



Dual Axis Solar Based Tracking System

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ABSTRACT

Today's world prefers the use of sustainable and renewable energy sources such as solar energy to reduce the reliance on non-renewable energy sources such as fossil fuels etc. Solar tracking system is the efficient approach to optimize the performance of solar panels under different weather conditions. This study explains the hardware design, implementation, and performance of a dual axis solar tracking system with different sensors. The paper highlights the increasing demand for solar tracking technology to maximize energy capture from photovoltaic (PV) cells embedded in solar panels. The tracker continuously aligns and adjusts both elevation angle and azimuth position of solar panel to follow sunlight entire day using microcontroller. The tracking system also incorporates weather sensors, such as rain and temperature detectors, to enhance performance and safety of panels during harsh weather conditions. The experimental findings according to different research shows that dual-axis system acquires 25-45% greater energy efficiency than single-axis trackers. However, Deep Neural Network (DNN)-based trackers use predictive algorithms for training phase to adapt the system to real-time environmental factors. This deep learning method is very complex to implement because large dataset is required for training purpose, but it is more accurate to give better results in varying sun patterns and climatic conditions. The increasing complexity and variability in demand explain the need for advanced technology in the upcoming centuries, which in this case comes in the form of DNN-based systems with superior performance and flexibility.

1. INTRODUCTION

Solar power is currently the most viable source of energy, mainly because the demand for renewable sources of energy is on the rise. Great potential is held by solar energy since it is clean and abundant; however, their efficiency depends on how well solar panels face the sun. As conventionally effective, fixed solar panels have their limitations to capture the maximum sunlight throughout the day. It is because of this limitation that solar tracking systems have been devised, and amongst these, dual-axis solar tracking systems are the most effectual way of orienting panels in accordance with the trajectory of the sun. A dual-axis solar tracker with a weather sensor represents one of

the most advanced developments in solar technology-as besides its basic principle of following the path of the sun in two directions-it is also capable of adapting to changes in environmental conditions, hence offering an optimization of energy production along with prolonging the life of the panels[1]. While solar energy is clean and renewable, the orientation of the solar panel with respect to the sun hampers its efficiency. Fixed solar panels, while serving their purpose, often do not catch all the sunlight throughout the day as the position of the sun keeps on changing. This may lower the general output of a system[2]. Due to this challenge, there have been

the developments of dual-axis solar tracking systems. These allow adjusting the solar panels in both east-west and north-south directions so that the panels always directly face the sun for maximum exposure[3]. This increases energy production very much by maximizing the amount of sunlight absorbed by the panels.

To further enhance efficiency and reliability, most dual-axis solar tracking systems come equipped with weather sensors. The sensors are constantly monitoring the atmospheric condition, while the detection of the wind velocity, temperature, and precipitation, among others, enables the positioning of the panel to realize minimal adverse impacts of the weather conditions and to prevent damage to equipment.

A dual-axis solar tracker changes the orientation of the solar panels both in azimuth angle and in elevation angle. It tracks the sun from the time of its rising to its setting, adjusting the seasonal variation in the height of the sun. This can improve the systems of dual-axis solar tracking by continuously having the optimal orientation and enhancing energy capture up to 30–40% compared with fixed panels[4]. This also makes them highly suitable for commercial and residential applications because they can maximize the output of the energy generated. Unlike single-axis trackers, which only adjust horizontally, a dual-axis system has full angular flexibility to directly point the panels toward the sun every day and every minute of the year.

But maximizing solar energy output is not solely a question of following the sun. Other external conditions of the weather, such as overcast, rain, wind, and extreme temperatures, would affect the efficiency and safety of the photovoltaic panels[5]. For those conditions, a dual-axis tracking system relies on weather sensors to perform state changes in real time due to environmental data[6]. The would-be scenario can be illustrated when the winds reach a critical value: the system tilts the panels to a flat position to decrease wind load, preventing structural damage. For example, rain sensors might actuate changes to prevent the pooling of water on the panel surface, while cloud detection systems can decrease the system's intensity of operation during low-light periods.

