Modern Trends in Renewable Energy Technology

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Dedicated to My Beloved Parents

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PREFACE

In day-to-day life, globally, people are using large amounts of energy, obtained mostly from fossil fuels. Since fossil fuels are rapidly depleting, there is a huge demand for new energy sources; besides that, fossil fuels also harm the environment by producing greenhouse gases (GHS), which cause various dramatic changes in the atmosphere. So, as a result, human beings have to satisfy all their needs by switching to Renewable Energy Sources (RES). Renewable energy is one of the biggest issues for the survival of the human race, especially in the development of technologies. RES are more finely comparable to fossil fuels, and deliver a very low amount of GHS. RES include wind, solar, bio-mass, tidal, and hydropower. Among them, the harnessing rate of energy from windfarms has rapidly increased due to its unlimited renewable energy production, which can be extracted endlessly.

This book is a critical study of recent trends in energy-extracting techniques at windfarms and solar powerplants. The first chapter is a brief discussion on the world's energy scenario, showing that the power sector is moving to renewable energy to generate electricity because conventional fossil-fuel powerplants are polluting the environment and harming living organisms. In chapter two, an elaborate study is conducted on various causes of powerplant pollution in the ecosystems. It is inferred that, every year, human death in large numbers is due to atmospheric pollution, which is mostly the result of the power sector. Adding to this, atmospheric temperature is also increased, causing vivid climatic change.

In chapter three, a study has been carried out on the sustainable growth of non-conventional powerplants such as solar power generation using crystalline silicon technology, concentrated solar thermal power, hydroelectric powerplants, Biomass powerplants, natural gas powerplants, ocean energy, and nuclear powerplants. From this study it is clear that power-generating companies are involving themselves in capacity-addition programmes to satisfy the future energy demand. At the end of 2016, the total installed capacity of renewable-energy based powerplants was 2,017 GW. The renewable energy sector showed marginal growth in 2016. In this year, the growth rate of solar PV was 47%, and 34%, and 15.5% for hydro and wind, respectively. In chapter four, the energy-efficiency enhancement of wind power plant is carried out. Adding to this, the harmonics mitigating technique is also presented because renewable-energy resources are vary seasonably, resulting in the fluctuation of the generation rate, causing harmonics content on the grid. Furthermore, windfarms are injecting reactive power into the grid; in this book, various harmonics and reactive powers mitigation techniques are discussed. In chapter five, the aging effect on solar PV, the effect of dust particles on solar PV, and the shading effect on solar cells are discussed. Furthermore, a broad study is carried out on the energy effectiveness enrichment of solar power generation. Previously, the cost of PV panel was challenging, but currently it has gradually decreased due to the brisk capacity addition. Moreover, the efficiency of solar panels is poor, and consequently several researchers have been involved in finding new materials, which resulted in the MPPT technique. Additionally, the accumulation of dust is a critical phenomenon that reduces the efficiency of the panel. Thus, an efficient cleaning mechanism needs to be introduced. However, the installation rate of solar-thermal based powerplants is slower than that of the other methods due to water scarcity. Worldwide, power quality is a crucial phenomenon to maintain the power system's stability. Since electric utility grids are highly interconnected with conventional and non-conventional energy resources, power fluctuation happens naturally, thus causing power quality problems on the grid. Besides, the load-management system in industries depends on the power electronics drives. These drives cause power-quality problems. Hence, industries must maintain the harmonics within the permissible limits. Chapter six concerns a critical discussion about power quality improvement methods and standard limits. In chapter seven, a real-time solar plant datum is presented with three units, each carrying 10 kWp. These solar-based powerplants not only save the cost of electricity but also reduce carbon emissions into the atmosphere. Finally, this book gives a lot of information about modern trends in wind and solar power technology. Alongside this, a reactive power and harmonics mitigation technique is also presented in the latest trends. The matter presented in this book is based on the latest valid references.

