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Performance Evaluation of a Low Cost Standalone Solar Photovoltaic System used for Rural Applications

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ABSTRACT

This paper presents the sizing of major system components in a DC power system used for rural applications along with the performance evaluation of a low cost, standalone solar photovoltaic (SPV) system using a single axis automatic sun tracking system. A 100-Watt SPV panel has been used in the experimental setup to generate maximum power. The tracking motor rotation is controlled using a simple, low cost; comparator based, closed loop electronic control circuit. The SPV panel drive mechanism uses the conventional worm-spur gear arrangement for rotating the SPV panel. The advantage of this system is that it can rotate the SPV panel using a low torque, low cost DC motor with very low per day energy consumption, which is less than 0.5 % of the daily energy generated and is almost free from maintenance problems. The system has operated quite satisfactorily over prolonged durations and has effectively tracked the sun to generate the rated power. Energy gain of the proposed system was41.75 % in comparison with an inclined fixed panel tilted at an angle equal to the latitude of Indore, Madhya Pradesh, India. The system can be used with advantage as a standalone SPV power generator in rural and remote places where power supply is either unavailable or erratic. A power system using DC appliances, a 12 volt battery and charge controller has been designed for a rural household to minimize installation cost.

KEY WORDS

SPV Panel sizing; Battery sizing; Sun tracking System; DC motor; Energy gain;

INTRODUCTION

This paper presents an optimum design of major system components used in a simple, reliable, low cost and efficient low power SPV generating system using a single axis automatic sun tracker. The proposed low power sun tracker to be used in the standalone power generating system is a simple closed loop electronic circuit in which the intensity of solar radiation is sensed and accordingly the SPV panel is aligned to remain normal to solar radiation at all times from sunrise to sun set by a DC motor. The light sensing devices are Light Dependent Resistors (LDRs), which can effectively respond to the entire spectrum of visible light. The LDR outputs are processed using a dual comparator in which one of the inputs will be a fixed reference voltage and the other input will be from the LDR. Depending on the difference of the two inputs, the comparators generate outputs that are fed to a motor driver circuit, which drives a DC motor and rotates the SPV panel using the worm-spur gear arrangement. The SPV panel thus aligns itself to remain normal to direct solar radiation from sunrise to sunset, thereby providing considerable energy gain for the SPV power generating system. After sunset a timer based bi-stable homing circuit will return the SPV panel back to the east facing position to start tracking afresh after sunrise on the subsequent day.

The proposed SPV system can be used as a stand-alone power generating system in rural and far-flung areas where power supply is erratic or unavailable. The system can be used to charge batteries using a charge controller or a hybrid inverter based on the availability of AC supply at the location of installation and requirement of the user. At locations where AC supply is unavailable, it would be a better option to use DC appliances, which can be directly driven by the battery, as it would not require an inverter, thus minimizing the system cost. At locations where AC supply is available, a hybrid inverter can be used, as it would be possible to use the existing AC appliances. However, this would increase the initial installation cost.

REVIEW OF TRACKING SYSTEMS

Literature review was carried out to investigate the type of drive systems used by researchers in sun tracking systems and the energy gain obtained thereby. Summarized information of the drive systems used and the energy gain obtained by several researchers has been shown in Table1.

Table 1. Summary of motors used and percentage energy gain of trackers

Sl. No.	Authors	Ref No	Type of tracker	Type of drive system	%Energy gain
1	Salah Abdallah, SalemNijmeh	1	Single axis Dual axes	DC motor with worm gear	32.61 to 48.73
2	Ali Al Mohammed	2	Single axis	DC motor with gear	40
3	Salah Abdallah	3	Single axis Dual axes	DC motor with worm and spur gear	15.69 to 43.87
4	George Bakos	4	Dual axes	AC motor with gear	Upto 46.46
5	Cemil Sungur	5	Single axis	DC motor with gear	32.5
6	B J Huang, F S Sun	6	Single axis	DC motor with gear	56
7	Abdallah, Badran	7	Single axis	AC motor with gear	24
8	Abu Khader et. al.,	8	Dual axes	DC motor with gear	30 to 45
9	Cemil Sungur	9	Dual axes	DC motor with gear	42.6
10	Ibrahim Sefa et. al.,	10	Single axis	DC motor with gear	45
11	B J Huang et. al.,	11	Single axis	DC motor with gear	23.6
12	Dakkak, Babelli	12	Single axis	DC Linear actuator	31
13	Senpinar, Cebeci	13	Dual axes	AC and DC motors with gear	13.25
14	Laughlin Barker	14	Dual axes	DC Linear actuator	30
15	Peng Zhang et. al.,	15	Dual axes	Stepper motors with worm and spur gear	36
16	Huang et. al.,	16	Single axis	DC Linear actuator	25 to 37
17	H S Akbar et. al.,	17	Single and Dual axes	DC motor	24.05 26.22
18	Michael Assaf	18	Dual axes	DC servo motors	30-40
19	Kamala and Joseph	19	Single axis	DC motor	57

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It is observed from Table 1, that most of the researchers have used DC motors while only some of them have used either AC or stepper motors. DC motors have been widely used because of the inherent advantages offered by them. Worm gear and spur gear arrangements have been used for controlling the movement of SPV panels to track the sun using either single axis or dual axes systems.

