DUAL AXIS SOLAR TRACKING AND POWER MANAGEMENT SYSTEM USING IOT

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ABSTRACT

With the increasing demand for energy, traditional sources are becoming scarce and the need to transition to non-traditional sources of energy is urgent. Solar energy is an inexhaustible form of energy that can be easily tapped from different parts of the world and converted to electrical energy by using devices such as solar panels. However, the output power of these photovoltaic (PV) panels is not constant as the sun moves from east to west and its angle of incidence varies with the season and time of the day. To maximize energy output from the solar panel, a dual-axis solar tracker (DAST) is necessary to rotate the panel about its horizontal and vertical axes. This system will ensure efficient tracking of the sun and optimal energy output from the solar panel. The proposed system will respond within the 0.2 sec to store the data in database. The whole 24 hour data of solar panel is utilized in the preferred system to analyse the data to validate the robustness of the system. The proposed system uses a microcontroller to adjust the position of the solar panel based on the movement of the sun, while the performance of the tracker is monitored through the use of Internet of Things (IoT) connected via Wi-Fi.

Keywords: Photovoltaic (PV) panels, Dual Axis Solar Tracker (DAST), Internet of Things (IoT)

I. INTRODUCTION

In recent years, renewable energy sources have gained significant traction as viable alternatives to traditional fossil fuels. Among these, solar energy stands out as one of the most promising due to its abundance and sustainability. However, harnessing solar power efficiently requires overcoming challenges such as variability in sunlight intensity and direction. To address this, advanced solar tracking systems have emerged as crucial components in maximizing energy output from solar panels. This project focuses on the development of a Dual Axis Solar Tracking and Power Management System using Internet of Things (IoT) technology. The system integrates precise tracking mechanisms with intelligent power management capabilities, aimed at optimizing energy generation from solar panels while ensuring efficient utilization and distribution of the harvested energy. Dual axis tracking systems offer a significant advantage over single-axis counterparts by allowing solar panels to continuously adjust their orientation along both the azimuth and elevation axes. This dynamic tracking capability enables panels to maintain optimal alignment with the sun throughout the day, thereby maximizing energy capture potential. By employing IoT technology, the system gains the ability to autonomously monitor environmental conditions and adjust tracking parameters in real-time, further enhancing its efficiency and adaptability. Key components of the proposed system include sensors for measuring sunlight intensity and direction, actuators for adjusting the orientation of solar panels, microcontrollers for data processing and control, and communication modules for IoT connectivity. Through seamless integration of these components, the system can dynamically adapt to changing environmental conditions and optimize solar panel positioning for maximum energy yield.

In addition to solar tracking functionality, the project also emphasizes power management aspects to ensure effective utilization of the harvested energy. This includes features such as battery storage systems, voltage regulation, and intelligent load management, allowing surplus energy to be stored for later use or distributed efficiently to power various applications. Overall, the Dual Axis Solar Tracking and Power Management System presented in this project represents a holistic approach towards enhancing the efficiency and reliability of solar energy systems. By leveraging IoT technology and advanced tracking mechanisms, the system aims to overcome traditional limitations associated with solar power generation, ultimately contributing to the widespread adoption of renewable energy solutions in various applications.
II. METHODOLOGY

2.1 EXISTING SYSTEM

- Existing systems for dual-axis solar tracking often lack integration with IoT technology, resulting in limited real-time monitoring and control capabilities.
- Conversely, conventional power management systems may not efficiently utilize harvested energy, leading to potential wastage and inefficiencies.
- This project aims to bridge these gaps by developing a comprehensive Dual Axis Solar Tracking and Power Management System.
- This system will seamlessly integrate IoT technology for enhanced monitoring, control, and optimization of solar energy generation and utilization.

2.1.1 Disadvantages

The disadvantages are

- Fault detection is difficult.
- Quite expensive.

2.2 PROPOSED SYSTEM

- The proposed IoT based dual axis solar tracker integrates Internet of Things technologies for enhanced efficiency and control.
- It features remote monitoring and control capabilities, sensor networks for environmental data collection, and data analytics for system optimization.

2.2.1 Advantages

The IoT based dual axis solar tracker offers numerous advantages, including

- Optimized energy harvesting through real time adjustments.
- Remote monitoring and control for efficient system management.
- Data driven decision making with insights from sensors and analytics.
- Predictive maintenance to reduce downtime and costs.
- A user friendly interface for transparent monitoring.
- Cloud connectivity for scalable data management.
- Adaptive tracking algorithms for optimal performance.

