ANALYSIS OF ELECTRIC ENERGY SELF-CONSUMPTION MAXIMISATION FOR TWO DIFFERENT GRID-CONNECTED BIPV SYSTEMS

Ludwig Kronthaler[1,2*], Giorgio Belluardo[1], Francesca Roberti[1,2], Walter Bresciani[1], David Moser[1]
[1] Institute for Renewable Energy, EURAC Research, Viale Druso 1, 39100 Bolzano (BZ), Italy
[2] Faculty of Science and Technology, Free University of Bolzano, Piazza Università 5, 39100 Bolzano (BZ), Italy
[*] Phone: +39 0471 055628; Fax: +39 0471 055699; E-mail: ludwig.kronthaler@eurac.edu

ABSTRACT: The majority of photovoltaic (PV) systems installed in Europe is connected to the grid. Next to technical issues, such as grid saturation or dimensioning effects, a decrease of feed-in tariffs puts the concept of feeding and drawing electric energy into/from the grid into question. The storage of produced electric energy and its subsequent usage onsite could - under certain circumstances - become a feasible solution for both existing and future installations. In some countries, feed-in tariffs already award self-consumption and dedicated incentives are at the moment under discussion.

The aim of this study is to find out and understand the conditions thereof, based on the monitoring data of two different building-integrated PV (BIPV) plants: one roof-integrated (Milland Church in Brixen-Bressanone, Italy) and one façade-integrated system (Ex-Poste building in Bozen-Bolzano, Italy). The balancing of electric energy production and consumption of the buildings is presented on a monthly and hourly basis respectively, including self-consumption rate and load duration curves. Different scenarios for the maximization of the self-consumption of PV generated electric energy are analyzed.

Keywords: Building Integrated PV (BIPV), Storage, Self-Consumption

1 INTRODUCTION

The photovoltaic (PV) energy sector grew rapidly in the past years. In Europe, this is not least due to generous incentives for PV system operators, typically based on subsidized energy feed-in tariffs and plans which reward the maximization of production. As a matter of fact, the majority of PV systems installed in Europe so far is connected to the grid [1]. Against the background of decreasing feeding tariffs, however, the concept of feeding and drawing electric energy into/from the grid has to be reconsidered from an economic point of view. An on-site storage of produced electric energy and its subsequent usage at the production site could - under certain circumstances - become a feasible solution for both existing and future installations. The aim of this study is to find out and understand the conditions thereof.

This study provides useful information for planners, installers, operators and energy advisers, showing theoretical approaches applied to real case studies to increase the amount of self-consumed electric energy from a PV system, using storage systems (batteries, hydrogen storage) and smart grid solutions. The analysis of the two different BIPV systems in this study offers two different vantage points for a theoretical optimization of the electric energy self-consumption of a building system.

2 APPROACH

The study is based on the monitoring data of two different building-integrated PV (BIPV) systems, one roof-integrated and one façade-integrated, described as follows. PV performance as well as shading and air gap analyses have been investigated in previous studies, cf. [2]–[5].

2.1 Roof-integrated PV system: Milland Church

The 19 kWp BIPV system of the Milland Church (Figure 1) in Brixen-Bressanone, Italy, holds 87 mono-crystalline modules. They are connected to the inverters in arrays of 3x3 strings (two arrays with 3x9 modules, one array with 3x11 modules). The PV system is integrated in a 34° tilted roof, 203.5° azimuth. The system was put into operation in October 2008 [2]. Since then, the total daily electric energy output of the PV installation was measured by the three inverters with a frequency of one day (eventually increasing to 15 minutes after a software upgrade in August 2011). The data for electricity consumption is taken from the electricity bills of the energy provider, i.e. from meter readings at routine intervals. Based on this data, the analysis for the Milland Church is done on a monthly basis for a 2 years period, from October 2010 to September 2012.