The proposed system uses a low wattage, 12 Volt DC motor along with a worm gear arrangement and has provided satisfactory results with encouraging values of energy gain during field tests conducted during the winter season.

MATERIALS AND METHODS

SPV panel

A 36-cell polycrystalline solar SPV module (Eldora 100P-Vikram solar make) with a maximum power rating of 100 Wp (V_{OC} = 21.84 V and I_{SC} = 6.11A) was used during the field test. The SPV panel physical dimension is (1152mm × 666 mm × 34 mm) and has a weight of 6.8 kg.[20].

Fig1: Inclined Fixed SPV panel

Fig2: Single axis inclined SPV system

Mild steel frame for fixed SPV panel and single axis tracker

The inclined fixed SPV panel was mounted on a mild steel (MS) L-section angle with an inclination equal to 23° (latitude of Indore) as shown in Fig. 1. As a thumb rule, fixed SPV panels are installed with an inclination angle equal to the latitude of the geographical location with the downward slope towards the south for year round optimum power output.

In the single axis tracking system shown in Fig. 2, the SPV panel is supported on sealed ball bearings into which the axial shafts of the SPV panel will fit in and rotate about this central axis. The bearings are fixed onto both vertical arms of a rectangular MS tube frame as shown in Fig.2, to allow frictionless rotation of the SPV panel. The compact worm gear system module is rigidly fixed to one end of the MS frame using fasteners. The SPV panel rotating shaft is then coupled with the gear box shaft for smooth rotation. The 12 V DC motor is coupled with the worm gear shaft for rotating the SPV panel.

TRACKING MOTOR DRIVE SYSTEM

A 3.5 rpm, 12 V DC, side shaft, geared motor has been used as the tracking motor in the proposed system. The DC motor draws a rated current of about 75mA when operating with a rated voltage of 12 V, hence the power consumption of the motor is about 900 mW. The DC motor drive circuit is quite simple, economically and technically advantageous to be used for bidirectional rotation of the SPV panel. The tracking system consumes only about 0.5% of the daily energy generated.

The DC motor is securely fixed to the gearbox to appropriately rotate the SPV panel for tracking the sun from east to west. The tracking motor shaft is securely coupled with the gear box shaft to ensure that the SPV panel

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which is coupled with the other gear box shaft is effectively rotated in both the east-west and west-east directions. Rotation of the tracking motor is controlled by a closed loop motor control system whose block diagram is as shown in Fig.3.

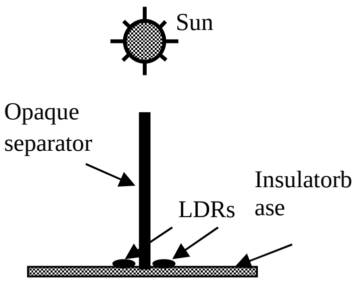

Fig 4: Arrangement of LDRs

Fig 3: Comparator based closed loop motor control circuit

The closed loop motor control system uses two Light Dependent Resistors (LDRs) mounted on the surface of SPV panel. They are used as light sensors in a closed loop system with dynamic feedback to track the sun continuously throughout the day.

The two LDRs are fixed on an insulating base and positioned on either sides of an opaque vertical separator sheet is shown in Fig. 4. As the sun starts moving towards the west, the opaque separator sheet will cast a shadow on the west LDR till mid-noon. The difference in resistances of the two LDRs will be detected by the comparator circuit and will cause rotation of the SPV panel until both LDRs come under direct solar radiation, thus aligning the SPV panel normal to solar radiation and generate maximum power. After mid-noon the separator sheet will cast a shadow on the east LDR as the sun moves towards the west and accordingly the SPV panel accurately tracks the sun generating maximum power at all times during the day until sun set.

When the SPV panel is not normal to incident solar radiation, the LDRs generate a differential error signal due to unequal solar radiation being incident on them. This differential error signal is processed by the comparator which then rotates the tracking motor until the SPV panel is normal to the incident solar radiation. When the SPV panel is normal to solar radiation, equal solar radiation is incident on both the LDRs, hence, the differential error signal becomes zero. The circuit is thus capable of tracking the sun using optical sensors to follow the sun movement in real time.

