Adaptive Solar Tracking & Smart Energy Management System for E.V

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Abstract: The rise of electric vehicles (EVs) and a need to implement sustainable energy solutions into transport increasing the connection between renewable energy systems. This paper aims to design and implement of an adaptive dual - axis solar tracking system integrated with smart energy management system for EV applications. This system is aimed to increase the generation of solar energy by adjusting photovoltaic panels dynamic towards the sun's direction during daytime. Microcontroller based control mechanism using light dependent resistance (LDR) is applied for real-time tracking using DC motors and servo motors. This energy is stored in a lithium-ion battery and intelligently managed through the charging module. Furthermore, a real-time monitoring and safety system is included for reliability and fault detection. This showed a significantly higher energy efficiency than traditional solar panels. This solution is cost effective and environmental friendly as the dependency on conventional charging infrastructure is decreasing

Keywords: Electric Vehicles, Solar Tracking System, Internet of Things (IoT), ESP32 Microcontroller, Renewable Energy, Smart Energy Management

INTRODUCTION

Concerns about environmental pollution and depletion of fossil fuels have made the renewable energy sources more popular. Solar energy is one of the most abundant and environmentally clean renewable energies, therefore it is an important part of sustainable energy solutions [1]. Nevertheless, conventional solar panels are typically static in position and therefore incapable of receiving the maximum solar radiation during the entire day [5].

In order to overcome this problem, solar tracking systems have been developed to adjust the position of solar panels according to the position of the sun. Among different types of solar tracking systems, dual-axis systems have shown better results compared to others due to their ability to track both horizontal and vertical movements of the sun.

On the other hand, the usage of electric vehicles is gaining momentum globally. Nevertheless, factors such as battery power and charging stations are still a hindrance [2]. The incorporation of solar trackers and EVs can enhance energy efficiency and extend the range of the battery [9].

The proposed system provides a practical and cost-effective approach for implementing adaptive solar tracking with real-time email-based monitoring for electric vehicle applications, which is not common in most existing systems.

PROBLEM STATEMENT

However, several challenges persist in the electric vehicle field despite the improvement in the technology:

Low driving range due to the batteries [2] Inadequate charging infrastructure [2] Inefficient use of renewable energy sources [9]
Low efficiency of fixed solar panels [5]
Solar panels cannot maintain optimal angles to face the sun; hence, the energy produced from the panels is less than the maximum possible [5]. Although the use of solar tracking systems can improve the efficiency of solar panels, the existing systems have low response times, inaccurate sensors, and inefficient control mechanisms [8]. In addition,

the majority of the electric vehicle systems do not have an integrated approach to harness solar energy and efficiently manage the energy for electric vehicle applications [9], [10].

OBJECTIVE

The main objectives of this research are as follows:

1. To develop a dual-axis solar tracking system to harness maximum solar energy [12]
2. To enhance the energy efficiency of the proposed system compared to traditional solar panel systems [13]
3. To develop a microcontroller-based intelligent tracking system [14]
4. To develop an efficient battery storage system [15]
5. To design a smart energy management and charging system [16]
6. To minimize the dependence on traditional charging systems [17]
7. To improve the performance of the EV [18]
8. To test the performance of the proposed system under real-time conditions [19]

LITERATURE REVIEW

It can be noted that the performance of solar energy systems is mainly affected by the solar radiation captured by the photovoltaic panels. It is observed that fixed solar panels are not efficient in utilizing the solar energy effectively due to their fixed position. Although the design of fixed solar panels is simple, their performance is limited by their inability to change their position according to the solar direction [5].

Different researchers have also proposed various solar tracking systems for the improvement of the performance of solar energy systems. In their study, Mousazadeh et al. compared various solar tracking systems and observed that the use of dynamic solar tracking systems can improve the performance of solar energy systems by utilizing the solar energy effectively. Similarly, Rizk and Chaiko observed the performance improvement by adjusting the solar panels according to the solar direction. It is observed from various comparative studies that the performance of dual-axis solar tracking systems is better than other solar tracking systems. In their study, Seme et al. observed that the dual-axis system can change the horizontal and vertical angles for the effective utilization of solar energy.

