

AI Based Solar Irradiance Prediction

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Abstract: *The increasing demand for renewable energy has made accurate short-term solar irradiation forecasting essential, especially for smart grid and off-grid applications. Solar power output varies with weather conditions, making real-time monitoring important. In the proposed system, environmental parameters such as temperature, humidity, wind speed, cloud cover, and solar irradiance are collected using IoT sensors and transmitted wirelessly to a cloud or central server. A machine learning model (such as LSTM, Random Forest, or Linear Regression) trained on historical and real-time data predicts the solar irradiation for the next hour. The predicted results are displayed through a web or mobile dashboard to support decisions related to energy distribution, storage, and usage. This IoT-based approach offers a scalable and cost-effective solution for improving the reliability of solar energy systems.*

Keywords: IoT, Solar Irradiance Forecasting, Machine Learning, Cloud Computing, ESP32, Smart Grid

I. INTRODUCTION

The increasing adoption of solar energy has created a strong need for accurate short-term solar irradiance prediction to improve power generation efficiency and grid stability. Solar irradiance is the power received from the sun per unit area, is highly dependent on time, seasonal variations, and atmospheric conditions. Traditional measurement-based systems using light sensors provide only real-time information and fail to predict future solar availability. To overcome this limitation, artificial intelligence techniques can be used to analyze historical solar and weather data and forecast future irradiance values. Optimizing solar energy systems requires precise sun irradiation predictions, particularly when considering smart grids, energy storage devices, and off-grid power options. In this system, an AI-based solar irradiance prediction system is developed using historical data. The model learns daily and seasonal solar patterns using parameters such as hour, month, temperature, and humidity. The real-time data can be analyzed with machine learning algorithms to create prediction models that can forecast solar irradiation for brief timeframes, like the next hour, which is particularly helpful for dynamic energy management systems. The trained model is deployed on the Hugging Face platform for cloud-based inference, while Node-RED is used for real-time visualization of predicted values. This approach enables reliable next-hour solar irradiance prediction without relying solely on physical sensors, making the system scalable, efficient, and suitable for smart energy management applications.

II. LITERATURE REVIEW

Several researchers have investigated the use of machine learning and data-driven approaches for predicting solar irradiance in order to improve the efficiency of solar power generation systems. Accurate solar irradiance forecasting plays a crucial role in renewable energy management, as it helps optimize solar power generation, grid stability, and energy storage planning. Studies have shown that forecasting solar radiation using historical weather data can significantly improve the performance of photovoltaic systems and support better integration of renewable energy into modern power grids [1]. Researchers have also highlighted that environmental parameters such as temperature, humidity, and sunlight intensity strongly influence solar radiation levels. Traditional statistical models often struggle to capture the complex relationships between these parameters and solar irradiance. As a result, machine learning techniques have been widely explored to improve prediction accuracy. These models are capable of learning patterns from large datasets and identifying hidden relationships between environmental factors and solar energy output [2].



Different machine learning algorithms have been investigated for solar irradiance forecasting, including linear regression, random forest, support vector machines, and neural network-based approaches. Among these techniques, deep learning models such as Long Short-Term Memory (LSTM) networks have shown promising results in time-series prediction tasks. LSTM models are capable of learning temporal dependencies in sequential data, making them suitable for predicting solar irradiance based on historical weather patterns and time-based features [3]. Recent research also focuses on integrating Internet of Things (IoT) technologies with machine learning models for real-time solar energy monitoring and forecasting. IoT-based sensor systems can collect environmental data such as light intensity, temperature, and humidity, which can be transmitted to cloud platforms for data analysis and prediction. This integration allows real-time monitoring of solar conditions and improves the reliability of solar irradiance prediction systems [4]. Furthermore, cloud-based platforms and data visualization tools such as Node-RED dashboards and machine learning model hosting services have been used to enable real-time data processing and prediction. These technologies allow efficient communication between IoT devices, machine learning models, and monitoring dashboards, thereby improving system scalability and accessibility for renewable energy applications [5]. Overall, the existing literature indicates that combining IoT-based environmental monitoring with advanced machine learning models can significantly improve the accuracy of solar irradiance forecasting. However, many existing systems rely only on historical datasets and lack real-time environmental sensing. Therefore, the proposed system aims to integrate real-time sensor data, machine learning prediction models, and cloud-based visualization to develop an efficient system for next-hour solar irradiance prediction.

