Highly Efficient Hybrid Multi Axis Solar Sun Tracking System for PV Power Stations

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Abstract:
The light, which is an inexhaustible source of solar energy, radiates solar energy, which is also considered green energy. The efficient collection of renewable energy from the photovoltaic solar cells (PV cells). In real-time, the location of the sun in the sky is constantly varying from time to time. The production of PV cells is strongly dependent on the light intensity of the sun, a basic reason for a typical PV cell to become low. Various control processes such as static solar trackers, single-axis solar trackers and dual axis solar trackers are present in the literature. This paper presents the design and construction of a cost-effective active dual-axis solar tracking system for tracking the movement of the sun to get maximum power from the solar panels as they follow the sun. The code has been developed using C++ programming language and targeted to Arduino UNO microcontroller. The performance of the Single-axis tracker was analysed and compared with the Dual-axis tracker and the proposed method is validated with the experimental approach and better results were obtained in dual-axis solar tracking with 14% more power gain compared to single-axis solar tracking.
Keywords: Solar energy, Dual-axis Solar tracker, Photovoltaic Panel, Light Dependent Resistor, Arduino Uno, Servo Motors.

1. Introduction

Solar energy has taken more popularity in recent years, i.e., alternative energy sources worldwide for their green energy. This energy supplies are of various forms, such as Hydropower, Wind Power & Biomass Energy, which are currently used worldwide for energy supply. Solar energy is both an integral and a prerequisite option for traditional renewable energy sources. A solar tracker is a device that orients the photovoltaic panels continuously, according to the changing position of the sun, and hence ensures that at every possible time the position of the solar panel is perpendicular to the sun to maximize efficiency. A solar tracker is a proven technology. If trackers are not

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used solar panels should be oriented in optimum position i.e., at a tilt angle equal to the latitude of the sun-facing south or northern hemisphere. In any solar application, the conversion efficiency is improved when the modules are continually adjusted to the optimum angle as the sun traverses the sky. As improved efficiency means improved yield, the use of trackers can make quite a difference to the income from a large plant. The conversion of UV radiations into useful forms of energy sources like Electricity or Heat energy is called solar energy. The technology used to convert solar energy directly into Electrical energy is known as photovoltaic cells or solar cells. There is a physical similarity between the P-N junction diode and solar cell. The sunlight which is absorbed by the PV cell which contains semiconductor materials knocks electrons from their atoms to produce electricity by allowing electrons to flow throughout the materials [1] [2]. Solar energy has become widely utilized and validated because of its sustainability, ubiquity, cleanliness, and abundance [3]. Solar power could provide 20TW of power approximately twice the world's consumption rate of Fossil energy estimated by different researchers through 0.16% of the land on Earth with 10% of efficient solar conversion systems [4]. This brings out the necessity of tracking mechanism in solar systems which in turn proves the potential of solar energy. To get the maximum energy from the solar cells, the solar radiation is always maintained perpendicular to the surface of the solar cells by this tracking mechanism which is also known as Electromechanical systems [5]. Smart trackers have been developed by researchers for a long period to maximize the amount of energy generation. Based on the latitude of the location of the sun, the static solar panel was positioned with a feasible tilted angle before solar tracking methods came into the picture. By introducing automated systems in this world of advanced scientific discoveries power generation can be improved by 50% than the existing power generation [6]. Based on their movement of degrees of freedom there are mainly two types of solar trackers. They are Single-axis and Dual-axis solar trackers. Further, they are classified into three systems based on their technology of tracking are Active, Passive, and Chronological trackers [7] [8]. Single-axis tracking systems were formerly used by researchers, where they follow only one direction (sun's daily motion) [9]. But the complex motion is followed by the Earth that incorporates the Daily motion and the Annual motion. The east to west direction of the Sun over the Earth is caused by the Daily motion whereas the Sun is tilted to a particular angle while on the move from East to West direction. This is caused by the Annual motion [10].

