Introduction to AI Techniques for Renewable Energy Systems

Edited by
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Preface

Artificial intelligence (AI) approaches are being developed to produce more accurate predictions of *renewable energy* using AI techniques, including their generation and impacts on the electric grid such as net load forecasting, line loss predictions, maintaining system reliability, integrating hybrid solar and battery storage systems. The book mainly deals with AI techniques for modeling, analysis, prediction of the performance, and control of renewable energy systems. This book will provide conceptual as well as practical knowledge about AI techniques used in renewable energy systems to the students, researchers, and academicians.

CHAPTER ORGANIZATION

This book is organized into 24 chapters in total.

Chapter 1 intends to study the brief introduction and past history relevant to artificial intelligence (AI) in fields of solar, wind, and other renewable energy sources.

Chapter 2 presents a study on issues and challenges of renewable energy and AI applications to resolve these issues.

Chapter 3 demonstrates the key challenges faced in renewable energy using machine learning and various AI applications in real-life scenarios.

Chapter 4 deals with enhanced computational power and hybrid transaction or analytical processing systems (HTAPS) enabling ML algorithms to optimize the energy and also the power sector on an outsized scale.

Chapter 5 highlights the importance of machine learning in research and development, and also focuses on its types and techniques.

Chapter 6 is designed to provide the ins and outs of hybrid renewable energy systems (HRESs) such as the configuration architecture, stability issues, maintenance, available optimization techniques, and performance predicting simulation software for HRESs.

Chapter 7 focuses mainly on the integration of solar photovoltaic (PV) and electricity board (EB) source for sustaining the electric power system to satisfy the energy demand throughout the adequate insolation.

Chapter 8 describes the various AI techniques and machine learning algorithms and how these approaches have been applied to different renewable energy (RE) types, especially solar energy.

Chapter 9 demonstrates the accuracy and effectiveness of the proposed optimizer; a 400-W domestic standalone SPV system and its specifications are used as a model for simulation in MATLAB.

Chapter 10 throws light on the various AI-based failure prediction strategies that are deployed on renewable source infrastructure.

Chapter 11 deals with the application of AI techniques in smart energy systems and is an effort to concise all the information on the optimization of solar energy systems for common-life applications.

Chapter 12 gives an idea about AI-enabled energy forecasting systems to handle fluctuations that may adversely affect the planning, designing, and operations according to the requirements.

Chapter 13 focuses on biomass resources and their products with their utilization for renewable energy based on the current trend of research and development in these sectors.

Chapter 14 discusses the integration of renewable energy-based smart grid that comes up with some new challenges which enhance the research in the field of AI.

Chapter 15 deals with the modeling, simulation, and analysis of small-scale photovoltaic energy system (PVES).

Chapter 16 describes about the deep learning-based fault identification of microgrid transformers.

Chapter 17 aims to compare and analyze different configurations of UPQC, namely, UPQC-I (interline), UPQC-MC (multiconverter), UPQC-DG (distributed generation) supplying loads, which are very sensitive toward voltage variations and critical in operation.

Chapter 18 discusses concepts of reliability and maintainability theory, which are concerned with our work for calculating the maintainability.

Chapter 19 focuses on different machine learning models and it's achievements for damage estimation capability to design and develop efficient wind turbines for wind energy systems

Chapter 20 utilizes the data from the two commercial solar cells and for the purpose of the validation of results, the IV and PV curves of each cell are presented along with the other statistical analyses, which have been performed at various temperature and irradiance levels.

Chapter 21 deals with the modern wind generation system and its monitoring of health in operating condition, recognition of smart gird (SG) subsystem's fault pattern, and control of SG based on real-time simulator.

Chapter 22 presents the estimation of parameters of thin-film solar panels using the newly developed reverse two diode model (RTDM) applying moth flame optimizer (MFO). RTDM being not a regular model used for parameter estimation, increases the complexity of the equations.

Chapter 23 describes the traditional time series forecasting to achieve effective energy resource planning that ensures the availability of the desired amount of natural gas for various manufacturing operations at appropriate point of time.

Chapter 24 addresses the security issue in the smart grid due to large data processing and proposed machine learning-based cyber security solutions for the intelligent grid.

