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Research Article

Energy Efficiency Studies - Modelling and Analysis of Solar Tracker System

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I N F O

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A B S T R A C T

Solar energy is of key importance to meet the increasing demands of the electrical power needs of the society as solar energy is available in abundance, is free, clean and pollution free in nature. In order to obtain more power by increasing the receptance of incident rays from sun, a solar tracking mechanism has been developed. This paper presents an energy efficiency case study of a single-axis solar tracker which converts solar energy to electrical energy. The tracker is programmed in such a way that it gets tilted to follow sun's movement accurately throughout the day. It was observed that the generated power output with tracking is higher in comparison to the fixed PV system.

Keywords: Solar Tracking, Microcontroller, Sun Elevation Angle, Real Time Clock, Photovoltaic (PV) panel, North-South (N-S) axis.

Introduction

In this modern era, where we are focusing attention on sustainable development, conservation of our valuable natural resources, rapid depletion of fossils fuels, increasing demand of energy, etc. solar energy is becoming more popular day by day. Being available in abundance and having the huge potential of conversion into electrical power, solar energy has an edge over other forms/ sources of renewable energy. Conversion of solar energy into the electrical form of energy can be done with the help of solar Photovoltaic (PV) cells. In order to make solar energy more viable, the efficiency of solar array systems must be maximized. As the amount of electricity generation is directly proportional to the intensity of sunlight falling on the photovoltaic panel, therefore availability and quality of solar energy at specific locations is of prime importance for the development of the system. In order to get the maximum output, a solar panel must be perpendicular to the light source. Since the sun follows the fixed trajectory throughout the day at specific geographical location, therefore the energy gained by the fixed solar photovoltaic panel is limited to some extent. This limitation can be overcome by any of the three methods[1] viz.

- By increasing the efficiency of power generation of the solar cells
- By increasing the efficiency of the control algorithms for energy conversion
- By adopting a tracking system to achieve maximum solar energy

The most feasible approach to maximize the efficiency of solar array systems is sun tracking. The movement of the sun with respect to the earth changes in a cyclic manner during the entire calendar year.[2] In order to track the position of the sun and to face the solar panel in the same fashion in order to receive the maximum radiation at any time defines the main purpose of the solar tracking PV system. Solar panels are generally stationary and hence cannot follow the movement of the sun. The solar tracking systems are designed to track the sunlight and try to collect the maximum amount of sunlight that is incident on the panel throughout the day. The solar tracker starts following the sun rays from morning and continue till evening and the process starts all over again. Solar-tracker is a mechanism that is designed as the mounting of photovoltaic panels to track the sun in such a way that the incident angle of solar radiation with the panels is as less as possible.