2.3 SOLAR PANEL THEORY

Solar panels, also known as photovoltaic (PV) panels, are devices that convert sunlight into electricity through the photovoltaic effect. Understanding the theory behind solar panels involves comprehending their construction, operation principles, efficiency factors, and applications in renewable energy generation.

2.4 CONSTRUCTION

Solar panels consist of multiple solar cells connected in series or parallel within a single module. Each solar cell is typically made of semiconductor materials such as silicon, which is doped to create a p-n junction. The most common types of solar cells are monocrystalline, polycrystalline, and thin film, each with different manufacturing processes and efficiency levels. The solar cells are encapsulated in a protective and transparent material, such as tempered glass, to withstand environmental factors.

2.5 OPERATION PRINCIPLES

Solar panels operate based on the photovoltaic effect, wherein photons from sunlight strike the surface of the solar cells, generating an electric current. This process involves several steps:

- **Absorption:** Photons with sufficient energy are absorbed by the semiconductor material of the solar cell, exciting electrons within the material.
- **Generation of Electron Hole Pairs:** The absorbed photons create electron-hole pairs within the semiconductor material, separating electrons from their atoms and creating free carriers.
- **Electron Flow:** Due to the built in electric field of the p-n junction, the free electrons migrate towards the n type (negative) side of the cell, while the positively charged holes move towards the p type (positive) side.
• **Collection:** Conductive metal contacts on the surface of the solar cell collect the electrons and holes, creating an electric current that flows through an external circuit connected to the solar panel.

• **Conversion:** The electric current produced by the solar panel can be utilized directly as DC electricity or converted into alternating current (AC) using inverters for grid-connected applications.

### 2.6 HARDWARE ANALYSIS

#### 2.6.1 Sensors

**LM35 Temperature Sensor:**

The LM35 is a precision integrated-circuit temperature sensor that provides an analog output voltage linearly proportional to the Celsius temperature. In a dual-axis solar tracking system, the LM35 sensor can be strategically placed to monitor the temperature of the solar panels or surrounding environment. This data can be crucial for optimizing the efficiency of the solar panels by adjusting their orientation and tilt angles.

**Dual-Axis Solar Tracking:**

The dual-axis solar tracking system continuously adjusts the position of solar panels in real-time to maximize solar energy capture. By integrating the LM35 temperature sensor data, the system can intelligently track the sun’s position while considering temperature variations. This ensures optimal solar panel alignment for maximum energy production throughout the day, especially in varying weather conditions.

**Power Management System using IoT:**

The IoT-enabled power management system integrates the data from the LM35 temperature sensor and other environmental sensors with advanced algorithms and connectivity features. Through IoT connectivity, the system can remotely monitor and control various parameters of the solar tracking system, such as panel orientation, tilt angles, and energy production.

**Description:**

The LM35 temperature sensor feeds temperature data to the dual-axis solar tracking system, enabling it to dynamically adjust the position of solar panels for optimal energy capture. This data is also transmitted to the power management system via IoT connectivity. The power management system processes this data in real-time, making decisions to optimize energy production and storage. Additionally, it provides remote access for monitoring and control, allowing users to adjust settings and troubleshoot issues from anywhere. This integrated approach maximizes the efficiency and reliability of solar energy systems, making them more suitable for a variety of environments and applications.

**LED**

Arduino Uno comes with built-in LED which is connected through pin 13. Providing HIGH value to the pin will turn it ON and LOW will turn it OFF.

**Vin**

It is the input voltage provided to the Arduino Board. It is different than 5V supplied through a USB port. This pin is used to supply voltage. If a voltage is provided through power jack, it can be accessed through this pin.

**5V**

This board comes with the ability to provide voltage regulation. 5V pin is used to provide output regulated voltage. The board is powered up using three ways i.e. USB, Vin pin of the board or DC power jack. USB supports voltage around 5V while Vin and Power Jack support a voltage ranges between 7V to 20V. It is recommended to operate the board on 5V. It is important to note that, if a voltage is supplied through 5V or 3.3V pins, they result in bypassing the voltage regulation that can damage the board if voltage surpasses from its limit.

**Ground**

These are ground pins. More than one ground pins are provided on the board which can be used as per requirement.

**Reset**

This pin is incorporated on the board which resets the program running on the board. Instead of physical reset on the board, IDE comes with a feature of resetting the board through programming.
This pin is very useful for providing voltage reference to the board. A shield is used to read the voltage across this pin which then select the proper power source.

**Pulse Width Modulation**

PWM is provided by 3, 5, 6, 9, 10, 11 pins. These pins are configured to provided 8-bit output PWM.

**Serial Peripheral Interface**

It is known as Serial Peripheral Interface. Four pins 10(SS), 11(MOSI), 12(MISO), 13(SCK) provide SPI communication with the help of SPI library.

