Design and Development of Hybrid Axis Solar Stalker for Improving Performance Parameters

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ABSTRACT
In this study an attempt has been made to acquaint the capricious nature of sky and accordingly significant changes in the solar tracker design are suggested.

Even though plethora of methodologies have been proposed in the past to improve the performance parameters of solar panels by employing tracking systems, yet they have primarily taken into account clear sky conditions, without considering much about the effect of clouds on the global radiation.

Keywords
Hybrid solar trackers, capture efficiency, solar tracker with adaptability to sun rays

1. INTRODUCTION
In a country like India where we have desert terrains in the west, which include Rajasthan, Gujarat, solar energy can be envisaged as a full-fledged mean for generating electric power. The applications of solar energy are making significant headway and this has formed the basis of perseverance towards achieving consistent increase in pace of harvesting solar power energy.

The performance of PV panel can be defined according two types of efficiencies, cell and capture efficiency. Cell-efficiency can be defined as the collector's ability to convert photons energy to DC energy. It is affected by voltage loss that can reach up to approximately 20% of the total power output, band gap loss (23%) and excess photon energy losses (33%) [17]. Capture efficiency can be defined as the ability of the collector to harvest the maximum possible amount of solar radiation that is available at a specific site. This can be affected by the design of the system and the method of mounting the collector, and is going to consider improving the performance of solar collectors in regards to the energy capture only.

Current PV manufacturing techniques are highly energy intensive. The typical EPBT (Energy payback times) for a single crystal-silicon cell is approximately 2.7 years, which means that a cell must be used for almost three years before the manufacturing energy costs are recouped [12].Technological developments in cell technology have reduced the EPBT time down to around a year, especially in the cases of organic film solar cells. i.e in case of single crystal silicon EPBT is 2.7 years, whereas for cadmium telluride it is one year [18].

Some tracking systems can be employed to enhance capture efficiency of the photovoltaic panels. Solar panels come in a plethora of designs. The designs range from simplistic with minimal increases in yield to intricate machinations that offer larger yields. Additionally, the consumer can also choose between either a single axis system or two axis system [15].

There are enormous studies, which concentrate on the approach that follows the position of the sun during the day without considering the effect of clouds on the global radiation. Solar irradiation impinging on a surface consists in direct, diffused, and reflected radiations. Although the largest fraction of the solar irradiation is direct, both diffuse and reflected radiation must be taken into account for the systems operation analysis [11].

Improving the harvesting of solar energy on cloudy days deserves wider attention due to increasing efforts to utilize renewable solar energy. In particular, increasing the output of distributed solar power systems on cloudy days is important to developing solar-powered home fueling and charging systems for hydrogen-powered fuel-cell electric and battery-powered vehicles, respectively, because it reduces the system size and cost for solar power systems that are designed to have sufficient energy output on the worst (cloudy) days [8]. The countries that are located beyond the 45°N (Northern Europe) are the least favourable locations for capturing beam irradiances such as Scotland, Ireland and Norway, these countries receive the least amount of beam irradiance, half of the global irradiance comes from the diffuse component and that's due to the heavy cloud cover [1].

The solar irradiance for a specific location is affected by different factors including the cloudiness and the change of the sun position. Therefore understanding the solar resource at the required location can significantly influence the performance of any system. One must not only characterize cloudiness, but also cloud opacity that is whether sun rays can penetrate through it or not. The components of beam and diffuse insulation can vary for different locations. The contribution of beam to diffuse can vary depending on the cloud cover at the sky [16].

As the cloud cover spreads in the sky it entails diffused radiations and decreases the portion of direct radiation. Hence, clear sky conditions which are subjected to high beam radiation are seen to be most suitable for beam collectors only such as solar concentrators. And at cloudy condition which receives significant diffuse radiation, the non-concentration collectors such as flat plate collectors are more suitable for these conditions.

For a bright overcast day, manufacturers typically suggest that 60% of the global radiation reaches the surface and on dark overcast days as little as 10% of the radiation gets through. These values are obtained by measuring the performance of the solar panel under bright and overcast conditions and comparing to the output expected under full sun intensity [14].

