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The strategic siting and the roofing area requirements of building-integrated photovoltaic solar energy generators in urban areas in Brazil

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Abstract

Building-integrated photovoltaic (BIPV) generators are typically small and distributed solar power plants that occupy virtually no space because they are part of the building envelope, and they generate power at point of use. A more widespread use of grid-connected photovoltaics (PV) is hindered by a number of reasons which include the declining, but still high costs of the photogenerated kilowatt hour, and the lack of knowledge about the benefits of distributed generation with PV in the urban environment. When strategically sited, PV generators integrated to building façades and rooftops in urban areas at limited penetration levels can benefit local feeders with these distributed ‘‘negative loads’’. A number of studies have been published, with learning curves demonstrating the cost-reduction potential of large-scale PV production, and in some markets the cost of PV electricity is approaching residential tariffs, the so-called grid parity. Due to the intermittent nature of the solar radiation resource, PV is considered non-despatchable power, but under some conditions, in sunny urban areas with electricity load curves dominated by air-conditioning loads, there is a high correlation between PV generation and feeder loads. In these situations, a considerable fraction of a given PV generator can be considered despatchable power. In this work we assess the potential of building-integrated, grid-connected PV generation in the state capital Florianópolis, in South Brazil. The deployment of six different commercially available PV technologies is compared with total roof area availability, solar generation profiles, and local feeder load curves for a selected number of urban areas in the city. Our results demonstrate the advantages of strategically siting PV generators in the urban environment.

Keywords: Grid-connected photovoltaics; Building-integrated photovoltaics (BIPV); Value of photovoltaic (PV) electricity

1. Introduction

From the beginning of its commercialisation, electricity has been supplied to residential, commercial and industrial consumers by means of centralized generation and complex transmission and distribution systems. To commercialise electricity, there are a set of quality and availability standards that utilities must comply with which depend on investments in generation, transmission and distribution (T&D), and these are reflected in the final tariff. The planning and operation of electricity services thus involves a compromise between minimising investment and operation & maintenance costs, and delivering a product that complies with minimum quality requirements. The traditional utility concept relies on a relatively small number of considerably large power plants which are not necessarily close to the urban centres where energy is consumed, and in a large country like Brazil (8.5 million km^2), T&D infrastructure and associated losses are not negligible.

Compared with a share of some 17% of the total world electricity generation, and in spite of the large distances from urban areas, hydropower generation plays a fundamental role in Brazil. The present installed capacity of 73 GW corresponds to over 75% of the national electricity supply. This represents less than 30% of the 260 GW hydroelectricity potential in the country [1]. Growing environmental restrictions, and the larger distances from urban centres to the remaining potential,

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however, are considerably increasing the costs of new hydropower plants; nevertheless, it is expected that about half of the new power generation projects in the next years will be either small or large hydro [1]. The Brazilian interconnected electricity system is one of the largest and most complex in the world, with an installed capacity of over 96 GW [2]. In 2001, with increasing demand due to favourable economic conditions, and a lack of investments in infrastructure, there was a shortfall and consequent rationing of electricity in some regions in the country which exposed the fragility of the centralized generation and distribution model in a large country.

In this context, grid-connected, building-integrated photovoltaic (BIPV) systems in urban areas can offer an attractive alternative to compose the energy mix in Brazil.

The large solar radiation resource availability in the country, the complementary nature of solar versus hydro availability (seasonality), and the distributed nature of BIPV must be taken into account in order to add value to this still costly energy source. The cost-reduction potential of PV has been extensively studied and discussed in the literature [3–7], and it is generally accepted that at the gigawatt/year production level, PV can become cost competitive with conventional grid electricity [4,6]. Grid-connected PV in countries like Germany, Japan, Spain and the US is presently in the 2 GWp/year range, and the trend to integrate PV to buildings in urban areas is likely to expand considerably in the near future if costs decline, and the full benefits of this benign power generating technology are taken into account.

In this work we use the performance data of a grid-connected BIPV installation operating continuously in the state capital Florianópolis, south Brazil (27°S), for over 9 years [8–10], and compare solar generation with a number of urban feeder[1] load profiles to determine the amount of a given PV installed capacity that could be regarded as despatchable power. We show that if conveniently sized and sited, distributed PV generators can assist daytime peaking feeders, adding to the value of the photogenerated kilowatt hour the value of the associated peak reduction avoided cost. We use the parameter effective load carrying capacity (ELCC), defined by Garver [11] and refined by Perez et al. [12–14], as a tool to establish priority areas in the strategic siting of PV generators in the urban environment, taking also into account the available roof cover areas of the existing building stock.

