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Smart Photovoltaic Solar Energy Systems: Integrating Internet Of Things (Iot) And Machine Learning

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Abstract: The Internet of Things' (IoT) potential has been made clear by a number of studies and research initiatives conducted over the past few years in a variety of application areas. Because solar energy is a sustainable foundation for human civilization and a renewable energy source, the Internet of Things' integration with solar-powered gadgets has undoubtedly revolutionized technology. Scholars have investigated how to use IoT to alter the network structure by identifying various ecosystem components for intelligent control of solar-powered cities. Numerous research have also been conducted on solar tracking and monitoring systems employing various IoT technologies with the goal of maximizing energy generation, improving efficiency, and automating control and monitoring. The main contribution of this study is to raise awareness of the integration of renewable energy with the fourth industrial revolution, which is the main focus of modern technology. Concepts like IoT are also essential for these important studies because large projects like smart cities are being pursued in many emerging nations like India. Additionally, by monitoring and optimizing the solar panels, the Internet of Things can assist save maintenance costs and boost solar panel efficiency. This technique could help with real-time energy management, making solar electricity more reliable and flexible to changing demand.

The most recent review of IoT applications for efficient solar energy use is given in this publication. The following applications of IoT are reviewed: solar energy tracking, power point tracking, energy harvesting, smart lighting systems, PV panels, smart irrigation systems, solar inverters, etc. Therefore, by combining solar energy and the Internet of Things, we can offer households and businesses long-term, cost-effective energy solutions that promote responsible growth and a brighter future. The study's findings demonstrate that the Internet of Things is highly effective in generating intelligent and effective solar energy from a vast number of devices. Future research and development on IoT applications for intelligent solar energy use is still very much in the early stages.

Keywords – Internet of Things (IoT), Photovoltaic PV) System Networks (BPNN) ,Adaptive Neuro Fuzzy Inference Systems (ANFIS).

I. Introduction

The global community is looking for sustainable energy solutions, and Internet of Things (IoT) applications require reliable and effective power sources. Designed for Internet of Things applications, this study introduces a novel hybrid renewable energy system that seamlessly combines wind turbines, solar photovoltaic panels, and hydrogen fuel cells. In addition to optimizing energy generation in real-time, our suggested solution uses machine learning algorithms to guarantee a continuous energy supply for customers and IoT devices, even in the face of changing climatic conditions. By significantly reducing reliance on non-renewable energy sources, this all-encompassing strategy fosters a more resilient and environmentally friendly energy infrastructure. Using hydrogen fuel cells puts our system in a unique position to store excess energy, guaranteeing steady power even when wind or solar outputs start to decline. Additionally, we have obtained real-time data on energy dynamics by synchronizing IoT devices with our energy system, which has allowed for unmatched optimization and decreased waste. The solution being demonstrated paves the road for a sustainable future by generating green energy efficiently while utilizing machine learning techniques and the constantly changing landscape of Internet of Things applications. When it comes to renewable energy sources for electrification, solar energy is one of the most alluring. A photovoltaic (PV) system is required to harness solar energy, which transforms solar light energy into direct electrical power. Anywhere there are adequate energy potentials, systems can be deployed. The main difficulty with PV systems is analyzing their performance, which varies depending on a number of characteristics and how well the system's components work. To evaluate its performance, a real-time monitoring system is therefore required. This paper provides an overview of the application of the internet of things (IoT) to PV system performance monitoring and real-time control. With pertinent debates, the necessity of IoT and its architecture for PV systems are highlighted. Understanding the real-time operating parameters is improved by the use of IoT. This facilitates the control of PV systems situated at remote locations, efficient and quick fault diagnosis, maintenance, and the collection of generation and performance data for analysis.

