat or mechanical power for use in homes or in industries by clean, harmless and non-polluting methods. But it is important to understand the differences between the technologies used by each of the different sources to make the right choice for any particular application.

The crude oil crisis which began in 1971 and the continuously increasing prices for fossil fuels, has adversely affected the economic growth of developing countries. This woke up the world to look for the alternative and sustainable energy solutions. Therefore, energy security calls for using renewable energy resources. With rapid economic growth, the demand for energy is increasing. Energy is by far the largest industry in the world. It is worth about US $ 7 trillion per year while the world's total GDP is about US $ 55 trillion. Thus, the energy industry is worth more than 10% of the entire world's economy. As reported by Renewable Energy World Magazine in their February 2, 2018 Issue, for the first time in history in 2017 in the 28 nation European Union, the power from renewables generated jointly by wind, solar and biomass was an all time high of 20.9% of all power, overtaking the power generated by coal which was down to 20.6%.

Since 1980s, the government of India (and many other governments) has introduced myriad of incentives for the use and promotion of renewable energy sources. This chapter has been written to make the reader aware of the vast potential of renewable energy and it also provides an overview of the various renewable energy technologies. It is expected that this chapter will encourage and motivate the reader to undertake further study and research with the ultimate aim to make the concerned renewable energy technology efficient, reliable techno-economical and commercially viable for the community at large. Table 1.1 shows a comparison of renewable and conventional energy.

Table 1.1 Comparison of Renewable versus Conventional Energy

S.No.	Criteria	Renewable Energy	Conventional Energy
1	Availability	Can be used without any treatment	Needs to be extracted and treated through laborious and environmentally damaging processes
2	Quantity available	Continuously replenish-able resource	Dwindling reserves
3	Transportability	No need to transport, used where it is available	Needs to be transported from the site rendering it environmentally harmful
4	Green house gases (GHG)	Nil	Releases green house gases
5	Energy security	Minimises reliance on dwindling resources such as oil, coal and others	Energy security remains at risk due to more dependence on oil
6	Pollution	Completely pollution-free	Pollution occurs at various levels

1.2 RENEWABLE ENERGY SOURCES BRIDGING THE ENERGY GAP

India is world's 3rd largest producer (3,44,690 MW) and 3rd largest electrical energy consumer as on September 2018. Massively expanding the large scale deployment of both centralised and distributed renewable energy including solar, wind, small hydro, biomass, and geothermal will ease the strain on the present transmission and distribution systems.

As on September 2018 (see Figure 1.1) India is having the 6th largest installed electric generation capacity of 3,44,002 MW. Of this total installed power, the contribution from thermal power plants is 2,22,906 MW (64.80%), large hydroelectric power plants is 45,293 MW (13.17%), nuclear power is 6,780 MW (1.97%) and that from all renewable sources put together is 70,648 MW (20.54%).

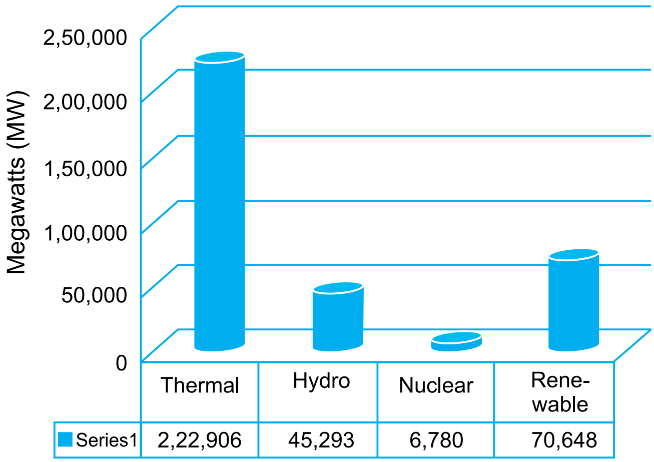

Figure 1.1 Installed Grid Connected Electrical Capacity in India (MW): As on September 2018.

