A SOLAR PHOTOVOLTAIC ELECTRICITY INSERT SOURCE IN THE STATE OF PARANÁ/BRAZIL: AN ANALYSIS OF PRODUCTIVE POTENTIAL

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Gerson Maximo Tiepolo[1],[2]; Jair Urbanetz Junior[1]; Osiris Canciglieri Junior[2]

1 – Department of Electrical Engineering, Technological Federal University of Paraná – UTFPR, Avenida Sete de Setembro 3165, Rebouças, CEP 80230-901, Curitiba, Paraná, Brazil.

2 – Graduate Program in Production Engineering and Systems – PPGEPS, Pontifical Catholic University of Parana-PUCPR, Rua Imaculada Conceição 115, CEP 80215-901, Curitiba, Paraná, Brazil

osiris.canciglieri@pucpr.br

Abstract

The theme of Sustainable Development has gained more and repercussion in the society spheres contributing to a greater awareness of the need for natural resources conservation, as well as the challenge of keeping promoting the socio - economic development of the regions. One of the key issues for this sustainable development is in the Electric Power Generation with the increasing use of renewable energy, and less harm to the environment. In this scenario, the state of Paraná historically has been one of the largest producers of electricity in the country, almost entirely through hydroelectric plants due to the large watershed in the state. However, the use of this source is in constant decline due to the hydric potential exhaustion, and also due to the pressure from society related to the environmental, social and economic impacts occasioned by its installation. To overcome these limitations, other sources have been studied and applied such as the biomass, the wind and photovoltaic in isolated systems. Most recently, as a function of the Call No. 13/2011 and the Resolution 482/2012 from ANEEL (Brazilian Electricity Regulatory Agency), there was also the possibility of generating electricity through Grid-connected Photovoltaic Power Systems. These systems have been widely employed in the urban environment as electricity generators near the distributed point of consumption, intensely applied in many countries, especially in Europe, usually requiring no additional area, since they can be installed on the roof of the building or integrated in it. This paper aims to present the Photovoltaic Map of the Paraná State, Brazil, which represents the potential for generating electricity through solar photovoltaic power, and also to compare the preliminary results of the values of electricity generation measured in the Grid-connected Photovoltaic Power System located at the Technological Federal University of Paraná (UTFPR) in the city of Curitiba, capital of Paraná – Brazil.

Keywords:
Sustainable Development, Renewable Energies, Distributed Generation, Public Policies

1 INTRODUCTION

In Brazil the main generation source of electricity comes from hydropower as it is considered a source of low cost since there is large number of river basins. However, the environmental impacts generated by these plants implantation has been increasingly under discussion as it is necessary to flood vast areas to create the reservoir which supplies the water that moves the turbines of the generators [1]. It should be also considered others impacts occurring during the plant implantation, such as the social, since the residents of the flooded areas must be transferred to other places that not always have the same infrastructure, as well as the financial impact of the affected region.

The solar PV in Brazil still requires more investments. Several studies about this energy source are being developed in universities over the country. However, the financial support for projects of electricity generation, through public and private initiatives, is still incipient. Especially in Europe, most of the investments occurred because of the public policies adopted and consequently the subsidies provided to increment the investments in this technology.

Following this tendency, the same is expected to happen in Brazil, although the country's situation concerning to the water reserves still influences on the aspect of temporarily postponing the more pronounced public policy investments in other sources.

In 2011, the Brazilian Electricity Regulatory Agency - ANEEL released the Call No. 13/2011 - Strategic Project: " Technical and commercial arrangements for solar photovoltaic generation insertion in the Brazilian energy matrix", which foresees the addition of 24.58 MWp of installed power, with four approved projects related to the Solar Stadiums for the 2014 World Cup program [2]. In the following year, it was enacted the 482/2012 regulation, also from ANEEL, and so that it begins the era of the distributed micro and mini generation in Brazil, that has allowed the electricity consumers generate part or all of their potential of electrical consumption using photovoltaic generators that work alongside the distribution network, under the energy exchange scheme.In this regulation were stipulated the type and maximum power of the generators and their respective generation category, where: for micro generation the generators have power up to 100 kWp (kilowatt peak); for mini generation, it is systems with an output exceeding 100 kWp up to 1 MWp [3]. Therewith, some initiatives have already begun to be implemented in 2011 and 2012, making the total implanted in Brazil exceeded the 3 MWp, which is a value well below of those existing in other countries, especially the Europeans ones.