II. Literature Review

The Internet of Things (IoT) and machine learning (ML) technologies have advanced so quickly that they have transformed many industries, most notably the energy sector. When combined with machine learning algorithms, IoT devices can ensure real-time monitoring and predictive analytics, which can help with efficient energy generation, storage, and consumption. The convergence of solar, wind, and hydrogen fuel cells is exemplified by hybrid renewable energy systems. These hybrid systems reduce the erratic nature of individual renewable energy sources and provide a sustainable green energy producing option. These systems may improve energy output based on environmental elements and consumption patterns, signaling a new era of environmentally friendly and effective energy management. They do this by influencing IoT for data collecting from various sensors and ML for data analysis. With its massive networks of linked gadgets, the Internet of Things (IoT) is spearheading the Fourth Industrial Revolution and revolutionizing our day-to-day existence. According to recent estimates, there will be more than 75 billion IoT devices globally by 2025. Although the rate of acceptance and technological developments is praiseworthy, there are drawbacks, particularly with regard to energy supply and consumption [1].

Determining the power supply capacity requires estimating the power generated by a solar system. Solar system modeling can be used for estimation. The process of creating a model that illustrates the relationship between input and output is known as modeling. Since a variety of factors affect the power generated by a solar panel, modeling the solar system is not an easy task.Data-driven modeling with machine learning is one of the various modeling techniques. This type of modeling, known as "black-box" modeling, uses input-output data pairings to build the model through a learning process. One strong and helpful technique for system modeling is machine learning [2].

Numerous systems, including complicated ones, have been modeled using machine learning. The paper provided a thorough analysis of machine learning models for energy systems. The use of machine learning to model fluid mechanics was introduced in. High accuracy is a promised benefit of machine learning modeling [3].

Smart homes, smart cities, and industrial systems are just a few of the industries where IoT devices require reliable, environmentally friendly energy solutions. Conventional energy sources, which are mostly derived from fossil fuels, are rapidly running out of energy and are a major source of carbon emissions worldwide. This calls for a switch to cleaner, more renewable energy sources [4].

Increased efficiency and dependability are promised by hybrid renewable energy systems, which mix several energy sources including solar, wind, and tidal in a harmonious manner. High-density energy storage could be possible with the addition of hydrogen fuel cells to these systems, guaranteeing a steady supply of energy even when renewable energy harvesting isn't as strong [5].

IoT applications have made extensive use of solar energy, the most plentiful energy source, however its sporadic nature still presents difficulties. Conversely, wind energy provides still another abundant supply, however its effectiveness may vary depending on seasonal and regional conditions. Hydrogen's potential as a clean fuel source has drawn a lot of attention in the past ten years, and its incorporation into hybrid energy systems is thought to be a crucial development for energy infrastructures of the future [6].

Machine learning algorithms are being included into energy management systems because of their ability to evaluate big data sets and generate predictions. These algorithms adjust energy supply to real demand and environmental conditions by dynamically optimizing energy generation, storage, and delivery. These developments are essential, particularly in light of the ever-changing energy requirements in IoT networks [7].

Because IoT devices are data-centric by nature, they can work in tandem with smart energy systems to produce a feedback loop in which data on energy usage further enhances and refines the dynamics of the energy supply. The environmental impact of IoT systems can be significantly reduced, overall system efficiency can be raised, and energy waste can be significantly reduced with this comprehensive and integrated approach. IoT and energy will become increasingly intertwined as the digital era develops [8]. Thus, developing intelligent, adaptable, and sustainable energy solutions is not only advantageous but also necessary for a more efficient and greener future. The architecture, benefits, and possible ramifications for the future energy and digital landscapes are examined in this study as it delves into the complexities of an IoT-specific hybrid renewable energy system [9].

The integration of redefining our energy paradigms is made possible by the combination of IoT and machine learning with hybrid renewable energy sources. With the help of artificial intelligence's predictive capabilities, the combination of solar, wind, and hydrogen fuel cells points the way toward a future in which energy is not only environmentally friendly but also effectively distributed and managed [10]. This synergistic strategy can efficiently address the issues created by the energy demands of several consumers, particularly the large number of IoT devices. Energy systems that are intelligent, flexible, and sustainable must be adopted as the world moves more and more toward a digitally connected environment. Investigating and implementing these cutting-edge hybrid systems is not merely a scholarly endeavour; rather, it is a critical step toward a sustainable and connected future [11].