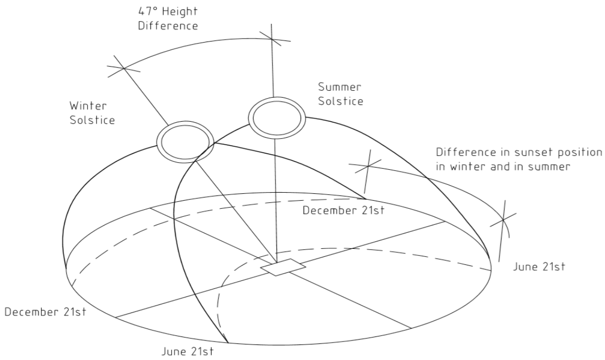


Figure 1.Illustration of the sun movement in reference to the solstices

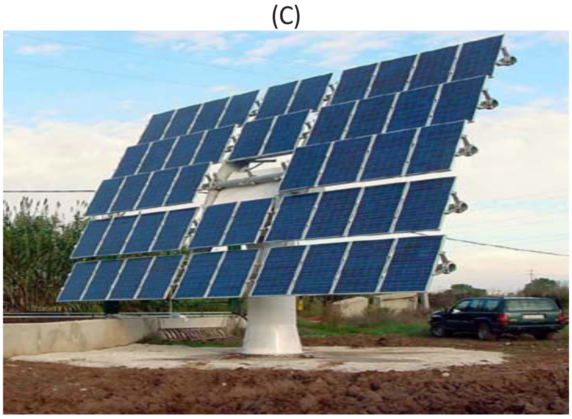
There are various types of solar trackers that exist, which vary in terms of cost and complexity. One can classify the sun-tracker mechanisms according to their: 1) Control system and 2) the movement they perform. According to the control system, sun-trackers are usually divided into active controlled sun-trackers and passive controlled sun-trackers.[3] The active controlled sun-trackers use motors and mechanical systems to transmit the correct movements for sun-tracking. These movements are commanded by a controller which can be based on photosensitive cells (which can detect the direction of the maximum light flux) or chronological systems. These systems are precise. But, on the other hand, they are complex and with high rates of maintenance. In order to enable the tracking, the motors consume energy and therefore the continuous movements are commonly prevented and thus it is preferable to use the step movements to save energy consumed in continuous tracking. Their associated costs are related to their precision accuracy. The passive controlled sun-trackers are those where no motor or gear is used, therefore they may be work on the property of low ebullition point of liquefied gas filled in the two cylinders mounted in the opposite end of the PV panel or on the concept of memory shaped alloys. The passive tracking systems are less accurate in reference to the active ones. In addition to the above, further classification of the trackers can be done on the basis of the movement they execute. Four types of trackers can be classified in this ground viz.

- Single-axis polar-mount, Figure 2(a),
- Horizontal-axis, Figure 2(b),
- Vertical-axis or azimuth, Figure 2(c)
- Dual-axis solar, Figure 2(d).

(a)

(b)

(C)



(d)

Figure 2.Classification of Sun Trackers according to the movement they perform (turning axes are highlighted). (a) Polar-mount sun-tracker; (b) Horizontal-axis sun-tracker; (c) Azimuth sun-tracker; (d) Dual-axis sun-tracker (polar-mount)

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Background and Literature Review

Many tracking systems were designed including passive and active systems with one or more axes of rotation.[5] One of the low-profile two-axis solar tracker designs consists of two coplanar and perpendicular linear actuators coupled with a single linkage arm and pivots that add to the high cost during development[6,7] "container-title:" "Solar Energy," page: "569-576", "volume: 97", "source": DOI.org (Crossref. Vaibhav et al. had developed time-based reconfiguration in order to get the Maximum Power Point (MPP) tracking in solar cell arrays.[8] They replaced two-dimensional arrays of PV cells by a single string of PV cells, using a modular, Time-Domain Array-Reconfiguration (TDAR) approach. The energy harvesting efficiency of the TDAR approach is more than 80% improved as compared to static (non-reconfigurable) strings of PV cells. In addition, some tracker's designs focused on the movement of the concentrated solar collector in place of PV panel.[9] They propounded the concept of 2-D non-imaging type Compound Parabolic Concentrator (CPC). Ahmad et al. developed the two-axes tracking system used a Programmable Logic Controller (PLC) to operate the photovoltaic solar module based on 10º altitude angle tracking and 1º azimuth angle tracking. It has the potential to increase solar panel efficiency by up to 23%.[10] Poulek and Libra developed the bifacial solar cell connected directly to D.C. motor.[11] Sadyrbayev et al proposed the design of sun tracking system consisting of 4 photo resistors, which are mounted on the sides of the photo module.[12] This dual-axis solar tracking system produced 31.3% more power compared with stationary photo module.

Most of the above articles discussed the active solar tracking system, but the discussions on the power consumption by tracking system was lacking.[13] Moreover, in the cloudy environment the active tracker has a limitation on the sensitivity part of the sensors as the difference in the signals provided by the sensors resulting into tilt of the PV Panel. In addition to it, in one of the designs, during cloudy days, fixed systems become more attractive than the PV Panel with tracking mechanism from the efficiency point of view.[14] Such limitations can be overcome with the help of proposed designs of solar tracking systems. This is the motivation behind this study. The objective of the current study is to study the efficiency of the solar tracking system. Considering both efficiency improvement and energy consumption, a model of solar tracking has been developed. In order to achieve the goal following methodology is used: -

