Original scientific paper

UDK 621.383.51:621.316.925(497.11)
DOI 10.7251/COMEN2501024M

# POSSIBILITY OF PRODUCING PHOTOVOLTAIC ELECTRICITY ON BALCONY FENCE IN PIROT, SERBIA

Ivana Radonjić Mitić[1*], Milutin Petronijević[2], Leonid Stoimenov[2], Dragoljub Mirjanić[3], Lana Pantić[1], Darko Divnić[3]

[1] University of Niš, Faculty of Sciences and Mathematics, Department of Physics, Niš, Serbia
[2] University of Niš, Faculty of Electronic Engineering, Niš, Serbia
[3] Academy of Sciences and Arts of the Republic of Srpska, Banja Luka, Republic of Srpska, B&H

[*] Corresponding author: ivana.radonjic-mitic@pmf.edu.rs

**Abstract:** In urban environments, PV panels are usually affixed on available buildings, but they can also be included in the initial architectural design of the constructions. PV panels mounting on/as balcony fences become frequent solution for creating PV systems in buildings. The idea of decentralized production and storage of electricity very close to the point of use represents an additional benefit. In this paper, the possibility of using PV panels in urban conditions, within the home installations of individual residential consumers with the placing of panels on the balcony fence, is analyzed. A detailed simulation of the complete PV system in the PVSYST software was used for the analysis of different mounting options for PV panels on the balcony fence. For an individual consumer from the "Household type 3" category with an annual consumption of about 6000 kWh, the installation of PV panels with a total power of 1650 Wp was analyzed. Different variants of installation of PV panels were simulated for the case of two different tilt angles ($0^o$ (vertical position) and $60^o$) and three different azimuthal orientations (south, east and west). Self-consumption is modeled through typical daily profiles, taking into account seasonal variation for a given type of consumer. The obtained results show that in the investigated PV system, photovoltaic energy can cover from 15.84% to 29.48% of considered household's self-consumption, depending on the tilt angle of the PV panels on the balcony fence and their azimuthal orientation.

**Keywords:** PV panel, balcony fence, electricity production, electricity consumption, household.

## 1. INTRODUCTION

In the era of energy transition, photovoltaic (PV) systems play an important role [1], not only for being sustainable and producing renewable energy, but also for decreasing prices while grid electricity prices are increasing. Therefore, the role of prosumers in the energy market is increasing [2].

Possibilities for simple and economical installation of PV systems are considered to achieve efficient and sustainable electricity production at the point of its consumption. Such solutions can be accomplished with building-applied photovoltaics (BAPV) where PV panels are attached to rooftops and facades of existing buildings, and also with building-integrated photovoltaics (BIPV) where PV panels incorporation in construction is planned in advance [3].

BIPV systems and one of its installation types such as balcony PV systems can increase energy efficiency of the building and decrease air conditioning use [4]. In this way, the transition to sustainable buildings is facilitated and the effects of climate change are mitigated. For wider utilization, several challenges have to be solved, such as PV systems adjustment to specific local climate and environmental conditions [5]. For tenants and apartment owners in buildings, the possibility for active involvement in the energy transition has started recently by mounting balcony photovoltaic systems [6].

The balcony is not only an additional quality space for the apartment usually highly exposed to solar radiation, but also a possibility for mounting PV systems and electricity production [7]. PV systems mounted on the balcony fences are to some extent new in Serbia but have a lot of potential and their share is growing. This kind of system can be also called plug-in PV or mini solar power systems, and refers not only to balcony PV systems, but also to systems assembled of a few PV panels mounted on rooftops, facades, in the garden, etc. [1].

The main contribution of this paper is a detailed, comprehensive analysis of the possibility of using a simple and affordable PV power supply with panels mounted on the balcony on the example of an individual consumer from the household category in the city of Pirot, Serbia. According to the author's knowledge, such analyzes have not been carried out in detail for settlements on the territory of Serbia, taking into account typical diagrams of daily consumption and for cases of different technical solutions for mounting PV panels and inverter systems. In some EU countries, the installation procedure of such plug-in PV systems is very simplified, with the introduction of restrictions on the maximum installed power. The set restrictions regarding the installed power should prevent excessive variable production, i.e. promote the basic idea of producing electricity for own consumption. Using the examples of different household consumption values in Serbia, this hypothesis was analyzed and the justification of introducing different values of the maximum power of the PV installation was critically assessed. Different technical solutions of the converting part of the PV installation, including small battery energy storages, were also analyzed.

This paper is organized as follows. After the Introduction, the second chapter provides an overview of PV systems using PV panels mounted on balconies. In the third chapter, a specific case study is presented on the example of an individual consumer from the household category. The main results and their discussion are given in the fourth chapter, while the corresponding conclusion is given at the end.

## 2. OVERVIEW OF PLUG-IN PV SYSTEMS

It is not easy to make a literature review concerning balcony PV systems since various terms are used. Also, balcony PV systems do not only refer to the PV panels mounted on balcony fences. Therefore, uniform terminology should be established [2]. Installations of PV systems on balcony fences (using balustrade or parapets) are expanding in many countries, especially in buildings where apartments represent a great number of dwellings. Having in mind benefits of these kind of systems such as contribution to sustainability of cities, PV installations in balconies have been promoted by some governments. Balcony capacity for photovoltaic electricity production mostly depends on the azimuthal orientation of the balcony and PV panels tilt angle, whereby it is considered that balcony PV systems can usually satisfy up to one third of the annual electricity consumption of the apartment [8].