The SPV panel tracks the sun throughout the day from the initial east position in the morning to the extreme west position in the evening. It continues to remain in this position after sunset because both the LDRs have insufficient solar radiation incident on them. Thus the SPV panel is not facing east on the subsequent day to continue tracking after sunrise. This problem is overcome by using a timer based homing circuit that can return back the SPV panel to face east side and start tracking the sun from next day morning. Limit switches located on the west side of the SPV panel detect its end position at the end of the day and stop the east-west rotation of the motor. Another limit switch on east side will stop the west-east rotation of the motor during the homing operation and keep it ready to track the sun for the subsequent day.

DETAILS OF EXPERIMENTAL SET UP

Performance test of the proposed single axis tracking system was carried out during the month of January 2017.Performance of the single axis tracker was compared with a fixed inclined SPV panel system. The fixed inclined panel was placed making an angle of 23° (latitude of Indore) with the downward slope towards south. A magnetic compass was used to locate the geographical N-S and E-W directions to align both the panels appropriately. Both the SPV panels were placed in such a way that no shadows were being cast on them

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during the entire day. Output voltage and currents were recorded manually at regular half hourly intervals, from 07.00 AM to 06.30 PM (11 hours 30 minutes of sunshine hours)for 10 days during the month of January using table top digital multi-meters as shown in the experimental set up (Fig. 5).

RESULTS AND DISCUSSIONS

Performance comparison of the proposed single axis tracking system in terms of its average daily output power and energy gain has been carried out for ten consecutive daysduring the month of January, 2017.

Fig. 6, shows the graph of Average power output Vs Time of the day in Hours for the proposed tracker. It is observed that the proposed single axis tracker has been able to generate an output power in the range of 30 W or more from around 8.00 AM to 5.00 PM, i.e. for nearly 9 hours in a day. On the contrary, the inclined fixed panel is not able to maintain their output powers in this range for more than 6 hours. The fixed panel produces a total per day output power of 979.02 W, while the single axis system produces 1392.25 W. Thus the energy gain of the single axis system is 41.75 %, which compares quite well with the values of energy gains obtained by researchers all over the world. Thus the performance of the proposed single axis tracking system is definitely much better than that of the fixed panel.

