PERFORMANCE OF THE FIRST GRID-CONNECTED, BIPV INSTALLATION IN BRAZIL OVER EIGHT YEARS OF CONTINUOUS OPERATION

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ABSTRACT: In September 1997 LABSOLAR, the solar energy research laboratory at Universidade Federal de Santa Catarina in Florianopolis – Brazil installed the first grid-connected, thin-film, building-integrated photovoltaic system in the country. The fully-monitored, double-junction amorphous silicon installation logs irradiation, temperature and electrical performance data continuously, at four-minutes intervals, and is connected to the public utility grid via four independent line-commutated sinewave inverters. After the initial Staebler-Wronski degration period, output performance has stabilised, with DC and AC performance ratios above 86% and 81% respectively at the system level, and an AC annual energy yield of 1277 kWh/kWp for a radiation level of 1529 kWh/m^2 at the site. We show the evolution of performance parameters since system commissioning, and demonstrate how this installation can assist in reducing demand peaks at the feeder to which the system is connected. The continuous operation of this installation for over eight years, with minimum maintenance and replacement costs, is a good example of the maturity and reliability of the amorphous silicon thin-film PV technology in a warm and sunny climate.
Keywords: Thin-film performance and reliability, grid-connected PV, building-integrated PV

1 INTRODUCTION

Photovoltaics (PV) in developing countries has traditionally been used in stand-alone configurations for isolated systems, where the distance to the public grid, and the disperse and low demand nature of consumers make it a good alternative to grid extension. However, residential tariffs in urban areas in Brazil can be as high as 14 Euro cents/kWh (some 70% of the residential tariff in Germany – currently the largest grid-connected market on earth), and solar radiation levels in urban centers of the Brazilian northeast are typically in the range of 2000 kWh/m^2/year (nearly twice the radiation levels in Germany), suggesting the case for grid-connected PV in the country. Furthermore, the continental size of Brazil (8,511,965 km^2), results in the need for a large and complex transmission and distribution (T&D) infrastructure and associated T&D losses, which justify the distributed generation model, that has in building-integrated photovoltaics (BIPV) one of its most elegant and ideal representatives. Grid-connected PV therefore makes a lot of sense in a country like Brazil.

In this context, the first grid-connected, thin-film, BIPV system was installed at Universidade Federal de Santa Catarina in Florianópolis, south Brazil (27^{o}S, 48^{o}W) in 1997 [1,2], and in this work we report on the reliable operation, and continuous and stable performance of this installation.

2 PV SYSTEM CHARACTERISTICS

Figure 1 shows the BIPV system, which was retrofitted to the solar energy research laboratory (LABSOLAR) building, and which includes a mix of 54 opaque and 14 semitransparent, double-junction, same bandgap, unframed a-Si PV glass-glass laminates, irradiation and temperature instrumentation and a dedicated data acquisition system. The 2kWp installation is divided into four sub-systems, which are individually connected to four single-phase, low-input voltage, line-commutated sinewave inverters that feed into the building's distribution system.

Since system start up, electrical parameters (DC and AC), horizontal and plane-of-array irradiation and ambient and back-of-module temperatures are logged at four-minute intervals. The 40 m^2 BIPV installation faces true north at latitude tilt (27^o), and is located next to the Baseline Surface Radiation Network (BSRN) solar radiation measurement facilities that LABSOLAR hosts for the World Meteorological Organization (WMO).

Figure 1: The 2kWp thin-film amorphous silicon BIPV system operating continuously since 1997 at the LABSOLAR building in Brazil.

3 PERFORMANCE RESULTS

After eight years of continuous operation the PV system output performance is stable at average DC and AC performance ratios (PR = ratio of the actual performance over the nameplate-rated performance at standard test conditions) of 86.3% and 81.6% with respect to nominal rating respectively. Annual AC energy yield for 2005 was 1277 kWh/kWp, for a 1529 kWh/m^2 radiation level at the site.

Table I shows the annual energy yields of the BIPV installation, and the annual radiation levels at the site for each year since start up. Comparing the annual yields with the corresponding annual solar radiation level, we can see that the energy yields are very consistent and stable. The relatively higher energy yield of the first year of operation can be ascribed to the stabilisation process which was still in progress during 1998.

