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Review Paper

A Comprehensive Review of Artificial Neural Network Techniques for Predicting Photovoltaic Output

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Abstract:- *Photovoltaic (PV) systems have gained popularity due to their ability to harness renewable solar energy, contributing to environmental sustainability and reducing dependence on fossil fuels. Accurately predicting PV power output is crucial as it enables efficient energy management to ensure a reliable and consistent energy supply from these renewable sources. This is where advanced methods like Artificial Neural Network (ANN) become important, as they can effectively handle the complexities and variabilities associated with solar energy generation. This paper reviews ANN techniques for predicting photovoltaic (PV) system output. It begins by highlighting the increasing significance of PV systems in renewable energy and the essential need for precise output prediction to optimize energy utilization. The review then focuses on ANNs as a preferred method for prediction, due to their ability to process complex, nonlinear data inherent in solar energy generation, offering a comprehensive analysis of various ANN configurations and their efficacy in different scenarios. The ANN techniques for predicting PV output, encompassing various aspects such as ANN configurations, neuron counts, and training methods are also included. It delves into the nuances of data collection in different geographical areas and the impact on ANN performance. The findings highlight the potential of optimized ANN settings to enhance the accuracy of renewable energy forecasting, suggesting future research directions in this domain.*

Keywords: *Photovoltaic Systems, Power Prediction, Artificial Neural Networks, Renewable Energy, Energy Efficiency*

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1. Introduction

For a long time, fossil fuels including natural gas have been the main source of energy in the world (1). However, there are several drawbacks to using them, which has raised questions. Fossil fuel combustion results in the atmospheric release of various pollutants, including sulphur dioxide (SO2) and nitrogen oxides (NO), as well as greenhouse gases (GHGs), such as carbon dioxide (CO2) and methane (CH4). There is a growing movement to switch to greener, more sustainable energy sources, like renewable energy, to lessen these drawbacks (2–4). Since Malaysia is located near the Equator, at latitudes 1˚ and 7˚ North and longitudes 100˚ and 119˚ East, it is suitable for using solar energy.

Photovoltaic (PV) panels are essential to the clean, sustainable energy source of producing electricity from sunlight. However, PV panels face issues because solar energy production is not constant. The weather, clouds and day-night cycles are some of the variables that affect how energy is produced. The PV panel can only generate an output equivalent to its rating. Based on Standard Test Condition (STC), PV panel requires irradiance 1000 Watts/meter, cell temperature 25C and no wind to provide power with its rated capacity. Hence, it is crucial to predict the output power of the PV panel to help in better planning and designing the PV system. While computational methods are commonly utilized for predicting PV power output, they involve extensive calculations and formulas. This complex process can sometimes lead to errors, including those caused by human involvement, thereby affecting the accuracy of the predictions. Hence, power output value prediction using a three configuration in Artificial Neural Network (ANN) will be developed to improve the prediction process. ANN can represent and solve difficult input-output relationships found in physical systems. They could also carry out intelligent tasks so that the human brain can produce value that is more accurate and nearest to its real value data compared to computational methods (5).

This research contributes to the field by exploring different environmental conditions effects the electrical performance of a photovoltaic system. The key contributions are as follows:

1. **Solar Energy Potential in Malaysia:** Malaysia's geographical location near the Equator makes it suitable for harnessing solar energy. Acknowledgment of the need to transition to cleaner energy sources, such as solar power.

2. **Challenges in Solar Energy Production:** Identification of issues in solar energy production, including variability due to weather, clouds, and day-night cycles. PV panels are limited by their rating and operate optimally under specific conditions defined by Standard Test Conditions (STC).

3. **Factors Affecting PV System Performance:** Various factors affecting PV system performance, including solar irradiance, weather conditions, installation location, and system design. Reference to the International Electrotechnical Commission (IEC) 60904-3 standard for testing PV panels under specific conditions.

4. **ANNs for PV Power Prediction:** Presentation of research projects utilizing ANNs to predict PV system output power. Mention of an ANN model optimized by a genetic algorithm and its high accuracy in hourly PV power output prediction.

