GREEN FINANCE AND THE AUTOMATE SOLAR TRACKING SYSTEM: ASSESSING EFFICIENCY, FINANCIAL IMPACT, AND ENVIRONMENTAL BENEFITS

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Abstract

The goal of this project is to create a functional solar energy prototype that can automatically adjust the solar panel's orientation towards the highest intensity of light using sensors. The researchers also want to evaluate the system's effectiveness and the financial implications of its cost. The researchers developed a tilted single axis solar tracker (TSAT) that ensures the conversion of solar energy into electricity is improved by aligning the solar panel with the sun's actual position. A microcontroller controls a DC stepper motor, which moves a mini PV panel based on signals from two basic but efficient light sensors, in order to make the experimental model of the device work. The performance of the solar tracker was assessed and analyzed experimentally. The financial impact of a TSAT was also calculated.

The researchers discovered that the tracked panel's financial impact was 7.5% lower than the tilted fixed panel's. They came to the conclusion that tracked panels are more financially advantageous and efficient than tilted fixed panels. The findings of this study show that TSATs are a promising technology for enhancing the efficiency of solar panels and lowering the cost of solar energy. Further research is required to enhance the TSAT design and make it more cost-effective.

Keywords: Financial Impact, Green Finance, Solar energy, Solar-tracking system (STS), PV panel, Renewable energy, Sustainability, Climate change, Energy efficiency.

Introduction

Every day, a significant amount of energy is extracted, transferred, transformed, and used worldwide. Fossil fuels account for 85% of the energy produced (International Energy Agency, 2009). Radiation is immediately converted into electrical energy by solar cells. The primary component of solar panels is silicon, which has an efficiency of up to 24.5% (Hill & Archer, 2001). There are two types of sunlight that reach the surface of the Earth:

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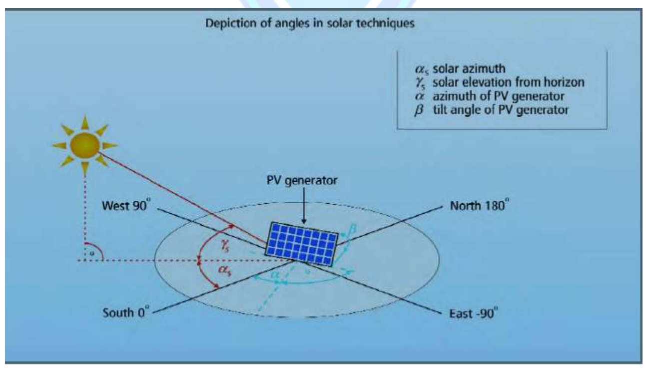
direct sunlight and diffused sunlight. The panel's overall output will rise if diffused light is reflected onto it by the reflectors (Rahman, Ahmed, Fahmi, Tasnuva, & Khan, 2009).The solar azimuth and altitude can be used to show the sun's height at any given place. Due south is typically expressed in solar panel systems as = 0°. The angle is denoted with a negative sign (east: = –90°) to the east and a positive sign (west: = 90°) to the west.

There was a lot of discussion regarding cost-cutting and solar cell performance between 1959 and 1970. The solar cells' efficiency was only 14% at the time. Paul Macready created the first solar-powered aircraft in 1981. With an efficiency of 36%, the most efficient solar cell was created in 1999 (The History of Solar Energy, 2023). 2012 saw the installation of the largest energy plant in history on an industrial scale, with a 200 megawatt (MW) capacity, at Golmud Solar Park in China. The Gujarat Solar Park in India, a group of solar farms dispersed around the Gujarat region with a combined installed capacity of 605 MW, is perhaps superior (The History of Solar Energy, 2023). Even if the cell wasn't very effective, it was discovered that solids might generate electricity without the need for heat or moving parts (History of solar energy, 2022). The scale of the installation, electricity costs, government incentives, land limitations, latitude, and local weather all have a role in the tracker type choice.