III. System Design

In order to ensure a thorough investigation into the hybrid renewable energy generation system designed for IoT applications, the methodology for implementing the IoT and machine learning based green energy generation using hybrid renewable energy sources of solar, wind, and hydrogen fuel cells was divided into separate phases. The application of machine learning (ML) in solar energy is growing in popularity as a way to maximize energy generation, improve system management, and increase prediction accuracy. To estimate power output, spot any problems, and improve system performance, machine learning algorithms can examine vast datasets of weather, solar panel performance, and other pertinent variables.

3.1 Machine Learning (ML) Model Development

Artificial Neural Networks (ANNs) are a state-of-the-art method for applying machine learning techniques. ANNs are made to handle large amounts of data in parallel, and they can perform nonlinear computations rapidly if they are properly trained with the correct data. Adaptive Neuro Fuzzy Inference Systems (ANFIS), Radial Basis Function Neural Networks (RBFNN), and Back Propagation Neural Networks (BPNN) are some well-known methods used in ANNs to match the functionality of different systems. Our self-adaptive system can train itself on a regular basis depending on local weather conditions and forecast the availability of local solar power thanks to the RBFNN features that we mainly use in this paper to train solar, wind, and hydrogen fuel energy data.energy from wind and hydrogen fuel. A 99% AUC (Area under the Curve) statistic is used in a machine learning-based method to estimate solar power generation with high accuracy. Preprocessing, feature and model selection, training, assessment, and deployment are all part of the process [12]. We gather and pre-process high-quality data from many sources, such as weather, solar irradiance, and historical solar power generation data, in order to manage missing values, eliminate outliers, and normalize the data. The model is trained using pertinent data including temperature, humidity, wind speed, and sun irradiance. Machine learning methods like Random Forest, Gradient Boosting, and Support Vector Machines (SVM) are used to generate precise predictions. A sizable dataset of historical solar power generating data as well as other pertinent variables are used to train the models. AUC and additional measures including accuracy, recall, and F1-score are used to assess the models' performance [13]. Following training, the machine learning models are put into use in a real-world setting to forecast solar power generation in real time. According to the findings, the suggested method predicts solar power generation with an accuracy of 99%, which can assist energy firms in managing their solar power systems more effectively, cutting expenses, and increasing energy efficiency.Figure.1shown the architecture of RBFNN Model

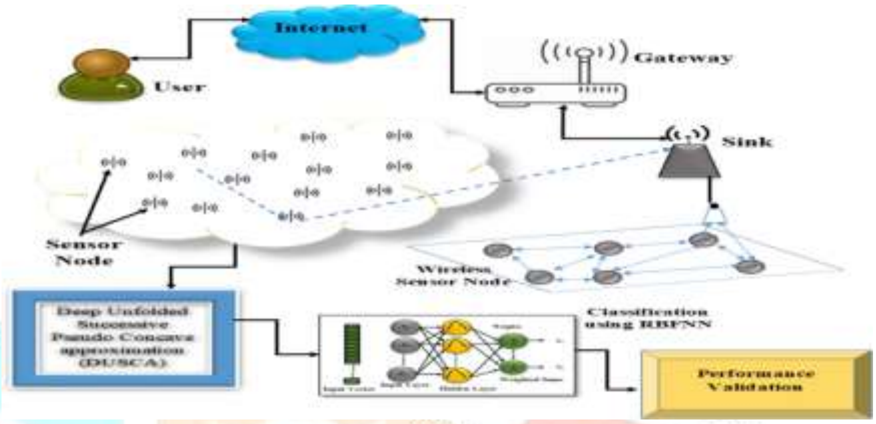

Fig.1 Architecture of RBFNN Model

Solar power generation has significantly increased as a result of the increased need for renewable energy sources. Complex solar power generation systems rely on a wide range of variables, including temperature, moisture content, sun irradiation, and rainfall. For energy firms to balance supply and demand, save prices, and improve energy efficiency, accurate solar power generation appraisal is essential. Approaches based on machine learning have demonstrated encouraging outcomes when it comes to directly forecasting solar power generation [14]. However, it takes a combination of data collection, pre-processing, point selection, model selection, training, evaluation, and deployment techniques to reach a high position of delicacy, comparable to 99 AUC (Area under the Wind. Using a 99 AUC measure, this research proposes a machine-learning-based method for highly accurate solar power generation prediction. Choosing relevant features, selecting appropriate machine learning algorithms, gathering high-quality data from various sources, and training the models on a sizable dataset of actual solar power generating data and other relevant features are all part of the process. AUC and other comparable metrics like perfection, recall, and F1-score are used to estimate the models' performance. Additionally, the learned machine-learning models are deployed in product terrain, where they may be utilized to Forecast solar power generation in real time. The suggested method can lower expenses, increase energy efficiency, and assist energy firms in better managing their solar power installations [15]. Precise PV power ventilation is required to address these shortcomings. In any case, it might also serve as a guide for PV power plant operations and power grid dispatching, which is important for both security and financial efficacy.

