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Renewable Energy and the Environment

Springer

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Preface

This book is intended to discuss a variety of recent and vital technical and non-technical issues related to the global energy, environment, and socioeconomic developments for professionals and students who are directly and indirectly involved in the relevant fields. The impetus for this book comes from our view that there is lack of a clear vision in the development of technology and policy on how to reach the mandatory renewable energy targets of the world to reduce greenhouse gas emission and exhilarate socioeconomic development. The chapters of this book have been structured in such a way that it provides a consistent compilation of fundamental theories, a compendium of current research and development activities as well as new directions to overcome critical limitations. This book will be of benefit to researchers, planners, policy makers, and manufacturers.

Chapter 1 aims to present the importance of renewable energy, its sources, present situation, and future prospects. In the modern and fast-growing civilization, the growth of energy consumption is the measuring parameter of social and economic growth. To meet this high energy demand, suggestions are also made to make the renewable energy more popular among investors. Implementation of these suggestions will help to increase the smooth penetration of renewable energy sources in electrical power systems to preserve economy and environment.

It has been becoming obvious that renewable energy can overcome the challenges thrown by conventional fossil fuel-based power plants. Among renewable energy sources, the solar photovoltaic (PV) has been gaining a significant popularity since last decade, and nowadays, the cost of electricity generation from solar PV system is comparable with those from traditional generation systems. By the end of 2016, the cumulative installed capacity reached around 300 GW, whereas it was only 17.06 GW in 2010. About 15,000 tons of carbon dioxide emission can be reduced every year by a 10 MW solar PV plants. The comparative technical specifications of different components of large-scale solar PV plant, e.g., solar module, inverter, tracker, and transformer, are presented in Chap. 2. In addition, necessary factors that influence the selection of a site for a solar PV plant are also discussed.

Existing power transmission infrastructures are not robust and less efficient due to the power loss over long distance. High-temperature superconducting (HTS) materials and technologies have become available to design and build power cables. Chapter 3 aims to present basic theoretical background knowledge of HTS cables. The necessary improvements required have been comprehensively identified to reach the goal of industrial and board application of HTS cables and transmission technologies which are potential critical elements for future power system renewables.

The oceanic wave, also known as a wind wave, has the high-power density compared to the other popular renewable energy sources. The conventional machineries are not suitable for the energy conversion from the sea wave. To extract maximum power, scientists around the world proposed a wide variety of new electrical machines. Some of such electrical machines with their properties and the prospects of a high-power density linear generator are discussed in Chap. 4.

A converter is an essential part of a wind energy system. The conventional rectifier–inverter arrangement contains a giant capacitor and produces harmonics distortion in its output. A matrix converter is now popular as it does not contain capacitor which has a bulky size. It can be provided in a simple construction to provide a wide range of output frequency. Chapter 5 introduces a modified algorithm for space vector modulation that reduces total harmonic distortion of the output voltage. Moreover, a modified open-loop control of matrix converter with indirect space vector modulation is introduced to provide constant frequency and output voltage even if the wind speed changed.

Recent trends of connecting small-scale generator lead to the concept of micro-grid. In smart grid environment, several micro-grids will work parallel to support the load demand. It is essential to keep the nodal voltage of grid-connected renewable energy systems within an acceptable limit. The major advantage that attracts the matrix converter for grid-interactive applications is its inherent capability of bidirectional power flow. It can be used as voltage regulators in the low-voltage (LV) distribution network by adding a series compensation voltage with a transformer. However, to achieve these functionalities, a proper switching scheme and commutation process are necessary. The major focus of Chap. 6 is to discuss different types of switching and commutation strategies for matrix converter that considers silicon carbide (SiC)-based junction field-effect transistors (JFETs), MOSFETs, and SiC-based MOSFETs. The experimental results reveal that the SiC-based MOSFET devices are the best for designing the matrix converter for micro-grid applications.

