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Comparative Analysis of Energy Generated By Solar Photovoltaic Modules Placed at Latitude Angle and Normal to the Sun

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Abstract

This paper presents a comparison of energy generated by solar photovoltaic modules when placed at different angles with respect to sunlight. Initially the PV modules are installed at an angle equal to the latitude of the location (Vellore) and then placed at angle normal to the sun. In both the cases, the energy generated by PV modules are measured and a comparative result made based on experimental results are presented here. The result proved that the energy generated by PV modules are high when placed at an angle normal to the sun.

Introduction

The sun is the earth's major energy source and radiates its energy from a distance of 150 million kilometers. This solar radiation reaches the outside of our atmosphere with an irradiance of about 1367 W/m^2. Of the total solar radiation reaching the earth's surface each year only a minute part is equivalent to global electricity demand today. The amount of radiation depends on geography and climate, particularly on latitude. The placement of PV module on the surface plays an important role in energy generation. Depending on the angle of installation of PV modules, the amount of energy generation varies. To study the effect of sun tracking and to determine the difference in energy generation by PV modules when placed at different angles are the prime objectives of this work. For fixing the PV module, there are basic angles need to be considered which are given below.

Declination angle (δ):

The declination angle is defined as the angle between the lines joining the centre of the earth to the centre of the sun with its projection on the equatorial plane of the earth. The variation in the declination angle is due to the inclination of the earth's polar axis and its revolution around the sun. The declination angle varies between -23.45°(Winter solstice) to +23.45°(Summer solstice). The declination angle is mathematically represented as

$$\delta = 23.34 \sin \{(360/365)^* (284+n)\}$$

where n is the nth day of the year starting from January.

Latitude angle (Φ):

Latitude angle is defined as the angular distance of a point on the surface of the earth from the equator.

Altitude angle (α):

Altitude angle is the angle on the vertical plane between the sun's rays and the projection of the sun's rays on the horizontal plane.

$$\alpha = 90 - (\theta z)$$

Optimal angle of fixed module:

The optimal inclination of the surface is given as $\beta = \Phi - \delta$. Here the value of δ changes every day. It means that β value also changes accordingly every day. It is impossible to change the position of modules everyday according to β value. Hence the average declination angle over a year is found out to be zero which results in $\beta_a = \Phi$.

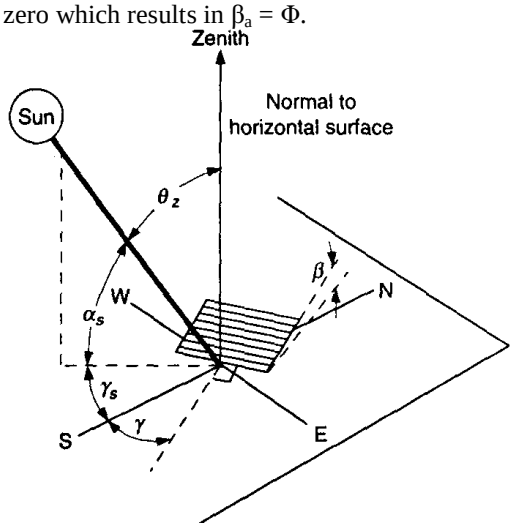

Figure 1. Diagram showing different solar angles

Experimental Setup

The experimental set up consists of two solar PV modules connected in series with a variable load resistance of (0-200) Ω, 2.5A is shown in figure 1. This experiment has been done on December 17th, 2012 and the declination angle is calculated as δ= -17.83 degrees. The latitude angle of Vellore is given as 12.56 degrees.

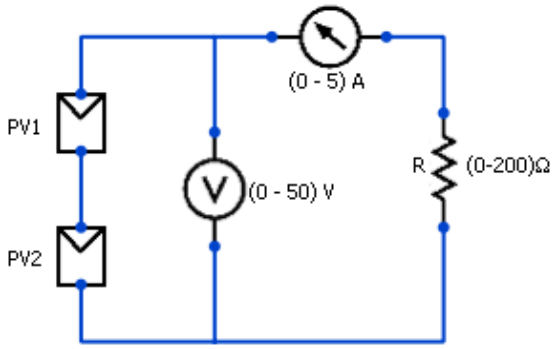

Figure 2. Circuit diagram of PV module for I-V measurement

To estimate the energy generated by PV module, two methods of installation are carried out in this experiment. In the first method, PV module is placed at a fixed angle equal to the latitude of the Vellore (Φ = 12.56 degrees) facing south. For this fixed angle method, the angle of PV module installation with respect to horizontal plane is fixed. In the second method, PV modules are placed exactly perpendicular to the sunlight.In order to determine the energy of PV modules, the I_V characteristics are measured for both cases at regular intervals. The open circuit voltage and short circuit current are measured at the beginning. The interval chosen here is about 15 minutes between measurements. After the measurement of I_V characteristic values, the power is calculated. Then the energy generated is computed by taking the product of peak power and time duration between measurements. The peak power of PV module is obtained from the table 3.