Placing PV panels on the balcony fence means that they are often in vertical position (tilt angle $90^o$), but their azimuthal orientation can be various. For south-facing vertically mounted PV panels, around 29% less electricity is generated per year compared to panels with $30^o$ tilt angle. Integration of vertically mounted PV systems into the grid is easier compared to horizontally installed PV systems due to lower monthly fluctuation between summer and winter yield [6].

Although the installation of PV panels on balcony fences represents a good solution for electricity production, in this case the PV panels are often not in their optimal position. Also, sometimes during the day they can be temporarily shaded by surrounding objects and trees. Accordingly, the selection of inverter technology is of vital importance for this kind of PV system [9].

One of the most significant factors for calculating the pace of balcony PV system's amortization is the sunshine hours. Other important factors are PV panels tilt angle and azimuthal orientation. Generally, the most electricity is produced with south-oriented PV panels. In certain cases, such as the time of the day when household consumes most of the electricity, or not south-oriented balcony fence, favorable orientation of PV system can be towards the east or west that should be especially taken into account for PV balcony systems without the storage unit. The pace of balcony PV system's amortization also depends on the electricity prices, whereby the profit of the balcony PV system can be calculated by the difference between the grid electricity price and the cost of the PV system. It is obvious that the amortization of balcony PV systems is faster for higher grid electricity price and lower cost of PV system [2].

Like any other, PV systems mounted on the balcony fence consist of PV panels, a DC to AC converter (inverter) and appropriate mechanical and electrical installation equipment. The mechanical installation of PV panels is easy and can be vertical or at a tilt angle α which is usually in the range of 60° to 90° (Figure 1). The small installed power of the PV panels simplifies the connection of the installation to the electrical grid because microinverters are used instead of classic on-grid inverters. These devices combine numerous functions, starting with communication, and ending with appropriate protection and security functions. One of the common names of these PV installations (plug-in PV system) comes from the way these installations are connected to an ordinary household single-phase socket. This simple method of connection can bring with it certain risks that come from the fact that the complete installation and connection can be carried out by users independently, without the need for experts and authorized persons to guarantee the quality and safety of the installations.

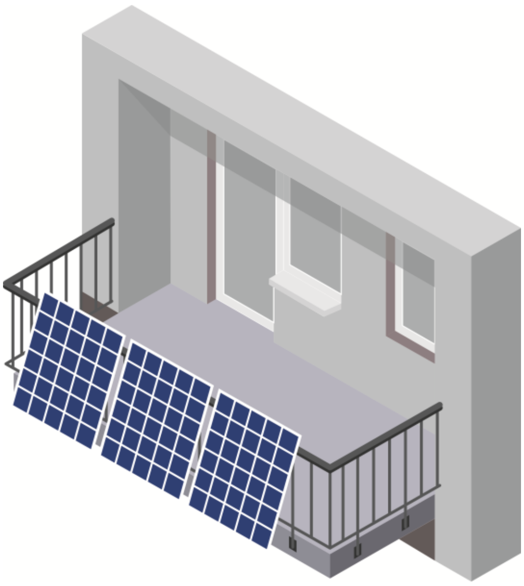

***Figure 1.*** *Example of balcony PV system*

The basic part of balcony PV systems are PV panels that can be of various types. Generally, monocrystalline silicon, polycrystalline silicon, and thin film PV panels are mostly present on the market. In the year 2023, the highest global annual production was with mono-Si technology [10]. Flexible PV panels can be an acceptable solution for curved balcony fences. Bifacial PV panels can absorb incident and albedo radiation from the front and the rear side getting higher power output [11] and represent good solution for balcony PV systems with appropriate balcony fence.

Wide commercial utilization of microinverters started in 2005. However, there are many topologies with advanced technologies and management, which are presented below [12]. A typical solar company microinverter topology is shown in Figure 2. It is a 2-stage system - the first stage is a DC/DC converter to obtain the maximum power point (MPP). Then the output voltage of the DC/DC converter is raised to a higher level by means of a high-frequency transformer. The second stage of the converter is the DC/AC converter, which connects the output voltage to the utility grid. Isolation is achieved by a high-frequency transformer in the DC/DC converter. Some microinverters have the optional possibility of charging the battery storage, which is also shown in Fig. 2. Connecting these small plug-in PV systems to the distribution network (on-grid operation) is easy, via a standard single-phase socket.

Apart from technical solutions for the safe and efficient installation of plug-in PV systems, the biggest influence on the number and wide spread of these systems is the bureaucratic procedures that allow the legal connection of such micro-generators to the electrical grid. In some countries, the procedure for installing micro-generators is very simplified and requires only notifying the Distribution Network Operator (DNO) with basic information about the installation of PV systems with microinverters [14]. In Germany and Austria, apart from formal notifications to the DNO and appropriate consents from neighbors in the case of residential buildings with multiple households, as of this year a new limit was set for restricting the maximum power of microinverters to a value of 800 W. In other European countries, including Serbia, the balcony PV area systems, including plug-in PV systems, are not regulated by appropriate legal norms. With the purpose of additional facilitation of balcony PV systems deployment, further simplification of grid connection provisions is expected,