III. SYSTEM ARCHITECTURE

The proposed system architecture for solar irradiance prediction integrates IoT-based environmental sensing, machine learning prediction, cloud communication, and real-time visualization. The architecture consists of multiple components that work together to collect environmental data, process it using a trained prediction model, and display the results to the user. The system begins with the sensor layer, where environmental parameters are measured using sensors connected to the ESP32 microcontroller. The BH1750 light sensor is used to measure the light intensity in lux, which represents the available sunlight. The DHT11 sensor measures temperature and humidity, which are important environmental parameters affecting solar radiation levels. The collected sensor data is processed by the ESP32 microcontroller, which acts as the main controller of the system. The ESP32 reads the sensor values and transmits the data wirelessly using its built-in Wi-Fi module. The data is sent using the MQTT communication protocol, which is a lightweight messaging protocol designed for IoT applications. The transmitted data is received by an MQTT broker, such as HiveMQ, which acts as an intermediary server between the ESP32 and the data processing system. The MQTT broker manages the communication by distributing published sensor data to subscribed applications. Next, the data is processed by the machine learning prediction module. A trained LSTM-based regression model analyzes the environmental parameters and predicts the solar irradiance for the next hour. The prediction model is deployed on the Hugging Face Model Hub, allowing it to be accessed through an API for real-time prediction. The predicted solar irradiance value is then transmitted to the Node-RED platform, which acts as the visualization and monitoring layer of the system. Node-RED processes the incoming data and displays the sensor readings and prediction results on an interactive dashboard. The dashboard provides a real-time graphical representation of both the measured light intensity and the predicted solar irradiance values. This enables users to monitor solar radiation conditions and forecast solar energy availability efficiently. Overall, the proposed system architecture combines IoT sensing, cloud-based machine learning prediction, and real-time visualization to create an intelligent system capable of predicting next-hour solar irradiance.

IV. METHODOLOGY

The proposed system for solar irradiance prediction combines IoT-based environmental sensing, machine learning prediction, and real-time visualization. The methodology followed in this project consists of several stages, including



data collection, preprocessing, model training, prediction, and visualization. The first step involves collecting environmental data using IoT sensors. The BH1750 sensor is used to measure light intensity in lux, while the DHT11 sensor measures temperature and humidity. These sensors are connected to the ESP32 microcontroller, which collects the real-time environmental parameters. The ESP32 transmits the collected sensor data wirelessly using its built-in Wi-Fi module. The sensor data is transmitted through the MQTT communication protocol, which is a lightweight messaging protocol designed for IoT applications. The MQTT broker, such as HiveMQ, receives the published sensor data and distributes it to subscribed applications for further processing. In the next stage, historical weather and solar irradiance data are used to train the machine learning model. The dataset contains parameters such as time, temperature, humidity, light intensity, and solar irradiance. The collected dataset is preprocessed by cleaning the data, removing missing values, and extracting important time-based features such as hour and month. After preprocessing, a machine learning prediction model is developed using the LSTM (Long Short-Term Memory) algorithm. LSTM is a type of recurrent neural network that is well suited for time-series prediction problems because it can learn patterns from sequential data. The model is trained using historical environmental data to understand the relationship between weather parameters and solar irradiance. Once the model is trained, it is deployed on the Hugging Face Model Hub, which provides cloud-based hosting for machine learning models. This allows the model to be accessed through an API for real-time prediction. During real-time operation, the environmental data collected from the sensors is transmitted to the prediction system. The trained model processes the input parameters and predicts the solar irradiance for the next hour. Finally, the predicted solar irradiance values and sensor readings are displayed on a Node-RED dashboard. The dashboard provides real-time visualization using gauges and charts, enabling users to monitor solar conditions and predicted irradiance values easily. Thus, the proposed methodology integrates IoT data acquisition, machine learning prediction, cloud deployment, and real-time visualization to develop an intelligent solar irradiance prediction system.

V. RESULTS AND DISCUSSION

The developed solar irradiance prediction system successfully demonstrates the integration of IoT sensing, machine learning prediction, and real-time visualization. The proposed system uses environmental sensors connected to the ESP32 microcontroller to measure parameters such as temperature, humidity, and light intensity. These parameters are continuously monitored and transmitted through Wi-Fi using the MQTT communication protocol. The hardware prototype consists of an ESP32 development board interfaced with a DHT11 temperature and humidity sensor and a BH1750 light intensity sensor. The measured environmental parameters are displayed locally on a 16×2 LCD display for immediate monitoring. The real-time experimental setup shows temperature, humidity, and light intensity values collected from the surrounding environment. The sensor data is transmitted to the processing system where the trained machine learning model predicts the solar irradiance value for the next hour. The trained LSTM-based prediction model processes the environmental parameters and generates the predicted solar irradiance value. The prediction results are then visualized using the Node-RED dashboard. The experimental results obtained from the prototype demonstrate that the system can successfully measure environmental parameters and estimate solar irradiance values in real time. For example, during testing, the light intensity measured by the BH1750 sensor was approximately 54,612 lux, and the corresponding predicted solar irradiance value displayed on the Node-RED dashboard was approximately 726 W/m² to 789 W/m². These values are consistent with typical solar radiation levels observed during midday under clear sky conditions. The Node-RED dashboard provides a graphical interface that displays both the measured light intensity and the predicted solar irradiance using gauge indicators. This visualization allows users to easily monitor solar conditions and forecast solar energy availability in real time. The results indicate that integrating IoT-based environmental sensing with machine learning prediction models can provide an efficient solution for solar irradiance forecasting. Compared to traditional estimation methods, the proposed approach enables real-time monitoring and prediction, which can support better solar energy management and planning. However, further improvements can be made by incorporating additional environmental parameters such as cloud cover, wind speed, and atmospheric pressure to improve prediction accuracy. Additionally, expanding the dataset and implementing multi-location prediction models can further enhance the



reliability and scalability of the system. Overall, the prototype demonstrates that combining IoT technology, machine learning models, and cloud-based visualization platforms can effectively predict solar irradiance and support the development of intelligent renewable energy management systems.

