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Smart Solar Plant Optimization Using MPPT Controller and IoT Alert System

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Abstract: This paper presents a smart solar monitoring and predictive maintenance system that improves the efficiency and reliability of photovoltaic systems using IoT and sensor integration with an MPPT charge controller. The system is based on an Atmega328 microcontroller and uses sensors to measure voltage, current, sunlight intensity, dust levels, and vibrations. Real-time data is transmitted through an ESP8266 Wi-Fi module to the ThingSpeak cloud for remote analysis. By comparing actual power output with expected values, the system detects performance issues such as shading, dust accumulation, or faults. It also predicts cleaning needs and identifies potential physical damage or disturbances. The system is powered by a solar PV panel integrated with and Maximum Power Point Tracking (MPPT)-based charge controller and battery backup to ensure reliable and uninterrupted operation. The implemented MPPT controller continuously tracks the maximum power point of the solar panel to maximize energy extraction and improve charging efficiency. The proposed solution minimizes manual maintenance requirements while providing an efficient, economical, and scalable approach for intelligent solar energy management.

Keywords: Solar Panel Monitoring, IoT-based System, Predictive Maintenance, ThingSpeak Cloud, MPPT Charge Controller, Renewable Energy, Real-time Data, and Remote Monitoring.

I. INTRODUCTION

Solar energy is widely considered one of the most promising renewable energy sources worldwide, with strong potential to replace carbon-intensive power generation methods [1],[2]. According to recent statements by the IEA, renewable energy has transitioned from a niche option to a mainstream energy source, with solar and wind leading the renewable energy market.

The performance of solar panels is influenced by several factors, some of which enhance power output while others reduce it [1]–[5]. Among these, solar irradiance plays a crucial role, as the electrical energy generated is directly related to the intensity of incident sunlight [5]–[7]. Dust accumulation is another critical factor, as particles deposited on the panel surface block sunlight and reduce the amount of radiation reaching the photovoltaic cells [6]. Additionally, higher panel temperatures lead to a decrease in output power, while ambient humidity also negatively impacts performance. Given the high investment cost of solar energy systems, maintaining maximum efficiency is essential.

This paper presents implementation of MPPT controller and an automated solution using sensor-based monitoring to ensure optimal operation of solar installations and to identify maintenance requirements. IoT technology is employed for real-time data visualization and alert generation. and, an MPPT solar charge controller is integrated to enhance overall system efficiency alongside the IoT-based monitoring system.

II. OBJECTIVES

The objective of this paper is to develop an IoT-enabled solar panel monitoring and predictive maintenance system integrated with an MPPT-based solar charge controller for improved energy efficiency and system reliability.

Objectives:

To implement an MPPT charge controller for extracting maximum available power from solar photovoltaic panels.

To measure and monitor voltage, current, and power generation of each solar panel.

To identify low-efficiency panels and generate maintenance alerts.

To predict panel cleaning requirements using dust sensor data.

To measure solar irradiance and estimate daily energy generation.

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To detect panel vibrations or movement indicating damage or theft.
To display and store system data and alerts on the ThingSpeak platform.

III. PROPOSED SYSTEM

The proposed system is composed of the following key modules:

- Solar photovoltaic panel (10W)
- MPPT-based charge controller
- ATmega328 microcontroller unit
- ESP8266 Wi-Fi communication module
- Sensors for voltage, current, dust, light intensity (LDR), and vibration detection
- 12V lead-acid storage battery
- LCD display and buzzer for indication and alerts

A. Working Principle

The system continuously acquires sensor data and processes it through the ATmega328 microcontroller. The generated output power is determined using:

$$P = V \times I$$

where V represents voltage and I represents current.
The calculated power is analyzed against the expected performance to identify any reduction in efficiency. The ESP8266 sends the monitored data to the ThingSpeak cloud platform, enabling remote supervision and analysis of the solar PV system.
Fig.1 illustrates the block diagram of the proposed model. The system integrates IoT technology for real-time monitoring of various physical parameters, while the MPPT charge controller is employed to enhance solar power extraction and improve overall energy conversion efficiency.

