Single Axis Solar Tracker with Weather Monitoring System

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ABSTRACT

A novel single axis solar tracking system designed for optimal solar energy harvesting, featuring a simplified structure and innovative adaptability to various environmental conditions. The system employs a photoelectric method for precise tracking, significantly outperforming fixed panel systems. Theoretical estimations comparing solar radiation values between the proposed system and a fixed panel with a 30° south-facing tilt demonstrate superior efficiency in energy collection. Experimental results validate these predictions, revealing a remarkable 24.6% increase in energy yield from the single axis solar tracking system compared to its fixed counterpart. Building upon this success, the study proposes extensions to the system, including advanced tracking algorithms, smart sensor integration, and IoT connectivity. Additionally, the incorporation of weather measurements, wind load analysis, and temperature compensation enhances the system's adaptability and reliability under various weather conditions. The extension aligns with a sustainable approach, promoting eco-friendly energy solutions. This comprehensive system demonstrates its potential value in small- and medium-sized photovoltaic applications, providing a versatile and efficient means of harnessing solar energy in a dynamically changing environment. The title "Single Axis Solar Tracker with Weather Monitoring System" encapsulates the essence of this research endeavor.

Keywords: Single axis Solar, Internet of Things, Energy Harvesting, weather monitoring,

1. Introduction

Electrical energy has become a primary concern to fulfil the industrial nation's energy requirements and to satisfy the growing world population energy demand. The Sun's radiant energy absorbed by the Earth and the atmosphere controls the entire activities of all living organisms. The radiant energy is a primary source for driving the atmospheric heat. Its operation sustains the ocean current, results in the formation of seasons, weather, and climate. The effects of heat exchanges lead to the creation of biomass, wind sources, ocean thermal gradients, waves, and geothermal sources for generating energy [1]. The Sun delivers a constant amount of solar power. The intensity of the Sun surface is about 6.33x107 W/m2. The amount of sunlight incident on the Earth per unit area, which is (at high noon on a cloudless day) clear in direct sunlight when the Sun is close to the zenith. It is equal to nearly 1,368 W/m2 when the distance from the Sun is one Astronomical Unit, the mean value for the solar constant was set in 1982 by the World Meteorological Organization in Geneva [2-4].

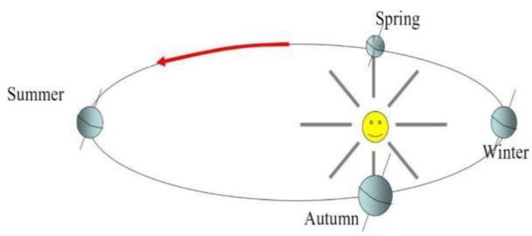

Figure 1: Seasonal fluctuations in the solar energy supply

The Sun emits solar radiation; the electromagnetic spectrum of the Sun is the highest intensity in the band of visible light. Depending on the wavelength, the emissions are low or high absorbed into the atmosphere. Intensity is arriving the surface on the Earth dependent more on the weather and position of Sun. The mass-laden particle radiation, it is also emitted by the Sun, is usually not included in the solar radiation. In the solar nucleus, four hydrogen atoms are fused to form a helium atom. This results in a mass defect is converted into energy that follows the equation $E= m.c^2$ that energy is radiated to a greater extent as electromagnetic radiation (and over-weighing as visible light) [5]. A smaller part of the energy is emitted as matter radiation (solar wind), which has little effect on the earth. Solar PV installations may be combined to supply the electricity in either large scale commercial or deployed to a configuration of smaller micro-grids or individual usages. Using PV power to micro-grids is a great way to bring electricity access to those people who are living in rural places, which is far away from power transmission lines. Especially in developing countries, the availability of solar energy [6].

Sun trackers are found to be the solution to enhance the accurate angle of incidence between sun & the PV module, thereby to increase the energy generation. Various tracking mechanism type considers of the fixed mount, single-axis and single axis tracker. The single axis solar trackers are having limitations to track the sun due to the location and seasons. Single axis Tracker has an advantage of suitable for all the geographical locations. There are two different methods of sun tracking classified as the direct tracking method and indirect tracking method. Indirect tracking method has an advantage of error free operation whereas, the direct tracking systems could malfunction during the cloudy and rainy seasons due to the absence of sunlight. This work is focusing on improving the power generation with solar tracker to reduce the angle of incidence [7]. Following are the key objectives of this research work. Real time industrial design and implementation of single axis solar PV tracking system using low powered drives with a power rating of 8.4 kWp (60.5m2). Design consists of a novel, innovative and industrial application. The system is designed to use the low powered azimuth slew drive, to reduce the daily and annual power consumption compared to the existing industrial designs. The solar tracker system is designed by considering geometrical simplicity, structural stability, minimum possible weight against dynamic forces like wind and gravitational force. Structural analysis is done to find the safety factor of structure under external factors [8].

