The study of photovoltaic systems performance using various azimuth angles and solar array tilt positions

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Abstract: The study of photovoltaic energy and load predictions have become essential with the increase of energy demand. The objective of this paper is to present an analytical study on the performance of photovoltaic system with various azimuth angles and solar array tilt positions. The output power of a solar module is mainly dependent on its tilt position, solar irradiation, type of solar cell, and the technical properties of the module. The data used in this work consist of two different locations. The outcome of this work shows that the energy production influenced heavily on the weather conditions, location, azimuth angles and tilt positions. Within this work, parameters such as planes-of-array irradiance, net to inverter output power, net to grid output power and performance ratio have been studied. The developed analytical study is anticipated to provide a better understanding on the energy production and load usage in accordance with suitable tilt angle of solar array in a specific location.

Keywords: Photovoltaic system, azimuth angle, solar panels tilt positions, energy efficiency

1. Introduction

The different approach of generating energy in non-polluting environment has open up interest in the exploration of renewable energy field [1,2]. The introduction of solar energy helps to reduce the rising concern on carbon dioxide emissions [1,3,4]. The major disadvantage of solar energy is the dependency on weather conditions and solar irradiation [5-7]. Therefore it is important to study the produced energy and load demand for a certain location. It helps the customer to install solar panels and determine the amount of energy can be generated from it. On the other hand, it is important for the electric utilities to determine the produced energy on hourly or monthly basis especially when planning and scheduling the power system.

Although solar manufacturer has a given a nominal for each output panels, however, not all panels produce specified values any time of day. The position of the solar panels are important in order to absorb the maximum solar radiation of the day which varies in accordance to the weather conditions [5-11]. The purpose of this paper is to study an economical method for PV generation in various solar array tilt positions. The study in this work is valid for Chennai, India and Beijing, China, however, the introduced method can be applied to the data collected in any geographical location. First, the theoretical background of the selected location and its dependence on weather conditions is presented. Then the results variation of azimuth angle and tilt positions are analyzed. Finally the paper discusses the PV systems performance in obtaining the maximum power based on azimuth angle and tilt positions.

2. Background Research

Installation of solar panels requires many factors to be taken into account. In order to maintain consistent maximum output over seasons, solar arrays are installed in various methods thought out the world. Sun’s irradiance plays important role in photovoltaic installation [12,13]. Therefore, it is crucial to determine the azimuth angle and solar array tilts position to make the solar array work on its maximum peak [5-7]. Photovoltaic works at its most efficient manner when maximum amount of light particles
from sun hits their cells at a perpendicular (90 degree) [14]. Hence, it is important for solar panels to be installed and tilted according to the sun’s movement. Other factors such as the layer ozone obstacles and seasons impact too play equal importance in determining the amount of sun reaches the location.[15,16] In this work, two location has been chosen which are Chennai, India and Beijing, China. The reason for this two areas selection as these two locations are very highly populated and large amount of power supply demand is required [17,18]. On the other hand, this two counties are of the largest solar panels installation throughout the world [18]. As an average, solar radiation in Chennai, India is 4-7 kWh/m²/day and Beijing, China is 3-7.5 kWh/m²/day [19]. Location coordinates for Chennai, India and Beijing are as shown in Table 1 [20].

Table 1: Location coordinates for Chennai and Beijing region

| Location          | Latitude    | Longitude  |
|-------------------|-------------|------------|
| Chennai, India    | 13.0827° N  | 80.2707° E |
| Beijing, China    | 39.9042° N  | 116.4074° E |

In general, the photovoltaic systems need to be aligned with the Sun’s movement to track the sun minute by minute since the sun moves throughout of the day [21]. In order to track the Sun’s movement, the automated solar tracker is used but it is very expensive as buying additional panels to compensate [19,22]. Furthermore, extra amount of power is used by the solar tracker to track the sun which negates much of its benefits. The highest point of sun is in the afternoon each day and it generates the most power. In this study, focus is given on the fixed solar panels. Determining the best position of azimuth and solar panels angles, the optimum performance of the system can be obtained. System Advisor Model (SAM) has been used as simulation tool in this study for both locations. The specifications for module, inverter and array parameters are presented in Table 2. The value settings are applied for both locations to maintain the consistency of results during simulation.

