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Automatic Positioning And Optimal Inclination Angles Of Photovoltaic Panels For Maximum Power Output

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Abstract
The efficiency of photovoltaic panel can be increased if it is placed in such a manner that incidence angle is null or almost small in respect to solar irradiation. This can be obtained by tracking the sun for movable structure and by proper selection of inclination angle for fixed structure and positioning of LDR. A case study is presented for deciding the optimum inclination angle for maximizing the output power of fixed structure PV panel in Ariyalur region of Tamil nadu state (India). To examine the effect of inclination angle on the output power of the PV panel, three PV panels have been installed at 30°, 40° & 45° angle of inclination .The values of open circuit voltage Voc and short circuit current Isc were measured on hourly basis for twelve month in the year 2014.The observation have been analyzed for finding the optimum angle of inclination of PV panel. Inclination angle is selected by LDR group output.

Keywords—Solar Tracking, Global Horizontal Irradiation (GHI), Dual Axis, Photo voltaic panel (PV panel),

I. INTRODUCTION

Energy is the basis for existence and development of human society. Threatened by the shortage of conventional energy and worse environmental condition, development of the renewable energy is the trend in the world and it is also the energy policy of our country. Solar energy systems are the newer options for clean and renewable energy. Solar cell is a key device that converts light energy into electrical energy in photovoltaic energy conversion. In most cases, semiconductor is used for solar cell material. The energy conversion consists of absorption of light (photon) energy producing electron hole pairs in a semiconductor and charge carrier separation. A p-n junction is used for charge carrier separation in most cases. In a P type semiconductor Fermi-level lies nearer to the valence band whereas in N type semiconductor Fermi-level lies nearer to the conduction band. When a p-n junction is formed, the Fermi-level tries to become equal. So there exists a band bending near the junction. Because of the band bending, the electrons find it difficult to flow from N region to P region and similarly holes find it difficult to flow from P region to N region. When light is made to fall nearer to the energy band bend region and if photon energy is bigger than the band gap energy, an electron hole pair is created which make the electron to move towards the conduction band and the holes moves towards the valence band. Many researchers have focused on the sun tracking schemes to optimize the tilt angle and orientation of solar panels based on sun irradiation. This paper presents a new means of controlling the sun tracking array with improved placing of LDR sensor.

The solar energy is converted to electricity by a photovoltaic cell or into thermal energy by a PV panel to heat water and air. The amount of solar radiations received on a PV panel depends on latitude, time of the day, time of the year, slope or tilt angle, surface azimuth angle & the angle of incident radiation.

The efficiency of PV panel can be increased if the panel is placed in such a manner that incident angle (angle between the sun rays and the perpendicular line on PV panel) is null or almost small .such a conditions is obtained in two ways. Firstly a tracking system is used so that a sun can be followed throughout the day and secondly, the panels are fixed in such a manner that angle of incidence is relatively small for most of time in a day. In first case, the efficiency of PV panel increases significantly as a proper tracking system make incidence angle almost null throughout the day. However, it is linked to major disadvantage of energy requirement of tracking system which includes motor drives to move the bulky system. The maintenance is another big issue. Hence, such a system is not viable for small power panels. Fixed panels are most commonly adopted PV panel structures.

When the PV panels are fixed, it is not possible to obtain the minimum incidence angle throughout the day. However, for achieving the reduced incidence angle for maximum duration the PV panels have to be installed with proper orientation and angle of inclination. The paper thus contributes towards an extensive analysis of the solar PV panel's data and presents an alternative to continuous sun tracking system by changing the angle of inclination using the LDR group output.

II.REVIEW ON SOLAR TRACKING

Number of works has been carried out by many researchers to track the solar power. Kalogiroa [1] and Alata et al. [2] suggested a tracking system which can be used with single axis solar concentrating systems. Roth et al. [3] and Bakos [4] constructed and tested two axis tracking system. Tomson [5] described mainly the performance of PV modules with daily two positions in the morning and afternoon. Results indicate that the seasonal energy yield increased by 10% over the yield from a fixed facing collector tilted with an optimum angle. Huang and Sun [8] has designed the solar tracking system called "one axis-3 position sun tracking PV module" with low concentration ratio reflector. This one axis tracking mechanism adjusted the PV position of three fixed angles during morning, afternoon and evening respectively. Lwin Lwin Oo and Nang Kaythi [9] have designed the two axis solar tracking using microcontroller. Surveying these journals, it is observed that the parameters such as the installation setup, tracking mechanism, cost of the experimental setup, efficiency, and design methodology has been given the highest priority based on the selected tracking method.

