POSSIBILITIES AND BENEFITS OF USING PHOTOVOLTAIC POWER PLANTS WITH MICROINVERTERS IN RURAL AREAS

Vytautas Adomavicius[1], Gintvile Simkoniene[2], Artem Dedenok[1]
[1]Kaunas University of Technology, Lithuania; [2]Lithuanian Maritime Academy, Lithuania
vytautas.adomavicius@ktu.lt, gintvile.simkoniene@ktu.lt, artem.dedenok@ktu.edu

Abstract. The article provides a brief overview of research on solar power plants with microinverters, highlighting their viability and input for reducing environmental pollution by greenhouse gases and halting the progression of climate change globally. Scientific articles indicate significant potential for using photovoltaic power plants (PVPPs) in both rural and urban areas. The reviewed articles disclosed that PVPPs with microinverters (MI) have significant advantages compared to PVPPs based on one common inverter for the entire PV array (or several powerful inverters for separated PV array branches). MI boosts the efficiency of PVPPs operation and quantities of produced electric power because MPPT tracks only a small group of solar modules per group (1, 2 or 4). Reliability of operation of more powerful PVPPs with MI is evident, as the failure of one MI or one solar module, only affects a small part of the entire PVPP, leaving the remainder operational. It also simplifies the installation, repair, maintenance, and dismantling of PVPP after the end of the power plant operation period, reduces power and energy losses, amplifying overall efficiency and shortening the payback period of PVPP. The electricity produced by PVPP with MI is primarily consumed by the building where the power plant is switched on, and the unused electric energy flows into the external power network. Research suggests integrating at least a few powerful PVPPs with MI into the internal network of a low-power hydroelectric power plant could enhance electricity production. The conclusions of the article include this statement.

Keywords: small-scale, stand-alone, solar power plants, microinverters, self-consuming.

Introduction

The Alliance of World Scientists founded at the Oregon State University in the US is an international assembly of scientists independent of both governmental and non-governmental organizations and corporations. The main goals of the Alliance are to prevent environmental pollution, stop climate warming and help humanity transition to a greener alternative to business as usual. The authors of this article aim contribute to the Alliance goals. Alliance scientists are writing scientific articles which titles begin with the words “Scientists’ warning < ... > ”. One of their articles and a link to the Alliance website are included in our list of references [1; 2]. They had over 27,000 members in 2023.

Producing electricity in rural and urbanized areas using solar power plants (PVPP) with MIs is useful in many aspects. At the beginning of the twenty-first century, a new kind of PVPP was created and used. The most important difference between the traditional and new structures is that string inverters are used in traditional PVPP to convert the direct current energy of a large number of solar modules into alternating current of standard parameters (DC/AC conversion), while MIs of the new structure perform this work only for one solar module, or a small group of solar modules – 2 or 4. The power of PVPP in traditional structures has to be increased on the DC side by connecting modules in series (in strings) in order to reduce power ($P = I^2 \cdot r$) and energy losses ($E_{losses} = E_{input} - E_{output}$). String voltage reaches up to 1.5 kV in this type of PVPP, but their currents remain small due to this way of connecting. In addition, traditional high-power PVPP use powerful string inverters with common maximum power point trackers (MPPTs). Such systems include a large number of solar modules, which often experience uneven conditions (shading impact module performance), so the maximum possible power of the solar module and entire string is quite often achieved only together with more or less losses. Connection diagrams of PVPP with MIs are presented in Fig. 1.

The first company that became interested in MIs and understood their advantages was the USA Ascension Technology (1991). The first commercially successful MIs have been in use since 2008. From that year until now, MIs have been sold quite successfully all over the world and their demand is constantly increasing. At the beginning, the price index of MIs was about 2-3 times higher than that of large PVPP string inverters. Over time, their prices decreased quite rapidly as did the prices of solar modules and all solar electric systems. Currently, the price index for MIs is about 0.45 $EUR \cdot W^{-1}$ (price index is equal to the price of MI in cents devided by its rated power in watts), and for high-power solar inverters (string inverters) – about 0.30-0.35 $EUR \cdot W^{-1}$. Such a small difference in the price indexes of inverters is not of great importance, because the power of PVPP with MIs is small and, as a result, no major financial problems arise. In addition, the difference in their price indexes decreases quite quickly over time, so it can be expected that these indexes will probably converge even more. The global PV microinverter market size in 2022 was 967.2 million USD. Projected market size in 2033 will increase by about 5 times – 4.630 billion USD [3]. For more useful information on current MIs, see references [4-7]. Global annual MI shipments in 2024 will be 21.57 GW, in 2025 – 29.41 GW.