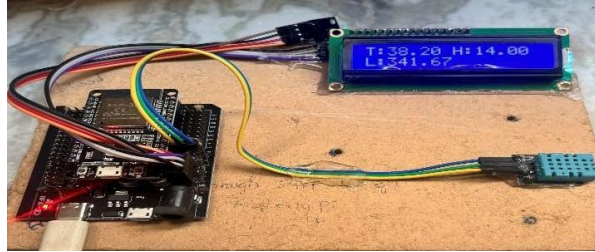


Fig No. 1: AI Based Solar Irradiation Prediction



Fig No. 2: Hardware Setup and Output Display

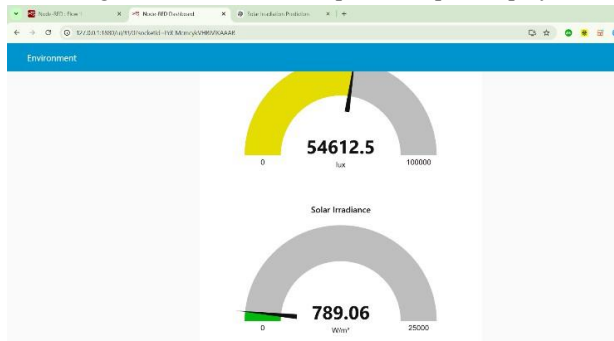


Fig. 3. Node-RED Dashboard Output of Solar Irradiance Prediction at 12:01 pm



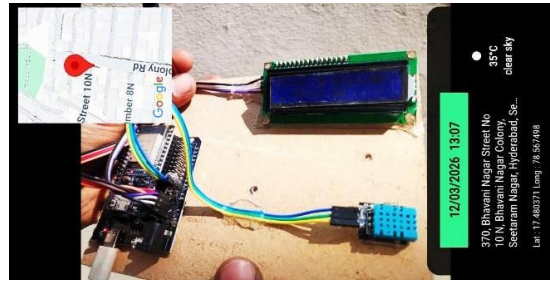


Fig No. 4: Hardware Setup and Output Display

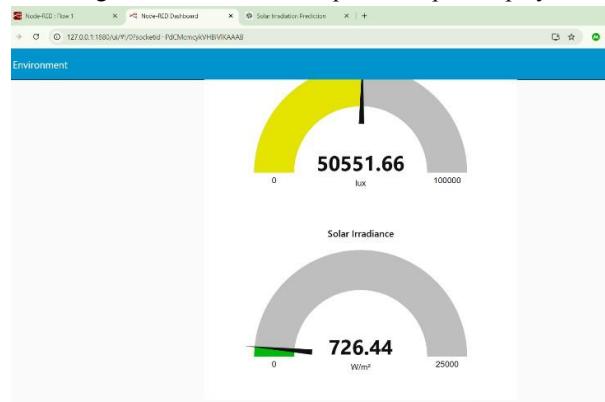


Fig No. 9: Node-RED Dashboard Output of Solar Irradiance Prediction at 01:07 pm

VI. CONCLUSION

This system presents an intelligent system for next-hour solar irradiance prediction using IoT and machine learning techniques. The proposed system integrates environmental sensing, data communication, machine learning prediction, and real-time visualization to develop an efficient solar monitoring solution. The hardware setup consisting of the ESP32 microcontroller, BH1750 light sensor, and DHT11 temperature and humidity sensor successfully collects real-time environmental data. These parameters are transmitted through the MQTT communication protocol to the processing system for further analysis. The collected data is used as input to the trained LSTM-based machine learning model, which predicts the solar irradiance for the next hour. The predicted results are visualized through a Node-RED dashboard, which provides real-time monitoring of both the measured light intensity and the predicted solar irradiance values. Experimental results demonstrate that the system can effectively measure environmental conditions and estimate solar irradiance levels with reasonable accuracy. The developed system shows that integrating IoT technology with machine learning prediction models can provide an effective solution for solar irradiance forecasting. Such prediction systems can support better planning and management of solar energy resources, improving the efficiency of photovoltaic power generation systems. Overall, the proposed system demonstrates the feasibility of combining sensor-based data acquisition, machine learning prediction, and cloud-based visualization for developing intelligent renewable energy monitoring systems. Future improvements can include integrating additional weather parameters, expanding the dataset, and implementing multi-location prediction capabilities to further enhance prediction accuracy and system scalability.

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