About the Editors

Suman Lata Tripathi is working as Professor, School of Electronics and Electrical Engineering, Lovely Professional University, India. She has over 17 years of experience in academics and has published over 35 research papers in refereed journals and conferences. She has organized several workshops, summer internships, and expert lectures for students. She has worked as a session chair, conference steering committee member, editorial board member, and reviewer in international/national *IEEE Journal* and conferences. She has been nominated for the "Research Excellence Award" in 2019 at Lovely professional University. She has received the best paper at IEEE ICICS-2018. Her areas of expertise include microelectronics device modeling and characterization, low power VLSI circuit design, VLSI design of testing, and advance FET design for IoT, embedded system design, and biomedical applications, etc.

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Sanjeevikumar Padmanaban (Member'12–Senior Member'15, IEEE) received a Ph.D. degree in electrical engineering from the University of Bologna, Bologna, Italy 2012. He was an Associate Professor at VIT University from 2012 to 2013. In 2013, he joined the National Institute of Technology, India, as a Faculty Member. In 2014, he was invited as a Visiting Researcher at the Department of Electrical Engineering, Qatar University, Doha, Qatar, funded by the Qatar National Research Foundation (Government of Qatar). He continued his research activities with the Dublin Institute of Technology, Dublin, Ireland, in 2014.

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S. Padmanaban has authored over 300 scientific papers and was the recipient of the Best Paper cum Most Excellence Research Paper Award from IET-SEISCON'13, IET-CEAT'16, IEEE-EECSI'19, IEEE-CENCON'19 and five best paper awards from ETAEERE'16 sponsored Lecture Notes in Electrical Engineering, Springer book. He is a Fellow of the Institution of Engineers, India, the Institution of Electronics and Telecommunication Engineers, India, and the Institution of Engineering and Technology, U.K. He is an Editor/Associate Editor/Editorial Board for refereed journals, in particular the IEEE SYSTEMS JOURNAL, IEEE Transaction on Industry Applications, IEEE ACCESS, *IET Power Electronics*, *IET Electronics Letters*, and Wiley-*International Transactions on Electrical Energy Systems*, Subject Editorial Board Member—*Energy Sources—Energies Journal*, MDPI, and the Subject Editor for the *IET Renewable Power Generation*, *IET Generation*, *Transmission and Distribution*, and *FACETS* journal (Canada).

1 Artificial Intelligence

A New Era in Renewable Energy Systems

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CONTENTS

1.1 INTRODUCTION

The emergence of technology has helps us to generate solutions to minimize the risk of human errors in the complex systems. Most of the technologies developed by scientists are inspired by natural system. Artificial intelligence (AI) is an interdisciplinary promising approach for prompting the human brain functions and incorporating them into the machine to make it human smart. In the modern world, science and technology is a remarkably strong venture with development of quantified self to empower the challenges faced by humans. AI is the mimic of human brain and programmed to the computer to use for several computer systems which have been generated, for example, to analyze electric circuits, to solve differential equations, to design for synthesis of complex chemical molecules, and to detect and treat diseases. Due to AI's systems degree, it is possible to understand and build a neural network to challenges, for human benefits [1]. In general, AI includes fuzzy logic, expert systems, and artificial neural networks (ANNs). These are very powerful tools of renewable energy and smart grid systems for design, stimulation, estimation, control, fault diagnostics, and fault-tolerant control [2]. AI is a creation of a system with human brain intelligence to find solutions of narrow specific manually unsolved tasks. For example, in a supervised learning process, the system will learn the mapping based on their input and output programms.

The pervasiveness of technology allows spreading it across all fields in the world, including energy systems, health, agriculture economics, engineering, marine, and others. In every field, consumption of energy is increasing drastically and is causing decline to fossil fuels. In such situation, many countries have shifted their focus to renewable energy resources such as wind and solar energy sources. The main purpose of AI is to understand the problems of human cognition, analyze circuits, limit the human speech, train the system and store the information to retrieve it. It includes powerful tools such as fuzzy logic, expert systems, and ANNs that are used for designing, simulating, controlling, and diagnosing faults in renewable energy systems and others. Genetic algorithm is also one of the optimum AI techniques that imitates the evolution and is based on natural selection which utilizes some of the genetic actions such as selection, crossover, and variation. Similarly, data mining is another potential technique used to predict information from large databases. Most of these techniques are used in the field of production control, customer behavior, and stock prices. Data mining is also applicable in astronomical and medical data. They are complex and require precise analysis to set up global technological systems. AI programs require a clear-cut explanation since detailed reasoning can be drifted out so as to reach adequate solutions. AI research in the energy field is majorly focusing on solving several technical issues. The most promising development in AI is artificial neural techniques, which can be used for wind energy source assessment and apex power point tracking in photovoltaic (PV) generators. Expert systems have helped in building efficient fault-tolerant control in modern grid systems. Currently, many countries are working in R&D of smart grid to replace and develop advanced, efficient smart grid, as older versions are insufficient to resolve some of the faults.

