energies

Perspective

Modern Use of Prosumer Energy Regulation Capabilities for the Provision of Microgrid Flexibility Services

Anna Ostrowska [1,*], Tomasz Sikorski [1], Alessandro Burgio [2,*] and Michał Jasiński [1,3]

1 Faculty of Electrical Engineering, Wroclaw University of Science and Technology, 50-370 Wroclaw, Poland
2 R&D Specialist and Independent Researcher, 87036 Rende, Italy
3 Department of Electrical Power Engineering, Faculty of Electrical Engineering and Computer Science, VSB-Technical University of Ostrava, 708 00 Ostrava, Czech Republic
* Correspondence: a.ostrowska@pwr.edu.pl (A.O.); alessandro.burgio.phd@gmail.com (A.B.)

Abstract: Due to the prospect of climate change and the challenges posed by the European Union to the modern power grid, a decentralized system based on distributed energy sources is being created from a centralized system based on utility power. It also involves new ideas on the operation and management of power grids, especially at the level of low-voltage distribution networks, where prosumers play a special role. In addition to the transformation of sources to renewables, the aim is to increase the flexibility of power grids by exploiting the regulatory potential of flexible grid components. The issue of grid flexibility assumes particular importance in the case of microgrids and local grids covered by the energy communities. Many posts describe the realization of the task of flexibility through energy storage, e.g., storing storage resources in electric vehicles or the use of energy transformation through conversion to heat, air compression air, or process cooling. However, there seems to be a lack of exploration of the topic, where the photovoltaic inverter could provide a flexible energy source while maintaining the rigor of power quality. This article presents current developments in low-voltage grids and the prospect of using prosumer installations to provide grid flexibility and stability.

Keywords: flexibility of microgrid; prosumer; photovoltaic inverter; energy community; energy market

Citation: Ostrowska, A.; Sikorski, T.; Burgio, A.; Jasiński, M. Modern Use of Prosumer Energy Regulation Capabilities for the Provision of Microgrid Flexibility Services. *Energies* **2023**, *16*, 469. https://doi.org/10.3390/en16010469

Academic Editor: Luis Hernández-Callejo

Received: 24 November 2022
Revised: 26 December 2022
Accepted: 28 December 2022
Published: 1 January 2023

1. Introduction

Various legislative authorities' actions, e.g., the NC RfG Network Codes on the requirements for connecting generating units to the grid, introduced by a European Union Commission Regulation, and the growing interest in renewable energy sources (RES), manifested by a significant amount of installed capacity power, which, for example, in Poland at the end of the second quarter of 2022, reached the installed capacity power of micro-installations at the level of 7 GW (a fourteenfold increase in the last three years), in the form of more than one million installations [1], has led to the strengthening of the regulations for the operation and connection of photovoltaic installations, contained in the EN 50549 standard [2]. The standard and national Distribution Grid Operation and Maintenance Manuals developed on their basis regulate aspects such as voltage operating range, voltage-related active power reduction, generation curtailment, and remote information exchange.

Photovoltaic (PV) installations, as the main object of interest due to their availability and efficiency of operation, are the most common among renewable energy sources connected to the public low-voltage (LV) distribution grid. A prosumer, that is, an entity—an individual or an industrialist—builds his prosumer installation on a generating unit and, as is increasingly common, with a battery energy storage (BES). Despite the satisfactory volume of energy produced from the photovoltaic installation, the grid operator faces many problems in the low-voltage grids. These range from problems with maintaining levels of power quality parameters to excess energy not used on an ongoing basis in the microgrid area and transmitted from the microgrid to the master system.

We distinguish between different types of prosumers depending on how they use electricity. The individual prosumer (home prosumer) uses energy for their own use to meet the needs of life. An industrial prosumer (including agricultural) uses energy mainly for their business needs. This involves the manner and terms of the contract signed with the grid distributor for the provision of energy supply services and, in the case of production by the prosumer, the receipt of energy. The prosumer entrepreneur is characterized by greater investment resources.

