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Conference Paper

Evaluation of Technical Feasibility and Economic Viability of Low Power Standalone Photo Voltaic Sun Tracking System

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Cost effective and hassle-free energy generation without causing environmental degradation is the need of the hour for saving mother earth and mankind from imminent devastation. Solar PV (SPV) energy generating systems are gifted solutions to overcome this acute problem. Energy generation using SPV systems is quite effective and efficient only if the SPV panels are aligned to be normal to the incident solar irradiation at all times during the day. This stringent requirement is fulfilled by mounting SPV panels on sun tracking systems. Single axis and dual axes sun tracking systems are widely used for generating a fairly good amount of energy by aligning the SPV panels to follow the sun throughout the day. This research paper presents experimental results and cost analysis to prove that a tilted single axis sun tracking system is a technically feasible and economically viable solution to this demanding requirement. Experimental investigation carried out over a period of one month during October,2016 has established that the energy gain of a tilted single axis sun tracking system turns out to be 31.91 % and that for a dual axes system is marginally more with just 35.3 %. Cost analysis of these systems has shown that the cost per kWh of generated energy for a tilted single axis sun tracking system is INR. 2.92and that for a dual axis tracking system is INR. 3.42, thus reiterating the fact that a tilted single axis sun tracking system can be used with advantage in low or medium power standalone SPV power generating systems.

Keywords: Sun Tracking Systems, Solar Photovoltaic Systems, Cost Analysis, Energy Gain.

INTRODUCTION

Population explosion is a major issue that has led to scarcity in several domains, the worst hit being energy sector. Power cuts have become an inevitable and accepted reality, especially in rural and sub urban parts of India. Power generating agencies concentrate mainly on providing uninterrupted power supply to urban areas at the cost of rural and sub urban population. Imposing power cuts has a telling effect on the social, industrial and economic progress of any country. Governments are therefore trying to encourage both domestic and industrial consumers to install standalone green energy sources, so that the demand on the energy distribution systems is reduced. Standalone SPV systems are the most widely propagated options for overcoming this imminent energy crisis. One of the most important reasons for encouraging the widespread usage of SPV systems is the steep reduction in the cost of PV panels and the overall installation cost during the current decade. These systems will continue to gain more popularity and usage with increased conversion efficiencies of the PV panels. With drastic reduction in installation costs, the cost per unit of energy is closely matching that of the conventional energy sources and sometimes is becoming even less.

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This economic viability of SPV plants is possible with an added advantage of reduced environmental pollution leading to a clean and green environment for the future generations. It then becomes imperative to choose the right type of standalone SPV system that can economically generate the required energy using technically robust SPV power systems.

This research paper presents an experimental analysis to substantiate the technical feasibility and economic viability of standalone, low power consumption SPV sun tracking systems that can be used with advantage. This analysis is based on experiments carried out on the rooftop of Chameli Devi Group of Institutions at Indore city, Madhya Pradesh over a period of one month during October, 2016. Indore city is situated at an altitude of 533 m with its geographical location defined by a latitude of 22.614° N and longitude of 75.887° E. The city receives an annual solar insolation of 5.14 kWh/m2/day and has around 300 sunshine days in a year. This is a really good condition, which can help in the generation of substantial SPV energy. When the readings were recorded during the month of October, most of the days had good values of Direct Normal Irradiance (DNI), this facilitated a good amount of energy generation. Atilted-single axis sun tracking system and a dual axes sun tracking system were the two closed loop tracking systems used in this analysis. The performance of these tracking systems was compared with that of a fixed-tilted system. The tilt angle of both the fixed and tracked system was equal to the latitude of Indore city, i.e. 23°. The PV panels were mounted with the downward slope towards south. Both the fixed and tracked systems used polycrystalline PV panels of Vikram Solar make with a power rating of 37 Wp. Calibrated, digital measuring instruments were used for measuring all the electrical parameters in the experiment. Inaccuracies associated with all the measuring instruments were taken into consideration while recording the experimental results. Due to clear weather conditions on most of the days, both the tracking systems were able to provide substantial average energy gains over the month-long duration.