With the help of a dual-axis tracking system that integrates weather sensors, it will ensure optimal

energy production. Further, durability and reliability will be achieved in solar panels. Weathering conditions can be quite intensive for solar panels, resulting in heavy maintenance and possible downtimes[7]. This reduces the possibility of material damage upon receiving real-time environmental data inputs, reducing manual intervention-the operating cost, therefore. In addition, the application of temperature sensors prevents overheating that could seriously lower the performance of photovoltaic cells, especially in very hot regions. Generally, a weather sensor-equipped Dual Axis Solar Tracking System is an intelligent, adaptive power harvesting solution. It optimizes efficiency in converting solar energy and, at the same time, protects the panels from damage for a longer life. The system forms one of the current important innovations in solar technology with advanced mechanical design and real-time environmental monitoring.

2. THEORETICAL FRAMEWORK

Several methods and technologies are used for making the dual axis solar tracking system. The research articles on the design and implementation of solar tracking system are listed below:

The research article uses ESP8266 microcontroller that serves as the primary control of photovoltaic movements. This microcontroller helps the system to follow the direction of sunlight based on the information coming from Light Dependent Resistor (LDR) sensor[8]. The value of different variables include current, voltage and temperature are measured. The microcontroller then processed and transmitted data to the user through the Internet of Things (IoT) media to the BLINK application. The experimental results show that the proposed dual axis solar tracking system with ESP8266 microcontroller and LDR has better accuracy, efficiency and speed with an average of 65% than manual monitoring system.

The performance of solar trackers can be checked through smartphones via Bluetooth modules. These modules are responsible for communication medium between Arduino and other android applications. The study also provides a comparative analysis between static and dual axis solar tracking system. The 2-axis system gives 11.5% more output power than the static tracking system[9].

A two-axis tracking system using Arduino Uno as the core controller of the system and four light dependent resistors (LDRs), to detect sunlight and maximum exposure. The system also uses two servo motors that rotate and adjust the solar panel in a specific direction for maximum exposure to sunlight. The efficiency of this system has been tested and compared with a single axial tracking system. The result shows that dual solar system provides more power and output.

This study utilizes machine learning (ML) technique for real-time detection and monitoring of dual-axis solar trackers and its efficiency. This method incorporates the Particle Swarm Optimization technique along with Deep Neural Network (DNN) to enhance the training phase for better performance of the system. DNN techniques are more complex and difficult to implement but give better results and more efficiency than the existing conventional methods[10]. The outcomes produced by the suggested model illustrate that it has earned greater accuracy than the existing techniques.

The closed-loop control dual axis solar tracking system is proposed and described in the article. In this article, UV sensor and micro electromechanical solar sensor (MEMS) are used to detect the position of sun for capturing maximum intensity. Furthermore, the system integrates an Arithmetic optimization-based PID (AOPID) controller for the proper adjustment of solar panel according to the MEMS and UV sensor readings. The main purpose of this controller is to capture maximum intensity of solar radiation by tilting and varying azimuth or elevated angle of solar panel[11].

This article presents the hybrid dual axis solar tracker system that incorporates electromechanical systems for optimizing solar tracking systems by using different methods and algorithms. The solar tracker is developed and monitored on different weather conditions using light sensors. The solar tracker follows the apparent position of sun in different seasons and months through electrical controlling device that constantly controls the tracker position and align it according to the sunlight. The electromechanical system makes this solar tracker a hybrid one different from static solar tracker. The result shows that the power gain of hybrid dual axis solar tracking system is almost equal to continuous one but hybrid tracker saves 44.44% more power in

the operation than the continuous solar tracker[12].

3. METHODOLOGY

The methodology of the Dual Axis Solar Tracking System with a Weather Sensor should be able to design and implement a system that always aligns the solar panels with respect to the sun's position to capture the maximum amount of available energy. This paper deals with solar tracking technology along with real-time environmental monitoring in which adjusting of the solar panel is based not only on sunlight but also on weather conditions like wind, rain, and temperature. The hardware setup integrates solar panels, actuators, sensors, and a microcontroller, while the development of control algorithms permits the movement of the panel and takes into account any changes in exogenous variables. The primary goal of this work is to increase the efficiency of energy generation from the sun, protect the system from meteorological aggressiveness, and gather and analyze data in constant pursuit of performance optimisation.