ABBREVIATIONS

WHO	World Health Organization
RES	Renewable Energy Source
GHS	Green House gases
PV	Photovoltaic
CPV	Concentrator Photovoltaics
CSP	Concentrated Thermal Solar Power
IEA	International Energy Agency
IPCC	Panel on Climate Change
GOI	Government of India
OTEC	Ocean Thermal Energy Conversion
MNRE	Ministry of New and Renewable Energy
NPCIL	Nuclear Power Corporation of India
PHWR	Pressurized Heavy-Water Reactor
VVER	Water-Water Energetic Reactor
ISO	International Organization for Standardization
ISI	Indian Statistical Institute
DFIG	Doubly Fed Induction Generator
EMI	Electromagnetic Interference
WPTES	Wind Power Thermal Energy Conversion System
DVR	Dynamic Voltage Resistor
TSSC	Thyristor Switched Series Capacitor
SFCL	High Performance Super Conducting Fault Current Limiter
EDLC	Electronic Double Layer Capacitor
PSS	Power System Stability System
ESS	Energy Storage System
LSC	Line Side Converter
VSC	Voltage Source Converter
HVDC	High Voltage Direct Current
SATCOM	Static Synchronous Compensator
VAR	Volt-Ampere Reactive
PCC	Point Of Common Coupling
PMSG	Permanent Magnet Synchronous Generator
IGBT	Insulated-Gate Bipolar Transistor
VSI	Voltage Source Inverter
PWM	Pulse Width Modulation

STATCOM	Static Synchronous Compensator
RMS	Root Mean Square
RVSC	Rotor-front Voltage Source Converter
SGIC	squirrel-cage inductiongenerator
PLL	Phase-locked loop
SC	Scalar Control
VC	Vector Control
DTC	Direct Torque
DPC	Direct Power Control
SMC	Sliding Mode Control
LCA	Life Cycle Assessment
EPR	Energy Payback Ratio
EPT	Energy Payback Time
MPPT	Maximum Power Point Tracking
UPFC	Unified Power Flow Controller
WPG	Wind Power Generation
TFR	Temporary Frequency Response
JNNS	Jawaharlal Nehru National Solar Mission
NIS	National Institute of Solar Energy
ITO	Indium Tin Oxide
Uv-Vis	Ultraviolet–Visible Spectroscopy
SEM	Scanning Electron Microscope
XRD	X-ray Powder Diffraction
FTIR	Fourier Transform Infrared Spectroscopy
ANN	Artificial Neural Network
DMR	Direct and Reverse Mode
MOSFET	Metal-Oxide-Semiconductor Field-Effect Transistor
EHV	Extra High Voltage
HV	High Voltage
UHV	Ultra High Voltage

CHAPTER ONE

THE WORLD ENERGY SCENARIO[1]

1.1 Conventional Energy Resources

For the past several decades, the rate of usage of fossil fuels has rapidly increased. Since they are depleting at a higher rate, this will lead to a scarcity of fossil-fuel resources in the future. Furthermore, fossil fuels are drastically affecting the environment, causing climatic change. Each year, about eight million tons of carbon are released into the atmosphere due to human activities. This includes 6.5 billion tons of fossil-fuel residues and 1.5 billion tonnes from deforestation. The top carbon-emissions countries at the end of 2015 were the United States (5,172,336 kt), the twenty-eight European Union countries (3,469,671 kt), and India (2,454,968 kt).Globally, coal-based powerplants emit 1,000 g CO_2/kWh (800 g/kWh for oil-based and 500 b/kWh for gas-based), whereas renewable energy powerplants, like solar and hydro, emit 50 g CO_2/kWh. The emission of CO_2 varies with respect to the calorific value of the fuel.