Figure 1: Roof-integrated PV system, Milland Church

2.2 Façade-integrated PV system: Ex-Poste building

The 26.7 kWp façade-integrated BIPV system of the “Ex-Poste” office building (Figure 2) comprises 162 polycrystalline PV modules, which are mounted on two sides of the building (South-East and South-West oriented). The modules are divided into 5 arrays (3x32 modules and 2x33 modules). The system was installed in the course of the building’s refurbishment in 2006. The electrical performance of the PV installation is measured by the inverters with a frequency of 15 minutes, whereas the total energy consumption is recorded by a dedicated monitoring system in hourly intervals [6], [7]. For this part of the study, an 11 month period (June 2011 to April 2012) of monitoring data was considered.

Figure 2: Façade-integrated PV, Ex-Poste building

3 RESULTS & DISCUSSION

3.1 Roof-integrated PV system: Milland Church

In the case of the Milland Church, the electric energy production and consumption (Figure 3) as well as the energy balance (Figure 4) shows a distinct summer-winter performance behaviour.

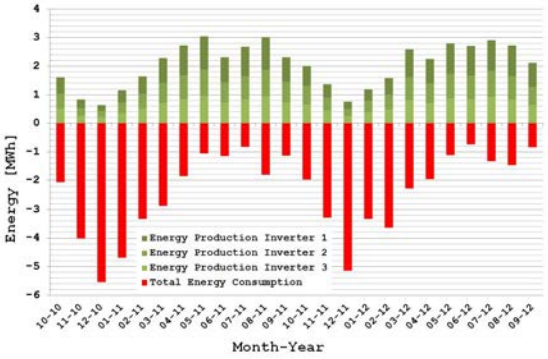

Figure 3: Monthly electric energy production (from inverters 1 to 3) and total energy demand, Milland Church, October 2010 to September 2012

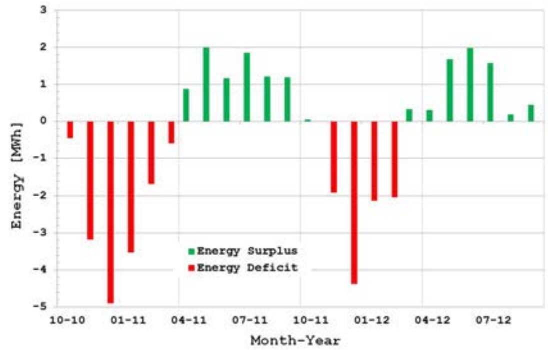

Figure 4: Monthly electric energy balance: surpluses and deficits of electric energy production, Milland Church, October 2010 to September 2012

The PV production in combination with a relatively low energy demand allows for a fair surplus from March/April to September/ October. On the other hand, a reasonable electric energy deficit occurs during the winter months, due to a low PV production and high energy demand – explicitly high in December, most likely due to a high number of ceremony days in this month.

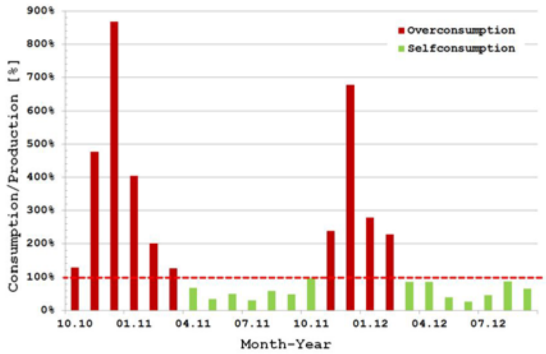

Figure 5: Monthly consumption over PV production ratio, consumption higher than PV-production (red) and consumption covered by PV-production (green), Milland Church, October 2010 to September 2012

Whereas the theoretical monthly self-consumption rate (i.e. the ratio of self-consumed electric energy to total PV produced electric energy) varies from 27% to 97.5% within the overproduction periods, the consumption within the peak months is up to 8 times higher than electric energy production in the winter months (Figure 5). In average, during the winter periods the electric energy consumption is about 3.5 times higher than the production.

