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FROM THE PHOTOVOLTAIC EFFECT TO A LOW VOLTAGE PHOTOVOLTAIC GRID CHALLENGE – A REVIEW

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Keywords: Photovoltaic cell; Development; Photovoltaic systems; Prosumers; Grid challenges; Possible solutions.

The paper investigates the progress of on-grid photovoltaic systems in Romania, particularly in the residential and commercial sectors. Emphasizing the financial stability offered by on-grid systems, the study underscores the predictability of solar production and the support from governmental incentives. The graphs and tables presented contain processed data from studies carried out by the governmental authorities. This research acknowledges the pivotal role of photovoltaic cell advancements in enhancing the efficiency and accessibility of on-grid systems. However, the swift expansion of solar capacity raises concerns regarding its impact on low-voltage power transmission grids, leading to fluctuations that may compromise electricity quality. Grid flexibility and battery integration are proposed to address these challenges, recognizing their potential benefits alongside associated costs and technical complexities. The central theme revolves around managing the transition towards sustainable and efficient energy infrastructure in Romania.

1. INTRODUCTION

The development and commercialization of photovoltaic systems (PVS) is an exciting journey that spans almost two centuries and involves a multitude of visionaries, scientists, organizations, and companies. This collective effort transformed how we harvest and use sunlight to generate clean electricity. In essence, the PVS story is about innovation and human cooperation. It began in the 19th century when scientists began exploring the possibility of converting light into electricity. These early discoveries sowed the seeds of an idea that would eventually change the course of energy generation.

In the late 19th century, after French scientist Edmond Becquerel discovered the photovoltaic effect, Charles Fritts took a significant step by creating the first photovoltaic cell [1], even if it had limited efficiency. Through his experiments with selenium, a semiconductor material he coated with a skinny layer of gold, Fritts observed that when this selenium-gold junction was exposed to sunlight, it generated electricity. The discovery was one of the first recorded cases of harnessing solar energy for electricity generation and opened the door to further exploration of solar energy. In 1884, on a New York City rooftop, Charles Fritts installed the first solar panels (Fig. 1).

Fig. 1 – Photo with the first solar panels installed on a New York City rooftop in 1884 [2].

In 1905, Einstein's photoelectric effect theory significantly contributed to understanding how light interacts with materials and how electrons are emitted from a material when exposed to light [3]. This theory had a major impact on the development of modern technologies, including those related to solar cells. One of the significant contributions earned Einstein the Nobel Prize in Physics in 1921.

In 1954, at Bell Laboratories, Daryl Chapin, Calvin Fuller, and Gerald Pearson made significant progress by developing the first practical silicon solar cell (registered to UNITED STATES PATENTS – Fig. 2). Unlike previous solar cells, which had limited efficiency and utility, the silicon solar cell was an essential change, with very high efficiency in converting sunlight into electricity. This was one of the first attempts to use monocrystalline silicon, the innovation marking the beginning of the modern era of photovoltaic panels (PV) and paving the way for their mass production.

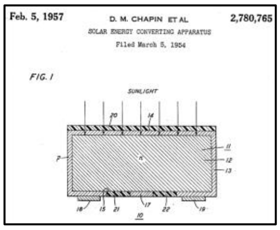

Fig. 2 – Patent of the first practical silicon solar cell [4].

One of the main directions of the development of silicon solar cells was the improvement of the materials used. Doped materials were investigated and used to optimize performance, using techniques such as wet etching and thin-deposition technologies to make the production process more efficient and economical. Polycrystalline silicon has become a widely used material for solar cells since the 1980s. Since the 2000s, thin-film solar cells such as copper-indium-gallium-selenium (CIGS) have begun to be developed and marketed [5]. Perovskite solar cells have become an increasingly important research topic since the 2010s and continue to be developed today [6,7]. Thus, it was possible to lower prices and increase the accessibility of solar cells for industries and residential consumers.

It is important to note that development and innovations in solar energy are continuous, and new types of solar cells and technologies are still in research and development to improve the performance, efficiency and affordability of solar energy.

