

Characterization of grid-connected photovoltaic systems in Curitiba, Brazil

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ABSTRACT

In the search for new options for the establishment of the energy matrix of Brazil, the Grid-Connected Photovoltaic Systems (GCPVS) are configured as an alternative to urban centers, because they allow the power generation at distributed mode, that is, generate energy at the place where it will be consumed and inject the surplus energy into the network. Faced with the prospect of installing Grid-Connected Photovoltaic System, the objective of this research is to characterize this type of photovoltaic system installed in Curitiba, State of Paraná, Brazil. This paper highlights that up to July 2017 the State of Paraná has 1031 GCPVS in operation, which corresponds to 6,6MW, while Curitiba has 204 GCPVS that represents 997.4 kW in operation, 82% of which are installed in residences. In addition, the study of a sample of 41 GCPVSs installed in Curitiba shows that 98% of these systems use multicrystalline modules, 75% use single phase inverters and 95% of these use inverters transformerless. This shows that the losses in the conversion process are reduced and the equipment is more compact using better technology than the inverters with transformer. Therefore, the main trend of photovoltaic energy market is to use transformerless inverters.

Keywords: Grid-Connected Photovoltaic Systems; Distributed Generation; Solar Energy.



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INTRODUCTION

The progressive increase in the consumption of electric energy and the shortage of water resources implies the search for alternatives to diversify the electric matrix of Brazil and supply the country's energy demand¹. Currently, renewable energies, such as solar energy, wind and biomass, are considered more sustainable options. Distributed photovoltaic solar generation, which involves the production of energy closer to the consumer's, is a new strategy that may be useful especially in large Brazilian cities², since the energy generated by the sun is inexhaustible, both as heat and light³.

Moreover, this type of energy has an huge potential to be exploited in Brazil. The installed and operating capacity of photovoltaic generation in the country is only 238 MWp (July 2017), according to the National Electric Energy Agency (ANEEL)^{4,5}. On the other hand, China, the country with the largest photovoltaic generation, has more than 77.4 GWp installed and in operation, of which 34.54 GWp were added in the year 2016, according to the International Energy Agency (IEA)^{6,7}.

However, there is still a lack in the literature of the characterization of the Photovoltaic Systems Connected to the Electrical Network (GCPVS) installed in Brazil. The knowledge of the main characteristics of this system may contribute to the insertion of the photovoltaic generation in the country's electric matrix and support a more sustainable energy planning.

Thus, the present work aims to evaluate the profile of the GCPVS installed in the city of Curitiba, State of Paraná, Brazil.

MATERIAL AND METHODS

This work is a descriptive study of the photovoltaic systems installed in the city of Curitiba, capital of the State of Paraná, Brazil. Initially, the main characteristics of power range and A or B Groups were pooled from the database of the National Electric Energy Agency - ANEEL (www.aneel.gov.br) to provide a broader overview of energetic scenario.

Then, a sample of 41 systems installed by the two main companies of the State (ELCO – 31 systems and SOLAR ENERGY – 10 systems) were selected for an in-depth analyses. Data made available by the companies on the power range of the inverters used, the mode of installation of the modules and the technology of the photovoltaic cells used were collected.

The variations of the power systems (both added and cumulative) were assessed over the years. Descriptive analyses were conducted with all variables and are reported as absolute and relative frequencies.

RESULTS AND DISCUSSION

According to data available on micro and mini generation by ANEEL, the State of Paraná has 1031 GCPVS installed and in operation (up to July 2017). These systems have a total value of 6.65 MWp, of which 2.98 MWp are installed at residential homes. The year 2016 showed the highest number of connections of the GCPVS with the utility network, comprising 538 connections. It is worth mentioning that in the first seven months of 2017, a total of 366 connections were recorded, which represents 2676.75 kWp installed in the State of Paraná^{8,9}. Figure 1 shows the evolution of the installed capacity of GCPVSs in Paraná⁸.

