

Automatic Photovoltaic Panel Positioning System Based on ESP32 Microcontroller

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Abstract— A concept has been proposed for using the popular ESP32 microcontroller to improve the efficiency of photovoltaic cells while simultaneously monitoring their operating. It has been demonstrated that the implementation of the proposed concept resulted in a 52% increase in efficiency. Furthermore, the solar panel mounted on a tracking system received 32.9% more solar radiation compared to a stationary panel during experimental investigations.

Keywords— *Tracker System, ESP32, Solar Cell, Efficiency Improvement, Online Monitoring*

I. INTRODUCTION

Over the past few decades, there has been rapid development of microcontroller-based devices, which have evolved from simple logic elements into highly efficient, highly integrated single-chip systems. Modern microcontrollers serve as the foundation for automation across numerous fields, particularly in the context of photovoltaic systems. They are employed for a wide range of functions aimed at enhancing the efficiency, reliability, and safety of photovoltaic devices. These functions include: control of maximum power point tracking (MPPT) algorithms; intelligent battery charge/discharge and load management; performance monitoring and energy generation data acquisition; control of automatic positioning systems; hybrid system management, and more. **Error! Reference source not found..Error! Reference source not found..** Data collection during the operation of photovoltaic installations is valuable for assessing the technology's potential and forecasting the performance of generation systems [3]. The integration of monitoring based on IoT technologies enables data visualization and remote control of key parameters without the need for direct human intervention. Consequently, the use of modern microcontroller-based devices allows for the optimization of photovoltaic system performance through precise real-time parameter monitoring and analysis, which contributes to more efficient energy utilization and timely detection of system anomalies.

II. LITERATURE REVIEW

An analysis of publications on the research topic indicates a growing interest in the use of devices that combine the control of photovoltaic panel operation with remote monitoring of system parameters.

In [4], the design and development of a device capable of monitoring photovoltaic panel parameters using IoT technology is described. The ESP32 microcontroller ensures the operation of measurement sensors and provides remote access to a web server for users. It is reported that, based on measurements taken over a 7-day period, the average daily power output was 140.2 VA, the panel temperature during the day reached 48.21 °C, and the illumination intensity was 31,380 lux.

Study [5] focuses on the design and development of a solar tracking system utilizing an ATMEGA-8L microcontroller, two servo motors, and a programmed algorithm for tracking solar light intensity to ensure the solar panel receives the maximum amount of sunlight. Following experimental investigations, the authors report a 19.73% increase in power generation compared to a fixed system. Despite the initial installation costs, it is stated that the development and implementation of such systems are both economically justified and environmentally responsible.

Publication [6] presents a monitoring system for photovoltaic stations using Internet of Things (IoT) technology. The authors propose monitoring parameters including photovoltaic cell temperature to assess efficiency and detect module overheating, as well as meteorological data such as ambient temperature, humidity, and wind speed. The developed interface allows for online monitoring of these values and real-time detection of photovoltaic module faults.

III. DEVELOPMENT OF HARDWARE AND SOFTWARE DESIGN

The key component of the system architecture, which forms the basis of the entire operation, is the ESP32 microcontroller. It controls the servo motors, ensures data collection from sensors, and implements control and online monitoring through a wireless network. During the development of the system, designed to enable solar panel orientation following the Sun's movement, special attention was paid to the choice of the tracking algorithm. Unlike simple photodetector-based systems, this work employs a precise solar position calculation algorithm described in [7],[8], which allows for highly efficient control of the azimuth and elevation angles (Fig. 1) to properly orient the panel. Additionally, the tracker is equipped with an LCD display, enabling system control and facilitating experimental studies under field conditions.

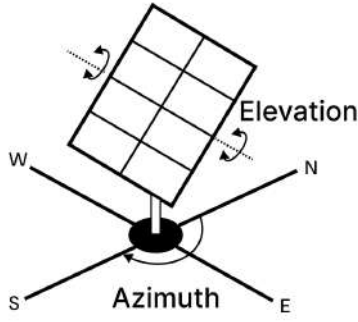


Fig. 1. Illustration of azimuth and elevation angles

Another important task successfully addressed within this development is the automation of experimental data collection from installed sensors. The implemented software enables efficient resolution of this challenge and allows flexible setting of the data recording interval with the required granularity according to the research conditions. The developed system (Fig. 2) operates fully automatically, permitting all necessary configurations to be set at the beginning of measurements and, thanks to autonomous power supply, enabling the conduction of experiments without additional interventions or continuous supervision. Efficient use of the energy generated by a photovoltaic panel is only possible when it operates at its maximum power point the mode in which it delivers the highest amount of electrical power. To achieve this, the electrical circuit incorporates an MPPT controller capable of functioning even at very low power levels, down to a few tens of milliwatts. This allows it to accurately determine the optimal load and ensure stable operation even for low-power solar panels.