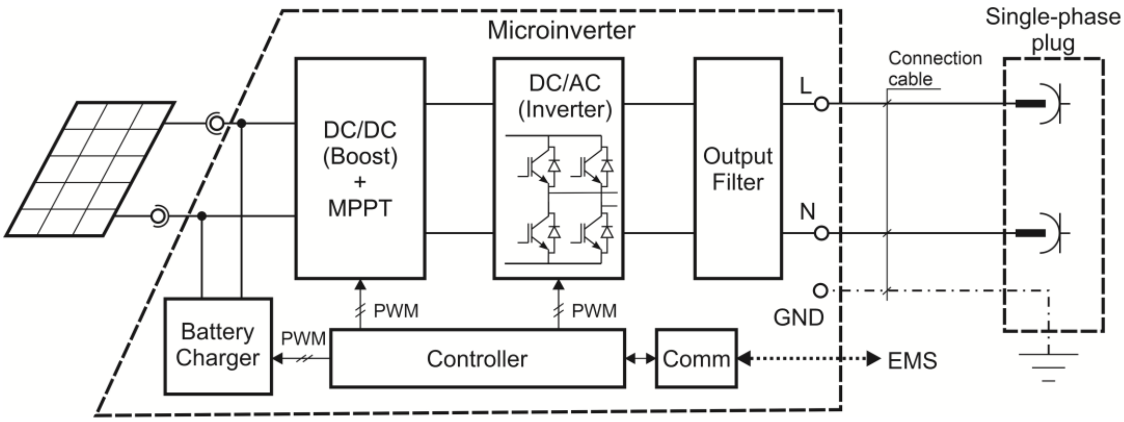


***Figure 2.*** *Two-stage microinverter [13] with plug-in connection*

followed by reduction of bureaucratic burdens, and supplementary subsidies [15].

## 3. CASE STUDY METHODOLOGY

The focus of this research was on the examination of on-grid PV systems that are simple to install and connect to existing electrical installations. As explained in the previous section, it involves a small-scale, single-phase PV system, with one or at most a few PV panels installed on balcony fences at tilt angles that are often not optimal. The orientation (azimuth angle) of the PV panels is dictated by the position of the balcony fence and the presence of other objects on the horizon that may lead to unwanted shading of the PV panels. Practically, it is necessary to examine all possible orientation variants, starting from the far east, through the ideal south, to the far west.

The first step in modelling is determining the average household consumption in the Republic of Serbia for each day of the year, broken down by hours. Ideally, these consumption profiles could be determined based on data obtained from measurements taken in a large number of households that represent typical consumers in the household category. However, the lack of adequate measuring devices that could register consumption in this way represents the first obstacle to the approach of modelling typical household load profiles. This problem is not only characteristic of the Republic of Serbia but is also typical for other countries in Europe, so alternative methods must be found to obtain the necessary data for modelling load profiles [16].

Based on publicly available data for 2023 from [17] and [18], it is known that the total electricity consumption of households delivered by the national DNO in the Republic of Serbia amounted to 13008 GWh, with the number of delivery points totaling 3367109. This effectively gives us an average annual consumption of 3863 kWh per household. Consequently, the average monthly consumption per household in the Republic of Serbia is 322 kWh. Determining consumption profiles by month and day for a typical household is more challenging based on publicly available data. This paper combines data available from user accounts for electricity consumption [19] and daily consumption profiles as outlined in [20]. Therefore, this paper uses the approach that is usually used to charge unregistered consumption, in this case, consumers from the household category. Specifically, consumers in the household category are classified into 7 types, according to criteria such as the type of active energy meter, total monthly consumption, the ratio of monthly energy consumed during off-peak tariff periods to total monthly energy consumed, and the ability to manage consumption.

Figure 3 compares data on the average monthly consumption of electricity for households in Serbia and one household analyzed in this case study. This household uses an air conditioner for additional heating during the transitional season (April, May, September and October) and for cooling during the summer (June, July and August). During the winter months (November, December, January, February and March), the main method of heating this household is central district heating. The data shown refer to the calendar year 2023 and show that the consumption of the analyzed household is higher than the typical household during all months. Annual consumption is 5955 kWh, which is about 54% more than the average.

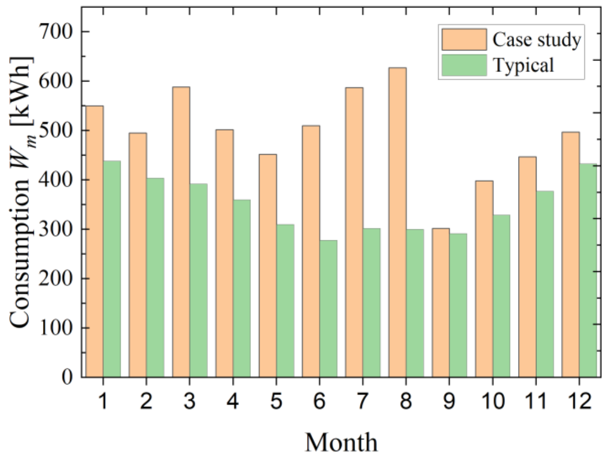


***Figure 3.*** *Monthly consumption profiles of a typical and case study household*

According to the classification from [20], both households (typical and case study) belong to category C. Figures 4(a) and 4(b) show the percentage distribution of the daily load of a household from category C for different seasons and for working and non-working days, respectively.

For the known monthly electricity consumption $W_m$ the daily consumption diagram can be modeled, based on the known dependencies of the coefficients $K_{wd}$ and $K_{nd}$ as follows:

$$W(h) = \frac{K_{wd}(h)}{100} \cdot \frac{W_m}{N_d}, \text{ for working days,} \quad (1)$$

and

$$W(h) = \frac{K_{nd}(h)}{100} \cdot \frac{W_m}{N_d}, \text{ for non-working days.} \quad (2)$$

where $N_d$ designates the number of days in a given month.

Data obtained on the basis of (1) and (2), and for monthly consumption from Fig. 3 were used for modeling own household consumption in the software PVSYST [21] and for further analyses.