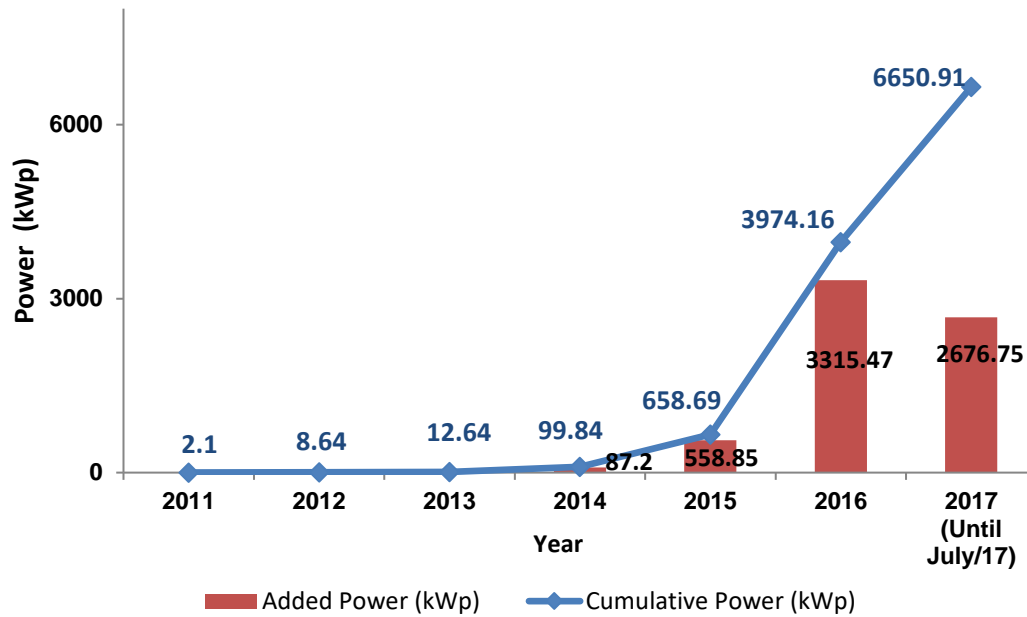


Figure 1 – Installed Power in the State of Paraná

The city of Curitiba has registered, a total of 204 GCPVSs installed and in operation from 2011 to July 2017, thus adding a power of 997.4 kWp. The highest number of connections were made in 2016, a total of 101 GCPVSs^{8,9}. It is important to highlight that before the publication of ANEEL's resolution n. 482 on the regulation of GCPVSs, Curitiba had already two systems installed. These systems are: (i) the GCPVS 2.1 kWp installed in the Green Office of the Technological Federal University of Paraná (UTFPR) in 2011, and (ii) the GCPVS 8.64 kWp of ELCO company, installed at the company's headquarters at the beginning of 2012. The ELCO's system was the first GCPVS to be homologated by the Energetic Company of Paraná (COPEL) on October 2nd, 2013⁹.

For three times from 2015 to 2016, an accumulated increase on the power range could be noticed - from 235.9 kWp to 733.08 kWp -. Additionally, in the first seven months of 2017 there is already a total of 264.32 kWp of installed power, as can be seen in Figure 2.

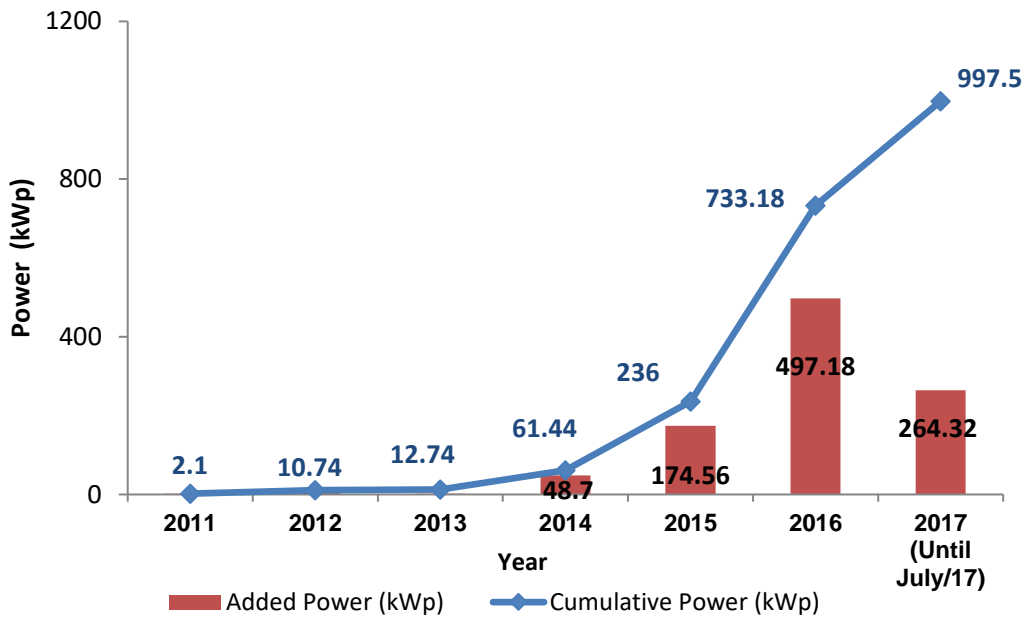


Figure 2 – Installed Power in Curitiba

Considering the consumer units installed in Curitiba, they are subdivided into Group A or B, according to the supply voltage. All units that have a power supply of 2.3 kV or more belong to Group A, whereas Group B is composed of units with voltage supply below 2.3 kV¹⁰. Figure 3 shows the consumer units groups of the GCPVS installed in Curitiba. Group B accounts for 96% of the installed systems, corresponding to a power of 809.13 kWp⁸.