This paper presents a thorough review of various artificial neural network techniques and their effectiveness in predicting the output of photovoltaic systems, aiming to provide a comprehensive understanding and insights for future research in this evolving field. Rest of the paper is organized as follows, Section I contains the general introduction of the research, Section II contain the introduction to PV system in Renewable Energy, Section III contain a power prediction in PV system, Section IV contain an overview of Artificial Neural Network (ANN), Section V contain related work of Artificial Neural Network Techniques for Predicting Photovoltaic Output, Section VI contain the recommendation in Predicting Photovoltaic Output by using ANN and concludes research work with future directions.

2. Introduction to Photovoltaic (PV) Systems in Renewable Energy

The term "renewable energy" describes energy produced from naturally replenishing resources like sunlight, wind, rain, tides, and geothermal heat. This definition aligns with the research that was published in IEEE, which highlights the importance and cost-effectiveness of using geothermal, biomass, wind, and solar energy sources (6). The term "renewable energy" describes energy produced from naturally replenishing resources like sunlight, wind, rain, tides, and geothermal heat. This definition aligns with research, which highlights the importance and cost-effectiveness of using geothermal, biomass, wind, and solar energy sources (7–10). These natural resources are essential to the shift to a more sustainable energy future because they are plentiful and environmentally sustainable.

Researchers' interest in solar photovoltaic (PV) energy conversion systems has grown significantly in recent years. Searching for alternative energy sources is prompted by worries about the global energy crisis and the risks posed by conventional energy sources to climate change. PV systems use solar radiation as their energy source. This naturally occurring fusion reactor is known as the Sun and the primary source of renewable energy is the sun. The average solar radiation reaching the Earth's surface is eight thousand times greater than the global average energy consumption (11). An average value of 1370 W/m2 in the outer atmosphere, the earth-atmosphere system only intercepts a small portion of the sun's 389 septillion (389 x 1024) W of radiation. This is known as the solar constant, and it is equal to I.963 calories/cm2/minute or 1.963 Langleys/minute (12). Because solar energy is abundant everywhere in the world, it is viewed as a potential alternative energy source (13,14). Using solar energy captured by photovoltaic panels to create electricity is one of the most promising markets in the renewable energy space. The photovoltaic industry is becoming more and more competitive globally, especially in Europe, China, and the US, because of its high investment requirements and potential for rapid growth (15).

A photovoltaic (PV) system is a device that uses solar cells to transform solar power into electricity. PV systems are not to be confused with other solar technologies, such as solar thermal or concentrated solar power, which are used for cooling and heating purposes. PV systems convert light directly into electricity. The electrical properties of semiconductor materials are used in the solar cell's operating principle to convert photovoltaic energy (16).

3. Photovoltaic System and Power Prediction

A photovoltaic (PV) system's function is to transform solar energy into electrical power that can be used, and solar radiation can be directly converted into electrical power in a clean, sustainable, and environment friendly (17,18). This system is a power system that uses photovoltaics, a technique to convert solar energy into direct current electricity using semiconducting materials that produce voltage or electric current in a material when exposed to light, to supply usable solar power. It is made up of several parts, such as solar panels that collect and transform sunlight into electricity, a solar inverter that converts DC electric current into AC electricity, and other electrical accessories for mounting, cabling, and metering systems that are necessary to put up a functional system. The role of a photovoltaic (PV) system in power prediction is essential for real-time economic dispatch, power system stability, and power quality (19). Precisely estimating PV system power generation is of the utmost importance because it affects security, grid connectivity, and solar energy efficiency. To tackle this challenge, several kinds of prediction technologies are utilized, such as physical, statistical, and artificial intelligence (AI) forecasting techniques. Effective PV power forecasting may also be helpful in lowering energy waste. PV system performance and integration into the power grid are highly dependent on the installation site, climate, and system design, all of which have a direct impact on the energy generation of these systems. For this reason, precise power prediction is crucial (20,21)

A photovoltaic (PV) system's electrical performance is an essential aspect that is affected by a few variables, including solar irradiance, weather, installation location, and system design as shown in Figure 1.

