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Performance Evaluation of a Solar Tree Design and a Fixed Solar Panel for Effective Solar Power Harnessing

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Abstract

Solar tree is an innovative concept of arranging the PV panels in the form of radially protruding outward branches from a central trunk replicating tree like appearance. There is spiral arrangement of braches on the trunk from bottom to top and having "n" spiral turns around it and a total of "p" number of branches from bottom to top arranged on the spiral path. Normally a phyllotaxic arrangement of branches and leaves in a plant is taken as reference for deciding the ratio n:p in a solar tree on the basis of Fibonacci ratios such as 1/3, 2/5, 3/8 and 5/13. In this work a solar tree based on 2/5 Fibonacci ratio is designed and its energy output in a particular time duration is compared with a fixed solar panel of equal capacity facing equal amount of solar insolation. It is observed from the results that solar trees are capable of producing more electrical energy as compared to fixed panels when placed in equal amount of solar insolation for the same time duration. This makes them suitable for being utilized in street lighting, domestic lighting and heating etc. Besides being more efficient they are better option as compared to fixed panels because they utilise just 1% of the land area utilized by the fixed panels for the same output capacity.

1. INTRODUCTION

More and more power generation from renewable energy sources is now-a-days being desired with the objective of meeting out the carbon footprint standards. The fossil fuel based power plants being major emitters of Co_2 in the environment engender green house heating. Solar energy has proven itself to be the most viable solution for renewable energy based power production. PV cells arranged in the form of solar panels are now-a-days common sight on the roof-tops of buildings for meting out their energy requirements. The panels are normally fixed at an appropriate angle of inclination depending on the latitude and longitude of the site [1]. Now-a-days trackers are also used with the panels to orient them in the line with the movement of sun such that it continuously faces maximum amount of insolation for maximizing the energy yield. The tracking however being passive in nature requires energy input for operation which becomes a liability from the point of the total energy output. There have been attempts to optimize the solar panel designs for obtaining maximum output power from them in the past. The solar tree designs are an effort in the same direction. Solar tree is an innovative concept of arranging the PV panels in the form of radially protruding outward branches from a central trunk replicating tree like appearance [2, 3]. There is spiral arrangement of braches on the trunk from bottom to top having "n" spiral turns around it and a total of "p" number of braches coming out from bottom to top along the spiral path. Normally a phyllotaxic arrangement of branches and leaves based on Fibonacci ratios such as 1/3, 2/5, 3/8 and 5/13 are taken as reference for deciding the ratio n:p in a solar tree. This arrangement helps in optimized capturing of falling insolation and its conversion into electrical energy in a given time duration as compared to a fixed panel. In this work a solar tree based on 2/5 Fibonacci ratio depicting the branch arrangement in a oak tree is designed and its energy output in a particular time duration is compared with a fixed solar panel of equal capacity facing same amount of solar insolation[4,5].

The pressure of growing population has resulted in shrinking of agricultural lands in many countries due to construction and industrialization. Moreover, the crisis and growing demand of food each year has resulted in pressure to create more and more cultivable land resources. The conventional PV plants have panels generally erected on land rendering it un-useful for agriculture. The solar trees have to some extent have provided solution to this situation as they require just 1% of the land in comparison with the conventional PV plants[6, 7].

This paper is organized as follows. In section 2, materials and methodology adopted for the design of solar tree is presented and result and discussion are presented in section3 and finally the conclusions of the work are presented in section 4.

2. MATERIALS AND METHODOLOGY

In this section the materials used for creating solar tree design and methodology adopted has been explained in detail. But before actual design considerations and approaches are discussed; it becomes important to explain a few important relevant terms as in subsequent sections.

2.1 Phyllotaxy

The term *phyllotaxy* coined by Charles Bonnet describes the arrangement or patterns of leaves on the plant stem. Three basic phyllotaxy in plants are *opposite*, *alternate or spiral* and *whorled* as depicted in figure 1.1. In *opposite phyllotaxy* two leaves arise from the same point (node) on the stem and are arranged in opposite directions while in alternate phyllotaxy the leaves arise from different nodes on the stem and are arranged in opposite direction. In *whorled* arrangement

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several leaves arise or appear to arise from the same node on the stem protruding in different directions[8. 9]. This arrangement is rather unusual as compared to opposite and spiral pattern. More than 80% of the plant species exhibit the alternate phyllotaxy such as in plants like potato, sunflower, rose and popular. *Alternate phyllotaxy* is the basis for designing the solar tree in this work which contains only one panel at each node placed alternately along the tree stem[1].

