SOLAR ENERGY ON AIRPORTS: THE IMPACT OF LARGE SCALE PHOTOVOLTAIC SYSTEMS ON DISTRIBUTION NETWORKS

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ABSTRACT: Over the last two decades, many photovoltaic (PV) systems have been connected to electricity distribution networks worldwide. Electricity utilities are often required to promote adaptations to their distribution systems in order to accommodate and to operate this kind of generators. This raises the issue of penetration limits for distributed PV generation. Airport buildings are typically large, isolated and free of shading, and they represent a great potential for the application of large scale PV systems. The energy demand patterns characterized by intensive utilization of air-conditioning, airport building energy demands correlates very good with solar generation profiles. For higher penetration ratios of distributed PV generation, to supply the energy levels demanded on airports, there are some concerns about voltage rise. Depending on the network configuration, severe problems might be faced, which would require costly grid structure upgrading. Also, protection schemes might eventually need adaptation to bidirectional power flows. The aim of this paper is to quantify the potential impact in the conventional distribution network where the airports are located. The results of the load flow analysis show that violations of the tolerated voltage rage only occur in worst-case scenario with zero load and maximal PV input.
Keywords: Large Grid-connected PV systems, Photovoltaic, Solar Airports, Load flow analysis

1 INTRODUCTION

Electricity power systems have been traditionally designed following a scheme characterized by centralized generation. A number of factors, such as environmental issues, liberalization of electricity markets as well as quality and security of supply, are continuously increasing demands that can often be better addressed by means of distributed generation (DG).

In recent years investments and incentives for the application of photovoltaic (PV) technologies have resulted in a considerable market pull, driven mostly by grid-connected applications [1-3], which can be regarded as an ideal DG source in urban environments [4, 5].

However, the use of PV solar systems as DG, should not decrease the quality and the reliability of supply. Reliability problems refer to sustained interruptions, insufficient power quality refers to failures and switching operations in the network. These disturbances are related to the 'short-circuit capacity', which depends on the network's internal configuration [6-8]. Airport buildings are usually large and horizontal, and they are typically free of shading; their façades and roofs can often accommodate photovoltaic modules [9].

Airport buildings can be ideal for the application of grid-connected PV systems, where energy demand and solar generation profiles frequently coincide, especially due to the extensive use of HVAC systems in these buildings [10]. In this context, we have studied in detail the energy demand profile at the Florianópolis International Airport in Brazil and in this work we report the impact of large scale PV systems on the distribution network where the airport is located.

2 THE DISTRIBUTION NETWORK

The distribution network where the Florianópolis International Airport is located is a typical electricity grid in Brazil. The network geometry studied is a multi-branched tree-type network, which corresponds to an urban distribution network - a feeder. It is located in a mainly residential area and includes 159 nodes in the medium voltage distribution network setup. The nodes represent the voltage switchers or connection points between different cables.

The nodes are numbered in compliance with the geometry of the network, distance from the substation and cable type. Fig. 1 shows the network configuration with some numbered nodes and the location of the Airport node, where nodes 0 to 46 represent the main log.

The network shown in Fig. 1 employs the cable types presented in Table I. The tree-network uses 336.4 MCM type cable for the main log and for the branches, a combination of the other cable types, where the 6 Cu type cable is used for 29% of the total length of the grid and 2 CA, 1/0 CA and 4 CA cable types for 15, 7 and 6% respectively.

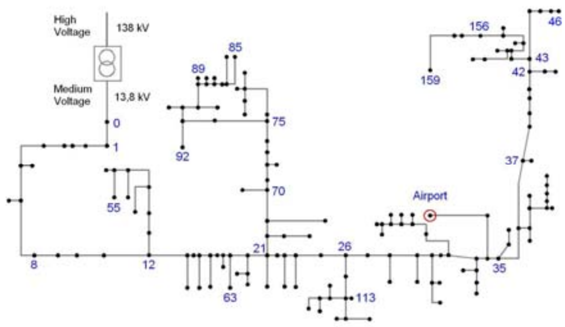

Figure 1: Network geometry where the Florianópolis International Airport is located

The load profiles from the whole distribution network and from the airport complex were obtained with the local utility company for an annual period from

June 2005 to May 2006 in 15 minutes time steps. The data were integrated in hour intervals. Fig. 2 shows the feeder and the airport annual average demand for the corresponding period.

Table I: Cable types used in the distribution network and respective electrical characteristics

Cable Name	Resistance (Ω/km)	Inductance (mH/km)
336.4 MCM	0.1900	1.0297
6 Cu	1.4820	1.3482
4 CA	1.5040	1.2898
2 CA	0.9480	1.2420
1/0 CA	0.5950	1.1969

The shape of the curve from the feeder in Fig. 2 shows a typical nighttime demand curve for the Brazilian energy consumption. The night peak is due to the usage of electric shower devices, which are switched on mainly in the evening, when people get home from work.