Although considerable progress has been made in the development of solar tracking as well as energy management systems, these advancements are mostly in isolation, without a comprehensive solution that can combine these two technologies in an efficient way. Most of the existing research works are based on improving the efficiency of solar tracking or battery performance in isolation. Therefore, a comprehensive solution that can efficiently enhance solar energy harvesting as well as energy management for electric vehicle performance is still a requirement. This research seeks to fill the existing gap in the literature by proposing a comprehensive solution that can efficiently combine solar tracking with energy management.

METHODOLOGY

The proposed system is based on an integrated system of adaptive dual-axis solar tracking and a smart energy management system, suitable for electric vehicle systems. The main idea behind this system is to maximize solar energy harvesting and utilize it efficiently for electric vehicle battery management.

The system is composed of six major parts, which are discussed below:

1. Solar Energy Generation Unit

2. Dual-Axis Solar Tracking Mechanism
3. Battery Storage System
4. Smart Charging System
5. Real time Monitoring System
6. Safety and Alerts System

1. Solar Energy Generation Unit:

The Solar Energy Generation Unit is the main source of power for the proposed system. The main function of this unit is to convert solar energy into electrical energy, regulate it, and supply it for storage and usage in electric vehicle system.

The conversion of solar energy into electrical energy takes place in the following manner. First, it is done using a PV panel, which is composed of many solar cells, usually made of semiconductor materials like silicon. The working of a PV panel is based on the photovoltaic effect, which converts incident solar radiation into direct current electrical energy.

In the proposed system, the PV panel is connected with a dual-axis tracking system, which keeps it at a right angle during the day. This increases the efficiency of the system, as maximum solar radiation is harvested during this period. Fig.1 indicates that the solar energy is converted into electrical energy, which is sent for power conditioning. This is done using a charge controller or voltage regulator, which maintains a constant voltage level. This component is very important, as it helps in preventing voltage levels from going too high.

Fig. 1: Solar panel

The generated electrical energy is channeled to the energy collection system where the energy is accumulated for storage. This step is aimed at ensuring that the energy is not dissipated and is efficiently channeled to the storage system.

The last step in this system is the storage of the energy. The DC power is channeled to a rechargeable lithium-ion battery for storage. This kind of battery is chosen for this system due to its high energy density and charging capabilities. The energy storage system acts as a reservoir for the energy generated in the system during the peak hours of the sun's availability.

The efficiency of the Solar Energy Generation Unit is boosted by the integration of solar tracking, appropriate voltage regulation, and energy storage mechanisms. This system is aimed at providing a constant source of power for electric vehicles without relying on other sources for charging.

2. Dual Axis Solar Tracking Mechanism

Dual Axis Solar Tracking Mechanism: This is another important component of the proposed system, which can help in maximizing solar energy production by keeping the solar panel in alignment with the direction of the sun's rays. Unlike other solar panels, which are fixed in a particular direction, this system can change the direction of the solar panel in horizontal as well as vertical directions.[7]

The main aim of this solar panel tracker system is to keep the solar panel perpendicular to the direction of sunlight rays at all times of the day. This can help in maximizing the amount of sunlight absorbed by the solar panel, thereby maximizing the efficiency of the solar panel.

The proposed system consists of four Light Dependent Resistors, Arduino Uno, and two servo motors.

2.1 Working Principle:

When sunlight hits the solar panel unevenly on the LDRs, a difference in resistance occurs due to the difference in light intensity. These analog signals are then sent to the Arduino Uno, which continuously compares these signals.