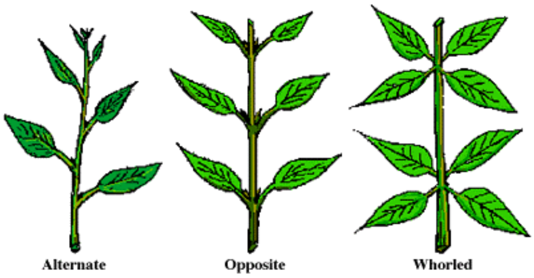

Figure 1.1 Basic phyllotaxy in plants

2.2 Design Methodology

The complete list of apparatus required and various materials used for designing the solar tree are presented in table 1.1. A PVC rod forms the tree trunk while aluminium sheets of different lengths and proper stiffness sufficient enough to sustain the weights of the panels without changing its position due to gravity are used to form the branches of the tree. A support base of aluminium for supporting the whole tree structure is placed on the bottom of the stem.

The branch positions on the stem are decided on the basis of 2/5 fibonacci pattern of Oak tree depicting *spiral phyllotaxy*. In this arrangement there are two spiral turns around the main trunk and the branches are placed at different positions on the trunk nodes coming on the paths of the spiral turns as depicted in the figure 1.2.

Table 1.1: Material and apparatus required for designing a solar tree.

S. No	Apparatus/Material Required	Quantity	Rating/Dimensions
1	PVC pipe	1	5ft. height
2	Aluminum strips	6	-
3.	PV panels (Ratings below)	6	-
	(i) Maximum power rating	-	3 watt
	(ii) Open-circuit voltage	-	10.8 volt
	(iii) Short-circuit current	-	0.37 ampere
	(iv) Rated voltage	-	8.82 volt
	(v) Rated current	-	0.34 ampere
	(vi) Module weight	-	1.15 kg
	(vii) Module dimension	-	200×200×17 mm
4.	Solar power meter	1	-
5.	Fluke digital multimeter, connecting leads and probes, IR cables	1 each	-
6.	Rheostat	1	150 Ω
7.	Fluke-view software	-	-

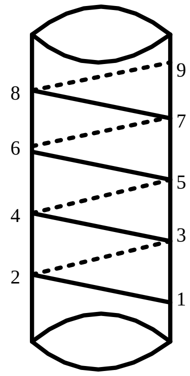

Figure 1.2 Branch positions on the trunk in 2/5 phyllotaxy.

The angle between any two consecutive branches for 2/5 phyllotaxy can be calculated as:

$$\frac{2}{5} \times 360^\circ = 144^\circ \text{(anti-clock wise)}$$

The angle between the branches is calculated in reference with the top most branch which is also considered as the first branch as depicted in figure 1.2. Also single branch is placed at each node according to 2/5 phyllotaxy pattern. Different lengths of branches are chosen in order to avoid the shadow of the top panels falling on the panels below them. The panels are placed at the end of each branch and the panel on the top-most branch is considered as the reference panel having the tilt of 29° with respect to ground which is equal to the latitude of the site (Pantnagar) where it is to be installed and oriented in south direction so as to obtain maximum insolation. The other 4 subsequent panels are placed at 144° anticlockwise from one another in reference with the first panel. The position of panels in the solar tree and position of conventional panel is presented in table 1.2.

Table 1.2 Orientation and tilt angles of panels in solar tree and conventional panel

	Solar Tree						Conventional Panel
	From Top to Bottom of Main Trunk						
	1st panel	2nd panel	3rd panel	4th panel	5th panel	6th panel	
Tilt angle	29°	7°	43°	79°	65°	29°	29°
Orientation	South	North-East	West-South	South-East	North-West	South	South

2.3 Experimental Procedure

The experimental process involves procedure for obtaining the values of power generated from the solar tree and the fixed panels as depicted in figure 1.3 by using the instruments shown in figure 1.4. Both the solar tree and the fixed panels were loaded to their rated capacity by monitoring the value of output current using a multi-meter. The variation in solar irradiance on the fixed panel and the panels of solar tree was also monitored using an irradiance meter. The readings were recorded for the month of June and July 2018, however looking into the space considerations the readings of only two days of these months have been presented in the subsequent sections.

