OPTIMUM SITING OF BUILDING-INTEGRATED PHOTOVOLTAICS IN URBAN ENVIRONMENTS IN BRAZIL: THE POTENTIAL OF PV IN ASSISTING DAY-TIME PEAKING FEEDERS

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ABSTRACT: Florianópolis, a city located in south Brazil (27ºS, 48ºW), is supplied by 56 feeders. Our interest is to identify which feeder could obtain more benefits with the implementation of a photovoltaic (PV) plant with a specific AC nominal power. Two factors are important in this analysis: the peak demand reduction value, and the LOLP (Loss of Load Probability, in failures per year), or LOLE (Loss of Load Expectation, in hours per year). We analyze the hourly demand curves of the 56 feeders with simultaneous PV power generation values obtained from a 2 kW_p building-integrated photovoltaic system (BIPV), located in Florianopolis, at Universidade Federal de Santa Catarina, connected to one of these feeders. The PV power selected for this study was 1000 kWp_{AC}, which corresponds to penetration level values between 10% and 20%, depending on the specific feeder considered. Our results show that if a small degree of LOLP and LOLE are acceptable, most of the installed PV capacity can be regarded as dispatchable.
Keywords: Building-integrated photovoltaics, grid-connected photovoltaics, distributed generation.

1 INTRODUCTION

Photovoltaics (PV) can contribute to a utility´s capacity if the demand peak occurs in the day-time period. Commercial regions with high midday air-conditioning loads have normally a demand curve in good synchronism with the solar irradiation profile [1]. Another factor, important in this analysis, is the comparison between the peak load values in summer and wintertime. The greater the demand in summertime in comparison with the demand in wintertime, the more closely the load is likely to match the actual solar resource [2].

Distributed PV reduces the amount of electricity that must pass through the electric grid, thereby relieving potential overloading of many grid components (*e.g.*, transformers). Reducing the number of hours of high loading on these systems also extends the life of the grid infrastructure [3].

In urban areas, commercial regions usually present day-time peak demand curves, and in residential regions the peak demand values occur in the late afternoon. Therefore, it is important to know the PV potential of the different regions of a city if we want to install a PV power plant, in order to select the feeder with the greatest capacity credit.

Florianópolis is located in south Brazil, having one of the lowest solar irradiation levels of all its territory (4500 $Wh/m^2/day$; the maximum value is 6300 $Wh/m^2/day$ in the northeast region). Nevertheless, it still is a very sunny site, and the city receives a great number of tourists in summer-time, when radiation levels peak, and therefore the electrical consumption is more than twice the winter consumption. Furthermore, the business and commercial heart of the city, located in the central region, presents a high midday air-conditioning demand, so that the load is in a good match with PV´s power output.

In this work we suppose the following: if we are to install a PV power plant with a specific power capacity in Florianópolis, and there is a choice of candidate locations, which feeder will be selected to benefit most from the distributed nature of PV, or, which feeder will lend the highest capacity to the PV plant installed. Two parameters are important for this choice: the demand peak reduction capacity and the number of failures (demand points not completely supplied by PV generation).

2 METODOLOGY

For the 56 feeders that supply the city, we identify two values: historical demand peak value without PV, and historical demand peak value with PV (peak demand minus PV generation at that particular instant) for a period of 2.5 years, using hourly values, and calculate the following factor:

POPR = ((historical demand peak without PV - historical demand peak with PV) / PV installed power) x 100%.

Where **POPR** is the Percentage of Peak Reduction relative to the PV nominal PV power. PV output profiles were obtained from real operating conditions of a 2 kWp PV plant operating in Florianopólis since 1997 [4-7].

Based on the historical demand peak values, we arbitrarily selected a PV power of 1000 kW, that represents a PV penetration level varying from 10% to 20% of the historical peak level for the selected feeders.

In a second step we build a graphic for each feeder with the following data:

- All demand values greater than the historical peak demand value minus 1000 kW (PV power).
- Corresponding demand minus PV generation. These values were organized in descending order of the demand minus PV generation values, and are shown in Figure 1.

Two horizontal lines, representing the historical demand peak value and the historical demand peak value minus PV power (1000 kW) were also plotted in Figure 1.

If we propose that the 1000 kW PV plant could be considered a dispatchable power source of 1000 kW, the demand with PV should never exceed the historical demand peak value minus the PV power value (limit value). If this value is exceeded, we can see how much the demand with PV exceeds this value and how often this situation takes place.

