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Solar-IQ: An IoT Based Smart Solar Monitoring and Intelligence System

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Abstract: With the growing need for energy that is renewable, solar power has become increasingly important as a source of energy. The efficiency of solar panels can be hampered by elements such as dust, fluctuating temperatures, improper maintenance, and inadequate monitoring. In order to address the aforementioned problems, the present project will provide a system referred to as Solar-IQ: Smart Solar Intelligence System which is based on Internet-of-things (IoT).

The system is intended to monitor different factors concerning the solar panels' efficiency such as voltage, current, temperature, light intensity, and generation of power. The data will be captured, analyzed using the microcontrollers, and then sent to the monitoring platform from where it will be evaluated and visualization will be done. Alerts will be issued concerning abnormal performances and maintenance needs.

Apart from the alert function, the system will assist in energy production monitoring and system efficiency evaluation via a straightforward user interface. The monitoring will help in minimizing power loss as well as extending the lifespan of the solar panels.

The Solar-IQ system is an economical and efficient approach to managing solar energy smartly. The system can be applied in households, industrial applications, and commercial solar power projects. This research illustrates the ability to improve renewable energy systems through the integration of IoT and smart monitoring methods.

Keywords: Solar Power, Internet of Things (IoT), Smart Monitoring, Renewable Energy, Energy Efficiency, Predictive Maintenance.

I. INTRODUCTION

The fast-growing demand for energy coupled with the exhaustion of traditional sources has highlighted the need for renewable sources of energy. Among various renewable sources of energy, solar energy is one of the most popular choices because it is not only sustainable but is also environmentally friendly. The problem is that the efficiency of solar cells can be significantly compromised owing to issues such as dust, weather changes, and temperature fluctuations.

Traditional solar energy systems do not possess any means of efficient monitoring or maintenance. In order to solve the above-discussed issues, it is becoming necessary to use smart monitoring solutions that rely on the Internet of Things (IoT) technology.

The Solar-IQ: Smart Solar Intelligence System aims to present a solution that would allow for efficient monitoring and enhancing of solar panel operations. Various sensors can be used to acquire vital information about the operational parameters such as voltage, current, temperature, and illumination. The gathered data can then be analyzed by the microcontroller to identify any fault, measure efficiency, and schedule maintenance procedures.

The primary purpose of developing this technology is to increase the efficiency, sustainability, and longevity of solar panels through smart monitoring and analysis of data.

II. OBJECTIVES OF THE PROJECT

The primary objectives of Solar-IQ: Smart Solar Intelligence System are as follows:

1. Monitoring solar panel performance through the measurement of voltage, current, temperature, and power output.

2. Enhancing the efficiency of solar energy production by detecting problems with dust or other performance-related abnormalities.
3. Monitoring the performance of solar panels via IoT-based sensors, which transmit information about the panels' performance to the cloud for processing and analysis.
4. Offering maintenance alerts regarding cleaning, faults, and other issues that may affect the longevity of solar panels.
5. Designing a smart dashboard to display data on energy production in an easily comprehensible manner.
6. Reducing energy losses via monitoring and maintaining the solar panel system.

III. REVIEW OF SIGNIFICANT TECHNOLOGICAL ADVANCEMENTS IN LITERATURE

3.1 Cooling and Thermal Management

The thermal nature of operation influences PV modules since the higher the module’s temperature is, the lower its output voltage and overall performance becomes. However, typical ways of cooling include water-based, air-based, and hybrid PV/T cooling, all of which require additional equipment, energy expenditure, and maintenance, and thus become too costly in terms of installation and operation. As for the suggested automatic solar panel cleaning system, its indirect contribution is linked to the thermal aspect of its functioning since the accumulation of dust negatively impacts the even distribution of heat across panels and may lead to hot spots. Thus, by maintaining a clean surface and promoting equal heating, the system improves panel efficiency and reduces wear and tear. Moreover, the process of cleaning involves the use of water, which cools down the panels for a period of time without the need for extra energy.