2. Methodology

The load profile of the Brazilian electricity system as a whole peaks in the early evening, and it is driven partly by lighting, but mostly by the electrical showerheads that can draw up to 8 kW, and are the most common water heating device in Brazilian households. Commercial areas in urban centres, however, present daytime peaking load profiles that are typically driven by air-conditioning, and which are fairly coincident with solar generation profiles and seasonality (usage profiles ranging from 9 a.m. to 5 p.m., peaking around noon or early afternoon in summer months). In these situations BIPV in urban centres can assist in peak shaving, delivering power when it is most needed and at point of use, minimising T&D losses and increasing grid capacity [15]. In the state capital Florianópolis, nearly 50% of the urban feeders are daytime peaking, and in this work we selected eight of them, representing different areas in the city, to carry out a more detailed study.

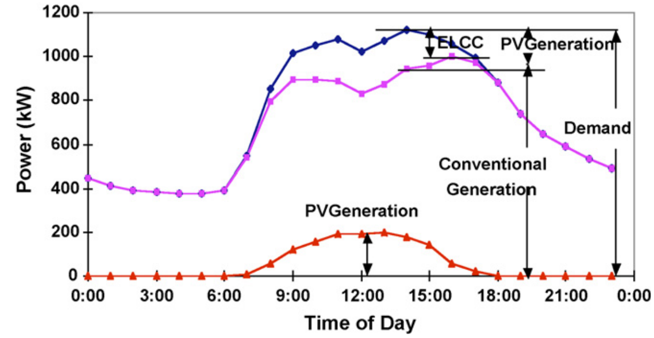

Fig. 1. Example of a typical daytime peaking urban utility feeder (TDE_07). The upper curve (blue diamonds) is the original load curve profile, the lower curve (red triangles) represents the PV generation for the corresponding clear day at a given PV penetration level, and the middle curve (magenta squares) shows the resulting load profile, with a considerably reduced peak which the feeder has to supply.

For each of the selected feeders we calculated the effective load carrying capacity (ELCC) [11–15] for different PV penetration levels,[2] aiming at identifying the potential contribution of grid-connected solar generation. Feeder load profile data were supplied by the local utility CELESC (Centrais Elétricas de Santa Catarina www.celesc.com.br) at 15-min intervals, and solar radiation, as well as PV generation data, were obtained from the fully monitored 2 kWp BIPV installation operating at LABSOLAR/UFSC's building since 1997 [8–10]. To calculate the ELCC, 12 clear days representing the 12 calendar months were selected, for which both solar radiation and PV generation profiles were available at 4-min intervals, and both feeder load data and PV generation data were averaged at hourly intervals for further processing. Clear day data were normalized with respect to the feeders' historic demand peak for each feeder, in order to determine the peak reduction percentage for further comparison. The ELCC was calculated as follows:

$$\mathrm{ELCC} = \left[\frac{(\mathrm{Peak\ C} - \mathrm{Peak\ CPV})}{\mathrm{PV}}\right] \times 100\% \quad (1)$$

where Peak C is the maximum historic demand value (kW), Peak CPV is the maximum historic demand value minus the respective PV generation, for a given PV penetration level (kW) and PV is the PV nominal installed capacity (kW).

Fig. 1 shows a typical daytime peaking feeder load profile (the TDE_07 feeder which will be further analysed), and the

[1] A feeder is defined as a section of the primary or high voltage distribution system derived from a single circuit breaking device in a distribution substation.

[2] The PV penetration level is defined as the percentage of the historic peak (AC kW) of a given feeder that is supplied with PV power (DC kW), and in this work we assumed a 80% performance ratio (i.e. ratio of actual AC power and rated DC power of the PV generator), based on the 9 years of monitoring of a BIPV installation operating at LABSOLAR/UFSC [8–10].