Table I: Seasonal electric energy production and consumption, energy balance and potential storage (long-term hydrogen storage with an efficiency of 40%), Milland Church, October 2010 to September 2012

Electric Energy	Winter 2010-11	Summer 2011	Winter 2011-12	Summer 2012
Production [MWh]	8,2	18,1	4,9	16,2
Consumption [MWh]	22,5	9,8	15,4	9,7
Balance [MWh]	-14,3	+8,3	-10,5	+6,5
Storage Potential* [MWh]	-	3,3	-	2,6

*40% total electric energy conversion efficiency assumed

Table I shows a seasonal summary of the total electric energy production and consumption of the Milland Church. It includes the theoretical electric energy storage potential (the electric energy that theoretically can be stored during overproduction and used later on in times of deficits), considering a long term storage solution with a storage and an overall electric energy conversion efficiency of 40%, which is an assumed value for hydrogen storage systems, cf. e.g. [8]. Thus, storing the overproduced electric energy in summer could theoretically deliver up to 20% of the winter demand.

Such a long-term storage solution could improve the electric energy self-consumption as seen in Table II. In winter 2011-12, for instance, the demand-production rate could have been reduced by 40% with stored electrical energy from summer 2011.

Table II: Seasonal electric energy consumption over production rates, comparison with and without storage (long-term hydrogen storage with an efficiency of 40%), Milland Church, October 2010 to September 2012

Demand-production ratio*	Winter 2010-11	Summer 2011	Winter 2011-12	Summer 2012
No storage	275%	54%	313%	60%
With storage	184%**	100%	187%	100%

* ratio electric energy demand to total PV produced electric energy

** calculated with data available for summer 2010, which were not taken into account for the analysis in this study

3.2 Façade-integrated PV system: Ex-Poste building

The PV installation of the Ex-Poste building cannot meet the building's electric energy demand in any season of the considered time period (Figure 6). The monthly electric energy consumption is between 4.5 to 12 times higher than the PV production at the same time.

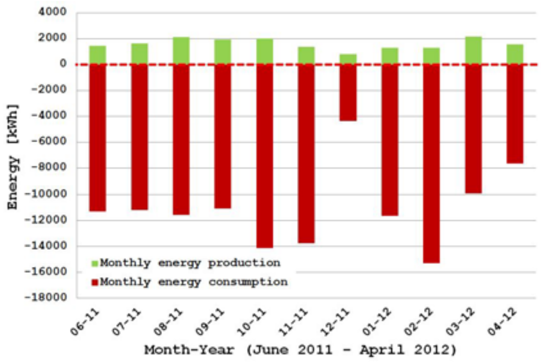

Figure 6: Monthly electric energy balance: PV production versus electric energy consumption, Ex-Poste building, June 2011 to April 2012.

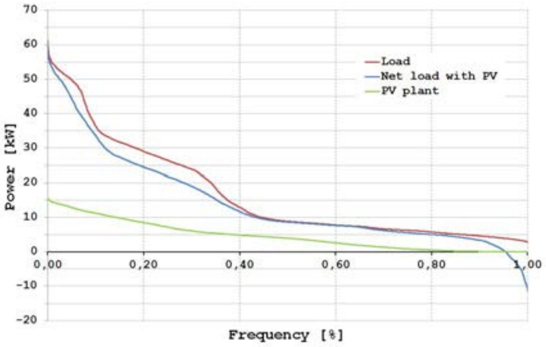

Figure 7: Electric load duration curve (with and without PV contribution) and PV power output duration curve, Ex-Poste building, June 2011 to April 2012.

Figure 7 shows the duration curve of all the building electric loads for the period June 2011 to April 2012. The peak load of about 60 kW is reached during winter time. The net load considering the contribution of the PV plant is also represented. It is evident that the PV plant reduces the building load during high electric energy demand (more than 20kW) of up to 20%, while it makes no appreciable impact on loads between 5 and 10 kW. The latter is most likely due to the fact, that this range of energy demand occurs overnight, i.e. at times when the PV production is zero. Another contribution by the PV plant is given at lower demands. In particular, for 5% of time an electric energy overproduction occurs. The overall electric energy surplus that can theoretically be re-used through the optimization of a self-consumption system amounts to 1375 kWh during the considered period. An overproduction scenario like this could be supported with a short-term battery storage solution.