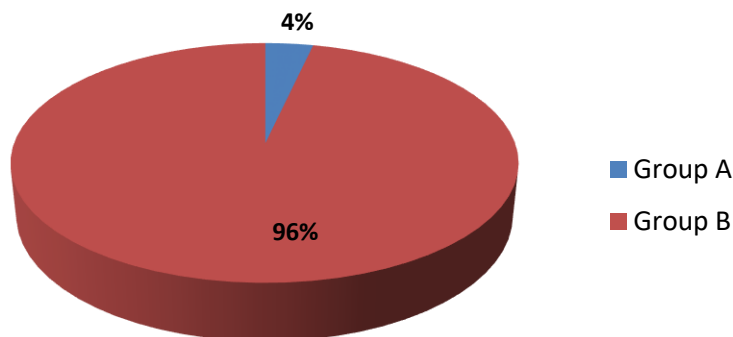


Figure 3 – Subdivision into consumer units (Group A and Group B) installed in Curitiba

This Group B is subdivided into residential, commercial and industrial units, as shown in Figure 4. Residential units correspond to 82% of the GCPVS installed in Curitiba, with a total capacity of 508.32 kWp, while the commercial units represent 29 of the GCPVS with a total power of 242.69 kWp⁸.

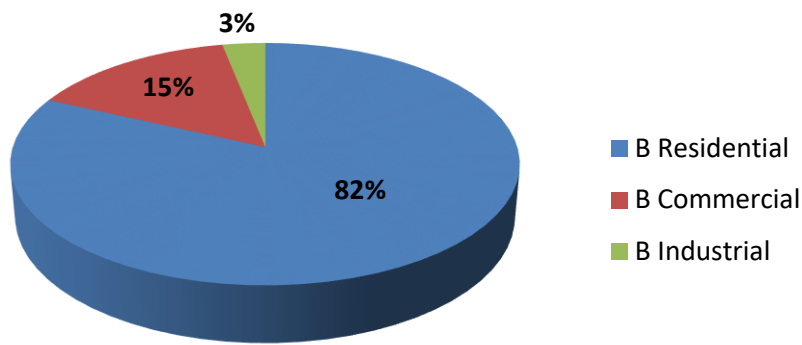


Figure 4 – Subdivision of Group B - Residential, Commercial and Industrial units in Curitiba

According to the power range of the systems, the GCPVSSs installed in Curitiba have three main divisions as shown in Figure 5. The systems with powers below 5 kWp are the great majority, with a total of 164 systems, representing 81% of the systems installed in the capital. Systems with power equal to or greater than 10 kWp are outnumbered, accounting for only 8%, (17 systems).

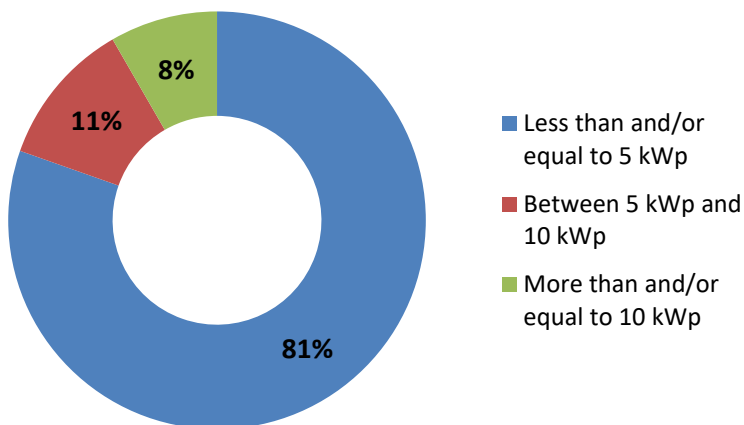


Figure 5 – Power range of the GCPVSS installed in Curitiba

Considering our sample of 41 GCPVSSs installed in Curitiba by ELCO and SOLAR ENERGY, 31 of them (75%) have power equal to or less than 5 kWp. Other 6 GCPVSSs have 10 kWp or more, representing 15% of the systems and lastly, only 4 systems (10%) have intermediate powers between 5 and 10 kWp (Figure 6).