Figure 1

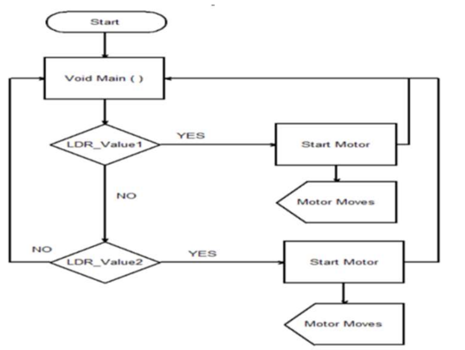
Angles in solar technology



The incline single axis tracker (TSAT) is our choice. The suggested tracking system aims to spin the solar panel in the direction of the plane with the highest light intensity. The PV panel can be mounted on a mounting base so that it rotates around the pivot point to do this. To begin the setup and design, we are assuming uni-polar single-axis stepper motors that are currently on the market. Although there are 200 steps throughout the entire revolution, only 100 are necessary to attain our functioning. Hardware designs take power and size into account.

Figure 2

Flow chart of LDR-Motor Control



The positioning, two numbers, and light-detecting resistor (LDR) were all on the PV panel's edge. Cables were used to connect the Analogue to Digital converter (ADC). The microcontroller was additionally connected to the ADC as an input.

Two ATMEL 80C51 microcontrollers are utilised: one for controlling stepper motors and LDRs, and the other to display the solar panel's output voltage. The sensors in the solar tracker prototype were positioned at the top in series with a resistor because it was intended for the output voltage at the junction point to grow as the light intensity increased. It was necessary to keep the voltage level at 12V. We maintained the tracker's regular orientation of sixty degrees. Subsequently, the tracker rotated with the sun in 1.8-degree steps from east to west in order to maximise its solar energy extraction.

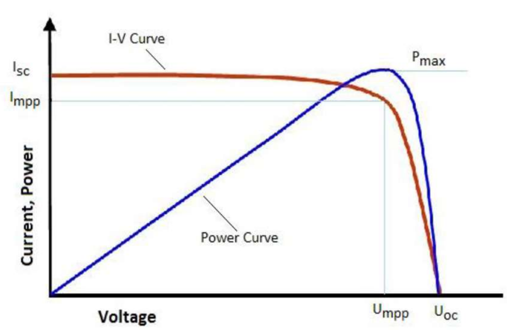
Design and Description

I-P and P-V characteristics of photo voltaic cell

The output power is also influenced by the time of day, season, panel location, and orientation (Khan, Tanzil, Rahman, & Alam, 2010). Figure 3 displays a solar cell's current-voltage and power-voltage characteristics (Khan, Tanzil, Rahman, & Alam, 2010).

Figure 3

I-V and P-V characteristics of photovoltaic cell



A surface's energy output rises as it is moved to face the sun. A tracking system makes it possible to attain relatively big radiation gains on days with high insolation and a high direct radiation factor. When

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compared to a horizontal surface, a tracking system can increase radiation by up to 300 percent in the winter and about 50% in the summer on sunny days.

Figure 4

Differences in irradiance on horizontal and solar-tracking surfaces for cloud-free days and 50° latitude

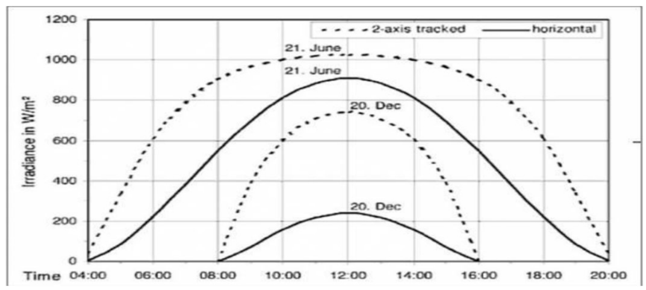


Figure 3 shows this pattern of effects. Compared to buying more solar panels, this is a considerably more economical alternative (Panait & Tudorache, 2008). Three strategies to raise the overall efficiency of the solar panel are to increase the cell efficiency, maximise the power output, and use a tracking system in conjunction with the solar panel (Piao, Park, Kim, Cho, & Baek, 2005). According to Saxena and Dutta (1990), solar tracking is a mechanised system that tracks the position of the sun and boosts the power output of solar panels by 30% to 60% when compared to a stationary system. Recently, a few solar tracking system design methodologies have been put forth (Khan & Ali, 2005; Koyuncu & Balasubramanian, 1991).