Hardware design begins with the dual-axis solar tracking mechanism, where solar panels are allowed to move on a horizontal and vertical axis. This will make sure that the panels will keep track of the path of the sun from the rise to the setting of the sun, hence during different seasons of the year. These include two motors that control azimuth for east-west rotation and elevation for north-south tilt, respectively. The solar panels will be mounted on a movable frame designed to handle the weight of the panels and the mechanical stress caused due to the motors' movement. Actuators or stepper motors are connected to the frame, and their movements are decided by the microcontroller according to the sensor inputs. LDRs are used as sensors to perceive sunlight intensity, through which the motors get a cue for adjustment in the panels[13]. These LDRs are strategically positioned at different positions around the solar panels to measure sunlight from different angles so that the panels are able to track the sun accurately. The control system plays an important role in ensuring that the panels track the sun with efficiency and respond to weather conditions. Its core is normally implemented by using an Arduino or Raspberry Pi, a microcontroller that processes the data from LDRs and weather sensors[14]. This

works under the principle of a tracking algorithm, which compares the light intensity detected by the LDRs on different sides of the panel. When the panel isn't oriented to the sun, an error in light intensity between sensors becomes the difference driving the motors to rotate the panel. The system continuously makes adjustments to the panels through a feedback loop until a point where each sensor has a similar amount of light intensity, meaning the panel would be directed directly towards the sun. Additionally, the microcontroller takes input from sensors dealing with weather: rain sensors, wind speed sensors, also called anemometers, and temperature sensors. This serves to change the orientation of the panel according to weather conditions for protection. For instance, in cases of high winds, it flattens the panels to reduce wind resistance while driving in. In instances of precipitation, rain sensors will drive them into a protective position.

3.1 Microcontroller

The microcontroller (Arduino or raspberry pi) is the main part of dual axis solar tracking system. It helps in monitoring and controlling all the main processes and operations involved in solar tracking systems. The controller picks data from the sensors, monitors the input data and gives commands to the motor to adjust and align the position of solar tracking system. The designed algorithms are programmed into the microcontroller that allows it to read input data coming from different sensors such as temperature, light and humidity. After that, the microcontroller makes instant decisions to align the orientation of system. The Atmega328 microcontroller can be used for this purpose because it is small in size, consumes low power and easily interface with other electronic components.

3.2 Solar Panel

Solar panel is the most vital part of the proposed system. It converts solar energy into electrical energy. In a dual axis solar tracking system, the main agenda is to increase the sunlight exposure throughout the daytime by continuously adjusting the panel position and orientation. The performance of a solar panel is constantly observed and monitored and aligns its position so that it captures maximum solar energy and gives the desired output to the system.

3.3 Servo Motor

The elevation and proper adjustment of solar panel can be done through servo motor in dual axis solar tracking system. It is helpful in moving the panel up and down to follow the vertical movement of sun. Servo motors are employed for their ability to rotate at a specific angle and maintain that position, which is crucial in tracking systems where necessary adjustments are required to keep the panel aligned with the sun's position for maximum exposure throughout the day.

3.4 DC Motor

DC motors are typically used for controlling the large movements and rotation of a solar panel on horizontal axis such as controlling the azimuthal position of a panel. In our proposed solar tracking system, a DC motor is used to direct the panel from east to west throughout the day. We can use microcontrollers and motor drivers to control the speed and direction of DC motor to follow the sunlight and its path smoothly.

3.5 Rain Sensor

In rainy weather, the rain sensor is used to detect rain and precipitation. When rain is detected, the rain sensor sends command to the controller to prevent the solar tracking system from water by moving it to a safer place. The system is titled to a place where no water is accumulated on the surface of a system. The rain sensor helps in protecting electronic devices and panel from water damage.