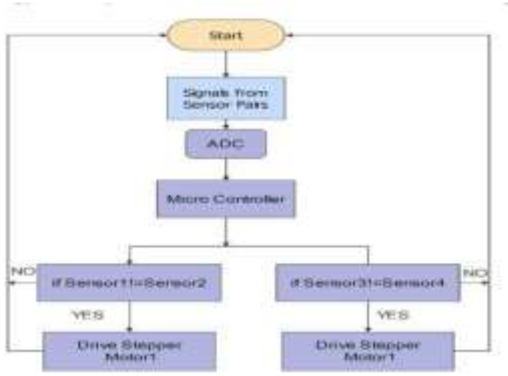

Fig.2: Block Diagram of Dual Axis Solar Mechanism

As Fig.2 indicates, if there is an increased light intensity on the left LDR compared to the right LDR, a signal is sent to the horizontal servo motor to turn the panel towards the left direction. Similarly, if there is increased light intensity on the top LDR compared to the bottom LDR, the vertical servo motor turns the panel upwards. This process continues until there is equal light intensity on all LDRs, indicating an optimal position with respect to the sun..

2.2 Control Logic:

The control algorithm is based on threshold comparison. A tolerance value is used to avoid unnecessary oscillations or movement due to slight changes in the light intensity.

Time delays and smoothness are also incorporated to increase the accuracy of the control algorithm and to avoid jerky movements.

Calibration of the LDR sensors is also important to increase the accuracy of the tracking performance.[8]

2.3 Circuit Diagram:

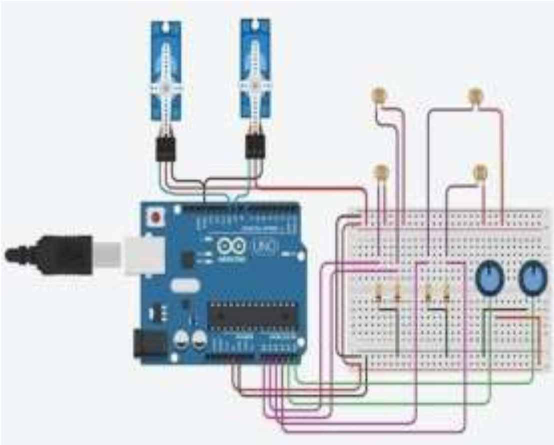

Fig.3 Circuit Diagram

Fig.3 Illustrate the circuit diagram and connections of the proposed dual axis solar tracker.

Advantages of Dual Axis Tracking:

It has been observed that the dual axis tracking system has the highest efficiency among the fixed and single-axis tracking systems, as the maximum solar radiation can be collected during the day.

Challenges:

However, the proposed dual axis tracking system may also face some problems, such as slower movement, misalignment of sensors, and mechanical problems, which need to be solved by proper programming, calibration, and alignment of the hardware.

As illustrated in the proposed system in the figure below (Fig.4), this mechanism plays a vital role in the generation of solar energy, making it suitable for electric vehicles, where energy efficiency is of critical importance.

Fig.4: Hardware layout

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3. Battery Storage System

The Battery Storage System plays an important role in the proposed system by storing the electrical energy produced from the solar panel and providing the necessary energy for the electric vehicle whenever required.[10]