Control Scheme of Solar Tracker

A solar tracker uses light sensors that are attached to the device to align a photovoltaic panel perpendicular to the sun's beams (Murtaza, 2012). The sun is high in the sky during the summer. The sun makes a shorter arc and is lower in the sky during the winter (Solar Trackers, 2023). It is also around for a shorter period of time. The cost of integrating existing solar trackers with solar panel systems is significantly higher than that of new models (Wattsuntm Solar Tracker Retail Price and Data Sheet, 2023).

Comparison Types of Solar Tracker

Two tube tanks in the thermo-hydraulic system are positioned at the sides of the PV array, and two shade sheets are installed over them. The fluid in the tanks will heat unevenly if the surface of the PV array is not facing the sun. The PV array rotates to face the sun as a result of the ensuing movement in weight (Deutsche Gesellschaft für Sonnenenergie, 2008).

Electrical circuitry in the form of light-sensing photo sensors or an electronic control system directs active trackers towards the sun. The tracker is then directed towards the direction of the sun by motors and gear trains in response to commands from the photo sensors or control system.

By rotating in the opposite direction at the same rate as the earth, the chronological tracker counteracts the earth's rotation (Lane, 2008). Since the sun moves 360 degrees around the globe each year, the rates are actually not exactly equal. When coupled with a pole mount, a chronological tracker is a very basic, possibly extremely accurate solar tracker.

We employ Single-axis horizontal solar trackers are a sort of chronological tracker that follow the sun's path across the sky from east to west from sunrise to dusk. Since the mechanism only revolves in one plane around one axis, they are known as single axis trackers (Solar Trackers, 2023).

Comparison of Types Stepper Motor

When selecting the stepper motor for the solar tracker prototype, five properties of the stepper motor were taken into account. A stepper motor can be used for open loop positioning, has good holding torque, is brushless, load independent, and has exceptional reaction qualities. Any type of energy is transformed into mechanical energy by it (Motor, 2023).

When powered by a sequentially switched DC power supply, a stepper motor produces discrete angular movements of nearly uniform magnitude (Stepper Motor, 2023). Stepper motors can be categorised according to their functions. The rotor points of VR motors, which have a simple iron rotor, are drawn towards the stator magnet poles on the basis of the theory that least reluctance occurs with minimum gap (Stepper Motor - Types, 2023). Permanent magnet rotors without teeth that are magnetised perpendicular to the axis of rotation make up PM stepper motors. When the windings are turned on in the clockwise order ABAB, the stepper motor will make 90-degree increments (Stepper Motor Guide, 2023).

The best features of both the PM and VR motors are combined to create the hybrid stepper motor. Similar to a VR motor, the rotor has many teeth (Stepper motor Basics, 2023). Two more classes comprise the Steeper Motor. One winding, with a centre tap for each phase, makes up a unipolar stepper motor. Each part of the windings is turned on in response to a different direction of magnetic field. With this configuration, a magnetic pole can be turned around without changing the current's direction (Stepper Motors, 2023).

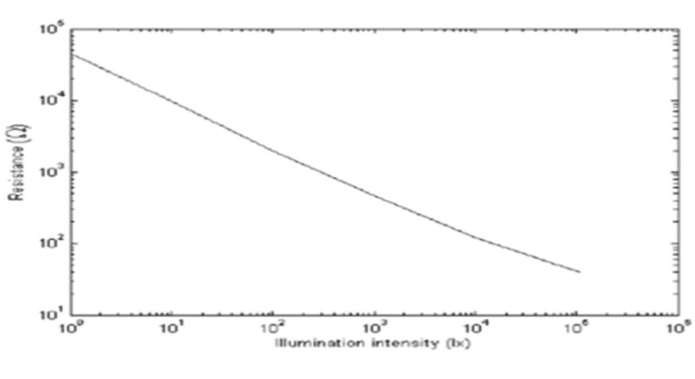
While there are many other kinds of stepper motors on the market, we will begin our configuration and design assuming a Uni-polar single axis motor. Although there are 200 steps in the revolution, only 100 can lead to our usefulness. Hardware designs take power and size into account.

Selection of Sensor

A resistor that changes in resistance in response to the amount of light it receives (Electric Motors, 2023). On the other hand, the LDR's resistance decreases and current flows when light shines on it (2023). The resistance value of the photo resistor under light illumination is shown in Figure 5.