In the near future, multiple energy sources having diverse characteristics will come into play in power systems. When a large number of renewable energy sources are interconnected with traditional power systems, it arises several critical challenges for the operation of the system. Intermittent nature of renewable energy and variable load demand on power systems make the control tasks more challenging. These challenges might cause the interruption of steady-state operation of the system and interrupt power supply to consumers. Chapter 7 attempts to present technical challenges related to the operation and protection that arise due to the large-scale interconnection of renewable energy. A detailed discussion on the necessity of implementation of control techniques is highlighted to ensure the continuity of service.

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About the Editors

Dr. Md. Rabiul Islam (M' 14, SM' 16, IEEE) received the **B.Sc.** and **M.Sc.** degrees from Rajshahi University of Engineering & Technology (RUET), in 2003 and 2009, respectively, both in Electrical and Electronic Engineering (EEE), and the **Ph.D.** degree from the University of Technology Sydney (UTS), Sydney, Australia, in 2014, in Electrical Engineering.

In 2005, he was appointed a Lecturer in the Department of EEE, RUET, where he was an Assistant Professor and Associate Professor from June 2008 to June 2015 and July 2015 to March 2017, respectively, and was promoted to a **Professor** in April 2017. He has authored and co-authored **more than 70 technical papers** (IEEE, IET, AIP, Elsevier, and Hindawi), **two books** (Springer), and **three book chapters** (Springer, IET). **Three more books** have already been accepted by Springer. His research interests are in the fields of renewable energy technologies, power electronic converters, electrical machines, and smart grid.

Dr. Rabiul is a **Senior Member** of the **IEEE** (USA), and a Member of IEB (Bangladesh) and the AIE (Australia). He received the University Gold Medal and Joynal Memorial Award from RUET for his outstanding academic performance while pursuing B.Sc. engineering degree. He also awarded some prestigious international scholarships, such as **Australian Government** International Postgraduate Research Scholarship (**IPRS**), University of Technology Sydney President Scholarship (UTSP), Asian Development Bank (**ADB**) Scholarship, and **Japanese Government Monbukagakusho** scholarship. He received Best Paper

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As a Lead Guest Editor, Dr. Rabiul has been invited to organize special issues in peer review high-quality Journals and Chair the sessions of some international conferences, e.g., ECCE 2017, IEEE ICIT 2016, ICECTE 2016, and ICEEE 2015. He has organized many IEEE technical sponsored international conferences such as ICEEE 2017 (Technical Secretary), IEEE ICIT 2016 (Special Session Organizer), ICECTE 2016 (Technical Secretary), ICEEE 2015 (Chair, Registration Committee), ICCIE 2015 (Organizing Committee Member), and IEEE COMPUMAG 2011 (Local Organizing Committee Member).

Dr. Naruttam Kumar Roy (M'10 IEEE) received his Ph.D. degree in Electrical Engineering from the University of New South Wales (UNSW), Australia, in 2013. As part of his Ph.D. research, he worked with the CSIRO Energy Technology, Newcastle, Australia. He is currently an Associate Professor in the Department of Electrical and Electronic Engineering at Khulna University of Engineering & Technology (KUET), Bangladesh. He previously worked as a Lecturer in the School of Engineering at Deakin University, Australia, and as a Research Publication Fellow at UNSW, Australia. He has also held a visiting appointment at CIITECH-METEC, Addis Ababa, Ethiopia.

Dr. Roy has published more than 50 peer-reviewed papers in reputed international journals and conferences as well as several book chapters through well-regarded publishers. His research interests include distributed generation, renewable energy, smart grids, FACTS devices, electrical machines, artificial intelligence, power electronics, and control applications. He received the **Best Paper Award** from the IEEE Conference on Industrial Electronics and Applications (ICIEA 2013) and **High Impact Journal Publications Award 2013** from UNSW. He also received a **University Gold Medal** from KUET recognizing his outstanding performance throughout his undergraduate studies. He has served as an Assistant Secretary, Member of Technical Program Committee, Track Co-Chair and Session Chair of a number of international conferences and workshops. He is an Associate Editor of Technology and Economics of Smart Grids and Sustainable Energy which is a Springer Journal. He is a member of the Institution of Engineers, Bangladesh (IEB), and the Institute of Electrical and Electronics Engineers (IEEE), USA.