3.2 Automatic Cleaning and Dust Elimination

Collection of dust significantly hinders the performance of solar panels especially in regions that are either polluted or dry, with energy yield losses of up to 30% – 50%. The design of this system employs automatic cleaning techniques with rotating brushes and controlled spraying of water to ensure thoroughness without causing damage to the surface of the panels. Servo motor systems control rotation and exert pressure on the surface of the panels. Diaphragm pump ensures efficient use of water by delivering water only when necessary. This is achieved by using a microcontroller that allows for controlled cleaning either periodically or when the need arises. Observation studies have revealed an increase of about 25% - 40% in the production of energy due to automatic cleaning.

3.3 Solar Panels Monitoring through IoT

For effective solar energy management, it is important to monitor the process constantly in order to improve performance and identify any flaws in the process. Despite being an automation model, the proposed system is capable of integrating itself with IoT in the future. With sensors that will include dust sensors, temperature sensors, and power/voltage monitors, real-time data will be captured. The data can then be uploaded into cloud systems for analysis. The user may be able to initiate cleaning sessions depending on the system status such as low energy production or dusty conditions. Through the IoT, it is possible to conduct early warning for faults such as motor and pumping system failure as well as faulty wiring connections.

3.4 Artificial Intelligence and Machine Learning

Artificial intelligence (AI) and machine learning (ML) enable more sophisticated approaches to maintaining and operating solar panels. In our suggested system, ML models will analyze historical and current data to determine ideal times for cleaning to be done rather than following a rigid schedule. This way, water and energy wastage will be minimized. Anomaly detection is one of the other areas where AI can help in detecting issues with the system. It will detect any unusual behavior within the system such as a sudden reduction in electricity production or poor performance by the actuators. Using AI technologies such as deep learning and time series analysis increases the accuracy of the system.

3.5 Perovskite Solar Cells and Other Advanced Solar Panel Materials

There have been numerous innovations within the realm of solar panel technology, with the most notable one being the development of high-performance solar panels made using materials like perovskite solar cells. These materials are advantageous in terms of cost-effectiveness and efficiency as opposed to their predecessors, silicon-based cells. Nevertheless, they remain highly susceptible to environmental influences such as dirt and water.

Hence, it is important to keep them clean and dry. The suggested automated cleaning method works efficiently for all sorts of solar panels, regardless of the material used, without damaging their surface.

IV. SYSTEM ARCHITECTURE

Solar-IQ: Smart Solar Intelligence System architecture comprises a solar panel, sensors, MCU, communication modules, and data monitoring interface. This system is designed for continuous monitoring of solar panel efficiency through the transfer of data for analysis and visualization purposes.

In the case of Solar-IQ: Smart Solar Intelligence System, the solar panel is used as the power source of the system. For measuring output current from the solar panel, the ACS721 current sensor is used, while for measuring the voltage of solar panels, the voltage sensor is used. Also, a temperature and humidity sensor is used for environmental condition monitoring.

In the proposed design, the ESP32 is used as an MCU, and all sensor signals received are processed using it. Then, the ESP32 sends the processed data to various output modules; these include TFT display used for real-time value display and LED indicators as output signals for easy status observation.
The ESP32 will use its internal Wi-Fi module to send the collected data to cloud services such as Google Sheets and Google Cloud for storage purposes. The stored data is subsequently used for analysis in order to determine the efficiency of the system. Data analysis can also be presented on a web dashboard.

This design will ensure real-time monitoring and remote access while also ensuring that the system becomes highly efficient.

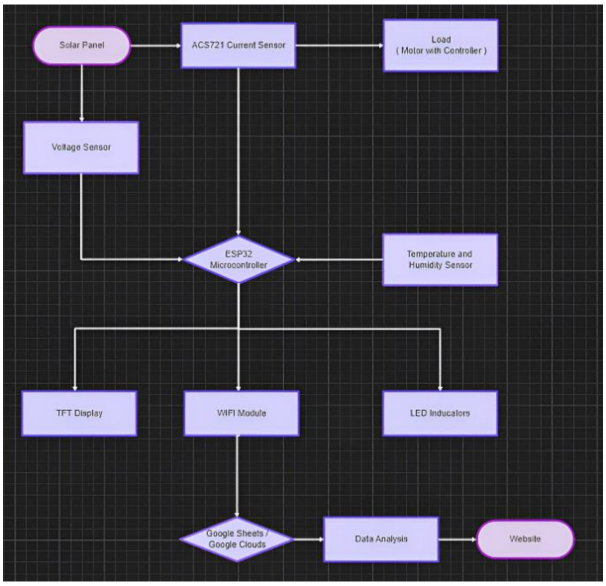

Fig.1 System Architecture of Solar-IQ Smart Solar Intelligence System

V. WORKING METHODOLOGY

In the suggested Solar-IQ: Smart Solar Intelligence System, it will be necessary to keep track of the solar power system's performance and send the obtained data to the cloud. Sensors, microcontroller, and IoT communication are incorporated to make sure that the process works effectively.