- Design of solar tracking system
- Fabrication
- Programming
- Data acquisition and analysis

Solar Tracking System

Mechanical System

The complete structural design of the solar tracker is shown in the figure 3. The total weight of the solar tracking system is 1.5 kg with overall dimensions of 310 mm x 310 mm x 80 mm. The designed tracker is so compact that it can be placed on the roof and may be mounted on the wall also. The main elements consist of a PV panel, stepper motor, electronic board and U-shaped aluminum structure. The design of the tracker enables the single axis movement of the PV panel preferably East to West while in operation. The motor located on one side of the aluminum structure actuates the PV panel during tracking. The base of the aluminum structure is designed in such a way that all the electrical assemblies as well as the battery can be mounted on it thus making the structure more compact.

Electrical System

The electrical part of the solar tracker includes a main controller unit i.e. Arduino mega 2560, lead acid battery, resistors, real time clock, sensors, etc. detailed as tabulated below: -

Table 1.Details of Electrical Components

S. No.	Item	Specifications	Function
1.	Arduino	Arduino Mega 2560	Main controller and memory storage device
2.	IC	LM317	Voltage regulator for solar cell output control
3.	IC	DS1307	Real time clock IC for accurate time and date
4.	Crystal	32.768 KHz	Crystal Oscillator for clock pulses to RTC
5.	IC	L293D	Motor driver IC for amplifying current and voltage
6.	IC Base	4 pin	Case to place IC
7.	IC Base	16 pin	Case to place IC
8.	Motor	DC 10 RPM	Angular movements are controlled using motor
9.	Resistor	10kΩ, 4.7kΩ, 220Ω, 680Ω	Resistors are used to control flow of current
10.	Variable Resistor	10kΩ	Its resistance can be varied by moving its mechanical body

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11.	Battery	6V	Energy storage
12.	Diode	IN4007	
13.	Sensor	Current Sensor ACS712	Hall effect sensor

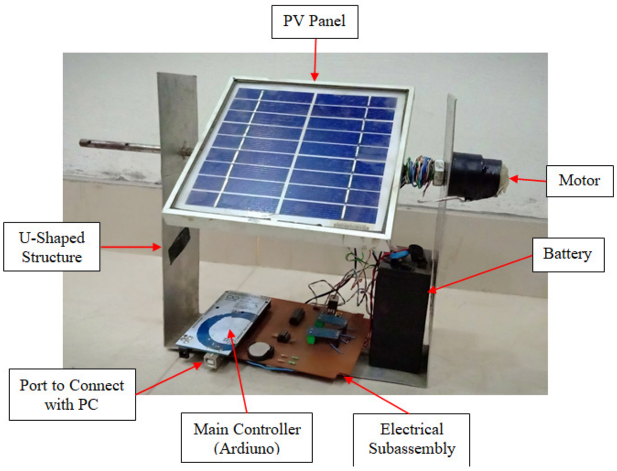

Figure 3.Picture of Actual Set up

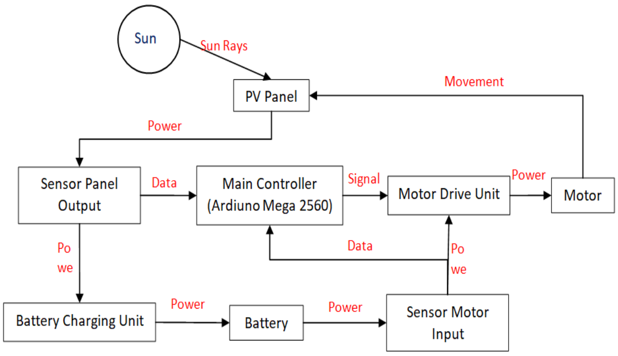

Figure 4.Block Diagram of Solar tracker

Working of Solar Tracking System

When sun light falls on the PV panel oriented at a certain angle, the solar energy gets converted into electrical energy. This generated electrical output is utilized to charge the battery through a battery charging unit. In order to record the output data of the electrical power generated by the PV panel throughout the day, a pair of sensors was used (Current and voltage sensor) which was further connected to the main controller unit (Arduino mega 2560). As programmed in the main controller unit, the real time clock sends the signal to the motor drive unit at a regular interval of time, which further activates the motor. In a parallel, the battery will provide power to the motor and tilt the PV panel at a desired angle. This power consumption by the battery for tilting PV panel is also connected to another pair of sensors (current and voltage sensor) to record the motor input data and thereafter save the data in the main controller.