Figure 2 shows the daily mean DC Performance Ratio over the eight-year period. The first 12 months are strongly marked by the light-induced degradation effect (Staebler-Wronski effect [3]), and after that period the system performance shows a seasonal variation typical of a-Si [4], with higher relative output in summer months, due to the higher operating temperatures (partial thermal annealing of the light-induced degradation) and spectral effects (lower Air Mass values in summer, leading to "bluer" spectra which are beneficial to a-Si), and a seasonal decline in relative output in winter. This behaviour is in contrast with the performance of the more traditional and market dominant crystalline silicon (c-Si) PV technology, which performs better in winter, and is typical of thin-film a-Si [4], which makes it an interesting choice of technology for operation in warm climates.

Table I: Annual energy yields of the 2kWp thin-film amorphous silicon BIPV installation, and annual radiation levels at the site.

Year	Yield (kWh/kWp)	Radiation (kWh/m²)
1998	1293	1452
1999	1231	1491
2000	1320	1620
2001	1254	1530
2002	1181	1479
2003	1264	1577
2004	1250	1505
2005	1277	1529

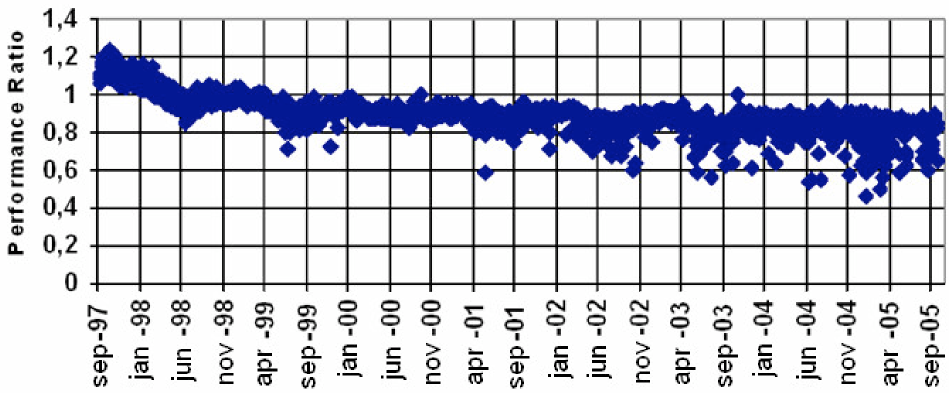

Figure 2: DC performance ratios (ratio of actual to expected performance based on nameplate rating at standard test conditions) of the amorphous silicon BIPV installation over eight years of continuous operation in Brazil.

The PV installation was started up on September 16th 1997, and Figure 3 shows the output performance of the system, at the AC level, for a clear day in September for each consecutive year since start up. Output power data for the 1998-2005 dates were normalized to the irradiance of the 1997 date to account for fluctuations in atmospheric conditions, and to the fact that clear days did not take place exactly on the same calendar date. Since PV modules were only washed by rainfall, the effect of dust and dirt on module surfaces, as well as of slight variations in module and ambient temperatures, are all contributing to the results shown in the performance curves. After the initial degradation and stabilisation of the Staebler-Wronski effect that can be noticed in years 1997 and 1998, the curves show that output performance has stabilised.

4 THE POTENTIAL OF PV IN ASSISTING DAY-TIME PEAKING URBAN FEEDERS

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 [5]. 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 [6].

For three consecutive days with different weather in summer 2002, Figure 4 shows the shape of the load curve of the urban feeder to which the 2kWp installation is connected, and a qualitative analysis of the beneficial effect on that curve peak of adding a PV generator, which can be regarded as a "negative load" to the feeder. The output of the PV installation was scaled up to improve visualization of the qualitative effect that this conveniently sited generator can have in reducing power demands for that particular (and typical of commercial urban areas) feeder [7]. The first day appearing in the figure (March 4th), shows a clear morning with a somewhat overcast afternoon; the next day (March 5th) was a completely clear day, and March 6th was heavily overcast. Because the load curve of this feeder is driven mainly by air-conditioning loads, which have a good match with PV generation, in all cases the presence of PV did guarantee that the demand peak was lowered (the amount of peak reduction depending on the amount of PV installed – the so-called PV penetration level [7]). This additional benefit of PV can have great value to the utility, and especially to the consumer in signing a lower demand contract. The good match of feeder demand and PV generation leads to high effective load carrying capacities (ELCC, as defined by Perez *et al.* [6]), which in the present case are close to 100%.