In terms of Brazil, the State of Paraná is one of the largest

producers of electricity through hydropower due to the large number of rivers basins, but has a pre-disposition for analysis and application of other sources such as biomass, wind and photovoltaic power. In relation to the photovoltaic source applications and studies are in the embryonic phase, requiring from the State of Parana more investment in this sector.

Based on that, this study was developed comparing the solar radiation values found in Brazil, more specifically in State of Parana, with the values from Germany. Then it is presented the way that the Photovoltaic Map of State of Paraná, Brazil was drawn and the radiation values measured in a system operating at the UTFPR in Curitiba, Paraná, Brazil, with a comparative analysis of these results. Finally it is presented the final conclusions.

2 SOLAR RADIATION

Brazil is privileged in terms of incidence of solar radiation when compared with European countries that lead the installed capacity of the Grid-connected Photovoltaic Power Systems.

The values of solar radiation found in the Brazilian Atlas of Solar Energy - 2006, as noted in Figure 1, indicate the country's vocation for electricity generation through solar photovoltaic source.

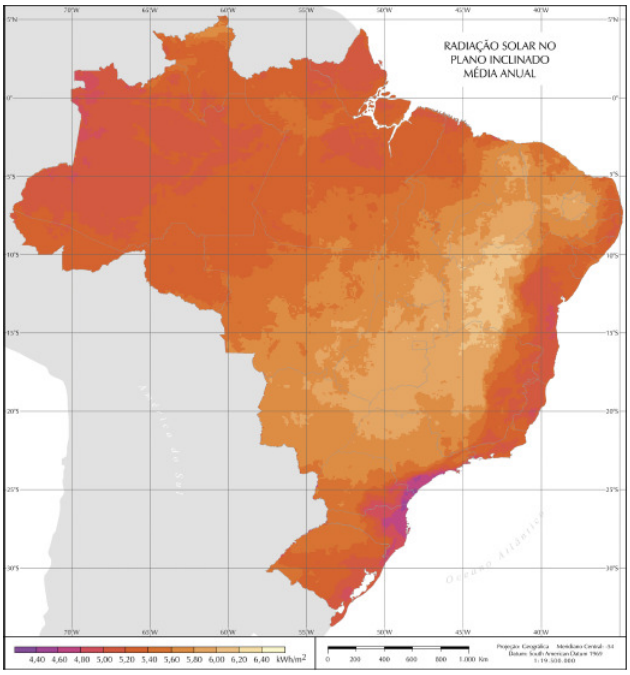


Figure 1. Global Solar Radiation Map on Inclined Plane - Annual Average. Source: [4]

The Brazilian Atlas of Solar Energy - 2006 shows the annual average of the daily total of solar radiation on the inclined plane incident in the Brazilian territory, with values ranging between approximately 1500 kWh/m²/year and 2500 kWh/m²/year [4].

Comparatively, using Germany as example, where until 2011 the installed capacity reached nearly 25 GWp, the solar radiation levels found there are approximately 40% lower than those obtained in Brazil [5], [6]. The German solar radiation map in kWh / m²/year and the electric energy productivity in kWh / kWp of can observed in Figure 2, which shows radiation values ranging between approximately between 1050 kWh/m²/year and 1450 kWh/m²/year.

Figure 2. Solar Map of Germany. Source: [7]

Through this information, it can be observed more clearly the potential of the Brazilian territory to generate electricity through photovoltaic panels.

In this perspective, this study searched to analyze the productive potential of the State of Paraná, located in southern region of Brazil. Figure 3 shows the location of the State of Paraná, Brazil.