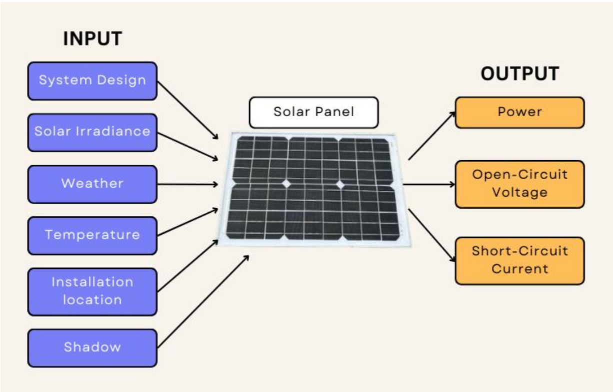

Figure 1: Aspect that effect a PV system's performance.

The importance of figuring out grid-connected solar electricity systems' steady-state performance at varying solar irradiances is highlighted by research in (22), photovoltaic (PV) system's performance varies depending on the weather (23).The amount of sunlight received directly affects the panel's energy output, and different weather conditions can have an impact on PV module performance. For instance, on a cloudy day, the sunlight is hindered from reaching the solar panels, resulting in a reduction in the energy output of the panel. Since they are a hassle-free and secure method of cleaning solar panels, rainstorms are helpful for them. PV modules can produce between 10% and 20% of their total output when it rains heavily. However, continuous heavy rain may reduce production due to light energy blockage. Since PV panels are designed and built to withstand winds of up to 170 mph, extreme wind conditions are not a major concern for them.

PV system performance is significantly impacted by temperature as well. The solar panel's output current increases exponentially with temperature while the voltage output decreases linearly. If the panels are not covered in snow or ice, cold weather has no effect on how well they function. Hot weather, however, will always result in lower output; the panel's efficiency will decrease by 1% for every degree above 77 degrees. Research that was published in IEEE Xplore supports these findings (24). It also points out how location, weather, and shadowing affect PV systems' ability to generate energy (25,26). A photovoltaic system's location determines how much sunlight it receives, which impacts how much energy it can produce. PV systems tend to produce more energy in regions with more sunlight, like the Mediterranean region in Europe or the desert regions of the southwestern United States, than in regions with less sunlight, like the Pacific Northwest in the United States or the northern latitudes of Europe.

The International Electrotechnical Commission (IEC) 60904-3 standard specifies the Standard Test Conditions (STC) for a photovoltaic (PV) panel as follows: the panel must be tested at an air mass of 1.5, an irradiance of 1000 W/m^2, and a cell temperature of 25°C (27–29). For this reason, these parameters will be used in this project to predict power output more precisely. These circumstances offer a foundation for evaluating various PV panels' performances in accordance with standardized standards. Additionally, research has demonstrated performance evaluations of grid-connected photovoltaic solar power systems under various circumstances, such as failures of the network (30).

These results highlight how crucial it is to take operational and environmental aspects into consideration when evaluating the electrical performance of PV systems. Hence, manufacturers and users can consistently evaluate the electrical performance of photovoltaic (PV) panels due to the STC, an industry-wide standard that enables accurate comparisons and ratings of solar panels. Determining the rated power and other features of solar PV panels requires the STC. It offers a standard reference point for assessing and contrasting the capabilities of panels made by different manufacturers.

4. Overview of Artificial Neural Network (ANN)

One kind of machine learning model that draws inspiration from the structure and operations of the human brain is the Artificial Neural Network (ANN) (31). Artificial neurons, the interconnected nodes which make up ANNs, are roughly modelled after the neurons found in a biological brain. Like synapses in a biological brain, every connection can communicate with other neurons. Applications for artificial neural networks (ANNs) include modelling, classification, time series prediction, fitness approximation, novelty detection, and decision-making in a sequential manner. To simulate the human brain, an artificial neural network (ANN) usually consists of input, hidden, and output layers with connected neurons, or nodes. The network's final output is generated by the output layer, whereas the input layer gathers information from the outside world in various forms. After processing input from the input layer or other hidden layers, hidden layers move on to the next layer (32).

Research presented in a previous paper demonstrates the range of real-world applications of artificial neural networks (ANNs). A wide range of multi-dimensional design space has been successfully predicted with good accuracy using artificial neural networks (ANNs) (33). It also has been used in several business applications. However, the outcomes of the research do not include the specific applications.