1.2 HISTORICAL PERSPECTIVES OF ARTIFICIAL INTELLIGENCE

The great contribution of some researchers in the development of AI gains momentum toward the change of the world's scenario. AI concept can be traced back to the ancient time when people used to mention machine learning in their mythical stories [3]. This belief has made to found an expression in many forms of AI to explore the origin and the reasons for our existence and to create workable technologies for improvement of quality of human life. Initially, people used to mention this concept as "mythical thinking machines." Later, in 10 AD–70 AD, Heron of Alexandria had written in his famous work *Pneumatica* that these mythical thinking machines were built to exhibit some form of tricked intelligence [4]. However, during that time, it was not possible to develop mechanical machines having all intelligence-based functionalities. In the 17th century, scientists worked on the development of complex machines with intelligence, where this concept was compared with animals (Descartes), which is the basis of mind, body, and soul for the treatment of animals [5]. This idea of comparing the animal body with machines and mind with the intelligence for operation of machines was the novel approach for understanding of AI [6]. There was a great furor against this concept by philosophers and mathematicians. The first consequences of mathematical logic to computers came in 1642 with the invention of the first mathematical calculator [7, 8]. It took almost 30 years to make a mechanical calculator perform functions such as division and multiplication.

The most striking attributes came at the end of the 19th century with a notable contribution from George Boole who invented Boolean algebra, which is the major component of modern computers. Almost at the end of the 19th century, Samuel Butler noted that the machines might be evolved like Darwinian evolution [9]. Samuel has correctly interrelated his concepts since nowadays, researchers and scientists are building a foundation for the early 20th century. It is important to note that in 1942 Isaac Asimov published the concepts that he contrived with allusion to his laws of responsible robotics pertaining to his belief in growing the AI [10]. He proposed three concepts with two laws. They are: robots are not harmful to humans; it obeys human orders (first law); and robots must protect its own existence (second law). Another professor from the University of Connecticut focused most of his research work on machine ethics [11]. In 1950, a conference was conducted by one of the youngest renowned computer scientists John McCarty to bring many computer scientists on a single platform to discuss the creation of machine intelligence. He is considered the "father of artificial intelligence." After 2 years, there was a drastic improvement in AI. In 1961, Marvin Minsky mentioned in his published paper the steps toward AI and he summarized much of his work during the first decade of AI [12, 13]. He was able to represent in frames what he called "society of mind." In a week-long Dartmouth Summer Research Project on AI (DSRPAI) conducted by Marvin and John McCarthy in New Hampshire, the word "artificial intelligence" was coined. The main objective of this project was to reunite scientists in different fields in order to build a novel research platform on machines that are able to simulate human intelligence. Newell and Simon's work on GPS was developed based on a psychological query and empirical methods [14]. It is important to note that contributions from the end of the 19th century help in understanding computers and their languages to store and retrieve information in a massive way. In 1977, Goldstein and Papert demonstrated and published the Dendral program [15, 16]. However, the probability of expanding AI started in the 1960s, and it took a huge leap forward in the 20th century. Initially, two laboratories were established and the burden was taken by MIT (Massachusetts Institute of Technology) and Carnegie Tech University (CMU), with the Rand Corporation establishing AI laboratories later in Stanford and Edinburg. Edinburg was the place where the first conference of AI was conducted in 1965. In 1969, International Joint Conferences on Artificial Intelligence (IJCAI) started biannual series on AI. In 1980, the American Association of Artificial Intelligence (AAAI) was established [17]. It has expanded by conducting conferences and a series of workshops, sponsoring scholarships, encouraging journals, and maintaining digital libraries.