The grid connected renewable energy in India is (see Figure 1.2): 70,648 MW (on September 2018), wind power 34,294 MW (9.9%) small hydro—4,493 MW (1.3%), biomass—8,839 MW (2.6%), Solar PV—23,023 MW (6.7%). India plans to make a massive switch over from coal, oil, natural gas and nuclear power plants to renewable energy power plants, as MNRE has targeted to have an installed capacity of 1,00,000 MW of solar power and 60,000 MW of wind power by the year 2022. The large scale deployment of solar and wind power projects which represent a bright spot on India's economic future needs to be continued even at a quicker pace in order to effect the smooth transition from fossil fuels to renewable energy sources.

In 1982, the foundation stone for harnessing renewable energy was laid in India by the establishment of the Department of Non-Conventional Energy Sources (DNES). In 1992 the DNES was converted into the Ministry of Non-Conventional Energy Sources (MNES) and later in 2006 it was re-christened as Ministry of New and Renewable Energy Sources (MNRE).

In order to fully exploit the indigenous renewable energy sources at its doorstep, the MNRE has been addressing several challenges to remove the barriers that are holding back the development, by formulating suitable policies and setting up demonstration

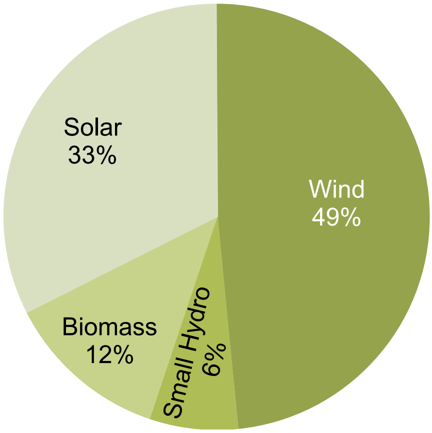

Figure 1.2 Overview of Grid Connected Renewable Energy Capacity in India (MW): As on September 2018.

projects for various types of renewable energy power plants in various parts of India build up investor confidence and to promote research even in the private sector.

Table 1.2 depicts the presently available potential of the grid connected renewable sources in India.

Table 1.2 Potential of Grid Connected Renewable Energy in India

S.No.	Renewable Energy Source	Potential Capacity	Assumed PLF (%)
1	Wind power	1,00,000	25
2	Small hydro power	15,000	45
3	Bagasse power	5,000	60
4	Biomass power	16,881	60
5	Waste-to-power	5,000	60
6	Solar CSP-based power	2,00,000	35
7	Solar PV power	2,00,000	20
8	Geothermal power	10,000	80

The initial policy support for renewable energy began in 1993 when MNES issued guidelines for purchase of power prescribing the power purchase tariff of ₹ 2.25 kWh with annual escalation of 5% for the power generated from renewable energy sources.

The renewable energy initiatives got a shot in the arm with the enactment of Indian Electricity Act 2003 and the State Electricity Regulatory Commissions (SERC), which states that *every utility will have to mandatorily purchase the energy from the renewable energy sector*. In 2011, the trading of renewable energy certificates (REC) started in India in line with the renewable purchase obligations (RPO) by various states of India. Under the National Action Plan for Climate Change (NAPCC), the government has set a goal for 15% of renewable energy (excluding the large hydroelectric power plants) and 15% of wind power by 2020 to promote renewable energy. India has reiterated its commitment by upscaling the renewable energy target to 175 GW capacity by 2022 to provide equitable sustainable development.

Table 1.3 provides an overview of the capital cost for 1 kW of energy and generation cost of 1 kWh of electrical energy from various energy sources.

Table 1.3 Energy Costs from Different Types of Energy Sources

S.No.	Energy Source	Capital Cost of 1 kW (Indian Rupees)	Generation Cost of 1 kWh (Indian Rupees)
1	Natural gas	27,500 to 82,500	2.16 to 3.38
2	Coal	1,04,500 to 3,19,000	1.08 to 2.16
3	Nuclear	2,47,500 to 4,12,500	15.66
4	Geothermal	1,40,400 to 1,89,400	5.4
5	Solar thermal	1,62,000 to 2,70,400	3.24 to 8.1
6	Solar photovoltaic	60,000 to 95,000	3.0
7	Wind	70,200 to 1,35,000	2.43 to 5.4
8	Biomass	Differs with technology	2.43 to 5.4
9	Tidal	Differs with technology	5.4
10	Wave	Differs with technology	6.48

1.3 SMALL HYDEL POWER PLANTS

A small hydroelectric (*hydel*) power plant essentially uses water pressure to drive a turbine, which in turn feeds into a generator that creates electricity. The small hydel power plant potential already identified in India is 15,000 MW, is largely unexploited (see Figure 1.2). Small hydel schemes use small dams or weirs, water storage reservoirs or diversion of the rivers' water flow through tunnels or canals. Many of the hydel plants in India could be seasonal especially in the hilly regions during the rainy season and can be used to power single properties or small villages, depending on the size of the installation.