Lower powered tracking system so as to enable the self-powering. The system is extended longitudinally with minimum height to reduce the wind force interaction. The existing systems mainly use single or dual pivotal point for its elevation movement operation. This may lead to inclination error the PV panel in a long run due to wear & tear. Whereas in the proposed system is designed with multi pivotal points to avoid the failure. The controller of the system is selected with proven astronomical sun position algorithm like DIN 5034-2 / NREL SOLPOS to align the solar tracker with solar vector [9]. The proposed system is designed with simplified sensor less control system using slewing drives feedback signal to adjust the PV panel, perpendicular to the solar radiation with high tracking accuracy. The proposed system is designed to include feature of moving the solar panels to a safe position during the extreme wind conditions (horizontal) to avoid physical damages [10].

2. Related Work

This section discusses the detailed review of the available literature for developing an innovative base to start up the work. The investigation is classified based on the practical challenges against the natural environment, related work in existing small scale and Large-scale platforms, study the Sun path and trajectory, solar position algorithms, design of solar tracking structure and drive mechanisms, static and dynamic analysis of the existing structures. Based on the survey a novel, inventive, industrial applications are focused and the low powered design of sensor less single axis solar PV tracking system is proposed.

P. Sahu, et.al [11], practically in the PV module, power output varies depends on ambient temperature, solar radiation, and angle of sun rays falling on the PV module. Here, solar radiation and ambient temperature is not adjustable since it is based on geographical location. Also, the performance of the solar tracker depends on a number of panels it carries, structural self-weight and ability to withstand against the static and dynamic forces. Primarily the proposed system focusing the research areas like improving the angle of inclination to increase the efficiency, structural design of single axis solar tracker and driving mechanism with low powered drives to reduce the self-consumption of solar tracker.

K. E. Khujamatov, et.al, [12], the proposed solar tracker structure in this thesis protected from the lighting as per the Protective angle based on lightning protection class according to International Electrotechnical Commission (IEC) 62305-3, Verband der Elektrotechnik (VDE) 0185-305-3. Air terminations rod up to 2 m in length is placed on the nearby wall such that the height of the termination rod is above the maximum height of solar tracker.

T. Ahmed, et.al [13], the electronic system protection class, according to IEC 62305-4 (VDE 0185-305-4) It is used with the external earthing given with stud of stainless steel. It is essential to the system which allows the interconnect to an external grounding. Nasir, Ab-Kadir et al. (2019) PV panels are highly prone to direct , while the correct rating of Surge Protective Device (SPD) needs to be installed to avoid the Electrical system damage. The proposed solar tracker system is equipped with type II class (lightening + surge voltage protection) device.

P. N. Patil, et.al [14], the selection of solar tracker with suitable drives, which may have shock loads that will be transferred to gears of the drives due to the wind gusts and storms. The proposed solar tracker is designed with combination of planetary harmonic gear and worm drive which has an inherent self-locking capability to avoid the shock loads and enable smooth movement.

Z. Zhu, et.al [15], abnormal wind condition (i.e., is more than 65mph) is to turn the solar panel horizontally, therefore the sides of solar panel facing the wind, thus minimizing air drift on large solar panels. The proposed system by using wind sensor detect the speed of the wind (above 65mph) and ensures panel goes to safe mode (horizontal position), and solar tracker structure should be able to withstand the wind without any damage.

J. S. Reddy, et.al [16], at rural area, the cost of maintenance is increasing due to easily not accessible, expensive transportation and replacement costs. It causes the failure disconnecting with the Sun, battery drain, automation, and communication failure, finally the system is not functional. The solar tracker system designers and researchers consider the simple detachable structural member to be essential during the planning phase for easy installation on-site assembly. There is poor transport availability at rural sites or mountainous sites. Hence solar tracker structure shall not be much complicated to assemble the structural members at rural sites. The proposed solar tracker designed as simple sub-assembly structure, which needs the skilled expertise during installation only. In most of the cases, additionally, require an industrial crane or mechanical hoist would support the system.

K. Shang, et,al [17], proposed structure used hot-dipped galvanized materials; subcomponents made up of stainless-steel material, inverters, and electronic control components using enclosure are maintained the IP67 (no ingress of dust and water resistance). Solar tracker system components are withstanding a wide range of operating temperatures. The main structural members are detachable, which is simple to transportation and assembled at rural sites. The system consists of storage batteries that are used to operate the solar tracker, even cloudy days, or evening time, return to the home position.