Result and Discussions

The experiment was performed on 26 April XXXX at Jalandhar with geographical coordinates (31.32^o, 75.57^o). The results of the experiment are discussed below:

Sun Angle and Panel Angle Versus Time

A sun-path chart was created, referring to the Jalandhar coordinate with the assistance of programming which is accessible at web site of the University of Oregon.[12] The Sun-path chart is the plot between the sun azimuth angle and elevation angle. This plot provides the value of both these angles throughout the day, at a given geographical location. The azimuth angle describes the location of the sun within the horizontal plane whereas the elevation angle determines the altitude of the sun within the sky. The North is outlined to possess an angle of 0° and the South has an angle of 180°. Additionally, to the representational process, the trail of the sun in terms of its elevation and azimuth angles, sun path charts indicate explicit times of the day. The plot indicates the time on an hourly basis for the period when the sun is available at that geographical location. Sun path chart is deliberated in Cartesian coordinates, in which the azimuth angle is shown in East to West as our location i.e. Jalandhar lies in northern hemisphere.

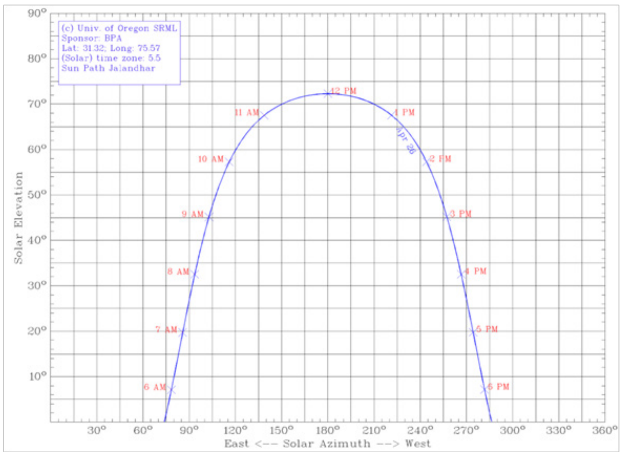

Figure 5.Sun Path Chart at Jalandhar Coordinates of Date 26-04-XXXX

Based on the above chart (figure 5), it is assumed that the sun travels from 0^o (sunrise) to 180^o (sunset) from 05:30 am to 06:30 pm. During these 13 hours the PV panel rotates 180^o, therefore the experiment was started at 8:30 am when the sun's angle is approximately 38^o. As per the plot shown in figure 6, one may conclude that the solar tracker is able to follow angle of the sun. Since the output/efficiency system depends upon the angle of the incidence of sun rays to the PV panel, therefore the synchronization between the Sun's movement and panel movement become very important factors in reference to the current study. The plot between the Sun angle/ panel

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angle with time is shown in figure 6 and correspondingly the data was tabulated in table 2. As per the plot the solar tracker is able to follow the sun with an accuracy of 97% (3% error).

Table 5.Hourly Data of PV Panel/ Sun Angle

Hours	PV Panel Angle	Sun Angle
0830	38^{o}	38^{o}
0930	50^{o}	52^{o}
1030	65^{o}	66^{o}
1130	77^{o}	81^{o}
1230	93^{o}	95^{o}
1330	105^{o}	109^{o}
1430	121^{o}	123^{o}
1530	132^{o}	137^{o}
1630	150^{o}	152^{o}
1730	162^{o}	166^{o}
1830	171^{o}	180^{o}