The second phase of the modeling is determining the size of the on-grid PV system that will be installed as a plug-in with PV panels that will be mounted on the balcony fence. As illustrative examples, an installation of PV panels with a maximum power of 800 W prescribed by German regulations was used, and another slightly more than double installation of 1650 W of maximum power with the option to store any excess energy produced in a lithium-ion battery. The ultimate requirement in this case study for both described installations is that all produced energy is used locally, thus with zero export restriction.

In order to calculate the daily, monthly, and annual amount of energy generated by a PV system, it is necessary to know data on solar radiation and temperature at a given location in the city of Pirot (N: 43.1569, E: 22.5858). In the simulations that follow, the data for the Typical Meteorological Year (TMY) available in the PVSYST software for the given location will be used. The influence of surrounding buildings and other obstacles (trees, street lighting poles, ...) was not analyzed, while data on the horizon was taken into account, bearing in mind

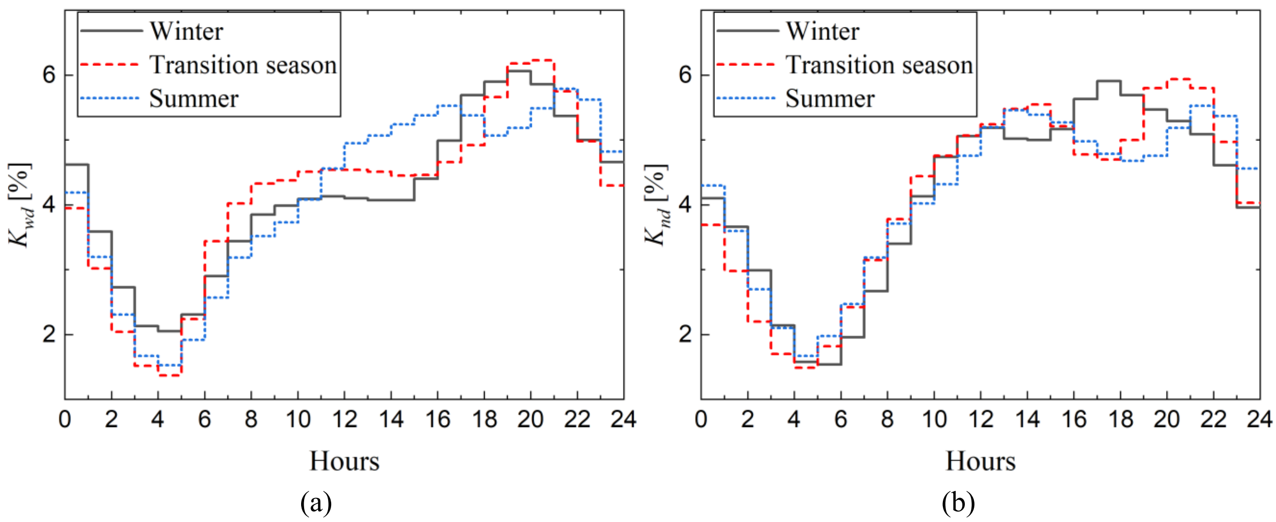


***Figure 4.*** *Daily load profiles for different seasons: working days (a) and non-working days (b)*

that the city is located in a valley surrounded by prominent mountain peaks.

## 4. RESULTS AND DISCUSSION

In the following simulations, a total of 10 different scenarios were created with the orientation of the panels to the east (E), south-east (SE), south (S), south-west (SW) and west (W), and for two different values of the tilt angle of the PV panels: fully vertical panels on the balcony fence ($\alpha = 90^o$) and a variant with panels placed at an angle of $\alpha = 60^o$ using a prefabricated structure. Simulations for these 10 scenarios were carried out for two different values of the installed power of the PV panels. The PV installation on the balcony fence consists in the first case of 2 panels with an individual power of 400 Wp, while in the second case 3 panels with an individual power of 550 Wp were used. Table 1 shows the technical characteristics of these PV panels at standard test condition (STC), where their dimensions are a very important detail for a specific installation.

***Table 1.*** *Technical characteristics of the PV panels*

| PV panel model No. | JKM400M-54HL4/ JKM400M-54HL4-V | LR5-72HPH-550M |
|---|---|---|
| Type of cells | P type monocrystalline | P type monocrystalline |
| PV panel nominal power | 400 Wp | 550 Wp |
| PV panel nominal efficiency | 20.48 % | 21.30 % |
| Short-circuit current | 13.78 A | 13.98 A |
| Open-circuit voltage | 36.98 V | 49.80 V |
| Dimensions (W x H x D) | 1722 x 1134 x 30 mm | 2278 x 1134 x 35 mm |

The initial simulations were carried out without any restrictions regarding the injection of produced energy into the AC network, therefore, with the basic idea of determining the amount of produced energy of PV panels $E_{pv}$ for a given location depending on the method of installation. Table 2 shows the results of the obtained amount of energy for the installed power of PV panels of 800 Wp, and Table 3 shows the results for the case of PV panels with an installed power of 1650 Wp.