Table 2: Table shows the modules, inverter and array setting used in this work

| Modules    | Values       |
|------------|--------------|
| Cell material | Mono-c-Si    |
| Module area     | 1.6 m²      |
| Module capacity | 335.2 DC Watts |
| Quantity      | 14           |
| Total capacity | 4.7 DC kW   |
| Total area     | 22 m²       |
| Inverters     | Values       |
| Unit capacity  | 3.8 AC kW    |
| Input voltage | 250-480 VDC DC V |
| Quantity      | 1            |
| Total capacity | 3.8 AC kW   |
| DC to AC Capacity Ratio | 1.23 |
| AC losses (%) | 1.0         |
| Array         | Values       |
| Strings       | 2            |
| Modules per string | 7        |

3. Results and Discussions

Plane-of-array (POA) is defined as the beam radiance incident on the entire array before shading and soiling factors are applied. From the results obtained in Table 3 and Table 4, it has been noticed that Chennai has more radiance incident than Beijing. The reason for this difference is mainly because of its geographical location and climate influence. Chennai is located in the thermal equator and on the coast as well, which prevents extreme variation in seasonal temperature [23]. On the other hand, Beijing is located in the region whereby mountains shield the city to the north, northwest and west [24]. Beijing receives 2,671 hours of bright sunshine annually whereas Chennai receives 2762 hours of bright sunshine annually [24]. As for Chennai, placement of arrays in the South, Southeast and Southwest give the optimum radiance within 0º-36º tilt angle. On the other hand, as for Beijing, azimuth with 0º-54º tilt angles in the position of South, Southeast and Southwest give the optimum radiation results. The Sun is always in the South in the northern hemisphere. Hence, regions between the latitudes of 23º and 90º, the modules on an array are directed to the south in order to get the most out of the Sun’s energy. In the
southern hemisphere, it is the opposite [27]. Though 0º tilt angle gives optimum results, but in reality panels are not recommended to be fixed totally flat on the roof. The reason is that the tendency of the rainwater to maintain on the panels are high. Therefore, it is suggested that that the panels mounted at an angle of at least 10º. It is important because it will allow any rain to run off the modules. Figure 1 shows the values of POA at various cities. If the rainwater pools on the surface of the solar panel, it is more likely to eventually get through the panels' seals and into the solar cells[8].

| Azimuth vs Tilt | 0º | 18º | 36º | 54º | 72º | 90º |
|-----------------|----|-----|-----|-----|-----|-----|
| North           | 5  | 4   | 3   | 3   | 2   | 1   |
| Northeast       | 5  | 4   | 4   | 3   | 2   | 2   |
| East            | 5  | 4   | 4   | 3   | 3   | 2   |
| Southeast       | 5  | 4   | 4   | 3   | 3   | 2   |
| South           | 5  | 4   | 4   | 3   | 3   | 2   |
| Southwest       | 5  | 4   | 4   | 3   | 3   | 2   |
| West            | 5  | 4   | 4   | 3   | 3   | 2   |
| Northwest       | 5  | 4   | 4   | 3   | 3   | 2   |

| Azimuth vs Tilt | 0º | 18º | 36º | 54º | 72º | 90º |
|-----------------|----|-----|-----|-----|-----|-----|
| North           | 3  | 3   | 2   | 1   | 1   | 1   |
| Northeast       | 3  | 3   | 2   | 2   | 1   | 1   |
| East            | 3  | 3   | 3   | 3   | 2   | 2   |
| Southeast       | 3  | 4   | 4   | 4   | 3   | 2   |
| South           | 3  | 4   | 4   | 4   | 3   | 2   |
| Southwest       | 3  | 4   | 4   | 4   | 3   | 2   |
| West            | 3  | 3   | 3   | 3   | 2   | 2   |
| Northwest       | 3  | 3   | 2   | 2   | 1   | 1   |

Figure 1: Figure 1(a) and Figure 1(b) show the values of POA (kW/m²/day) at Chennai, India and Beijing, China regions respectively for various azimuth and tilt angles