An input layer, one or more hidden layers, and an output layer normally make up the architecture of an Artificial Neural Network (ANN). Artificial neurons, or interconnected nodes, make up each layer, and the connections between these nodes are weighted accordingly. The first layer of the network receives the data, which is processed by the hidden layers before being sent to the output layer, which outputs the computed result. The nature of the input data and the complexity of the problem being solved determine the specific architecture as well as the number of hidden layers and nodes within the layers. Another important component of the architecture is the activation function of each node, which determines the output given set of inputs.

There are various types of artificial neural networks (ANNs), including recurrent neural networks (RNNs) and feedforward neural networks. Recurrent neural networks (RNNs) have feedback connections that enable them to process data sequences, whereas feedforward neural networks process data in a single direction, from the input node to the output node. Neural network applications include process and quality control, chemical compound identification, electrical load and energy demand forecasting, and financial predictions made by analysing historical data of financial instruments (34). These uses demonstrate the adaptability and strength of ANNs in resolving challenging issues and producing precise forecasts.

5. ANN for PV Prediction

The application of artificial neural networks (ANNs) for predicting photovoltaic (PV) system output power has been the subject of multiple research projects. An ANN model optimized by a genetic algorithm is suggested in one study for the prediction of PV power. Meteorological variables like air temperature and solar radiation are used to train and test the ANN model. The correlation coefficient (R) and mean square error (MSE) are used to assess the model's performance. The testing process yielded a high correlation coefficient R=99.972% and mean square error MSE=2.3091%. The research shows that the suggested model for hourly PV power output prediction is accurate and dependable, which qualifies it for use in PV system design and supervision, particularly when real values measurement is missing (35). The results of the research support the suggested model's efficacy in precisely projecting the PV power production time series, making it a useful resource for electrical engineers who work with PV systems.

In a different research, PV power is predicted using various ANN strategies based on meteorological variables like temperature and radiation. Research on the application of Artificial Neural Networks (ANNs) to photovoltaic (PV) power prediction has been conducted in the renewable energy field. Various ANN strategies are applied to forecast PV power depending on meteorological factors. The research shows that the NARX model outperforms the static ANN in forecasting PV power at different time scales, with a reduced forecasting error. It does this by comparing the performance of static ANN and Nonlinear Auto-Regressive models with exogenous input (NARX) model (36). This research demonstrates how well ANN models, particularly the NARX model, predict PV system output power with accuracy, providing important information for PV system integration into power grids.

In a third study, an ANN is trained to precisely predict a PV module's output power. Like how a neuron in the human brain processes signals, a neural network processes the dataset (inputs and outputs) of a dynamical system, for which developing a mathematical model is a difficult undertaking. Its beauty lies in the fact that no comprehensive information about the dynamical system is needed, as gathering data for that system is a time-consuming and complex process. The functionality of neurons is necessary for the operation of ANN (37). To predict the parameters of photovoltaic cells more accurately under various conditions, a more accurate model is established, and the combined model is used to predict the parameters of photovoltaic cells. The main goal of the research in (38) is to develop a simple and accurate neural network model, considering the continuity of time, to accurately predict the photovoltaic cell parameters under any condition, the photovoltaic characteristic curve, and the maximum power point at any time can be obtained at the same time.

Apart from that, an ANN network is used in a study to predict solar photovoltaic energy in Jordan's central and southern regions (39). Next, a different study develops an ANN model for predicting solar power output on an hourly and daily basis. Artificial Neural Network (ANN) takes into consideration several variables, including historical PV power production data, ambient temperature, wind speed, and solar radiation (40). Furthermore, an ANN model for forecasting solar energy generation from photovoltaic generators was presented in a paper by (41). The model optimizes solar power production and management by using weather forecasts for microgrid control, showcasing the potential of artificial neural networks. These studies show that ANNs can accurately forecast the power output of photovoltaic systems, which is helpful for maximizing the efficiency and performance of these systems.

6. Conclusion and Future Scope

In conclusion, to manage energy effectively, PV power output needs to be predicted. ANN is a computer model that work based on how the human brain is organized and functions. They are an essential part of artificial intelligence and machine learning, especially deep learning. This system will be implemented to calculate equations in power output prediction without assuming variables. Future research should focus on improving data collection methodologies, tailored to specific geographical areas. Further exploration into ANN configurations, including optimizing the number of neurons and refining training methods, is recommended. These advancements will enhance the accuracy and efficiency of photovoltaic output predictions, contributing significantly to the renewable energy sector.

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