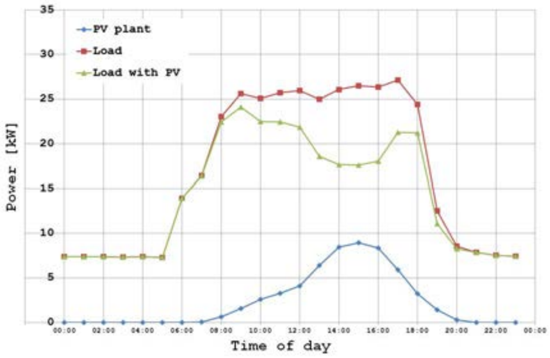

Figure 8: Average hourly load and PV production, Ex-Poste building, averaged for June 2011 to April 2012

Figure 8 shows the effect of the PV production on the building load over the time of the day, averaged over the considered period June 2011 to April 2012. In average, the PV system contributes up to 34% to the building total electrical energy demand at peak production after noon.

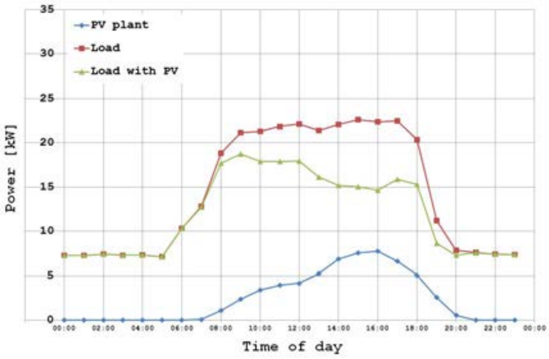

Figure 9: Average hourly load and PV production in summer, Ex-Poste building, averaged for June – September 2011 and April 2012

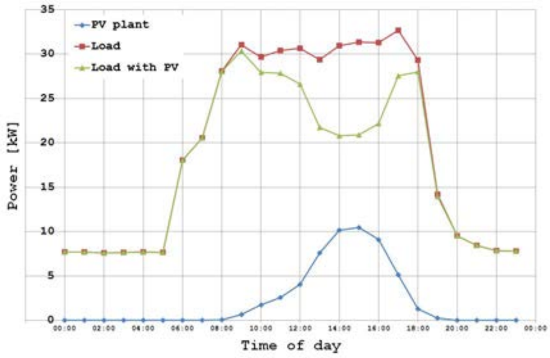

Figure 10: Average hourly load and PV production in winter, Ex-Poste building, averaged for October 2011 – March 2012

Figure 9 and Figure 10 show the difference of the average hourly load and PV production between summer and winter period. Although the average electric energy demand (load) is higher in winter compared to summer, the ratio of the PV contribution over the total load is almost the same for both seasons: in winter it reaches up to 33%, in summer up to 35%. This can be explained with the fact that the façade-integrated (90° angle of installation) PV system has a higher average peak power in winter compared to summer, because of the lower angle of incidence of the sunlight on the PV array.

3.3 Combination Milland Church – Ex-Poste building

One of the possible electric energy distribution scenarios considers geographical proximity of the Ex-Poste building and the Milland Church (or any other PV plant close by respectively).

Figure 11 shows the theoretical electrical connection of the two sites for the period June 2011 to April 2012. With the Milland Church's electric energy overproduction used to cover the electrical loads of the Ex-Poste building, a theoretical improvement of up to 20% can be seen during the summer months. As the energy balance of Milland Church in winter is negative itself, there also cannot be any improvements in the combination with the Ex-Poste system during winter.