IV. IoT-Based Architecture for Hybrid Renewable Energy System

The communication infrastructures in HRES are essential components that provide data interchange between controllers, the control center, and data resources (sensors and meters). The system architecture is defined by the flow of information from various entities to enable remote monitoring and control operation [19]. Many micro grid applications will be supported by the sensing, communication, processing, and actuation options that the Internet of Things will offer. First, a communication network is used to collect and send measured data to the local control center. This data is then used to make judgments, and control commands are transmitted via the communication network and executed by controllable equipment. Centralized and distributed schemes are the two primary categories of communication systems that could be taken into consideration. All data are sent to a central control center in the centralized scheme, where they are processed and control directives are sent to things that can be controlled. The local controller is used to receive and process all data in the distributed scheme [16]. Local control centers must communicate with one another via the communication network in order to manage the entire system. The communication level between the HRES local controller and the micro grid control center is the main focus of this work. It allows for the collection and transmission of data about the various renewable energy sources and loads to a central controller, which then decides on the best course of action for the system.

Energy is a basic requirement for development, and its demand is rising due to a number of political and economic causes, technological breakthroughs, and the world's population growing faster than before. Coal, diesel, nuclear, and other traditional energy sources that are being used to generate electricity are rapidly running out. Therefore, it is imperative that we switch to non-traditional energy sources. Wind and solar energy are readily available year-round and provide excellent backup sources. The need to use these systems more efficiently has increased due to the rising demand for renewable energy supplies. The outcome of this is the hybrid energy system [17]. A hybrid energy system is created when two or more energy systems are combined. Here, two energy sources are used: solar and wind. The hybrid system can be controlled by IOT. Physical things that have been connected with sensors, software, electronics, and network connectivity to enable data collection and sharing are referred to as the Internet of Things, or IOT. When the grid is not available, IOT is used to turn on and off a home's solar and wind energy sources via a secure website. A prototype has been developed to control the switch between these two energy sources [18]. With this prototype, it may be able to control the energy sources in a home because of technical developments that provide electricity customers with sensors, metering, transmission, distribution, and flexibility. The Internet of Things (IoT) is one of the most important contemporary technologies that improves people's quality of life and intelligence. Devices that enable connection between a machine and the cloud are referred to as Internet of Things (IoT) devices. This technology makes it easier for connected devices to share data on the available network [19]. From any location in the world, the user can utilize the internet to manage devices and access data. It is an ecosystem of web-enabled gadgets that use computers, sensors, and other communication hardware to retrieve and send data.Two categories exist for energy resources Resources with a limited supply that could run out in a few years are referred to as non-renewable energy. For example, petroleum, natural gas, and coal. Natural resources are abundant sources of renewable energy. Tidal, wind, and solar energy are a few examples of energy sources. IoT Hybrid Renewal Energy Systems are depicted in Fig. 2.