***Table 2.*** *Overview of annual PV energy production for different tilt angles and azimuthal orientations and with total PV installed power of 800 Wp*

| | East | South-East | South | South-West | West |
|---|---|---|---|---|---|
| $\alpha = 90^o$ | 560 kWh | 722 kWh | 764 kWh | 742 kWh | 596 kWh |
| $\alpha = 60^o$ | 766 kWh | 978 kWh | 1065 kWh | 995 kWh | 795 kWh |

***Table 3.*** *Overview of annual PV energy production for different tilt angles and azimuthal orientations and with total PV installed power of 1650 Wp*

| | East | South-East | South | South-West | West |
|---|---|---|---|---|---|
| $\alpha = 90^o$ | 1156 kWh | 1490 kWh | 1580 kWh | 1532 kWh | 1230 kWh |
| $\alpha = 60^o$ | 1581 kWh | 2020 kWh | 2204 kWh | 2056 kWh | 1644 kWh |

The results from Tables 2 and 3 show that the total, annual amounts of $E_{pv}$ energy are less than the household's self-consumption, but in order to assess the actual participation of PV production in the household's self-consumption, it is necessary to simulate the consumption in an adequate way. The consumption models from Figure 3 and Figure 4 have been implemented in the PVSYST simulation software and the new results are displayed by month. The monthly consumption of both household types is modeled with seasonal variations, taking into account working/non-working days. Profiles of hourly self-consumption were generated as a csv file and were imported into the PVSYST software.

Figure 5 shows simulation results with modeled local consumption for a typical household connected to the distribution network for vertically mounted PV panels with a power of 800 Wp, and for identical PV balcony system mounted at an angle of $60^o$. The pictures show the following quantities: $E_{Solar}$ - energy produced from PV panels that is used in self-consumption, and $E_{Grid}$ - energy from PV sources that is injected into the distribution network. It can be seen that the excess energy injected into the network with south oriented vertically inclined PV panels is quite small and that practically more than

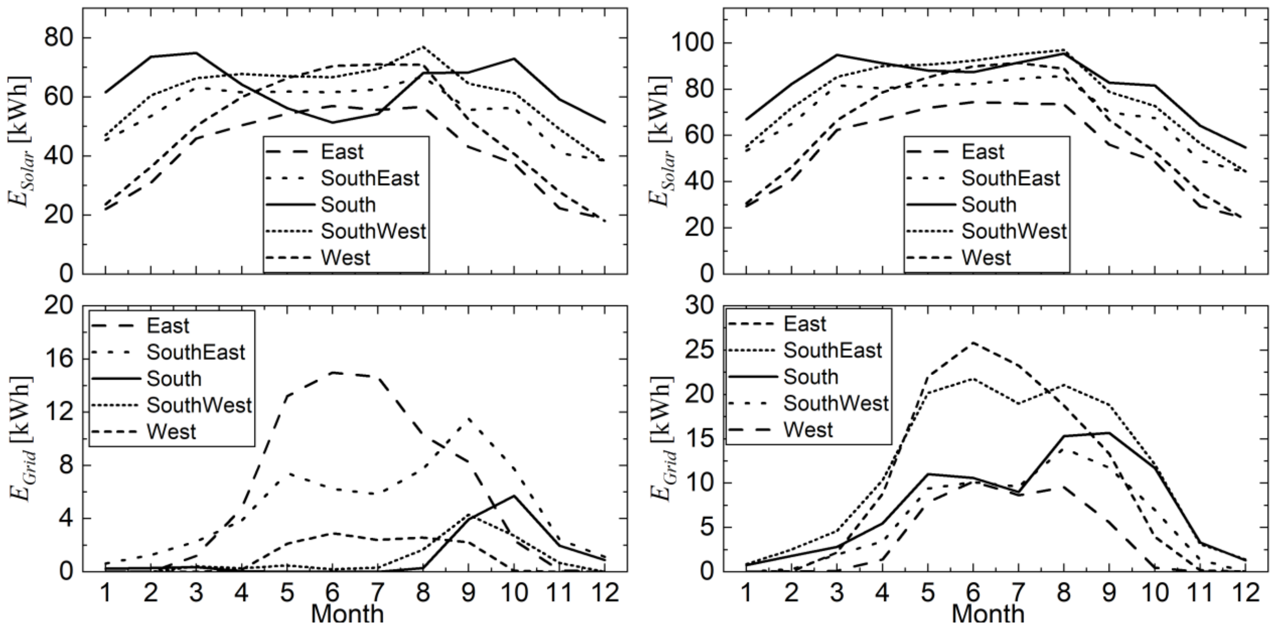


***Figure 5.*** *Results of 800 Wp balcony PV system use in typical household with vertical (left) and 60º (right) tilt angle PV panels for different azimuthal orientations*

99% of the energy is used by local consumers. The highest value of the energy injected into the network for the case of vertically placed panels with east azimuthal orientation is 69.9 kW. For the case of PV panels with an inclination of 60º, the highest value of $E_{Grid}$ is for South-East orientation (135.78 kWh). For South orientation, the annual value of $E_{Grid}$ is 88.74 kWh. The percentage of local production in total consumption, depending on the method of PV panels mounting, is shown in Table 4.

***Table 4.*** *Overview of annual PV energy production for different tilt angles and azimuthal orientations and with total PV installed power of 800 Wp*

| | East | South-East | South | South-West | West |
|---|---|---|---|---|---|
| α = 90º | 12.73% | 17.19% | 19.45% | 18.92% | 15.13% |
| α = 60º | 16.77% | 21.76% | 25.25% | 23.93% | 19.46% |

The next group of results, shown in Fig. 6, is given for the case study household, first for the 800 Wp installed power of the PV panels for two different tilt angles and for five azimuthal orientations. It is observed that the amount of energy injected into the network is the highest in the case of the eastern orientation of the PV panels and represents 2.8% of the energy produced by the PV panels. Table 5 shows an overview of the percentage coverage of self-consumption with energy coming from PV panels. The graphical and tabular results indicate that in the case of PV panels with an installed power of 800 Wp placed on the balcony fence, it is not necessary to install battery storage. Based on the results from Fig. 6 and from Table 5, it can be concluded that for households with increased consumption due to the use of air conditioners, the optimal installation is the balcony PV system facing South. The installation of 800 Wp PV panels does not significantly affect the grid in terms of injecting additional energy that is not used by local consumers.

