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Effect of Tilt Angle on the Performance of Solar Photovoltaic Power Plant – A Quantitative Approach

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Abstract

Solar photovoltaic systems have now become integral part of Indian as well as global power systems. Rooftop and ground mounted solar systems have become very popular across India these days. The ground mounted systems produce large scale power and hence, are used for industrial applications also. This paper presents a detailed analysis of a 100-kW solar photovoltaic system with the different tilt angles taken into consideration for orientation of solar panels. Three different tilt angles 23°, 38° and 8° are considered in the software PVSyst® and output yield over a year are compared for the location of Rajkot, Gujarat, India. The findings are presented in the numeric form as well as in the graphical form.

Keywords: Solar photovoltaic systems, tilt angle, azimuth angle, power yield per annum

INTRODUCTION

Solar Photovoltaic (PV) power generation all over the world is gaining high attention due to clean, sustainable, and green energy. Hundreds and Thousands of MW capacity solar photovoltaic power plants have now become reality. Recently, in the state of Gujarat a thousands of MW solar PV plant has started its commissioning. The Ministry of new and renewable energy (MNRE) and the state of Gujarat is also focusing on promoting this clean energy producing power plants. Climate change discussions around the world have initiated the Renewable Purchase Obligation (RPO), Renewable Energy Certificates (RECs) in India. The Power producers, the transmitters, and Distribution Companies (DISCOMs) are being motivated to generate more and more power by the solar PV systems. The state of Gujarat leading in solar PV generation concerning the installed capacity and the upcoming projects. Net Metering and Tax benefits are the main attraction for installing these power plants at the industrial scale. Carbon footprints are getting reduced with these power plants and overall, Mankind may now think of a lesser pollution produced by the conventional thermal power plants. Advanced technologies in solar panel generation like bifacial and Mono-PERC have also given the added advantages to the power producers to accommodate the solar power plants in less space [1–6]. For the stand-alone systems battery technology is also getting advanced. Figure 1 presents the basic block diagram of the grid-connected systems. The generation of electricity by photovoltaic effect is a well-known phenomenon. The sunlight by photovoltaic conversion is converted into electricity. By using inverters, DC generated power is converted in AC for feeding to the grid as well as to use it locally. The maximum power point tracking (MPPT) technologies and various algorithms have been in use for years that enables the power producers to extract maximum possible power with their systems [7–11]. This paper presents a complete analysis of a 100-kW solar power plant with variation in the tilt angle of solar panel mounting.

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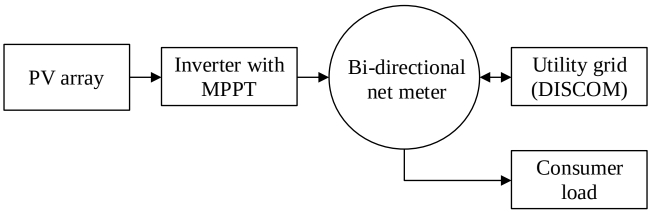

Figure 1. Block diagram of the grid-connected systems.

As shown in Figure 1, the PV array is connected to an inverter with MPPT and then to bidirectional meter that registers energy incoming and outgoing from the systems. Finally, a system is connected to the grid.

The issue of mitigating voltage growth in distribution networks with distributed generation was tackled by Carvalho et al. A distributed automatic control method was suggested to reduce the active power injection-induced voltage rise. The suggested method leaves distribution network operators (DNOs) to their custom of managing voltage for load demand; instead of controlling bus voltage, it ensures that generator injections by themselves do not result in a notable voltage rise [2].

TILT ANGLE AND ITS IMPORTANCE

Tilt angle is defined as the angle of tilt or the angle at which solar panel is inclined. Figure 2 shows the tilt angle of solar panel. Normally, solar panels are mounted at a tilt angle approximately equal to the latitude of the location. Tilt angle has a major role to play in the output yield of a solar power plant. As the tilt angle varies, the output of solar PV system over a year varies greatly. In this paper location Rajkot was selected as shown in Figure 3, with the latitude and longitude of 22.3247°N and 70.8069°E. The tilt angles under consideration were 23°, 38° and 8° respectively for the analysis of a 100-kW solar PV plant.