Prof. Saifur Rahman is the Founding Director of the Advanced Research Institute (www.ari.vt.edu) at Virginia Tech where he is the Joseph R. Loring Professor of Electrical and Computer Engineering. He also directs the Center for Energy and the Global Environment (www.ceage.vt.edu). He is a Fellow of the IEEE and an IEEE Millennium Medal winner. He is the President of the IEEE Power and Energy Society (PES) for 2018–2019. He was the Vice President for publications of IEEE and a member of the governing board in 2006. He was the Founding Editor-in-Chief of the IEEE Electrifications Magazine and the IEEE Transactions on Sustainable Energy. He served as the Chair of the US National Science Foundation Advisory Committee for International Science and Engineering from 2010 to 2013. He is a Distinguished Lecturer for the IEEE PES and has lectured on smart grid, smart cities, energy-efficient buildings, renewable energy, demand response, distributed generation, and critical infrastructure protection topics in over 30 countries on all six continents.

He received his B.Sc. degree from Bangladesh University of Engineering and Technology, in 1972, M.S. degree from Stony Brook University, New York, in 1975, and Ph.D. degree from Virginia Tech in 1978, all in Electrical Engineering. His industry and government experience includes work with the Tokyo Electric Power Company in Japan, the Brookhaven National Laboratory in New York, Duke Energy in North Carolina, Consultancy for the World Bank in the United Nations, US Agency for the International Development, and the Asian Development Bank.

Acronyms

AC	Alternating current
ARENA	Australian Renewable Energy Agency
a-Si	Amorphous silicon cell
a-Si/μc-Si	Amorphous and micro-morph silicon multi-junction
AWS	Archimedes wave swing
BESS	Battery energy storage system
BS GPP	Binary cycle geothermal power plant
CC	Copper conductor
CdTe	Cadmium telluride
CE	Common emitter
CFC	Chlorofluorocarbon
CI[G]S	Copper-indium-[gallium]-[di]-sulfide
CO	Carbon monoxide
CO2	Carbon dioxide
c-Si	Crystalline silicon
CSP	Concentrating solar power
DC	Direct current
DDS	Direct drive system
DG	Distributed generator
DHI	Diffuse horizontal irradiance
DNI	Direct normal irradiance
DNO	Distribution network operator
DS GPP	Dry steam geothermal power plant
DSC	Dye-sensitized cell
DSM	Demand-side management
DSP	Digital Signal Processing
EJ	Exajoule = 1018 Joule
EPRI	Electric Power Research Institute
EU	European Union
EV	Electric vehicle

FS GPP	Flash steam geothermal power plant
FSPMLG	Flux-switching permanent magnet linear generator
GHG	Greenhouse gas
GHI	Global horizontal irradiance
GIS	Geographic information system
GSM	Global system for mobile communication
GW	Gigawatts
HAWT	Horizontal-axis wind turbine
HE	Hall effect
HFO	Heavy fuel oil
HPDPMLG	High-power density permanent magnet linear generator
HPP	Hydropower plant
IAEA	International Atomic Energy Agency
IEA	International Energy Agency
IGBTs	Insulated-gate bipolar transistors
IPCC	Intergovernmental Panel on Climate Change
IRENA	International Renewable Energy Agency
IRP	Instantaneous reactive power
ISVM	Indirect space vector modulation
JFET	Junction field-effect transistors
kWh/m2/year	Kilowatt-hour per meter square per year
LFO	Light fuel oil
LG	Linear generator
LV	Low voltage
MAS	Multi-agent system
MC	Matrix converter
MGCC	Micro-grid central controller
MOSFET	Metal oxide semiconductor field-effect transistor
MOSFETs	Metal oxide semiconductor field-effect transistors
MPPT	Maximum power point tracker
MW	Megawatts
NO2	Nitrogen oxide
OLTC	On-load tap changer
OTC	Ocean thermal energy conversion
OWE	Oceanic wave energy
PCC	Point of common coupling
PCSs	Power-conditioning systems
PM	Permanent magnet
PMLG	Permanent magnet linear generator
PMSM	Permanent magnet synchronous motor
PMx	Particulate matter
PTO	Power take-off
PV	Photovoltaic cell
RES	Renewable energy source
RMC	Reverse matrix converter