***Table 5.*** *Percentage coverage of case study household self-consumption for different tilt angles and azimuthal orientations with total PV installed power of 800 Wp*

| | East | South-East | South | South-West | West |
|---|---|---|---|---|---|
| α = 90º | 9.19% | 11.94% | 12.79% | 12.43% | 9.99% |
| α = 60º | 12.50% | 16.06% | 17.68% | 16.58% | 13.31% |

An attractive and affordable solution is the installation of additional PV panels, together with a suitable microinverter. This idea finds its justification in the fact that the analyzed household uses an

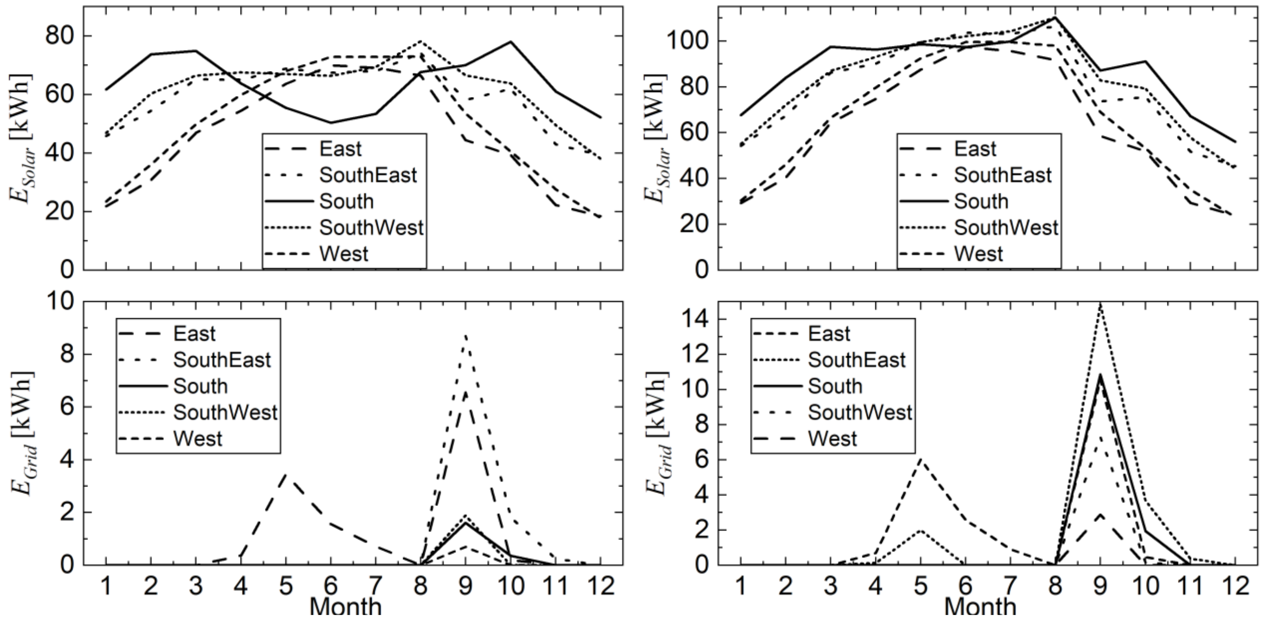


***Figure 6.*** *Results of 800 Wp balcony PV system use in case study household with vertical (left) and 60$^o$ (right) tilt angle PV panels for different azimuthal orientations*

air conditioner, mostly in the summer months, when the expected production from PV panels is the highest. A detailed simulation of a PV system with an installed power of 1650 Wp was performed, again with the local consumption of the household from the case study. Fig. 7 shows the obtained results, and an additional better insight into the results can be acquired from Table 6. It is observed that the increase in the installed power of the PV panels leads to an increase in the injection of energy into the distribution network, which can be problematic from the aspect of grid codes of DNO, but also from the aspect of profitability of the investment. The largest amount of injected energy (490.66 kWh) is for South-East oriented PV panels placed with a tilt angle of 60$^o$, which represents 24.29% of the total energy produced from PV panels.