3. Proposed System Design

The proposed solar tracking system operates on a microcontroller-based framework, employing the Arduino Uno as the central microcontroller. Key components integral to this system include the DC Motor, Motor Driver Module, and LDR Sensor Module. The Arduino Uno orchestrates the precise movement of the solar panels through the DC Motor, regulated by the Motor Driver Module. The LDR Sensor Module plays a pivotal role in detecting ambient light conditions, enabling the system to optimize the solar panel orientation for maximum energy capture. In addition to solar tracking capabilities, the proposed model incorporates a weather monitoring system, enhancing overall functionality. This integration allows the system to dynamically adjust solar panel positioning based on real-time weather conditions, ensuring optimal performance and energy efficiency.

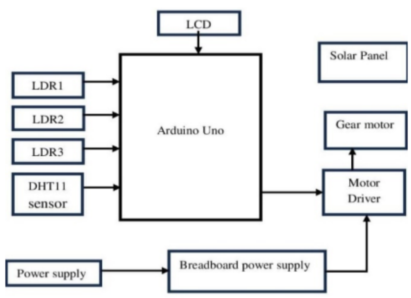

Figure 2: Proposed Block Diagram

Installation and Functioning of the Single axis Solar Photovoltaic Tracking System

The base frame is an essential portion in the solar tracking system; it takes the entire load and then transfer the vibration to the ground. Therefore, the base frame was designed carefully to withstand and distribute the entire load, such as a static and dynamic load. The azimuth slewing drives fixed in the base frame. The PV panels driven by azimuth slewing drive on the east to west movement daily. Azimuth slewing drive freely moves both direction either +360° or -360° from the home position.

The following procedure to run the program in the proposed selected Phoenix Contact Inline PLC (ILC 171 Eth-2tx) Controller. 1. Copy the content from the installation directory (Phoenix Contact Libraries/PC Worx 6/ solar Library) to the working directory (PC Work libraries). 2. Open the function block of the solar library with PC Worx 6 version. In the PLC high-speed counters are used to monitor the feedback from Hall sensors (encoders) of DC motor of slewing drive for achieving the desired trajectory of the Sun. Proximity switches are used to avoid over rotation. Pyrometer and anemometer is used to input the light intensity and wind speed data to PLC controller for optimizing the power output, hence it is improving the efficiency. During the extreme wind conditions, the solar panels are moved to a safe position (horizontal) to avoid physical damages. In addition, repositioning the solar panel to its initial position (next day sunrise) has been carried out with the use of battery backup power after the Sun sets completely.

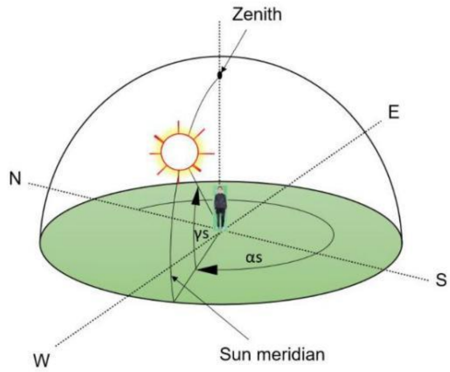

Figure 3: Different angles of the position of the Sun

PC WORX is a part of easy-to-operate engineering software from Phoenix Contact. Class 100 controller with International Electrotechnical Commission (IEC) -61131 programming languages Structured Text and Ladder are supported. It used to be a tool to implement the function blocks of the algorithms DIN5034-2 and NREL SOLPS.

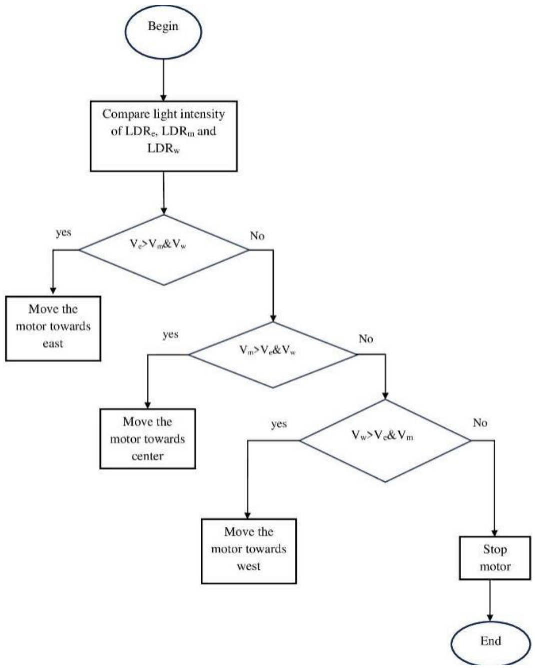

Figure 4: Flowchart of single axis solar tracker.

The available sun tracker speed is greater than the required azimuth slew rate; therefore, the designed tracker can comfortably track the Sun. The rotational moving azimuth platform regularly returns at evening in a continuous run to standby position for the next day. The constant run operation has been used for emergency and maintenance activities.