3.6 Temperature Sensor

The temperature sensor is responsible for monitoring the temperature changes in the environment of the solar panels. The high temperature reduces the efficiency of solar tracking system and damages the components. The electronic devices installed in the system have specific optimum temperature. At this temperature, electronic devices operate properly with maximum efficiency. High temperatures can reduce the efficiency of solar panels or even damage sensitive electronic components. The incorporation of a temperature sensor will automatically adjust the operation of the panels in the case of exceeding optimum temperature, it can thus reduce the tracking speed or switch on active cooling[15]. This will also make sure that the panels remain within their safety operating temperature limits for efficiency.

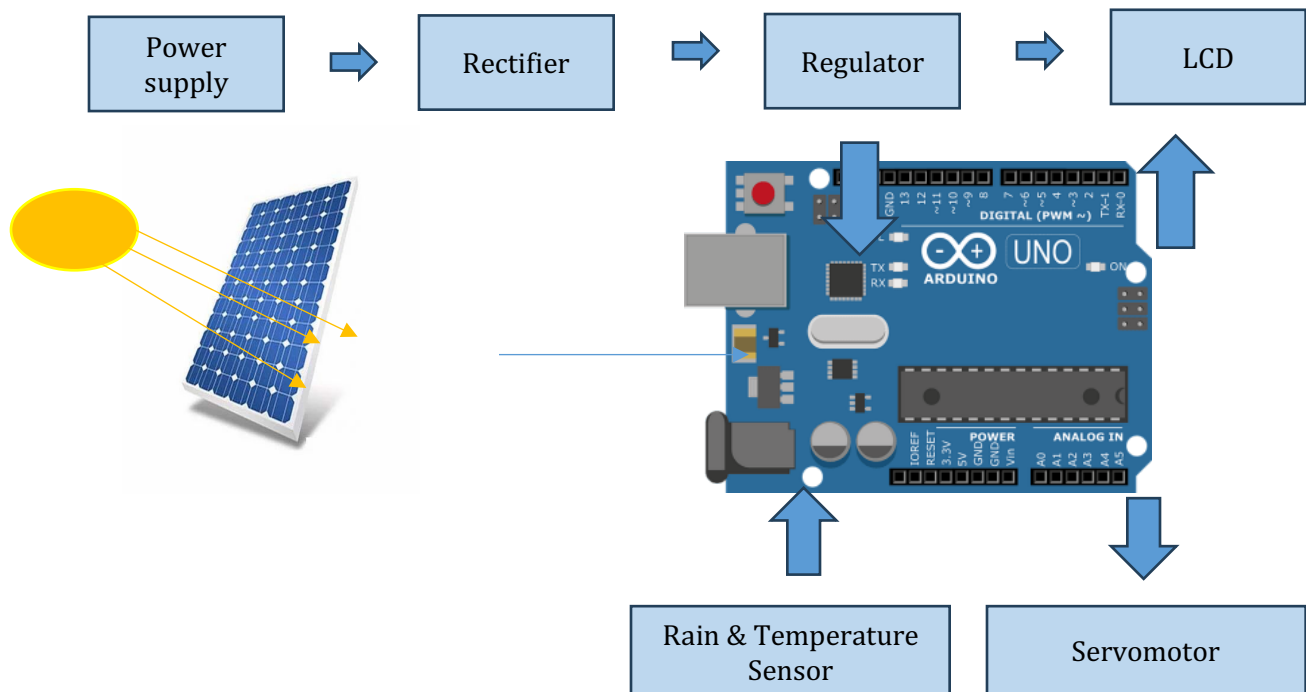


Figure 1: Block Diagram of Dual Axis Solar Tracker System

4. DISCUSSION ON THE RESULTS

The performance assessment of the Dual Axis Solar Tracking System showed that solar energy capture was increased significantly as compared to static and a single-axis tracking systems. That double-movement all-day approach netted the dual-axis system a much higher level of power production during testing, particularly in areas with a lot of sunlight angles throughout the day. This dual-axis system moved not only in the horizontal axis but also vertically, ensuring that it would always receive the maximum amount of sunlight given the predominately overhead trajectory from which said rays emanated. It allowed them to have a face the sun at all times almost perpendicularly and thus, were already very efficient in terms of energy conversion[16]. This indicates that dual-axis tracking systems perform better than static and single-axis systems in regions with less stable solar light conditions, especially near the horizon at low angles during morning hours, dawn and dusk. Utilization of the dual-axis system consistently provided emission reductions up to 40% in “best case” solar energy production compared with a fixed-tilt array during peak sunlight hours. The static system only takes in the most possible sunshine when the sun is exactly on the line of sight