Table 1
The six commercially available PV module technologies used in this work and related characteristics

PV module technology	Module area (m^2)	Rated power (W)	EFF_{STC} (%)	T_{COEFF} (%/°C)	EFF_{NOCT} (%)
a-Si	1.12	64	6.30	0.00 [21]	6.30
CdTe	0.72	50	6.90	−0.20 [22]	6.62
CIS	0.73	60	8.20	−0.45 [22]	7.46
p-Si	0.64	75	11.60	−0.40 [22]	10.67
m-Si	1.26	170	13.50	−0.40 [21]	12.42
HIT	1.18	180	17.30	−0.33 [23]	16.16

NOCT = 45 °C.

parameters defined in Eq. (1) above which are used to calculate the ELCC parameter.

The ELCC was calculated for a series of PV penetration levels, ranging from 1% to 50%, and for eight of the 35 urban feeders in Florianópolis.

In order to determine whether the respective feeder area building stock could accommodate the necessary amount of PV generators needed to supply the respective fraction of the total feeder load, we estimated the total available roof cover area [16] for five of the eight feeders selected. We have also used six different commercially available PV technologies which present different solar-to-electricity conversion efficiencies, to correlate the available roofing areas with each particular PV technology area requirements. Table 1 shows the PV module technologies, specific module area and power for the selected models, STC[3] efficiencies (EFF_{STC}), temperature coefficient of power (T_{coeff}), and nominal operating cell temperature (NOCT) efficiencies (EFF_{NOCT}), for the three thin-film PV technologies a-Si (hydrogenated amorphous silicon), CdTe (cadmium telluride), CIS (copper, indium gallium diselenide), as well as for the more traditional p-Si (poly-crystalline silicon), m-Si (single-crystalline silicon), and the hybrid HIT (heterojunction with intrinsic layer) PV technology developed by Sanyo. Final PV module efficiencies used in this work were NOCT-corrected from STC catalogue efficiencies considering a NOCT temperature of 45 °C and the following equation:

$$EFF_{NOCT} = EFF_{STC}\left\{1.00 - \left[\frac{|T_{COEFF}| \times \Delta T}{100}\right]\right\} \quad (2)$$

These results were used to assess the potential of using each of these technologies in the selected urban areas with regard to the different PV penetration levels presented.

3. Results and discussion

The urban feeders selected are located in different areas of the city which present various building characteristics as described in Table 2 The ICO_07 and ICO_10 feeders are located in the city centre, serving a vertical, high-rise, high-density building stock; the TDE_07 feeder serves the UFSC campus and surrounding areas, with mixed building characteristics; feeders ICO_04, CQS_11, and TDE_03 serve a mostly residential and horizontal buildings area; feeders ICO_05 and TDE_04 supply a mixed residential/commercial area, with a building stock comprised of both multi-storey buildings and horizontal single-family dwellings. Table 2 also shows the respective total available roof area.

Fig. 2 exemplifies the high correlation of a daytime peaking feeder with the solar generation profile. For the TDE_07 feeder, and simulating a 10% PV penetration level, we show the corresponding load profile (upper curve: blue diamonds) for the three consecutive days with the different climate conditions represented by the lower curves (solar generation: red triangles), and the resulting load minus PV generation profile (middle curve: magenta squares). The upper straight (blue) line represents the historic feeder maximum peak, and the lower (red) straight line can be regarded as a new demand value that we define as the maximum peak with the integration of PV, and which should not be exceeded (demand limit with PV) to maximise the benefits of PV as a peak shaving tool. On Monday morning (4 March 2002), with an overcast sky, demand was low. In the afternoon, with higher values of solar irradiation, the demand increased, but was compensated by the enhanced PV generation. On Tuesday (5 March 2002), a clear day with high solar irradiation levels, demand was high, and solar generation was also high. On Wednesday (6 March 2002), a heavily overcast day, demand was reduced to values below the PV penetration level of 10%, meaning that there was no (or very little) PV generation available, but the new feeder demand peak limit was nevertheless not achieved, because loads (e.g. air-conditioning) were also low and in phase with the overcast conditions.

We have identified the historic demand peak for each of the eight feeders analysed, and have calculated the ELCC for PV penetration levels ranging from 1% to 50%. Fig. 3 shows the evolution of the ELCC with the increase of the participation of

Table 2
Building characteristics and available roof area for each feeder urban region

Feeder ID	Building characteristics	Available roof area (m^2)
ICO_07	Vertical	82,469
ICO_10	Vertical	39,271
TDE_07	Mixed	442,182
ICO_04	Horizontal	271,843
ICO_05	Mixed	209,446
CQS_11	Horizontal	n.a.
TDE_03	Horizontal	n.a.
TDE_04	Mixed	n.a.

n.a.: not available.