Currently, the most common types of solar cells are those made of monocrystalline silicon and polycrystalline silicon

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and are used in a variety of types of PVS, each with specific characteristics that suit the needs and conditions required. Depending on the needs and applications, they make up PVS of various types, as well as for special applications (satellites and space missions). Here are some of the most common types of PVS:

– *PVS for homes (residential)* are designed to provide residential electricity. These systems can provide the energy needed to power homes, as well as charge batteries to store surplus energy;

– *commercial PVS* are similar to residential ones, but are sized to power commercial buildings, educational institutions or industries. Business systems can help companies reduce energy costs and meet their sustainability goals;

– *hybrid PVS* – integrate PV with other energy sources, such as wind turbines or fossil fuel generators. Hybrid systems are useful in areas with variable energy resources, such as areas with variable winds or in locations where solar resources are limited in certain seasons;

– *off-grid PVS* are completely independent of the main power grid and are used in areas without access to electricity or in remote locations such as mountain huts or islands;

– *photovoltaic sun tracking systems* are equipped with mechanisms that rotate PV to track the position of the sun throughout the day. This maximizes exposure to direct sunlight and increases electricity production;

– *portable PVS* are mobile and can be transported and installed in various locations. They include portable PV, batteries and a charge controller;

– *embedded PVS in infrastructure* – some infrastructure projects include PV integrated into construction, roads or guardrails to generate electricity and support lighting networks or other devices, thus helping to reduce the carbon footprint of the infrastructure.

Each type of PVS has specific advantages and limitations, and the choice of a system depends on the specific needs of the user, environmental conditions and energy goals.

2. IMPROVEMENT OF PHOTOVOLTAIC SYSTEMS

Beyond the different types of PVS, research continues in photovoltaic technology and can bring new innovations and options in the future. Technological advances have played a crucial role in lowering costs and improving the performance of PVS:

– *photovoltaic cells* – their evolution, presented in the introduction of this paper, was and is an area of intense research. Development and significant advances in technology have a profound impact on the efficiency, durability and cost of PVS;

– *thin film technology* – such as CdTe (cadmium telluride) and CIGS (copper indium gallium selenide), enable the production of lighter and more flexible solar cells. They can be used in a wider range of applications, including integration into building materials and flexible solar modules;

– *tandem solar cells* uses multiple layers of solar cells with different absorption spectra to increase overall efficiency. They can achieve significantly higher efficiencies than traditional solar cells;

– *storage technologies* – the development of lithium-ion batteries and other energy storage technologies allow surplus energy produced during the day to be stored for use at night or on cloudy days;

– *transparent solar panels* can be integrated into windows or glass surfaces, and can be used in buildings to generate electricity without blocking natural light;

– *solar printing* is an emerging technology that uses special printers to apply solar materials directly to various surfaces;

– *development of inverters* – the quest for enhanced conversion efficiency has led to the incorporation of artificial intelligence techniques, as demonstrated in the work cited as [8]. This approach indicates a departure from methods, showcasing a paradigm shift towards intelligent systems for optimizing the performance of inverters. Efforts have been directed towards mitigating secondary effects, such as reactive power. For example, authors of [9] propose optimal reactive power management strategy by applying a recent and performant metaheuristic, namely the sine-cosine algorithm. This strategy not only addresses efficiency concerns but also underscores the significance of managing reactive power to optimize overall inverter functionality. In the pursuit of innovation, advanced control and monitoring technologies have been integrated into inverter systems. The development of diverse inverter topologies, such as the multilevel inverter with a fuzzy logic controller as explored in [10], represents a nuanced approach towards achieving higher performance and control precision. The utilization of fuzzy logic control adds a layer of adaptability and intelligence to the inverter system, contributing to its robustness in diverse operating conditions. The exploration of three system structures, as outlined in [11], has been instrumental in realizing advantages such as lower harmonic content. The consideration of micro-inverters and master inverters underscores the importance of adhering to network standards and regulations. At the same time, the development of autonomous micro-grids is also important, where there is no energy infrastructure. The authors of [12] specifically focuses on the performance parameters of microgrids, such as voltage-frequency regulation, dynamic and steady-state response.