1.3 APPLICATIONS OF AI

AI has unique applications where complicated languages allow to make quicker, better, accurate predictions than manual methods. It has many branches, such as fuzzy logic, ANN, adaptive network-based fuzzy inference system (ANFIS), and data mining. ANN is inspired by the nervous system of humans, i.e., connections between elements to establish a specific function by adjusting the connections between elements [18, 19]. Mapping multiple inputs to get a single output, pattern classification, recognition, association and generation of meaningful patterns are some of the applications of AI. AI applications have also been successfully extended to other fields such as engineering, mathematics, meteorology, medicine, neurology, economics, and psychology. One of the interesting applications of AI is the recognition of sound and speech. In 1960, the adaptive linear combiner was developed, which is a very useful law [20]. Most of the neural networks depend on algorithms, mathematical models, and nonlinear operations, which include maps of noise. AI is also applicable in market trends, weather forecasting, thermal and electrical load prediction, exploration of mineral sites, and prediction of data collected from sensors [18, 19]. Analysis of medical signatures, electromyography, and identification of explosives and military targets are other applications. One of the interesting applications of AI is in PV electricity production. The main objective of AI application is to produce viable solar emission info for real-time designing and forecasting of solar radiation and steam generators. Generating PV modules, designing solar collectors, heating controllers, sun tracking and building controlled solar air conditioning systems, predicting temperature and radiation, and developing PV-diesel and solar-wind hybrid systems are other encouraged applications [21, 22]. Another interesting domain of AI is molecular biology. AI can be applied to design and analyze scientific data, solving wide problems, hierarchical patterns, and knowledge-based maintenance and obtaining knowledge acquisition technologies. AI has momentum in the field of molecular biology for the last few years. Nutritional meal planning is another important issue for cancer patients whenever they undergo chemotherapy. Through AI, the meal components with nutrition were designed in Mary to greater variety. Now, this Mary is used as a public tool; similarly, other additional nutritional elements such as carbohydrates and cholesterol are also added to the design of the foods. AI has large applications for cancer patients such as resolving drug and dosage parameters. One of the designs for drugs and doses is quadratic phenotypic optimization platform (QPOP). This model will help in reducing the toxicity of drugs with maximum output in preclinical studies. With the QPOP platform, nearly 14 chemotherapeutic drugs were screened and are used for several cancer treatments such as multiple myeloma [23]. The combination of drugs, such as decitabine and mitomycin C, markedly shown improvement in outcomes in mouse models [24]. Designing of biomarkers is another advantage of AI [25]. The step forward in treatment of cancer patients is targeted therapies genomic alterations and treatment responses [26, 27]. Therefore, AI analysis of electronic health records and patient biomarker data may affect trial outcomes [28]. Some of the applications of AI in renewable energy with AI apps are shown in Figure 1.1.

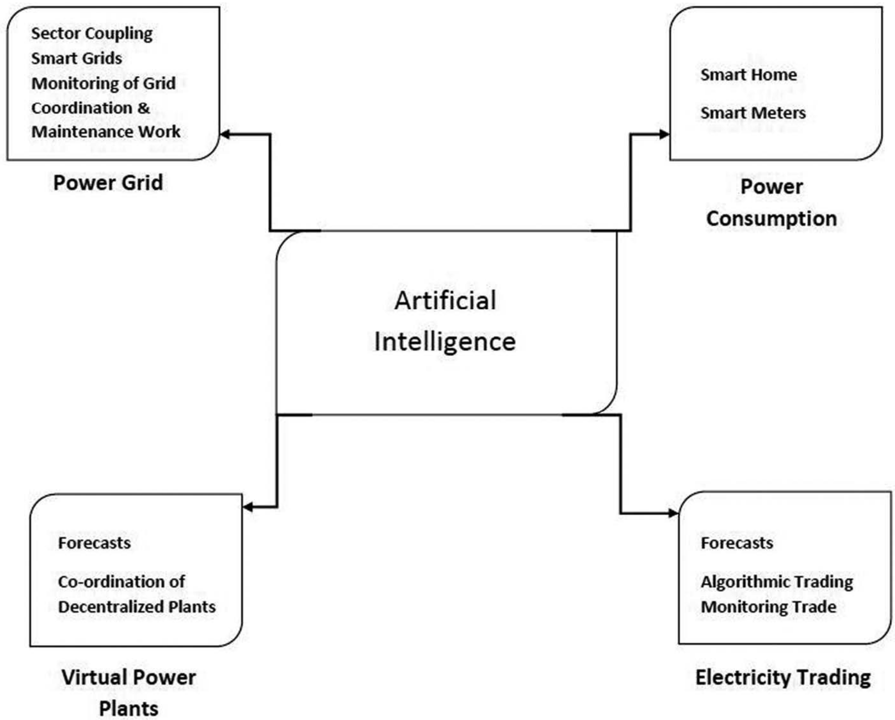

FIGURE 1.1 Some applications of AI in renewable energy with AI apps.