[3] STC = standard test conditions. PV module cell temperature = 25 °C; irradiance = 1000 W/m^2; Spectral content of light = AM 1.5.

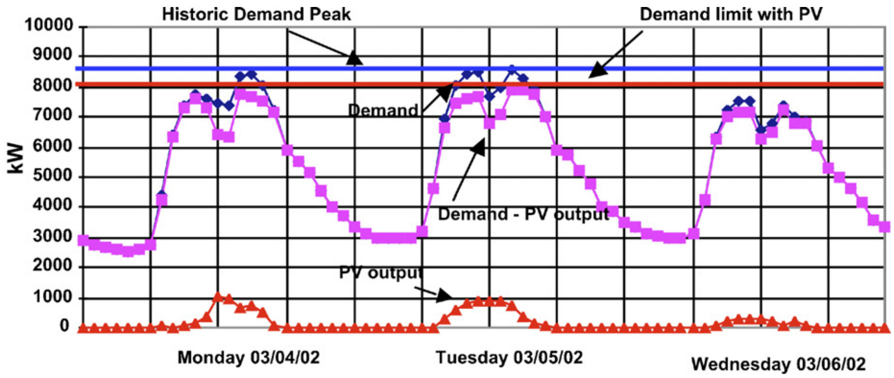

Fig. 2. Demand behaviour of feeder TDE_07 for three consecutive days with distinct solar radiation profiles. The upper curve (blue diamonds) is the original load curve profile, the lower curve (red triangles) represents the PV generation for the corresponding clear day, and the middle curve (magenta squares) shows the resulting load profile which the feeder has to supply. Even on a cloudy day the "demand limit with PV" level was not exceeded.

PV (i.e. the PV penetration level) in the power supply of the respective feeder. We present this set of curves as a strategic siting tool which can assist the local utility in assigning peak shaving value (capacity) to the amount of PV installed. With the results shown in Fig. 3 it is possible to prioritise the installation of PV in the urban environment, selecting first the urban regions served by feeders which lend a higher ELCC to PV, in order to obtain the maximum peak reduction potential for a given PV installed capacity.

Table 3 shows the historic demand peak (Peak C), the total nominal DC installed power capacity for a PV system installation at a 20% PV penetration level (P_{DC}), and the total required roof area for installing such an amount of PV, for each of the six commercially available module technologies. Different P_{DC} and area values for other PV penetration levels can be easily determined by linear extrapolation. When installing a certain amount of PV in the metropolitan area of Florianópolis, these results indicate that among all the feeders analysed, ICO_10 (located in a downtown, vertical, high-rise, high-density area), TDE_03 (located in a predominantly residential area), and CQS_11 (located in a mixed commercial/residential area) would benefit most from the distributed nature of solar generation up to a 11–12% PV penetration level. From Table 3, it is possible to conclude that this corresponds to some 3 MWp of PV evenly distributed on rooftops of the existing buildings among these three urban areas. Feeder ICO_10 shows a consistently high ELCC of over 70%, up to a PV penetration level of 45% which corresponds to an extra 3 MWp, and CQS_11 re-emerges as one of the most suitable to incorporate PV up to nearly 15% penetration, with another 0.4 MWp which can be installed with maximum benefits. To maximise the peak shaving potential of PV in the metropolitan area in this case, these results indicate that only after installing at least 6 MWp connected to feeders CQS_11, TDE_03 and ICO_10 should one consider installing PV connected to any other of the feeders analysed. As a next step, Fig. 3 also shows

