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Solar PV Based Energy and Power Prediction System Using Recurrent Neural Network

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ABSTRACT: The proposed project focuses on optimizing solar power generation using a Solar Maximum Power Point Tracking (MPPT) system integrated with a Long Short-Term Memory (LSTM) recurrent neural network (RNN) model for power estimation. The system incorporates a 125-watt solar panel coupled with a boost converter topology to efficiently track and optimize the solar array to harness the highest amount of power available. The generated power is directly supplied to the load, ensuring an optimal utilization of the solar energy. Real-time monitoring and data logging are implemented through integration with the Thing Speak cloud platform, facilitating remote access and storage of power production data. The data gathered acts as the basis for instructing the LSTM RNN model, allowing for precise forecasts of upcoming power production. By leveraging the capabilities of LSTM, a specialized RNN architecture for sequence prediction, the system enhances forecasting accuracy and adapts to varying solar conditions. The integration of MPPT technology, real-time monitoring, and LSTM-based prediction enhances solar power utilization and improves the sustainability and reliability of energy generation systems. The project presents a comprehensive solution for efficient solar power management and forecasting, with potential applications in renewable energy systems and smart grid technologies.

KEYWORDS: LSTM, RNN, MPPT, GRU, P&O, Solar Panel, IoT, AI

I. INTRODUCTION

The increasing need for environmentally friendly energy sources has driven progress in solar power innovations. Efficiently utilizing solar energy is essential to optimize power generation and guarantee the sustainability of solar-powered systems. This project introduces a comprehensive approach to enhance solar power generation through the integration of a Solar Maximum Power Point Tracking (MPPT) system and LSTM - RNN model. The heart of the system lies in a 125-watt solar panel, coupled with a sophisticated boost converter topology for optimal power extraction. The MPPT system continuously modifies the solar panel's operating point to maximize power output, guaranteeing optimal utilization of solar energy resources. This harvested power is then seamlessly directed to the load, ensuring a sustainable and reliable energy supply. To augment the system's capabilities, real-time monitoring and data logging are achieved through integration with the Thing Speak cloud platform. This enables remote access and storage of power production data, fostering a deeper understanding of system performance. Leveraging this data, the project employs an LSTM RNN model, a specialized neural network architecture designed for sequence prediction, to forecast future power generation accurately. This integration of MPPT technology, cloud-based monitoring, and advanced neural network prediction establishes a robust framework for enhancing solar power utilization. The project focuses on tackling the issues related to solar power fluctuations while also promoting the advancement of intelligent and flexible energy systems, laying the groundwork for a sustainable energy landscape.

II. RELATED WORK

History of proposed work:

1. **Challenges in Solar Energy Production:** One of the challenges with solar energy is its intermittency. Solar power generation fluctuates based on weather conditions, time of day, and other factors, making it difficult to predict accurately.
2. **Role of Predictive Systems:** Predictive systems, particularly those based on machine learning and artificial

intelligence (AI), have emerged as solutions to address the unpredictability of renewable energy sources like solar. RNNs are a specific type of neural network design that excel in handling sequential data, proving to be highly effective in tasks involving time-series prediction.

3. **Reason for RNNs:** The reason for using RNNs in this project is their capability to capture the temporal dependencies found in sequential data. Solar energy generation data is inherently sequential, as it varies over time based on factors like weather conditions, time of day, and seasonal changes. RNNs can learn patterns from historical data and use them to make accurate predictions about future energy and power output.

Current Trends:

Currently popular trends include:

1. Cutting-edge Deep Learning Architectures such as Transformer-based models, LSTM and Gated Recurrent Units (GRUs).
2. Hybrid models that combine multiple forecasting techniques, including statistical methods, machine learning algorithms, and physical models.
3. Edge Computing and IoT Integration.

Need for project work:

1. **Optimizing Solar Energy Integration:** With the increasing adoption of solar photovoltaic (PV) systems, there's a growing need for accurate prediction of solar energy generation.
2. **Enhancing Energy Management:** Accurate predictions of solar energy generation facilitate better planning and decision-making for energy management at various scales.
3. **Improving Grid Integration:** Incorporating significant amounts of solar power into the electricity grid brings about technical difficulties in terms of grid stability, voltage regulation, and frequency control. Grid operators can predict changes in supply and demand, optimize grid operations, and implement balancing mechanisms like energy storage and demand response efforts when they have current and accurate predictions of solar power production.

The project's contribution to optimizing energy integration is achieved through the provision of precise solar energy generation forecasts, enhancing grid stability, and supporting energy management practices towards a sustainable energy future.