Figure 1.3: Experimental Solar-Tree and Fixed Solar Panel

Figure 1.4: Experimental set-up for measuring the power output from solar tree and fixed panel

3. RESULTS AND DISCUSSION

The output power variations from the solar tree (STP) and conventional fixed panel (SCP) are given in figures 1.5 and 1.6 respectively, while the variations in the solar irradiance falling on each panel is presented in figure 1.7. It can be observed clearly from the power curves that the output power from the solar tree is higher as compared to the conventional fixed panel and as a result the total energy production in the given time duration also is much higher as compared to the conventional fixed panel. A comparison of the output yields of the fixed panel and the solar tree are presented in table 1.3. The power output from the solar tree in 6 hours duration from 11.00 am to 5 pm is 177.06 watt and the corresponding energy output is 1.06236 Kwhr while from the fixed panel in the same time duration the output power is 152.64 and the corresponding energy output is 0.91584 Kwhr.

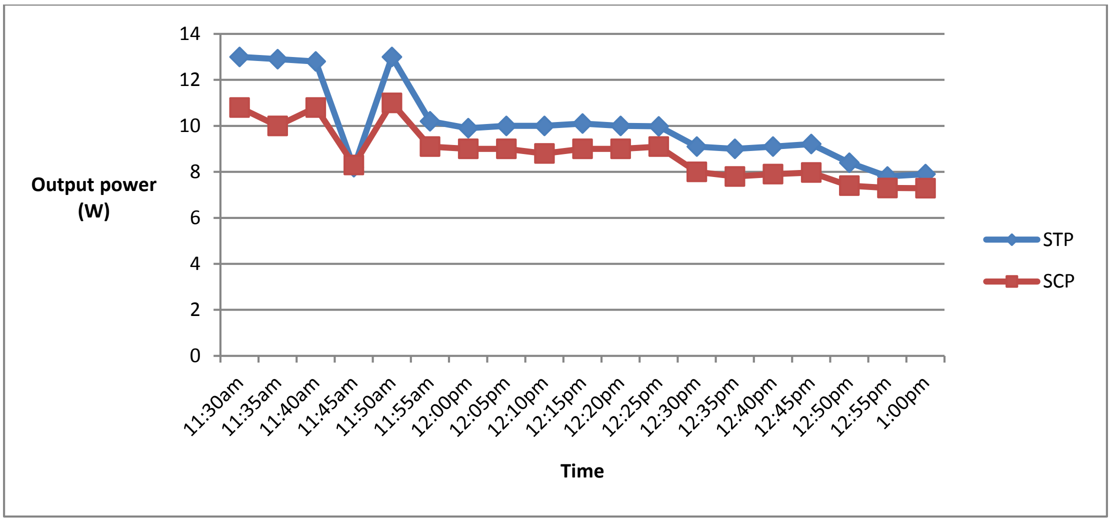

Figure 1.5: Output power variation in solar tree and conventional panel.

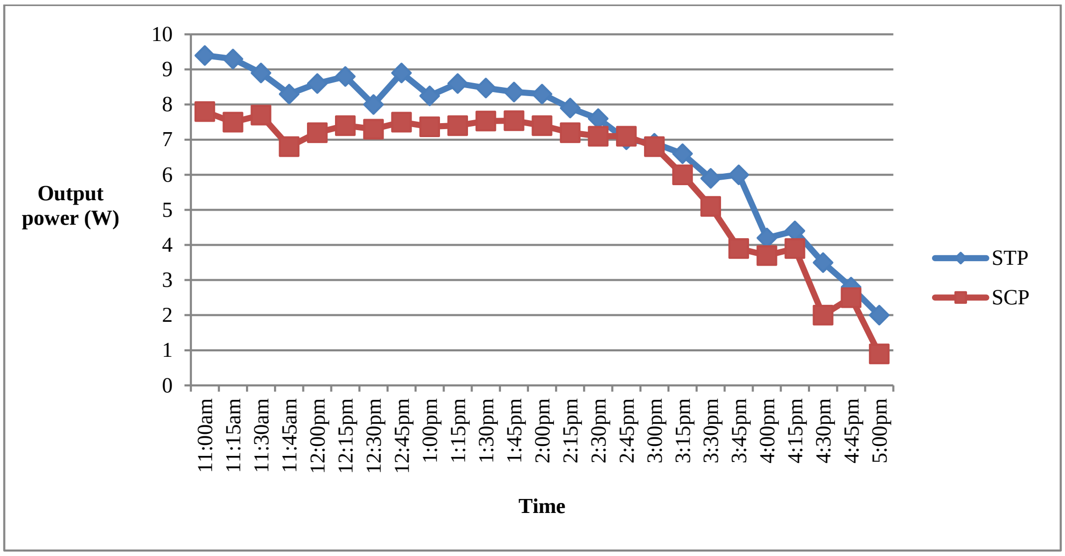

Figure 1.6: Output power variation in solar tree and conventional panel.