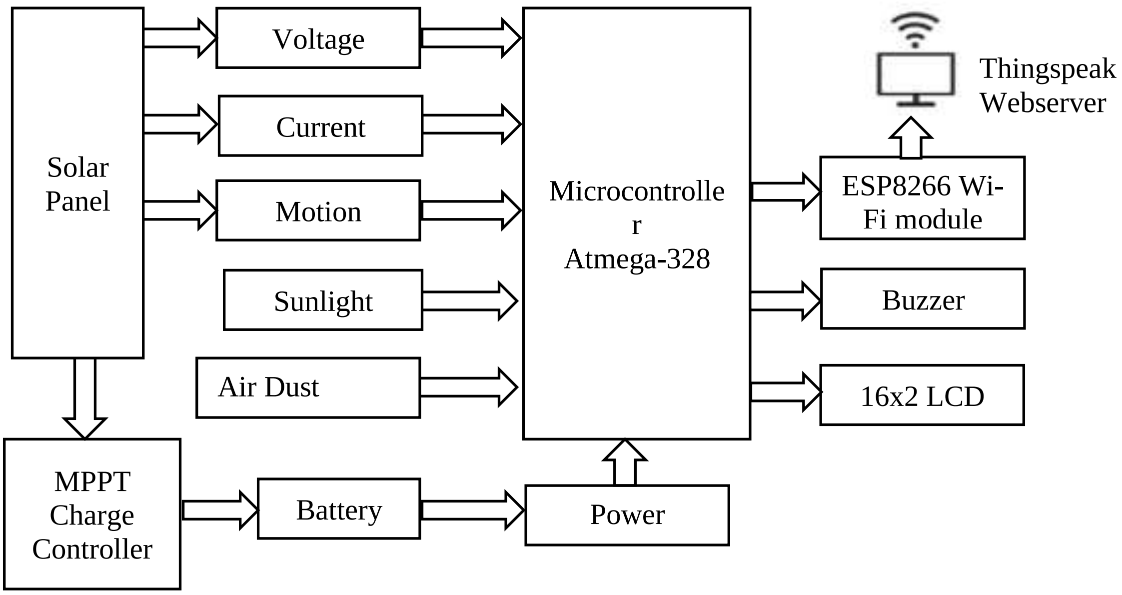

Fig.1 System Block Diagram

The proposed system operates through continuous sensing, data processing, and IoT-based communication for automated monitoring and maintenance of the solar PV system. Both hardware and software modules work together to provide efficient performance analysis and fault detection.

1. Power Monitoring

The ATmega328 microcontroller acts as the central processing unit of the system. Voltage and current sensors continuously measure the electrical output of the solar panel. The generated power is calculated using:

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$$P = V \times I$$

The measured power is compared with the expected output of the panel. If the generated power drops below the normal operating range, the system identifies the panel as inefficient and indicates the requirement for maintenance or inspection.

2. Dust and Sunlight Monitoring

A dust sensor is used to monitor the level of dust particles around the panel environment. Higher dust accumulation can reduce panel efficiency over time; therefore, the collected data is utilized to estimate suitable cleaning intervals. An LDR-based light sensor measures sunlight intensity to estimate the expected daily energy production. If the actual power output is lower than the estimated value under adequate sunlight conditions, the system may indicate dirt accumulation or electrical faults.

3. Vibration and Security Monitoring

A vibration sensor is attached to the panel structure to detect unusual movement or shocks. Such disturbances may occur due to strong wind, physical damage, or unauthorized handling of the panel. When abnormal vibrations are detected, the system generates an alert, thereby also supporting theft prevention.

4. IoT-Based Data Communication

The ESP8266 Wi-Fi module transfers all monitored sensor data to the ThingSpeak cloud server. Users can remotely access real-time system parameters, maintenance notifications, power trends, dust conditions, and vibration alerts through a web interface.