At first, the solar panel converts the sun's rays into electrical energy and powers the load. The electrical values are constantly monitored with the help of sensors. The current sensor ACS712 is connected to the load in series, so it can record the current value of the whole system. The voltage sensor is based on the voltage divider design and monitors the voltage of the solar panel through the ESP32 analog input pins.

The environmental parameters (temperature and humidity) should also be tracked, as they play an important role in solar panel performance. For this purpose, DHT11 sensors will be used. All the collected data such as voltage, current, temperature, and humidity will be analyzed by the ESP32 microcontroller.

Furthermore, the system determines the produced energy from the formula Power = Voltage x Current. The recorded parameters and power are shown on the TFT display. Moreover, the ESP32 utilizes the Wi-Fi feature to send the information to the cloud storage platforms such as Google Sheets.

In addition, the system detects any faults that may arise due to abnormal situations such as low voltage, overcurrent, or overheating of the equipment. In this regard, the LEDs give an indication of the status of the system. The recorded data is then used for performance evaluation and preventive maintenance of the solar panels.

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VI. HARDWARE AND SOFTWARE REQUIREMENTS

1. **Hardware Components:** Hardware components used for the Solar-IQ Smart Solar Intelligence System are:
    a. ESP32 Microcontroller: For the data processing and IoT communication purposes.
    b. ACS712 Current Sensor: To measure the current of solar panel.
    c. Voltage Sensor: To measure the output voltage of the solar panel.
    d. DHT11 Sensor: To measure temperature and humidity.
    e. ST7735 TFT Display: To display the system parameter in real-time.
    f. 12V Solar Panel: Source of energy.
    g. LED Indicators: Indicating the fault and status of the system.
2. **Software Requirements:**
    a. Software components required for the above mentioned smart system are:
    b. Arduino IDE: Programming the microprocessor ESP32.
    c. Embedded C/C++: Programming language for the development of system.
    d. Libraries: WiFi.h, HTTPClient.h, Adafruit_GFX, Adafruit_ST7735, and DHT library.
    e. Google Sheets/Cloud: For storing the data in cloud.
    f. Python: Data analysis programming language.

VII. IMPLEMENTATION

The designed Solar-IQ system was implemented through hardware integration of the sensors, processors, display screens, and internet connectivity components.

7.1 Module Implementation

The entire system comprises several modules, such as the sensing module, processor module, display module, and IoT module. All these modules are interconnected to form an integrated solar monitoring system.

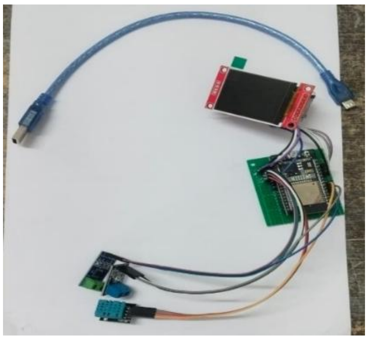

Figure.2 Hardware Implementation of the Solar Monitoring System

7.2 Sensing Module Implementation

The sensing module contains two sensors: the voltage sensor and the DHT11 sensor for measuring environmental conditions. This module captures the electrical characteristics and environmental factors of the solar system.

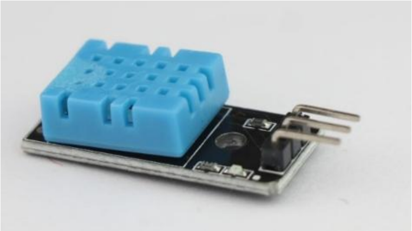

Figure.3 DHT11 Sensor for Measuring Environment Parameters

Figure.4 Voltage Sensor Module

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The voltage sensor is connected between the solar panel terminals to measure the output voltage. It drops the voltage value to an acceptable level that matches the ESP32 analog inputs. The DHT11 sensor is connected to the ESP32 digital pin to sense the temperature and humidity, which impact the performance of the solar panel.

