EVALUATION OF THE PERFORMANCE OF FAÇADE MOUNTED PHOTOVOLTAIC MODULES. DO WE NEED A SENSOR WHEN WE HAVE SATELLITE DERIVED IRRADIANCE?

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ABSTRACT: A Building Integrated façade PV system is studied and the performance of a 8 months period of operation is reported. An alternative method based on satellite data for reference values of insolation is described together with an analysis of the reliability and the downsides of the method. The plant presents the interesting characteristics of being composed by two façades at a 90^o degrees angle facing SE and SW direction.
The performance analysis requires a translation of the Global Horizontal Irradiation (GHI) data computed from the Meteosat Second Generation satellite to Global Tilted Irradiance (GTI) data at 90^o degrees and at two different azimuthal angles. The reliability of the method is discussed comparing provided GHI data with values measured by a pyranometer. The energy production from modules at different orientation is analysed and the results are critically compared with other PV plants configurations for a better understanding of BIPV façade systems.
An intermittency parameter is also provided which could prove useful for planning of BIPV systems and to compare performance of plants based on different renewable energy sources.
Keywords: BIPV, c-Si, Façade, Shading, Satellite solar radiation

1 INTRODUCTION

For a precise monitoring of a PV plant performance, reference systems for the measurement of incoming irradiation are needed and this is achieved through the use of either high quality spectrally matched reference cells or pyranometers. The use of hardware reference system is not always possible due to unavailability (eg: backdated monitoring of existing plants), planning flaws (eg: shaded position) or monitoring system malfunction (eg: flaws in maintenance and clean-ups, logger malfunction, lightning). In these cases an alternative method is required to gain information about incoming insolation and thus calculate performance ratios. In this paper we have used irradiation calculated from Meteosat Second Generation imagery and atmospheric parameters and data translation algorithm to obtain tilted irradiation at an angle of 90^o of a façade system corrected for shading for the calculation of the performance ratio (PR).

2 DESCRIPTION

The studied system is integrated in an office building ("Ex-Poste") situated in the city-centre of Bolzano, Italy. The two sides of the building exposed towards South (respectively SE and SW) are almost entirely covered by the modules with a total area of 212.5 m^2. Modules technology is crystalline silicon and the nominal power of the plant is 26.7 kWp. The system installed on the façade is divided into 5 strings (3 with P_n = 5.28 kW and 2 with P_n = 5.445 kW) with inverter 1 connected to modules on the SE façade, inverter 2 to modules facing both directions and inverter 3,4 and 5 to modules on the SW façade.
The façade is smooth and vertical, hence module tilt is 90° (with respect to the horizontal plane). A reference cell and a PT100 sensor were installed to measure irradiance and back of module temperature but data were acquired only for a limited period due to an electrical fault. An alternative method to provide values of irradiance was therefore sought and applied in this work.
All values presented in this work are related to the AC side. Solar radiation comes from SolarGIS database and is calculated from Meteosat MSG satellite data covering a period from 2004 to date [1]. The primary parameters are calculated at full satellite resolution (approx.. 4x5 km at mid-latitudes) and include global horizontal (GHI) and direct normal irradiance (DNI) calculated every 15 minutes. The new model is based on the principles of Helioclim-2 calculation scheme and operational model [2]. The advancements of the model [3] improved results in mountains, coastal and arid zones, and for periods with snow coverage. IEA SHC Task 36 and MESOR recommendations were used for data validation using over 70 validation sites for GHI measurements and approximately 40 sites for DNI measurements [4]. Derived solar parameters can be calculated at a spatial resolution up to 80 meters using new disaggregation method and Digital Elevation Model SRTM-3. The derived GTI is calculated using Perez transformation formula [4,5,6]. However, in this study shading correction was applied using measured on site shading diagrams.
In this paper we present an alternative method for reference values of irradiance (from satellite) to be combined with PV power plants where hardware reference systems are not available. The reliability of the data is analysed and the performance of the PV system mounted on the building façade is discussed.