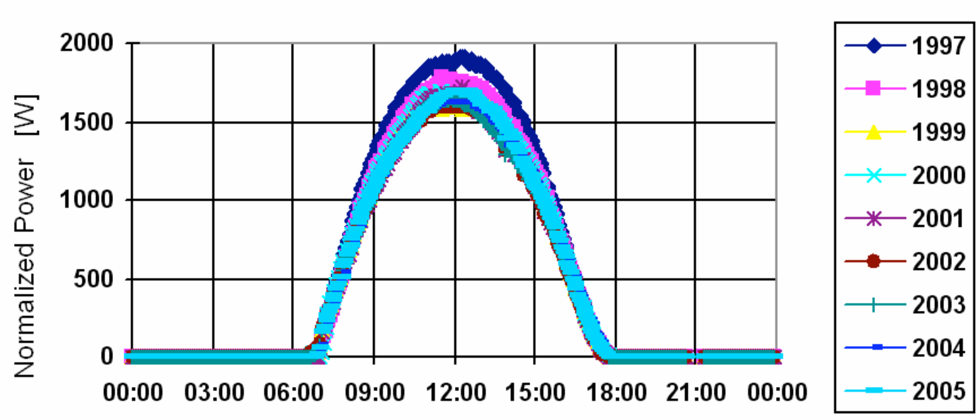

Figure 3: AC output power (W) daily profile of the 2kWp amorphous silicon BIPV installation, for clear days in September each year since start up. Data for the 1998 – 2005 dates were normalized to the irradiance of the 1997 date. No corrections were applied to account for module temperature effects or effects of dust/dirt on module surface.

5 CONCLUSIONS

We have shown results on the continuous operation of a 2kWp thin-film a-Si PV installation operating in Brazil for over eight years, with high annual energy yields and performance ratios.

The typical seasonal effect of a-Si, shown in Figure 2 and elsewhere in the literature demonstrating that a-Si is a better performer in summer, the fact that a-Si PV modules stabilise at a higher output performance level in warm climates [8-10], and the reliable performance of the PV system reported in this paper, demonstrate that this technology is well suited for BIPV installations in the urban environment in Brazil.

The extensive amount of performance data available for this PV installation should be useful to validate performance assessment tools and models, like the ColSim Simulation Model developed by researchers at the Fraunhofer Institute for Solar Energy Systems [11]. In a context of extensive deployment of the grid-connected PV technology, like in Germany at present and perhaps in Brazil in the near future, these tools are of great importance for PV system operators and investors.

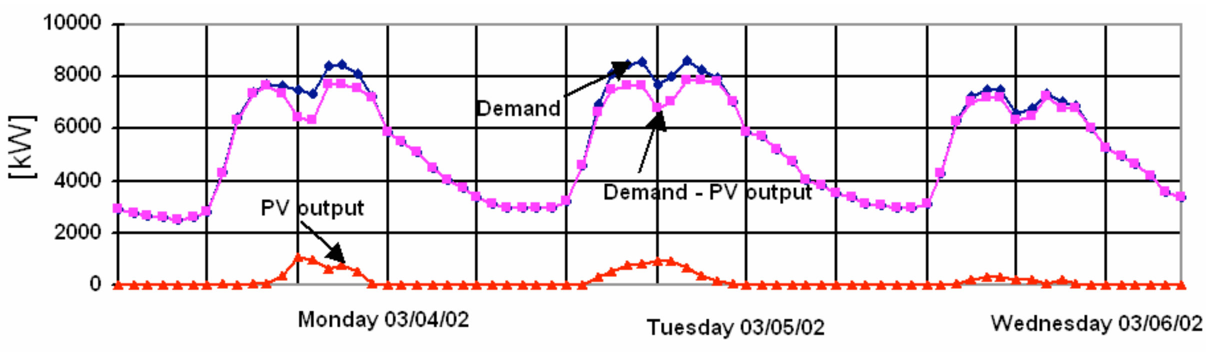

Figure 4: Actual demand curve (blue diamonds), PV generation (red triangles – scalled up to demonstrate potential behavior) and effect of PV generation in reducing demand curve (magenta squares) at the feeder to which the 2kWp BIPV system is connected, for three consecutive summer days in year 2002

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