Net to inverter is defined as the amount of power is supplied to inverter upon the solar panels power generation. Figure 2 and 3 show the values of Net to inverter. From the results in Table 5 and Table 6, it has been noticed that Chennai give the maximum power to inverter at South azimuth with 0º-18º tilt angle. As for Beijing, South azimuth with 36º-54º tilt angle gives the optimum power to inverter.
Table 5: Net to inverter (DC kWh) output values accordance to azimuth versus tilt angles at Chennai, India region

| Azimuth vs Tilt | 0°  | 18°  | 36°  | 54°  | 72°  | 90°  |
|----------------|-----|------|------|------|------|------|
| North          | 7530| 6930 | 5770 | 4320 | 3100 | 2230 |
| Northeast      | 7530| 7320 | 6090 | 4910 | 3780 | 2880 |
| East           | 7530| 7320 | 6660 | 5740 | 4720 | 3720 |
| Southeast      | 7530| 7590 | 7090 | 6150 | 4960 | 3730 |
| South          | 7530| 7700 | 7270 | 6260 | 4820 | 3420 |
| Southwest      | 7530| 7590 | 7090 | 6160 | 4960 | 3720 |
| West           | 7530| 7330 | 6670 | 5760 | 4730 | 3710 |
| Northwest      | 7530| 7050 | 6100 | 4920 | 3780 | 2880 |

Table 6: Net to inverter (DC kWh) output values accordance to azimuth versus tilt angles for Beijing, China region

| Azimuth vs Tilt | 0°  | 18°  | 36°  | 54°  | 72°  | 90°  |
|----------------|-----|------|------|------|------|------|
| North          | 6000| 4770 | 3570 | 2650 | 2040 | 1810 |
| Northeast      | 6000| 5110 | 4130 | 3310 | 2700 | 2240 |
| East           | 6000| 5880 | 5470 | 4880 | 4160 | 3380 |
| Southeast      | 6000| 6600 | 6710 | 6360 | 5610 | 4540 |
| South          | 6000| 6900 | 7250 | 7030 | 6260 | 5020 |
| Southwest      | 6000| 6600 | 6700 | 6430 | 5580 | 4520 |
| West           | 6000| 5860 | 5440 | 4850 | 4130 | 3350 |
| Northwest      | 6000| 5100 | 4110 | 3290 | 2680 | 2220 |

Figure 2: Figure 2(a) and Figure 2(b) shows the values of Net to inverter (DC kWh) at Chennai, India and Beijing, China region respectively for various azimuth and tilt angles.

Table 7: Net to grid (AC kWh) output values accordance to azimuth versus tilt at Chennai, India region

| Azimuth vs Tilt | 0°  | 18°  | 36°  | 54°  | 72°  | 90°  |
|----------------|-----|------|------|------|------|------|
| North          | 7190| 6610 | 5500 | 4100 | 2930 | 2080 |
| Northeast      | 7190| 6990 | 5810 | 4670 | 3580 | 2710 |
| East           | 7190| 6990 | 6350 | 5470 | 4490 | 3520 |
| Southeast      | 7190| 7250 | 6760 | 5860 | 4710 | 3530 |
| South          | 7190| 7360 | 6940 | 5970 | 4580 | 3230 |
| Southwest      | 7190| 7250 | 6770 | 5870 | 4720 | 3220 |
| West           | 7190| 6990 | 6360 | 5480 | 4500 | 3510 |
| Northwest      | 7190| 6730 | 5810 | 4680 | 3580 | 2710 |
Table 8: Net to grid (AC KWh) output values accordance to azimuth versus tilt angles at Beijing, China region

| Azimuth vs Tilt | 0°   | 18°  | 36°  | 54°  | 72°  | 90°  |
|-----------------|------|------|------|------|------|------|
| North           | 0°   | 5720 | 4530 | 3380 | 2490 | 1900 | 1670 |
| Northeast       | 45°  | 5720 | 4270 | 3920 | 3200 | 2530 | 2090 |
| East            | 90°  | 5720 | 5600 | 5210 | 4630 | 3950 | 3200 |
| Southeast       | 135° | 5720 | 6300 | 6400 | 6060 | 5340 | 4310 |
| South           | 180° | 5720 | 6590 | 6910 | 6690 | 5060 | 4780 |
| Southwest       | 225° | 5720 | 6290 | 6390 | 6050 | 5320 | 4290 |
| West            | 270° | 5720 | 5590 | 5180 | 4610 | 3920 | 3170 |
| Northwest       | 315° | 5720 | 4860 | 3900 | 3110 | 2520 | 2070 |

Figure 3: Figure 3(a) and Figure 3(b) shows the values of Net to Grid (AC KWh) for Chennai, India and Beijing, China respectively for various Azimuth and Tilt angles

Net to grid is defined as the amount of power is supplied to grid after calculating energy losses in inverter and modules upon the solar panels power generation [25]. The variation in results may due to be power loss in the inverter during the DC to AC conversion, module mismatch, wiring and connections [25]. From the results in Table 7 and Table 8, it has been noticed that Chennai gives the maximum power to inverter with South azimuth with 0°-18° tilt angles. As for Beijing, South azimuth with 36°-54° tilt angle give the optimum power to inverter.