III. LITERATURE REVIEW

MPPT algorithms are an effective method to maintain the operation of photovoltaic systems, optimize output, and address nonlinear characteristics. Various strategies have been employed to achieve maximum power output, including conventional algorithms. Furthermore, soft computing techniques can be employed to optimize PowerPoint generation. This study thoroughly examines and compares six MPPT approaches for solar systems, highlighting the superiority of Incremental Conductance over traditional methods. While soft computing methods offer enhanced efficiency, their effectiveness relies on users' understanding of their functioning, which is more intricate compared to conventional MPPT techniques [1]. Key differentiating factors among these approaches include their digital or analog nature, design complexity, sensor prerequisites, convergence time, effectiveness range, and hardware costs. Selecting the correct algorithm is essential for users as it influences the electrical efficiency of the PV module and reduces costs by decreasing the quantity of solar panels needed to generate the required electricity.

The solar PV array achieves peak power output through the use of MPPT, specifically the P&O algorithm, which minimizes oscillation and maximizes efficiency compared to other MPPT methods. The Perturb and Observe algorithm is straightforward and user-friendly for optimal solar power extraction. To improve the conversion efficiency of a PV structure, one can utilize DC-to-DC boost converter and an MPPT algorithm. The DC/DC Boost converter introduces a duty cycle to increase the voltage level of the PV system. MATLAB has been employed to create and test MPPT algorithms in a simulated environment, allowing for the modeling of the PV array and boost converter [2].

Solar energy is a plentiful renewable energy source that the sun provides to the earth at no cost. When utilized in place of non-renewable energy sources such as fossil fuels and petroleum-based products, it can be a good energy source. Instead of using NRES to generate energy, solar cells can use the light from the sun to power their devices. Over the ages, there have been several changes made to the evolution of solar cells. Solar cell cost and efficiency are

obstacles to progress in the field. Operators need to understand the fundamental workings and topologies of various solar PV systems using extensively verified MPPT techniques in order to choose the best solar PV cells for a given area [3]. The writers of this paper examined and studied the research on solar PV cells as it has grown over the past many years and provided an explanation of the trends and behaviors that they expect to see. This article also tries to highlight the various studies and innovations that contribute to the benefits of solar energy.

In nature, solar energy is abundant, free, and sustainable all year long, while other resources are running out. Solar energy is transformed into a variety of forms, including heat and electricity. Photovoltaic (PV) arrays found in solar panels are capable of directly converting light into power. The maximum efficiency of a photovoltaic cell is 30%. As a result, the output power is low relative to the input. To attain high efficiency, panels must run at their maximum power point (MPP). Temperature, output voltage, and solar irradiation all affect a PV module's output characteristics. Because of the nonlinear characteristics of the PV cell's current-voltage (IV) and power-voltage (PV), a control circuit or algorithm must be designed to ensure that the cell is tuned operating at peak power output irrespective of the load and external factors such as temperature and light fluctuations. [4] Since the panel output characteristics are nonlinear, modeling and simulation are required before using them in PV system applications. An innovative perturbation and observation method with a variable step size is introduced to enhance the efficiency of a photovoltaic system by accurately tracking its maximum power point.

This study includes a simulation model of a solar controller circuit that may be applied to PV power plants in the field of solar inverter design. The MATLAB/Simulink block sets are used to create the model. The MPPT algorithms of the Perturb and Observe, Incremental, and Conductance methods are utilized in the model to integrate a DC-DC Boost converter. Waveforms produced by Simulink are used to validate results [5].

The globe is currently moving closer to a situation in which the production of electricity is heavily dependent on renewable energy sources. The characteristics, appeal, and practicality of microgrids for supplying consumers' electrical needs in the future inspire scientists and researchers to focus on sustainable energy sources. Photovoltaic (PV) devices can be used to generate electrical energy from solar radiation. PV power has nonlinear characteristics, and its display is strongly influenced by solar radiation and temperature. [6] We need a MPPT Controller to address these problems and produce the most power possible under all environmental conditions. While there are many kinds of MPPT techniques, Perturb & Observe and Incremental Conductance are the most widely used and traditional methods. Although the INC based MPPT algorithm is quite complex, it performs better than the P&O MPPT technique at a given solar intensity. The main objective of this study is to assess the effectiveness of INC and P&O-based MPPT algorithms using real-time data of irradiance in order to determine the most optimal approach in the Dhanbad environment. The National Aeronautics and Space Administration's (NASA) hourly data of solar irradiance for Dhanbad served as the basis for the case study. The Simulink/MATLAB system is employed for model replication and result organization.