4 DISCUSSION

To evaluate the reliability of the data, the global horizontal irradiation (GHI) from SolarGIS data was compared with values read by a secondary-standard pyranometer (Kipp and Zonen, CMP11, recently calibrated) situated at a few km distance at the Airport Bolzano-Dolomiti (ABD) plant also monitored by EURAC [7]. Fig. 1 shows the ratio between measured monthly insolation and values from SolarGIS database. Although the latter has a different spatial resolution in comparison to point measurements which can result in

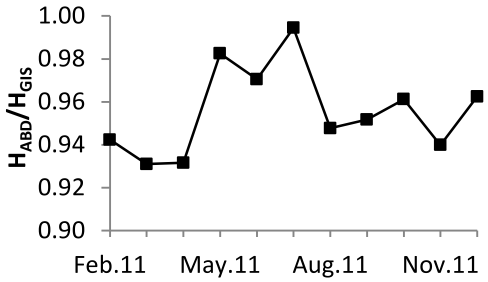

Figure 1: Ratio between monthly measured GHI at ABD site and satellite derived GHI

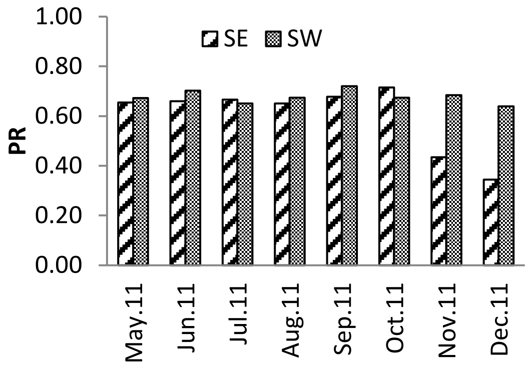

Figure 2: Performance Ratio of the façade system along SE and SW orientation (no shading correction)

higher uncertainty in such highly complicated mountain landscape, a general satisfactory agreement is seen with ratio close to unity in summer probably due to less haze, pollution and shading effects.

The corresponding Global Tilted Irradiance (GTI) at 90° was then used to calculate the performance ratio PR of the plant differentiating also in azimuthal angle depending on the façade orientation (Fig 2). The performance ratio is defined by the international standard IEC 61724 [8] as the final energy yield of a PV system, $Y_{f,}$ divided by the reference yield Y_r, the latter being the ratio of the in-plane global insolation H and the irradiance under STC (G = 1 kW/m^2). It has to be stressed at this point that no temperature correction has been applied and this will be subject of further studies.

In Fig. 2, PR from inverter 1 (SE) and inverter 5 (SW) were chosen. PR values are between 0.6-0.7 which is typical of façade systems [9] due to high losses in temperature and reflectance [10]. Fig 2 points out some problems in the months of November and December with a dramatically reduced value of PR in the SE direction: this could be either due to the inaccuracy of the used method during the mentioned period or to some failures in the production of energy. To better understand the behaviour it is necessary to check the output from the inverters individually. Table 1 summarises the production of energy for the inverters during the studied period.

From Table 1 it becomes clear that the energy produced by the modules under inverter 1 underperform compared to inverter 5 during the last two months of the year: this is due to shading from the mountains in the vicinity in the east direction with a tremendous effect on the electricity produced. Considering an average PR value of 0,66, the energy lost due to shading can be estimated to a value of about 250 kWh only on inverter 1 during winter months. Figure 3 show the normalised production and satellite derived irradiance during a

Table 1: Monthly final yield for inverter 1 and 5 (SE and SW orientation respectively)

	Monthly Final Yield [kWh/kW$_p$]		
Month	SE Inverter 1	SW Inverter 5	% Diff
May 2011	76,37	72,74	4,99
Jun 2011	55,64	57,02	-2,42
Jul 2011	71,79	64,54	11,25
Aug 2011	79,55	79,97	-0,52
Sep 2011	74,21	79,58	-6,75
Oct 2011	84,82	74,99	13,10
Nov 2011	42,37	58,13	-27,12
Dec 2011	21,20	35,42	-40,15

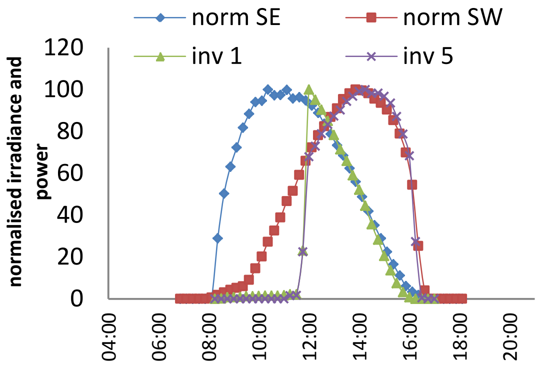

Figure 3: Daily profile on 11-01-2012 of normalised production (inv 1, inv 5) and irradiance (norm SE, norm SW)