A. Sun Earth Geometry & Inclination Angle of PV Panels

The angle of inclination of PV panels depends upon the location of panels and sun-earth geometry. The sun-earth geometry involves the study of earth's rotation and revolution as well as the tilt angle of earth's axis. earth's rotation refers to the spinning of our planet on is axis, because of rotation, the earth's surface moves at the equator at a speed of about 467m/s. the earth's revolution refers to the orbiting of earth around the sun. This celestial motion takes 305.26 days to complete one cycle. As the earth rotates and orbits around the sun, there are significant seasonal and hourly positional changes of the sun. The relative position of the sun in a major factor in the performance of the PV panels.

Duffle and Beckman gives "rules of thumb" that to give maximum annual energy availability, a surface slope to latitude is optional and the surface should face to the equator. It means, a solar collector in southern hemisphere should face to the north with slope equal to its latitude to get maximum solar radiation. Number of studies have been carried out in different countries of the world to obtain the optimum tilt angle of PV panels were obtained through global data. In this paper, the optimum tilt angle to maximize output power is estimated by PV panels installed in University College of Engineering, Ariyalur, India which has latitude of 11° 77.

B. Studied Photovoltaic System

Power generation of PV system depends on various factors such as, solar irradiation ,time of day, day of year, power conversion efficiency, PV panel tilt, whether conditions and many more. Among the above parameters the direct solar irradiation is the most significant factor for calculating the power generated by a PV panel. the power generated in a day is a function of power efficiency(η),sunlight intensity(Ga,W /m^2),incident angle(θ),no of PV panels(n),area of a PV panels(A,m^2).

To overcome the energy shortage in country, government of India has started Jawaharlal Nehru solar mission and under this many cities have been declared as model solar cities.As a part of this work, PV panels have been installed on many buildings in Ariyalur to harness the solar energy to meets its energy requirements.

$$p = \sum_{\theta sunrise}^{\theta sunset} (\eta \times Ga \times cos\theta \times n \times A)$$

To obtain the optimum angle of inclination of PV panels at Ariyalur, experimental set up consisting of 3 solar panels has been installed at UCEA, Anna university, Ariyalur. These PV panels of 100w each have been installed at an inclination angle of 30°, 40° and 45° (as dictated by LDR group).

In this research, a yearlong recorded data is recorded and analyzed to reveal the PV performance from January 1st, 2014 to December 31st, 2014. There are 3 panels installed which are facing south and tilted at an angle of 30°, 40° and 45° with the horizontal. Each panel is connected to a charge controller unit which charges a 150Ah, 12h tubular battery. The battery is connected to an inverter through which a load of 40W tube light and a 60W fan is connected in 3 rooms. Block diagram for the experimental setup consisting of different ammeters, voltmeters, battery and inverter.

As the voltage is measured at open circuit and current is measured at short circuit so the switching scheme is designed so that there is load cut off while taking the readings, the load is reconnected to the CCU for the charging of the battery. From the battery the supply is given to the inverter which is further supplying the AC load.

III. PROPOSED METHODOLOGY

In this research work, it is proposed that the light dependent resistors are placed in rhombus shape as mentioned in Figure 1. This type of positioning of LDR provides two advantages; one benefit is that even if one or two LDR fails, the system is unaffected; the other one is that shading effect is minimized. Solar tracking is done using these LDR's output. The tracking scheme is explained clearly in methodology section. The inclination angles has been obtained the LDR comparator output.

