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PHOTOVOLTAIC ENERGY PREDICTION ANALYSIS CONSIDERING TILT AND AZIMUTHAL ORIENTATION IN BRAZIL

Gabriel Mendonça de Paiva[1], Sérgio Pires Pimentel[1], Enes Gonçalves Marra[1] and Bernardo Pinheiro de Alvarenga[1]

[1] Federal University of Goias, Goiânia (Brazil)

Abstract

This article is about the analysis of photovoltaic (PV) potential generation in the city of Goiania, Goias, Brazil. The main objectives of this work are to predict reliably the energy production considering tilt and azimuthal orientation in this location and analyze the energy behavior and system performance along a simulation process. With the use of PVsyst, an example system of 2.5kWp of polycrystalline silicon had been considered for simulations of 1387 possible tilt-orientation sets in 5° scale. The annual energy production and the system Performance Ratio were obtained. As a conclusion, 180 of the total configurations were considered acceptable for payback time projects. The optimal energy generation set found differs from typical slope equal to location's latitude and orientation to north and was in 25° tilt and -5° azimuth, still leading to over 8 years payback time considering. As energy behavior, the system sensibility for azimuthal deviation is higher as higher is its plane tilt.

Keywords: Energy prediction, PV systems, PVsyst.

1. Introduction

One of the main advantages of Distributed Generation based on PV technology is the possibility of building integration, therefore the energy is generated close to the load (Macêdo, 2006). The integration of PV modules over building's roofs hides two important factors in which PV generation depend: tilt and azimuth angles. PV energy production depends in fact on many parameters such as PV array peak power, solar irradiation on module plane, module temperature, inverter efficiency and size, maximum power point tracking losses and other losses (Notton et al., 2010).

In order to make reliable energy prediction considering all main factors which influence PV generation, a simulation process with reliable data is required. It is well known that different irradiation data results in different predictions. When multi-year time series are used as reference for radiation data, deviations of 1% were found to Typical Meteorological Year (TMY) values and over 3% to synthetic data series (Cabecauer et al., 2011). Those deviations in total irradiance are different depending on plane tilt and location.

Also, different time resolution data may lead to different prediction and design as well. Using hourly average data, some important irradiation peaks and its respective inverter losses due to power limiting may not be noticed compared to one minute or 10 seconds resolutions (Burger and Ruther, 2006).

This study analyses the behavior of annual energy production and annual performance ratio of an example grid-connected PV system related to the variation of tilt and azimuth angles in the location of Goiania, Brazil. The reason of particular interest on these annual parameters is because Brazil currently has a policy which makes it possible for consumers only to reduce its electricity bills and not to sell energy, known as net metering. However, if the energy produced during a month exceeds the load demand it could be accounted in further periods up to three years later, in terms of revenues. In this case, those annual parameters could be applied for designing grid-connected (or stand-alone) PV systems. The radiation data related to this paper is compared with other available radiation data for this location.

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2. Simulation characteristics

A simulation model of a grid-connected PV System was created on PVsyst software. The chosen methodology of simulations on PVsyst can be described as a process of determination of the system output energy in periods of one hour along a year, based on the input parameters variation for each specific hour and mathematical models of the whole system.

The PV array is composed by series connection of 10 modules of 250Wp p-Si from YINGLI SOLAR (model YL-250P-29b). The solar inverter is a high frequency transformer (HFT) inverter from INGETEAM (model Ingecon Sun 2.5HF). Table 1 presents the main parameters for both module and inverter.

Tab. 1: Parameters of PV module and inverter of the simulated system.

PV Module	Solar Inverter
Yingli Solar YL250P-29b	Ingeteam Ingecon 2.5HF
P_{nom} = 250Wp	P_{nom} = 2500Wp (AC power)
I_{SC} = 8.831A	Min MPP Voltage = 130V
V_{OC} = 37.78V	Min Voltage for Pnom = 125V
I_{MP} = 8.263A	Max MPP Voltage = 450V
V_{MP} = 30.26V	Absolute Max PV Voltage = 550V
–	Power treshold = 20W

Other parameters defined on PVsyst were considered: 30m length of 2.5mm² cables in the DC side, resulting in 225.6mΩ of total cable resistance; standard PVsyst 1% MPPT loss; and 2.5% loss for voltage fixing. A fixed 5% loss due to soiling over the modules was also considered, independent of the module slope, although it tends to be higher in low inclination and lower in high inclination positions. This is because some estimations from some places result in average 5% soiling losses (Caron and Littman, 2013), even though measurements in the current location and for specific module inclination should be done for more realistic soiling evaluation. Losses of 0.5% were determined for system unavailability. The constant related to albedo irradiation estimation on tilted surface was defined as 0.2, a typical value used for urban areas.