Therefore in the regions where sky remains cloudy for the considerate amount of time in a year, neither we can't switch off our tracker, as in the mean time, sun continues rotating in the western direction, nor the operation of the system in dual axis mode, can satiate the requirement.

Hence from the perspective of energy saving, in order to seamlessly overcome this issue, we can switch our dual axis tracker to single axis mode during the overcast day. The hybrid axis stalker is the one which uses convergence of both dual axis and single axis type systems. That is the system normally operates in dual axis mode but during cloudy season it will switch automatically on to the single axis mode.

Accordingly we have considered three cases:
Clear sky: PV panel must be rotated such that it tracks maximum direct radiation from the sun. For this purpose the system is allowed to work in dual-axis mode.

Partially cloudy: This is the case when sky has white clouds. These clouds mainly transmit incoming solar radiations but scatter it; consequently we have both direct and diffuse radiations. So during this time panel is rotated but its tilt is kept fixed. For this purpose the system is operated in single-axis mode

Totally cloudy: This is the case, when sky has black clouds, and these primarily reflect solar radiation and cool the surface of the Earth, thereby making intensity of sunlight falling on tracker zero. Hence the panel is kept static during this time.

Hence after analyzing few cloudy days respectively from each season i.e. winter and summer, two calibrated values were summarized. One, which acted as threshold to determine whether the climate was sunny, or cloudy/night and the other as a threshold to further classify cloudy and night.

The authors in [9] made a tracking algorithm where they employed dual axis tracking during sunny days, which according to them improved the overall capture of solar energy by a given area of modules by 30 – 50% versus modules with a fixed tilt and kept the system steady during overcast conditions, as their assumption focussed on diffuse radiations to be isotropically-distributed over the whole sky. However as cloud has random nature no general model for solar positioning on cloudy days can be finalized.

We can have two empirical diffuse radiation models isotropic and anisotropic models. The isotropic models assume that the intensity of diffuse sky radiation is uniform over the sky dome. Hence, the diffuse radiation incident on a tilted surface depends on the fraction of the sky dome seen by it. The anisotropic models assume the anisotropy of the diffuse sky radiation in the circumsolar region (sky near the solar disk) and isotropically distributed diffuse component from the rest of the sky dome [14].

2. LITERATURE REVIEW

The authors in [7] proposed several ways to improve the efficiency of solar power, based on the various surveys and analysis, which they conducted for these methods. As per their findings the conversion efficiency of the panel can be increased by changing the composition of the material with which solar panel is made. Sunlight is always in a changing perspective, so the generating capacity of solar cells changes with time. Adoption of automatic tracking system increases the generating capacity, thereby reducing the cost of the investment.

The system proposed in [5] used a single axis position control scheme, which ensured 25 to 30% of more energy conversion than the existing static solar module system. Here the model of the tracker comprised of induction motor, relays and contactors. Relay employed was connected to the energizing winding of a contactor, which while turning on energized contactor winding, this in turn makes the motor run in forward motion. VFD (variable frequency drive) is employed for speed control.

Authors in [10] implemented sun tracking mechanism (SSTM) using smart memory alloy (SMA). The SMA element used in SSTM device senses as well as actuates the system to position the solar receptor. To activate SMA thermal stimulus is provided by concentrating the incident solar radiations on it.

3. DESIGN PARAMETERS

Design methodology used for this research is based on literature survey and many experts had been consulted who are working in related field.

In the inception, the proposed system is kept extreme eastwards unlike a fixed panel, which usually has south facing. As soon as the Sun rises, tracker will start tracking it and hence accordingly our PV panel will move. From the perspective of energy saving, the design has been employed such that it focuses on reduction in power consumption, so here chronologically firstly tracker tracks the sun, then adjusts the panel in accordance and thereafter goes to sleep mode for some time, until Sunrays again deviate.

The proposed prototype is the convergence of mechanical assembly and the control circuit. Mechanical structure needs to be perceived keeping in mind various design factors. Selection of actuators must be done so as to make an efficient and cost effective system. In the proposed system, stepper motor has been employed, unlike as done in [5], where DC motor has been used, DC motors have high inertia and don't abruptly stop on the desired position, hence are less accurate in this case. Researchers [2] have used DC geared motor. The inclusion to gears increases unnecessary complexity to the system.