5. Power Supply and Energy Management

The monitoring system is powered using a 10W solar PV panel connected to a 12V sealed lead-acid battery. An MPPT-based charge controller is implemented to improve energy extraction from the solar panel and provide efficient battery charging. This ensures continuous operation of the system even during low irradiance conditions.

6. Local Display and Alerts

A 16×2 LCD module displays important parameters such as voltage, current, power, and light intensity for on-site monitoring. Alert indications can also be provided through a buzzer for immediate attention.

7. MPPT Charge Controller

The MPPT charge controller continuously tracks the maximum power point of the solar panel to achieve efficient energy conversion. It enhances power utilization, improves voltage regulation, increases charging efficiency, and maximizes energy harvesting from the PV system.

Overall System Function

The proposed model combines IoT-based sensing and MPPT technology to achieve intelligent solar panel monitoring and efficient power management. The system supports real-time supervision, predictive maintenance, fault identification, and improved energy utilization through continuous data analysis.

B. Design Of MPPT Charge Controller

TABLE I : SYSTEM SPECIFICATIONS

Parameter	Value
Solar Panel Power	10W
Solar Panel Voltage (Vmp)	18V
Solar Panel Current (Imp)	0.85A
Battery Voltage	12V
Battery Capacity	1.3Ah
Load Resistance	70Ω (for testing)
Microcontroller	ATmega (Arduino UNO/Nano)
PWM Pin	Digital Pin 9
PWM Frequency	~490Hz

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The proposed work focuses on the design and implementation of an MPPT charge controller for charging a 12V, 1.3Ah sealed lead-acid (SLA) battery using a 10W, 12V solar photovoltaic panel. The system is developed using a buck converter configuration comprising a power MOSFET, inductor, diode, and PWM-based control through a microcontroller to achieve efficient power conversion and regulated battery charging. The controller is designed to maximize energy extraction from the solar panel while improving charging efficiency and overall system performance. The design and implementation are carried out based on the following system specifications.

C. MPPT Algorithm

The proposed system is developed using a buck converter for efficient power conversion and battery charging. An IRFP250 MOSFET is employed as the main switching device to regulate power flow. The switching operation is controlled through a PWM signal generated by the microcontroller.

The MPPT charge controller operates using the Perturb and Observe (P&O) algorithm, which continuously tracks the maximum power point of the solar panel. The operating procedure of the algorithm is as follows:

1. The solar panel voltage and current are continuously measured.
2. Output power is calculated using:

$$P = V \times I$$

3. The PWM duty cycle is slightly adjusted.
4. If the output power increases after the adjustment, the controller continues changing the duty cycle in the same direction.
5. If the output power decreases, the direction of duty cycle variation is reversed.