The tilted single axis tracking system provided an average energy gain of 31.91 % while the dual axes tracking system provided an average energy gain of 35.30 %. It is observed that there is no significant difference between the energy gains of the two tracking systems.

LITERATURE REVIEW

Several investigators around the world have worked on the design, development and performance evaluation of both the single axis and dual axes SPV sun tracking systems. Their performances have been compared with fixed-inclined SPV panels and energy gains have been estimated. Most of the investigators have obtained reasonably good energy gains using both these tracking systems (S.P. Singh et al., 2017).

Table I shows the various values of energy gains obtained by researchers for both single and dual axes tracking systems. It is observed from Table I that the energy gain values of single axis SPV systems vary from a minimum value of 20 % to a maximum value of 59 % and for a dual axes system, the energy gain varies from a minimum value of 6.7 % to a maximum value of 60.45 %. Differences in the values of energy gains obtained by these researchers can be attributed to several factors like, geographical location of the experimental site, season during which experiments were conducted, weather conditions on the day when readings were recorded, number of days considered for calculation of energy gain and positioning of the fixed and tracking systems during experimentation. However, the values of energy gains for both the single and dual axes trackers as mentioned by the researchers have been compiled and tabulated for study.

TABLE I: SUMMARY OF LITERATURE REVIEW

S/No.	Authors/ Year of Publication	Ref. No.	% Energy gain		
			Min	Max	Avg
Single axis sun tracking systems					
1	Saxena& Dutta (1990)	2	30	60	40
2	Khalil & El Singaby (2003)	3	--	--	50
3	Abdallah (2004)	4	34.4	37.5	35.95
4	Al Mohammed (2004)	5	--	--	20
5	Sungur (2007)	6	--	--	32.5
6	Abdallah&Badran (2008)	7	--	--	22
7	Sefa et al., (2009)	8	--	--	45
8	Colak&Demirtas (2010)	9	--	--	45
9	Rustemli et al., (2010)	10	--	--	29.4
10	Al-Haddad & Hassan (2011)	11	--	--	57
11	Beg et al., (2011)	12	--	--	23
12	Hamed & El Moghany (2012)	13	--	--	24
13	Dakkak & Babelli (2012)	14	--	--	31
14	Hu & Yachi (2013)	15	--	--	59
15	RitikaWahal et. al. (2015)	30			17.61
Dual axes sun tracking systems					
1	Patil et al., (1997)	16	--	--	30
2	Helwa et al., (2000)	17	--	--	30
3	Abdallah&Nijmeh (2003)	18	--	--	41.3
4	Khadera et al., (2006)	19			37.5
5	Rubio et al., (2007)	20			47.5
6	Rebhi et al., (2009)	21			18.75
7	Sungur (2009)	22	--	--	42.6
8	Huang et al., (2009)	23	--	--	6.7
9	Al Naima & Al Taee (2010)	24			22.5
10	Senpinar&Cebeci (2012)	25			14
11	Wang & Lu (2013)	26	--	--	28.3
12	Sadyrbayev et al., (2013)	27	--	--	31.3
13	Zhan et al., (2013)	28			16.5
14	Azizi&Ghaffari (2013)	29	--	--	60.45
15	RitikaWahal et. al. (2015)	30	--	--	50.92

It is to be noted that the energy gain values of the single axis and dual axes tracking systems match quite closely and the difference between them is observed to be quite marginal. Experimental results obtained by the authors for both the single axis and dual axes tracking systems over a period of one month confirm the above-mentioned results. The energy gain obtained for single axis system was 31.91 % and that of the dual axes system was 35.30 %.