As far as control circuit is concerned, the first session are devoted to develop a proper logic with which the heart of system that is, micro controller will work. It is a major component in tandem with light sensors. Features such as analog comparator (AC), analog to digital converter (ADC), universal synchronous asynchronous receiver transmitter (UART), and timers make ATmega series microcontroller an obvious choice [3].

Since we are referring to the optical tracking mode, hence photo sensitive devices as sensors have been roped in to sense the sunlight. We can use photoresistors, photodiodes, and phototransistors. Based on electric design, intensity of light and direction of light a comparison can be drawn which helps in choosing the suitable device. In [6] several tests were performed, where it was found that response of photodiode was too oscillatory, where as photoresistor had good response and phototransistor's response was too abrupt. Hence photo resistors or light dependent resistors are employed for this purpose. Also their resistance depends on light intensity rather than heat. So whether a day is sunny or cloudy LDRs will be able to determine all conditions precisely based on the intensity of light falling upon them (Fig.1).

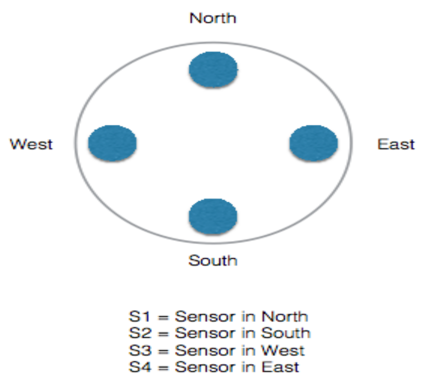

Fig. 1: Sensor arrangement

The analog signal from sensor is sent to micro-controller, which compares it with desired threshold and performs the required actions of rotating the solar panel depending upon the direction of the sun so as to achieve maximum illumination as a result of the sunrays falling on solar panel.

3.1 Illustration of Tracking System

A detailed block diagram and flowchart of the system are given below (Figs. 2 and 3).

Explanation of flow chart:

S - Difference between the intensity of horizontal sensors

S'- difference between the intensity of vertical sensors

C'- intensity of sensor in partially cloudy day

I- intensity of sensor in dark light (usually rainy or night time)

In the very inception we will read difference of the opposite sensors. If S is greater than the intensity of sensor in cloudy day (C'), it implies that it is not a cloudy day, subsequently our system will run in dual axis mode.

In case S is less than C', we will again compare it with intensity of light in dark. If value of S exceeds that of I, it indicates that the currently it is neither rainy nor dark, so it will prompt the system to work in single axis mode.

If S is less than that of I, this symbolizes night hence tracker will adjust itself to the original position. As the sun gradually changes its position, therefore the controller will wait for sometime before going back to the first step and the process continues.