The simulation process which estimate the PV annual energy generation had been done a synthetic hour data series based on monthly averaged values of irradiation data from NASA's satellite. The annual irradiation was compared to other available radiation data, like Project SWERA (Brazilian Atlas of Solar Energy SWERA), Meteonorm (available on PVsyst) and INMET (Institute of Meteorology of Brazil). Table 2 shows the equivalent irradiation on the horizontal plane over one year period from different radiation data.

Tab. 2: Annual Irradiation on the horizontal plane for different radiation databases.

Reference	I_{HOR} annual (kWh/m²)
Project SWERA(range)	1788 - 2044
NASA(average)	1927.5
Meteonorm(average)	1829.0
INMET(average)	1854.2
INMET(range)	1793 – 1926.1

The available data on PVsyst are average years from NASA (satellite) and Meteonorm (interpolation of solarimetric stations over the world). The data from INMET are measurements obtained from a solarimetric station with hourly measured values, installed in the city of Goiania, which leads to a range of annual incident irradiation on the horizontal plane from 1793 to 1926kWh/m², a variation of +3.8% or -3.3% from average value, considering a period of 12 consecutive years of measurements.

The available data from Project SWERA is a map of equivalent sun hours incident on the horizontal lpane of all regions of Brazil and it's obtained from interpolation of solarimetric stations over Brazil. The map of sun hours lead to a range of annual incident irradiation on the horizontal plane from 1788 to 2044kWh/m² for the state of Goias, a variation of ±7% from the average value of 1916kWh/m².

The irradiation model used to determine irradiation in tilted planes was the Perez model (Duffie and Beckman, 2013), also available on PVsyst. The annual analysis is a result of hourly simulation of the complete system under synthetic hourly variation of climate data.

3. Simulation results

The system was simulated for all possible configurations in 5° scale of tilt and orientation variation, resulting in a map of 1387 possible sets of annual energy production and system Performance Ratio. During this process, the input parameters were fixed in the values determined in section 2.

Figure 1 shows the tilt angle or slope (β) and the surface azimuth angle (γ_s). As this case of study is related to a city of Brazil (South America), negative azimuth values mean that the module has rotated from north to east direction and positive values mean that it rotated to west direction.

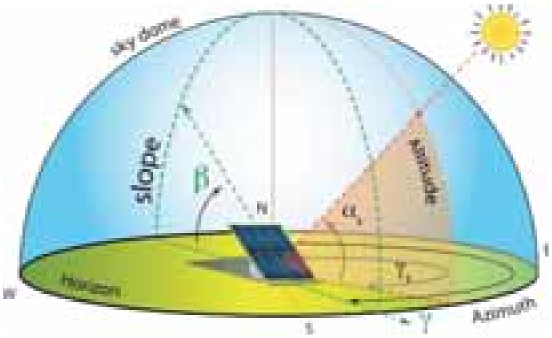

Fig. 1: Solar geometry defined for the energy prediction analysis.

The results analysis shows that the common sense (and traditional procedure) of tilting PV solar panels to a value equal to the location's latitude and 0° azimuth did not lead to optimal output. It was noticed that a maximum energy production for 5° scale of 3833kWh/year would occur when plane tilt = 25° and azimuth = -5° (or 5° to east direction). These conclusions were obtained mainly because of the albedo influence on total irradiation, which is calculated on PVsyst trough Equation 1. When the albedo constant ρ_g is omitted, the optimal generation gets closer to location's latitude (-16.7°).

$$I_{alb} = I\rho_g \left(\frac{1-\cos\beta}{2}\right) \quad \text{(eq. 1)}$$

In addition, 180 of the total possible configurations obtained less than 5% annual loss compared to the optimal set, meaning that there are many possible positions which lead to satisfactory energy production when only energy output or payback time are considered in the project.

Also from results analysis, it is possible to observe the system sensibility according to azimuth deviation considering fixed tilts. Figure 2 shows that the azimuth deviation of 180° in lowly tilted systems lead to low annual energy production losses, while in highly tilted systems, the annual loss increases.

Considering 15° of tilt inclination angle, the generation loss for 180° azimuthal deviation is around 15%, while in 90° tilt, the reduction from northbound is over 60%. Another interesting result concerning the azimuth deviation is that in highly tilted systems, the optimal energy generation was obtained in -55° azimuth, in east direction. The annual production was also higher in 55° azimuth than in 0°. This behavior was observed in module inclinations of 80° or higher for Goiania and this result could be verified to other locations.