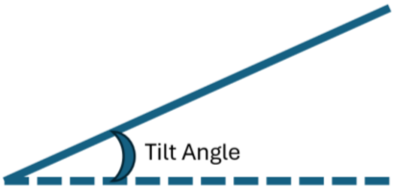

Figure 2. Tilt angle for a solar panel.

Figure 3. Site selection at Rajkot, Gujarat, India.

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The goal of building microgrids is to eliminate reliance on fossil fuels and conventional utility system outages by utilising locally accessible renewable energy sources. Microgrid architectural design heavily relies on unit scale. The best possible system configuration in terms of total system cost and size will result from a well-chosen combination of dispersed components. The type and quantity of units considered when forming a microgrid will have a big impact on the total system size.

SYTEMS UNDER CONSIDERATION

As stated earlier, 100-kW solar photovoltaic (PV) power plant was considered for software analysis with PVsyst® The Azimuth angle was kept zero and hence, the orientation of the solar panels was facing "true south." For the selected site, data given by PVsyst® various parameters are presented in Figure 4. Table 1 presents the specifications of the selected solar panels and Table 2 presents the datasheet of an inverter.

	Global horizontal irradiation	Horizontal diffuse irradiation	Temperature	Wind Velocity	Linke turbidity	Relative humidity
	kWh/m²/mth	kWh/m²/mth	°C	m/s	[-]	%
January	139.8	40.0	20.3	2.39	3.712	47.2
February	150.3	45.0	23.2	2.60	3.997	44.6
March	189.6	67.0	28.0	3.10	5.075	39.2
April	202.3	74.1	31.1	4.10	5.793	42.3
May	210.2	89.6	33.1	5.20	6.556	50.9
June	161.8	96.9	31.3	5.00	8.532	67.5
July	115.0	78.9	28.9	4.60	8.930	79.0
August	118.1	86.0	27.8	4.20	7.800	81.3
September	142.3	79.7	27.9	3.40	6.046	77.9
October	157.6	70.9	29.7	2.30	5.481	52.7
November	135.0	50.2	25.9	1.89	5.207	46.9
December	128.6	44.4	21.8	2.20	4.153	49.3
Year	**1850.6**	**822.8**	**27.4**	**3.4**	**5.940**	**56.6**

Figure 4. Various parameters for the selected site.

Table 1 Specifications of the solar panels.

Parameter	Value
Panel technology	Si-poly
Nominal power at STC	335 W
Open circuit voltage	46.65 V
Voltage at MPP (V_{mpp})	38.50 V
Short circuit current	9.00 A
Current at MPP (I_{mpp})	8.7 A
Number of cells in series	72
Tolerance	± 2%
Series resistance (Rse)	0.44 Ω
Shunt resistance (Rsh)	2400 Ω
Make	Redren Solar

Table 2 Specifications of the inverter.

Parameter	Value
Make	ABB
Operating voltage	300–950 V
Maximum input voltage	1000 V
Nominal power	50 kW AC
Operating frequency	50 Hz
Number of modules in series	15
Number of strings	20
Number of inverters	2

RESULTS AND DISCUSSION

Three different tilt angles viz. 23°, 38° and 8° respectively were considered for the system under study. The results for these cases are presented one by one hereunder.

Case 1 Tilt Angle = 23° (Approximately Equal to Latitude Angle of Selected Location)

Simulating the system under consideration for the tilt angle equal to 23° (Equal to the latitude angle of Rajkot, Gujarat, India, the location of the system under study) gives results as shown in Figure 5. Monthly output from January to December summation gives yield per annum is 162 MWh/year with the specific production 1613 kWp/kW/year and the nominal production 4.42 kWp/kW/day.