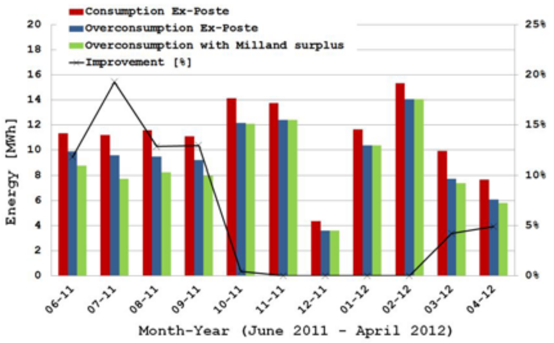

Figure 11: Monthly electric energy balance: Ex-Poste combined with Milland Church, June 2011 to April 2012

4 CONCLUSION

As expected, the results of the Milland Church's electric energy balance show that in summer the PV system easily produces enough electric energy to make up for the church's consumption. The self-consumption rate with 56% for summer 2011 and 63% for summer 2012 respectively is not at the best possible rate. In winter it is the other way around – a high energy demand and low PV production lead to overconsumption with self-consumption rates of some 300%. Overall, an optimization of the self-consumption rate could be realized by using a long-term storage system. Thus, the self-consumption rate of the summer season could be brought up to 100%, while decreasing the rate up to 40% in winter. Such a system could consist of an electrolyzer (generating hydrogen with over-produced PV energy), a hydrogen storage tank and a fuel cell (to convert the hydrogen back into electric energy).

The energy balance of the Ex-Poste building shows typical results for a business building – high electric energy demands during office hours and a constant base load overnight. The BiPV system contributes its part to the demand, but can rarely make up for it completely. The Ex-Poste building self-consumption can only be improved by storing the overproduced electrical energy in these seldom moments. For such kind of short-term storage solutions, a battery system could be used.

The theoretical combination of both Milland church and the Ex-Poste building represents an electric energy distribution scenario without any storage systems involved. During summer, the excess electric energy of Milland Church could be used directly for the demand of the Ex-Poste building, which would be reduced up to 20%. This way, no conversion and storage losses would occur and the only losses involved would be transmission losses between the two buildings.

5 ACKNOWLEDGEMENTS

The Authors would like to thank the European Regional Development Fund (ERDF) for co-financing the PV Initiative project (Bolzano Province 1a-2009).

6 REFERENCES

[1] J. Montgomery, 'Europe's 2011-2012 PV Installs: Two Tales of Growth', Renewable Energy World, 01-Feb-2012. [Online]. Available: http://www.renewableenergyworld.com/rea/news/article/2012/02/europes-2011-2012-pv-installs-two-tales-of-growth. [Accessed: 14-Dec-2012].

[2] L. Maturi, M. Armani, W. Bresciani, M. Del Buono, and W. Sparber, 'PV roof integration, a case study in northern Italy: how modules arrangement influences the PV performance', presented at the 24th PVSEC, Hamburg, 2009, pp. 4256 – 4258.

[3] D. Moser, W. Bresciani, M. Nikolaeva-Dimitrova, and L. Maturi, 'EuroSun 2012 – 6 Months Monitoring of Roof Integrated Modules and Performance Comparison in Different Installation Types', presented at the EuroSun, Rijeka, 2012.

[4] L. Maturi, W. Sparber, B. Kofler, and W. Bresciani, 'Analysis and monitoring results of a BIPV system in northern Italy'.

[5] D. Moser, M. M. Nikolaeva-Dimitrova, A. Skoczek, and T. Cebecauer, 'Evaluation of the performance of facade mounted photovoltaic modules - Do we need a sensor when we have satellite derived irradiance', presented at the 27th European Photovoltaic Solar Energy Conference and Exhibition, Frankfurt, 2012.

[6] A. Troi, M. Tribus, A. Costa, W. Haberer, D. Parisi, and W. Sparber, 'Energetic refurbishment and architectural valorisation: the ex-post building in Bozen/Italy', presented at the Ökosan, Weiz, 2009.

[7] A. Troi, M. Tribus, A. Costa, W. Haberer, D. Parisi, and W. Sparber, 'Towards Zero Energy Renovation: Ex-Post Building in Bolzano/Italy', presented at the 25th International Conference on Passive and Low Energy Architecture, Dublin, 2008.

[8] R. E. Clarke, S. Giddey, F. T. Ciacchi, S. P. S. Badwal, B. Paul, and J. Andrews, 'Direct coupling of an electrolyser to a solar PV system for generating hydrogen', International Journal of Hydrogen Energy, vol. 34, no. 6, pp. 2531–2542, Mar. 2009.