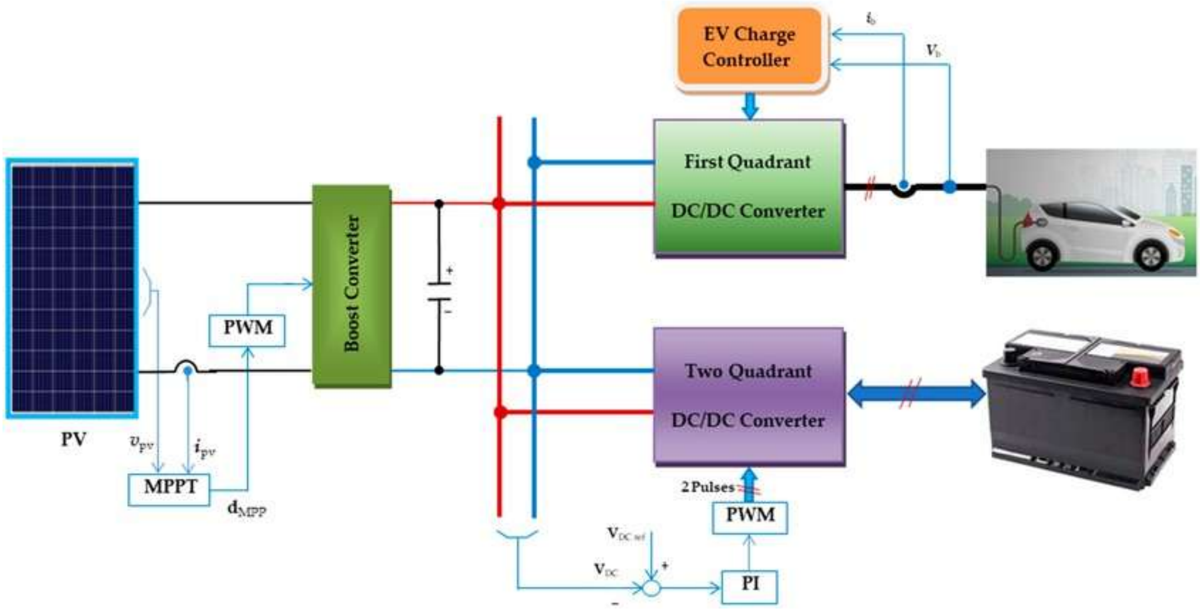

Fig.5: Battery Storage System

It is evident from Fig.5 that this system uses a rechargeable lithium-ion battery due to its high energy density, lightweight structure, and low rate of self-discharge.

3.1 Energy Storage Process:

The electrical energy obtained from the solar panel is regulated by a charge controller. The charge controller regulates the voltage and current of the electrical energy. The electrical energy obtained from the solar panel is then fed into the battery. The charge controller ensures the battery is not overcharged or discharged. The battery stores electrical energy. During peak sun hours, the battery stores electrical energy obtained from the solar panel. In case of insufficient electrical energy from the solar panel, the battery supplies electrical energy to the EV load system.

3.2 Battery Monitoring Parameters:

To ensure efficiency and safety, several battery parameters are monitored. The battery parameters include:

- Voltage – The battery voltage indicates the charge level.
- Current – The current indicates the charge and discharge rate.
- State of Charge (SoC) – The SoC indicates the capacity of the battery.
- Temperature – The temperature ensures safe battery operation.

The State of Charge (SoC) is one of the most critical battery parameters. The SoC indicates the capacity of the battery. The SoC ensures efficient battery operation.

3.3 Battery Management and Protection:

A battery management and protection system is implemented. The battery protection and management ensure safe battery operation. The battery protection and management ensure protection against:

- Over voltage
- Over current
- Short circuit
- Over heating

3.4 Thermal Management:

Temperature plays a vital role in battery operation. Temperature affects battery performance. The battery performance is affected by extreme temperatures. The battery is affected by extreme low and high temperatures. Fig.6 shows that the battery is equipped with a cooling mechanism. The cooling mechanism ensures the battery operates at a safe temperature.

Fig.6: Cooling System

3.5 Importance in EV System:

The battery storage system plays a vital role in the performance of the electric vehicle. The battery storage system directly affects the range of the electric vehicle. Efficient storage of electrical energy ensures the proper functioning of the electric vehicle and optimizes the utilization of renewable energy sources.

Thus, the battery storage system improves the stability of the system, optimizes the utilization of electrical energy, and ensures the proper functioning of the electric vehicle.

4. Smart Charging System:

The Smart Charging System regulates and optimizes the battery charging operation of the proposed system. The Smart Charging System ensures the efficient utilization of electrical energy from the solar panel and other power sources.