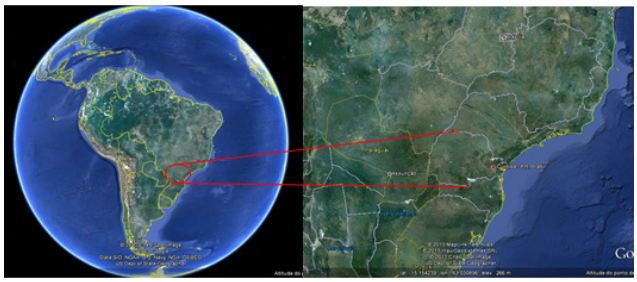


Figure 3.State of Parana Location, Brazil. Google Earth.

3 DETERMINATION OF THE ELECTRICITY GENERATION POTENTIAL IN THE PARANÁ STATE THROUGH SOLAR PHOTOVOLTAIC POWER

In this research were selected 48 cities in the state of Paraná in a sample form, distributed as evenly as possible, to cover all regions of the state. Figure 4 shows the State of Paraná Map with the identification of the cities used as basis of the research.

It was identified its latitude and longitude according to the register of the Google Earth application for each of the selected location. Based on these coordinates and using the database of the Brazilian Atlas of Solar Energy - 2006

for the inclined plane were identified the radiation values of each of site.

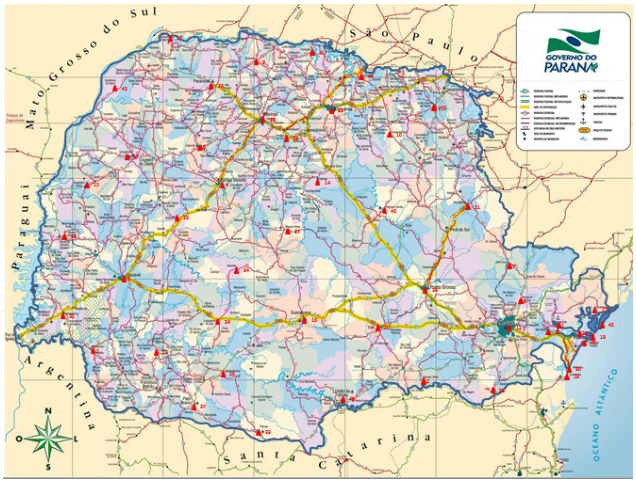


Figure 4. State of Parana Map with the researched 48 locations. Source: [8]. Adapted by the author

For this study, the data researched in the Atlas for determining the radiation values for each of the locations was made using the database in the inclined global plane, as to obtain higher performance in the Grid-connected Photovoltaic Power Systems, they should be inclined as the latitude of the point where the PV system will be installed.

To obtain the predicted values of electricity generation in each of the locations, it was considered the following requirements:

- System Potency: 1 kWp;
- Performance Ratio: 75 %;
- G_{STC}: 1 kW/m²;
- Inclination of the PV system: accompanies the latitude of the studied area (greater production of electricity for Grid-connected Photovoltaic Power Systems);
- The PV system orientation: oriented to True North (geographical).

The Performance Ratio is the relationship between the productivity (kWh / kWp) and the number of sunshine hours to 1000W / m² incidents in PV panel, usually linked to a year of operation, this magnitude is expressed in percentage [9]. Otherwise, it is possible also to say that this value represents the performance discounting losses in the system such as: losses in the inverters, in the connections, and particularly losses due to the temperature elevation in the modules because of the ambient temperature.

The values of daily power generation planned for each of the localities were calculated through the established criteria.

It is important to point out that these criteria are the same used for the elaboration of the photovoltaic maps by the European Commission [7], i.e.: solar electricity potential [kWh / kWp] generated by a 1 kWp system per year with photovoltaic modules mounted at an optimum inclination and assuming system performance ratio 0.75.

Based on these calculations, it is possible to verify the distribution of the values of annual electric energy in kWh, for every 1 kWp implanted, where it was found the following values:

- Lower electricity value: 1275 kWh/year;
- Higher electricity value: 1575 kWh/year.

From the information generated by the map to 1kWp systems, it is possible to determine the predicted values of power generation for any potency of photovoltaic system to be installed in any of the regions of the state. The PV map of the State of Paraná-Brazil is presented in Figure 5.