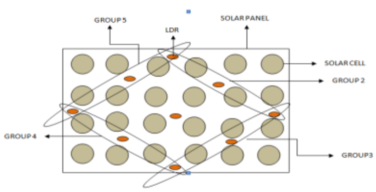

Fig .1. ***Diagram of LDR position.***

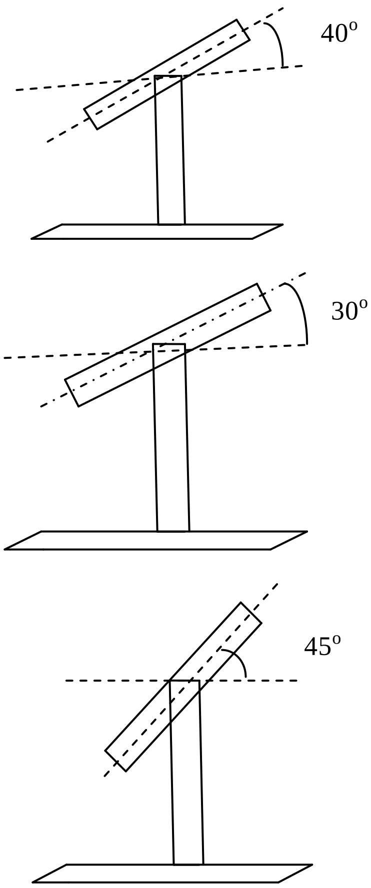

Fig. 2. ***Inclination of PV panels.***

IV. EXPERIMENTAL SETUP

C. Position of LDR

The solar tracking mechanism is done using stepper motor interfaced with microcontroller. The signals to the stepper motor are given by the microcontroller based on the LDR sensor output. The position of LDR sensors with shading effect is given in Figure 3.

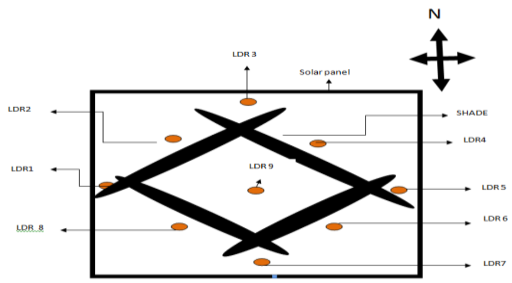

Fig. 3.*Shading effect of LDR*.

D. LDR sensor circuit

LDR is a device which responds to sun light i.e. when LDR is unexposed to sun light, its internal resistance is nearly 1.5MΩ whereas when it is exposed the internal resistance reduces to 25Ω.

The LDR circuit is connected in series with a resistor to form a potential divider circuit. The light-sensitive part of the LDR is a wavy track of cadmium supplied. Light energy triggers the release of extra charge carriers in this material, so that its resistance falls as the level of illumination increases. LDR is connected in potential divider fashion so that the output voltage (and current) is directly proportional to the light intensity. The output voltage is given by the following equation

$$V1 = (R1/R1+R2) \times Vcc \quad (1)$$

$$V2 = (R2/R1+R2) \times Vcc \quad (2)$$

The LDR circuit is shown in Figure 4. The Vcc supply given to the LDR is taken from the power supply unit. The power supply unit can be designed for suitable voltage. In standalone system the Vcc supply can be taken from the battery.

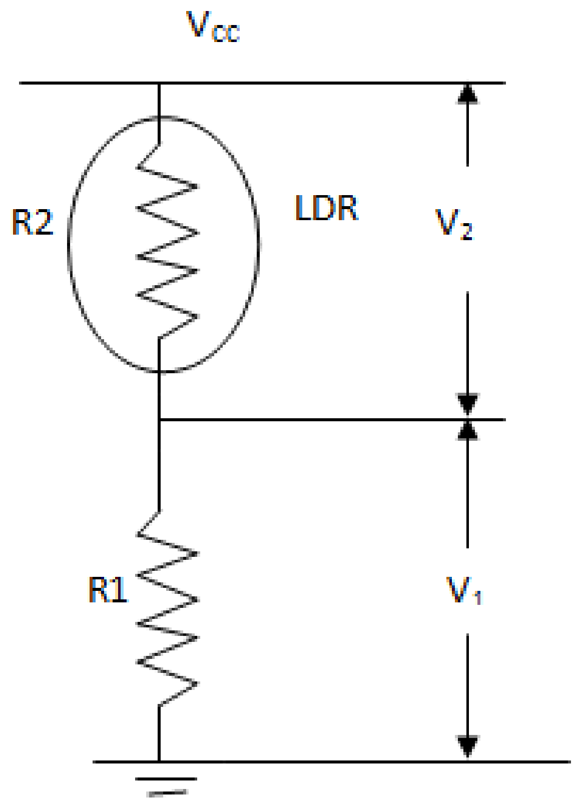

Fig .4. ***LDR Circuit.***

E. Comparator Unit

The comparator unit comprises of Operational Amplifier as shown in Figure 5. Since the voltage range is small, Operational Amplifier gives us good resolution in the output. The gain of the Op-Amp is adjusted according to the need of the circuit. The Op-Amp used in the circuit is LM324 which can amplify 5 to 6 volts. The Op-Amp which follows the comparator unit is the sign changer.