Case 2 Tilt Angle = 38° (15° More Than the Latitude Angle of Selected Location)

Simulating the system under consideration for the tilt angle equal to 38° (15° more than the latitude angle of selected location Rajkot, Gujarat, India, the location of the system under study) gives results as shown in Figure 6. Monthly output from January to December summation gives yield per annum is 160 MWh/year with the specific production 1591 kWp/kW/year and the nominal production 4.36 kWp/kW/day. So, there is decrement of approximately 1.5% power output when tilt angle is increased by 15° with respect to the latitude angle.

Case 3 Tilt angle = 8° (15° Less Than the Latitude Angle of Selected Location)

Simulating the system under consideration for the tilt angle equal to 38° (15° less than the latitude angle of selected location Rajkot, Gujarat, India, the location of the system under study) gives results as shown in Figure 7. Monthly output from January to December summation gives yield per annum is 156 MWh/year with the specific production 1551 kWp/kW/year and the nominal production 4.25 kWp/kW/day. So, there is decrement of approximately 4% power output when tilt angle is decreased by 15° with respect to the latitude angle.

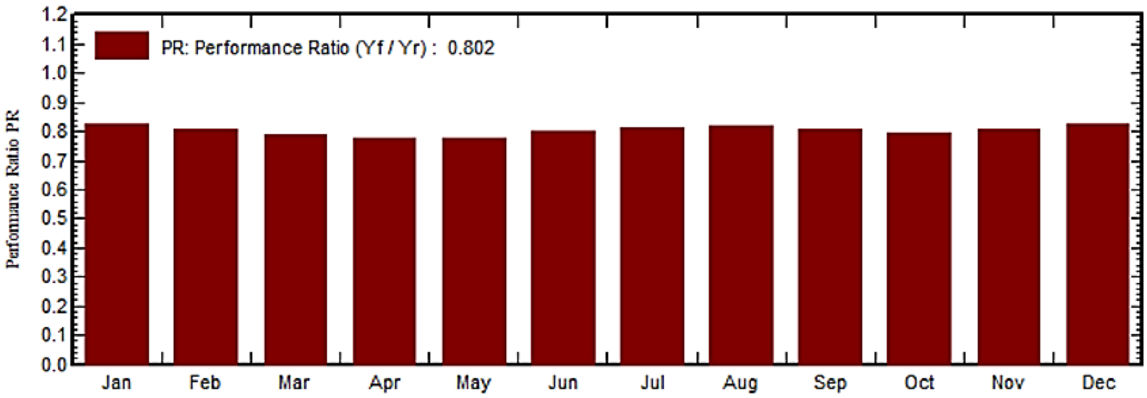

Figure 5. Performance ratio for the tilt angle equal to 23°.

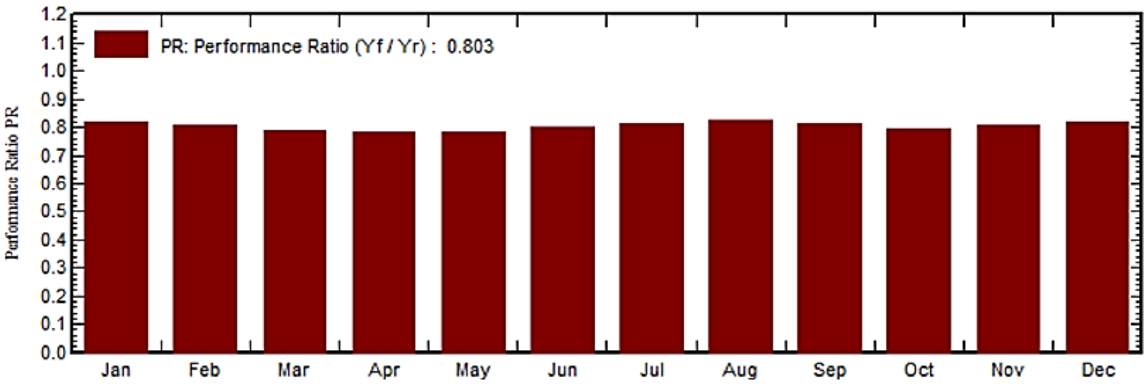

Figure 6. Performance ratio for the tilt angle equal to 38°.