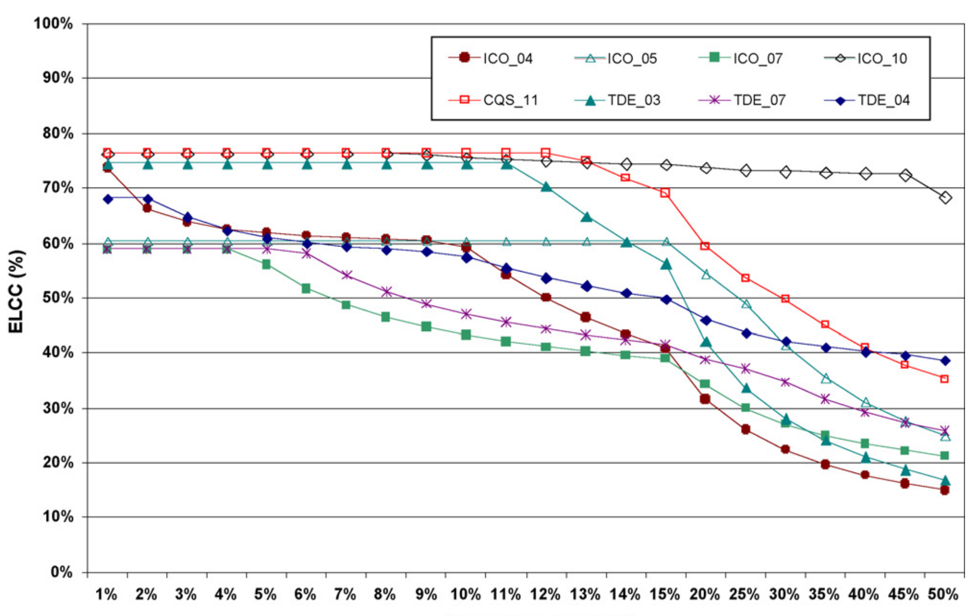

Fig. 3. Evolution of the ELCC parameter for each of the eight urban feeders selected vs. PV penetration level. The PV penetration level corresponds to the fraction of the corresponding feeder's historic load peak.

Table 3
Historic demand peak, nominal DC capacity for PV system installation at 20% PV penetration level, and required roof area for each of the six commercially available PV module technologies

Feeder ID	Peak C (kW)	P_{DC} (kWp)	Required roof area for each PV module technology (m^2)					
			a-Si	CdTe	CIS	p-Si	m-Si	HIT
ICO_07	9533	1907	30,263	28,801	25,558	17,869	15,351	11,798
TDE_07	9524	1905	30,235	28,773	25,534	17,852	15,337	11,787
ICO_04	8861	1772	28,130	26,770	23,756	16,609	14,269	10,967
ICO_05	7208	1442	22,883	21,776	19,324	13,511	11,607	8,921
ICO_10	8581	1716	27,241	25,924	23,005	16,084	13,818	10,620
CQS_11	9533	1907	30,263	28,801	25,558	17,869	15,351	11,798
TDE_03	8256	1651	26,210	24,943	22,134	15,475	13,295	10,218
TDE_04	8293	1659	26,327	25,054	22,233	15,545	13,354	10,264

Different P_{DC} and area values for other PV penetration levels can be easily determined by linear extrapolation.

that around 0.8 MWp could be connected to feeders ICO_04 and TDE_04, corresponding to a PV penetration level of up to around 4%, with maximum peak shaving potential (ELCC ranging from 63% to 73%). Following a partial levelling-off of the ELCC at 60% up to a PV penetration level of 8–9% for these two feeders, and the appearance of feeders ICO_05 and TDE_07 with the same ~60% ELCC level up to PV penetration levels of 15% and 6% respectively, another 2.4 MWP could be strategically sited around these feeders, before installing any more PV capacity in other feeder areas, totalling some 10 MWp. The methodology translated by Fig. 3 allows further iteration steps in order to optimise the siting of PV systems in an orderly and strategic manner, and reveals the advantages of the distributed nature of disperse PV generators.

Table 3 shows, for the eight feeders analysed, and the six commercially available PV module technologies studied, the surface area requirements for installing these generators at a PV penetration level of 20% which corresponds to some 14 MWp of PV capacity. Peak C was already defined in Eq. (1), and P_{DC} is the PV generator nominal DC (direct current) power at the corresponding PV penetration level, 20% in this case. Comparing these figures with the roof areas available at each of the corresponding feeder urban regions shown in Table 2, we conclude that even using the least efficient and more area-intensive PV technology (thin-film amorphous silicon), there is enough area to accommodate these 14 MWp of PV on the existing building stock roofs. Out of the five feeders for which the available roof cover areas were calculated, only in the vertical, high-rise, central area served by feeder ICO_10 would a higher than 30% PV penetration level face limitations in surface area availability for the deployment of the a-Si technology. All the other PV technologies could be easily accommodated at even higher PV penetration levels. Previous studies have shown [17–19] that in the urban environment, PV fractions larger than 20% might result in operational problems in the despatch strategies of distribution utilities, and as Fig. 3 shows, the ELCC starts declining strongly at these levels, indicating that the largest benefits come from a more evenly spread distribution of PV among the various feeders in a metropolitan area.