Various (renewable) energy sources comprise prosumer installations: photovoltaic systems that produce electricity, ready to be converted into any other form of energy; solar collectors, heating the heating medium, which is not directly a source of electricity but allows one to reduce the energy demand in the balance of the building; wind and water turbines, which convert the mechanical energy of wind or water into electricity; and finally, hydrogen fuel cells.

This paper describes the areas of current research in the management of prosumer installations and produced electricity to optimize operation, minimize costs, and balance the energy generated and consumed. The given solutions in the area of the flexibility of prosumer microgrids have different directions depending on the layer occupied in the microgrid architecture—hardware layer, communication layer, control systems and energy market management, and the area of knowledge explored—engineering, economics, electronics, computer science or cyber security.

Renewable Energy Sources

The basis for the creation of microgrids is the source of energy, in particular, renewable energy sources, which are key to the net-zero transition. Renewable energy sources listed in the literature [3] are highlighted in Table 1, and the characteristics of each source are compared in terms of suitability in electricity generation and the flexibility of microgrids.

Table 1. Comparison of renewable energy sources in the context of electricity generation.

Source	Weather Dependency	Power Adjustment Range	Connection Level	Flexibility in Microgrids and Controllability
photovoltaic installation	yes	full power range	individual prosumer and group supply	available (power balance control)
wind turbine	yes	limited from above and below	distribution network, group supply	none (can be turned on and off)
hydroelectricity	some extent	full power range	distribution network	available (quick adjuster)
hydrogen fuel cell	no	full power range	data not available	available (quick adjuster)
geothermal energy	no	full power range	distribution network	n/a
biomass, biogas	some extent	from about 60% of rated power	individual and agricultural prosumer, distribution network, group supply	available, from the minimum parameters of the alternator

It is worth noting that the sources mentioned can be divided by weather dependency. Photovoltaic and wind power are highly weather-dependent and hard to forecast for further than a day ahead. Photovoltaic installation is more predictable due to the fact that the Sun operates at rigid hours and analogously during a given period of the year. For wind turbines, determining the timing depends on whether it is an off-shore generator, where winds are more constant than with on-shore generators. Production from windmills intensifies at dawn and dusk but does not have such rigidly defined hours as solar power. Water-based power generation is weather-dependent in some respects. Water levels that depend on the season and region matter for river and pumped storage power plants. The level of biomass and biogas obtained also depends in part on the weather, which affects the conditions for growing crops for biofuels and, thus, the quantity and quality. Independent of the weather are hydrogen fuel cells and geothermal power plants.

The photovoltaic installation is characterized by operation in a wide range of power and can be connected to individual and industrial prosumer installations and as farms to power a group of consumers. The prosumer installation is a flexible source, and it is possible to regulate the balance of active and reactive power.

The biggest disadvantage of a wind turbine is that it operates with a limitation from below when the wind is too low and from above when the wind is too high. Although the rated parameters are matched to the conditions in which the turbine operates, the operation of the turbine is not constant but variable, and there is no possibility of adjusting the power on the turbine. It is only possible to brake the turbine for safety reasons. In practical applications, wind turbines are designed for larger capacities and connected to the medium-voltage distribution grid. They are not applicable to prosumers [4].

Hydroelectric power plants have a wide range of capacities but are limited from the bottom up to get the parameters for turbine acceleration. For pumped storage power plants, a wide range of power output is possible, and in particular, the power plant can be put into operation very quickly for either generation or reception of energy. Hydropower plants are designed for larger capacities and are connected to the medium-voltage distribution grid.

Hydrogen fuel cells have a wide range of applications from small to large capacities and for vehicles. There is no information on connecting such a source to the public distribution network. Power regulation is extensive. The problem for the moment is hydrogen storage [5].

Power plants operating through geothermal have a wide and fixed power range, controllable within the range of a given generator. The only problem is that the variety of conditions for a geothermal-based power plant depends on geography, which means that geothermal is not the optimal solution for energy production for every region due to accessibility to the inner layers of the Earth.