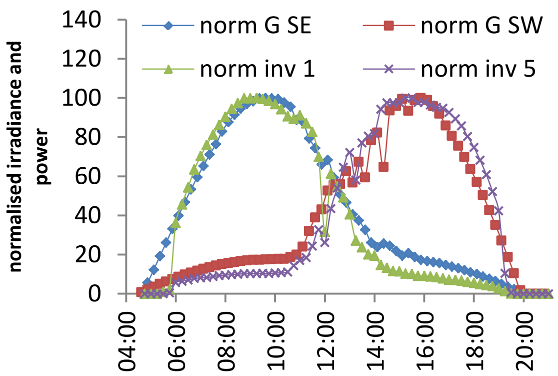

Figure 4: Daily profile on 19-06-2011 of normalised production (norm inv1, norm inv5) and irradiance (norm G SE, norm G SW)

winter day pointing out the effects of mountain shading in the morning; this particularly affects the modules under inverter 1. Figure 4 shows the normalised production and satellite derived irradiance in a summer day; the agreement is extremely satisfactory.

The low PR values for November and December in direction SE is then due to a derived high value of insolation from GIS data during that period where the correction for mountain shading needs to be considered. Fig. 5 shows the normalised GTI satellite derived irradiance after correction for shading using a measured shading diagram. The benefit of the correction is clearly visible with good correlation between irradiance and production (see Fig 3 and Fig 5).

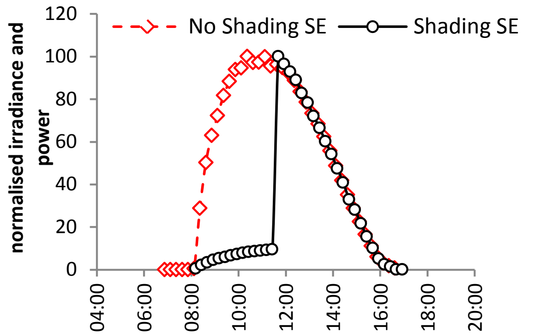

Figure 5: GTI satellite derived irradiance without (red line, squares) and with shading (black line, circles) (direction SE)

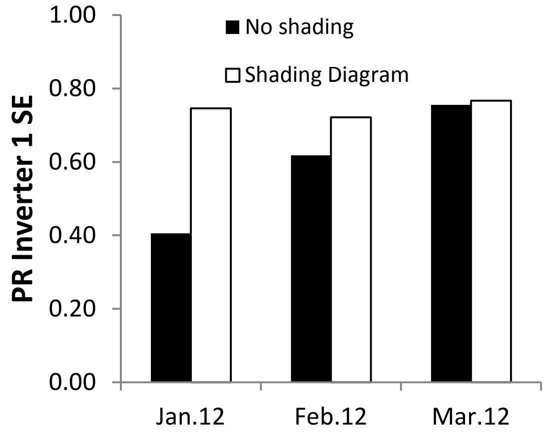

Figure 6: Performance Ratio with GTI without shading (black), with shading from shading diagram (white)

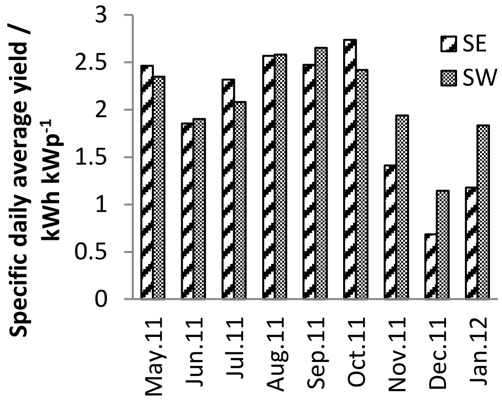

Figure 7: Daily average specific yield

Fig. 6 shows the PR for the modules under inverter 1 (direction SE) using satellite derived irradiance with and without shading correction. PR from shading corrected values is always slightly larger than the PR from not corrected values: this is due to lower irradiance in presence of shading. The shading diagram was measured directly on site and includes shading also from near objects.