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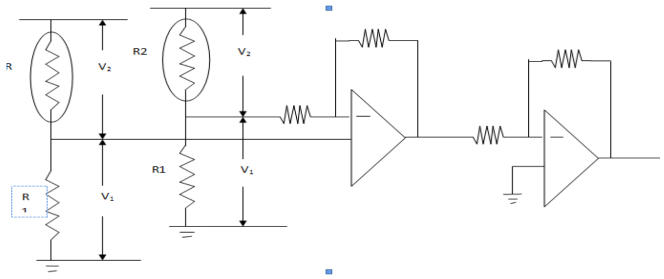

Fig. 5. ***Comparator of two LDR circuit.***

F. Solar Panel Setup

Fig.6. ***Photograph of the experimental setup.***

The total number of solar cells present in the panel used is 36 (9 × 4 cells). Each solar cell is of rectangular shape with dimensions 15.5 cm × 7.8 cm. The maximum no-load voltage indicated by the manufacturer is 21 Volts. The maximum Voltage obtained in field conditions is nearly 20 Volts.

TABLE 1. COMPARISON BETWEEN TRACKING AND FIXED PANEL

S.No	Sun Position	Sensor's which have active high output	Sensor's which have active low output
1.	East	4,5,6	1,2,8
2.	West	1,2,8	4,5,6
3.	North	2,3,4	6,7,8
4.	South	6,7,8	2,3,4
5.	North East	3,4,5	1,8,7
6.	South East	5,6,7	1,2,3
7.	North West	1,2,3	5,6,7
8.	South West	1,8,7	3,4,5
9.	Noon	All sensors output are high	--

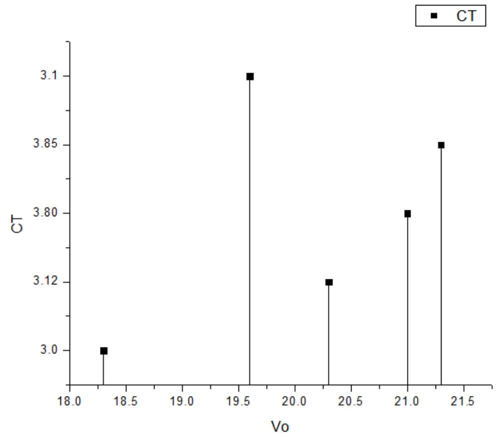

Fig.7. Voltage Vs Current for various load values.

TABLE 2.COMPARISON BETWEEN TRACKING AND FIXED PANEL

Time	Fixed SP*		Tracking SP* With 4 LDR Placed at centre of 4 edges		Tracking SP* with rhombus shaped LDR positioning	
Hrs	***Volt***	***CT***	***Volt***	***CT***	***Volt***	***CT***
7-9 AM	17.8	1.5	18.3	3.0	19	3.1
9-11 AM	19	3.11	20.3	3.12	20.4	3.28
11-1 PM	20	3.15	21	3.80	21	3.82
1-3 PM	21.3	3.23	21.3	3.85	21.8	3.91
3-5 PM	18.2	1.8	19.6	3.1	19.5	3.2

*SP – Solar Panel

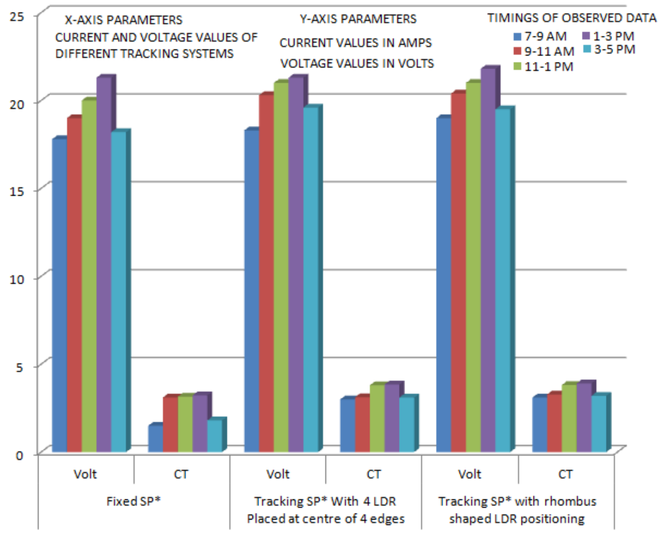

Fig .8. Tracking SP* With 4 LDR Placed at centre of 4 edges.