An important parameter is the quantity of hours per year that the demand with PV exceeds the “limit value”. We named this parameter as PV-LOLE (PV Loss of Load Expectation). The PV-LOLE differs from the conventional LOLE definition in the fact that the conventional LOLE considers a complete Loss of Load in hours per year, and the PV-LOLE is a partial Loss of Load of the PV generation alone, and does not necessarily mean a feeder failure, due to the limited (20% maximum) contribution of PV in supplying the respective feeder.

We calculate also the PV-LOLP (PV Loss of Load Probability) values for all the feeders with day-time demand peak. Comparing the PV-LOLE and PV-LOLP values we obtain the mean time, in hours, of failures. For example, if a PV-LOLE = 8 hours per year and a PV-LOLP = 4 failures per year, mean that, on average, a failure in the PV supply has a duration of two hours.

3 RESULTS

We follow up on a previous report where we studied the load behavior of feeders in Florianópolis, and the match between load and solar irradiation [6]. We found that the feeder with the largest peak reduction factor has also the smallest PV-LOLE value. This feeder is located in a commercial region of the city (named CQS_11), with a historical peak demand value of 9533kW, so that the PV penetration level is 10.5%.

Figure 1 shows the graphic with the demand without PV and demand with PV values for feeder CQS_11.

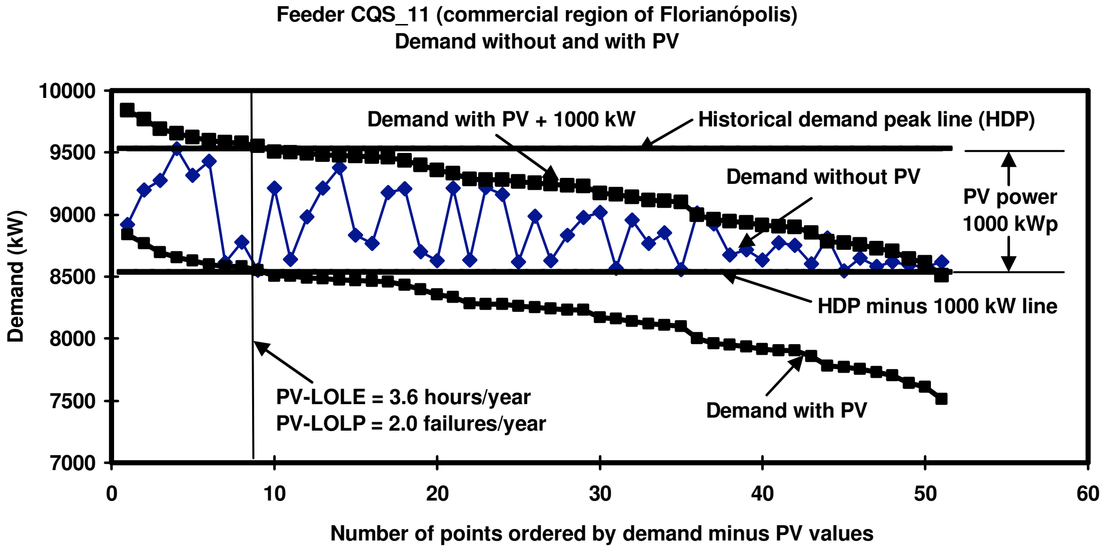

Figure 1: Demand and demand with PV values of the feeder CQS_11.

From Figure 1 we can obtain the following information:

- Only 51 times the demand values were larger than the historical demand peak minus PV power (9533kW – 1000kW). This small number of high demand values confirms the high summer-time energy consumption in this commercial region (for this feeder, CQS_11, the demand peaks occurred in March).
- Only nine times, out of 21888 demand readings, the “Demand with PV” value was larger than 8533 kW. This corresponds to a PV-LOLE value of 3.6 hours per year.
- Five failures occurred in these 2.5 years, corresponding to a PV-LOLP value of 2.0 failures per year. Two failures with duration of one hour, two with duration of two hours and one with duration of three hours.
- The largest demand with PV value is 8840 kW (worst case). This corresponds to a POPR=69.3% or, in other words, the 1000 kW_{AC} PV plant, in the worst case, supplied the equivalent of 693 kW.
- Observing the demand, and the demand with PV values, we can conclude that: if the solar irradiation level is high, the demand is also high, and when the solar irradiation level is low, the demand is also low. This evidences the high correlation between demand and solar radiation intensity in regions with high air-conditioning loads.
- We added 1000 kW to each “demand with PV” points, exactly the nominal PV power. These points appear in the upper curve in Figure 1; the curve named “Demand with PV + 1000 kW”. We can observe that, in practice, the PV generation reduced the points of high loading by an amount close to its nominal power. We can say that, except for the failures shown before (3.6 hours per year), the PV generation reduced the higher demand points by approximately 100% of the nominal installed PV power.