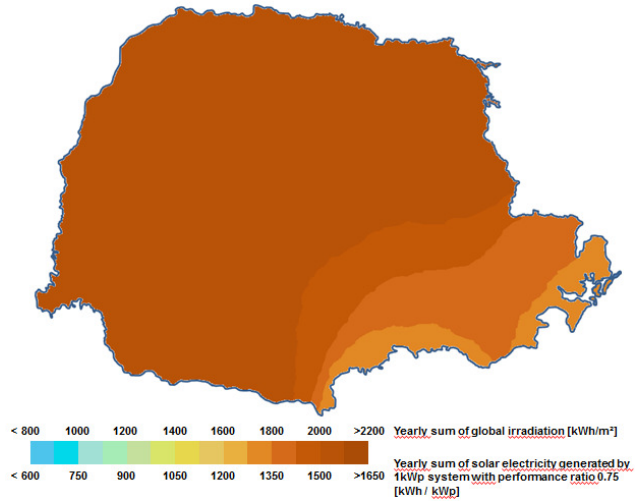


Figure 5 .Photovoltaic Map of the State of Parana. Source: the author

4 GRID-CONNECTED PHOTOVOLTAIC POWER SYSTEM OF THE UTFPR EM CURITIBA, PARANÁ

The Grid-connected Photovoltaic Power System of the UTFPR has an installed capacity of 2.1 kWp (10 KYOCERA modules of polycrystalline silicon technology, model KD210GX-LP connected in series) and a single-phase inverter in 220V of 2kW power rating (PVPOWERED model PVP2000). This system started to operate on 14 December 2011, occupying an area of 15m² on the roof of the building [10]. Figure 6 illustrates the PV panel and the inverter of the Grid-connected Photovoltaic Power System of the UTFPR, Curitiba.

Figure 6 – Photovoltaic Panel and inverter of UTFPR, Curitiba. Source: [9].

The radiation values incident on the photovoltaic panel of the UTFPR that was the basis for calculating the performance ratio of the PV system were obtained from the database of the SWERA Project (Solar and Wind Energy Resources Assessment), and a pyrometer installed along the photovoltaic panel.

For the period between January and June 2012 the database of the SWERA Project (average of ten years) was used and resulted in the Brazilian Atlas of Solar Energy [4], in conjunction with the RADIASOL program.

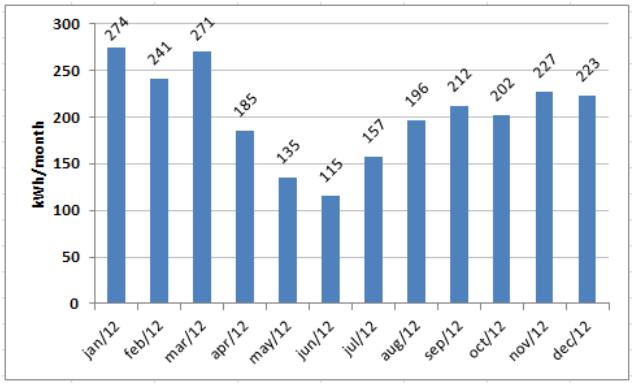
This program, made available by the Federal University of Rio Grande do Sul [11], from the insertion of the radiation values on the horizontal plane, allows the identification of the radiation values for any plan (different inclinations and azimuth deviation from North).

From July 2012 it started to be used the radiation data obtained through the pyrometer installed with same inclination and orientation of the photovoltaic panel, that is, 15 ° inclination and azimuth deviation 22 ° west.

For a Grid-connected Photovoltaic Power System installed in Curitiba, the optimal inclination is 25 ° oriented toward true north. However, for the system in UTFPR it was decided to follow the alignment of the building (deviation azimuth relative to north 22 ° west), and the inclination adopted was the same of the roof of the building (15° inclination).

Because this inclination and orientation were not ideal, the value of the performance ratio of the analyzed system was 0.70, lower than the amount considered internationally for Grid-connected Photovoltaic Power System which is 0.75. Based on this performance, the system generated the following amounts of electrical energy in kWh / month, as shown in Graph 1.