3. DEVELOPMENT OF ON-GRID PHOTOVOLTAIC SYSTEMS ON THE RESIDENTIAL AND COMMERCIAL MARKET IN ROMANIA

In the current economic context and in an effort to reduce the consumption of fossil resources and switch to cleaner and more sustainable energy sources, on-grid PVS are usually the most used. The reasons may be diverse:

– *financial stability* → electricity prices can be volatile and can be influenced by various factors, such as fluctuations in fossil fuel prices or political changes. PVS offer owners some financial stability, as solar energy production is predictable and independent of market factors;

– *government support* → is essential for creating a favorable environment for the development and expansion of PVS in the network. To encourage the adoption of grid-connected PVS, governments and international organizations offer incentives, rebates and tax credits that can significantly reduce initial installation costs and accelerate the payback period for system owners;

– *selling surplus energy* → is an option many owners of such systems consider to maximize financial benefits. This practice involves providing surplus electricity to the public distribution grid and can be an efficient way to earn additional income;

– *simplicity of installation* → can be added to electrical infrastructure without requiring major changes;

– *environmental responsibility* → contributes to reducing carbon emissions and using cleaner energy sources, which is important in the context of climate change;

– *community benefits* → can help create a distributed energy source in communities, reducing the need to transport electricity over long distances.

So here are some additional reasons that support the preference for on-grid photovoltaic systems, especially in areas with developed infrastructure and access to the power grid.

4. THE EVOLUTION OF THE NUMBER OF PROSUMERS IN ROMANIA

The term “prosumer” is a mixture of the words “producer” and 'consumer' and is used to describe an entity (usually a household or business) that generates, consumes, stores, and can trade electricity produced from renewable sources [13].

The prosumer concept has become increasingly important with the increasing adoption of renewable energy and the emphasis on sustainability and energy independence. In Romania, the first person became a prosumer in 2012 by connecting to the national energy grid with a PVS [14]. The process was difficult and expensive, but over time, the legislation in Romania adapted and became much more permissive and, at the same time, encouraging. Subsequently, by the beginning of 2020, according to ANRE (National Energy Regulatory Association), the number of prosumers was 271. After this date, an inflection point occurs where things change radically. This effect is based, on the one hand, on Directive 2018/2001/EC (RED II) [15] of the European Parliament on the promotion of the use of electricity from renewable sources, which provides for a 40% share of renewable energy sources in final consumption by 2030 at European level. On the other hand, by making a series of amendments and additions to the national legislative framework, Romania aims to promote the distributed production of energy from renewable sources. Two funding programs were created:

– *Casa verde Photovoltaics,* which spans several sessions and focuses on home consumers.

– *Electric UP program,* created exclusively for companies such as hotels, restaurants, and cafes.

The implementation led to a significant increase in the prosumer community. This shift in the energy paradigm has prompted a transition towards a decentralization model of electricity production at the local level.

Considering the provisions of Article 73, paragraph (10) of *Law no. 123/2012, introduced* by *OUG no. 143/2021,* [16] ANRE monitors, by publishing an annual report, the development and functioning of prosumers. As regards the dynamics of the evolution of the number of prosumers, in the analysis carried out for January 2020 – December 2021 [17], we observe a constant upward trend in the number of prosumers during the first nine months of 2020. This continuous increase was followed by a significant acceleration between September and December 2020 (Fig. 3), marking the implementation of legislative changes that increased the installed capacity from 27 kW to 100 kW.

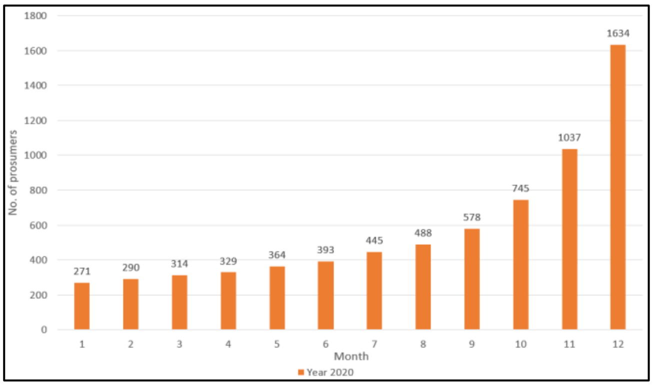

Fig. 3 – 2020 monthly evolution of the number of prosumers.

The evolution of installed power in 2020 is illustrated in detail in Fig. 4, providing significant insight into the transformations in solar energy. Relevant data reveal two distinct trends in this time frame. In the first part of the year, the increase in installed power is constant but timid, a period marked by increased attention and gradual familiarity with the benefits of renewable energy sources. In the second part of the year, the evolution experiences a significant improvement from month to month. The data shown in Fig. 4 reflect a numerical increase and a change in mentality and priorities regarding energy sources.