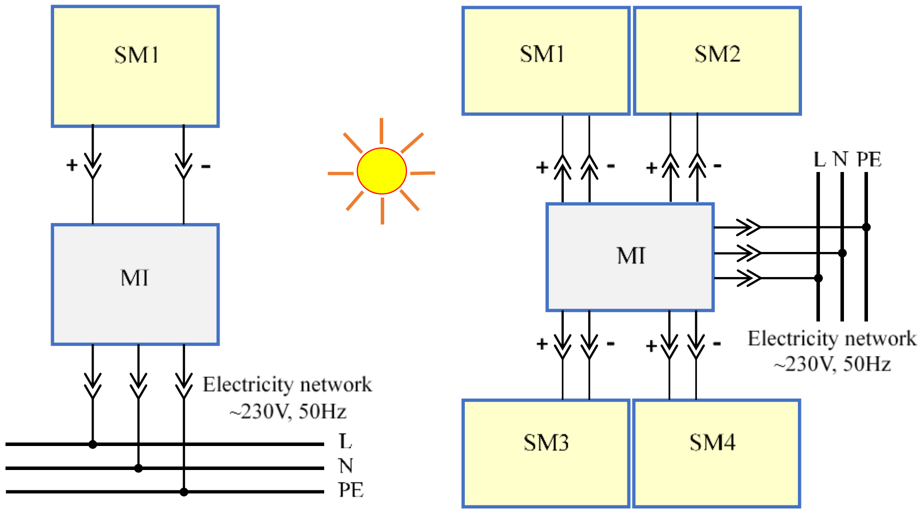

Fig. 1. **Small-scale PVPP with microinverter MI connection diagrams:**
with one solar module SM1 (left figure) and with four solar modules SM1-SM4 (right figure)

The first scientific articles in this area were devoted to the research of small-scale PVPP with MIs (100-250 W). The articles evaluated this innovation positively [8-10]. Later articles examined small-scale, three-phase systems [11-12]. The article [13] concluded that self-consumption is already attractive, but storage in batteries is currently not a profitable solution in Portugal. The article [14] solves the problem of creating MIs for PVPP. The possibility of using PVPP with MIs to supplement the power network when it lacks energy is analyzed in article [15]. Japanese researchers examined residential PV-battery systems, focusing on enhancing self-consumption for peak shaving to reduce power bills [16]. Many researchers have studied residential self-consumption systems in various countries in accordance with local conditions, looking for ways to increase efficiency [17-23]. The articles deal with other problems as well: power quality problems of microinverters [24], influence of supercapacitors on a system's operation quality [25], energy use profiles of PVPP with microinverters [26], techno-economic analysis of self-consumption [27], design characteristics of microinverters [28], and other aspects. Of course, PVPP with string inverters may also be used in rural areas. A small Jasmine farm in Latvia has PVPP, which produces an average of 5564 kWh and consumes up to 5000-7000 kWh of electricity per year [29].

Innovative grid-connected small PVPP with MI, used in many countries around the world, does not require any project for installation in a house, apartment, or business. There is also no need to conclude any contract with representatives of the power system because the very safe smart MIs used in these small PVPP work reliably (extended warranty – up to 25 years) and all other equipment has a multi-year warranty. These MIs are connected to the power grid through a standard single-phase (or three phase) plug into a standard power outlet. The electricity produced by the small PVPP is primarily consumed by the house (apartment, private institution, company), and only the unused power balance flows into the external power grid. Therefore, it is inappropriate to install PVPP with MI that has too much rated power because the excess energy goes to the power system. When the solar modules are connected to MI and the output cable of MI is not yet connected to the mains, there is no voltage on the cable plug. Only when the cable plug is inserted into the electrical network, after a certain time, alternating electric current will appear at the output of MI, provided that the electrical network works normally and has the correct voltage and frequency.