rms	Root mean square
RoR	Run over river
rpm	Revolution per minute
SC	Switched capacitor
SCADA	A supervisory control and data acquisition
SCIG	Squirrel-cage induction generator
SCR	Silicon-controlled rectifier
SDG	Sustainable development goal
SEIG	Self-excited induction generator
SHPP	Storage Hydropower plant
Si	Silicon
SiC	Silicon carbide
SM	Superconducting magnet
SMLG	Superconducting magnetic linear generator
SOC	State of charge
SOx	Sulfur oxide
SVM	Space vector modulation
SVR	Step voltage regulator
THD	Total harmonic distortion
TREIA	Texas Renewable Energy Industries Alliance
TWh	Trillions of watt-hour
TWh	Terawatt-hour
UC	Unit commitment
UK	United Kingdom
UN	United Nations
UNDP	United Nations Development Program
UNFCCC	United Nations Framework Convention on Climate Change
UNGA	United Nations General Assembly
USD	United States Dollar
UV	Ultraviolet
VAWT	Vertical-axis wind turbine
VSC	Voltage source converter
W	Watts
WBG	Wide band gap
WECS	Wind energy conversion system
WSN	Wireless sensor network
WT	Wind turbine

Symbols

E	Kinetic energy (J)
M	Mass (Kg)
V	Velocity (m/s)
P	Power (W)
ρ	Density (kg/m^3)
A	Swept area (m^2)
C_p	Power coefficient
r	Radius (m)
$x,\ s$	Distance (m)
t	Time (s)
$\frac{dm}{dt}$	Mass flow rate (kg/s)
$\frac{dE}{dt}$	Energy flow rate (J/s)
F	Force (N)
a	Acceleration (m^2/s)
P_r	Pressure in mm of Hg
VP	Vapor pressure of water vapor
T	Temperature in degree Kelvin
C_p	Coefficient of performance
P_e	Power output
η_m	Efficiency (mechanical transmission)
η_g	Efficiency (electrical conversion)
Z	Sun of the zenith angle
I_s	Cell saturation of dark current
V_T	Thermal voltage
K	Boatman's constant
T_c	Cell's working temperature
q	Electron charge
n	Identity factor
g	Gravitational acceleration
Q	Flow rate in cubic meters per second

H	Height of waterfall in meter
η	Efficiency
$p(t)$	Vertical position of the oceanic wave
$v(t)$	Vertical displacement of the oceanic wave
H_m	Height of the oceanic wave
θ_i	Initial phase angle of the oceanic wave
T_w	Period of the oceanic wave
v_t	Translator velocity
P_τ	Pole pitch of the PMLG
f_g	Generated frequency
Φ_{ag}	Air gap flux
E_p	Induced emf/phase
k_w	Winding factor
N	Turn number
m	Mass of an object
ρ	Density of the object
h	Height of the object
E_p	Potential energy of the object
E_{pw}	Potential energy of the oceanic wave
P_w	Wave power per unit of wave crest length
a,b,c	Input phase voltages
A,B,C	Output phase voltages
$\mathrm{C_p}$	Power coefficient of the turbine
λ	Tip speed ratio
β	Rotor blade pitch angle
P	Mechanical power
$\mathrm{\rho}$	Air density in g/m^3
$\mathrm{A_r}$	Turbine rotor area in m^2
$\mathrm{R_r}$	Rotor blade radius
$\mathrm{v_w}$	Wind speed in m/s
$\mathrm{I_{IN}^*}$	Reference input current
I_γ	Second vector of the current source rectifier
I_δ	First vector of the current source rectifier
d_γ	Duty cycle of the second vector of the current source rectifier
d_δ	Duty cycle of the first vector of the current source rectifier
$\mathrm{m_c}$	Current modulation index of rectifier
θ_c	Angle between reference input current and first vector
$\mathrm{d_{0c}}$	Zero vector duty cycle of current source rectifier
V_β	Second vector of the voltage source inverter
V_α	First vector of the voltage source inverter
d_β	Duty cycle of the second vector of the voltage source inverter