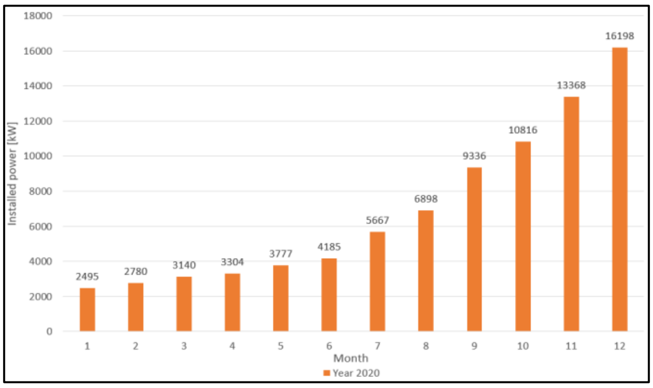

Fig. 4 – 2020 monthly evolution of the installed power.

During 2021, according to the same report [17], it was noted that the prosumer sector became extremely dynamic within the electricity sector. The entry into force of the above-mentioned regulations [16] catalyzed a notable transformation in the energy landscape, culminating in the registration of 13596 prosumers at the end of the mentioned period (Fig. 5) which have accumulated as installed power 84 946 kW (Fig. 6).

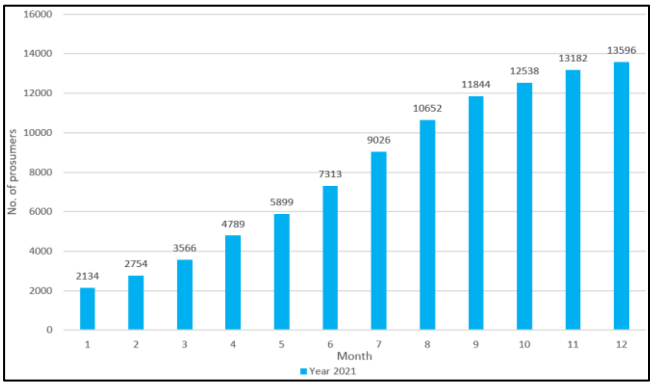

Fig. 5 – 2021 monthly evolution of the number of prosumers.

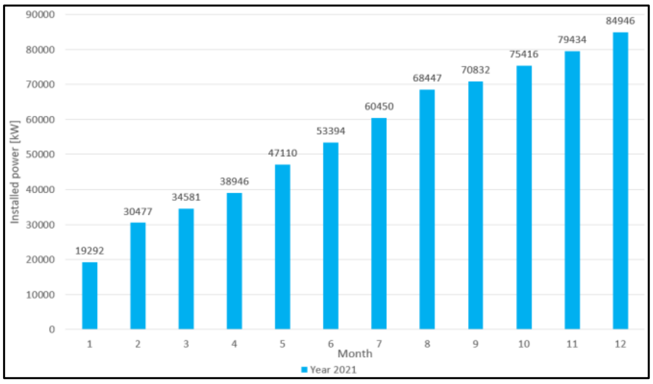

Fig. 6 – 2021 monthly evolution of the installed power.

The above data were obtained by analyzing the total number of prosumers, regardless of the type of renewable energy source they used [17]. Table 1 below provides data on the number of prosumers and installed power according to the type of energy conversion used by the power generation plant.

Table 1

Prosumers number and installed electrical power/ type of energy conversion source for 2021

No.	Energy conversion type	No. of prosumers	Total installed power [kW]
1	Solar	13 588	78 139
2	Biogas	1	6760
3	Wind	5	27
4	Hydro	1	15
5	Biomass	1	5
Total		13 596	84 946

13 588 prosumers use solar energy to produce electricity, totaling a total installed power of 78 139 kW. Thus, with the help of calculation (1), we can deduce an average of the installed power per prosumer at the end of 2021:

$$P_{solar} = \frac{P_{solar\ total}}{No_{solar\ prosumers}} = \frac{78\ 139}{13\ 588} \cong 5.75\ \text{kW/prosumer} \quad (1)$$

Continuing with the progress of the number of prosumers, the analysis for 2022 reveals an interesting trend [18]. In the first half of the year, nothing remarkable is observed. Still, between July and December, this trend increases with the entry into force of legislative changes on the rules for trading electricity generated in renewable plants. The final result at the end of the year indicates an impressive number of 40 159 prosumers (Fig. 7).