The installation of PVPP with MI is very simple and does not require a lot of effort. MI is attached to the back of the solar modules and the output DC cables of the solar modules are connected to the input cables of MI through standard connectors. The MI output cable is connected via the plug to any socket inside the building. As a result, the building receives an alternating current of electricity from the solar modules. Any qualified and licensed electrician can install and maintain this PVPP. Maintenance of this type of small PVPP has become quite similar to that of household electrical appliances that are connected to electrical outlets through plugs.

Materials and methods

A small-scale PVPP with a microinverter has been installed in the Renewable Energy Systems and Energy Storage Laboratory of the Kaunas University of Technology in order to understand its structure, operating principle, and characteristics. The connection diagram of PVPP with two MI is presented in Fig. 2. Both microinverters MI-1 and MI-2 in this PVPP have their own modular energy meters, Wh_1 and Wh_2. This PVPP makes it possible to monitor how much electricity was produced and delivered to the faculty power grid from the day of installation on April 15, 2019. The type of modules SM-1 and SM-2 is 60.6-WF-215, and their rated power is 218 W. The total power of the solar modules of this PVPP is 436 W. I_{MI}, I_L, I_N are the currents from MI, load, and power networks. The rest of the devices (voltmeters, ammeters, watt meters and energy meters) enable monitoring of the parameters of the produced energy by changing the load of this PVPP by the rheostat R_L. This PVPP (see Fig. 2) produced over 2 MWh of free electricity for the faculty in less than 5 years.

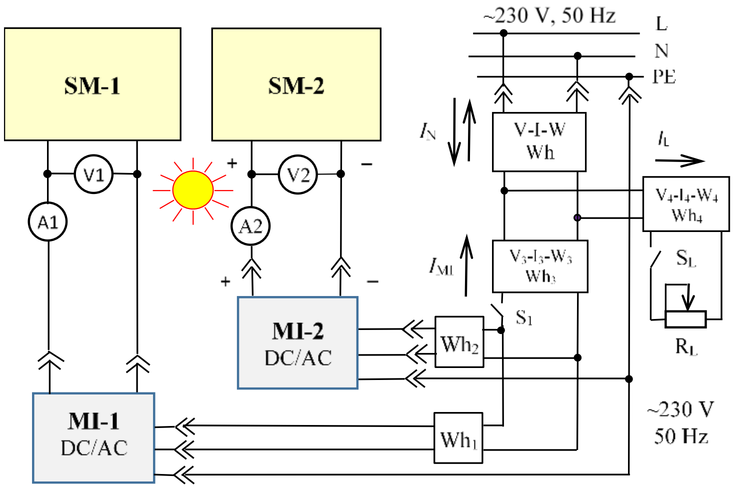

Fig. 2. **Small-scale experimental PVPP with two microinverters**

One of the tasks of this paper was to show the simplicity of the installation of this type of PVPP, to study and evaluate its operation, and to provide explanations to consumers who would like to install such PVPP in their homes, farms, or institutions in order to reduce their electricity costs. This article is beyond the scope of economic evaluation of PVPP with MI, however, almost all energy specialists who are at least a little familiar with this type of PVPP know that installing them in the internal electric network of their home or workplace is beneficial. These power plants are very popular in Germany and other developed countries leading in RES-based electric power production. As a result, it is no coincidence that the pace of MI production around the world is rapidly increasing. It is safe to say that both PVPP with MI and traditional PVPP will be developed successfully, and the price of electricity produced by them will continue to decrease significantly. Studies show that the operation efficiency of solar modules will increase almost twice – 40% [30].

Table 1 shows the results of how PVPP with microinverters distributed the power P_3 and current I_3 produced based on the load power P_4 and the load current I_4 when the sun irradiance stayed about the same. The sky was clear, and the test took only about 5 minutes, so the solar irradiance changed only very slightly. The main results of this experiment are submitted in Fig. 3. The power produced by PVPP with MI is marked as PMI (the red line), the power supplied from the experimental power plant into the electric network – as PN (the green curve) and the load power – as PL (the blue curve). The PMI power supplied from PVPP with MI due to the constant solar irradiance was almost constant (about 274÷277 W) as the sky was clear.