Most of the researchers have opted to use single axis SPV systems because of the important advantages like low fabrication cost when compared to a dual axes SPV system. In addition to the cost factor, technical complexity and maintenance are other problems that go against a dual axes system. Finally, the economic viability can be evaluated after calculating the cost per unit energy generated by both the sun tracking systems.

THE PROPOSED SYSTEMS

It was planned to develop sun tracking systems that could be technically feasible and economically viable so as to be easily affordable and within the reach of rural and suburban population. The systems were designed and developed by granting top priority to cost economics. Thus, each and every functional block used in the tracking systems was designed and developed to fulfill this major criterion. The following appropriate measures ensured that the tracking systems could meet the desired expectations

- Design of the mechanical support frame of the SPV tracking systems
- Design of the gear mechanism to be used with the motor
- Estimation of torque requirement of the tracking motor
- Design of electronic motor control circuit
- Type of PV panel used in the system

The mechanical structures used in both the trackers were designed using CATIA software. Based on this optimum design, appropriate sized rectangular mild steel (MS) tubes were used in the fabrication of the supporting mechanical structure to reduce the overall cost. Size of bearing and bearing seats were selected to tolerate the weight of the SPV panel after considering the wind load. Thus, cost cutting was accorded top priority at each and every stage of the mechanical structure fabrication.

A helical worm gear with suitable gear ratio was designed, keeping in mind the rate at which the SPV panel has to rotate during the tracking process. The sun moves by 1° in every 4 minutes, hence the movement of the panel is too slow which necessitates a gear ratio that will require optimum torque for the tracking motor.

The tracking systems would require a suitable motor for aligning the PV panels to be normal to the incident solar irradiation. From literature review it was observed that most of the researchers used either DC motors or stepper motors. After carrying out detailed analysis, it was decided to use geared low power, low rpm-high torque DC motors because it would be easy to have bidirectional rotation with effective and easy control. The motor driver circuit IC (L293D) used for controlling the bidirectional rotation of DC motors is simple and cost effective.

The heart of both the sun tracking systems is the electronic motor control circuit. It was observed during literature survey that most of the researchers used microcontroller based motor control circuits. After the initial rounds of analysis, it was decided to use a closed loop motor control circuit with optical sensors for tracking the sun accurately. The most effective optical sensors widely used by most of the researchers all over the world are the Light Dependent Resistors (LDR). Major benefits of using LDRs as light sensors are that they can withstand extreme weather conditions; they are quite sensitive to incident solar radiation and are cost effective. Hence, it was decided to use a comparator based closed loop electronic control circuit with LDRs in the proposed sun tracking systems for fool proof operation and cost effectiveness.

There is always an option to use either mono crystalline or poly crystalline PV panels in SPV power generating systems. Mono crystalline panels are preferred when space is at a premium and it is required to generate more power using lesser number of PV panels. Mono crystalline PV panels have higher conversion efficiencies when compared to poly crystalline SPV panels, hence are able to generate more power per sq. mtr. This however is at the cost of a higher price tag. The life span of both the types of PV panels are almost identical (25 years), hence it was decided to use poly crystalline SPV panels in the proposed systems due to their cost effectiveness.

Polycrystalline SPV modules (Vikram Solar make) with a maximum power rating of 37 Wp were used in all the three SPV systems. The PV panels used here have a VOC = 22 V and ISC = 2.7 and a conversion efficiency of 14%. 90 % of rated output generation is guaranteed during the first 12 years and 80 % during the next 13 years. Hence, an average value of 85% generation is considered in the cost analysis. (Vikram Solar - Eldora Series Poly Crystalline PV solar module Technical data sheet).

MATERIALS AND METHODS

A. Fixed-Tilted PV panel

The fixed-tilted PV panel was rigidly fixed on to an inclined base structure with the downward slope towards south and the angle of inclination being equal to 23°, which is equal to the latitude of Indore city. The inclined structure was then rigidly fixed on to a pedestal using fasteners (Fig. 3). An inclinometer was used to fix the angle of inclination.