1.4 APPLICATIONS OF AI IN WIND RENEWABLE ENERGY SYSTEMS

Fossil fuel consumption all over the world is increasing day by day; therefore, the need for electric energy is also increasing. Effective ways of electric power generation are inherently dependent on the world economy. One of the sources for substitute renewable energy is wind. In large geographical areas such as Mexico, it was determined that the renewable energy wind is a periodical phenomenon [29]. Countries such as Mexico have a high demand for renewable energy sources because of the increase in prices of fossil fuels and high demand to minimize environmental contaminants that fossil fuels generate [30]. For better optimal designs and operations of wind energy systems, new strategies are continuously developed by many researchers [31]. Because of low-speed winds, this system does not have the same viability in all locations and is more uncertain than solar energy systems. Preferred locations of wind farms are offshore and high-altitude sites. In 2014, Norway's contribution toward renewable energy was 98%. Brazil has contributed 73.4%, New Zealand 79%, Venezuela 62.8%, and Colombia 70%. The traditional method that is used in generating wind energy is, first, installation of windmills in the farm; the wind will rotate the turbine and due to this the kinetic energy is changed to mechanical energy, which then transformed into electric energy. The first wind turbine with a capacity of 12 kW was installed in Ohio in 1887–1888. An overall growth rate of

9.96% is observed in installing wind energy scope when correlated with the previous year's scope scope in the European Union. The annual installation increased from 48 GW in 2006 to 141 GW in 2015, where the annual growth was more than 9% [32]. From 2010 to 2015, China was leading in installing the wind power units. In 2006 and 2007, Germany has greater statistics in the installation of wind power systems. In 2008 and 2009, the United States has a greater number of installed wind power units, but in 2008, both the United States and Germany contributed similar statistics in wind power systems that were installed. The efficiency of power generation using wind turbine can be increased by gathering the past wind data at turbine location. Accurate forecasting of wind speed cannot be done but this can be predicted using the past data of the wind speed. Using data analytics and AI, there are two different approaches to prediction of wind speed.

1.5 MODELING AND SIMULATION STUDIES OF AI IN WIND RENEWABLE ENERGY SYSTEM

Most of the wind designs can be recognized with the mathematical formula $V(k + l)$ of the wind vector, where $V(k)$ is based on the previous m measurements $V(k)$, $V(k - 1)$, …, $V(k - m + 1)$.

For a better wind speed forecast, l is chosen to be small; therefore, it is called short-term wind speed prediction. Wang and his co-workers have produced a general procedure to produce fuzzy rule [33, 34]. The fuzzy model will predict the wind speed and these are used to produce electrical power, especially at the wind units. ANN is a favorable technology for wind speed forecasting [35]. The proposed ANN will have fewer neuron numbers and it will have accurate wind prediction results in less time in different fields such as transient detection, approximation, pattern recognition, and time series prediction. $V(k)$, $V(k - 1)$, …, $V(k - m + 1)$ are the measured wind speeds in time series, and based on this $V(k + l)$, …, $V(k + 2)$, $V(k + 1)$ are predicted or estimated wind speeds, and some properties of time series such as standard deviation, slope, and average are calculated and these values are given as inputs to the fuzzy or neural network predictor. The fuzzy rule base will be reduced if we reduce the inputs to the fuzzy interface system. This will give all the speeds of wind without sacrificing the estimated wind speed. Accuracy of the prediction and the learning process speed will be increased by reducing the ANN size for a neural network. In the period 2002–2005, many investigations were carried out using real wind speed data in Rostamabad in northern Iran. For every 30-minute interval, these measured data were averaged and the data for the months of February, May, August, and November were averaged for the period 2002–2004 [36]. The data are used as train data for the neural network and measurements for the year 2005 are used as test data. The absolute error between predicted and real values is called RMSE – lesser the value, the better the wind speed estimation. On the other hand, the neural method gives very little error in both the COD and RMSE values, where the absolute change will be less the 20%. To determine the certainty, one's prediction from a certain model is done by COD where its value varies from 0 to 1, 0 for the menial speed forecast and 1 for best accurate speed prediction [36].