Figure 5

Resistance value of LDR at various illumination level of light (Khan, Tanzil, Rahman, & Alam, 2010)



Equivalent Circuit Diagrams of Solar Cells

In theory, a solar cell made of silicon material that has been doped with p and n is a large-scale silicon diode (Deutsche Gesellschaft für Sonnenenergie, 2008).

The diode or solar cell is connected in a forward-biased direction if there is a positive voltage at the p-doped anode and a negative voltage at the n-doped cathode.

Current flow is blocked in the reverse-biased direction if the diode is connected in that direction.

V = VD

I = –ID= –I0 x (eV/m x VT–1)

A monocrystalline solar cell's breakdown voltage can range from 12 to 50 volts, depending on the material and quality of the cell (Deutsche Gesellschaft für Sonnenenergie, 2008). The forward voltage of the cell is estimated to be 26 about 0.5 volts.

V = VD

Iph = c0 x E

I = Iph – Id

Radiation from the light causes free charge carriers to be produced in the solar cell. A power source and a diode connected in parallel makes up an illuminated solar cell. The photoelectric current Iph is generated by the power source (Deutsche Gesellschaft für Sonnenenergie, 2008). The photocurrent's magnitude shifts the diode characteristic curve in the reverse-biased direction.

Table 1

Comparison Table of Equivalent Circuit

Parameters: Voltage	**Formula sign**	**Unit**
Solar cell terminal voltage	V	V
Diode Voltage	Vd	V
Temperature Voltage	Vt	V
Currents:		
Solar cell terminal current	I	A
Diode current	Id	A
Saturation current in diode reverse biased direction	Io	A
Photo current	Ip	A
Current through parallel resister	Ip	A
Diode factor	M	-
Coefficient of photo current	Co	m^2/V
Solar irradiance of cell	G	W/m^2

Basic Circuit Design of LDR Control Circuit

Electric cables were used to communicate between all component elements and sub-elements. a resistor that changes in resistance in response to the amount of light it receives (Electric Motors, 2023). An LDR's resistance is normally very strong, but when it is exposed to light, it drastically decreases. The resistance of the LDR is high when the light level is low, which stops electricity from flowing. Nevertheless, the LDR's resistance decreases and current flows when light strikes on it (Electric Motors, 2023). The photo resistor's resistance value under light illumination is shown in Fig. 4. The 23-electret microphone, which exclusively detects pulsed light, is a lesser-known light detector. Its electret membrane serves as an ideal absorber (2023). The most obvious use for an LDR is to have a light switch on by itself when it reaches a specific light level. Camera shutter speed can be adjusted with LDRs. The camera shutter speed would be adjusted to the proper level and the light intensity would be measured using the LDR.

Figure 6

LDR Control Circuit

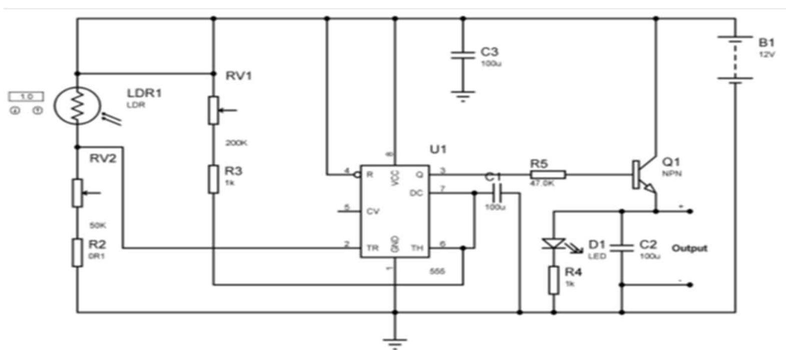
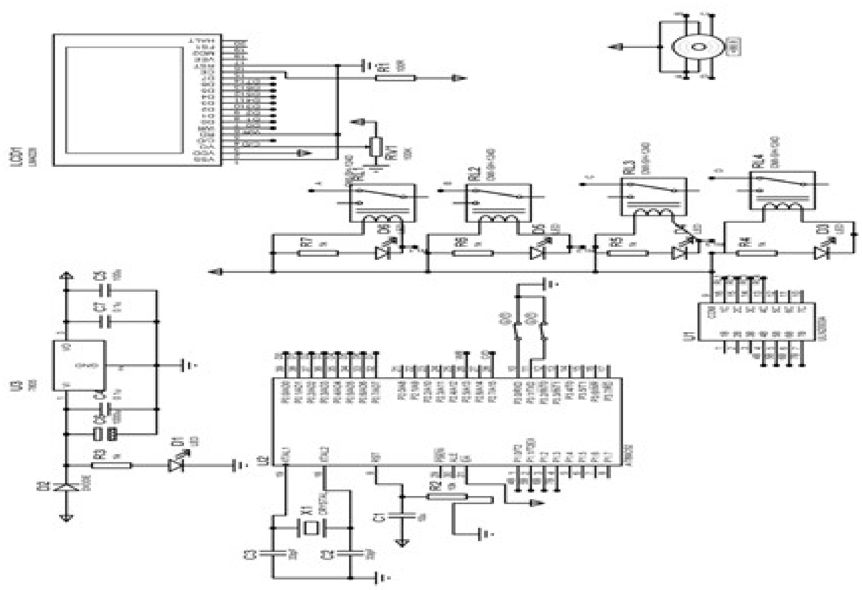