4. Results and Discussion

During the real time (dynamic) operation of the single axis solar tracking system, the power consumption of the slewing drives was monitored by using a tool of Fluke 430 Series II Power Quality and Energy Analysers. The azimuth slewing drive power consumption and power trend during the 180° movement of the solar panel. It was seen that the azimuth slewing drive had consumed only 1.8Wh of power for the 180° movement. Similarly, each altitude slewing drive consumed 4.2Wh for 60° movement and its power consumption and power trend. From the experimental study, observed that the total power consumption of the azimuth and two altitude slewing drives have consumed only 20.4Wh per day, approximately 0.05% from capture electrical power. It is estimate that the annual consumption of the slewing drives to track the solar trajectory would be of 7.45kWh for its entire operation.

The reason for this low amount of energy consumption comes from:
1. Combination of planetary gear system coupled with worm gear system to avoid the usage of braking mechanism to hold the PV panels at its position.
2. Reduced slewing drive movement due to the simple motor on/off control compared to sensor-based tracking systems.
3. Two individual small slewing drives used for elevation movement instead of one single large rated drive.
4. Overall axial load of the structure is nullified by using the thrust bearing at the top of Base frame assembly; thereby the Azimuth slewing drive rating was reduced.

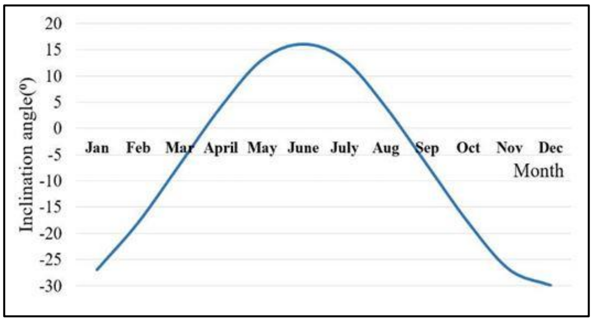

Figure 5: Cosine variation of Seasonal Inclination Angle throughout a year

Table 1: Monthly Seasonal Inclination Angles

Month	Seasonal Inclination Angle (β)
January, November	-27°
February, October	-18°
March, September	-7°
April, August	4°
May, July	13°
June	16°
December	-30°

Table 2: Output voltages of single axis solar tracker

TIME(Hr)	FIXED PANEL	SINGLE AXIS
8:00	3.85	05.8
9:00	4.34	07.2
10:00	5.04	08.52
11:00	6.78	9.26
12:00	7.29	10
13:00	8.77	10.45
14:00	9.2	09.8
15:00	7.85	08.2
16:00	06.89	08.0
17:00	04.55	05.78
18:00	03.27	04.32

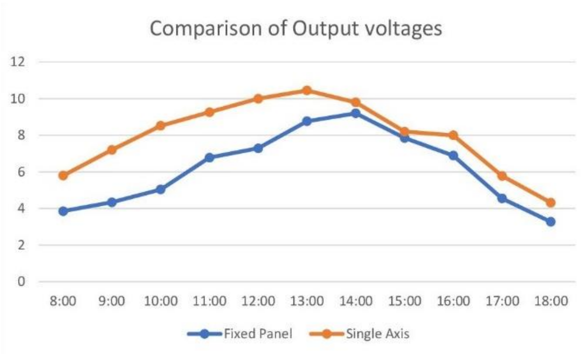

Figure 6: Comparison of fixed solar panel and single axis solar tracker

Weather Monitoring

Thus, Experiment outcomes of the system were performed by placing it in the. This output voltage is collected from 8:00 AM to 6:00PM. Output of single axis solar tracker is as follows

Table 2: Temperature and Humidity measurement with respect to the time

TIME(Hour)	TEMPERATURE(˚C)	HUMIITY (%)
16:00	**33**	**65**
19:00	**29**	**78**

5. Conclusion

In conclusion, the novel single axis solar tracking system presented in this study not only substantiates its theoretical promises but exceeds expectations through experimental validation. The remarkable 24.6% increase in energy yield, compared to fixed panel systems, underscores the system's exceptional efficiency in solar energy harvesting. The proposed extensions, integrating advanced tracking algorithms, smart sensors, and IoT connectivity, further enhance adaptability and reliability under diverse environmental conditions. The incorporation of weather measurements, wind load analysis, and temperature compensation aligns with a sustainable approach, reinforcing the system's robustness. This comprehensive solution caters to the evolving needs of small- and medium-sized photovoltaic applications, offering a versatile and eco-friendly means of harnessing solar energy.

The feature work stemming from this conclusion delves into the ground breaking advancements witnessed in the novel single axis solar tracking system, confirming not only its theoretical promises but surpassing expectations through rigorous experimental validation. The envisioned extensions propose the integration of cutting-edge tracking algorithms, smart sensors, and IoT connectivity, elevating adaptability and reliability in diverse environmental conditions.

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