LONG-TERM PERFORMANCE OF THE FIRST GRID-CONNECTED, BUILDING-INTEGRATED AMORPHOUS SILICON PV INSTALLATION IN BRAZIL

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ABSTRACT

In this paper we present the performance assessment of the first grid-connected, building-integrated, thin-film PV system installed in Brazil in 1997. In the 12-years period since start up, the $40m^2$, 2kWp double-junction amorphous silicon BIPV generator operated continuously, with minimum downtime and high performance ratios. We also discuss reliability issues related to system design and inverter performance and replacement for the continuous operation of this distributed energy source in the urban environment of a warm-climate metropolitan state capital in Brazil.

INTRODUCTION

This paper follows up on reporting and demonstrating the reliable operation and the continuous performance monitoring of the first grid-connected, building-integrated, thin-film PV system installed in Brazil in 1997. The $40m^2$ BIPV installation (see Figure 1) 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 First grid-connected thin film BIPV system installed in Brazil (1997), with a mix of 54 opaque and 13 semitransparent, double-junction, same band gap, unframed amorphous silicon (a-Si) PV glass-glass modules.

This distributed energy source in the urban environment contrasts with the traditional Brazilian utility concept that relies on a relatively small number of considerably large power plants, normally located not close to the urban centers where energy is consumed. In a large country like Brazil (8.5 million km^2), transmission and distribution (T&D) infrastructure and associated losses are not negligible, and utilities could benefit from PV distributed generation [1-3]. Despite those positive aspects political barriers and mainly costs still restrain diffusion of distributed grid-connected PV systems in Brazil. However, conventional electricity prices are increasing and is expected that residential tariffs and PV electricity costs should reach grid-parity sometime in the present decade [4].

EXPERIMENTAL

The PV system design and configuration, as well as the reliable and consistent performance of the a-Si thin-film installation in the warm Brazilian climate for the first ten years of continuous operation, have been presented in detail elsewhere [4-8]. A four sub-system design strategy using four inverters was originally adopted in order to minimize the risk of total system downtime and output losses in case of inverter failure, and because the PV system uses inverters made overseas [5]. The original design used four separate 650W line-commutated sinewave inverters instead of one inverter with the total PV system power rating. This strategy was devised so that in case one inverter failed, the PV modules connected to that inverter could be reassigned and distributed among the remaining three inverter units, since each 650 W unit was fed by a 500Wp PV panel. This had also allowed tor operation close to the inverter's maximum efficiency, which lies well below its maximum continuous rating [9]. This strategy was used until the end of 2008, and it proved to be overly zealous, as the PV inverters reliability has demonstrated that a single system configuration for small residential PV installations can still result in high reliability levels. After two of the original small inverters failed, and were meantime no longer in production, the PV system was retrofitted with a new, high-efficiency 2500W inverter, replacing the four, 11 years old, original, low DC input voltage (30V) 650W inverters. The PV modules were rewired for high voltage (390V) DC operation. The 2kWp BIPV installation is now formed by a 5-strings mix of 52 opaque (4 strings of 13 modules) and 13 semitransparent

(1 string of 13 modules) unframed, double-junction, same bandgap a-Si glass-glass laminates, irradiation and temperature sensors and inverter. Figure 2 shows the schematic diagram for the new system configuration with main electrical parts.

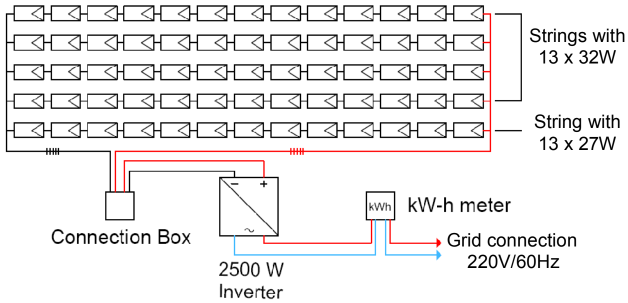

Figure 2 Schematic diagram for the 2kWp amorphous silicon PV system configuration. The PV panel is formed by a mix of 52 unframed a-Si glass-glass laminates modules wired in 5 strings: 4 strings of 13 x 32W opaque and 1 string of 13 x 27W semitransparent modules.