Figure 3. Solar PV module Kit used in this experiment.

Table -1: When the PV modules are fixed at angle Φ = 12.56 degrees.

Time	3.05 pm			3.20pm			3.35pm		
S.No.	V(V)	I(A)	P(W)	V(V)	I(A)	P(W)	V(V)	I(A)	P(W)
1	40.1	0	0	40.1	0	0	39.8	0	0
2	39.3	0.2	7.86	39.3	0.22	8.646	38.8	0.19	7.372
3	38.9	0.31	12.059	39.2	0.25	9.8	38.6	0.25	9.65
4	38.7	0.36	13.932	39	0.28	10.92	38.2	0.29	11.078
5	38.4	0.42	16.128	38.8	0.32	12.416	37.9	0.35	13.265
6	38.2	0.47	17.954	38.6	0.38	14.668	37.6	0.4	15.04
7	37.8	0.55	20.79	38.3	0.43	16.469	37.2	0.46	17.112
8	36.9	0.71	26.199	37.8	0.51	19.278	36.4	0.55	20.02
9	35.9	0.84	30.156	31.7	1	31.7	35.2	0.67	23.584
10	34.3	0.99	33.957	32	1.02	32.64	32.7	0.81	26.487
11	30.5	1.13	34.465	20.3	1.06	21.518	27.5	0.89	24.475
12	21.3	1.14	24.282	20.4	1.06	21.624	14.6	0.94	13.724
13	12.8	1.22	15.616	2.4	1.18	2.832	1.2	0.96	1.152
14	1.1	1.26	1.386	0.9	1.13	1.017	0.8	0.97	0.776
15	0	1.27	0	0	1.22	0	0	0.98	0

Table -2: When the PV modules are placed normal to sunlight Φ = 90 degrees.

Time	3.05 pm			3.20pm			3.35pm		
S.No.	V(V)	I(A)	P(W)	V(V)	I(A)	P(W)	V(V)	I(A)	P(W)
1	39.6	0	0	40.2	0	0	40	0	0
2	39.6	0.22	8.712	39.5	0.2	7.9	39.2	0.2	7.84
3	39.5	0.26	10.27	39.3	0.24	9.432	39	0.22	8.58
4	39.4	0.28	10.27	39.2	0.27	10.584	38.8	0.26	10.088
5	39.1	0.32	11.032	39	0.32	12.48	38.6	0.31	11.966
6	38.9	0.37	12.512	38.7	0.39	15.093	38.4	0.35	13.44
7	38.4	0.48	14.393	38.3	0.48	18.384	38.2	0.39	14.898
8	37.8	0.59	18.432	37.8	0.57	21.546	37.8	0.46	17.388
9	37.1	0.7	22.302	37.2	0.66	24.552	37.1	0.56	20.776
10	35.9	0.84	25.97	36	0.82	29.52	35.7	0.73	26.061
11	32.8	1.06	34.768	30.2	1.09	32.809	32.1	0.9	28.89
12	23.8	1.1	26.18	17.7	1.11	19.647	32.2	0.9	28.98
13	14.6	1.18	17.228	1.1	1.22	1.342	21.8	0.93	20.274
14	1.2	1.23	1.476	1	1.21	1.21	14.8	0.98	14.504
15	0	1.16	0	0	1.25	0	0	1.05	0

Table 3: Peak power measured in both cases

Time	Peak power (W)	
pm	Φ = 12.56°	Φ = 90°
3.05	34.465	34.768
3.2	32.64	32.809
3.35	26.487	28.98

Results

The energy generated by PV modules when placed at latitude angle and normal to the sun light is calculated by using the equation shown below. The peak power is obtained from table 3 and time duration between measurements is 0.25 hours.