d_α	Duty cycle of the first vector of the voltage source inverter
m_v	Voltage modulation index of inverter
θ_v	Angle between reference output voltage and first vector
d_z	Zero vector duty cycle of voltage source inverter
V_s^{abc}	Voltage vector of stator's winding
V_r^{abc}	Voltage vector of rotor's winding
i_s^{abc}	Current vector of stator's winding
i_r^{abc}	Current vector of rotor's winding
λ_s^{abc}	Stator's winding flux linkage vector
λ_r^{abc}	Rotor's winding flux linkage vector
r_s^{abc}	Resistance vector of stator's winding
r_r^{abc}	Resistance vector of rotor's winding
L_{SS}	Self-inductance of the stator winding
L_{sm}	Mutual inductance between stator winding
L_{rr}	Self-inductance of the rotor winding
L_{rm}	Mutual inductance between rotor winding
L_{sr}	Maximum value of Mutual inductance between stator and rotor winding
L_{ls}	Leakage inductance of stator winding
L_{lr}	Leakage inductance of rotor winding
q	Ratio between output voltage and input voltage
Saa, Sbb, Scc, Sdd, Snn	Main switching states for two-, three-, and four-step commutation
S0, S1, S2, S3, S4…Sn	Intermediate switching states (from S0 to Sn) for four-step commutation
D1, D2, D3…DN	Body diodes for different switches
S1d, S2d, S3d…Snd	Direct switches for two-, three-, and four-step commutation
S1r, S2r, S3r…Snr	Reverse switches for two-, three-, and four-step commutation
SW1, SW2	Bidirectional switches
Sz1, Sz2	Zero switching loss switches
Sb1	Bride rectifier bidirectional switch
SJ1, SJ2	SiC-JFET switches
V1, V2	Generalized supply voltages
V_{GS}	Switch gate to source voltage
V_{DS}	Switch drain to source voltage
I_{DS}	Switch drain to source current
G, D, S	Switch symbolized as gate, drain, and source
SG1, SG2	GaN device cascade switches
V_G	Grid side voltage
V_{PCC}	Voltage at point of common coupling (PCC)
R	Resistance of the distribution feeder

X	Reactance of the distribution feeder
$OLTC$	On-load tap changing transformer
P_L	Active power consumed by the load
Q_L	Reactive power consumed by the load
P	Active power flowing through the feeder
Q	Reactive power flowing through the feeder
P_{DG}	Active power generated by the renewable DG
Q_{DG}	Reactive power generated by the renewable DG
$\widehat{V_{\mathrm{PCC}}}$	Phasor quantity of DG bus voltage (PCC voltage)
$\widehat{V_G}$	Phasor quantity of grid voltage
$\hat{I}$	Phasor quantity of current flowing through distribution network
$E\angle\delta$	Converter output voltage
$Z\angle\theta$	Line impedance
ω	Angular frequency
D_P, D_Q	Droop coefficient
δ	Phase deviation
$K_{PP}^{Tertiary}$	Proportional gain for tertiary control of active power
$K_{IP}^{Tertiary}$	Integral gain for tertiary control of active power
$K_{PQ}^{Tertiary}$	Proportional gain for tertiary control of reactive power
$K_{IQ}^{Tertiary}$	Integral gain for tertiary control of reactive power

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