The main objective of the smart charging system is to control and regulate the flow of electrical energy depending upon the availability of electrical energy. The smart charging system optimizes the utilization of electrical energy by choosing between electrical energy from the solar panel and other power sources.[9]

4.1 Working Process:

As depicted in Fig.7, the proposed smart charging system regulates and optimizes the battery charging operation by first generating electrical energy through the solar panel. The electrical energy is then fed to the charge controller, which regulates the electrical energy and optimizes its utilization. The proposed smart charging system optimizes the utilization of electrical energy by choosing electrical energy from the solar panel. In case of a lack of electrical energy from the solar panel, the proposed smart charging system optimizes the utilization of electrical energy from

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other power sources.

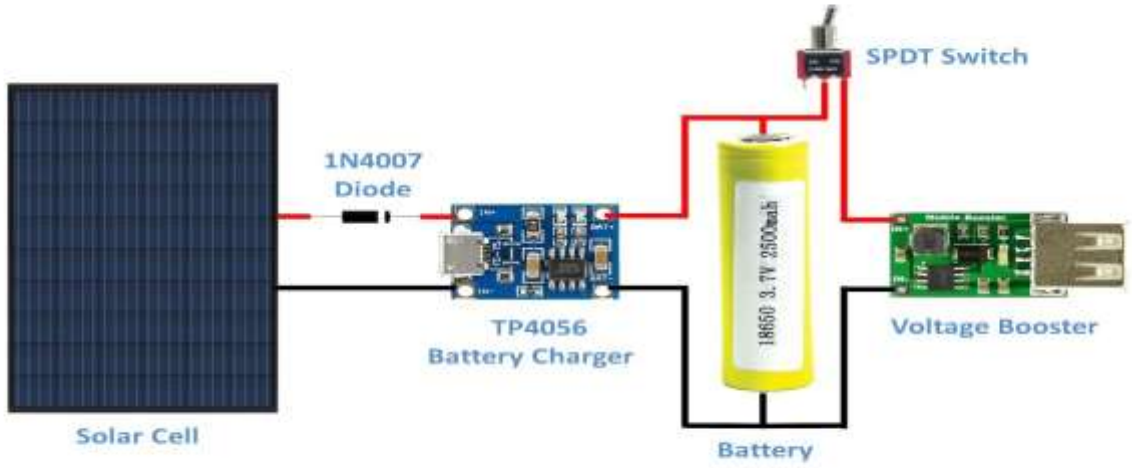

Fig.7: Charging System

4.2 Charging Control Mechanism:

The system is constantly monitoring battery-related factors, such as voltage, current, and state of charge. Based on this, the charging rate is regulated, and any dangerous conditions are avoided.

The smart charging system has different stages for charging, which are as follows:

- Bulk Charging – The maximum current is supplied for faster charging
- Absorption Charging – Voltage is maintained, and current is reduced
- Float Charging – Maintains the battery in a fully charged state

4.3 Protection Features:

To ensure the safety of the battery, several protection mechanisms are integrated into the system, which are as follows:

- Overcharging Protection – This prevents the battery from being damaged
- Over Current Protection – This prevents the battery from being damaged
- Short Circuit Protection – This prevents the system from failing
- Reverse Polarity Protection – This prevents the battery from being damaged

4.4 Efficiency Optimization:

The smart charging system reduces energy loss by promoting efficient power supply, thus maximizing battery life.

4.5 Role in Electric Vehicles:

In the context of the EV system, the charging system is crucial for the longevity of the batteries and the charging efficiency. Moreover, the system can provide a cost-effective and green energy solution by utilizing the solar energy source.

Thus, the proposed Smart Charging System can improve the energy efficiency, provide a secure environment for the batteries, and maintain the power availability for the proposed EV system.

5. Real Time Monitoring System:

Real Time Monitoring System is a crucial part of the proposed system. This system will provide the user the facility to monitor the system from a remote location.