with the angle of your panel which usually happens at solar noon. The efficiency of static panels drops as the sun moves across the sky, both before and after that[17]. Meanwhile, the dual-axis tracking system tracks the sun through the day and always keeps the panel perpendicular to its angle of incidence.

This was on top of an apparent energy gain of some 15-20% compared to a single-axis tracker that just handles the sun's horizontal movement (azimuth). Single-axis trackers are a good next step from static systems, but they only track east to west and do not accommodate the sun's movements in elevation. In other words, the panels can sometimes still waggle in the vertical plane (usually from off-peak sun elevations during sunrise or sunset) on broader time or seasonal scales. The dual-axis system corrects this weakness by automatically compensating for both azimuth and tilt and the panels are always directly facing the sun.

The addition of humidity and rain sensor further increases the performance, reliability and protection of a system. During rainy and windy weather, the system autonomously adjusted the solar panels to a safer position or place, reducing the risk of damage and ensuring that the system could continue operating effectively once normal

weather conditions returned. This new feature adds a protective layer to the system which is not present in single axis system and also increases the lifespan of the solar tracker system. Although the efficiency is slightly reduced in capturing maximum radiation, the system is more reliable in varying environmental conditions.

From the point of view of global system efficiency, a two-axis system may make, on average, a total energy gain of about 25-45 % above that available to a fixed-mounted system and some 15-20 % above that available to a single-axis tracking system, for the duration of test. This is especially true in the morning and late afternoon hours when the sun is low on the horizon. The double-axis system tracks the movement of the sun in both the horizontal and vertical plane. This assures that all hours can ensure identical amounts of energy-generating output. Its operation, however requires extra motors and sensors which makes it more complex. However energy generation and system resilience outweigh the extra expense due to quite frequent changes in sunlight angles and weather conditions in certain regions.

The dual-axis solar tracking system goes well above and beyond the static and single-axis systems when it comes to energy efficiency and reliability. The system manages to orient the solar panel in the azimuth and elevation directions; thus, more energy gets captured over an even wider range of solar angles, especially if the Sun's angle changes through the course of the year. This would add to the installation and maintenance costs, but long-term positive energy savings would compensate for increases in the complexity of the system as well as offer a long-life expectancy of the systems. This is particularly significant if the systems are deployed in environments that relate directly to maximizing the availability of solar energy.

Contrasted to this, DNN-based trackers model optimal solar panel orientation with much higher accuracy based on intricate and learned patterns of weather, sun position and energy output data[18]. Unlike dual axis systems reacting to instant sensor data, DNN-based trackers rely on historical data, satellite information and machine learning to predict sunlight changes in advance so the panels are ready before then. This predictive capability enhances the optimization of energy because the DNN system can take into account periods of low

sunlight or cloudy conditions by adjusting the angles of panels by a small amount or switching to more efficient configurations. The ability to learn continuously from different data sets enables DNN trackers to outperform mechanical tracking systems, especially when the sunlight conditions are changing and nonideal[19].

Such dual-axis systems provide tremendous enhancement in the energy gathering process compared to static and single-axis systems. However, since the mechanical elements of DC and servo motors govern such systems, accuracy and response time come into question. Mechanical wear, motor calibration, and sensor drift all generate small inefficiencies over time. DNN systems are less affected by such mechanical constraints because it's mainly a software-based system. Once the architecture of the system is established, a DNN tracker can monitor how well it enhances prediction accuracy over time based on additional data collection and training of the model. This self-learning capability comes out in terms of increased efficiency in the long term as the system learns better on variations in sunlight as well as the environment.