Fig 7 shows the daily average specific yield, Y_d, (based on the real number of days when data is available) which gives the equivalent number of hours per day the plant would work at nominal power. During summer months, this value is more than halved compared to plants at optimal tilted angles where values around 6 hours are

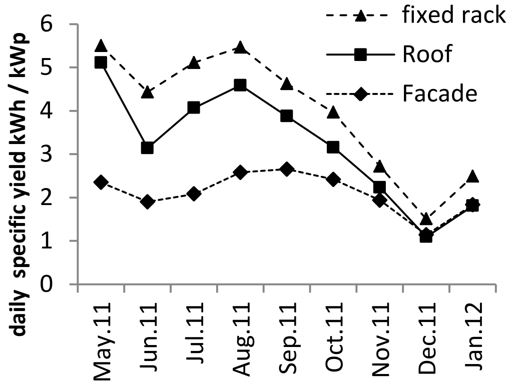

Figure 8: Daily average specific yield for c-Si in three different installation types: fixed rack, roof integrated and facade

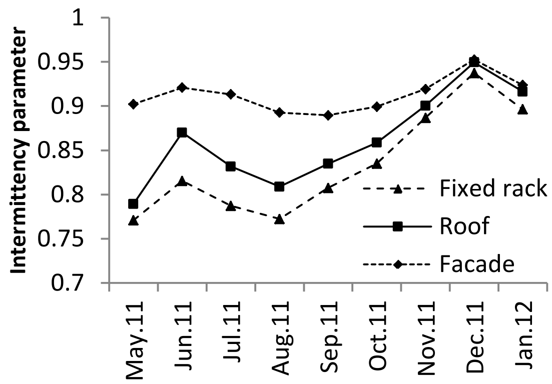

Figure 9: Intermittency parameter for three different installations at similar latitude

observed at this altitude. Fig. 7 also shows the problems with shading during winter months with large production losses. The specific daily average yield shown in Fig 7 can also be used to compare equivalent working hours at P_n with other installation types (all c-Si). Fig 8 shows the comparison with a fixed rack installation (30^o tilt angle, 188.5^o azimuth angle) installed at the Airport Bolzano Dolomiti [7] and with a roof integrated system (34^o tilt angle, 203.5^o azimuth angle) [11]. Y_d is lower compared to both systems due to the high angle of incidence, working temperatures, reflectance etc.

The yearly energy production for the 12 months period May 2011-Apr 2012 exceeds 600 kWh/kWp for all fivee inverters and specifically 772 kWh/kW$_p$, 650 kWh/kW$_p$, 724 kWh/kWp, 785 kWh/kWp and 795 kWh/kWp for inverter 1,2,3,4 and 5 respectively. This compares with Y_a=1475 kWh/kW$_p$ for a pc-Si installed at ABD Airport on a fixed rack system (30^o tilt angle) and Y_a=1250 kWh/kW$_p$ for the roof integrated system (34^o). From the values for the façade, the influence of shading is evident where modules under inverter 1,4 and 5 are less affected being installed at higher levels. At this alpine latitude the equivalent working hours of the plant during summer months is halved compared to fixed rack. This difference is less during winter due to a higher incident angle of the sun.

In this study we have also investigated the availability in time of the produced energy using a monthly intermittency parameter where 1 is zero production and 0 would correspond to 24 hours a day at nominal power. $IP = 1 - \frac{E}{24 \cdot d \cdot P_n}$, where E is the energy produced, d is the number of days and P_n the nominal power. Such a parameter could be used to compare different renewable energy sources which all suffer from intermittency problems. Fig 9 shows the comparison where the data for the façade are for the modules under inverter 5. Fig. 9 shows IP for the three installations described above: the working time for the plants are in the range of 5-10%, 5-20% and 7-23% for the façade, roof and fixed rack installations, respectively.

CONCLUSIONS

A façade system with a faulty reference cell has been studied using satellite data for reference values of insolation. The obtained results are critically discussed and the effects of shading due to mountains and near object evaluated. The solar radiation data derived from meteorological satellites is a good candidate as a source of solar data characterised by in spatial and temporal uniformity, maintenance free from client side and very high data availability. Comparison with high quality ground meteorological stations can improve the understanding of specific features of such data. The reliability of derived satellite data was proved with GHI values within 2% of GHI measured with a calibrated pyranometer during summer where shading effects are negligible.

Although the specific energy yield of a system mounted on a façade is more than halved compared to optimal angle tilted systems in summer, this difference is considerably reduced in winter. Furthermore, if energy per covered horizontal area is considered, systems mounted on façades show very high potential for energy production in buildings.

A comparison in terms of Y_d and *IP* was also given. The trend is similar for the three installations situated in the same geographic area; the façade installation presents a maximum in September with 2.5 kWh/kW$_p$/day and IP = 0.89 and a minimum in December with 1.1 kWh/kW$_p$/day and IP = 0.95. As expected, shading become more important during winter due to the low sun elevation behind the surrounding mountains.

Acknowledgment

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