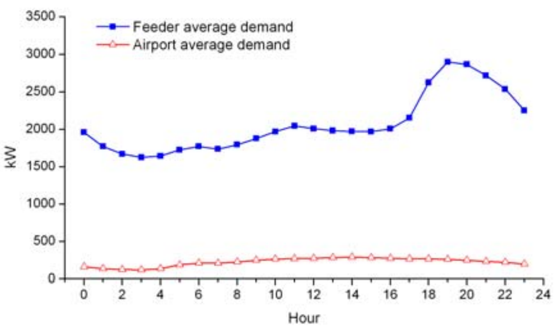

Figure 2: Feeder and airport annual average demand

The characteristic curve of the airport energy demand shows the highest demand close to noon with peaks between 11 and 14h. The demand percentage attributed to the airport complex corresponds to 11% of the total energy demand of the feeder.

In the accordance with the utility company standards the voltage of the network should preferably stay within 0.95 and 1.05 p.u. when a decentralized generation as PV systems is connected [11]. The unit p.u. stands for Per Unit which corresponds to the voltage relative to the nominal value which is 13.8 kV in the medium voltage network in Florianópolis. An additional limit to the network was the feeding node that was limited to a voltage 0.97 and 1.03 p.u. in order to accommodate the PV integration.

3 POWER FLOW SIMULATION

3.1 Scenarios

The aim of the case studies is to determine the voltages in the middle voltage distribution network when a large amount of PV power generation is integrated into the network within the local utility company limits. A total of seven scenarios was created and simulated to high light these issues. The input data sets comprised the following:

- Scenarios with different PV input

The first scenario considers that all the annual energy consumption (1.9 GWh) of the airport would be supplied by PV system. Other three scenarios consider that the system would supply 67%, 50% and 33% of the energy consumption. The annual medium irradiation for Florianópolis (4.028 kWh/m²/day) was used to calculate the PV power of the systems and resulted in 1,670; 1,113; 835 and 557 kWp, for scenarios A, B, C and D respectively [10].

The PV generation for the four different scenarios was calculated taking into account the real solar irradiation levels with a one-hour time resolution, taken from a 2kWp building-integrated PV system installed close to the airport facility [12-14]. For each month, the day with maximum irradiation level and the correspondent demand of the airport complex was selected.

Fig. 3 shows an example for the first four PV scenarios simulated, for the month of January 2006, as well as the airport's demand load curve. The final load at the airport node was calculated as a subtraction of the PV generation from the demand values per hour. Negative values mean that the PV system is feeding energy into the network.

The loads for the remaining nodes were calculated taking the total network nominal load minus the nominal load from the airport node, and dividing this value by the number of remaining nodes. With the result of this calculation, the final load is determined multiplying the derived key to the network demand for each hour of the selected day. When there is no load at the respective node, the final load is zero.

The fifth scenario (scenario E) was generated with the same model as above, but using two times the consumption data from the airport complex to the airport node. The sixth scenario is when an airport node presents the same situation of the previous scenario, but at the remaining nodes; the load is zero. This means that all PV generation is feeding into the network. Let us assume that as worst-case scenario.

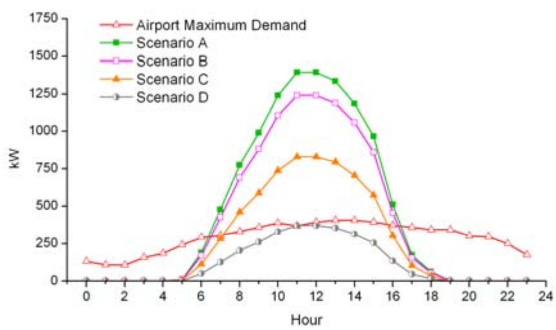

Figure 3: PV generation for scenarios A, B C and D for the day with maximum irradiation level in January 2006 and the corresponding airport demand

- Baseline Scenario

The Baseline Scenario was created to compare the results between the scenarios. The loads for all nodes are the same from the scenarios A, B, C and D, and no PV generation is available.

3.2 The power flow tool

To evaluate the power quality we used a load flow analysis [15]. For this analysis it is assumed that all load and generation are 3 phase symmetric. So, the result will be the same for all phases. The grid is represented by the admittance matrix, which contains all elements of the equivalent circuits. The algorithm for solving the load flow equations is implemented in the open source language R [16]. As slack node the high voltage grid (Fig. 1) was set. At this node, the voltage is fixed the reference voltage of 13.8 kV. In the calculation, all voltages are referred to this voltage. The slack node also must absorb/provide the needed/surplus power. The load flow analysis was repeated for each time step.

3.3 Simulation results

In total, 84 cases were simulated corresponding to 12 months for each scenario created. The results of all cases show the final voltage in kV for each node from the network in hourly time-steps.

To analyze the results at the airport node, a graphic of voltage versus hour was plotted with the results from the baseline scenario and for scenarios A, E and worst-case. Fig. 4 shows the result. Scenarios B, C and D were not plotted because the values are between the baseline and the A scenarios. January 2006 was the month with the highest irradiation levels and was selected to demonstrate the results.