7.3 Processing Module Implementation

The processing module is implemented using the ESP32 microcontroller, which is the main controller in the system.

Figure.5 ESP32 Control Unit That Performs Data Processing and Communication

The ESP32 collects and processes sensor data and prepares it for output display and sending. Data processing involves data transformation, calculation, and decision-making. The microcontroller makes sure that there is communication between all modules and manages the entire process.

7.4 Display Module Implementation

The display module displays the parameters that are monitored.

Figure.6 TFT Display Used to Display Output

ESP32 microcontroller is connected with the TFT display through SPI interface. Parameters like voltage, temperature, humidity, and power are displayed on the screen in real time. The display keeps changing with time to give immediate feedback to the user.

7.5 Hardware Integration

In this phase, all hardware parts are integrated together. All components are soldered on a PCB/perfboard to facilitate better connections. Connections are done carefully to reduce noise and possible wiring errors. The system is encased in a box to protect it from any form of physical damage.

7.6 System Testing

The Solar-IQ system underwent testing to determine whether it operates properly. Various tests were conducted on the system to assess its functionality. The sensors gave precise measurements, while the display accurately displayed the data in real-time. Additionally, the system correctly identified any irregularities in its operation, including low voltage, when the solar panel is disconnected.

VIII. PROPOSED ALGORITHM

Step 1: Initiate the program.
Step 2: Begin initialization of the ESP32 microcontroller.

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Step 3: Begin initialization of all sensors, including the ACS712 current sensor and DHT11 temperature and humidity sensor.
Step 4: Begin initialization of the TFT screen for data display purposes.
Step 5: Connect to Wi-Fi to establish an IoT connection.
Step 6: Gather voltage sensor data, and then translate the ADC values into voltages.
Step 7: Gather current sensor data, and then translate the ADC values into currents.
Step 8: Gather data from the DHT11 temperature and humidity sensor.
Step 9: Calculate power generation using the equation below:
        $Power = Voltage \times Current$
Step 10: Determine system state:
        If the voltage is lower than the threshold, return Low Voltage.
        If the current is higher than the threshold, return High Current.
        If the temperature is higher than the threshold, return Overheating.
        Otherwise, return Normal Operation.
Step 11: Display all data readings on the TFT screen.
Step 12: Send all data readings to Google Sheets via Wi-Fi using an HTTP request.
Step 13: Pause for a pre-defined sampling period.
Step 14: Repeat steps 1 to 13.
Step 15: Terminate the program.
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IX. RESULTS

The implementation and testing of the Solar-IQ: Smart Solar Intelligence System was completed successfully. The system was able to monitor the parameters of solar panels including voltage, current, temperature, and humidity in real-time mode. The ESP32 microcontroller efficiently acquired sensor data and displayed them on the TFT display.

In addition, the system effectively transferred acquired data to Google Sheets via Wi-Fi, allowing remote monitoring. The system correctly displayed the generated power depending on measured voltage and current values.

As shown during testing, the system could identify unusual events like low voltage and high temperatures. LED lights accurately displayed the status of the system. Moreover, environmental data obtained from the DHT11 sensor assisted in evaluating the effect of temperature on the performance of solar panels.

The findings indicate that the developed system is accurate, reliable, and appropriate for monitoring solar panels in real-time mode. The incorporation of IoT technology enhanced remote monitoring and data recording.

X. ADVANTAGES

1. Real-Time Monitoring: The system enables real-time monitoring of the parameters of the solar panels, including voltage, current, temperature, and power.
2. Remote Monitoring: With IoT integration, users can monitor the performance of the solar panels from any remote location using cloud-based services.
3. Increased Efficiency: Through continuous monitoring, it is possible to improve the efficiency of the solar panels.
4. Affordable System: The system makes use of inexpensive hardware such as the ESP32 microcontroller board and sensors.
5. Fault Detection: The system is capable of detecting faults, including low voltage, overheating, and excessive current.
6. Preventive Maintenance: The system facilitates the maintenance of the solar panels by giving alerts.
7. Ease of Use: The TFT display ensures user-frindly interface.

XI. LIMITATIONS

1. Voltage Measurement Range is Limited: The circuitry of the system based on a voltage divider limits the voltage measurement range to 20V only. The high-capacity solar cells cannot be monitored using this approach.
2. Accuracy Limits of Current Sensors: The ACS712 current sensor (version for 30A) has low accuracy when measuring minor currents. As a result, accurate power calculation cannot be performed.