Biomass and biogas operate on the principle of a conventional generator, which needs the combustion of biofuel to produce energy. The power range depends on the device used. It can be connected to prosumer installations, supply a group of consumers, or supply the medium-voltage distribution network. Power regulation is available, but the amount of power depends on the quality of the fuel (crop).

It is natural that each of the sources listed in Table 1 can be expanded with energy storage (battery or mobile), which will increase the availability of energy in these sources by storing energy beyond the time of their target availability (this especially applies to solar and wind power, which can not be activated at any time due to weather-dependence and well-dependence). Therefore, these battery-based energy storage facilities and electric vehicles can be treated as secondary sources with high availability because, once charged, these devices operate in electricity production mode. They are also of great importance in making microgrids more flexible, as described in Section 3.

2. Statistical Analysis of Recent Research on the Flexibility of Microgrids

In order to discuss the prospects for development and planned directions of research on the flexibility of distribution networks with prosumers' participation, an analysis of the research conducted to date and the current state of knowledge concerning the field was conducted (state of the art). The search was conducted on the basis of the methodology presented in this section.

Methodology

The analysis of the current state of knowledge and previous research was conducted with the help of the scientific database Scopus, published by Elsevier, which contains a significant collection of peer-reviewed literature. The search was restricted to the following collections: literature in published English, in the subject area of energy, and not older than 3 years (collection current as of 15 November 2022). The collection of literature limited to the stated conditions included three articles made available through early access for 2023. The methodology for the analysis of literature resources is presented in Figure 1.