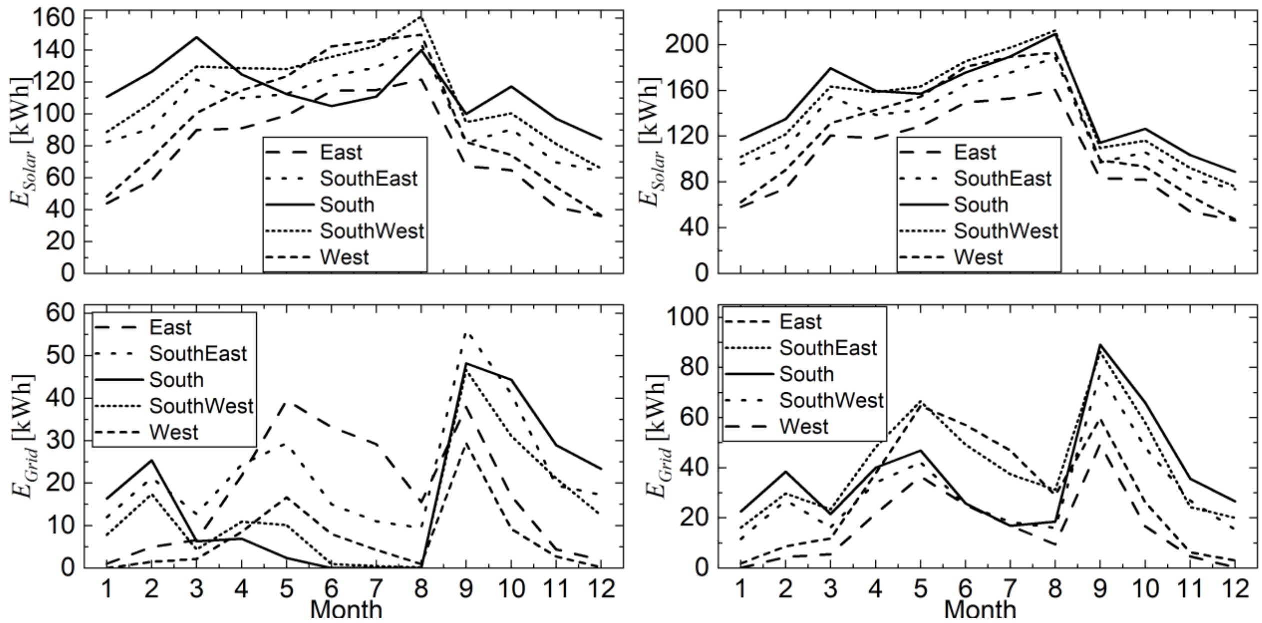


***Figure 7.*** *Results of 1650 Wp balcony PV system use in case study household with vertical (left) and 60$^o$ (right) tilt angle PV panels for different azimuthal orientations*

***Table 6.*** *Percentage coverage of case study household self-consumption for different tilt angles and azimuthal orientations and with total PV installed power of 1650 Wp*

| | East | South-East | South | South-West | West |
|---|---|---|---|---|---|
| α = 90° | 15.84% | 20.49% | 23.13% | 22.92% | 19.25% |
| α = 60° | 20.63% | 25.69% | 29.48% | 28.51% | 24.39% |

It can be concluded that the installation of additional PV panels on the balcony fence cannot contribute proportionately to the improvement of the energy independence of the household, without the use of battery storage. In recent years, solutions with hybrid inverters have appeared on the market, which enable battery charging and even off-grid operation of the local network. The increase in the installed power of PV panels on the balcony fence, especially in the case of households with increased self-consumption in the evening, highlights this trend, of course with the necessary detailed techno-economic analysis of the justification for the investment and determination of the optimal battery capacity.

## 5. CONCLUSION

The balcony is not only an additional outdoor part for the apartment, but also a space with the possibility for PV electricity production. Photovoltaic building applications represent the key for achieving sustainability goals. Although the electricity production from balcony PV systems is still low, they could be an important factor for electricity consumption in households especially in multi-story buildings and contribute to the energy transition.

The proper sizing of the balcony fence PV system depends on several factors, the most important of which is the daily profile of self-consumption, as well as the possibility of installing PV panels in terms of inclination and azimuthal orientation. A detailed simulation analysis that takes into account the daily profiles of self-consumption showed that the consumption savings of a typical household in Serbia is in the range from 12.73% to 25.25% of the total household consumption for the case of an installed balcony PV system of 800 Wp, which is common today in some European countries. In the case of a household with increased consumption due to intensive use of air conditioners during the summer and transition season, the installation of 800 Wp PV panels saves from 9.19% to 17.68% of the used electricity. A double increase in installed power does not contribute to a double increase in savings due to variation in daily consumption and seasonal differences. Therefore, it is necessary to consider the possibility of using battery storage in further research.

## 6. ACKNOWLEDGEMENT

This paper was done with the financial support of the Faculty of Sciences and Mathematics, University of Niš, Republic of Serbia, and of the Agreements 451-03-66/2024-03/200124 and 451-03-65/2024-03/200124 on the realization and financing of scientific research work of the Faculty of Sciences and Mathematics, University of Niš in 2024 by the Ministry of Science, Technological Development and Innovation of the Republic of Serbia. This work was also supported by the Agreement 451-03-65/2024-03/200102 with the Ministry of Science, Technological Development and Innovation of the Republic of Serbia.

## 7. REFERENCES

[1] D. Gögelein, M. Von Schwerin, and V. Herbort, "PV System Installation Assessment Based on Power Measurement for Balcony Power Plant Applications," *IEEE J Photovolt*, vol. 14, no. 4, pp. 571–582, Jul. 2024, doi: 10.1109/JPHOTOV.2024.3384914.

[2] T. P. Breit, "Balcony PV power plants in Austria: Public support for adoption and differences in implementation between Austria and Germany." doi: 10.34726/HSS.2023.113066.

[3] I. Radonjić *et al.*, "An impact of fly ash on photovoltaic panel performance in the built environment: A case study," *Energy Build*, vol. 318, p. 114485, Sep. 2024, doi: 10.1016/J.ENBUILD.2024.114485.

[4] Z. R. K. Abojela, M. K. M. Desa, and A. H. Sabry, "Current prospects of building-integrated solar PV systems and the application of bifacial PVs," *Front Energy Res*, vol. 11, p. 1164494, Apr. 2023, doi: 10.3389/FENRG.2023.1164494/BIBTEX.

[5] N. Skandalos *et al.*, "Building PV integration according to regional climate conditions: BIPV regional adaptability extending Köppen-Geiger climate classification against urban and

climate-related temperature increases," *Renewable and Sustainable Energy Reviews*, vol. 169, p. 112950, Nov. 2022, doi: 10.1016/J.RSER.2022.112950.