Table 1.1. Comparison of emission characteristics of fuels

Pollutant	Hard coal	Brown coal	Fuel oil	Other oil	Gas
CO_2 (g/GJ)	94,600	1,01,000	77,400	74,100	56,100
SO_2 (g/GJ)	765	1,361	1,350	228	0.68
NO_x (g/GJ)	292	183	195	129	93.3
CO (g/GJ)	89.1	89.1	15.7	15.7	14.5
Non-methane organic compounds (g/GJ)	4.92	7.78	3.7	3.24	1.58
Particulate matter (g/GJ)	1,203	3,254	16	1.91	0.1
Flue gas volume total (m^3/GJ)	360	444	279	276	272

Electrical energy plays a vital role in the sustainable development of the social and economic status of a country. Globally, due to the rapid growth of populations, urbanization, and industrialization, the requirement of energy is gradually increasing every year. As on January 26, 2018, the total generating capacity of the world's powerplants was 22,158.5 TWh. This includes 41.5% from coal, 22.1% from natural gas, 16.1% from hydro, 4.2% from other renewable resources, and 12.2% from nuclear. Presently, about 60% of electrical energy is produced by utilizing coal, which has a high mineral content. The quality of coal is based on the calorific value of the powder; this includes burning temperature and ash content, sulfur, and other traceable elements. If the calorific value is poor it produces huge amounts of fly ash during burning. Besides that, the coal-based thermal powerplants emit carbon dioxide, sulfur dioxide, nitrogen oxides, and dusts during the burning process. These also vary with respect to calorific value. For example, Indian coal is of low calorific value, high ash content (about 22–33%), and high carbon content [1] [2]. Besides that, other fossil-fuel powerplants, such as gas and oil, also cause negative environmental effects (see Table 1.1 above). However, coal-based powerplant emissions are comparatively higher than others.

However, the demand for electrical energy is doubling every year, following the rapid urbanization and industrialization of the world. Therefore, per-capita electricity consumption has increased each year. According to World Bank data, per-capita electricity consumption was 3126.326 kWh per person by the end of 2014. This is much higher when compared to the year 2000 (2385.66 kWh). For example, as of December 31, 1947, the per capita electricity consumption in India was 16.3 kwh. It has escalated rapidly every five-year plan, especially after the fourth five-year plan. As of March 31, 2015, the per-capita electricity consumption in India was 1010 kwh; this is very low when compared to any other developed country [3]. Hence, to meet the energy demand, power-producing companies are increasing the generating capacity of powerplants by capacity addition; nevertheless, it is necessary to reduce the generation of electricity from conventional thermal powerplants to meet the world's agreements regarding the reduction of carbon footprints. The thermal powerplants are located nearer to fuel reservoirs so that the distance between generation station and distribution station is marginal, which causes transmission and distribution loss. According to IEA data, the world's transmission and distribution loss is 8.264%. Consequently, the power-generating companies are trying to minimize this loss. Thus, there is a necessity to decentralize power generation. Therefore, the renewable energy resource-based powerplants are occupying a significant portion of decentralized power generation.

In recent years, the electricity-generation rate from renewable energy has increased rapidly. Renewable-energy resources are harnessed from natural assets which are naturally restocked on a human timescale, such as sunlight, wind, rain, tides, waves, and geothermal heat. Solar energy is converted into electrical energy using concentrator photovoltaics, concentrated solar power, artificial photosynthesis, and solar architecture. As of 2015, the total installed capacity of solar power was 227.1 GW, which includes 8.5 GW of Indian solar-power generation. Conversely, the higher initial cost, abundant availability of sunlight and land, low efficiency of solar panels, and emission of toxic fumes during the manufacturing process have led engineers to prefer wind energy to solar. Wind energy is also a form of solar energy. Wind is formed due to the following factors: (1) the uneven heating up of the atmosphere by the sun; (2) the irregularity of the earth's surface; and (3) the rotation of the earth. This wind force is used to rotate a wind turbine; the turbine is coupled with a generator through a common shaft, resulting in electrical-energy production. This generated electrical energy is proportional to one third of the wind speed and the square of the power of the rotor speed. Hence, wind farms with larger rotors with a longer hub height produce more power than others. Wind turbines are mainly classified into horizontal and vertical axis turbines. The vertical axis wind turbine is further classified as a Darrieus wind turbine, a Giromill, a Savonius wind turbine, and a Twisted Savonius turbine [4] [5] [6] [7]. Onshore windfarms are installed nearest to the load centre in order to reduce transmission and distribution loss. However, the operating and decommissioning processes of onshore wind farms will harm soil, water, and livestock. Furthermore, this has a negative lifecycle impact on the ecosystem due to the mining of steel and limestone in other parts of the world. On the other hand, offshore windfarms are installed away from the load centre and generate energy to feed the load centre through a long transmission line, which increases the losses; other disadvantages are higher installation and operating costs, but wind resources are abundant offshore compared to onshore, and are comparatively less harmful to living organisms [8] [9] [10] [11].