B. Single Axis Sun Tracking System

An appropriately designed mechanical support frame using rectangular MS tubes was used to mount the poly crystalline SPV panel of a single axis SPV system. The MS frame is placed inclined at an angle of 23° which is equal to the latitude of Indore city. The inclined MS frame is rigidly fixed to a pedestal using threaded fasteners. The PV panel is held in position using axial shafts mounted on sealed bearings that are rigidly fixed at the top end of the vertical arms as shown in Fig. 1.

The worm gear assembly along with the tracking DC motor is mounted on one side of the vertical arms. A 3.5 rpm, 12 V DC, side shaft, geared motor issued as the tracking motor. This motor draws a load current of about 65 mA; hence, power consumption of the motor is as low as 0.75W. The tracking motor rotation is controlled by an electronic closed loop motor control circuit which is designed using a dual comparator IC (LM358) as shown in Fig. 5. Two LDRs separated by an opaque sheet (Fig. 6) are connected in series with a voltage source and used as light sensors to track the sun accurately. As the sun moves from east to west, a shadow is cast by the opaque separator on the east LDR while the west LDR is fully exposed to solar irradiation. This causes a difference in value of resistance of the two LDRs resulting in a differential voltage output. These voltages of the two LDRs are fed to the two comparators in which one of the inputs is connected to a reference voltage. The two comparators then drive a motor driver circuit (L293D) which in turn causes rotation of the motor in such a way that the SPV panel rotates towards the west so that it remains normal to the incident solar radiation throughout the day from sunrise to sunset

C. Dual axes Sun Tracking System

The mechanical support frame used for the dual axes system is designed using CATIA software so that a stable and firm structure is designed using rectangular MS tubes of minimum dimensions to reduce weight and cost. The support frame is almost similar to that designed for the single axis system, but instead of mounting this structure on an inclined frame, it is mounted on bearings so that the entire support frame is capable of rotating in the altitude (north-south) plane in accordance with the sun's movement during the day. The base of the support frame is then rigidly fixed on to a pedestal using fasteners as shown in Fig. 2.

In a dual axes SPV sun tracking system, it is required to have rotation of the SPV panel in both the azimuth (east-west) and the altitude (north-south) planes. This is made possible using two sets of gear mechanisms with their respective motors. The two DC motors are controlled using two independent closed loop electronic motor control circuits which are designed using two dual comparator ICs, with each control circuit using 2 LDRs as shown in Fig. 6. In all, 2 dual comparators, 4 LDRs and two motor driver circuits are used in this dual axes SPV sun tracking system. Operation of the electronic motor control circuit is similar to that used in the single axis system. The SPV panel is therefore aligned to be perfectly normal to the incident solar radiation at any instant of time thus enabling the panel to generate maximum PV output power.

DETAILS OF EXPERIMENTAL SETUP

Technical feasibility of the proposed systems was established by carrying out experimental tests on the single and dual axes systems over a period of one month on the rooftop of our college building. This field test was conducted immediately after the monsoon season. Performance of the single and dual axes trackers was compared with a tilted fixed PV panel. The fixed panel was installed making an inclination of 23° (latitude of Indore) with the downward slope towards south. A magnetic compass was used to locate the geographical north-south and east-west directions to position both the tracking systems appropriately and an inclinometer was used to adjust the inclination angle. The tracking systems were rigidly fixed on to three feet high pedestals to avoid any shadows being cast on the SPV panels. All readings were recorded manually using calibrated digital meters as shown in the experimental set up (Fig. 4) at regular half hourly intervals, between 6.30 AM to 6.00 PM (Total duration of 11 hours 30 minutes).