DNN systems can also reduce unwanted motor movement by beforehand ascertaining the optimum path and angular corrections. In a two-axis system, small corrections may be in order to align more often. Predictive tracking minimizes mechanical strain on motors, elongates the life of the system, and reduces maintenance costs more so than traditional mechanical tracking systems.

Technology can be a highly important role in agriculture, as it has the capacity to enhance yields, improve crop quality, and minimize the effects of agricultural activities on the environment. Within recent years, agriculture has begun to use renewable forms of energy, such as solar power, to contribute toward reduced carbon footprints of farm operations. Solar tracking systems do not only produce clean energy but can also use remote weather monitoring within the agricultural field. In fact, real-time data on weather parameters such as temperature, humidity, and rainfall can ensure the proper scheduling of irrigation, pest control, and crop management. This work presents the most important idea of presenting a system in which the efficiency of solar panels will be improved so that constant power can be provided to the sensor in the agricultural field and real-time data can be

transferred to the application. In this research study, a mechanism on improving photovoltaic array arrangement with solar power and producing maximum energy has been presented. The proposed system changes direction in the two axes, namely azimuth and elevation, by detecting the difference between the position of the sun and the panel to track the sun based on a light-dependent resistor. A testbed with a hardware experimental setup is designed to test the system's ability to track effectively based on the position of the sun. The Android app, which demonstrates real-time data, transfers the weather data to the app using a GSM/WiFi module. This research improves the existing system. Some of the results are presented, showing a relative increase up to 52% in power generation. Applying intelligent AI techniques with a QoS algorithm improves the quality of service that the existing system generates[20].

In the discussion of results, many different techniques are elucidated, and each technique has its own mode of performance and efficiency. AI, DNNs, and IoT are some of the advanced technologies that can be implemented to make solar tracking systems twice as efficient and effective. With the adoption of AI and DNNs, the tracking system would be transformed from a reactive one that waits for real-time sensor data to predict the environmental pattern and historical weather data. DNNs can model complex relationships between solar irradiance, cloud cover, temperature, and all the other factors to predict optimal panel positioning and accordingly the system can adjust its orientation in advance to catch maximum energy even when the conditions are rapidly changing. Another primary role of IoT technologies is in enabling real-time data communication between sensors, actuators, and control systems to remotely monitor and diagnose while optimizing the system. Together, the deployment of AI, DNNs, and IoT will enable higher automation and adaptability levels while working with dual-axis trackers, including higher energy output, lower mechanical wear, and more optimal responses towards environmental changes.

5. CONCLUSION

The dual-axis solar tracker system has proven to be very effective in enhancing solar energy consumption under different weather conditions.

The tracking system has the ability to move in horizontal (azimuth) and vertical (elevated) directions following the sun's path throughout the day for maximum reception of solar power. The temperature, rain and humidity sensors aid in improving the safety and performance of system in varying weather patterns that can cause damage or wear and tear of the system. DC and servo motors are used to control the position and orientation of the tracking system. The sensors give commands to the microcontroller or Arduino based on the information received from different sensors and then generate output according to the given data. To sum up, the dual-axis solar tracking system can be an effective approach to optimize capture of solar energy. Typically, a tracker is more efficient than static single-axis systems when solar angles vary throughout the day. The complexity of the system requires a larger initial investment and more maintenance than other systems but long-term increase in energy production offset the disadvantages, making it an attractive option for solar alternative in varying weather conditions.

• Recommendations

The global shift towards AI, DNN and IOT techniques make it possible to design and implement solar based tracker in real time monitoring under different weather conditions. The deep learning based dual and hybrid axis solar based trackers are more effective and efficient leading to more accurate outcomes. However, these techniques are not easy to implement as it requires predictive algorithms and a larger amount of dataset in the form of multiple climatic conditions and varying intensity of sun. The combination of CNN, LSTM and GRU techniques in designing a model serves as an innovative approach for future research. These techniques contain both temporal and spatial domain. By integrating these algorithms, the designed model achieves superior accuracy and performance as compared to the previous research.

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