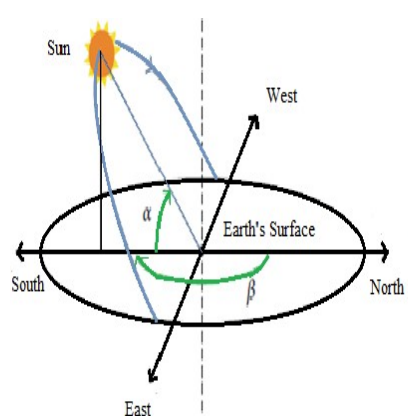

Figure.1: Demonstration of Solar angles [i] Altitude angle (α), [ii] Solar Azimuth angle (β).

The path of the sun corresponds to a day in the early fall or late winter seasons in the northern hemisphere, that is just before the spring equinox or just after the fall equinox. Solar noon is the time of day when β=180º, i.e., the sun is directly at the south and is halfway between sunrise and sunset. Angle 'α'is the angle between the sun's position and the horizontal planed of the earth's surface while angle 'β' specifies the angle between a vertical plane containing the solar disk and a line running due south [11]. When the tilted angle of the solar tracking system is been synchronized with the seasonal changes of the Sun's altitude, maximum solar tracking can be achieved [12]. To ensure that the maximum efficiency of the solar panel is not being used by the Single-axis tracking systems there is an ideal tracker that allows the solar modules to direct towards the sun. This ideal tracker compensates for the changes in both altitude angle of the sun (throughout the day) and latitudinal offset of the sun (during seasonal changes) and whereas a Dual-axis tracking system would ensure Cosine effectiveness of one. In comparison between Active and Continuous tracking, sensors determine the position of the sun continuously in the sky during the day. The monitor or controller i.e., motors will be triggered by the sensors to move the mounting system so that the solar panels will always be perpendicular to the sun throughout the day. If the tracker is not perpendicular to the sun, the sun rays will not be perpendicular to the solar panels as a result there will be a difference in light intensity on one sensor compared to another. Due to this difference in light intensity, the direction of the tracker can be determined so and tilt the solar panels to be perpendicular to the sun. This method of tracking the sun is reasonably accurate to expect only on very cloudy days as it is hard to senses and determine the position of the sun in the sky for the sensors [13] [14]. The trackers which move in response to the variation in pressure at both the ends of the solar tracker is occurred due to the gas pressure created by the solar heat on a low boiling point in the compressed gas fluid which is driven to one side or the other to move the system. Although this method is not accurate for tracking the sun [15] [16]. The time-based tracking system is one where the structure is moved at a particular rate all day and even for different months which is known as Chronological trackers. Hence to rotate at an average rate of only one revolution per day the Motor or Actuator is been controlled. In this mechanism, the energy efficiency of the solar tracker is increased [17]. To track the sun's moment accurately Dual axis solar tracking system is highly necessary. To track the sun for the light intensity variation with precision the Active or continuously tracking systems are also necessary. Therefore, power gain from this system is highly efficient [18]. The system uses two different Motors continuously in two different axes to attain thus Power gain and compared to the time-based tracking system it consumes a certain amount of extra Power. There-fore to minimize the power loss a combination of time-based and Active tracking systems can be a desirable alternative to the tracking system. Ultimately the motive of this research is to design and implement an Active Dual axis solar tracking system with a time-based tracking technique and in turn, can be named ad Hybrid Dual axis tracking system which minimizes the power consumption of motor while tracking the sun's position precisely.

2. Methodology

The principal part is Arduino Uno, a microcontroller with a single board. It is low-cost and has an open-source physical computing platform as well as a programming environment for writing applications for the board. Other key components are LDR

{Light Dependent Resistors}, Servo engine, Resistors, Solar panel. The technique used is seen in Figure1. Sensors, e.g., LDRs is used for the solar monitoring system. The Arduino Uno analogue pin A0 to A3, which serves as the systems' input, is connected to four LDRs. A built-in analogue converter is used to transform an LDR's analogue value (Pulse Width module) into a digital one.