System electrical parameters (DC and AC), plane-of-array irradiance and ambient and back-of-module temperatures are monitored at 5-minute intervals by the inverter internal data acquisition circuit and stored in an external data logger. Figure 3 shows the diagram of the PV system data monitoring and logging equipment. Data stored in the logger can be read with a PC or accessed and read via the internet.

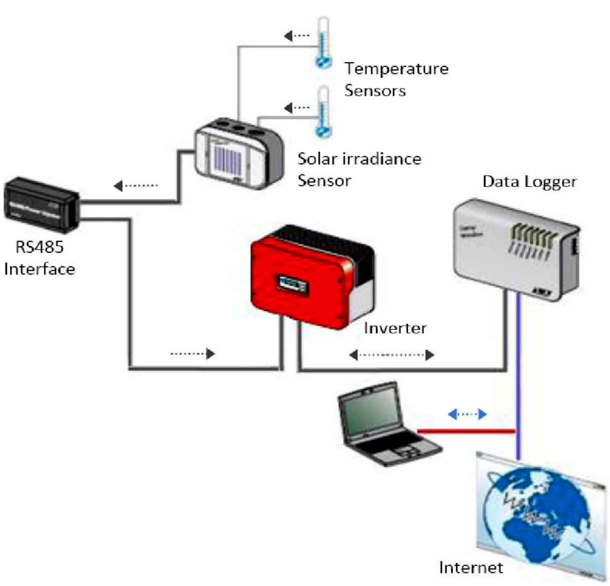

Figure 3 Diagram of the 2kWp thin film BIPV system data monitoring and data logging equipment: solar irradiance sensor, temperature sensors, RS 485 interface, inverter (internal data acquisition circuit) and data logger. Stored data can be read with a PC or accessed via the internet.

RESULTS AND DISCUSSION

The 2kWp PV generator was installed in September 1997, and system performance over the first 12 months was strongly marked by the light-induced degradation effect (Staebler-Wronski effect) [10]. After that period, system performance shows a seasonal variation typical of a-Si [11], 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). Figure 4 shows solar irradiation at the site (kW/m^2/year) and energy generated (kWh/year) profiles from 1998 to 2009.

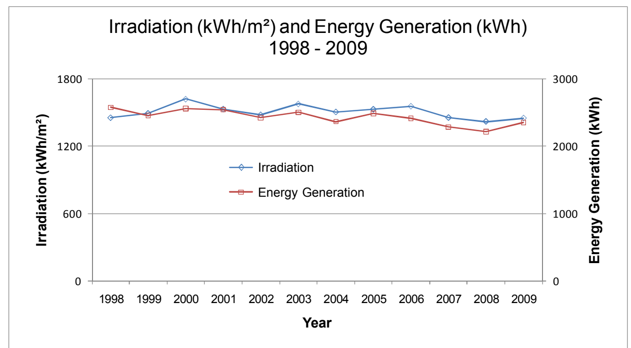

Figure 4 Solar irradiation (kWh/m^2) and energy generation (kWh) profiles over 12 years of operation of the 2kWp amorphous silicon PV system in Brazil.

As Fig 4 shows, a significant improvement in annual energy generation was noticed after retrofitting the installation with the new high-efficiency latest-generation 2500W inverter. Annual energy output in 2009 returned to a level similar to first years of operation. Figure 5 shows AC energy yield over the 12 years period.

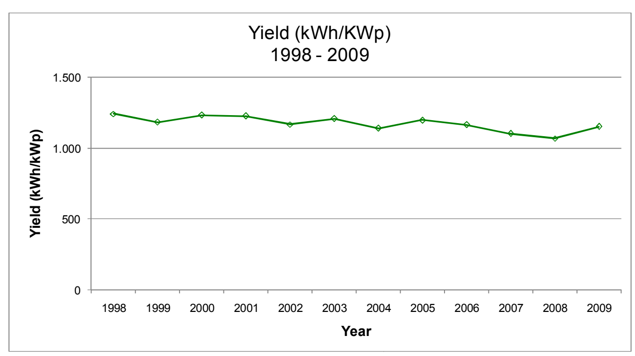

Figure 5 AC energy yield over 12 years of operation of the 2kWp amorphous silicon PV system in Brazil.