3. Measurement Limitation of Environmental Sensors: The sensor DHT11 cannot provide precise measurements, since its measurement range is much narrower than that provided by sensors like DHT22.
4. Connection through Wi-Fi Required: The functioning of IoT depends on the Wi-Fi connection. If the Wi-Fi connection fails, the process of data transfer will stop working.
5. Energy Storage Not Monitored: The current model of the system lacks the ability to monitor batteries' characteristics, including charging state, voltage, or performance.

XII. FUTURE SCOPE

1. MPPT Incorporation: To enhance the efficiency of the solar panels.
2. Battery Level Monitoring: To monitor the voltage levels and charge level of batteries.
3. Mobile Application: For remote monitoring purposes.
4. High-Quality Sensors: For precise measurements.
5. Smart Grid System: For effective energy management.

XIII. APPLICATIONS

1. Residential Solar Systems: Can be used for monitoring solar panels in residential buildings.
2. Commercial Solar Systems: Applications in industries and office spaces for tracking performance.
3. Solar Power Plants: Real-time monitoring of solar power plant performance.
4. Intelligent Energy Management Systems: Renewable energy management systems.
5. Research and Education Projects: Can be used for educational purposes to understand IoT-based solar energy monitoring.

XIV. CONCLUSION

The Solar-IQ: Smart Solar Intelligence System has been successfully designed and implemented. This system has been capable of measuring important parameters such as voltage, current, power generation, and temperature. The application of the Internet of Things (IoT) made remote monitoring and recording of data possible.

This project clearly shows the efficiency and effectiveness of intelligent solar panels. This project proves that with the help of smart monitoring and IoT, a lot of problems that come with solar energy systems can be resolved. The results show that the system is affordable and user-friendly.

In conclusion, this project proves the importance of smart monitoring when dealing with renewable energy systems.

REFERENCES

[1]. R. Parthiban and P. Ponnambalam, “An enhancement of the solar panel efficiency: A comprehensive review,” *Frontiers in Energy Research*, vol. 10, Art. no. 937155, 2022.

[2]. W. Charfi, M. Chaabane, H. Mhiri, and P. Bournot, “Performance evaluation of a solar photovoltaic system,” *Energy Reports*, vol. 4, pp. 400–406, 2018.

[3]. D. Kumari, N. Jaiswal, D. Punetha, S. K. Mourya, and S. K. Pandey, “$CsGeI_3$ perovskite-based solar cells for higher efficiency and stability: An experimental investigation,” *IEEE Journal of Photovoltaics*, 2025.

[4]. R. Khan *et al.*, “Device modeling and performance enhancement of ecologically viable $CsGeI_3$-based perovskite solar cells: A detailed investigation of charge transport layer technology,” *Nano Select*, 2025.

[5]. C. Taruna, L. Halim, and B. M. Arthaya, “Initial concept for increasing polycrystalline fixed solar panel efficiency with water treatments,” in *Proc. Int. Conf. Mechatronics, Robotics and Systems Engineering (MoRSE)*, 2019, pp. 180–185.

[6]. H. Mote *et al.*, “Automatic solar panel cleaning system,” *Journal of Automation and Automobile Engineering*, vol. 10, no. 1, pp. 38–46, 2025.

[7]. M. Baiceanu, T. Catalina, and A. Damian, “Experimental and simulation performance investigation of a hybrid PV/T solar panel,” in *Proc. 7th Int. Conf. Energy Efficiency and Agricultural Engineering (EE&AE)*, 2020, pp. 1–5.

DOI: 10.17148/IJARCCE.2026.15429

[8]. B. Sreewirote, A. Noppakant, and C. Pothisarn, “Increasing efficiency of an electricity production system from solar energy with a method of reducing solar panel temperature,” in *Proc. IEEE Int. Conf. Applied System Innovation (ICASI)*, 2017, pp. 1308–1311.

[9]. M. A. A. Mamun, M. M. Islam, M. Hasanuzzaman, and J. Selvaraj, “Effect of tilt angle on the performance and electrical parameters of a PV module,” *Energy and Built Environment*, vol. 3, pp. 278–290, 2022.