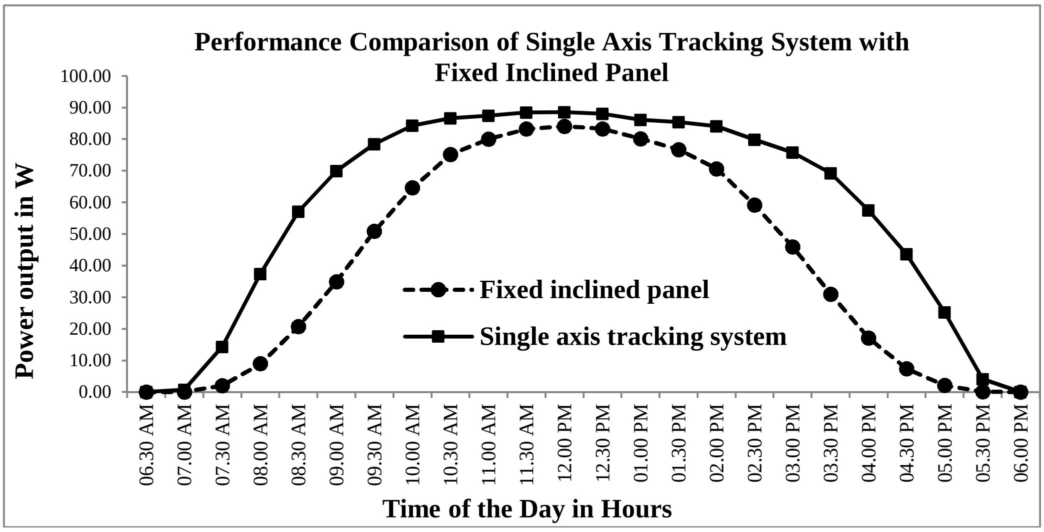

Fig 6: Power out of fixed inclined panel and single axis tracking system

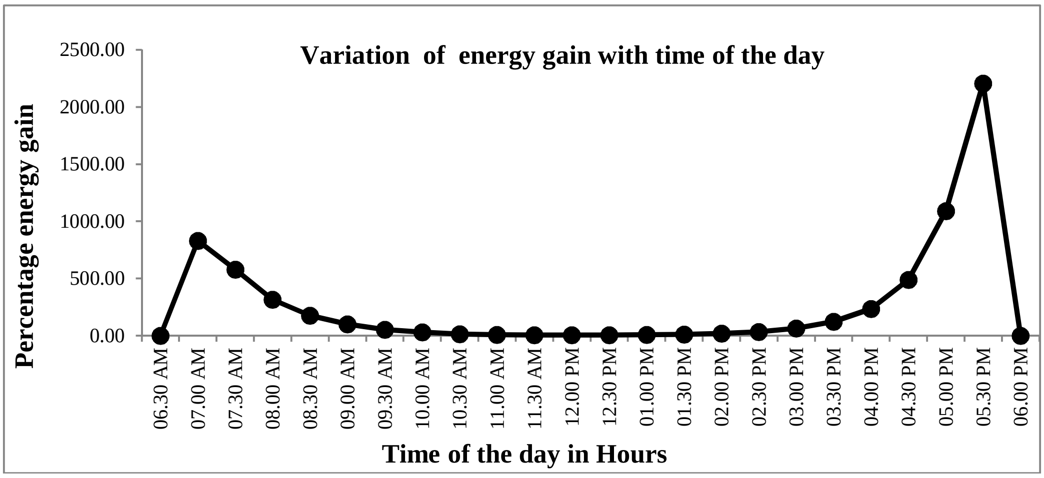

Fig 7: Variation of energy gain of single axis tracking system with time

Fig. 7, shows the graph of variation in energy gain with time of the day in Hours. It is observed that the energy gain is quite high in the morning and evening times and almost becomes negligible during mid-noon. Thus the single axis tracking system is capable of generating high level of energy output for extended time duration.

SIZING OF SPV PANEL, BATTERY AND CHARGE CONTROLLER:

Table 2. Calculations for energy consumption /day

Sl. No.	Appliances used	Power (W)	Quantity	Usage time (Hrs)	Energy consumption (Wh/day)
1	12 V LED bulb	7	1	5	35
2	12 V LED bulb	11	1	5	55
3	12 V DC Fan	20	1	5	100
4	12 V DC TV	28	1	5	140
Total energy consumption per day					330
Total energy consumption/day with system losses≈ (330×1.3)					**429**

a) Sizing of SPV modules :

Power rating of the SPV panel to be used = (Energy Consumption in Wh/day) ÷ 4.32

where 4.32 is the panel generation factor that depends on the time duration of generation of rated power output by the SPV panel in India.

i.e. SPV panel required = 429/4.32 = 99.31W≈100 W

Thus a 100Wp SPV panel can be used to effectively charge the battery used in the system.

b) Sizing of battery :

Deep cycle batteries which are designed for deep discharge and rapid recharge are used in this power generating system for efficient operation. The battery must be capable of storing sufficient energy to operate the appliances during night and also on cloudy days. Battery sizing for the proposed system is calculated using the following standard formula:

Battery capacity (Ah) = [(Total Wh/day) × (No. of days)] ÷ [0.85× 0.6 × 12 Volts]

The factor 0.85 takes care of the battery losses and the factor 0.6 takes care of the depth of discharge. 12 Volts is taken as the nominal battery voltage used in the system. Number of days is decided by the duration for which the battery has to drive the appliances. Here the battery backup is provided for two days.

Battery capacity (Ah) = (429 × 2) ÷ (0.85× 0.6 ×12) = 140.2 Ah

Thus a 12 Volt, 150Ah rating battery can be used to operate the system satisfactorily.

c) Sizing of solar charge controller:

The solar charge controller is used to effectively charge the battery and avoid overcharging of the battery, so as to prolong battery life. Its rating depends on the current and voltage capability of the SPV panel. As per standard practice, sizing of the charge controller is done by multiplying the short circuit current (I_{SC}) of the SPV panel by a factor of 1.3.

I_{SC} of the 100Wp SPV panel as noted from the specification sheet is 6.11 A

Therefore current rating of charge controller = (6.11× 1.3) = 7.943 A

Thus a charge controller with a rating of 12 Volt, 10 Amp can be used [21, 22].

CONCLUSION

A simple, cost effective standalone DC power generating system has been designed to be used for rural applications. Systematic sizing of its major components like the SPV panel, battery and charge controller has been carried out to design an efficient and effective system. A simple, low cost single axis sun tracker is used to charge the battery. Energy consumption of the tracking system is close to 0.5 % of the daily energy generation. Energy gain of the proposed single axis tracker is evaluated to be 41.75%, which is quite an encouraging value during winter season. Practical evaluation of system performance has demonstrated satisfactory performance results. Use of a single axis tracker instead of a fixed panel prolongs the productive time of rated power generation and increases the panel generation factor. This reduces the sizing of major components used in the SPV power generating system. The proposed SPV power generating system can be up-scaled with advantage and used as a standalone power generating system in remote rural and hilly areas for higher energy requirements.

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