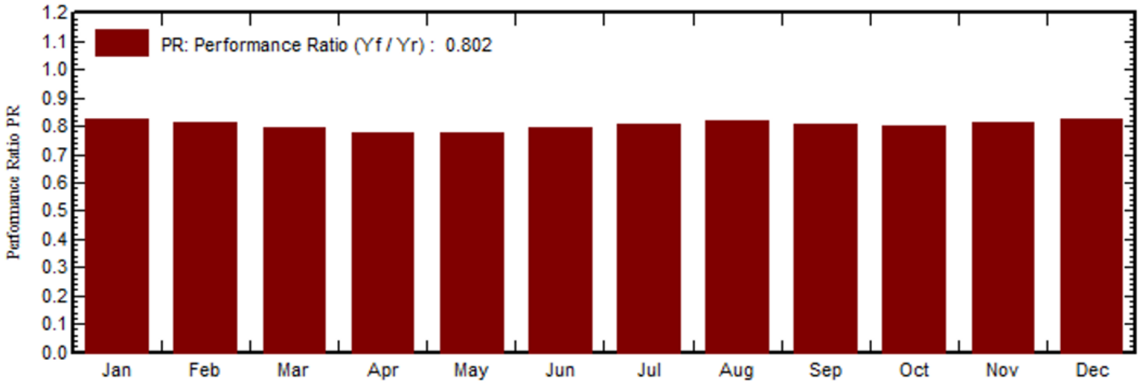

Figure 7. Performance ratio for the tilt angle equal to 8°.

DISCUSSION

Today's world is bewildered by issues such as air pollution, global warming, and the rising cost of fossil fuels, as are environmental engineers and scientists. The harsh effects of the industrialization race are becoming apparent. One of the main concerns is emissions, particularly from thermal power plants and automobiles. In order to meet the growing energy needs caused by the growing population, new power plants must be put into operation. Because it is a green source, photovoltaic (PV) power generation has a significant role to play in this context. The emissions from the manufacture of PV power's component parts are the only ones connected to its generating. Following installation, they harness solar radiation to produce electricity without releasing any greenhouse gases into the atmosphere. PV arrays are created by these modules. PV arrays can be put in locations that are generally useless, such as roofs, deserts, isolated areas, canal tops, unusable terrain, and many more. When the power source and load impedance are equal, a power source will provide a load with its maximum power (Maximum Power Transfer Theorem). Regrettably, batteries are not a solar array's optimal load, and this mismatch leads to significant efficiency losses. Think about a photovoltaic array that can provide its maximum power at an operating voltage of about 17 volts and is intended to charge 12-volt batteries. The easiest way to charge is to just connect the PV array straight to the battery. Because the battery is a power source, the voltage it presents to the PV array is opposite. This causes the array's working voltage to drop to the battery's drained voltage, which is much below the array's ideal operating point.

CONCLUSION

This paper presents the analysis of variation of the tilt angle for a 100-kW solar power plant at the location Rajkot, Gujarat, India. Three cases viz. 23°, 38° and 8° are taken for the system study. For all these cases output power yield over a year, specific production per annum and nominal production per day are compared. The study shows that there is a considerable effect of tilt angle on the output power yield. If tilt angle equal to latitude angle is taken as the reference angle, the variation for 15^0 more tilt angle will decrease power output by approximately 1.5% and the same figure is approximately 4% when considering 15° less tilt angle.

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