Energy = Power * time (watt-hour)

$E = (P_{m1} * \Delta t_1) + (P_{m2} * \Delta t_2) + (P_{m3} * \Delta t_3)$

Energy generated by the PV module when placed at latitude angle is 23.39 watt-hours and when placed at normal to sun is 24.14 watt-hours. The difference in energy gain is due to the angle of placement of PV module and also the amount of solar insolation falling on the module. Even-though PV modules produce maximum power when placed at perpendicular direction to the sun, it is complex to track the sun always. The I_V and P_V characteristics of the PV module when placed at latitude angle of Φ = 12.56° is shown below in figure 4, 5 and 6. The output waveforms when modules placed at Φ = 90° is shown in figure 7, 8, and 9.

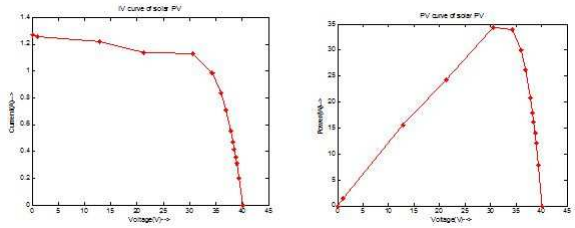

Figure 4. I_V and P_V curve of solar PV at Φ = 12.56° t = 3.05 pm

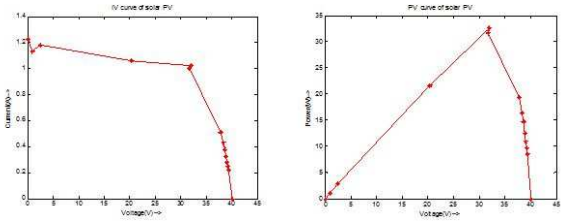

Figure 5. I_V and P_V curve of solar PV at Φ = 12.56° t = 3.20 pm

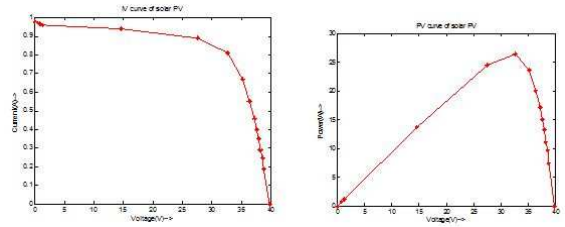

Figure 6. I_V and P_V curve of solar PV at Φ = 12.56° t = 3.35 pm

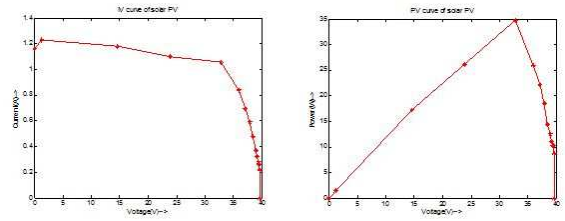

Figure 7. I_V and P_V curve of solar PV at Φ = 90° t = 3.05 pm

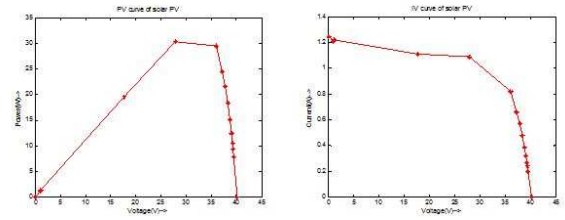

Figure 8. I_V and P_V curve of solar PV at Φ = 90° t = 3.20 pm

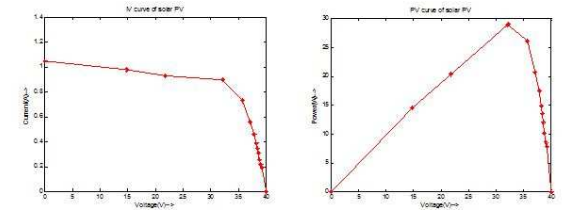

Figure 9. I_V and P_V curve of solar PV at Φ = 90° t = 3.35 pm

Conclusion

In this paper an experimental set up of solar PV module has been made to determine the energy generation. Two methods of installation have been carried out to determine the difference in gain of energy generation by PV modules. In the first method of installation at latitude angle, the energy generated is 23.39 watt-hours. The energy generated in the second method when module placed in normal to the sun is 24.14 watt-hours. This experimental study proved that energy generation is more when the modules are placed in normal direction to the sun, because the light intercepted by the module is more when compared to the first case.

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