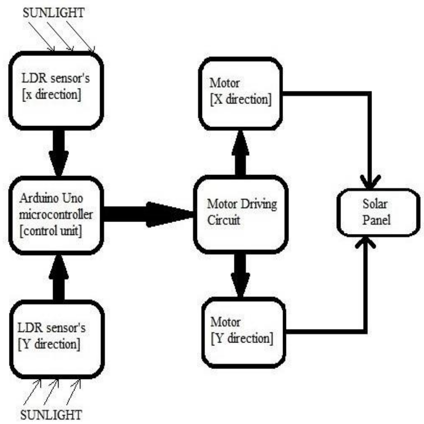

Figure.2: Dual Axis Solar Tracker Hardware Diagram Block Implementation.

For moving servo motors, the values of the PWM pulse are used. You choose the optimum luminous intensity from one input of the LDR and the servo motor moves over the direction of the solar panel with regard to the LDR in the programming. The motor rotation is four points: 0°, 45°, 90°, and 180°. The positions of the LDR are divided into four positions i.e., Right, Left, Up, and Down. The four positions allow the highest intensity of sunlight to be detected. A LDR analogue input is obtained from the microcontroller and is converted by an Analog-Digital converter into a Digital Signal. The solar panel rotation is determined by the performance of the Servo engine.

Hardware Implementation:

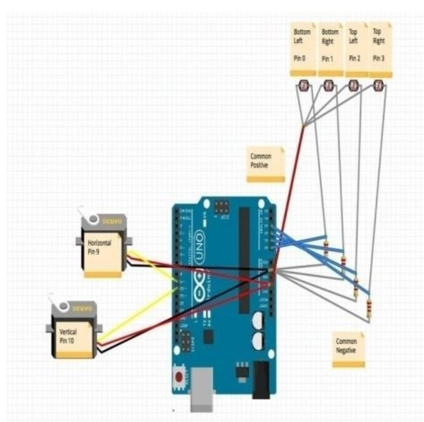

Figure.3: Displays the configuration and connections of the hardware modules.

To design the full Dual-Axis Solar Tracker, the above equipment is implemented and integrated.

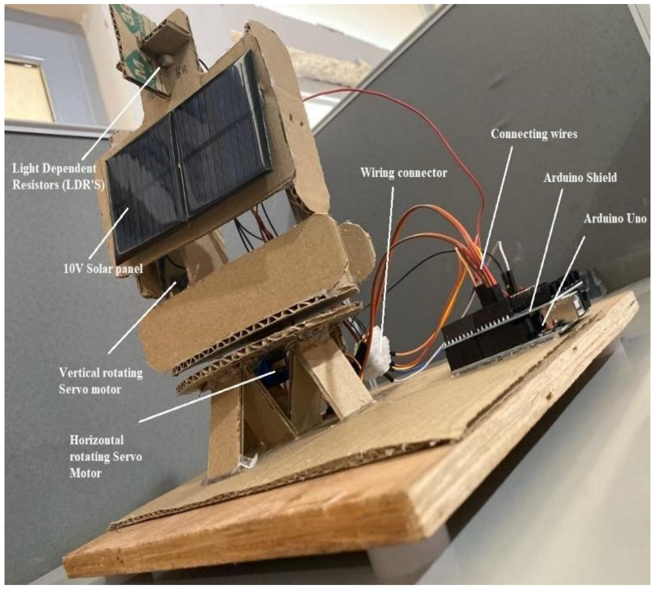

Figure.4: Proto Type model of Dual Axis Solar Tracker

The list of the components are mentioned in the below table.