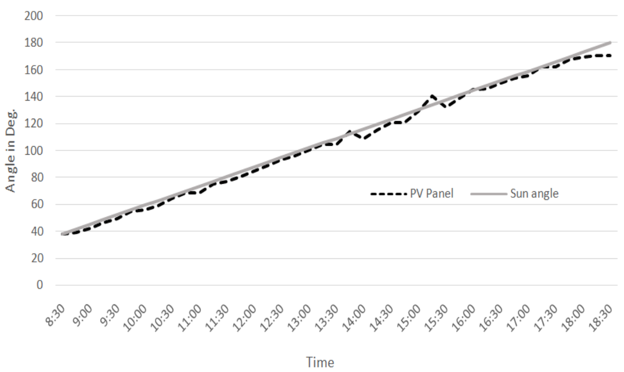

Figure 6.Plot between Sun/PV Panel Angle vs Time

Power Versus Time

The plot shows that the Power/ current generated with a solar tracker is always more than that of a fixed solar panel with no tracking. Thus, trackers can help in collecting the additional energy at times (morning and winter) when the incident sun rays are at the highest angle of inclination. In order to validate the proposed solar tracker system, it was necessary to compare the experimental results for the fixed PV panel with the solar tracker system. In the plot the solar tracker produces an overall higher power (or efficiency) output as compared to the fixed solar panel. Here, the efficiency elaborated as the fraction of the variation between the sum of generated power by fixed panel and tracking systems to the power generated by the fixed panel for the entire period of observation. The efficiency obtained by the experiment is about 27 % higher than that of fixed the system. As compared to the various solar trackers referred to in the introduction part of this paper, the average efficiency is lying in the range of 12 to 15% and hence the proposed design is slightly higher comparable to the existing design. During the complete day the solar tracking system was inefficient during the noon period when the solar irradiance collected by both the fixed as well as with tracking systems is almost the same. Therefore, the power generated by the fixed panel is quite comparable to that generated by solar tracking systems and hence almost zero efficiency was gained for that period. This became the reason why the researchers were more inclined towards the fixed panel especially for the locations where the maximum solar irradiance was received in the noon time only.

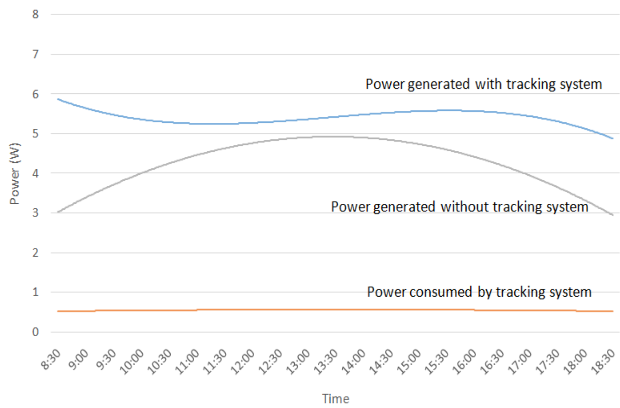

Figure 7.Plot between Power and Time

Conclusion

The performance of the designed single axis solar tracking mechanism was experimentally tested and compared with the fixed PV panel. In conclusion, it can be inferred that a solar panel embedded with a tracking system can have greater attractive features as compared to the fixed solar panel. This tracker follows the sun path in a very accurate manner leading to the only 3% inaccuracy. With reference to power generation the overall efficiency is 27% higher than the fixed mechanism. Moreover, the tests showed that the power used by the tracking system was much less than that of power gained by tracking system. It infers that the designed solar tracking systems were to charge their own batteries and they would be entirely self-sufficient except for maintenance. However, during the cloudy days, the net output energy generated by the solar tracker is expected to be either close or might be smaller than the fixed one, due to the energy consumed by the tracking system. For future research, the system with the same concept can be developed for dual axis solar tracking by feeding the data of the sun's movement throughout the year while programming. The design of this solar tracker is quite flexible in nature as it enables the programmer to change the intervals of the angular movement of the PV panel. Moreover, while feeding the geographical coordinates in

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its programming, the same tracker will work efficiently at that specific location. In addition to it, this design has the provision to capture and record all the data in the computer for further analysis.

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