V. RESULT AND DISCUSSION

From the experimental setup various parameters for power calculations were recorded for each hour between 09:00 A.M. to 05:00 P.M. the readings are recorded for various days during different months of the year 2014. The open circuit voltage (Voc) and the short circuit current (Isc) were measured and power is calculated on hourly basis for 12 months from January to December. The formula used for calculating power is,

$$POWER = Voc \times Isc \times FF$$
$$FORMFACTOR(FF) = 0.7267$$

The direction of rotation of solar panel is performed as per the data present in Table 1.The direction of high radiation is sensed by the LDR group output. For eg. When LDR (4, 5, 6) group gives high output and LDR (1, 2, 8) gives low output then the direction of solar panel has to take east side.

The data recorded was for different seasons in varying weather conditions such as cloud, partially cloudy and clear day and this data is used to calculate the average power generated in a particular months of the year. However for comparison and analysis purpose the reading for bright sunny day .The inference after analyzing the data for one year is that the radiation is high for angle of 30^0,40^0,45^0 for selected months in an year.

Various values obtained in a day from morning 9 am to 5 pm are given in Table 2. The load used was variable Rheostat Load. The average voltage value of the no-load voltage obtained of the solar panel with tracking system is 19.7 Volts and of the fixed panel system is 17.3 Volts. The short circuit current is found to be nearly 3.8 Amps in tracking system whereas in non-tracking system it is found to be around 3.15 Amps. It can be observed that an increase of voltage by 13% is found in sun tracking system. Voltages and currents readings for different load conditions are tabulated in Table 4. Inference from the observed data indicates that there is sufficient increase in current values with increase in load values. Comparison of Voltage and current for different loads are given in fig 10 & fig 11.

The output power of PV panels with 30°,40° and 45° of tilt angle .It is observed that power output is highest is highest for 30° inclination in the month of January .However in the month of April the power generated for 40° and 45° are comparable .in the month of July the measured power is highest for PV panel at 30° as compared to 40° and 45°.the values of power at a angle of 30° becomes more in the month of September .the power generated by the PV panel at an angle of 45° is highest among the three panels in the month of December .

The measurements are also made for short circuit (Isc) for the three PV panels during different month of the year .for 30° it can be seen that the average short circuit current (Isc) is higher in the month of April and September whereas it is smaller during the month of July and December. The reason for such outcomes can be due to the impact of changing the solar irradiation and climate conditions during these month as the month of April and September has quite even weather whereas July experiences heavy rainfall and December has extremely cold conditions and dew effect in Ariyalur.

The average power calculated during a full sunny day during different days of the year 2014.it is analyzed that the average power calculated during the month of January is more for 30° and 45° in the month of April and continued till the month of July .the average power again becomes more for 45° in the month of December.

In order to find the percentage power difference during different seasons of the year for different seasons of the year from different PV panels the calculations has been made. The percentage difference (PD) in the output is calculated using,

$$\%PD = \frac{OUTPUT\ POWER(45°) - OUTPUT\ POWER\ (30°)}{OUTPUT\ POWER\ (45°)}$$

Analysis of these plots shows that, the PD for the month of January shows a significant difference in output power throughout the day. There is a power difference of minimum 6% in morning and maximum 18% in evening which is quite significant. This indicates that, a PV panel with 45° inclination is good as compared to 30° inclination for the month of January.