Table 1

PVPP with MI load test results

No.	Load parameters		Common output of MI		Electricity network		Power losses
	PL (*W*4)	*IL*(*I*4)	*PMI* (*W*3)	*IMI* (*I*3)	*PN* (*W*)	*IN* (*I*)	*ΔP*
	W	A	W	A	W	A	W
1	0	0	344	1.07	314	1.09	30
2	27.4	0.12	343	1.08	289	0.99	26.6
3	55	0.22	343.2	1.08	263.1	0.89	25.1
4	84	0.32	343.5	1.08	238	0.79	21.5
5	153	0.48	343.5	1.08	174.5	0.62	16.0
6	224	0.76	342.7	1.08	108.7	0.41	10.0
7	292.5	1.02	342.7	1.08	45.8	0.26	4.4
8	363	1.29	342.9	1.09	-17.3	-0.33	-2.8
9	432	1.56	342.8	1.10	-80.3	-0.52	-8.9
10	500	1.82	343	1.09	-142.6	-0.77	-14.4
11	570.4	2.08	343	1.10	-206.7	-1.02	-21.4

The load power PL was increased step by step, so the power delivered to the network PN decreased step by step until it equaled the generated power PMI. Then the load used not only all the generated PVPP power but also started to "borrow" power from the electric network (therefore, the power taken from the network has a minus sign).

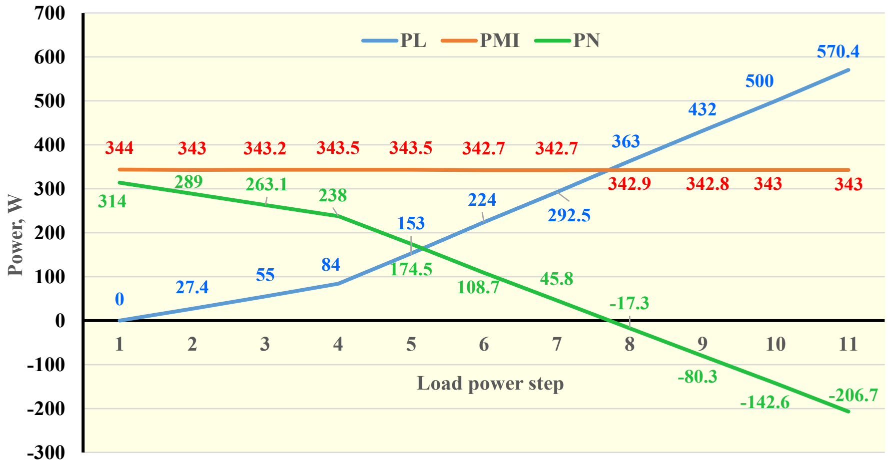

Fig. 3. **PVPP with microinverter power distribution when increasing its load**

Results and discussion

Our research and review results for the presented articles allow us to confirm the following main advantages of PVPP with MI compared to traditional PVPP: The operation efficiency of PVPP and the amount of electricity produced increase; power and energy losses in PVPP are slightly reduced; the payback time of the power plant is shortened; the reliability of the powerful PVPP of this type increases (when one microinverter fails, only a small part of the entire PVPP fails, and the rest works); the installation, maintenance, repair, and dismantling of PVPP after the end of the power plant operation period are greatly simplified, which reduces the costs of installation and dismantling the plant. The shipment of microinverters for the coming years is rapidly increasing: their global supply in 2024 will be 21.57 GW, and in 2025, 29.41 GW [31]. A powerful breakthrough is taking place not only in PVPP with MI but also in the entire area of solar energy: the global annual installed capacity of PVPP in just one year (2023) exceeded the entire global capacity of nuclear power plants (NPP) installed in the 70-year history of these power plants [32]. Over the last year (until April 2024), the prices of the cheapest solar modules have fallen to 0.08 EUR·Wp^{-1}, the most desirable ones to 0.13 EUR·Wp^{-1}, and the highest quality ones to 0.21 EUR·Wp^{-1} [33].

PVPP with microinverters are very suitable for those electricity users who constantly consume energy during the day in various small companies and institutions: support of electric car battery charging stations, continuously operating refrigerators in stores and their indoor lighting systems, electricity storages with high-capacity batteries (they can sell the accumulated energy during the hours when the price of electricity is the highest), in laundries, sewing shops, in buildings with air conditioning equipment in the summer period, and in other institutions that have a lot of computers or other electricity-using equipment that constantly consumes significant amounts of energy. There are also cases where the power of PVPP with MI is greater. Small hydropower plants (HEPPs) provide excellent conditions for integrating at least a few PVPPs with MI into electricity production alongside HEPPs. In this way, it would be possible to increase the total electricity production in a small HEPP by utilising the cheap electricity produced by PVPP with MI by almost 100%. The combined operation of both power plants would increase electricity production on days when electricity is in the highest demand and most expensive. This means that PVPP with MI can work not only for self-consumption but also for the entire low voltage distribution network (AC 400V), which is available to all users connected to it.