In order to see the improved performance of ANN method, a hybrid method is adopted which is a combination of neural and fuzzy methods. Data from Tasmania, Australia, are used to measure wind energy using the ANFIS method on a very short-term basis [37]. Even though it is a neural network, functionally, it is equivalent to the fuzzy inference model and thus it is called a neuro-fuzzy system [37]. The prediction is done by ANFIS at the height of 40 m, which has only 3% of the mean absolute percentage error when compared with the actual wind speed at the same height of 40 m. The RMSE between the predicted values of ANFIS and the actual values of wind is 0.230. In general, every input is presented by two fuzzy sets only, and sometimes three sets are also considered as common. With the increase of extra membership functions, the accuracy of the result will increase but it will take more time to train the model or the neural network. The architecture of the ANFIS consists of six layers, where each layer has a different application. Layer 1 is an input layer where it just sends the crisp external signals to layer 2. Layer 2 is called fuzzification layer where fuzzification is performed by each neuron. Layer 3 is called a rule layer where each neuron corresponds to a single fuzzy rule. Layer 4 is known as the normalization layer where normalized firing strength of the given rules is being calculated by taking the inputs from all neurons in the rule layer. Layer 5 is called a defuzzification layer. Every neuron in this layer is connected to the corresponding normalized neuron, and input of ×1 and ×2 is also received. Layer 6 is a single summation neuron where it sums all the defuzzification neurons and produces the output *y* for the ANFIS model [37].

1.6 APPLICATIONS OF AI IN SOLAR RENEWABLE ENERGY SYSTEMS

In today's world, climate change is one of the major threats currently faced by the people. As these challenges are considered by the government and various energy solution providers, it has become important for them to provide a sustainable mode of renewable energy. This made the renewable energy an alternate source to fossil fuels which we are currently using [38]. Due to climatic conditions and depletion of nonrenewable energy rapidly, research and development on sustainable energy have increased, and it affects all countries and enterprises [39]. When compared to other areas, solar energy applications are very expensive in remote areas since devices such as pyranometers which are used to measure solar radiation perfectly, are either present in only some locations or absent [40]. The increase in energy consumption from several decades has risen fright of using up reserves of resources in coming future [41]. With the tough year ahead, production and exhaustion of distinct types of fossil fuels to give energy constitute notable changes in environment [42]. According to the World Energy Forum prediction, the energy fuels such as oil, coal, and gas reserves will be drained in the coming 10 decades. Normally, the primary consumption of fossil fuel in the world is over 79% and of that over 57.7% is consumed by the transport and is drained rapidly [43]. India needs to improve energy equipping for population, and speedy improvement in economy poses a discouraging challenge.

1.7 MODELING AND SIMULATION OF SOLAR RENEWABLE ENERGY SYSTEMS

The solar energy application has become an interesting research topic. Advancement in AI has brought about more significant results in weather forecasting and henceforth in upgrading the renewable energy and more secure access. Solar energy is considered as the better common and famous source of sustainable energy, as the sunlight is abundant in nature and access to this is simple when compared to others [39]. The solar power plants convert the energy from sunlight by using either intensive solar power plants, known as concentrating solar power (CSP) plants, or solar PV plants [44]. The CSP plants generate electricity from solar without emitting any harmful gases. This results in not polluting the environment [39]. Coming to solar PV plants, PV effects are used in order to generate electricity [44]. The CSP plants use steam turbines in order to convert sunlight into electrical energy. These plants can also run with fossil fuels when there are cases like blocking of the sun or at night times [45]. Despite all these, there are some disadvantages in solar energy. Till now there is no best tech in order to transform the electrical energy into storage medium. But there are three technologies currently in use and up to some extent they provide a feasible storage solution. They are thermal energy, smart power unit depository, and hydrogen fuel cells [39]. These three provide a reliable storage medium for the generated renewable electricity. The PV storage systems are used in generating electricity from the solar energy. These systems are divided into on-grid, off-grid, and hybrid systems. The on-grid systems continuously fluctuate and modify the state of the battery according to alterations in the potential of the sun and the charge status. The on-grid systems consist of a group of inverters that convert DC power to AC and store it in the battery pack. On the other hand, the off-grid systems convert the DC power to AC power and supply to the systems or to battery units. The hybrid solar PV systems unite the on-grid systems with additional battery modules. These systems are more complex and very cost-effective [39]. PV systems encounter a problem that is nothing but the most appropriate resolution of their dimensions. The optimization problem was dealt with by using hybrid energy storage technology which was proposed by Li et al. [46].