At the single-building level and for different regions in Brazil, we have recently shown that for the typical four-storey residential buildings that are common in the urban areas studied [20], PV penetration levels ranging from 30% to over 50% (depending on latitude and local solar radiation profiles) can be reached, even when using the lowest efficiency PV technology a-Si. ELCC benefits, however, are considerably lower at these higher PV penetration levels, as Fig. 3 indicates. It should also be mentioned that Florianópolis, located at the south-end of the country, presents one of the lowest solar radiation levels in Brazil (1500–1600 kWh/m^2/year on average) [20]. For the Brazilian central and northeast regions, not only are the solar radiation levels considerably higher, but the intensive use of air-conditioning results in an even more closely related match between power demand and solar generation profiles. In these cases, higher benefits from PV generation, translated by higher ELCC values in these regions, can be expected.

4. Conclusions

We have studied the behaviour of grid-connected, building-integrated photovoltaic solar energy conversion in the built environment of a metropolitan area in a Brazilian state capital, aiming at maximising the benefits of the distributed nature of PV generation. Using the effective load carrying capacity parameter to correlate solar energy availability in urban areas with the respective utility feeder power demands, we have shown that for a selection of metropolitan areas there is good coincidence between energy demand and generation. These areas usually present large air-conditioning loads which result in a good match between power demand and solar availability. For fractions of PV penetration up to 20%, this synchronism was translated by ELCC values starting at more than 75% which can be interpreted as a metric for PV plant despatchability, and also as a priorization tool for PV siting and integration in the urban environment.

For the daytime peaking utility feeders selected, we have also estimated the available building stock roofing areas availability, in order to determine whether there is enough surface area available for integrating PV generators to the penetration levels desired. We have carried out calculations of roofing area availability versus requirements for PV integration for the six commercially available PV technologies. Our results show that even when using the least efficient, thin-film amorphous silicon PV modules, the urban areas considered in this study could easily accommodate enough PV generators on the existing building stock roofs up to at least a 30% PV penetration level in the worst case (vertical, high-rise urban area). In more residential, horizontal building stock areas, where there are more suitable roofing areas available for installing PV generators as shown, higher PV penetration levels can be used. However, in these areas the ELCC parameter is intrinsically lower than in more commercial areas, where air-conditioning loads dictate the respective feeder load profiles.

When installing solar photovoltaic systems in the urban environment, the ELCC methodology can be used to strategically site these distributed generators integrated to the building envelope, and maximise the benefits of these clean, quiet, and in this case zero-area-requirement mini power plants. With the more widespread use of BIPV systems, and the consequent cost-reductions resulting from larger production volumes, PV siting optimisation tools should play an important role in making the cost of solar electricity more competitive with conventional grid power.