Graph 1. Generation of electric energy in kWh/month of the Grid-connected Photovoltaic Power System of the UTFPR in Curitiba. Source: the author.



Between 01/01/2012 and 31/12/2012, the analyzed system generated 2:44 MWh/year, and in terms of productivity, the system in operation showed the value of 1160 kWh/kWp.

5 ANALYSIS OF THE RESULTS

Through the Photovoltaic Map of the State of Paraná, Brazil, in the region of Curitiba, it was productivity values between 1350 and 1425 kWh / kWp.

For the system in operation in UTFPR the value of productivity obtained from the measured values of electric power generated and from the radiation incident on the plane of the photovoltaic panel, was 1160 kWh / kWp.

Comparing the values presented by PV map of the state of Paraná with the values measured by the system in operation in UTFPR, Curitba, it is observed that the measured value was below the range of values provided by the map. This is due to the following factors:

- Inclination and orientation of the system in operation in UTFPR do not follow the optimum values for the area under consideration;
- The existence of another building nearby the system in operation causes shading in the photovoltaic panel at the end of the day, and consequently decreasing in its productivity;
- Nevertheless, considering the radiation values measured by the pyrometer from July 2012, it was observed that these values are, on average, 10% lower than the values shown in the SWERA database, which were used to prepare the PV map;
- Based on the values of radiation measured, the average value of the performance ratio of the system in operation was a value of 0.70, lower than the International average of 0.75 found in Photovoltaic systems;
- The values of electrical energy obtained in the PV map were calculated using the value of international averages equal to 0.75, which is used by the European Commission in the elaboration of the European maps;
- It was also observed that in the months of May and June, the values of electricity generated by the system in operation were lower than expected. This was mainly due to an average of rainfall higher than expected, and that consequently caused radiation values below historical average of 10 years used by SWERA;
- Disregarding these two months, the monthly average of the system in operation would be 219 kWh, approximately 10% lower than the monthly average of the photovoltaic map, that is, 236 kWh (for the referred system, with 2.1 kWp implanted), and therefore, consistent with the values predicted by the map, since the measured radiation data were also below the average of the values in the SWERA database;
- Another important factor is related to the pyrometer used for measuring radiation data in the operating system, whose performance is far below to the pyrometers CMP11 from Kipp & Zonen, used in solarimeters stations in standard SONDA (National Organization of Environmental Data System) from the Brazilian Institute for Space Research – INPE that provide important information to guide data radiation of the SWERA project.

6 CONCLUSION

It is inevitable that investments in renewable energy sources such as photovoltaic are in the spotlight, through the evolution of the used technologies, and respectively, by the reduction of the cost of installation and significant improvement in these technologies efficiency, to the point of comparing the costs related to other historically important sources like hydroelectric and thermoelectric.

The objective of the research was to present an initial analysis of the productive potential through photovoltaic systems connected to the grid power for the State of Paraná, Brazil.

The selection of 48 cities allowed that, valuable information could be obtained, in a sample form, regarding to the potential for the generation of electricity in each identified region.

The elaboration of the Photovoltaic Map of the State of Paraná enables the perception of the regions and their different potential of electricity generation, identifying the different values of generated electricity for each region, predicted annually for each 1kWp installed, according to the assumptions defined and with performance ratio of 0.75.

The development of the Photovoltaic Map of Parana, Brazil, within the criteria established by the European

Commission, enables the comparison of the results with other photovoltaic maps of the European countries.

It was observed that the electricity values generated by the Grid-connected Photovoltaic Power System found on Photovoltaic Map of the State of Paraná are between 44% and 61% higher than those found in Germany (a country with implanted photovoltaic potential by 2011 of 24 GWp), demonstrating the potential of this source in the State of Paraná, Brazil.

The comparison with the real values obtained from the system in operation in UTFPR, in the city of Curitiba, Paraná, Brazil, were fundamental for the analysis and validation of the photovoltaic map prepared, whose data allowed further reflection and analysis on the PV system.

The information presented in this paper are an important step in determining future investments through this source in the State of Parana, Brazil, as well as in the elaboration of specific policies to encourage research and development of this important energy source.

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