Table 1: List of Components

Sl. No.	Components	Specifications	Qty
1	Micro-controller	Arduino Uno 328AT-MEGAP	1
2	Solar Panel	5V, 200mW	1
3	Servo motor	MG995 180º	2
4	LDR's	LDR 5mm	4
5	Arduino Shield	Proto Shield REV3	1
6	Connecting wires	Male-female Jumper wires	As per required
7	Wiring connector	Terminal block screw type	1

3. RESULTS AND DISCUSSION

The study of the power output of a solar panel. The conduction and experimentations have been conducted in Bangalore, India.
Current and voltage values obtained from the static panel, single-axis tracking, and Dual-axis tracking systems for various times in a day are shown in Table 2.1. it is seen that at 8:00 am compared to the static solar panel there is much improvement in the currents of both the tracking systems which is shown in Table 2.1. There is a difference in the current

values in these three tracking systems as time goes on and decreases till 11:00 am. Then the sun starts to rotate more towards the west, this difference will rise again. The values 0.47A, 0.48A, and 0.50A respectively are the highest currents of static solar panel, single-axis tracking system, and Dual-axis tracking system at 12:30 pm. The voltage has no direct relation with sunlight intensity as in the case of voltage the variation is comparatively low. The maximum output power of the Static solar panel and both the tracking systems is shown below in Table 2.2. This Table also shows the power gain of the tracking systems over the static solar panel and between two tracking systems for a different period. At 12:30 pm it is found that the maximum output power of static solar panel, single-axis tracker, and Dual-axis tracker, respectively are 3.814W, 3.889W, and 3.956W. As the Dual-axis tracking systems can precisely track the sun at these times much more power gain can be obtained and not in a Single-axis tracking system. For all these technologies power fall was very fast from 3:30 pm to 5:30 pm because of the low duration of daylight. The total power of the static panel, Single-axis tracking system, and Dual-axis tracking system throughout the day are 45.41 W, 56.69 W, and 58.24 W respectively. So the average power gain of a Single-axis tracking system over the static panel is 25.62%. Similarly, the average power gain of Dual Axis tracking system over static panel is 28.10% and over Single-axis tracking system is 4.19%.

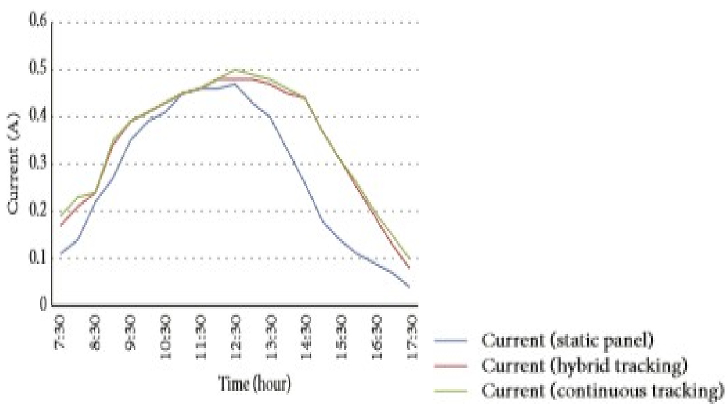

Figure.5: Demonstration of Time v/s Current curve for Dual axis tracking system, Single-axis tracking system, and Static solar panel.

Table 2.1 Current and voltage values of static and tracking panels at different times in a day.

Time (hours)	Static solar panel		Single Axis Tracking		Dual-axis tracking	
	Current (A)	Voltage(V)	Current (A)	Voltage(V)	Current (A)	Voltage(V)
7:30	0.11	7.82	0.17	7.82	0.19	7.92
8:00	0.14	7.82	0.21	7.82	0.23	7.92
8:30	0.22	7.83	0.24	7.83	0.24	7.9
9:00	0.27	7.9	0.34	8	0.35	8
9:30	0.35	7.93	0.39	7.98	0.39	7.98
10:00	0.39	7.92	0.41	7.92	0.41	7.92
10:30	0.41	7.88	0.43	7.92	0.43	7.92
11:00	0.45	7.88	0.45	7.88	0.45	7.88
11:30	0.46	7.88	0.46	7.88	0.46	7.88
12:00	0.46	7.88	0.48	7.88	0.48	7.88
12:30	0.47	7.88	0.48	7.88	0.50	7.88
1:00	0.43	7.88	0.48	7.88	0.49	7.88
1:30	0.4	7.77	0.47	7.81	0.48	7.81
2:00	0.33	7.79	0.45	7.83	0.46	7.93
2:30	0.26	7.71	0.44	7.71	0.44	7.83
3:00	0.18	7.63	0.37	7.76	0.37	7.9
3:30	0.14	7.54	0.31	7.7	0.31	7.86
4:00	0.11	7.52	0.25	7.73	0.26	7.86
4:30	0.09	7.41	0.19	7.71	0.20	7.71
5:00	0.07	7.39	0.13	7.65	0.15	7.71
5:30	0.04	7.33	0.08	7.5	0.1	7.64