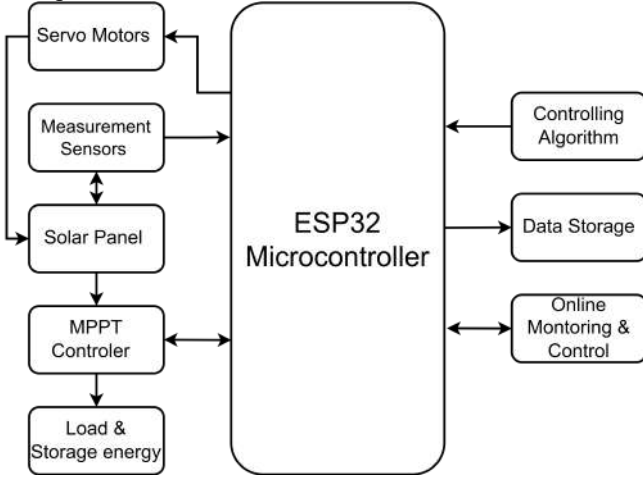


Fig. 2. Block diagram of the developed system

Thus, the proposed system combines high-precision orientation, automated data collection, and efficient energy utilization, making it suitable both for research purposes and practical use in autonomous solar installations.

IV. RESULT AND DISCUSSION

The experiments conducted to evaluate the effectiveness of the proposed system were carried out in the afternoon of June 20, on a day with variable cloudiness, during the period

from 13:58 to 17:58. For an objective assessment of the results, two polycrystalline panels measuring 165×165 mm with identical characteristics were placed side by side: one panel was fixed on a stationary structure, while the other was mounted on a tracker with position updates of the angles every 10 minutes. The output parameters of the panels power (Fig. 3) and the insolation level reaching the panel surface (Fig. 4) were automatically recorded by sensors and saved to an SD card in a fully autonomous mode without external intervention.

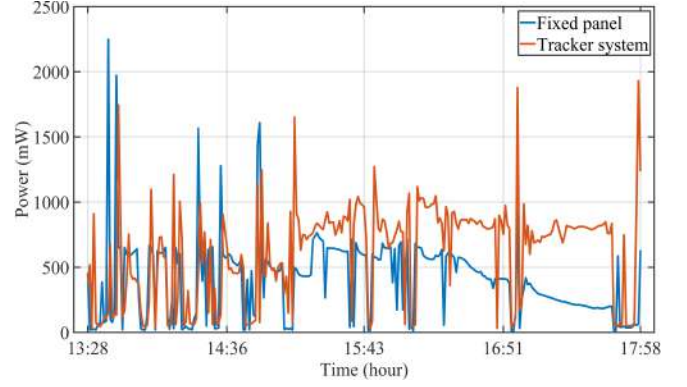


Fig. 3. Experimental values of generated power

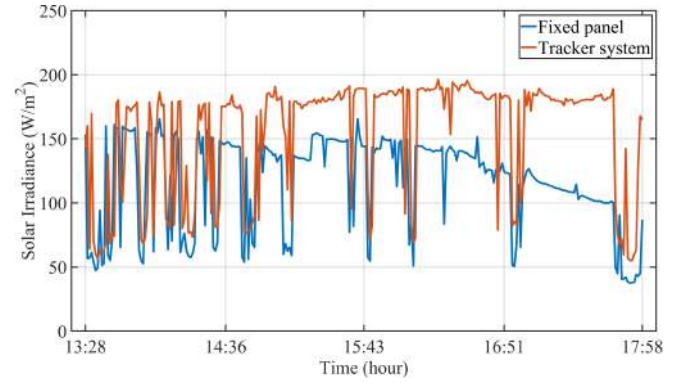


Fig. 4. Experimental values of panel surface irradiance

The efficiency calculations, performed according to formulas (1) and (2), demonstrate a significant increase in energy conversion efficiency, clearly highlighting the critical role of the photovoltaic cell's tilt angle relative to the direction of incoming solar radiation. These results confirm that even slight deviations from the optimal angle can noticeably impact the overall system performance.

$$\Delta W = \frac{\sum W_{\text{tracker}} - \sum W_{\text{fixed}}}{\sum W_{\text{fixed}}} \cdot 100\% \quad (1)$$

$$\Delta E = \frac{\sum E_{\text{tracker}} - \sum E_{\text{fixed}}}{\sum E_{\text{fixed}}} \cdot 100\% \quad (2)$$

Based on the obtained experimental data, an increase in generated energy of 52% was recorded, which represents a significant improvement in efficiency. The illumination data, recorded by the lux meter throughout the entire measurement period, indicate a 32.9% increase in solar insolation received by the panel surface compared to the fixed panel.

The obtained result confirmed the initial hypothesis, and the measured values fall within the range reported by other researchers [9],[10].

V. CONCLUSION

The application of the ESP32 microcontroller is proposed to address the current challenge of improving the efficiency of photovoltaic converters by optimizing the tilt angle relative to solar radiation. A key advantage of the implemented concept is the simultaneous control of the tracker operation and monitoring of photovoltaic cell parameters using a single microcontroller. This integration reduces system complexity, lowers implementation costs, and enables more compact and autonomous solar energy solutions.

The efficiency evaluation results of this system demonstrated a 52% increase in energy generation, which is significant and, in the long term, will ensure the payback of the system's cost through increased energy.

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