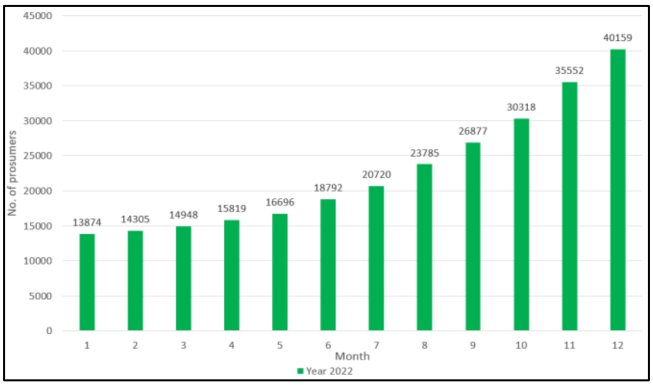

Fig. 7 – 2022 monthly evolution of the number of prosumers.

The total installed power, shown in MW this time, is highlighted in Fig. 8.

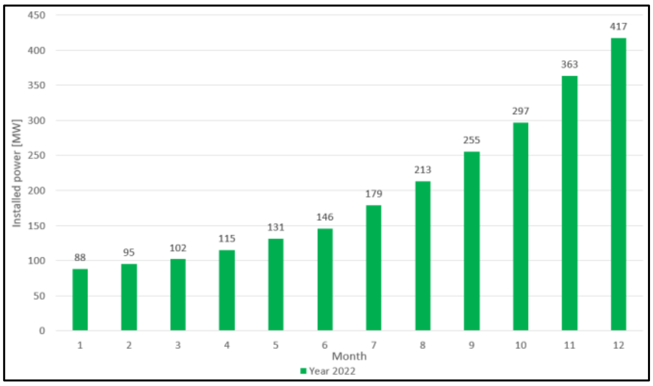

Fig. 8 – 2022 monthly evolution of the installed power.

For the year 2022 [18], the number of prosumers, as well as installed capacity by type of energy conversion used, are presented in Table 2.

Table 2

Prosumers number and install electrical power/ type of energy conversion source for 2022

No.	Energy conversion type	No. of prosumers	Total installed power [kW]
1	Solar	40 157	409 628
2	Biogas	1	6760
3	Wind	4	22
4	Hydro	2	300
5	Biomass	4	701
Total		40 168	417 411

The calculation of the average installed solar power per prosumer (calculation 2) at the end of 2022 demonstrates that this installed power has approximately doubled its value. This denotes that prosumers tend to use electricity more and more.

$$P_{solar} = \frac{P_{solar\ total}}{No_{solar\ prosumers}} = \frac{409\ 628}{40\ 157} \cong 10.20\ \text{kW/prosumer} \quad (2)$$

A very important thing to note is that the electricity distribution operators to which prosumers are connected have yet to identify any prosumer that owns a storage facility for the electricity produced [18].

In the context of the annual evolution of the number of prosumers connected to the electricity distribution network at the end of 2022 [18] and considering the encouragement of the development of renewable electricity production capacities owned by prosumers from the same year, it is estimated that at the end of 2023, there will be approximately 140 000 prosumers (Fig. 9). The figure is realistic because, within the implementation of the Environmental Fund Administration (AFM) *Casa verde fotovoltaice* 2023 program [19–27], the number of new electricity generation capacities with financial support will be 87 500 (Table 3).

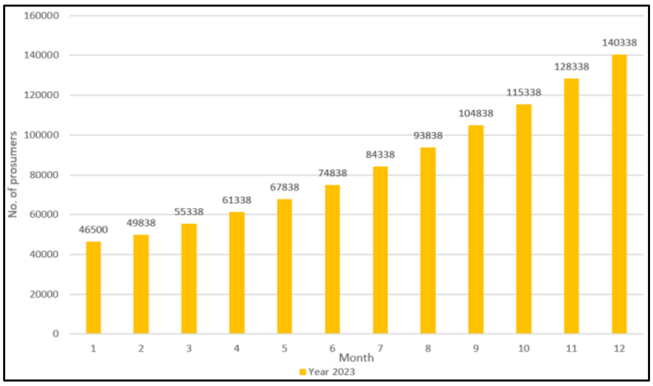

Fig. 9 – 2023 predicted the monthly evolution of the number of prosumers.