**Two-Wire Interface**

It is called Two-wire Interface. TWI communication is accessed through Wire Library. A4 and A5 pins are used for this purpose.

**Serial Communication**

Serial communication is carried out through two pins called Pin 0 (Rx) and Pin 1 (Tx). Rx pin is used to receive data while Tx pin is used to transmit data.

**Communication and Programming**

Arduino Uno comes with an ability of interfacing with other other Arduino boards, microcontrollers and computer. The Atmega328 placed on the board provides serial communication using pins like Rx and Tx. The Atmega16U2 incorporated on the board provides a pathway for serial communication using USB com drivers. Serial monitor is provided on the IDE software which is used to send or receive text data from the board. If LEDs placed on the Rx and Tx pins will flash, they indicate the transmission of data. Arduino Uno is programmed using Arduino Software which is a cross platform application called IDE written in Java. The AVR microcontroller Atmega328 laid out on the base comes with built in bootloader that sets you free from using a separate burner to upload the program on the board.

2.7 LDR

The Light-dependent resistors made with photosensitive semiconductor materials like Cadmium Sulphides (CdS), lead sulfide, lead selenide, indium antimonide, or cadmium selenide and they are placed in a Zig-Zag shape as you can see in the pic below.

![LDR](image.png)

**Fig.1 LDR**

Two metal contacts are placed on both ends of the Zig-Zag shape these metal contacts help in creating a connection with the LDRs. Now, a transparent coating is applied on the top so that the zig-zag-shaped photosensitive material gets protected and as the coating is transparent the LDR will be able to capture light from the outer environment for its working.

2.7.1 LDR Working Principle

It works on the principle of photoconductivity whenever the light falls on its photoconductive material, it absorbs its energy and the electrons of that photoconductive material in the valence band get excited and go to the conduction band and thus increasing the conductivity as per the increase in light intensity.

Also, the energy in incident light should be greater than the bandgap gap energy so that the electrons from the valence band got excited and go to the conduction band. The LDR has the highest resistance in dark around 1012 Ohm and this resistance decreases with the increase in Light.
DC motors

Geared DC motors can be defined as an extension of DC motor which already had its details demystified here. A geared DC Motor has a gear assembly attached to the motor. The speed of motor is counted in terms of rotations of the shaft per minute and is termed as RPM. The gear assembly helps in increasing the torque and reducing the speed. Using the correct combination of gears in a gear motor, its speed can be reduced to any desirable figure. This concept where gears reduce the speed of the vehicle but increase its torque is known as gear reduction. This Insight will explore all the minor and major details that make the gear head and hence the working of geared DC motor.

12 Volt Battery

A 12-volt direct current (DC) battery is a common type of battery used in numerous applications ranging from automotive to marine, backup power systems, solar energy storage, and portable electronics. Understanding the theory behind a 12V DC battery involves comprehending its construction, chemical reactions during charging and discharging, voltage characteristics, capacity, and maintenance considerations.

2.8 SOFTWARE ANALYSIS

2.8.1 Embedded C

Embedded C is a set of language extensions for the C Programming language by the C Standards committee to address commonality issues that exist between C extensions for different embedded systems. Historically, embedded C programming requires nonstandard extensions to the C language in order to support exotic features such as fixed point arithmetic, multiple distinct memory banks, and basic I/O operations.

In 2008, the C Standards Committee extended the C language to address these issues by providing a common standard for all implementations to adhere to. It includes a number of features not available in normal C, such as, fixed point arithmetic, named address spaces, and basic I/O hardware addressing.

Embedded C uses most of the syntax and semantics of standard C, e.g., main() function, variable definition, data type declaration, conditional statements (if, switch, case), loops (while, for), functions, arrays and strings, structures and union, bit operations, macros, etc. A Technical Report was published in 2004 and a second revision in 2006.

2.8.2 Embedded System Programming

Embedded systems programming is different from developing applications on a desktop computer. Key characteristics of an embedded system, when compared to PCs, are as follows: Embedded devices have resource constraints (limited ROM, limited RAM, limited stack space, less processing power) Components used in embedded system and PCs are different; embedded systems typically use smaller, less power consuming components. Embedded systems are more tied to the hardware. Embedded systems are programmed using different types of languages:

- Machine Code
- Low level language, i.e., assembly
- High level language like C, C++, Java, Ada, etc.

