GRID-CONNECTED PV APPLICATION IN THE AMAZON REGION: A CASE OF STUDY OF A 3.3 kWp SYSTEM

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ABSTRACT
The main goal of this paper is to describe and analyze the performance of a grid-connected PV system installed in the Brazilian Amazon Region. The system analyzed here is composed of a 3.36 kWp PV generator and a 2.8 kW inverter, was installed and has been operating since December 2011 at GEDAE’s Laboratory of Renewable Energy and Energy Efficiency, in the city of Belém, State of Pará, Brazil. The paper presents electricity production and efficiency results obtained with the operation of this system. These results contribute to minimize the lack of operational information about grid-connected PV systems in the region, since almost all grid-connected systems in Brazil are located in the southern, southeastern or northeastern regions. Operational results of such systems contribute to the understanding of their operation in hot and humid climates such as the one in the Amazon Region. In spite of the existence of a significant number of cloudy days in the measurement period, it is estimated that the values of annual production are higher than some southern and southeastern Brazilian states. In addition, generation data close to 15 kWh in sunny days were verified for the measurement period.

1. INTRODUCTION
According to the National Energy Balance (Balanço Energético Nacional - BEN), 2011 - base year 2010, the hydroelectric power plants represent 71.2% (80.69 GW) of installed electric power generation in Brazil (1). However, the search for a decentralized power generation and consumption tends to modify these values. The use of Grid connected Photovoltaic System (GCPVS) in residential, industrial and other applications, is an alternative for the diversification of electricity generation in the country. GCPVS technology is little used in Brazil and according to the National Electrical Energy Agency (Agência Nacional de Energia Elétrica - ANEEL), there are less than 2 MW of installed capacity (2). Therefore, the Grupo de Estudos e Desenvolvimento de Alternativas Energéticas (GEDAE) has been developing projects to evaluate this type of application. This paper is a result of the research regarding operational performance of GCPVS in the city of Belém-PA, Brazil.

2. SYSTEM DESCRIPTION
The GCPVS basically comprises three elements: a 3.36 kWp PV generator, a 2.8 kW inverter, model GT2.8-NA-240/208 UL-05, and the AC electric grid bus of 220 V. The PV generator is oriented 19° northwest with a tilt angle of 14°, and is composed of 15 modules, model KC 120, and 13 modules, model AP120, each with nominal power of 120 Wp. For an optimized configuration of the PV generator, the modules were separated in two strings, one with 14 modules KC 120, and the other with 13 modules AP120 and 1 module KC120. These strings were connected in parallel to complete 3.36 kWp of installed PV generator capacity. Figure 1 shows the PV generator
installed on the northern side of GEDA E’s laboratory roof, and Figure 2 shows the line diagram with the system connections.

![Fig. 1: View of 3.36kWp PV generator, installed on the building’s roof.](image1)

![Fig. 2: Line diagram of the GCPVS installed at GEDA E’s laboratory.](image2)

The data acquisition process and visualization of the electric variables on both DC and AC buses of the GCPVS is carried out by a dedicated microcomputer. This system is shown in Figure 3, where the communication with the inverter through a serial cable RS232, and the screen of the data acquisition program can be seen.

![Fig. 3: Data Acquisition System dedicated to GCPVS.](image3)

3. OPERATIONAL RESULTS

Prior to the analysis of the GCPVS operation, this item presents a quick description of the consumption of electric power measured in the building where the system is installed. This analysis was accomplished for two months of electricity consumption monitoring of GEDA E’s laboratory. The measurements were taken during the months of July and August 2011, to give the reader a notion of the building’s energy consumption, which is presented in Figure 4.
The lack of data for some days of the two months was due to problems with the microcomputer. Based on the data shown in Figure 3, it is possible to have an idea of the average daily consumption of the building, as can be seen in Table 1.

**TABLE 1 - AVERAGE DAILY CONSUMPTION OF ELECTRICITY IN THE BUILDING, BY FINAL END USE.**

<table>
<thead>
<tr>
<th>Days/Final</th>
<th>Climatization (kWh)</th>
<th>Equipment (kWh)</th>
<th>Illumination (kWh)</th>
<th>Total (kWh)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Work days</td>
<td>103.36</td>
<td>36.15</td>
<td>5.94</td>
<td>145.46</td>
</tr>
<tr>
<td>Weekends and holidays</td>
<td>17.33</td>
<td>12.07</td>
<td>0.39</td>
<td>29.79</td>
</tr>
<tr>
<td>All days</td>
<td>72.08</td>
<td>27.40</td>
<td>3.92</td>
<td>103.40</td>
</tr>
</tbody>
</table>

Figure 5 shows the irradiance on the plan of the PV generator for a sunny day (July 23, 2011), and the measured load profile of the building for the three final end uses.
According to the data obtained from the monitoring system, an average daily generation of about 10.75 kWh was observed, corresponding to 10.40% of the total average daily electricity consumption of the building. According to the experimental data, it is possible to detect significant variations of Performance Ratio, due to operational problems in the PV generator and AC connections. The average value for this parameter in the monitoring period is 64.8%, which is considered to be a good performance (Table 2).

### Table 2 – Average Daily Values for GCPVS Generation (DSP), GCPVS Contribution to Electrical Consumption (DCC) of GEDAE’s Laboratory, Performance Ratio (PR), and Incident Solar Irradiation (SI).

<table>
<thead>
<tr>
<th>Month</th>
<th>DSP [kWh]</th>
<th>DCC [%]</th>
<th>PR [%]</th>
<th>YF [h/day]</th>
<th>SI [kWh/m²]</th>
</tr>
</thead>
<tbody>
<tr>
<td>December 2011</td>
<td>10.53</td>
<td>10.18</td>
<td>70.12</td>
<td>3.58</td>
<td>4.68</td>
</tr>
<tr>
<td>January 2012</td>
<td>10.11</td>
<td>11.09</td>
<td>71.58</td>
<td>3.44</td>
<td>3.44</td>
</tr>
<tr>
<td>February 2012</td>
<td>10.63</td>
<td>10.28</td>
<td>52.62</td>
<td>3.76</td>
<td>3.76</td>
</tr>
<tr>
<td>Average</td>
<td>10.42</td>
<td>10.51</td>
<td>64.77</td>
<td>3.59</td>
<td>3.96</td>
</tr>
</tbody>
</table>

The weather conditions have a significant influence in the availability of solar resource and, consequently, in the electricity production of the GCPVS (3). This fact is demonstrated in Figure 7, where the AC electrical power generated by de GCPVS is shown for different solar resource profiles.

![Generated Power vs Irradiance](image)

Fig. 7: AC electrical power generation and irradiance on the plane of the PV generator for a sunny and a cloudy day.

4. **CONCLUSION**

The practical results demonstrate some operational aspects of the GCPVS and the functionality of this type of installation in the conditions of the city of Belém-PA, Brazil.

According to the data presented, the PV generated energy is currently responsible for 10.5% of the consumption of the building. According to the average daily yields (3.59 kWh/kWp), the PV power peak required to supply the demand of the laboratory is approximately 29 kWp.

5. **ACKNOWLEDGMENTS**

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6. **REFERENCES**

(2) BIG - Balanço de Informações de Geração. Agência Nacional de Energia Elétrica, 2011