In the proposed system, the email-based system is implemented for the Real Time Monitoring System. This system will create a basic client-server communication model. In this system, the microcontroller (Arduino Uno) will be the client part, and the communication system (ESP8266 Wi-Fi Module) will be the server part.

5.1 Working Process:

The proposed system will continuously collect the real-time information from various sensors and modules. The sensors and modules include:

* Battery Voltage
* Current
* State of Charge (SoC)
* Temperature
* Solar energy generation status
* Real time location

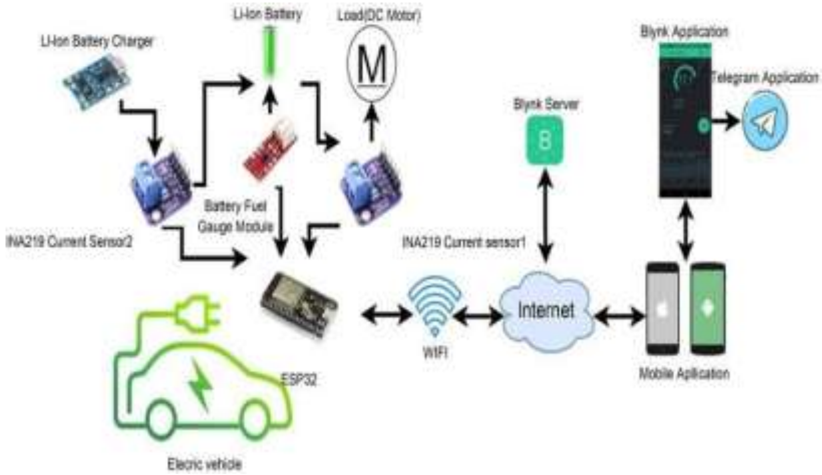

Fig.8: Real time Monitoring

Fig.8 also shows that this data is being processed by the microcontroller and sent to the cloud or server through the Wi-Fi module. Then this data is sent by the server to the user through email at specific intervals or based on certain conditions.

5.2 Email-Based Monitoring:

This email-based monitoring system enables the user to get updates regarding the system status.

Fig.9 : Email Based Monitoring Report

Fig.9 this approach provides a simple yet effective method for remote monitoring without requiring complex mobile applications.

The email may contain the following details:

* Battery level (SoC)
* Charging status
* Temperature condition
* Energy generation status
* Alerts (if any fault is detected)

5.3 Client Server Architecture:

The proposed system uses a basic client-server architecture, as shown below: Client - Microcontroller System (Data Sender)
Server - Email Server/Cloud Platform User - Recipient of Data via Email
This ensures a reliable method of data transmission and access.

Advantages:

- Real-time System Monitoring
- Remote System Access from Any Location
- Low System Implementation Cost
- Easy System Integration

Challenges:

- Internet Connectivity Required
- Possible Delay in Email Transmission
- Limited Real-time System Visualization

5.4 Role in EV System:

The proposed system plays a vital role in the EV system as it is critical to ensure the reliability, safety, and performance of the system. The EV user can monitor the system and be alerted of any issues through the proposed system.

The proposed Real-Time Monitoring System increases the intelligence of the system and user awareness, allowing efficient utilization of energy resources.

6. Safety & Alert System:

The Safety and Alerts System is a vital part of the proposed system that aims to ensure safety during operation, detect any fault in the system, and notify the user accordingly.

Several risks may occur in a solar-powered electric vehicle system, such as overcharging the battery, battery overheating, short circuiting, and voltage fluctuations. Therefore, a safety system is crucial to protect the system hardware as well as the user.

6.1 Working Principle:

The safety system operates by continuously collecting data from the sensors and monitoring modules installed in the system. The parameters that are continuously monitored are:

* Battery Voltage
* Charging Current
* Temperature
* State of Charge (SoC)
* System Operational Status

The data collected is processed in real time using a microcontroller unit and compared with a set of threshold values. If any parameter exceeds the threshold limit, it is considered a fault in the system.