Annual AC energy yield for 2009 was 1149Wh/kWp, for a 1449kWh/m^2 radiation level at the site. This increase in system performance can also be ascribed to the inverter high efficiency (max. 94.1 % for the Sunny Boy, in comparison with max. 90.0 % for the earlier Würth inverters), and additionally to lower power losses in DC side wiring and connections due to the higher voltage configuration with the new inverter. The old PV panel configuration had maximum output voltage in the range of 25-30Vdc matching with inverter maximum input specification. As the new inverter accepts higher input voltages, in the range of 220-480V, currents are now in the order of ten times lower after PV panel rewiring. Output levels for calendar year 2008 in comparison with calendar year 1998 show that after the initial and strong degradation experienced in the first three months of operation (September to December 1997), performance ratio (PR = ratio of the actual AC performance over the nameplate-rated DC performance at standard test conditions) levels have degraded around 1%/year, dropping from 85% in 1998 to 75% in 2008. Figure 6 shows the behavior of PR (%) over the 12 years period. As a result of the retrofitting of a new inverter and the consequent rewiring of the PV array, a pronounced recovery of the performance ration can be seen, which restored AC power output to a level similar to that of the first years of operation.

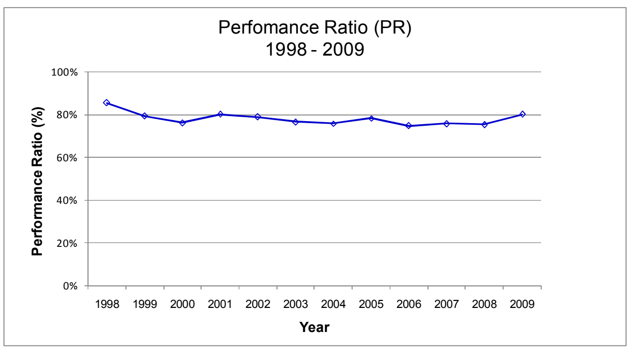

Figure 6 Performance ratio (PR) over the 12 years period of the 2kWp amorphous silicon PV system in Brazil. As a result of the inverter replacement and system rewiring at higher DC levels, performance ratios in 2009 returned to a level similar to that of the first years of operation.

CONCLUSIONS

This paper reported on the 12 years of continuous operation of the first grid-connected, thin-film PV installation in Brazil. We showed the reliable, long term performance of an amorphous silicon PV generator in a warm-climate country, with high solar radiation resource availability and high operating module temperatures. After 12 years of continuous operation the PV system output performance is stable at average AC performance ratios of over 80% with respect to nominal DC rating. This consistent and reliable performance of the a-Si PV system confirms our previous results and demonstrates that the a-Si PV technology is well suited for BIPV installations in the urban environment in Brazil. Since PV modules were only washed by rainfall, the effect of dust and dirt on module surfaces, as well as of variations in module and ambient temperatures, are all contributing to the results presented. We ascribe the high stabilized performance levels of this generator to the year-round high operating temperatures at the site. In a four-year round-robin experiment carried out in Arizona-USA (PTU-ASU), Colorado-USA (NREL) and Florianopolis-Brazil (our lab), we have previously demonstrated that a-Si is a good performer in warm climates [12]. As Brazil has an expected increase in energy demand of some 5% per year, grid-connected PV can assist as a distributed energy generation resource in urban areas. The performance parameters of the a-Si 2kWp PV system presented here can be checked in real time over the internet at the site http://www.sunnyportal.com/Templates/PublicPageOverview.aspx?plant9e74494f-8850-4508-a49a-3e10dc6e3d96& splang=en-US.

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