Table 3
New electricity production capacities no. with the financial support of AFM 2023

No.	Romanian geographic region	New electricity production capacities
1	București-Ilfov	4993
2	Center	12253
3	North East	13974
4	North West	12001
5	South East	10620
6	South	14045
7	South West	8715
8	West	10024
9	Cult units	875
Total		87500

5. ON-GRID PV SYSTEMS → CHALLENGE FOR THE NATIONAL LOW VOLTAGE GRID

The integration of distributed photovoltaic energy results in unique benefits such as reduced losses on electricity transmission lines, increased resilience of these grids, and reduced generation and operating costs [28]. However, the PVS can also negatively impact electrical transmission systems, especially if their penetration level is high. These impacts can dependent on the size and also the location of the PVS:

– *Reverse power flow*. In a conventional distribution system, the power flow is predominantly unidirectional, originating from the medium voltage system and directed towards the low voltage system. However, as the integration of PVS reaches higher penetration levels, a noteworthy shift occurs, particularly during peak sunlight hours, such as in the middle of the day. At these times, the cumulative net production from PVS can surpass the concurrent net demand within the distribution network. Consequently, a reversal emerges in the direction of power flow, with electricity moving from the low voltage side back to the medium voltage side. This phenomenon of reverse power flow introduces challenges, including the overloading of distribution feeders and increased power losses. Automatic voltage regulators, strategically positioned along distribution feeders to maintain a stable voltage profile, are adversely affected.

– *Voltage fluctuation along distribution feeders is common* when solar power is integrated. The intermittent nature of solar energy generation, influenced by factors such as sunlight intensity, can lead to variations in the electrical output from PVS, affecting the voltage levels. This becomes more significant with the increase in photovoltaic energy production capacities. Voltage fluctuations can lead to violations of existing electricity quality standards. Electrical surges can cause, among other things, two counterproductive effects: ***electrical appliances are supercharged***, the value of the electrical voltage exceeding the standard power supply range 230 V ±10% [29]; ***interruption of electricity production*** by PVS due to the detection of too high a value of the electrical voltage of the low voltage network (the threshold is 230 V + 10%), and the resumption is made only after the completion of the minimum waiting time (preset by installers to the value set by the regulations in force). According to distributors, the mandatory minimum waiting value in Romania is 15 minutes. An example is demonstrated via two screenshots obtained from the interface of an ON-grid inverter operating in a three-phase residential system. Figure 10 shows that the maximum allowed value of the electric voltage exceeded, reaching 257 V, due to the overproduction of energy.

Fig. 10 – Overvoltage of the low voltage grid.

Figure 11 illustrates the initiation of the protection mode in the inverter, which resulted in an interruption of the PVS production between 14:10 and 14:25 on 26.03.2023.

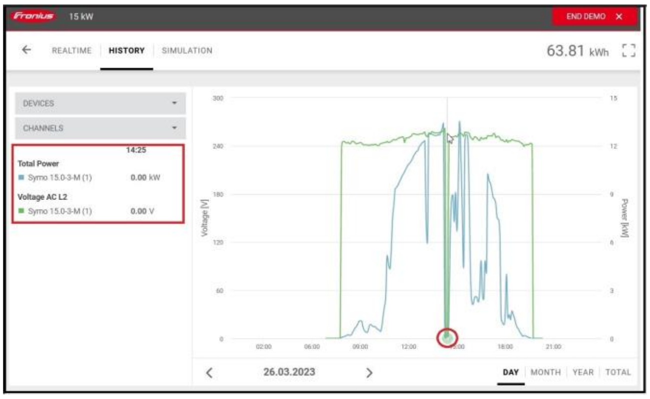

Fig. 11 – Activation of the inverter protection mode followed by an interruption of electricity production.

To eliminate these inconveniences, one option would be to make the low-voltage network more flexible.