Microhydro plants typically below 100 kW basically consist of two types: impulse and reaction type. *Flow* is the speed of water passing in each second. The rate of flow is called *flow rate* (Q) measure in litres per second. *Head* (H) is the vertical level difference of water in metres from the source (say settling tank) to the turbine level. The greater is the head, the greater will be the power output. The types of turbine to be chosen depend on the 'flow rate' and the 'head' of the source of water flow that is available. The amount of potential energy available at a site can be determined by multiplying the 'head' (in metres) by the 'flow rate' (litres per second) by 9.81 m^2 (gravity).

The power 'P' available from a hydel power plant is given by:

$$P = \eta GHQ \tag{1.1}$$

where,

η = Efficiency of the hydro turbine (between 80%–95%)
G = Gravitational constant (9.81 m/s^2)
Q = Flow rate of water (in cubic metre per second)
H = Head of water (in metres)

EXAMPLE 1.1

A small stream drops 30 m down the side of a mountain producing a water flow rate of 700 l/min past a fixed point. How much power could a small hydel power plant generate, if the type of water turbine used has a maximum efficiency (η) of 90%?

Solution:

$$P = \eta G H Q$$

where,

η = 90%

G = 9.81 m/s^2

H = 30

Q = 0.01166 m^3/s (i.e. 1000 l is equal to 1 m^3, so 700 l is equal to 0.7 m^3. One minute is equal to 60 s, then flow rate of 0.7 m^3/min is equal to 0.01166 m^3/s)

$$\therefore \quad P = 0.9 \times 9.81 \times 0.01166 \times 30$$

$$P = 3.088 \text{ kW}$$

i.e., equivalent to over 27,054 kWh, i.e., (i.e., 3.088 × 24 × 365) of free hydroelectricity annually.

1.3.1 Types of Impulse Turbines

These 'high head' water turbines rely on the force of the water striking the water wheel impellers. The impulse types are more popular as they are essentially simpler in design and therefore have relatively less maintenance issues as compared with reaction types.

Pelton turbines are essentially small cup shaped buckets arranged around a wheel. In this system, the water is pushed through a gradually narrowing pipe to increase the pressure as it reaches the turbine and strikes the buckets to cause it to move and turn the electric generator connected to it. It operates most efficiently at high head and low flow situations.

The *Turgo impulse* wheel turbine is a more efficient version of the Pelton turbine. Here also the water pressure is increased by the narrowing pipe, but the water jet is angled in such way that it hits more of the cup shaped buckets to create a faster revolution.

1.3.2 Types of Reaction Turbines

The reaction turbines are highly site specific and are scaled down versions of the Francis turbine and Kaplan turbine. The rotations of the turbines depend on the pressure created by the water rather than the speed with which it hits the turbine. The designs of the impellers of these two types of turbines are also different. They are highly efficient compared to the impulse turbines.

The *Francis turbine* is a device that has a spiral casing where the water is directed through vanes on a rotor. It is used in medium head and high flow situations.

The *Kaplan turbine* (also called *Propeller turbine*) acts like the propeller of a boat adjusting to the flow of water.

Continued research and development of these technologies can still be undertaken for commercially profitable business in India.

1.4 GEOTHERMAL POWER PLANTS

Geothermal energy makes the use of the energy stored as heat in the water deep below the earth's surface. Different types of geothermal energy are given below:

- **Direct geothermal energy** wherein the geothermal hot water is available very close to the earth's surface that can be used directly for heating, bathing or washing.
- **Ground source geothermal** wherein the geothermal hot water resource is a little deep, but by boring it can be accessed for heating, bathing or washing.
- **Geothermal power plants** wherein the hot water (having very high temperature) or steam is deep underground, but can be accessed by boring for generating geothermal steam and then, the electricity.