D. MPPT Implementation

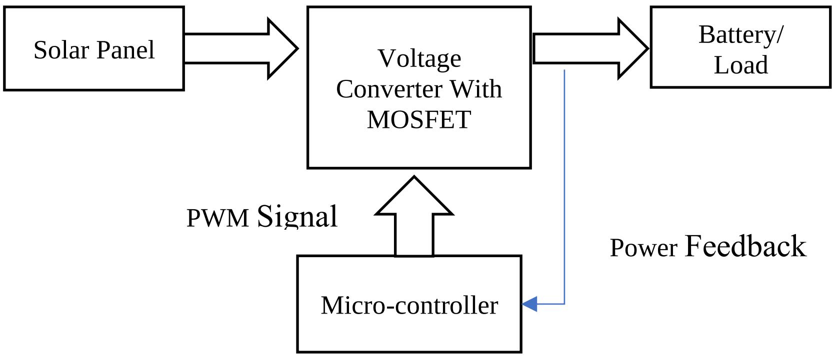

Fig. 2. MPPT Block Diagram

1. MOSFET: IRFP250
   - V_DS: 200V
   - I_D: 30A
   - Low R_DS(on): ~0.085Ω
2. Inductor: 20mH
   - Buck Converter Inductance Calculation:
     L =((V_in - V_out)/ΔI_L)× (D/f)
     V_in = 18V, V_out = 12V, ΔI_L ≈ 0.3A, f = 100Hz considered, D=0.66
     So, L= ((18-12)/0.3)x(0.66/100)
     L = 0.0132H
   - Chosen: 20mH for better ripple reduction
3. Diode: 10BQ015 (Schottky)
   - Voltage Rating: 15V
   - Current: 1A
   - Low Forward Drop: ~0.4V
4. Capacitors
   - Input: 220µF
   - Output: 470µF
5. Microcontroller to generate PWM
   - Uses ATmega PWM on Pin 9

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- analogWrite() function
- ~100 Hz PWM frequency

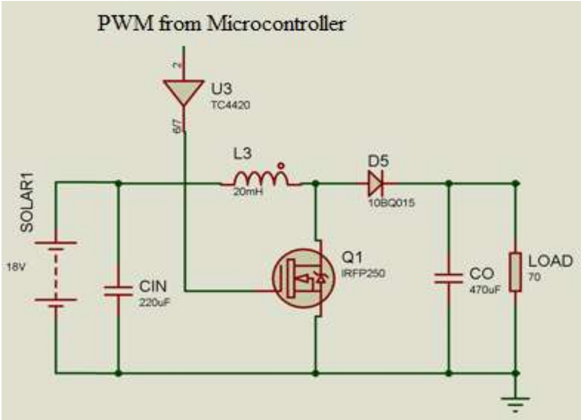

Fig. 3: MPPT Charge Controller

IV. HARDWARE IMPLEMENTATION

Fig.4: Hardware Implementation

V. RESULTS

In figure 3, display showing the process to upload data on webpage, whereas result of webpage is shown in fig. 5(a). In that calculated values from microcontroller are shown in numeric display whereas alert status are shown in lamp indicator form. When the motion detected, lamp indicator of motion alert field will turn on. This can be seen in fig.5(b).When the motion detected, lamp indicator of motion alert field will turn on.

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Fig.5: a)Webpage results before fault occurs and b) Webpage results after fault or accident occurs

TABLE II: POWER TRACKING ANALYSIS OF MPPT

Condition	V_in (V)	I_in (A)	P_in (W)	V_batt (V)	I_batt (A)	Efficiency (%)
Initial (No Load)	18	0.1	1.8	12	0	-
Mid Tracking	17.2	0.7	12.0	11.8	0.85	83.6
Full Load (Battery + 70Ω)	17	0.85	14.45	12	1.0	~83%

TABLE IIII: SYSTEM RESULTS

Parameter	Expected Range	Observed Range
Voltage (from panel)	12V – 18V	11.8V – 19V
Current (with load)	0.3A – 0.85A	0.4A – 0.87A
Power Output	3.6W – 10W	2.3W – 12W
Dust Level (clean air)	< 0.15 mg/m³	0.08 – 0.12 mg/m³
Dust Level (dusty air)	> 0.25 mg/m³	0.28 – 0.35 mg/m³
Light Intensity	2000 – 4000 lux	0 – 4500 lux
Vibration Detection Time	< 1 second	0.8 seconds
Data Upload Interval	Every 15 seconds	Every 15 Sec

VI. CONCLUSION

We believe that this system will be helpful for increasing the efficiency and maintenance alert for solar power plants. This will ultimately reduce the troubleshooting time and manpower needed for maintenance work. Also with the features of energy generation prediction and cleaning time prediction, it will be easy to manage things. Due to use of IOT, a remote monitoring is possible.
By considering all the situations and possibility, we decided the objectives for system and chosen components which are helping to achieve the desire target. Though, design of circuit is critical due to non-availability of some of module in

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Protius software. Whereas due to the use of Arduino development tools, reduce difficulties during programming & troubleshooting was reduced.

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