III. MODELLING AND ANALYSIS

3.1 CIRCUIT DIAGRAM

The solar panel has a maximum output voltage of 9V. A potentiometer is used to reduce the voltage at the analog pin A0 of node MCU. The motor driver consists of an H-bridge circuit which enables it to reverse the input to the DC motor based on the signals from Arduino.
The Fig. 2 shows the circuit diagram of the dual axis solar tracking system

3.2 BLOCK DIAGRAM

A solar tracking system utilizes various components to optimize the efficiency of solar panels by orienting them towards the sun. It includes Light Dependent Resistors (LDRs) positioned at different points on the panel to measure light intensity. These LDRs are connected to a Node MCU microcontroller board, which processes the signals and controls the motor driver responsible for adjusting the panel's position. The following block diagram as the proposed system for project Shown in below Fig.3.

To ensure safety and efficiency, limit switches are incorporated into the system. These switches serve as safety measures by automatically turning off the motor when the solar panel reaches its maximum travel in either direction. Additionally, an LCD (Liquid Crystal Display) screen provides real-time information about the system's performance, such as the position of the solar panel and the voltage output.

3.3 SCOPE OF STUDY

The project explores the use of a solar panel or a solar power concentrator coupled with two low voltage DC motor actuators to track the sun in both the horizontal and vertical axes. Four light sensors (LDRs) are mounted on the solar panel which is the inputs to measure the differences in light intensities to be able to move the system and track the direction of the sun. Each pair of these Light sensors feeds into comparator circuit that compares the intensities and commands the actuators through a motor driver IC.
3.3.1 Notes

1. Hours of rotation away from a time (e.g. noon) when the collector is accurately aligned.

2. Maximum seasonal variation (at summer or winter solstice), as compared with accurate alignment at equinox.

3. Jump up to: Greater due to higher reflectance at high angles of incidence.

For example, trackers that have accuracies of ±5° can capture more than 99.6% of the energy delivered by the direct beam plus 100% of the diffuse light. As a result, high-accuracy tracking is not typically used in non-concentrating PV applications.

### Table 1: Direct power losses due to misalignment

<table>
<thead>
<tr>
<th>Angle i</th>
<th>Hours [a]</th>
<th>Loss</th>
</tr>
</thead>
<tbody>
<tr>
<td>0°</td>
<td>-</td>
<td>0%</td>
</tr>
<tr>
<td>1°</td>
<td>-</td>
<td>0.015%</td>
</tr>
<tr>
<td>3°</td>
<td>-</td>
<td>0.14%</td>
</tr>
<tr>
<td>8°</td>
<td>-</td>
<td>1%</td>
</tr>
<tr>
<td>15°</td>
<td>1</td>
<td>3.4%</td>
</tr>
<tr>
<td>23.4°[b]</td>
<td>-</td>
<td>8.3%</td>
</tr>
<tr>
<td>30°</td>
<td>2</td>
<td>13.4%</td>
</tr>
<tr>
<td>45°</td>
<td>3</td>
<td>30%</td>
</tr>
<tr>
<td>60°</td>
<td>4</td>
<td>&gt;50%[c]</td>
</tr>
<tr>
<td>75°</td>
<td>5</td>
<td>&gt;75%[c]</td>
</tr>
</tbody>
</table>

3.4 SINGLE AXIS TRACKER

Single axis trackers have one degree of freedom that acts as an axis of rotation. The axis of rotation of single axis trackers is typically aligned along a true North meridian. It is possible to align them in any cardinal direction with advanced tracking algorithms. There are several common implementations of single axis trackers.

#### 3.4.1 Horizontal Single Axis Tracker (HSAT)

The axis of rotation for a horizontal single axis tracker is horizontal with respect to the ground. The posts at either end of the axis of rotation of a horizontal single axis tracker can be shared between trackers to lower the installation cost. This type of solar tracker is most appropriate for low latitude regions. Field layouts with horizontal single axis trackers are very flexible. The simple geometry means that keeping all of the axes of rotation parallel to one another is all that is required for appropriately positioning the trackers with respect to one another.

![Fig.4: 4MW Horizontal Single Axis Tracker (HSAT)](image-url)
3.4.2 Vertical Single Axis Tracker (VSAT)

The axis of rotation for vertical single axis trackers is vertical with respect to the ground. These trackers rotate from east to west over the course of the day. Such trackers are more effective at high latitudes than horizontal single axis trackers are. Field layouts must consider shading to avoid unnecessary energy losses and to optimize land use.

![Fig.5: Vertical Single Axis Tracker (VSAT)](image)

Also, optimization for dense packing is limited due to the nature of the shading over the course of a year. Vertical single axis trackers typically have the face of the module oriented at an angle with respect to the axis of rotation. As a module tracks, it sweeps a cone that is rotationally symmetric around the axis of rotation.