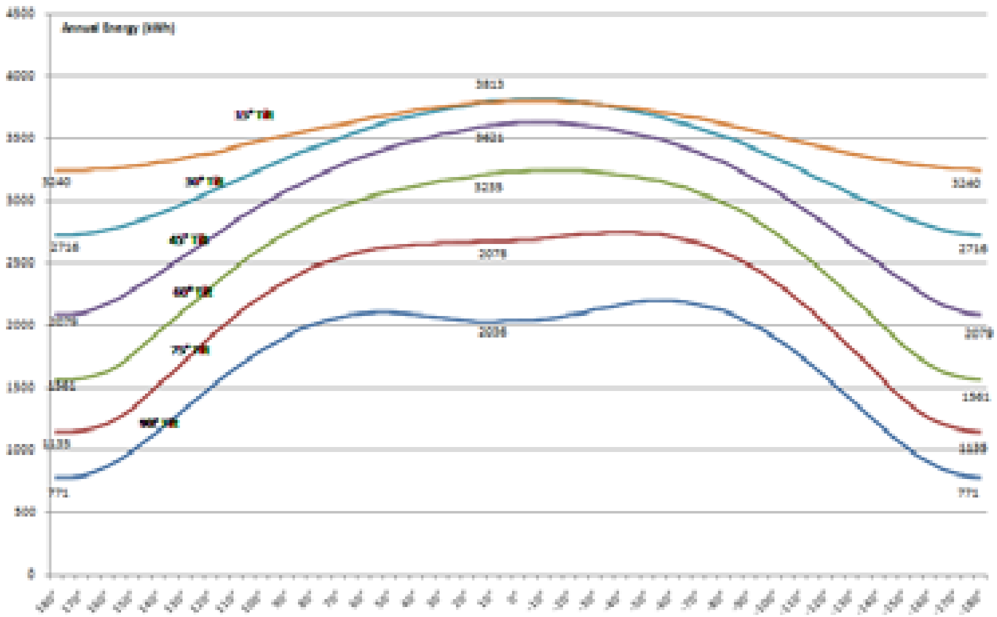

Fig. 2: Annual energy production in kWh/year as a function of azimuth for different tilt angles for the 2.5kWp system.

By now considering the Performance Ratio of the system observed during the simulations, it resulted in a range of values around 73 and 75% for most configurations and only reached lower values of 68% in extremely bad output configurations, when annual losses over 60% were obtained in respect to optimal. Figure 3 presents the PR behavior considering tilt and azimuth variations.

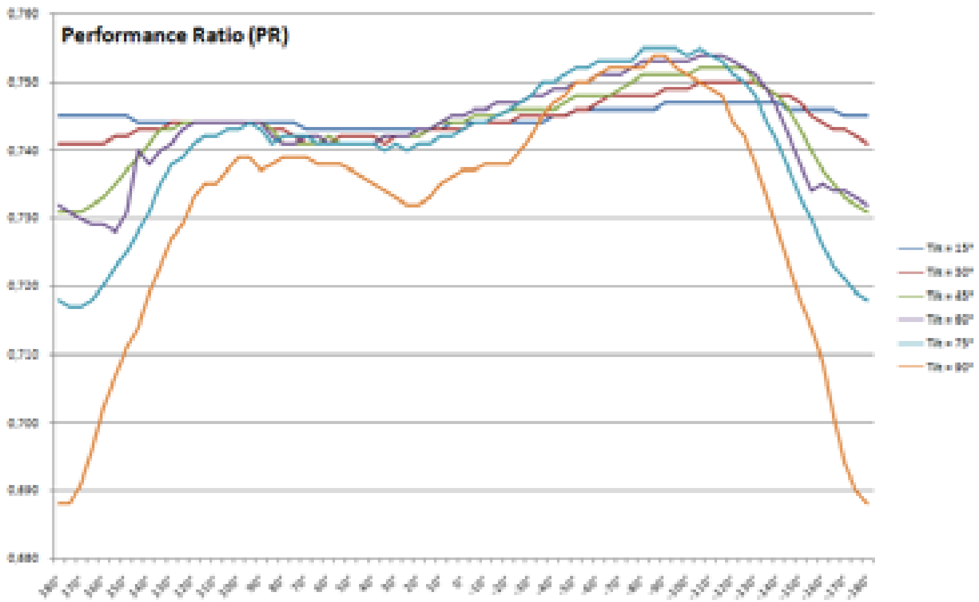

Figure 3: Annual Performance Ratio in % as a function of azimuth for different tilt angles for the 2.5kWp system.