As on September 2016, the total installed capacity of wind power in India was 28083 MW. During 2015, the total installed capacity for wind powerplants was above 60 GW, which is comparable to that of earlier installations. Around the world, a total capacity of 432,883 MW is obtained from windmills; this is 17% higher than the previous year. At present, China is in the first position with an installed capacity of 145,104 MW of wind energy, followed by the European Union, the United States (141,579 MW), Germany (74,472 MW), and India (44,947 MW). Based on IPCC reports, wind energy has a considerable prospective for the reduction of greenhouse gases, both in the long and short term. The expected wind share in the power sector is about 20% by 2050, which will enhance the reduction of greenhouse-gas emissions [12] [13].

CHAPTER TWO

POLLUTION OF THE ECOSYSTEM[2]

Table 1.1 clearly shows that the emission of greenhouse gases and other unwanted particles varies with respect to the nature of the fuel used to generate electricity. As an example, the earth's temperature is increasing every year, which leads to an increase in the sea level due to the melting of glaciers. From the global climate change, the observed data shows that the year 2016 was warmer than the preceding years. Added to that, pollution from powerplants causes premature deaths or may lead to such health issues as ischaemic heart disease, stroke, chronic obstructive pulmonary disease, lung cancer, and acute lower respiratory infections in children. According to the World Health Organization, 6.5 million deaths per year are caused by internal and external air pollution. The primary cause of air pollution is thermal powerplants, especially coal-based powerplants. Thermal powerplants emit greenhouse gases, namely CO_2, CH_4, N_2O, and fluorinated gases. These gases play a vital role in the climatic changes. Also, they increase the melting rate of glaciers, thereby increasing the sea level. Besides this, the coal-based powerplants emit ozone gas, which is a colourless, odourless, and reactive gas with three atoms of oxygen. Naturally, ozone gas is abundant in the stratosphere; this ozone gas layer absorbs ultraviolet radiation from sunlight. Therefore, the power-generating industries are facing two types of problem. The first is increasing the power-generation capacity to meet the future energy demand, and the second is protecting the environment from the harmful emission from powerplants. In day-to-day life, globally, people are using large amounts of energy, obtained mostly from fossil fuels. Since the fossils are rapidly decreasing, this creates an enormous energy demand globally; besides this, it also harms the environment by producing greenhouse gases (GHS), and causes various dramatic changes in the atmosphere. So, as a result, human beings have to satisfy all their needs by switching from conventional energy to renewable energy sources (RES). Renewable energy is one of the biggest issues for the survival of the human race in the development of technologies. RES are more finely comparable to fossil fuels, and deliver a very low amount of GHS. RES include wind, solar, biomass, tidal, and hydropower [14].