3.4.3 Dual axis trackers

Dual axis trackers have two degrees of freedom that act as axes of rotation. These axes are typically normal to one another. The axis that is fixed with respect to the ground can be considered a primary axis. The axis that is referenced to the primary axis can be considered a secondary axis. There are several common implementations of dual axis trackers. They are classified by the orientation of their primary axes with respect to the ground. Two common implementations are tip tilt dual axis trackers (TTDAT) and azimuth altitude dual axis trackers (AADAT).

The orientation of the module with respect to the tracker axis is important when modeling performance. Dual axis trackers typically have modules oriented parallel to the secondary axis of rotation. Dual axis trackers allow for optimum solar energy levels due to their ability to follow the Sun vertically and horizontally. No matter where the Sun is in the sky, dual axis trackers are able to angle themselves to point directly at the Sun.

IV. RESULT AND DISCUSSION

The direction of motion changes when there is a difference of 0.8 V between the output voltage at one LDR compared to the output voltage of the LDR at the opposite end.

4.1 THE POSITION OF THE PANEL AT SUNRISE

The Directionally Adjustable Solar Tracker (DAST) system is designed to enhance the efficiency of solar panels by dynamically adjusting their position to optimize sunlight absorption throughout the day. Initially, the panels are positioned with an optimal tilt angle and azimuth angle, both of which vary depending on the specific location.

![Fig.6: Solar panel facing towards east](image)

The Directionally Adjustable Solar Tracker (DAST) system is equipped to follow the direction of brighter sunlight. Initially, the panel is positioned with an optimal tilt angle and azimuth angle, both of which vary depending on the specific location's geographical coordinates.

The tilt angle refers to the angle at which the solar panels are inclined relative to the horizontal plane. This angle is typically adjusted to maximize solar radiation absorption, taking into account factors such as the time of year, latitude, and desired energy output.
4.2 THE POSITION OF THE PANEL AT SUNSET

When the sun moves towards the west, the west LDR registers a higher output voltage compared to the east LDR. This triggers the DC geared motor to rotate in the westward direction, causing the entire panel to shift in the same direction. The LCD provides real-time feedback on the motor's rotation direction and other relevant information.

Fig. 7: Solar panel facing towards west

4.3 THE AUTOMATIC MOVEMENT BACK TO THE INITIAL POSITION

The DAST monitors LDR output voltage, adjusting panels eastward when light decreases. It waits 20 seconds post light-off to confirm sustained decrease, avoiding unnecessary movements.

Fig. 8: Solar panel is stationary when there is no light

4.4 BLYNK APP FOR THE SOLAR PANEL MONITORING SYSTEM

Now we will design application in the Blynk in order to monitor the status of the solar panel in the mobile. If you do not have Blynk application, download it from the play store, and make account. During the registration enter a valid email id, because while making the Blynk application you will be emailed an Authentication token which you will have to use in the Nodemcu ESP8266 programming. So, after downloading and installing the Blynk Application, Open the Blynk application.

4.4.1 Guide to using Blynk application

➢ Click on the create new project.
➢ The Auth token will be sent to the email which will be used in coding. Now in the widget box select the gauge. Now we will give it name voltage and use it as virtual pin V0 and set the maximum value to 25.
➢ Then select ESP8266 and in hardware select NodeMCU and in connection type select Wi-Fi. Give the name to the project in our case the project name is solar panel monitor and click on create.
➢ Click on the PIN and select virtual pin V0.
➢ Now insert labeled value and give it name as temperature and set the value between 18 to 100.
➢ Now insert another label and give it name humidity and assign it virtual pin 2 Now again in the wedge box we will insert a super chart and give it name as voltage and select the virtual pin V0 and give the minimum and maximum between 0 to 25.
➢ Now click on the add data stream and we will make graph for both temperature and humidity. Our Blynk App for the Solar Panel Monitoring System is ready.

V. CONCLUSION

In summary, the dual-axis solar tracker (DAST) represents a cost-effective and straightforward approach to boosting solar panel efficiency. Its ability to adaptively adjust panel positions in response to the sun's movement offers a significant advantage for maximizing energy capture. Additionally, integration with Internet of Things (IoT) technology enables real-time monitoring of panel output, ensuring optimal performance. The implementation of DAST holds promise for improving solar energy harvesting, thereby reducing reliance on traditional energy sources. Utilizing a comprehensive 24-hour data set enhances system responsiveness, enabling...
quick adjustments to track the sun's path accurately. Looking forward, there's potential to enhance DAST systems further, particularly by incorporating advanced control methods such as Artificial Intelligence. This would enable even greater efficiency gains, supporting the ongoing transition towards sustainable energy practices.

VI. REFERENCES