When solar irradiance is high, households also have a number of opportunities to use solar energy cheaply. On sunny days, it is possible to choose jobs and activities that require the use of various household power tools. This can include cooking in electric stoves and teapots, washing, ironing clothes, heating water in an electric boiler, charging batteries, including those of low-power vehicles (electric bicycles, electric scooters), working with computers, electric sewing machines, watching TV, drying fruits, mushrooms, and berries in electric dryers, pumping water for watering gardens with an electric pump, and performing all other possible tasks.

One of the most important tasks that must be solved in order to install PVPP with MI at home or in the workplace is determining the optimal power of this power plant. It is easiest to calculate the optimal power of a power plant in cases where electricity is used continuously in a company or institution. Then it is enough to look at the readings of the electricity meter in the morning and in the evening at the end of work and then calculate the daily energy consumption. It is recommended to choose the power of PVPP with MI in such a way that the amount of electricity produced on a clear summer day approximately corresponds to the amount of energy consumed per day. Electricity production on other less clear and cloudy days will be lower; the solar power plant will not produce all the required energy but only a greater or less part of it, which will be used in all available electric loads. The missing part of the energy will come from the distribution electric network. Full self-sufficiency will not be achieved, but having your own PVPP with MI can cover a considerable amount of all consumed electricity at a price several times lower compared to that supplied from the grid.

Conclusions

1. A review of scientific articles and other information sources on PVPP with microinverters was carried out, which revealed the viability of this type of solar power plants, the rapid development of their installation around the world, and the lagging behind some countries from the leaders. In these countries, the main reason for the delay is a lack of information on the subject.
2. The analysis of information on PVPP with MI showed that this type of solar power plants has considerable potential for use in both rural and urbanized areas. Their owners could significantly reduce expenditures on electricity by choosing the optimal power of these power plants and skillfully operating them (approximately up to 2 times).
3. The article presents a proposal to install PVPP with microinverters in small-scale power plants that generate an alternating voltage of 400 V. Small-scale hydropower plants (HEPPs) provide a good chance for integrating at least a few PVPPs with MI. It would allow increasing the total electricity generation in HEPP (at least up to 10%). This means that PVPPs with microinverters can use power not only internally but also to supply power to external distribution networks.
4. Producing electricity, installing, maintaining, and decommissioning plants at the end of their service life have never been simpler or more efficient globally thanks to PVPPs with MI.

Author contributions

Conceptualization, formulation of the idea of the article, search for information sources and their analysis, evaluation of the significance of information sources (V. A., G. Š.), performing experiments and analysing the obtained data (A. D., V. A), drawing of figures (A. D., V. A.), writing and draft first version preparation (V. A.), editing of the article (G. Š.), preparation of the final version V. A.), preparation of report slides (A. D.) acquisition of financing, presentation of the report at the conference (G. Š.). All authors read and agreed with the final published version of the manuscript.

References

[1] Tomlinson B., Torrance A.W., Ripple W.J. Scientists warns on technology. Journal of Cleaner Production, vol. 434, 2024. [online] [12.01.2024]. Available at: https://doi.org/10.1016/j.jclepro.2023.140074

[2] Website of Alliance of World Scientists (AWS). Oregon State University, USA. [online] [11.01.2024]. Available at: https://scientistswarning.forestry.oregonstate.edu

[3] Future Market Insight. PV Micro Inverters Market Outlook for 2023 to 2033. Technical Report. [online] [11.01.2024]. Available at: http://tiny.cc/uhyvxz

[4] Bhor A., Neumeister K. Microinverters: Everything You Need to Know in 2024. EcoWatch, February 12, 2024. [online] [12.11.2023]. Available at: https://tinyurl.com/nhfrz3b7 Sendy A. Solar Reviews, March 11, 2023. Solar inverters: pros and cons of string inverters vs. microinverters. [online] [02.12.2023]. Available at: http://tiny.cc/thyvxz