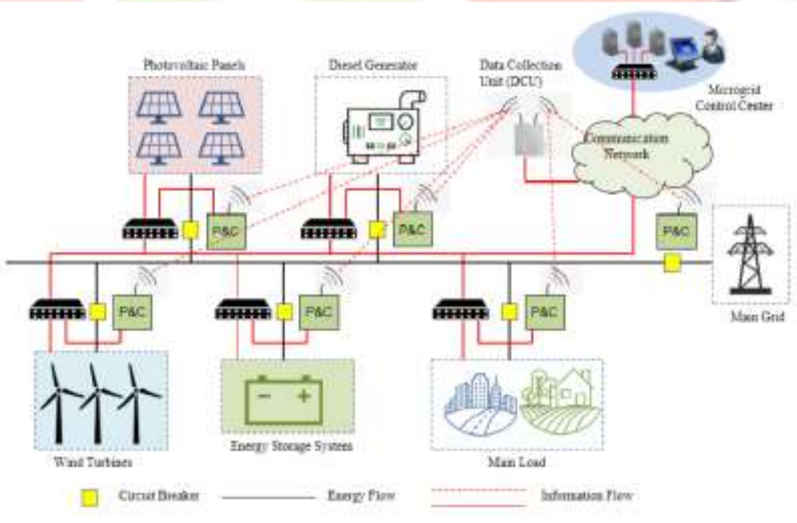

Fig.2 Hybrid Renewal Energy Systems

V. ADVANTAGES & APPLICATIONS

5.1 Advantages

1. Real-time Monitoring: It enhances resource management and optimization by enabling real-time monitoring of energy production, consumption, and storage.
2. Increased Efficiency: By combining many energy sources, including solar, wind, and grid electricity, the system can operate more efficiently, maximizing the usage of renewable energy sources and lowering reliance on non-renewable ones.
3. Reliability and Resilience: By providing backup power from many sources, the system's hybrid architecture improves reliability and resilience by ensuring a consistent supply of electricity even in the case of outages or changes in one energy source.
4. Environmental Benefits: By utilizing renewable energy sources and managing energy use, the system reduces its impact on the environment and carbon emissions. This slows down climate change and helps achieve sustainability goals.
5. Scalability: The system's modular design enables scalability by making it easy to incorporate new technologies or add additional energy sources or components as needed to accommodate changing energy demands.
6. Remote Monitoring and Control: Internet of Things connectivity enables remote monitoring and control of the system. Preventive maintenance, troubleshooting, and optimization are made possible by this, which reduces downtime and improves system performance in general.

5.2 Applications

1. Renewable Energy Integration: Monitoring the quantity of energy coming into the grid or being locally stored from renewable sources, such as wind or solar.
2. Smart networks: Monitoring power flow inside smart networks to ensure efficient electricity use and distribution, as well as to spot and address any anomalies or systemic problems.
3. Energy Management in Buildings: Hybrid energy systems, such as those that integrate solar panels, batteries, and grid connections, must be utilized to monitor power flow within buildings in order to optimize energy efficiency and save costs.
4. Industrial Applications: Monitoring power flow in industrial facilities to ensure that critical equipment operates continuously and to optimize energy use for environmentally friendly and cost-effective solutions.
5. Remote Monitoring: Using Internet of Things (IoT) devices, remote or off-grid sites where traditional energy infrastructure may be constrained can have their power flow monitored to guarantee a consistent and dependable supply of electricity from hybrid energy sources.

VI. CONCLUSION

In the pursuit of sustainable energy solutions for the Internet of Things (IoT), the combination of machine learning with hybrid renewable energy sources, as demonstrated in this study, represents a significant advancement. According to our research, when properly utilized, solar, wind, and hydrogen fuel cells can not only reliably power Internet of Things applications but also mitigate the usual unpredictability seen with individual renewable energy sources. A Long Short-Term Memory (LSTM) model was used to properly forecast the energy consumption patterns of Internet of Things (IoT) devices. This is crucial for proactive energy resource management. Additionally, as compared to other solutions in the sector, our method not only supports green energy but also takes into account the distinct and changing needs of IoT infrastructures, ranging from large smart cities to smart households. This flexibility, which is emphasized by real-time predictions and modifications, is an example of a significant development in energy-efficient systems. Additionally, this article has implications for further research and applications. Even though the current system has shown a lot of promise, there is still room to add more renewable energy sources and adapt the system to other geographic and climatic conditions To improve accuracy, the machine learning model can also be further improved by taking into account other neural network topologies or prediction algorithms.

Outside of the technical sphere, this study reiterates the more general objective of environmental sustainability in technological development. As global connection increases, there is a corresponding obligation to reduce the environmental impact. This goal is demonstrated by our study, which provides a model that combines innovation and conservation. Building on this basis would help future efforts in this field by expanding the possibilities at the intersection of IoT and green energy.

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