6.2 Fault Detection and Response:

The system is designed to detect various fault conditions that may arise during operation, such as:

* Over Voltage: Battery Voltage exceeds a certain limit
* Over Current: Current flow exceeds a certain limit during charging or discharging
* Overheating: Temperature exceeds a certain limit
* Short Circuit: Sudden change in current flow
* Sensor Fault: Sensors fail to show any output

If any fault is detected in the system, the safety system takes the following actions:

* Immediately stop the charging process

* Activate cooling system (in case of high temperatures)

* Isolate the faulty component (if possible)

* Send a notification to the user

6.3 Alert Mechanism:

The alert system is connected to the Real-Time Monitoring System. When a fault is detected, the system will send an alert message to the user via email. The message will include the following information:

* Type of fault detected

* Current system status

* Suggested action (if required)

This will enable the user to take prompt action.

6.4 Control Logic:

The system employs a threshold-based decision-making logic. Each system parameter is assigned a threshold limit. When the system parameter crosses the threshold limit, the control logic activates the alert condition.

For example:

If the temperature crosses the threshold limit, the system will activate the fan and send an alert message.

If the voltage crosses the threshold limit, the system will stop the charging and send an alert message.

6.5 Role in EV System:

As shown in Fig. 10, the electric vehicle's safety is the top priority. The integration of the Safety and Alerts System will enable the electric vehicle to operate safely within the threshold limits. This will improve user confidence.

This module adds strength to the entire system by providing intelligent fault detection capabilities.

Fig.10: Hardware Structure

6.6 Algorithm of the System:

Step 1: Initialize all sensors and system components Step 2: Read LDR sensor values
Step 3: Determine maximum light direction Step 4: Adjust solar

panel using servo motors
Step 5: Generate electrical energy via solar panel

Step 6: Store energy in battery system

Step 7: Monitor battery parameters (Voltage, SoC, Temperature) Step 8: Control charging using smart charging system
Step 9: Activate cooling system if temperature exceeds limit Step 10: Send real-time data via monitoring system
Step 11: Trigger alerts if abnormal condition detected Step 12: Repeat process continuously

RESULT & DISCUSSION

The proposed system was successfully designed and implemented as a prototype model integrating solar energy generation, dual axis solar tracking system, battery system, smart charging system, cooling system, and real-time monitoring system.

Each component was tested for performance under real-time conditions to assess the efficiency and functionality of the proposed system.

According to the experimental results, the proposed system for tracking the solar energy can improve the energy output by 25-30% compared to the fixed solar panels under the same conditions.

1. Solar Energy Generation:

The solar panel can generate electrical energy under the condition of sunlight. It was observed that the energy generation depends on the light intensity and the orientation of the solar panel. When the solar panel is oriented correctly under the sunlight, the maximum voltage is produced.

Time	**Fixed Panel Output (W)**	**Tracking System Output(W)**
9 AM	120	150
11 AM	180	240
1 PM	220	310
3 PM	170	260
5 PM	110	140

2. Solar Tracking Performance:

The performance of the dual-axis solar tracking system was checked using LDR sensors and servo motors. The system was able to sense the change in light intensity and adjust accordingly. However, during testing, certain drawbacks were also observed, which are as follows:

* The response of the tracking system was very slow

* The system was moving in the wrong direction slightly

* The vertical movement of the system was not working properly

The above-mentioned drawbacks were because of incorrect alignment of sensors, incorrect calibration of LDR values, and insufficient torque of the motor.