[5] Sendy A. Solar Reviews, March 11, 2023. Solar inverters: pros and cons of string inverters vs. microinverters. [online] [11.11.2023]. Available at: https://shorturl.at/9izyF

[6] Reliable solar microinverters. [online] [11.01.2024]. Available at: https://tinyurl.com/3rpyxk8k

[7] PROJOY electric. PSOL Series. Micro Inverter. [online] [11.01.2024]. Available at: www.projoy-electric.com

[8] Sher H. A., Addoweesh K. E. Micro-inverters — Promising Solutions in Solar Photovoltaics. Energy for Sustainable Development, vol. 16, 2012, p. 389-400. [online] [13.01.2024]. Available at: https://doi.org/10.1016/j.esd.2012.10.002

[9] Pisano M., Bizzarri F., Brambilla A., et al. Micro-Inverter for Solar Power Generation. International Symposium on Power Electronics, Electrical Drives, Automation and Motion. IEEE Transactions on Power Electronics, vol. 8, 2012, pp. 109-113. doi: 10.1109/SPEEDAM.2012.6264547

[10] Scholten D. M., Ertugrul N., Soong W. L. Micro-Inverters in Small Scale PV Systems: A Review and Future Directions. Australasian Universities Power Engineering Conference, AUPEC 2013, Hobart, TAS, Australia, 29 September - 3 October, 2013. Published in IEEE Xplore: 30 January 2014. [online] [11.11.2023]. Available at: 10.1109/AUPEC.2013.6725465

[11] Amirahmadi A., Hu H., Grishina A. et al. Hybrid ZVS BCM Current Controlled Three-Phase Microinverter. IEEE Transactions on Power Electronics, vol. 29, issue 4, April 2014, pp. 2124-2134. [online] [03.12.2023]. Available at: 10.1109/TPEL.2013.2271302

[12] Chen L., Amirahmadi A., Zhang Q., et al. Design and Implementation of Three-Phase Two-Stage Grid-Connected Module Integrated Converter. IEEE Transactions on Power Electronics, vol. 29, issue 8, August 2014, pp. 3881-3892. [online] [11.01.2024]. Available at: 10.1109/TPEL.2013.2294933

[13] Camilo F. M., Castro R., Almeida M.E., Pires V.F. Economic assessment of residential PV systems with self-consumption and storage in Portugal. Solar Energy, vol. 150, 2017, pp. 353-362. [online] [20.10.2023]. Available at: http://dx.doi.org/10.1016/j.solener.2017.04.062

[14] Nandhini S., Seyezhai R., Sowmya V., Umarani D. Design and Implementation of Micro-inverter for Photovoltaic Application. International Journal of Pure and Applied Mathematics, vol. 118, No. 24, May 10, 2018, 21 p. [online] [20.10.2023]. Available at: https://shorturl.at/swktR

[15] Dong D. , Mohammed A., Todorovic M. H., et al. A PV Residential Micro-inverter with Grid-support Function: Design, Implementation and Field Testing. IEEE Transactions on Industry Applications, vol. 54, issue 1, Jan.-Feb. 2018, pp. 469-481. [online] [20.10.2023]. Available at: https://doi.org/10.1109/TIA.2017.2752680