Another option would be upgrading current on-grid systems by integrating specific batteries into PVS. The result can be positive as the batteries act as a load and take the peak voltage during the maximum power produced. This can be done by:

i. adding batteries and replacing the inverter, the equipment would be expensive. Each established inverter manufacturer works exclusively with specific batteries;

ii. adding batteries alongside various inverter/ solar chargers, requiring different wiring for integration, for instance, AC-DC (the energy storage system is coupled with an AC power source such as a PV inverter), DC-DC coupling (the energy storage system is coupled with a DC power source directly such as PV panels). In addition to the integration of batteries in the PVS, their control is also important to eliminate possible risks of use. Thus, solutions can be proposed to improve the safety and longevity of batteries in grid-independent PVS by applying machine learning techniques for fault detection and diagnosis [30].

– *phases unbalance*: the utilization of single-phase inverters in small residential PVS is a common practice, However, a potential challenge arises when these inverters are not evenly distributed among different phases of the system.

To moderate voltage unbalanced, specific solutions can be considered: ***proper inverter distribution*** → ensuring an even distribution of single-phase inverters among different phases is crucial; ***monitoring and control systems*** → implementing advanced monitoring and control systems can help detect and address voltage unbalanced issues in real-time; ***education and awareness*** → simple guidelines on how to distribute inverters and manage loads can contribute to maintaining a balanced electrical system.

– *harmonic distortion*, stemming from the use of power inverters to convert DC to AC in PVS. It arises when the waveform of the current or voltage deviates from the ideal sinusoidal shape, introducing frequencies that are multiples of the fundamental frequency. Here are some implications of this problem: ***overheating in capacitor banks*** → capacitors are commonly used in power systems to correct power factors and improve system efficiency. Harmonics can cause overheating in capacitor banks; resonance issues → harmonic distortion can determine resonance in the power system; ***false operation of protection devices*** → harmonic currents can interfere with the proper functioning of protective devices.

These problems also can have remedies such as the selection of high-quality inverters → choosing inverters with advanced technology and built-in harmonic filtering capabilities that can contribute to reducing harmonic distortion; ***filtering and power conditioning*** → installing harmonic filters and power conditioning equipment can help mitigate harmonic distortion. These devices suppress or eliminate unwanted harmonics, ensuring a cleaner and more sinusoidal waveform.

6. CONCLUSION

Continuous advancements in the efficiency and affordability of photovoltaic cells, leveraging the photovoltaic effect, have been instrumental in the widespread adoption of PVS. The evolution of on-grid PVS in Romania is marked by significant growth driven by financial stability, government support, and environmental considerations. The concept of prosumers has gained prominence, with a notable increase in their numbers following legislative changes and supportive programs.

This growth challenges the national low-voltage power grid, leading to voltage fluctuations and potential disruptions. These issues necessitate innovative solutions, including considering advanced technologies such as energy storage systems and hybrid configurations.

The ongoing evolution underscores the need for a balanced approach, considering the environmental benefits, economic implications, and technical requirements. The trajectory indicates a continued upward trend in adopting on-grid PVS, with an increasing focus on addressing grid compatibility issues and enhancing overall system resilience.