Figure 7

Circuit design of steeper motor and LCD display



Design of Hardware of TSAT Prototype

Made of Aluminum material

Tilt angle (Pakistan Region) = 60 degree

No. of LCDs = 2

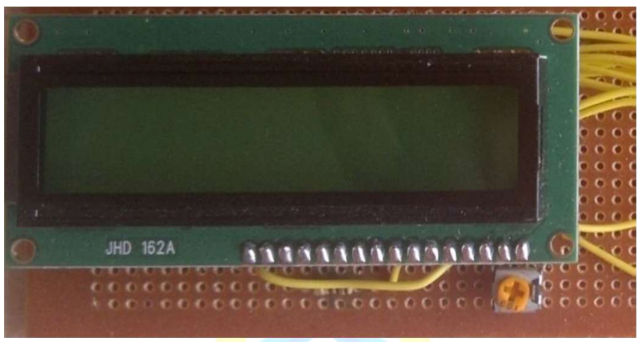
Total Display character = 16

No. of lines = 2

Length * width = 3"*1"

Figure 8

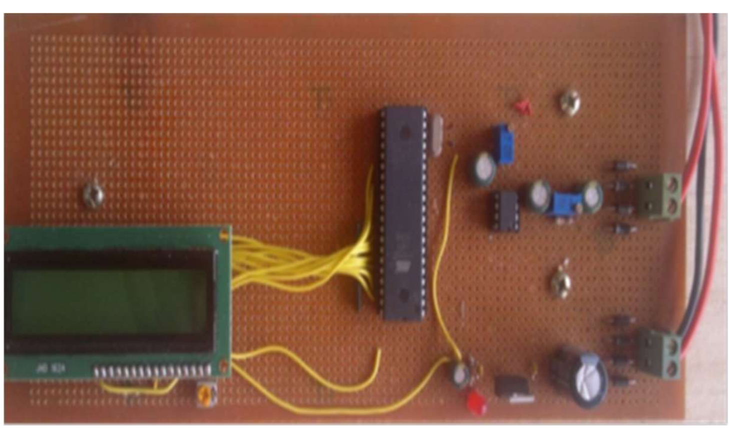
LCD Display



Diodes 1N4007 are used in rectification. For filtering, use a 1000 uF 35 VOC (1) and a 104 J (2) capacitor. LM7805 voltage regulator: 12 V input, 5 V output. LED to indicate power on. One watt of 1 k ohm resistor is used to limit current. Three 100uF 25V capacitors for filtering. Diode 1N4007 for voltmeter input signal input. 103 (10k) variable resistors are used to adjust the input. For the A/D converter and input signal generator for the controller, use IC A/D converter 0831. For the clock pulse, use oscillator 11.0592 and non-polar capacitor 33nF. LCD with variable resistor 1003 (10k ohm) configured.