The main component of the solar energy generation is sunlight. There are many methods and predictions in order to forecast the solar radiance of sun, by forecasting weather and other climatic conditions. To approximate the solar radiance, few of the procedures are utilized but they are efficient when there is less spatial resolution than complex ones such as mountainous areas [47]. Due to this an artificial-based technique using ANN was put forward by Bosch et al. [48] that predicts the solar radiance even on terrains. Several other algorithms to predict the solar radiance include ANN and neuro-fuzzy inference systems [21]. ANN is used for identification of optimal operating point of PV systems [49]. To teach the ANN controller in order to identify the maximal operating point, a gradient sinking algorithm is used [19]. Using ANN, the solar radiation was predicted where there is no coverage of direct measurement instrumentation [40]. This prediction has a 93% accuracy of solar radiation with a mean absolute percentage error of 7.3%. Another method, back-propagation neural network (BPNN), is also used for forecasting the solar radiation. In the years

1988–2002, global solar radiations were predicted using BPNN; for the year 2002, the RMSE value obtained by using this method was 2.823×10^4 [50]. Using BPNN, daily solar radiation was estimated with an RMSE of 5.0–7.5% [48].

Predictions of solar radiation using ANN models with distant back-propagation algorithms were carried out by Premalatha and Valan Arasu [51]. In this, they considered two ANN models, and nine inputs were given to ANN model as trained data. The first model considered four stations, and the second model consisted of five stations in India. The two models are tested using the trained data and the algorithms. Among the two models, the model with five stations (model-2) depicted greater accuracy when calculated with LM (Levenberg-Marquardt Back Propagation) algorithm since it has shown lesser RMSE with a value of 1.0416 and a maximum linear correlation (R) of 0.9545. ANFIS is a hybrid method that combines both neuro-fuzzy and fuzzy logic. It is used to suspect clarity index and daily solar emission forecasting with RMSE 0.0215–0.0235, modeling PV power supply with 98% accuracy [52]. Therefore, by using AI we can predict the factors required to generate solar energy accurately with least error, which reduces the operational cost and human error. By using solar energy, the emission of greenhouse gases can be decreased, which encourages us to produce more renewable energy. It has very less impact on producing carbon dioxide and global warming emissions. In India, it is expected that nearly 60,000 MW of power will be produced from renewable energy sources during 2031–2032. The investment required to build a solar power plant is very high. It requires more land for installing more panels. It works only during daytime (i.e., in sunlight) and thus the energy cannot be collected during the night. In order to process the equipment using solar energy at night, the energy needs to be stored in batteries and supplied to the components.