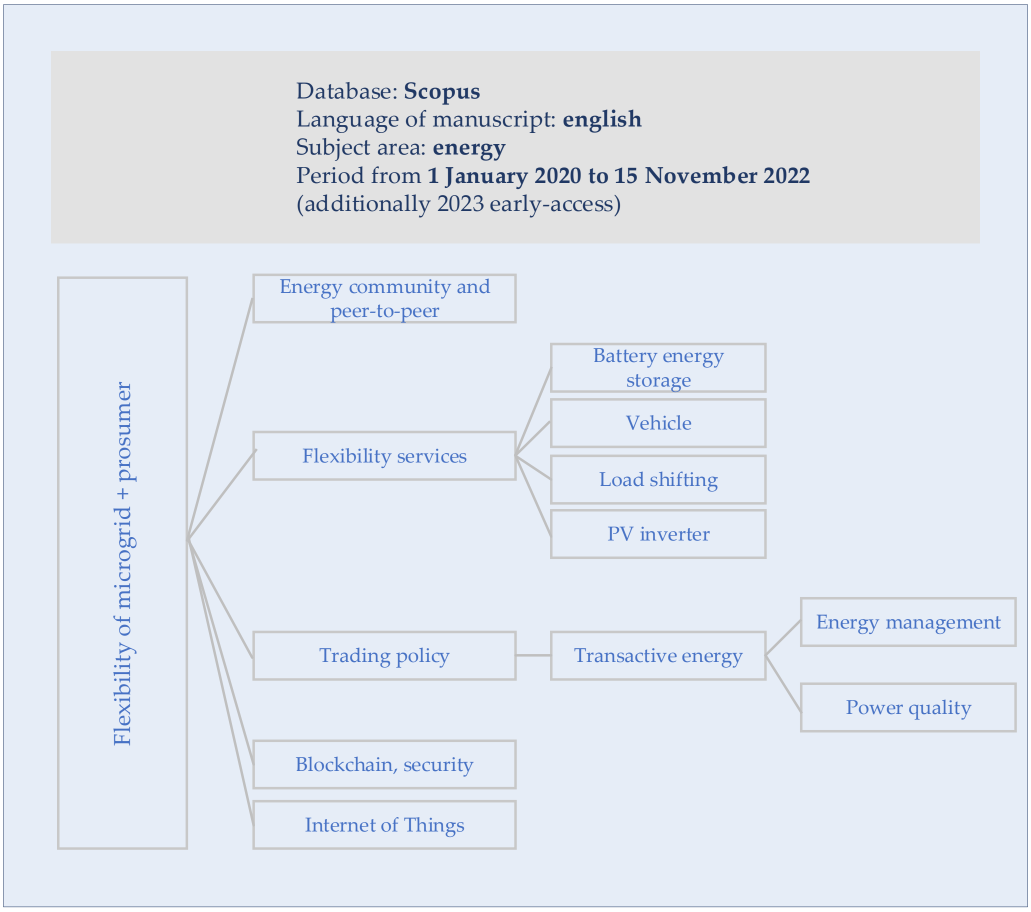

Figure 1. Methodology of analysis of literature resources in terms of selected development directions in the area of electricity grid flexibility, including the contribution of photovoltaic installations.

The main topics of the literature were the "flexibility of microgrid" and "prosumer" keywords. The number of articles in this subject area in the last three years is 166 papers, which are articles, reviews, conference papers, or short surveys. In addition, in order to check the interest in the topic of the flexibility of microgrids over the years, the number of articles published on the topic since the first mention in 2015 was checked. The total number of articles from 2015 to 15 November 2022 (not including early access) is 206 papers. The number of published articles in a given year is shown in Figure 2.

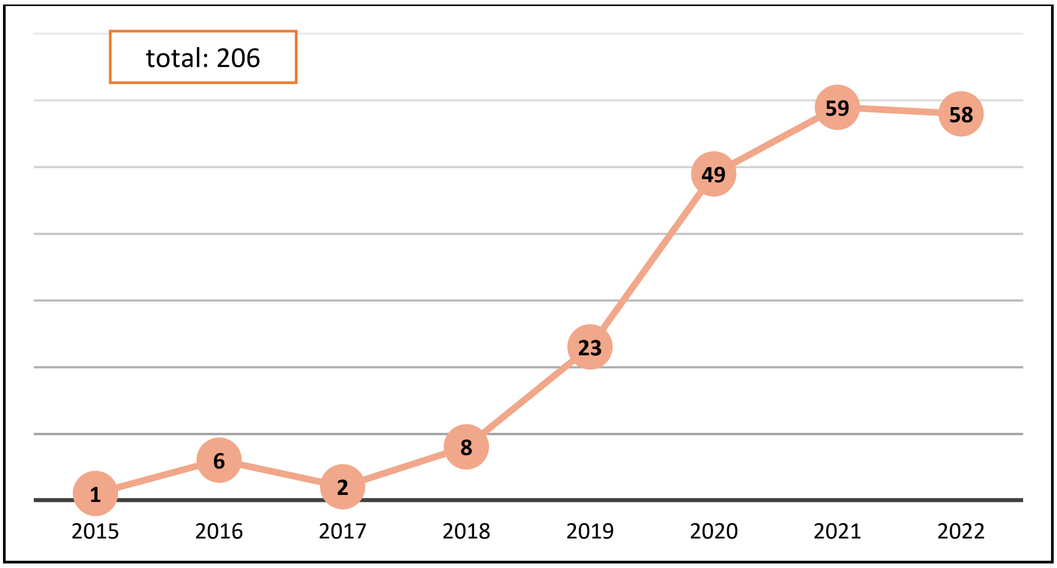

Figure 2. The number of papers published in consecutive years in the areas of electricity grid flexibility and prosumer participation.

An analysis of the number of articles on the topic by year since 2015 shows that the popularity of the topic of electricity grid flexibility and prosumer engagement has been increasing since 2018. Interest in the topic has continued in recent years.

The resulting database of papers over the past three years was analyzed for keywords and leading themes. The main topics of the papers were highlighted and presented in Table 2: energy community and peer-to-peer (P2P), flexibility services, trading policy, blockchain/security, and the Internet of things (IoT). The table indicates the number of articles assigned to a topic.

Table 2. Summary of the number of articles assigned to each keyword corresponding to research directions on the topic of grid flexibility with references.