Figure 9

Voltage Display Circuit



Sensors

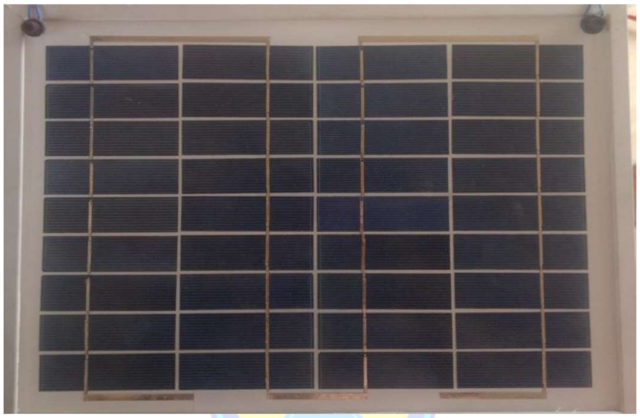
Type of sensor used is LDR made of silium plastic.

Quantity = 2 numbers

Sensors are placed on each corner of upper plane of solar panel.

Figure 10

Placements of Sensors



Calculation of Steeper Motor

Size of panel = 1foot * 1 foot, for 10 Watt

Weight of Panel = 1/2 kg, Weighed

Capacity of stepper motor = weight of panel * factor of safety (for wind etc.)

= 1/2kg * 3 = 1.5kg

Power of Motor = 40 watt

Design of system was implemented by following steps which can be seen in figure 9.

Figure 11

A view of Implemented Prototype

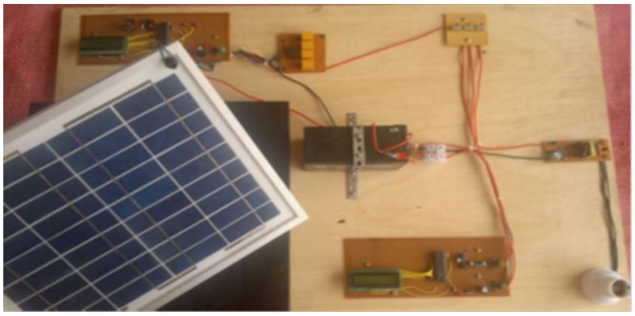


Table 2

Observations and Calculations, Day 1

	UNTRACKED PANEL				TRACKED PANEL					
Time	Voltage	Current	Power	%age Power	Voltage	Current	Power	%age Power	Difference	Remarks
6:00	10	0.23	2.3	23	13	0.25	3.25	32.5	9.5	
7:00	12	0.28	3.36	33.6	13	0.29	3.77	37.7	4.1	
8:00	13	0.29	3.77	37.7	14	0.29	4.06	40.6	2.9	
9:00	12	0.24	2.88	28.8	14	0.33	4.62	46.2	17.4	
10:00	10	0.19	1.9	19	13	0.23	2.99	29.9	10.9	
11:00	13	0.3	3.9	39	14	0.34	4.76	47.6	8.6	
12:00	13	0.3	3.9	39	14	0.34	4.76	47.6	8.6	
13:00	12	0.24	2.88	28.8	13	0.26	3.38	33.8	5	Clouds
14:00	12	0.24	2.88	28.8	13	0.27	3.51	35.1	6.3	Partially clouds
15:00	12	0.24	2.88	28.8	14	0.29	4.06	40.6	11.8	
16:00	12	0.24	2.88	28.8	14	0.32	4.48	44.8	16	
17:00	12	0.23	2.76	27.6	13	0.24	3.12	31.2	3.6	Partially Clouds
18:00	12	0.08	0.96	9.6	12	0.08	0.96	9.6	0	Clouds
19:00	3	0.06	0.18	1.8	3	0.06	0.18	1.8	0	
Average				26.74				34.21	7.47	

Results

It was necessary to keep the voltage level at 12V. We maintained the tracker's regular orientation of sixty degrees. Subsequently, the tracker rotated with the sun in 1.8-degree steps from east to west in order to maximise its solar energy extraction. First, we took an open circuit voltage measurement. We measured the in-circuit current, resistance, and angles at which the tracker must rotate for a closed circuit, which corresponds to a constant voltage. By comparing the output power of the tracked panels under observation with the output power of fixed panels of the same capacity and attributes, we were able to determine a gain in efficiency of 28%.

According to the IESCO tariff, average current price of per unit electricity for domestic consumer is at off-Peak Rs. 35.57 and in peak hours it would be Rs. 41.89 per unit. At tracked panel, 7.47 units are produced more than the simple fixed panel.