[6] Dr. Harry Wirth, "Recent Facts about Photovoltaics in Germany - Fraunhofer ISE." Accessed: Jul. 19, 2024. [Online]. Available: https://www.ise.fraunhofer.de/en/publications/studies/recent-facts-about-pv-in-germany.html

[7] S. Freitas and M. C. Brito, "Bifacial PV integrated on building balconies," in *32nd European Photovoltaic Solar Energy Conference and Exhibition*, 2016. doi: 10.4229/EUPVSEC20162016-6DO.8.1.

[8] R. H. Valdivia-Sisniegas, "Increasing PV solar collection using the upper edges in balconies," *J Phys Conf Ser*, vol. 2600, no. 4, p. 042009, Nov. 2023, doi: 10.1088/1742-6596/2600/4/042009.

[9] A. Kyritsis *et al.*, "Households with Fibre Reinforced Composite BIPV modules in Southern Europe under Net Metering Scheme," *Renew Energy*, vol. 137, pp. 167–176, Jul. 2019, doi: 10.1016/J.RENENE.2017.09.068.

[10] "Photovoltaics Report - Fraunhofer ISE." Accessed: Aug. 02, 2024. [Online]. Available: https://www.ise.fraunhofer.de/en/publications/studies/photovoltaics-report.html

[11] J. Zhong *et al.*, "Development and challenges of bifacial photovoltaic technology and application in buildings: A review," *Renewable and Sustainable Energy Reviews*, vol. 187, p. 113706, Nov. 2023, doi: 10.1016/J.RSER.2023.113706.

[12] C.-T. Phan-Tan, "Design and Implementation of a Micro-Inverter for Photovoltaic Applications," 2017. doi: 10.13140/RG.2.2.29887.15529.

[13] P. Frgal, "AN4664, On-Grid Solar Microinverter on Freescale MC56F82xx/MC56F82xxx DSCs - Application Notes," 2013.

[14] "All G98 forms – Energy Networks Association (ENA)." Accessed: Jul. 31, 2024. [Online]. Available: https://www.energynetworks.org/publications/all-g98-forms

[15] "Bundesnetzagentur - Press - Growth in renewable energy in 2023." Accessed: Jul. 31, 2024. [Online]. Available: https://www.bundesnetzagentur.de/SharedDocs/Pressemitteilungen/EN/2024/20240105_EEGZubau.html

[16] H. Zsiboracs, A. Vincze, G. Pinter, and N. H. Baranyai, "Exploring the Grid Electricity Saving Potentials of Using Hybrid PV Systems in European Countries: A Comparative Study," *IEEE Access*, vol. 11, pp. 90698–90714, 2023, doi: 10.1109/ACCESS.2023.3307465.

[17] Energy Agency of the Republic of Serbia, "2023 Energy Agency Annual Report." Accessed: Jul. 18, 2024. [Online]. Available: https://www.aers.rs/Files/Izvestaji/Godisnji/Izvestaj%20Agencije%202023.pdf

[18] National DSO Elektrodistribucija Srbije, "2023 Yearly Report." Accessed: Jul. 18, 2024. [Online]. Available: https://www.elektrodistribucija.rs/o-nama/informacije/dokumenta/GI_2023.pdf

[19] "Почетна - Електропривреда Србије." Accessed: Sep. 01, 2024. [Online]. Available: https://portal.eps.rs/home

[20] "Distribution Grid Codes." Accessed: Aug. 23, 2024. [Online]. Available: https://www.aers.rs/FILES/AktiAERS/AERSDajeSaglasnost/2017-07-19_Pravila%20o%20radu%20ED-ODS%20EPS%20distr.pdf

[21] "PVsyst – Photovoltaic software." Accessed: Aug. 01, 2024. [Online]. Available: https://www.pvsyst.com/

# МОГУЋНОСТ ПРОИЗВОДЊЕ ФОТОНАПОНСКЕ ЕЛЕКТРИЧНЕ ЕНЕРГИЈЕ НА ОГРАДИ БАЛКОНА У ПИРОТУ, СРБИЈА

**Сажетак:** У урбаном окружењу фотонапонски (PV) панели обично се постављају на расположиве зграде, али се могу укључити и у почетни архитектонски дизајн грађевина. Монтажа PV панела на/као балконске ограде постаје често решење за креирање PV система у зградама. Идеја децентрализоване производње и складиштења електричне енергије врло близу места коришћења представља додатни бенефит. У овом раду анализирана је могућност коришћења PV панела у градским условима, унутар кућних инсталација индивидуалног стамбеног потрошача са постављањем панела на огради балкона. За анализу различитих варијанти монтаже PV панела на огради балкона коришћена је детаљна симулација комплетног PV система у софтверу PVSYST. За индивидуалног потрошача из категорије „Домаћинство тип 3“ са годишњом потрошњом од око 6000 kWh, анализирана је уградња три PV панела укупне снаге 1650 Wp. Симулиране су различите варијанте уградње PV панела и то за случај два различита угла нагиба (0$^{o}$ (вертикални положај) и 60$^{o}$) и три различите азимутне оријентације (југ, исток и запад). Сопствена потрошња моделована је преко типичних дневних профила уз уважавање сезоналне варијације за дати тип потрошача. Добијени резултати показују да у испитиваном PV систему фотонапонска енергија може да покрије од 15,84% до 29,48% сопствене потрошње посматраног домаћинства, а у зависности од угла нагиба PV панела на огради балкона и њихове азимутне оријентације.

**Кључне ријечи:** PV панел, ограда балкона, производња електричне енергије, потрошња електричне енергије, домаћинство.

**Paper received: 4 September 2024** **Paper accepted: 31 March 2025**