IV. METHODOLOGY

Advancements in solar power technologies have been driven by the increasing need for sustainable energy solutions. Efficient utilization of solar energy is vital to optimize power generation and guarantee the effectiveness of solar-based systems. This project introduces a comprehensive approach to enhance solar power generation through the integration of a MPPT system and a LSTM- RNN model [7]. The heart of the system lies in a 125-watt solar panel, coupled with a sophisticated boost converter topology for optimal power extraction. The MPPT system continuously adapts the solar panel's operating point to maximize power output, optimizing the use of solar energy resources. This harvested power is then seamlessly directed to the load, ensuring a sustainable and reliable energy supply. To augment the system's capabilities, real-time monitoring and data logging are achieved through integration with the ThingSpeak cloud platform. Leveraging this data, the project employs an LSTM RNN model, a specialized neural network architecture designed for sequence prediction, to forecast future power generation accurately. This integration of MPPT technology, cloud-based monitoring, and advanced neural network prediction establishes a robust framework for enhancing solar power utilization.

Block Diagram:

Fig. 1. depicts the block diagram of the proposed system, providing a brief overview of its workflow.

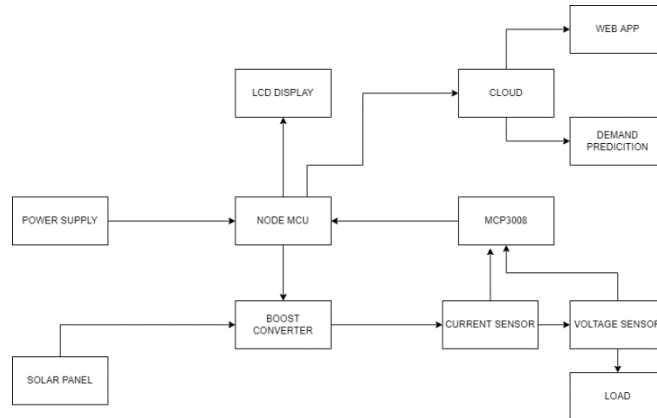


Fig. 1. Block Diagram of the proposed system

A solar panel is connected to a boost converter. the output of the boost converter is connected to a power supply. the power supply is connected to a Node MCU (which likely stands for node microcontroller unit) [8]. The Node MCU has three connections: to an lcd display to the cloud which is further connected to web app and demand prediction to an MCP3008, which is a type of analog-to-digital converter (adc). The MCP3008 is connected to two sensors: a current sensor and a "voltage sensor both the current sensor and the voltage sensor are connected to a load.

Circuit Diagram:

The prototype circuit connection serves as a crucial step in the development of our innovative system, offering a tangible representation of our design concept. This stage bridges the gap between theory and practical application, allowing us to test and validate our ideas in a real-world setting. By meticulously connecting each component according to the circuit diagram, we can evaluate the functionality, efficiency, and reliability of our system shown in the fig. 2.

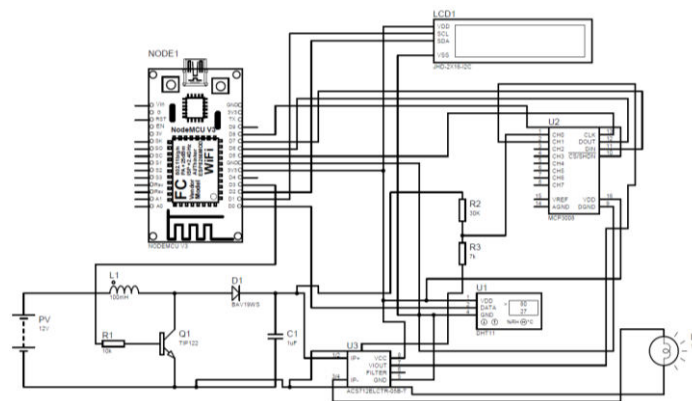


Fig. 2. Circuit Diagram

The hardware model is represented by a circuit diagram in Fig. 2. It illustrates the circuit connections between components such as NodeMCU, MCP3008, ACS712 Current Sensor, Voltage sensor, MCP3008 ADC, and LCD Display.

Algorithm of Proposed Work:

- 1. Data Collection:** Gather historical data on solar panel energy production, including current and voltage readings.