Table 2.2 Power values of static and tracking systems and the corresponding Power gain over static panel.

Time (hours)	Static panel Power (W)	A single-axis tracking panel Power (W)	A dual-axis tracking panel Power (W)	Power gain by a single-axis system over static panel (%)	Power gain by Dual-axis system over static panel (%)	Power gain by Dual-axis system over Single-axis system (%)
7:30	0.86	1.32	1.91	35.29	42.83	49.65
8:00	1.09	1.64	2.4	33.33	39.89	42.65
8:30	1.72	1.87	2.8	8.33	9.14	18.84
9:00	2.13	2.72	3.42	21.58	23.82	31.98
9:30	2.77	3.11	3.931	10.81	12.81	19.85
10:00	3.08	3.24	4.12	4.87	4.87	11.16
10:30	3.23	3.4	4.56	5.13	6.13	13.51
11:00	3.56	3.54	4.7	4.81	6.89	14.22
11:30	3.64	3.62	5.012	4.39	7.79	15.16
12:00	3.64	3.78	6.8	4.166	9.823	19.95
12:30	3.70	3.78	7.21	6.391	12.24	22.36
1:00	3.38	3.78	7.4	10.41	12.24	23.59
1:30	3.10	3.67	7.74	15.32	17.09	28.73
2:00	2.57	3.52	7.62	27.04	29.52	35.83
2:30	2	3.39	7.44	40.90	41.81	49.4
3:00	1.37	2.87	6.92	52.16	53.01	61.53
3:30	1	2.38	6.43	55.77	56.67	67.77
4:00	0.82	1.93	4.04	57.19	59.52	72

4:30	0.66	1.46	3.5	54.47	56.75	65.43
5:00	0.51	0.99	2.15	47.98	55.27	55.79
5:30	2.13	0.6	2.76	51.13	61.62	73.14

4. CONCLUSION

This paper introduces a scale-down, active dual-axis solar tracking device architecture to provide an effective solar distributed system. The device has been successfully designed and run. The prototype is designed to make it workable. The benefits of the proposed dual axis tracker are (i) the servo engine is the most effective solution as the solar panel's driving mechanism with lower energy than the stepper engine/permanent magnet-DC motors with gears. The power consumption is reduced. (ii) The proposed tracker is cost-effective: quick and accurate. It also defines the remainder of the tracker. (iii) The controller is an economical Arduino Uno: a one-board microcontroller; an open-source software-oriented electronics platform. A designed solar tracking system are used in remote areas for the generation of small-scale solar PV power. It may also be used in street solar systems or other independent solar photovoltaic applications. (i) Higher technical difficulty, making it more difficult to get things inaccurate, are the drawbacks of the proposed Dual Axis tracker. (ii) Lower lifespan and lower reliability and (iii) Unreliable performance in cloudy or overcast weather. The economical and environmentally friendly Hybrid Dual axis tracking system also can be a great technique in utilizing the superiority of solar energy thus solving the increasing demand for Electricity problems. The running efficiency of the solar PV panel can be further enhanced by developing an automatic dust sensor wiper for maintaining absorption of solar radiations by the solar PV panel. In addition, there are various approaches to improving performance and changes to the procedure can be achieved to increase the results. Finally, the main facets of this project are the affordability, performance, independence, ease of transport and preparedness for use.

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