Although not exploited, India's geothermal potential stands at 10,600 MW of power (see Figure 1.3). Ministry of New and Renewable Energy (MNRE) of India has already taken an initiative for implementing the demonstration projects in geothermal

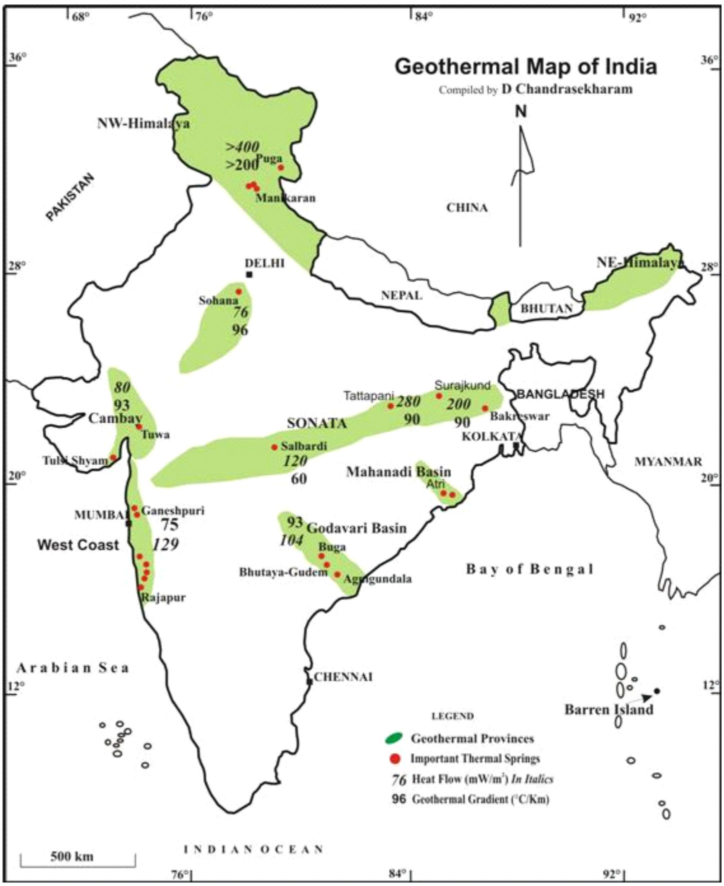

Figure 1.3 Geothermal Map of India (mW/m^2).
Courtesy: www.renewbl.com.

energy. Under this programme, geothermal resource assessment studies will be supported for bringing the data on potential geothermal energy exploitation sites, especially in the states of Jammu and Kashmir, Himachal Pradesh, Uttarakhand, Chhattisgarh and Jharkhand.

1.5 SOLAR POWER PLANTS

Sun is the prime free source of inexhaustible energy available to most of the energy sources. Next to wind power, solar power is the fastest growing renewable energy in the world.

Being a tropical country, India is blessed with lots of sunshine for most of the time in a year. India lies in a sunny tropical belt (of high insolation) of total theoretical potential over 5000 trillion kWh annually (see Figure 1.4). Jawaharlal Nehru National Solar Mission (JNNSM) is an example which is initiated by MNRE to tap this resource.