Table 3: Tracking Position Data AT 10.00AM

NOLOAD VOLTAGE:19.7 TIME:10:00AM		
LOAD	***VOLTAGE***	***CURRENT***
0Ω(SC*)	2.5	3.64
1Ω	5.9	3.50
2Ω	9.1	3.38
3Ω	12.1	3.24
4Ω	14.5	3.04
5Ω	15.9	2.76
7Ω	17.2	2.22

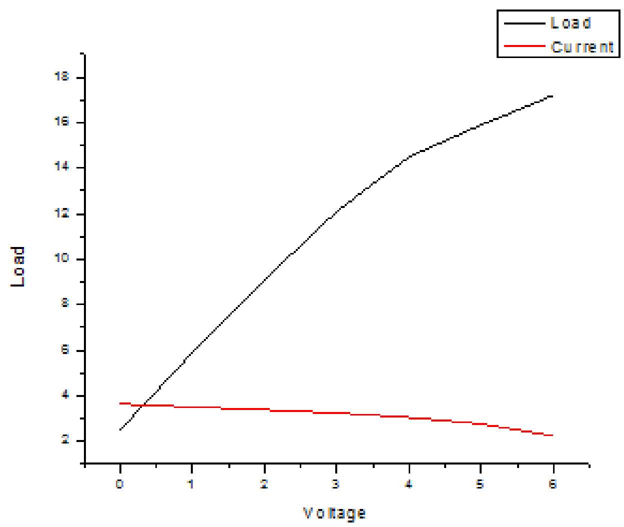

Fig .9 .Voltage Vs current for the year 2014.

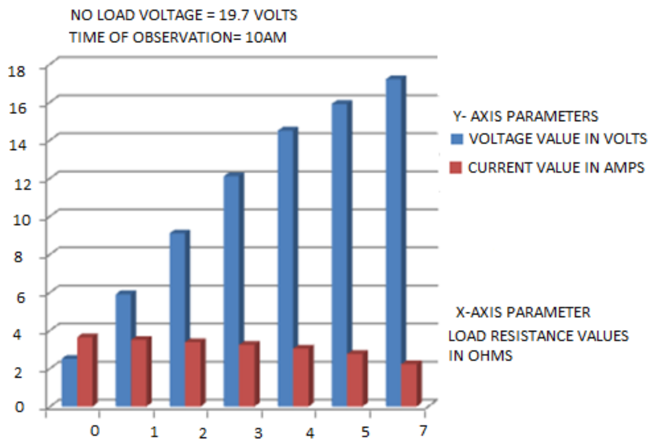

Fig .10. Comparison of voltage and current at 10 AM for different loads.

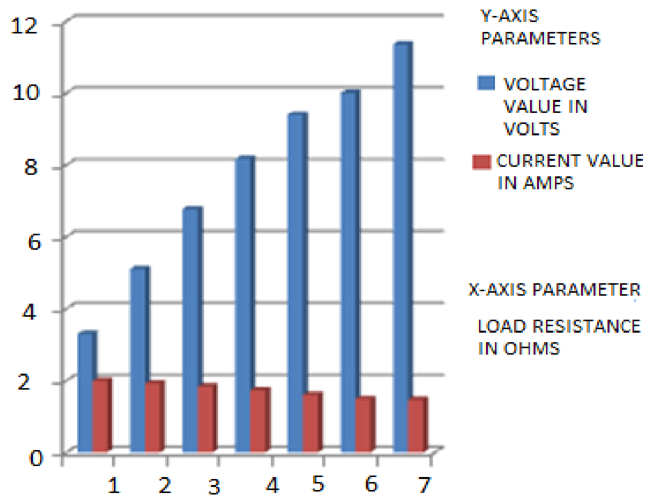

Fig.11. Comparison of voltage and current at 3 p.m. for different loads.

6. CONCLUSION AND FUTURE WORK

This paper presents a new means of controlling the sun tracking with improved placing of LDR Sensors in the solar array panel. The results also indicate that there is increase in voltage by 13-15%. This is an initial work done in Ariyalur location in Tamilnadu, India. The scope of improvements in this work is manifold, as it is felt that this design is a miniature scale model which could be replicated in much larger scale.

The short circuit (Isc) and output power vary with the change in position of sun from morning to evening. In all the three panels, the short circuit current (Isc) and power output has been observed to be higher from the PV panel with 30° inclination during the month of April to September. However the short circuit current (Isc) is higher for 45° inclined PV panel from January to March. It is concluded that, as per the location of Ariyalur the sun is overhead during summer season starting from April to September. The 30° inclination is optimum, whereas for the rest of the year, the angle of the year, the angle of the panel can be adjusted to 45° .so with biannual change the efficiency of PV panel can be enhanced to great extent.

As a part of future work, Field Programmable Gate Array implementation of this work along with Maximum Power Point Tracking algorithm can be done. Solar panel paralleling can be done, based on the obtained result, for operating single phase induction motor for domestic application.

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