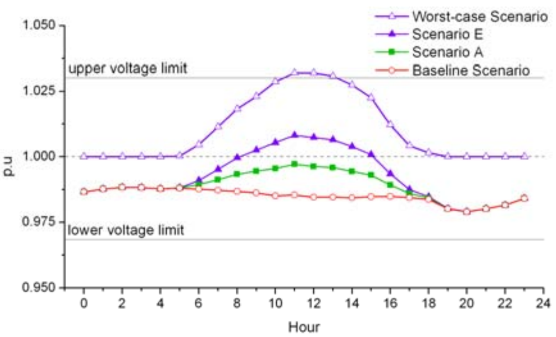

Figure 4: Voltages at the airport node for the Worst-case, E, A and Baseline scenarios for the period January 2006

When there is no consumption at airport node (worst-case scenario) the voltage hits the upper voltage limit. The worst-case scenario defines the situation for dimensioning the grid and often limits the installed PV capacity. But the other scenarios show that PV generation could improve the voltage at airport node, even when a high penetration level is feeding at the airport as in scenario E (3.34 MWp).

Despite the fact that the airport complex presents a demand peak close to noon, the results of the voltages show that the lowest values are obtained at evening hours, strongly influenced from the load profile of the feeder as Fig. 2 shows.

Low penetration levels as in scenarios C and D demonstrated small positive effects at airport node because to the amount of PV generation is mostly used to supply the demand from the airport complex. In months with low irradiation levels, as June, the differences between the results from the scenarios are very small. For all month, the voltages fluctuations between scenarios A and B are not significant.

To see the results of the power flow simulation on the network, we plotted a graphic with the final voltages at the main log of the network, but we added the nodes from the line that includes node 159, the node more distant from the substation. Fig. 5 shows the result. The period and the scenarios showed are the same scenarios from Fig. 4. The airport node does not belong to the main log, but it is connected on the node 34. In the graphic, we showed the link with the airport node to demonstrate were the PV system is located. We also choose the hour with maximum and minimum voltage levels from Fig. 4 (11 and 20h) to plot the scenarios results because the other results are between these values.

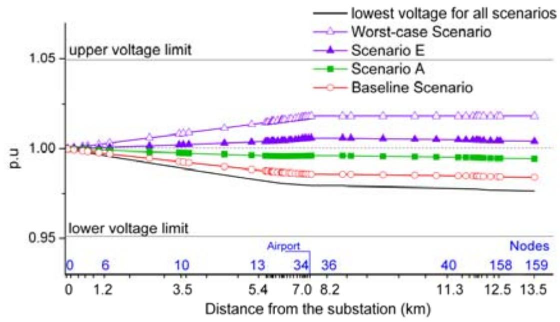

Figure 5: Voltages at the main nodes from the network plotted in accordance with the distance from the substation, for the Worst-case, E, A and Baseline scenarios for the period January 2006

Analyzing these results, we see the shape from the baseline scenario curve, and it is clear the gap from the voltage at substation and the node 34. After this point, the voltage stays practically constant. This can be explained when we analyze the network loads. From 7,740 kVA (nominal load), 77% are distributed before node 34 and the remaining is distributed until the network end. Scenario A, a 1.6 MWp PV system, is able to soften the gap and can improve the voltage in the network to levels near 1.0 p.u. with high irradiation levels. Comparing the voltage levels between baseline scenario with scenario A, the contribution of the PV system achieves 1% and with scenario E, 1.6%.

Once more, low PV penetration level has a small positive effect to network and the difference between scenario A and B is not notable.

All scenarios show voltage levels within the network utility company standards when we analyze the whole grid. The lower voltages occur at the same hour for all scenarios and show the same results, excluding the worse scenario, which stays at 1.0 p.u voltage level.

4 CONCLUSION

In our case-study, the network voltage profile is related with network geometry and the location of nominal loads. The location of airport node is after 77% of the total nominal load of the feeder and despite of that, the PV system of 1.6 MWp could improve the voltage of the grid near 1.0 p.u for the hours with high irradiation levels.

The simulation results demonstrate that the mismatch between PV production and electricity consumption can not be fully compensated. Thus the PV is unable to shave the network load peak appearing in our cases in the evening hours. To influence the evening peaks it is necessary to regard different generation technologies, like cogeneration or storage technologies.

The results from scenarios A, B, C and D, designed to supply the airport complex energy consumption up to 100%, stayed within the local network utility company standard showing improvement in the voltage level until 1%.

The results also demonstrated that high penetration levels of PV power generation, as from the worst-case scenario, may cause voltage problems at the airport node when certain circumstances are applicable. But for realistic load situations the PV input only at airport complex does not cause any violations of the voltage range. This will change dramatically if feed-in of PV is distributed over the whole grid and decentralized generation exceeds the total load of the distribution grid.

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