Although the PR does not perform significant variations as function of module positioning, the factors that influence on it change significantly from optimal to minimal production configurations, like inverter efficiency losses, temperature losses in respect to Standard Test Conditions and incidence angle losses, due to light reflection. Inverter efficiency losses increase from 4% to 9%, losses from module temperature decrease from 11% to 4%, losses from incidence angle increase from 3% to 8% and from module efficiency due to low irradiance level increase from 0.5% to 7.5%.

4. Energy prediction analysis

If the irradiation incident in the module plane is compared to the global horizontal irradiation, the annual transposition factor could be obtained on PVsyst. Table 2 presents the transposition factors considering the use of Perez's model on PVsyst.

Tab. 2: Transposition Factors for different tilt and azimuth angles for Goiania obtained by Perez model on PVsyst.

Azimuth / Tilt	-90°	-75°	-60°	-45°	-30°	-15°	0°	15°	30°	45°	60°	75°	90°
90°	0.56	0.59	0.61	0.60	0.59	0.58	0.57	0.57	0.58	0.59	0.59	0.57	0.54
80°	0.64	0.68	0.70	0.71	0.70	0.70	0.69	0.69	0.69	0.69	0.68	0.66	0.62
70°	0.72	0.76	0.79	0.80	0.81	0.81	0.80	0.80	0.79	0.78	0.77	0.74	0.70
60°	0.79	0.84	0.87	0.89	0.90	0.90	0.90	0.90	0.88	0.87	0.84	0.81	0.77
50°	0.85	0.90	0.93	0.95	0.97	0.98	0.98	0.97	0.96	0.94	0.91	0.87	0.83
40°	0.91	0.95	0.98	1.01	1.02	1.03	1.03	1.03	1.01	0.99	0.96	0.93	0.89
30°	0.95	0.99	1.01	1.04	1.05	1.06	1.06	1.06	1.04	1.02	1.00	0.97	0.93
20°	0.98	1.01	1.03	1.05	1.06	1.07	1.07	1.06	1.05	1.04	1.02	1.00	0.97
10°	1.00	1.01	1.02	1.03	1.04	1.05	1.05	1.04	1.04	1.03	1.02	1.01	0.99
0°	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00

Comparing the annual energy generation to the transposition factor values, it can be concluded that there is a strong linear dependence of energy generation on irradiation incident on module's planes.

The amount of energy output from a grid-connected PV system can be estimated from Equation 2 (Pinho and Galdino, 2014), when P_{PV} is the generator nominal power at STC, PR the performance ratio and sun hours are the equivalent hours of 1000W/m² irradiation per day obtained for the module plane in the specific location.

$$E(kWh) = P_{PV}\,(Wp).PR.\text{sun hours}.365 \qquad \text{(eq. 2)}$$

From Equation 2, it is possible to explain the linear dependence of energy output as function of incident irradiation on the module's plane, but it is also the result of the product of irradiation (in the form of equivalent sun hours) and the performance ratio.

Equation 2 also shows that the energy production by the PV system during a full year may vary in the range of incident irradiation on the horizontal plane from 1788 to 2044kWh/m². Then, as the energy output has a linear dependence on the irradiation and the PR will probably be near the same results of Figure 3.

5. Conclusions

It can be concluded that there are several tilt-orientation configurations that lead to satisfactory energy production in PV generation for this specific location in Brazil, since a number of180 (from 1387 possible) sets of tilt-azimuth configurations result in less than 5% annual energy losses in respect to optimal configuration.

Additionally, it was found that considering the solar irradiance available in Brazil, the optimal tilt-azimuth set was 25° module inclination and -5° azimuth which is not the typical inclination angle equal to local's latitude and orientation equal to 0° north. This example project would still lead to over 8 years payback time considering energy costs and policy in 2015.

Other conclusion is related to annual power production from PV System. Specific to fixed tilts, the annual production becomes more sensible to azimuthal deviation as higher is its inclination. The Performance Ratio of a system is almost invariable for tilt and azimuth deviation and only becomes significantly lower for extremely low production configurations (in this case, over 60% annual losses in respect to optimal), positions that are almost unviable for payback time projects.

Considering the location in Brazil related to this study, the energy generation of a PV system is linearly dependent on the irradiation, which means that a variation of ±7% from the prediction in this paper may be classified as acceptable relative to real variations for different year periods.

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