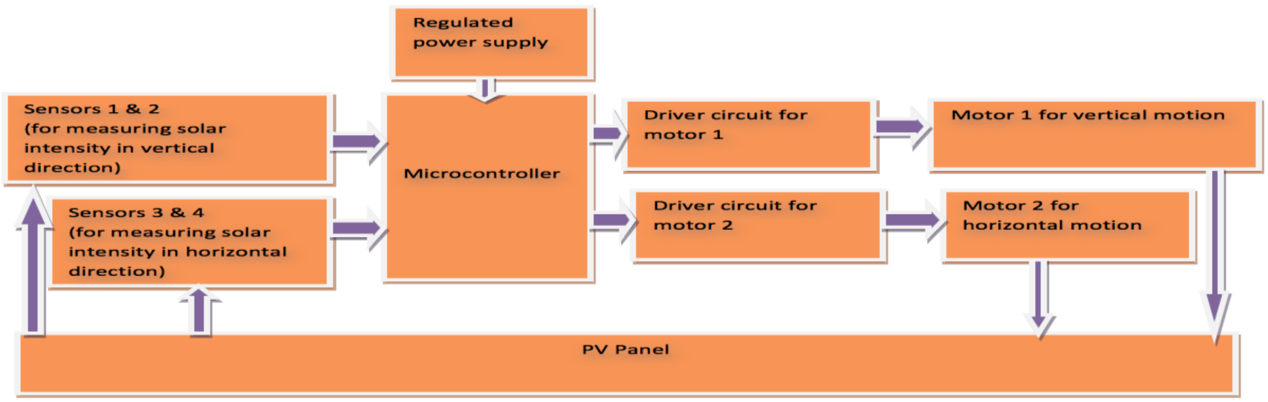

Fig. 2: Block diagram of tracking system

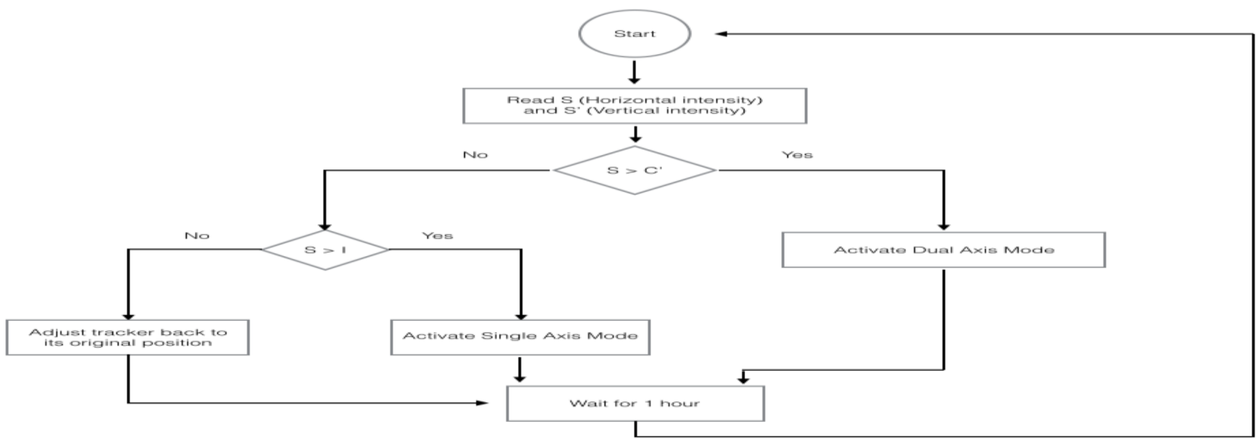

Fig. 3: Working of tracking system

4. PERFORMANCE PARAMETERS

Performance parameters	**Measurable parameters**	**Relation between performance & measurable parameters**
Maximum power	Voltage and current	$P_m = V_m I_m$
Efficiency	Solar irradiance	η = output power/ (Solar irradiance * area of panel)

Solar irradiance can be measured using solar pyranometers, by keeping them in same plane as that of PV panel. Open circuit voltage (V_{oc}) and short circuit current (I_{sc}) are very significant parameters for PV system performance analysis. Under ideal conditions, if the series and shunt losses are neglected from a PV cell then the product of V_{oc} and I_{sc} is equivalent to the maximum electrical power available from the cell [4]. Voc and Isc must be taken under no load conditions, due to the losses their product is never equal to Pmax and consequently we must calculate V_{max} and I_{max} by keeping some load across the panel.

These performance attributes of PV panel can be evaluated using a detailed experiential assessment, which is already under process to test the credibility of the findings.

5. CONCLUSION

In this work, an attempt has been made to design & develop a prototype, which will be used to trap the solar radiations even in the overcast sky to convert it into electrical energy. The work includes the design of microcontroller and other circuits. Main aim behind developing this kind of concept is to maximize the use of renewable form of energy by the way of capturing maximum solar radiations falling on solar panel and, therefore, able to increase the efficiency of the solar panel. The design consists of electric circuit connected to micro-controller which will control the movement of stepper motor connected to solar panel. This will help the solar panel to change directions according to the movement of the sun & work efficiently in cloudy conditions by capturing maximum energy possible from the sunrays falling on the solar panel. Thus, this work has been an attempt to add-up to the renewable sources of energy & increase the use of solar energy, thereby, solar panels by providing the users with an improved design to maximize the efficiency possible from the solar radiations.

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