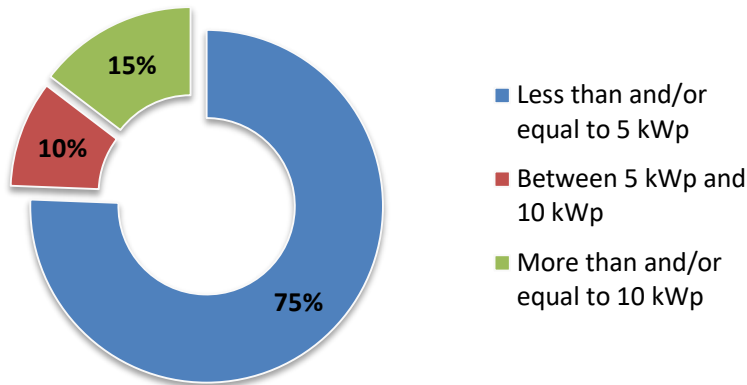


Figure 6 – Power range of the 41 GCPVSs installed in Curitiba

These GCPVSs use mainly inverters without transformers (95% of the systems) (see Figure 7), because this reduces the energy losses in the inverter and consequently increases the energy efficiency of the system. In addition, transformerless inverters have more advanced technology components and are more compact than transformer inverters¹¹. More than half of the systems (21 GCPVS, 51%) use inverters with a power of 3 kW, while 12 GCPVS (29%) use inverters with a power of 2kW, and 6 GCPVSs with a power of 10 kW (15%) (see Figure 8).

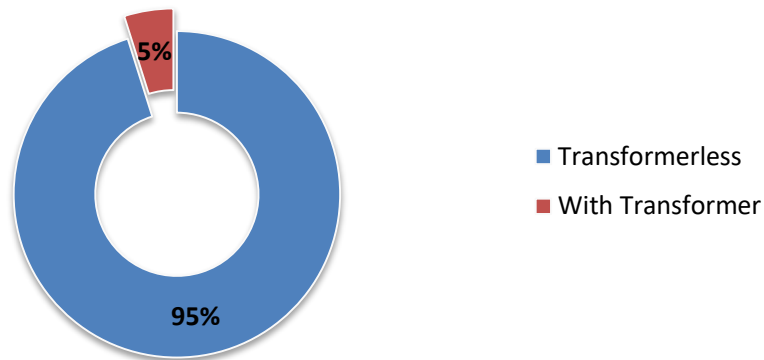


Figure 7 – Type of inverters employed in the GCPVSs installed in Curitiba

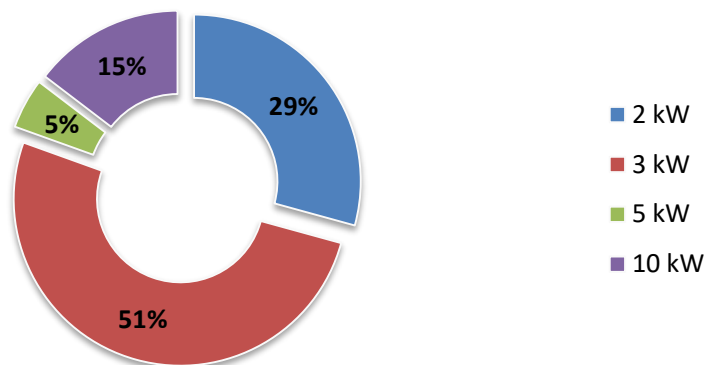


Figure 8 – Inverters power of the GCPVSs installed in Curitiba

Regarding to photovoltaic cell technology, it was possible to verify that 98% of these GCPVSSs use polycrystalline silicon. The remaining system by ELCO (8.64 kWp system, the first homologated in the State of Paraná) uses monocrystalline as technology.

All 41 GCPVSSs have been installed following the orientation of the roof of the buildings where they are installed and are geographically oriented. Ideally for Curitiba, the systems should be oriented to the geographic north (azimuthal deviation equal to or very close to zero) and with a slope equal to or very close to the value of the latitude of the city, which is 25 degrees. These specificities allow to maximize the incidence of irradiation in the photovoltaic modules and, consequently to increase the generation of electric energy, all year round. Finally, there is a predominance of residential home-installed systems, that proves the feasibility of the distributed solar photovoltaic generation as an excellent alternative to supply the energy demand in the great urban centers of the country. In addition, the evident growth of the photovoltaic generation systems in the electric matrix of Curitiba in the past years highlights the potential use of this strategy.

Our study has some limitations. It was possible to evaluate only a sample of the GCPVSSs installed in Curitiba, since no further information about the remaining systems was available. However, we were able to provide an overview of the current energetic scenario and highlight the main strenghts and weaknesses of the systems.

CONCLUSION

The main contribution of this work is the survey of the profile of the photovoltaic systems connected to the electric grid installed in Paraná. Currently, the State has 1031 GCPVSSs in operation which represents a power range of 6.65 MWp. The 41 installed GCPVSSs in Curitiba are mainly employed in residential units with powers of up to 5 kWp, using cells with polycrystalline technology, inverters without transformer and are installed following the geographic orientation of the respective roofs.

Thus, our study confirms the applicability of the distributed photovoltaic generation systems in urban environments. The GCPVSSs can effectively provide electric energy near to the points of consumption, requiring no additional area, since they are installed on building's roofs.

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