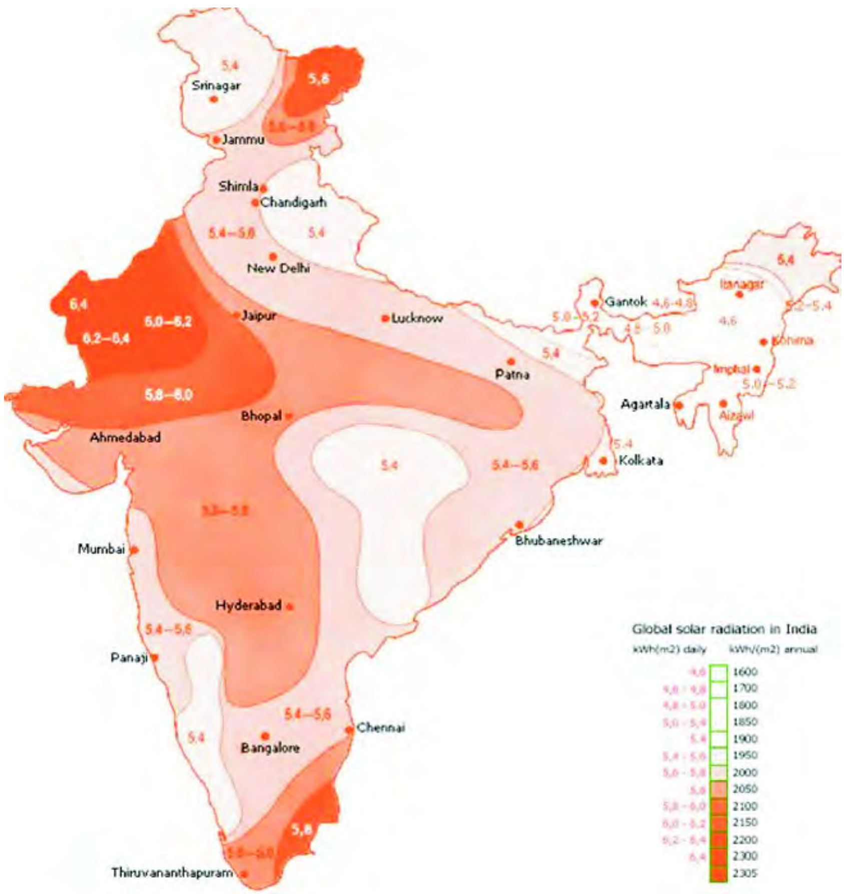

Figure 1.4 Solar Map of India: Annual mean daily global solar radiation in kWh/m^2/day. *Courtesy:* www.renewbl.com

The high costs of solar power have been decreasing significantly with the sharp drop in the prices of solar panels. The current cost of production (after bidding) is around ₹ 3.00 per kWh. This includes operation and maintenance, amortised/depreciated capital costs, loan repayment costs and other expenses such as insurance. With the level of technology advancement that is going ahead, it is expected that the costs of production of solar PV power plants will come down to ₹ 3 per kWh by 2022. Further, with JNNSM and other Generation Based Incentives (GBI) through MNRE, there is a great scope to tap the solar power.

The challenges and constraints for the use of solar power are also there. The per capita land availability is a scarce resource in India. Dedication of land area for exclusive installation of solar panels might have to compete with the other necessities that require land. The amount of land required for utility scale solar power plants (currently, it is approximately 1 km^2 for every 20 MW–60 MW power generated) could pose a strain on India's available land resource.

Although the present high cost of solar PV, high population density (land scarcity) and technology obsolescence are seen as the bottlenecks and barriers, there is still a lot of potential for solar power in India which needs to be tapped.

For producing grid-connected electric power, following two major types of solar energy technologies are commercially viable:

- Concentrated solar power (CSP) technology
- Solar photo voltaic (PV) technology.

The government of India is expected to spend $19 billion on these till 2022. By putting solar CSP and solar PV together, JNNSM attempts to reach an installed capacity of 100 GW by 2022.

1.5.1 CSP Technology

Solar thermal electric energy (STE) generation concentrates the sunlight to create heat in order to run a heat engine which turns a generator to generate electricity. Concentrated solar power (CSP) plants produce electric power by converting the sun's energy into high temperature heat using various mirror configurations. The working fluid in the heat engine that is heated by the concentrated sunlight can be a liquid (water, oil) salts or a gas (air, nitrogen, helium). The amount of power generated by a CSP plant depends on the quality of the reflector design and material and of course, on the amount of direct sunlight impinging on the reflector. The efficiency of a CSP is often between 30% and 40% and is capable of producing considerable amount of kW/MW of power. Today India has only 52.5 MW of CSP projects in operation in different parts of the country.

Heat storage is a far easier and efficient method which makes the solar thermal attractive for large scale energy production as compared to the solar PV which can only work during daylight. Heat can be stored during the day and then converted into electricity at night.

Following are the four commercially accepted CSP technologies for each of which various design technology variations exist:

- Parabolic trough