From the above critical study the following conclusions are made. The power extraction rate of wind powerplants is highly dependent on wind speed and the swept area; the power extraction rate is increased by increasing the swept area of the rotor. Windfarm energy output is drastically affected by machine availability, followed by wake effect and turbine aging. Modern windfarms are incorporated with the MPPT technique, which is used to extract the optimum power from the turbine. When windfarms are connected to the grid in the mode of a star, this is economical since it has a lower insulation cost than a ring or radial connection. When compared to DC, AC offshore windfarms have lower installation costs, but the energy loss is high in the case of AC. Usually, an HVAC transmission system is used in the interconnection between windfarms and the grid; perhaps HVDC is economical when the distance between the generating station and the grid is about 55–70 km. Rotor-side converters are used to maintain active and reactive power, while a grid-side converter is used to sustain the constancy of DC link voltage as well as over-protect the power on the grid. The compensative devices DVR, SFL, and TSCC are used in the power system to enhance the performance of the gird under faulty conditions. However, the power-quality issues are improved by the STATCOM and SVS connected to the conventional grid. The failure rate of the vector speed control technique is about 14%, which is low by PLL. More than 50% of windfarms are made by DFIG, but the aging factor could influence the deterioration of the brush, due to which BDFIG is used. Wind energy is successfully forecasted by the hybrid technique, which includes statical and physical methods. The voltage control is effectively operated when it is installed at PCC, whereas frequency control is performed by wind turbines or windfarms. The low-frequency oscillation is rectified by the power oscillation damping control. Modern windfarms have energy-storage techniques such as electronic double-layer capacitors, batteries, thermal energy storage, and super capacitors. The type of energy-storage technique is chosen depending on the primary factor. When wind turbines are placed in the wind direction at 60°, 120°, 240°, and 300° they deliver a higher energy yield than at other angles. A wind generator's performance is significantly affected by seasonable variation, and so the wind farms are hybridized with other renewable energy resources such as solar and hydropower plants. Furthermore, a concentric solar collector is mounted over the tower to collect thermal energy from sunlight. This type of configuration is costly but generates much power.

CHAPTER THREE

RENEWABLE ENERGY[3]

3.1 The Significance of Non-conventional Energy Resources

Renewable energy refers to energy from a source that is not depleted when used, such as solar, wind, and wave. The worldwide growth of renewable energy's power technology is awesome due to several new technologies allied to enhancing the efficiency of renewable-energy powerplants, cost-effective technologies, and financial support from the government and environment concerns. Worldwide, 195 countries have made an agreement to reduce the atmospheric temperature by two degrees Celsius. Since 2016, 161 GW of renewable energy powerplants have been added. At the end of 2015, the total installed capacity of renewable energy powerplants was 2017 GW. In addition, the heat-generating capacity is 38 GW of thermal energy by renewable energy's heat-generating methodology. Furthermore, the renewable energy sector provides 8.1 million job opportunities directly or indirectly. More than ever, solar and bio-based powerplants offer more jobs. Excluding that, large-scale hydropower plants provide 1.3 million jobs around the world. Throughout the entire world, Asia accounts for 77% of the newly installed powerplants based on wind and PV technology. In 2016, renewable energy sectors shared 68%

of the total capacity production. This includes 47% of PV, 34% of wind, and 15.5% of hydropower plants [15].

According to REN21's 2016 report, the worldwide energy consumption of people from the renewable energy sector was 19.2%; also, the energy production from 2014 to 2015 was 23.7%. This included an 8.9% share from traditional biomass, 4.2% from modern biomass, solar heat, and geothermal, 3.9% from hydroelectricity, and 2.2% from wind, solar, and geothermal. These renewable energy resources are guaranteeing not only energy security but also climate-change mitigation [16] [17] [18] [19].

3.2 Solar-power Generation

At present, renewable energy resources are playing a noteworthy role in the sustainable development of countries. Furthermore, both developed and developing countries are rapidly increasing the harnessing rate of electrical energy from renewable energy resources; since conventional powerplants produce electricity from the consumption of fossil fuels, they create various environmental issues such as greenhouse gas emission, climate change, and global warming. The non-conventional energy resources are wind, solar, tidal, hydroelectric, and geothermal, which are obtained directly or indirectly from the sun. These energy resources improve the environment. Among them, the available solar irradiation is abundant, which is continuously tapped from light energy; this is emitted from the sun in an unlimited manner. The term "irradiation" refers to the amount of solar-energy incident per unit area per unit of time. Solar power is converted into useful electrical energy in two ways: solar PV panels and solar collectors. The material used for a solar PV panel is mc-Si, amorphous silicon (a-Si), thin-film technology like a copper indium di – selenide (CIS), copper indium gallium selenide (CIGS), and cadmium telluride.