[16] Li Y., Gao W., Ruan Y. Performance investigation of grid-connected residential PV-battery system focusing on enhancing self-consumption and peak shaving in Kyushu, Japan. Renewable Energy, vol. 127, 2018. [online] [20.10.2023]. Available at: https://doi.org/10.1016/j.renene.2018.04.074
[17] Espinoza R., Munoz-Ceron E., Aguilera J. de la Casa J Feasibility evaluation of residential photovoltaic self-consumption projects in Peru. Renewable Energy, vol.136, 2019. [online] [20.12.2023]. Available at: https://doi.org/10.1016/j.renene.2019.01.003
[18] Talavera D. L., Munoz-Rodriguez F. J., Jimenez-Castillo G. and Rus-Casas C. A new approach to sizing the photovoltaic generator in self-consumption systems based on cost–competitiveness, maximizing direct self-consumption. Renewable Energy, vol. 130, 2019, pp. 1021-1035. [online] [04.01.2024]. Available at: https://doi.org/10.1016/j.renene.2018.06.088
[19] Barzegkar-Ntovom G. A., Chatzigeorgiou N. G., Nousdilis A. I. et al. Assessing the viability of battery energy storage systems coupled with photovoltaics under a pure self-consumption scheme. Renewable Energy, vol. 152, 2020, pp. 1302-1309. [online] [20.10.2023]. Available at: https://doi.org/10.1016/j.renene.2020.01.061
[20] Roberts M. B., Brucea A., MacGilla I. Impact of shared battery energy storage systems on photovoltaic self-consumption and electricity bills in apartment buildings. Applied Energy, vol. 245, 1 July 2019, pp. 78-95. Available online: https://doi.org/10.1016/j.apenergy.2019.04.001
[21] Fachrizal R. and Munkhammar J. Improved Photovoltaic Self-Consumption in Residential Buildings with Distributed and Centralized Smart Charging of Electric Vehicles. Energies, 2020, vol. 13, 1153. [online] [20.10.2023]. Available at: https://doi.org/10.3390/en13051153
[22] Gomez-Gonzalez M., Hernandez J. C., Vera D., Jurado F. Optimal sizing and power schedule in PV household-prosumers for improving PV self-consumption and providing frequency containment reserve. Energy, vol. 191, 2020, 116554. [online] [12.01.2024]. Available at: https://doi.org/10.1016/j.energy.2019.116554
[23] Fernandez J. M. R., Payan M. B., Santos J. M. R. Profitability of household photovoltaic self-consumption in Spain. Journal of Cleaner Production, vol. 279, 2021, 123439. [online] [13.02.2024]. Available at: https://doi.org/10.1016/j.jclepro.2020.123439
[24] Tamrakar E., Patel R. N., Kumar A. et al. Experimental Investigation and Power Quality Analysis of Solar Micro-inverter for different Operating Conditions. E3S Web of Conferences 405, 02024, 2023, 14 p. Available online: https://doi.org/10.1051/e3sconf/202340502024
[25] Jaszczur M., Hassan Q. An optimisation and sizing of photovoltaic system with super capacitor for improving self-consumption. Applied Energy, vol. 279, 2020, 115776. [online] [15.02.2024]. Available at: https://doi.org/10.1016/j.apenergy.2020.115776
[26] Šriupša L., Vaitkūnas M., Baronas A., Dosinas J. Analysis of Self-generated PV Energy Consumption Profiles in Prosumers Microgrid. International Journal of Sustainable Energy. 2023, vol. 42, No. 1, pp. 1583–1602. [online] [15.02.2024]. Available at: https://shorturl.at/fmGKZ
[27] Lage M. R., Castro M. G., et al. Techno-economic analysis of self-consumption schemes and Energy communities in Italy and Portugal. Solar Energy, vol. 270, 2024. [online] [09.03.2024]. Available at: https://doi.org/10.1016/j.solener.2024.112407
[28] Ritson S. and Elkhateb A. An Overview of Microinverter Design Characteristics and MPPT Control. Queen's University Belfast - Research Portal. Published 2020, 10 p. [online] [15.03.2024]. Available at: https://pureadmin.qub.ac.uk/ws/portalfiles/portal/286936784/2009.06055v1.pdf
[29] Stanka N., Aboltins A. The efficiency of grid-tied PV systems on small farms in Latvia. BoZPE, Vol. 10, No 1/2021, 111-118.online] [15.03.2024]. Available at: https://shorturl.at/ratku
[30] Grünwald M., Michaud S. How tandem solar cells can speed the energy transition. World Economic Forum Meeting, January 15, 2024. [online] [17.03.2024]. Available at: https://shorturl.at/qxE36
[31] Zhan Z. Analysis of current situation of microinverter industry. Sep. 19, 2023. [online] [08.04.2024]. Available at: Analysis of current situation of microinverter industry (linkedin.com)
[32] Fell H. J. IRENA-Chef: Alleine in 2023 wurden mehr Erneuerbare Energien zugebaut, als die Atomenergie in 70 Jahren insgesamt erreicht hat. PV magazine Deutschland. 23 April, 2024. [online] [08.04.2024]. Available at: https://www.pv-magazine.de/2024/04/23/
[33] Schachinger M. Solar module prices hovering at all-time lows. PV magazine, April 22, 2024. [online] [20.02.2024]. Available at: https://www.pv-magazine.com/2024/04/22/