2. **Data Preprocessing:** Clean and normalize the data, split into training/testing sets, and engineer features like power ($P = IV$).
3. **Model Building:** Design an LSTM-based ANN using Keras, specifying input layers, LSTM layers, and an output layer.
4. **Training and Validation:** Train the model on the training set, validate on a separate set, and optimize hyperparameters to prevent overfitting.
5. **Prediction and Deployment:** Use the trained model to predict future energy production based on current and voltage readings and deploy for real-time predictions.

Flowchart:

A flowchart for a Solar PV based Energy and Power Prediction System using Recurrent Neural Network would visually represent the sequential steps involved in the operation of the system. Flowchart of the proposed work is shown in figure. 3.

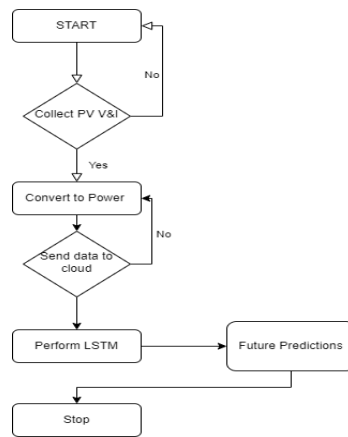


Fig. 3. Flowchart of proposed work

It illustrates the process from data collection to prediction using various symbols and connectors. This flowchart serves as a comprehensive guide for understanding the functioning of the system and its key components.

V. EXPERIMENTAL RESULTS

To improve the efficiency of solar energy harvesting, the solar MPPT-based power generation prediction system described here integrates cutting-edge technology such as boost converters, sensors, ADCs, NodeMCU controllers, and LSTM neural networks. The system uses predictive capabilities to forecast future power outputs in addition to using MPPT to optimize power generation in real-time. Graph of power generated in different temperature is shown in figure. 4.

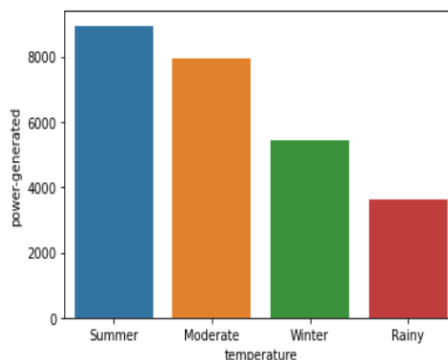


Fig. 4. The graph shows the power generated in Different Temperatures

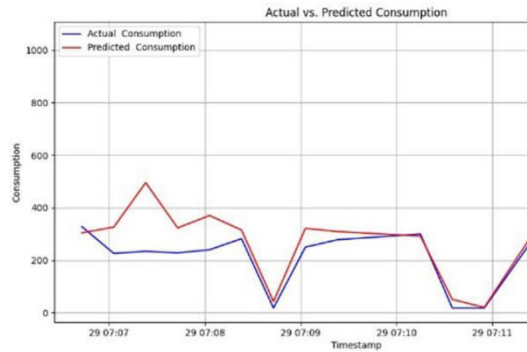


Fig. 5. Solar PV Forecasting

The system exhibits a proactive approach to energy management by utilizing machine learning techniques such as LSTM. This allows for improved resource use and promotes sustainable energy practices. Graph for solar PV forecasting is shown in figure. 5.

VI. CONCLUSION

To sum up, to improve the efficiency of solar energy harvesting, the solar MPPT-based power generation prediction system described here incorporates cutting-edge technology such boost converters, sensors, ADCs, NodeMCU controllers, and LSTM neural networks. The system uses predictive capabilities to forecast future power outputs in addition to using MPPT to optimize power generation in real-time. The system exhibits a proactive approach to energy management by utilizing machine learning techniques such as LSTM [9]. This allows for improved resource use and promotes sustainable energy practices. This integrated system's successful deployment demonstrates how it has the potential to completely transform solar power generation by improving its adaptability and responsiveness to changing climatic circumstances.

Regarding future scope, more developments could be investigated to improve the system's functionality. Prediction accuracy can be increased by integrating extra sensors to track environmental factors like air quality and cloud cover. Furthermore, even more accurate predictions might result from the addition of more advanced machine learning models or hybrid models that combine LSTM with other methods. By adding more solar arrays and predictive models, the system's scalability can be increased and a full network for large-scale energy management can be established. The system can also be made more reliable and useful in a variety of contexts by doing research into energy storage technologies and communication protocol optimization for data transfer to the cloud. All things considered, the system that is being presented establishes the groundwork for future study and advancement in smart solar energy systems, with an emphasis on predictive analytics and effective energy use.

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