Table 9: Performance ratio values accordance to azimuth versus tilt angles at Chennai, India region

| Azimuth vs Tilt | 0°   | 18°  | 36°  | 54°  | 72°  | 90°  |
|-----------------|------|------|------|------|------|------|
| North           | 0°   | 0.78 | 0.78 | 0.77 | 0.75 | 0.73 | 0.72 |
| Northeast       | 45°  | 0.78 | 0.78 | 0.77 | 0.76 | 0.75 | 0.74 |
| East            | 90°  | 0.78 | 0.78 | 0.78 | 0.77 | 0.77 | 0.76 |
| Southeast       | 135° | 0.78 | 0.78 | 0.78 | 0.77 | 0.77 | 0.76 |
| South           | 180° | 0.78 | 0.78 | 0.78 | 0.77 | 0.77 | 0.76 |
| Southwest       | 225° | 0.78 | 0.78 | 0.78 | 0.78 | 0.77 | 0.76 |
| West            | 270° | 0.78 | 0.78 | 0.78 | 0.78 | 0.77 | 0.76 |
| Northwest       | 315° | 0.78 | 0.78 | 0.77 | 0.76 | 0.75 | 0.74 |

Performance ratio is a measure of a photovoltaic system’s annual electric generation output in AC kWh compared to its nameplate rated capacity in DC kW, taking into account the solar resource at the system’s location, and shading and soiling of the array [25]. Figure 4 shows the values of performance ratio for different cities.

Performance ratio = annual energy (kWh) / (annual POA total radiation (nominal) (kWh) x module efficiency (%)
Table 10: Performance ratio values accordance to azimuth versus tilt angles at Beijing, China region

| Azimuth vs Tilt | 0°   | 18°  | 36°  | 54°  | 72°  | 90°  |
|-----------------|------|------|------|------|------|------|
| North           | 0°   | 0.81 | 0.79 | 0.77 | 0.76 | 0.76 |
| North           | 45°  | 0.81 | 0.79 | 0.79 | 0.78 | 0.78 |
| East            | 90°  | 0.81 | 0.81 | 0.81 | 0.81 | 0.8  |
| Southeast       | 135° | 0.81 | 0.82 | 0.83 | 0.82 | 0.81 |
| South           | 180° | 0.81 | 0.82 | 0.83 | 0.83 | 0.81 |
| Southwest       | 225° | 0.81 | 0.82 | 0.82 | 0.82 | 0.81 |
| West            | 270° | 0.81 | 0.81 | 0.81 | 0.81 | 0.80 |
| Northwest       | 315° | 0.81 | 0.79 | 0.78 | 0.78 | 0.77 |

Figure 4(a) and Figure 4(b) shows the values of performance ratio for Chennai, India and Beijing, China respectively for various azimuth and tilt angles.

From the results in Table 9 and Table 10, it has been noticed that Chennai gives the maximum performance ratio at South Azimuth with 0°-36° tilt angle. As for Beijing, South azimuth with 36°-72° tilt angle gives the best performance ratio. Alternately this studies also indicates that panels can be installed in the South azimuth position with its location’s latitude for optimum function of the solar panels in Chennai and Beijing. This is because the latitude is the same as the angle of the sun in the sky halfway between midwinter and midsummer. During winter, the sun will be about 15 degrees higher in the sky in summer and 15 degrees lower in the sky [8,26]. Hence, tilting the panels to the midway point will maximize the sun captured throughout the year [8].

4. Conclusion

From this work, it shows that the azimuth or the direction of the face of solar panels and the tilt of the panel play significant role in obtaining the maximum power efficiency. The solar irradiance, the net to inverter power, net to grid power and performance ratio has been studied in this work. Although, the study has been carried out in two regions, the study can be implemented in other geographical location as well. Hence, the maximum energy and higher efficiency can be produced if the direction and tilt angle of solar panels are placed accordingly. From the study, it shows placing the solar panels close to latitude position of the selected location gives the optimum results in terms of power generation. Hence, it is important to determine the correct tilt positions and azimuth angles for solar panels as it can help to generate most energy form the installed solar power system.

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