7.47*35.57 = Rs. 265.71 (Off-peak Hours)

7.47*41.89 = Rs. 312.92 (Peak Hours)

Therefore, total saving of Pak Rupees of Rs. 267 to Rs. 312.92 would be done on daily basis and it would be almost Rs. 9,000/- approximately on monthly basis. Hence, installing tracked panels have higher rate of return on investment. Yearly, it would become Rs. 108,000/-. If a system costs you about 1 million Pak Rupees and produce 7.5% more than the payback period of investment would be decreased and can shorten upon to four years, if a user install tracked panels.

Stepper Motor Advantages as compare to others

If the windings are fully energised, the motor has its maximum torque when it is in the stationary state. It responds to starting, halting, and reversing very well. Because there are no carbon brushes and the motor's life is solely dependent on the bearing's longevity, this motor is incredibly dependable. Open-loop control is achieved by the motor's response to digital input pulses, which simplifies and lowers the cost of controlling the motor.

Conclusion

The project has demonstrated how to use a microcontroller to track the location of the sun. In particular, it shows how to place a solar panel at the location of highest light intensity to maximise solar cell output using a functional software solution. The prototype is a way to track the sun in both favourable and unfavourable weather conditions. Additionally, the tracker has the ability to initialise the beginning position on its own, negating the need for additional photo resistors. The straightforward system control mechanism of the developed tracker is its most appealing feature. Through software-based solutions, the tracker also offers developing nations a profitable way to include it into their solar system at a relatively low cost (DAYIO\LU, & Turker, 2021).

When compared to a stationary structure with the same installed power, the solar tracking PV system performs better, with a 12% higher equity internal rate of return and a 9% shorter loan payback duration, despite greater investment expenses. The production of solar panels can be increased by up to 25% with the help of an autonomous solar tracking system, according to the US Department of Energy. This implies that a system with a tracking system might produce up to 12,500 kWh of electricity annually instead of the typical 10,000 kWh. Energy bills may decrease as a result of the increased output of electricity. An autonomous solar tracking system, for instance, might save a homeowner with a 5 kW solar system who resides in a state or vicinity where the average electricity bill is $0.15 per kWh up to $187.50 annually.

In addition to the savings on energy bills, the increased output of electricity can also generate additional revenue. Solar panel owners can sell excess electricity back to the grid, and the amount of electricity they can sell can be increased with an automatic solar tracking system. The financial impact of an automatic solar tracking system will vary depending on a number of factors, including the size of the solar system, the location, and the electricity rate. However, in most cases, the system will pay for itself within a few years.

Automating the solar tracking system is a valuable investment that can significantly increase the financial and environmental benefits of solar power. By tracking the sun's movement across the sky, automatic solar tracking systems can ensure that solar panels are always receiving the maximum amount of sunlight, which can increase the output of electricity and reduce energy costs. In addition, automatic solar tracking systems can help to reduce greenhouse gas emissions, improve air quality, and reduce our reliance on fossil fuels.

The production and use of solar energy has a number of major and significant environmental advantages. Carbon dioxide (CO2) emissions are one of the greenhouse gases that can be significantly reduced by producing energy using solar power rather than fossil fuels (Rehman, Rauf, Ahmad, Chandio, & Deyuan, 2019). The atmosphere's hazardous emissions are decreased by solar energy. There is no need to harvest and process limited materials in order to produce solar energy. Solar energy doesn't require water to operate, in contrast to other power sources (Van Wijk, van der Roest, & Boere, 2018).

Small areas of private land, such as your roof, can have solar panels placed with an automated solar tracking system. For many years to come, lower energy costs and a decreased dependency on fossil fuels can both be achieved with solar energy (Afzal, Afzal, & Nishtar, 2023; Khalid, Zia urRehman, & Asghar, 2016; Shahsavari & Akbari, 2018). A timely decision to invest in every suitable investment opportunity could pay you back with high rate of return (Mumtaz, Munir, Mumtaz, Farooq, & Asif, 2023), like solar panels or system investment for energy generation. For instance, a typical homeowner, using solar energy to power their entire home is the same as eliminating the emissions produced by driving a normal car 19,316 miles a year (Aggarwal, 2019).

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