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References

[1] Agência Nacional de Energia Elétrica (ANEEL), Atlas de Energia Elétrica do Brasil, 2nd ed., Agência Nacional de Energia Elétrica, 2005, , p. 43.
[2] Agência Nacional de Energia Elétrica (ANEEL), Matriz de Energia Elétrica. Available at: www.aneel.gov.br/15.htm, Agência Nacional de Energia Elétrica: access on October 13, 2006.
[3] J. Cody, T. Tiedje, A learning curve approach to projecting cost and performance in thin-film photovoltaics, in: Proceedings of the 25th IEEE Photovoltaic Specialists Conference, Washington, USA, (1996), pp. 1521–1524.
[4] M.S. Keshner, R. Arya, Study of potential cost-reductions resulting from super-large-scale manufacturing of PV modules, Report NREL/SR-520-36846, National Renewable Energy Laboratory, Golden, CO, USA, 2004, pp. 1–50.
[5] H. de Moor, G.J. Schaeffer, A. Seebregts, L. Beurskens, E. Durstewitz, W. Alsema, W. van Sark, H Laukamp, P. Boulanger, C. Zuccaro, Experience curve approach for more effective policy instruments, in: Proceedings of the Third World Conference on Photovoltaic Solar Energy Conversion, Osaka, Japan, (2003), pp. 2624–2627.
[6] S.R. Ovshinsky, The material basis of efficiency and stability in amorphous photovoltaics, Solar Energy Materials and Solar Cells 32 (1994) 443–462.
[7] V. Parente, J. Goldemberg, R. Zilles, Comments on experience curves for PV modules, Progress in Photovoltaics Research and Applications 10 (2002) 571–574.
[8] R. Rüther, Experiences and operational results of the first grid-connected, building-integrated, thin-film photovoltaic installation in Brazil, in: Proceedings of the Second World Conference on Photovoltaic Solar Energy Conversion, Vienna, Austria, (1998), pp. 2655–2658.
[9] R. Rüther, M.M. Dacoregio, Performance assessment of a 2 kWp grid-connected, building-integrated, amorphous silicon photovoltaic installation in Brazil, Progress in Photovoltaics: Research and Applications 8 (2000) 257–266.
[10] R. Rüther, M.M. Dacoregio, I. Salamoni, P. Knob, U. Bussemas, Performance of the first grid-connected BIPV installation in Brazil over eight years of continuous operation, in: Proceedings of the 21st European Photovoltaic Solar Energy Conference, Dresden, Germany, (2006), pp. 2761–2764.
[11] L.L. Garver, Effective load carrying capability of generating units, IEEE Transaction on Power Apparatus and Systems 85 (1966) 910–919.
[12] R. Perez, W. Berkheiser III, R. Stewart, Analysis of Licoln Center experimental data for investigation of photovoltaic peak load matching potential, Report ASRC 1281 to the New York Power Authority, Determination of photovoltaic effective capacity for New Jersey, 1989, pp. 1–29
[13] R. Perez, R. Seals, C. Herig, Photovoltaics can add capacity to the utility grid. Golden, CO, NREL, Brochure DOE/GO-10096-262, 1997, pp. 1–4.
[14] R. Perez, T. Hoff, C. Herig, J. Shah, Maximizing PV peak shaving with solar load control validation of a web-based economic evalution tool, Solar Energy 74 (2003) 409–415.
[15] C.S. Jardim, P. Knob, R. Rüther, Study of photovoltaic potential in urban areas with daytime load peaks, in: Proceedings of the 20th Conference on Passive and Low Energy Architecture—PLEA 2003, Santiago, Chile, (2003), pp. 1–6.
[16] I. Salamoni, Metodologia para Cálculo de Geração Fotovoltaica em Áreas Urbanas, Aplicada a Florianópolis e Belo Horizonte, Master Thesis, Programa de Pós Graduação em Engenharia Civil, Universidade Federal de Santa Catarina, Florianópolis, Brazil, 2004, pp. 1–140.
[17] R.O. Mueller, B.K. Cha, R.F. Giese, C. Maslowski, Residential solar-photovoltaic power systems: the need for battery storage, in: Proceedings of the International Symposia on Alternative Energy Sources and Technology, Montreal, Canada, (1980), pp. 1–10.
[18] M.A. Khallat, S. Rahman, A model for capacity credit evaluation of grid-connected photovoltaic systems with fuel cell support, IEEE Transactions on Power Systems 3 (1988) 1270–1276.
[19] A. Faaborg, Impacts of power penetration from photovoltaic power systems in distribution networks, IEA Task V Report IEA-PVPS T5-10:2002, 2002, pp. 1–24.
[20] M. Ordenes, D.L. Marinoski, P. Braun, R. Rüther, The impact of building-integrated photovoltaics on the energy demand of multi-family dwelling in Brazil, Energy and Buildings 39 (2007) 629–642.
[21] R. Rüther, H.G. Beyer, A.A. Montenegro, M.M. Dacoregio, I.T. Salamoni, P. Knob, Performance results of the first grid-connected, thin-film pv installation in Brazil: high performance ratios over six years of continuous operation, in: Proceedings of the 19th European Photovoltaic Solar Energy Conference, Paris, France, (2004), pp. 1487–1490.
[22] S. Nann, K. Emery, Spectral effects on PV—device rating, Solar Energy Materials & Solar Cells 27 (1992) 189–216.
[23] SANYO, Sanyo Solar Ark. http://www.sanyo.com/industrial/solar.