The behavior of all the other analyzed feeders with day-time demand peaks is similar to the behavior of the CQS_11 feeder. Figure 2 shows the values obtained for feeder TDE_07, which supplies the University region where the BIPV system is installed.

The historical demand peak of the TDE 07 feeder is 9524 kW, and only 133 times the demand values where higher than 8524 kW, or 9524 kW minus 1000 kW (the PV power). From these 133 points, 112 could have been entirely supplied by the PV generation, so that the "demand with PV" values would be shifted below the 8524 kW value. The largest demand with PV value is 9017 kW (worst case), corresponding to a POPR = 50.7%.

Table 1 shows the seven feeders with the best PV-LOLE and PV-LOLP values.

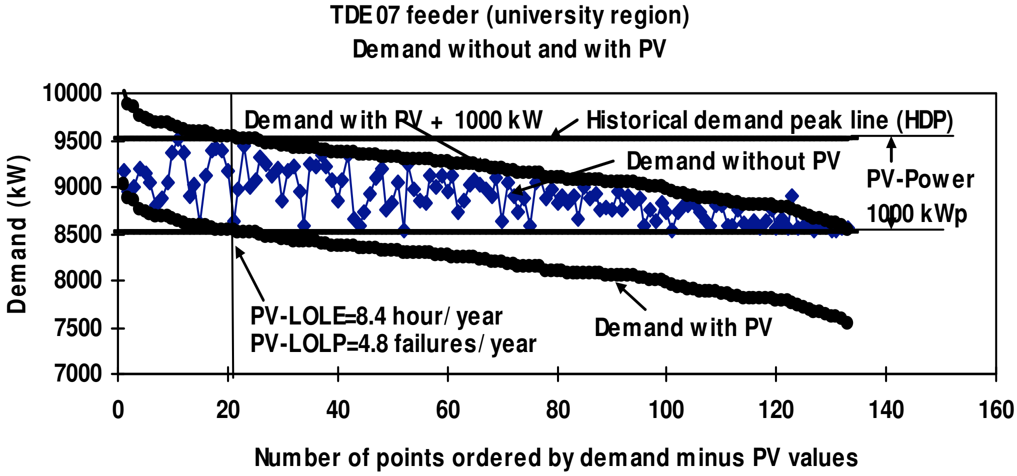

Figure 2: Greatest demand without and with PV contribution for the TDE 07 feeder (University region)

For all the seven feeders from Table I, the quantity of high demand values (values larger than the historical demand peak minus 1000 kW) is relatively small, varying from 51 (CQS_11) to 133 (TDE_07). This confirms the high electrical consumption in summertime in comparison with wintertime in this urban center. The PV-LOLE values, varying from 3.6 to 13.3 hours per year, and the POPR values varying from 41.4% to 70.9% indicate that, for these seven regions of the city, the use of a 1000 kW PV power plant will reduce the demand peaks significantly, with a very small probability of failure to supply the proposed "load minus 1000 kW" level.

Table I: The seven feeders with the PV-LOLE and PV-LOLP values

Feeder	Failures	Quantity of demand values greater than demand peak minus 1000 kW	PV-LOLE	PV-LOLP	POPR
CQS_11	9	51	3.6	2.0	69.3
ICO_07	12	54	4.8	2.0	70.9
ICO_08	20	79	8.0	3.2	52.0
ICO_11	28	98	11.2	4.4	50.7
ICO_12	21	111	13.3	6.3	41.6
TDE_04	24	181	9.6	5.6	62.1
TDE_07	21	133	8.4	4.8	50.7

4 CONCLUSIONS

The use of strategically sited PV power plants can reduce significantly the summer demand peaks in regions where the load reflects commercial customers demand for midday air-conditioning. The small quantities of partial failures, or instants where the PV generation did not supply completely the demand in the 2.5 years period analyzed, is an indication of the benefits which a particular feeder will have with the PV generation plant.

We observed that, excepting the previously mentioned points of failure (from 3.6 to 13.3 hours per year for the seven selected feeders), the PV generation plant reduces the higher demand points by approximately 100% of the nominal installed PV power. If these PV-LOLE and PV-LOLP values are acceptable for a specific feeder, we can consider that the PV plant can be viewed as a dispatchable power source with close to 100% of its nominal power. The failures due to PV can be viewed as partial failures, and are not necessarily leading to a complete feeder failure due to the relatively small PV penetration level (20% maximum).

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