Fig.1 Tilted single axis sun tracker

Fig.2 Dual axes sun tracker

Fig.3 Tilted fixed PV panel

Fig. 4 Experimental set up

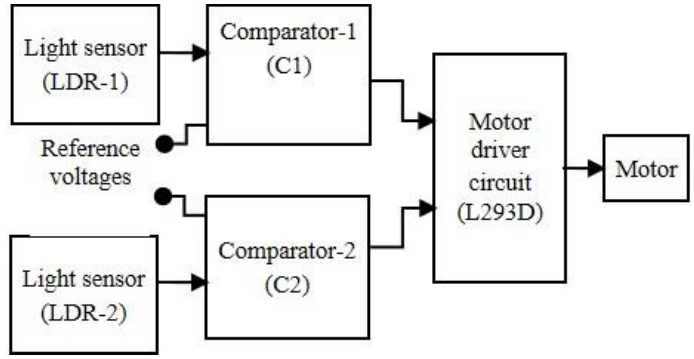

Fig.5 Block diagram of closed loop motor control circuit

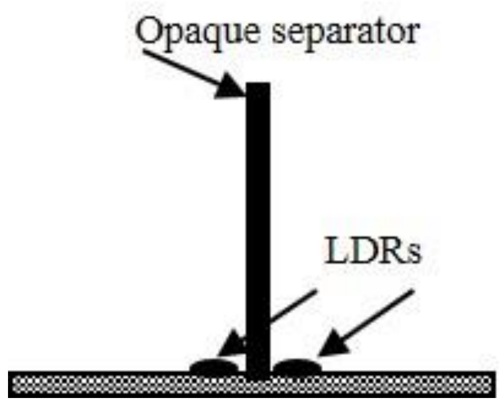

Fig. 6 LDR light sensors

RESULTS AND DISCUSSIONS

Performance analysis of the three systems in terms of their average daily output energy and energy gain has been carried out using the readings recorded over the entire month. It is observed that the average per day energy output of the single axis tracking system is almost the same as that of the dual axes tracking system. The single axis system has an average per day energy output of 178.5 Wh and that of a dual axes system is 183.08 Wh. The fixed tilted panel has an average value of 135.32 W has shown in the graph (Fig. 7).

The energy gain is calculated using the relation:
Energy gain: [(ET – EF) / (EF)]

Where ET is energy generated by tracked system and EF is energy generated by fixed system.

Energy Gain of single axis system will be equal to:
[(135.32 – 178.50)] / (135.32) = 0.3191 = 31.91 %

The percentage energy gain of single axis tracking system is 31.91 % while that of the dual axes tracking system is35.30 %. The energy gain difference is also marginal with an increase close to 3 %. The economic viability of these systems can be estimated by carrying out the cost analysis of the two systems.

TABLE II: AVERAGE PER DAY ENERGY OUTPUT

Average per day Energy output recorded during the month of October, 2016 (R_L = 8 Ohms)				
Fixed system average per day Energy output	**Tracking systems average per day Energy output**		**Percentage Energy Gains of tracking systems**	
Fixed-Inclined	Single axis	Dualaxes	Single axis	Dual axes
135.32Wh	178.5Wh	183.08 Wh	31.91	35.30

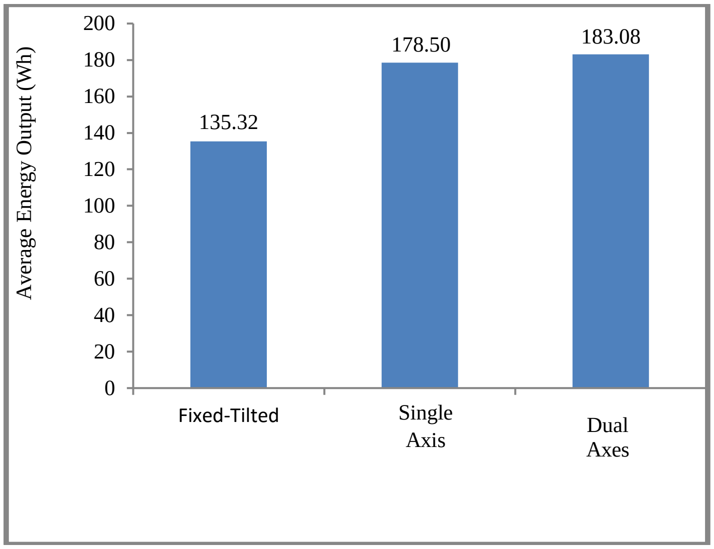

Fig. 7 Graph showing average per day energy

COST ANALYSIS

The economic viability of tracking systems can be evaluated by determining the cost per kWh of energy generated by the tracking system. Cost analysis of the tracking systems is carried out as follows:

Both the tilted single axis tracking system and the dual axes tracking systems were fabricated with locally available materials, components and accessories in the college workshop. The breakup of fabrication cost of the single axis and dual axes tracking system are appended below

a. Cost of fabricating mechanical structure of single axis tracker - INR. 1200.00
b. Cost of electrical and electronic components for motor control system- INR. 800.00
c. Cost of PV panel- INR. 2000.00
d. Total cost of single axis tracking system and PV panel - INR. 4000.00
e. Cost of fabricating mechanical structure of dual axes tracking system - INR. 1800.00
f. Cost of electrical and electronic components for motor control system- INR. 1200.00
g. Total cost of dual axes tracking system and PV panel - INR. 5000.00

From the cost analysis it is observed that the fabrication cost of the dual axes tracking system is about INR. 1000.00 more than that of the single axis tracking system.

Solar PV panels have an estimated life span of about 25 years with an annual reduction in energy output, we can calculate the annual energy generation of the tracking system by considering an average of 85% of the rated power generation over a period of 25 years. Table III below shows the lifetime energy generation of the tracking systems

Table III: Cost Analysis of Single and Dual Axes System

S/No	**Type of Tracker**	**Per day average energy output (Wh)**	**Per month energy output (kWh)**	**Net Annual energy output (kWh)**	**Total life time energy generation for 25 years (kWh)**	**Cost of SPV tracking system (INR)**	**Cost per unit of energy (INR)**
1	Single Axis	178.50	5.36	64.26	1365.53	4000.00	**2.92**
2	Dual Axes	183.08	5.49	65.91	1460.58	5000.00	**3.42**

It is observed from the above table that the cost per kWh (Unit) of energy generated by the single axis sun tracking system is INR. 2.92And that for a dual axes tracking system is INR. 3.42. It is a known fact that maintenance charges for a dual axes system will be more than that of a single axis tracking system due to the system complexity. In spite of overlooking maintenance charges, the cost per kWh (Unit) of energy generation for a dual axes tracking system is more than that of a single axis tracking system. Hence, it is always advantageous to use a single axis tracking system from the economic point of view.

CONCLUSION

From the experimental and economic analysis of the two tracking systems, we have arrived at the following conclusions:

- From the experimental analysis carried out over a period of one month, it is observed that the tilted single axis tracking system provides exemplary values of energy gains in the range of 31.91 % when compared to a fixed tilted PV system from a similar experimental analysis carried out over the same duration simultaneously, the dual axes tracking system has provided an almost close value of energy gain in the range of 35.3 % when compared to a fixed tilted PV system
- Cost analyses of the PV power generating systems indicate that the cost per kWh for a single axis tracking system is INR. 2.92 and that for a dual axes tracking is INR.3.42.
- From the experimental and cost analysis it can be inferred that it is advantageous to use a tilted single axis sun tracking system instead of dual axes sun tracking system.
- The proposed single axis tracking system can be up-scaled and used with advantage as standalone power

generating system to generate clean and green energy that can evade environmental degradation.
- When up-scaled to generate energy on a large scale, the cost per kWh of energy generated can be comparable with that of conventional energy sources or even less.
- These standalone systems can be used with advantage in far flung remote areas where conventional power supply is not available due to difficulty in laying power lines.

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Vikram Solar - Eldora Series Poly Crystalline PV solar module Technical data sheet.

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