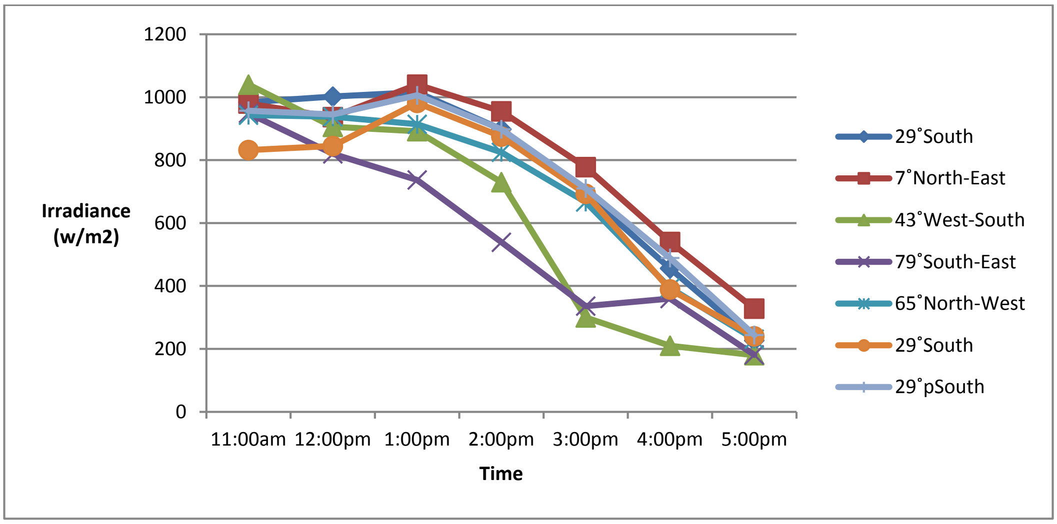

Figure 1.7: Irradiance variation on the different panels of the solar tree.

Table 1.3: Energy yield from a solar-tree and a conventional fixed panel.

Time	Output power (Solar Tree) (W)	Output power (Fixed panel) (W)
11:00am	9.4	7.8
11:15am	9.3	7.5
11:30am	8.9	7.7
11:45am	8.3	6.8
12:00pm	8.6	7.2
12:15pm	8.8	7.4
12:30pm	8	7.3
12:45pm	8.9	7.5
1:00pm	8.25	7.37
1:15pm	8.6	7.4
1:30pm	8.47	7.53
1:45pm	8.36	7.54
2:00pm	8.3	7.4
2:15pm	7.9	7.2
2:30pm	7.6	7.1
2:45pm	7	7.1
3:00pm	6.9	6.8
3:15pm	6.6	6
3:30pm	5.9	5.1
3:45pm	6	3.9
4:00pm	4.2	3.7
4:15pm	4.4	3.9
4:30pm	3.5	2
4:45pm	2.8	2.5
5:00pm	2	.9
Total power	177.06	152.64
Total Energy Output	177.06x6=1.06236 Kwhr.	152.64x6=0.91584 Kwhr

4. CONCLUSION

In this work the performance of a designed solar tree and a fixed conventional capacity of 18 watts capacity have been compared in terms of their output power when the solar irradiance falling on both the solar tree and the conventional fixed panel are under equal amount of falling insolation. It is observed that since the panels on the solar tree are arranged as per 2/5 phyllotaxy of like in oak trees it is capable of optimizing the output power as compare to the conventional fixed panel. From the data recorded it is imperative that the solar panel produced 22.42 watts more than the conventional fixed panel during the complete operating period of 6 hours. It can also be interpreted from the solar irradiance data falling on each panel of the solar power plant that change in the amount of irradiance affected the output power from the conventional panel more than the total output power from the solar tree. From the results obtained it can be interpreted that solar trees can be more effective means of converting the falling irradiance as compared to the conventional fixed panels. Hence, it is expected from the governments to take effective measures for encouraging their use and installations by providing necessary financial and policy support.

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