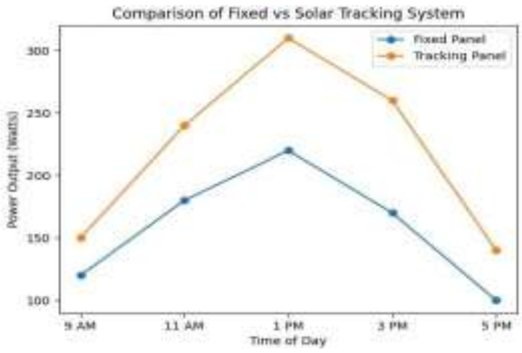

Fig.11: power output comparison

Fig.11 indicates that the tracking system has a higher power output than the fixed panel.

3. Battery Storage and Charging:

The battery storage system was able to store the generated power and provide the load with the required power.

The smart charging system was able to charge the battery in a controlled manner, avoiding overcharging and providing the required voltage levels.

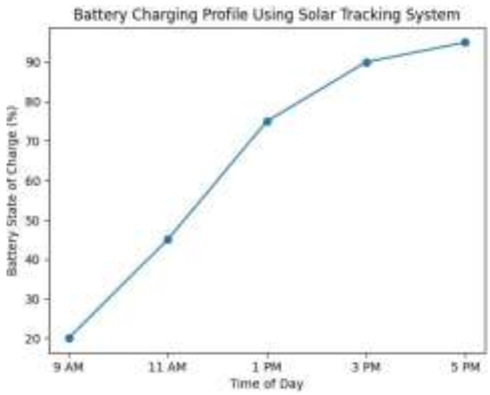

Fig.12: Battery charging profile

Fig.12 shows that the battery charging profile shows a steady increase in charge level, indicating efficient energy storage.

4. Real-Time Monitoring:

The email-based system was also successful in sending the required information in real time. The user was also able to receive information regarding the status of the battery, charging status, etc.

5. Cooling and Safety Performance:

The cooling system was also successful in keeping the system within a safe temperature range. The safety system was also successful in detecting abnormal status, thus ensuring safe operation of the system.

DISCUSSION

The system was tested, and it was observed that the results were received at different times of the day. It was also observed that the position of the panel was critical in this regard. It was observed that when the panel was fixed, it was not generating consistent power during the day.

After using the tracking system, it was observed that it was able to adjust itself according to the sunlight. As a result, it was generating more power for a longer time, especially during the afternoon.

The charging of the battery was also smoother, unlike when it was fixed. The charging was gradual, showing better use of available power.

Some issues were also observed during testing. At times, it was also observed that the panel was not moving perfectly, and there was a delay in response. This can be improved for better results.

The system was working properly, showing better use of solar tracking and management.

Prototype Model:

Fig.13: Developed prototype model

Figure 13 shows the prototype of the proposed system for the integration of solar energy generation, dual-axis solar tracking, battery storage, and real-time monitoring.

CONCLUSION

In this research work, the design and development of an "Adaptive Solar Tracking and Smart Energy Management System for Electric Vehicles" were proposed. In this system, the integration of various modules for the generation of solar energy, dual-axis solar tracking system, battery storage system, smart charging system, cooling system, real-time monitoring system, and safety system were included.

The implementation of the dual-axis solar tracking system enhances the efficiency of the system compared to the existing solar panels. This system tracks the position of the sun and maintains the solar panel's position according to the direction of the sun's rays. This maximizes the utilization of the solar energy available for the system. In addition, the integration of the smart energy management system optimizes the energy utilization and enhances the efficiency of the system.

The battery storage system acts as a backup for the system. In the proposed system, the integration of the smart charging system optimizes the charging and utilization of the battery. Moreover, the cooling system maintains the optimal working temperature for the system.

In the proposed system, the real-time monitoring system was implemented using an email- based system. This enhances the accessibility of the system. In the proposed system, the safety system was implemented for the system's safety from abnormal conditions.

During the implementation of the proposed system, certain difficulties were faced in the solar tracking system.

FUTURE SCOPE

Possible future enhancements could be:

- AI-based solar tracking
- Advanced battery management
- Development of a mobile application
- Better IoT integration
- Using flexible solar panels
- Implementation in real EVs

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