1.8 CURRENT TRENDS AND FUTURE PROSPECTS OF AI

Currently, AI is present in many areas and is much developed in the area of renewable energy. AI is being used in predicting, designing, controlling, monitoring, and optimizing renewable energy models. Compared to the first quarter of 2019, this year the global usage of renewable energy has risen to 1.5%. After the completion of more than 100 GW of solar PV and 60 GW of wind power projects in 2019, the renewable energy generation has increased to 3% [53]. As per the renewable energy policy network (REN), at least 10 GW of energy each was produced from 32 countries globally in 2019. For most of the countries, producing energy from solar and wind is cost effective than from other sources such as coal and thermal [54]. India is producing 75 W of electricity from solar and wind energy. It may increase up to 175 W by 2022 and to 500 W by 2030 [55]. Physical methods are also used for predicting the renewable energy. These methods are efficient in forecasting atmospheric movements but they require large computation resources since a lot of data are required to assess. Physical methods are suitable only for short-term forecasting [56]. The main aim in wind energy is to predict the wind power ahead and we can plan accordingly with the predicted data. ANN methods are considered as the best estimation models in to predict wind power. The major drawback in ANN methods is that their performance varies with the location. For example, BPNN methods may provide an accurate estimation of wind power in one site; in another site, the radial basis function neural network (RBFNN) can be used as the best estimation model [57. Fuzzy logic can also be used in predicting, but the major problem in this is that it should generate a large number of fuzzy rule bases. In order to generate less rule base for fuzzy logic, a proposed model is defined based on ANN and fuzzy logic, which helps in generating less rule [57]. By using some algorithms, we can decide which places are suitable to build wind farms; this may result in less operating costs [58]. The numerical weather prediction method is efficient in short-term forecasting, while ANN and statistical methods are best in very short-term forecasting [37]. Hybrid model ANFIS is also the best model in estimating the very short-term forecasting but the training of ANFIS may fail if the set consists of insufficient variation to properly model the characteristic data [37]. Germany has developed a deep learning neural network model which helps in saving the lives of birds by not being killed by the wind turbine blades. A camera is attached near the turbine and predicts the movement using image processing, so when a bird approaches the blades, the turbine is automatically switched off [59]. Although there are models to forecast the wind speed such as physical, conventional statistical, and spatial correlation models, there are some disadvantages with these models, e.g., a statistical model cannot forecast high noise, fluctuation, and irregular nonlinear trends, spatial correlational model finds it difficult to predict the wind speed since the model needs more information like wind speed values of spatial correlated sites, etc. [60]. Now, considering the solar energy, the main usage of AI is in predicting the solar radiation. ANN in line with solar energy is used for monitoring the thermal ratings and rise of temperature of overhead power lines, depending on the meteorological conditions. It is also helpful in determining the solar irradiance [19]. The hybrid model ANFIS is used for determining the frequencies from the temperature as well as the duration of sunshine [61] and the modeling of the PV power supply system with 98% accuracy [57]. BPNN is used to measure the global solar radiation. Forecasting solar radiation by BPNN consists of higher value coefficients [57]. Another method that is used for predicting the short-term solar power is the support vector machine (SVM). Compared to other methods such as RBFNN, the SVM methods perform better, having a mean absolute error of 62 W/m^2 [57]. The solar radiation is higher in India when compared to countries like Germany, where the solar radiation ranges from 800 kWh/m^2 to 1200 kWh/m^2 [62]. Some of the hybrid AI methods are used in solar energy systems, e.g., in estimating the PV power using the hybrid evolutionary optimization of ANN with particle swarm optimization and genetic algorithm [63]. Genetic swarm optimization of BPNN [64] predicts the solar radiation using a combination of autoregressive and moving average (ARMA) and time delay neural network [65]. By using AI, we can improve safety, integration of micro grids, etc., in solar energy. The world is running on fossil fuels currently and for sure they are running out and none will be left over after. This may lead the world to begin changing its course, relying on the renewable energy completely. This takes much more advancement in the area of AI being used in the renewable energy. Everything currently is being automated and we may not be surprised if the world is completely automated in the near future. All the renewable energy monitoring may be automated and checked by the machines. New methods and algorithms may predict all the conditions perfectly without any errors and make human lives easier and the environment less polluted. An estimation given by the German Advisory Council on global change states that 50% of energy will be accounted for renewable energy by 2050 [66]. The International Renewable Energy Agency suggests that renewable energy can account for 60% or more of many countries' total final energy consumption and all countries may consider the use of renewable energy in their total energy use by 2050. Hence, progress in conventional applications of AI provides the opportunities to design and develop new mechanisms for specific applications in the near future.

1.9 CONCLUSION

AI is an emerging technology in renewable energy systems. Many researchers have made efforts to integrate the applications by innovative approaches for a sustainable environment. Wind and solar energy have enabled us to assess the potentiality through neural-based approaches. Computer science and analytical techniques in the field of biology have been applied to understand basic machine learning to application challenges in medicine and agriculture. In order to advance this technology, multiple strategies were used to pace the progress for human challenges. Hence, this chapter focused on applications of AI in the fields of solar, wind, and other renewable energy sources. Moreover, it emphasizes the concepts of different AI technologies with few examples such as solar and wind renewable energy systems. It deals with a major breakthrough in acceptance, modeling, and simulation studies with current trends and future prospects of AI technologies. Hence, progress in conventional applications of AI provides opportunities to design and develop new mechanisms for specific applications in the near future.

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Machine Learning-Enabled Cyber Security in Smart Grids

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