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REFERENCES

1. C.E. Fritts, *On a new form of selenium photocell*, American Journal of Science, s3-26 (156), pp. 465–472 (1883).
2. https://www.smithsonianmag.com/sponsored/brief-history-solar-panels-180972006/
3. A. Einstein, *Über einen die erzeugung und verwandlung des lichtes betreffenden heuristischen gesichtspunkt* (*on a heuristic point of view concerning the production and transformation of light*), Annalen der Physik, **322**, *6*, pp. 132–148 (1905).
4. https://s3.documentcloud.org/documents/702765/solar-cell-patent.pdf
5. B. Barman, P.K. Kalita, *Theoretical Investigation on Performance Enhancement of CIGS Based Solar Cells*, Journal of Nano- and Electronic Physics, **12**, *6*, pp. 1–4 (2020).
6. A. Furasova, P. Voroshilov, D. Sapori, K. Ladutenko, D. Barettin, A. Zakhidov, A. Di Carlo, C. Simovski, S. Makarov, *Nanophotonics for Perovskite Solar Cells*, Advanced Photonics Research, **3**, *9*, pp. 1–20 (2022).
7. A.K. Verma, *Challenges and Potential of Perovskite Solar Cells*, Journal of Ravishankar University, **35**, *2*, pp. 67–75 (2023).
8. S.R. Das, P.K. Ray, A.K. Sahoo, K.K. Singh, G. Dhiman, A. Singh, *Artificial intelligence based grid connected inverters for power quality improvement in smart grid applications*, Computers & Electrical Engineering, **93**, 107208 (2021).
9. M. Burlacu, V. Năvrăpescu, A.I. Chirilă, I.D. Deaconu, *Optimal reactive power management for microgrids based on photovoltaic inverters using sine-cosine algorithm*, Rev. Roum. Sci. Techn. – Électrotechn. et Énerg., **67**, *2*, pp. 117–122 (2022).
10. D. Beriber, A. Talha, A. Kouzou, A. Guichi, F. Boukhafaa, *Multilevel inverter for grid-connected photovoltaic systems*, Rev. Roum. Sci. Techn. – Électrotechn. et Énerg., **67**, *2*, pp. 105–110 (2022).
11. M.A. Ilie, D. Floricău, *Grid connected photovoltaic systems with multilevel converters – modeling and analysis*, Rev. Roum. Sci. Techn. – Électrotechn. et Énerg., **68**, *1*, pp. 77–83 (2023).
12. P. Kumar, M. Kumar, N. Pal, *An efficient control approach of voltage and frequency regulation in an autonomous microgrid*, Rev. Roum. Sci. Techn. – Électrotechn. et Énerg., **66**, *1*, pp. 33–39 (2021).
13. A.N.R.E – National Energy Regulatory Authority, *Order no. 228/2018 for the approval of the Technical Norm "Technical conditions for connection to public interest electrical networks for prosumers with active power injection into the network"*.
14. https://www.greenpeace.org/romania/articol/1198/lucian-popescu-primul-roman-care-s-a-conectat-la-retea-cu-un-sistem-fotovoltaic-pentru-a-obtine-energie-curata/
15. https://eur-lex.europa.eu/legal-content/en/TXT/PDF/?uri=CELEX:32018L2001
16. Government law no. 143/2021 for the amendment and completion of the Electricity and Natural Gas Law no. 123/2012, as well as for the modification of some normative acts.
17. https://anre.ro/wp-content/uploads/2023/03/Raport_prosumatori_2021.pdf
18. https://anre.ro/wp-content/uploads/2023/05/Raport-prosumatori_2022.pdf
19. https://www.afm.ro/main/media/comunicate_presa/2023/comunicat_presa-fotovoltaice_bucuresti_ilfov-2023_05_19.pdf
20. https://www.afm.ro/main/media/comunicate_presa/2023/comunicat_presa-inscrieri_epuizate_regiunea_centru-2023_05_24.pdf
21. https://www.afm.ro/main/media/comunicate_presa/2023/comunicat_presa-epuizare_fonduri_fotovoltaice-2023_05_29.pdf
22. https://www.afm.ro/main/media/comunicate_presa/2023/comunicat_presa-regiunea_nord_vest-2023_06_06.pdf
23. https://www.afm.ro/main/media/comunicate_presa/2023/comunicat_presa-regiunea_sud_est-2023_06_09.pdf
24. https://www.afm.ro/main/media/comunicate_presa/2023/comunicat_presa-epuizare_fonduri_fotovoltaice-2023_06_14.pdf
25. https://www.afm.ro/main/media/comunicate_presa/2023/comunicat_presa-inscrieri_sud_vest_s-au_incheiat-2023_06_19.pdf
26. https://www.afm.ro/main/media/comunicate_presa/2023/comunicat_presa-inscrieri_incheiate_regiunea_vest-2023_06_22.pdf
27. https://www.afm.ro/main/media/comunicate_presa/2023/comunicat_presa-inscrieri_incheiate_unitati_de_cult-2023_06_27.pdf
28. https://www.linkedin.com/pulse/integrating-solar-energy-grid-challenges-remedies-ye-min
29. https://eur-lex.europa.eu/legal-content/EN/TXT/PDF/?uri=CELEX:32019R1782&from=es
30. N. Sabri, A. Tlemçani, A. Chouder, *Real-time diagnosis of battery cells for stand-alone photovoltaic system using machine learning techniques*, Rev. Roum. Sci. Techn. – Électrotechn. et Énerg., **66**, *2*, pp. 105–110 (2021).