Main Direction of Research	Number of Papers
energy community and peer-to-peer	99
flexibility services	96
• battery energy storage	68
• vehicle	55
• load shifting	15
• PV inverter	7
trading policy	70
• transactive energy	68
• energy management	27
• power quality	10
blockchain, security	25
Internet of things	24

The most widely covered topics are energy community and peer-to-peer (99 papers) and flexibility services (96 papers). This was followed by trading policy (70 papers), blockchain, security (25 papers), and IoT (24 papers). Sub-topics can be distinguished for flexibility services and trading policy. For flexibility services: battery energy storage (68 papers), vehicle (55 papers), load shifting (15 papers), and PV inverter (7 papers). The term trading policy is subsumed under the term transactive energy, including subtopics: energy management (27 papers) and power quality (10 papers). For the listed main and sub-keywords, the number of articles published in these areas since the first publications appeared in 2015 is shown. In Figure 3, the number of published articles is shown cumulatively.

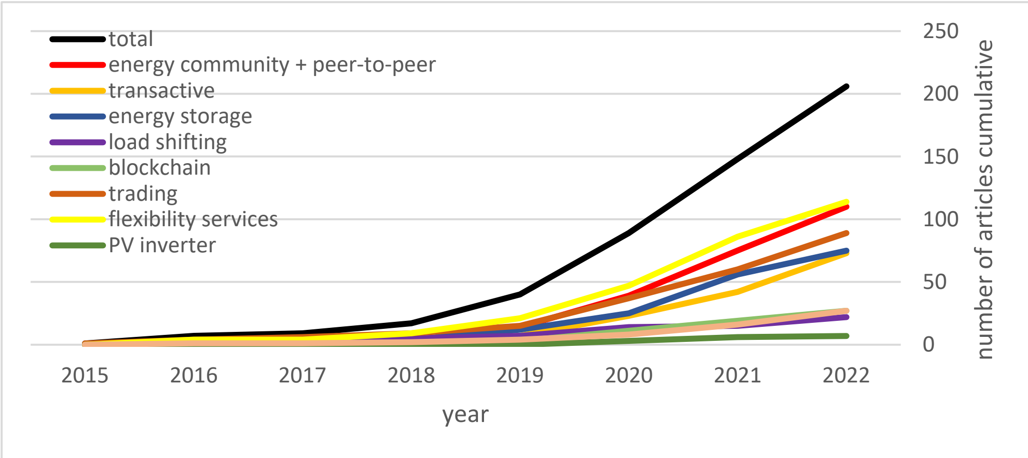

Figure 3. The number of articles published in a given year cumulatively from 2015 for each keyword corresponding to the research directions on the topic of grid flexibility.

For all published articles on these specific keywords, the trend is upward from 2018 to 2019. The largest increase in the number of articles is for the topics of energy community + peer-to-peer and flexibility services. Additionally, energy storage is gaining popularity in particular. Trading policy and transactive energy are also frequently covered topics. Mentioned, but not as popular, are the topics of load shifting, IoT or blockchain, and security. The least popular of the flexibility services sub-topics is the area of PV inverters.

3. Results

On the basis of the literature base selected in the search and the filtering of the work with the topics from Table 1, the architecture of the low-voltage distribution grid connected to the National Power System (NPS) with the participation of distributed sources was developed. The architecture makes it possible to establish the current structure forming the microgrid and allows one to organize current and future research directions concerning the area of grid flexibility.

Ongoing Research Topic on Field of Flexibility Service

Low-voltage distribution grids with a high concentration of distributed sources, including prosumer installations, are described and studied in articles depending on the criterion considered. In order to facilitate the discussion of current research directions, the electricity grid from the prosumer's point of view can be described as follows (based on Figure 4). The basic unit in the grid is the prosumer, i.e., a participant in the NPS who is both a consumer and a generator of energy. The installation of an individual prosumer or industrial prosumer consists of generation units (PV, wind turbine, solar collectors), offtake, and energy storage in the form of thermal storage, battery energy storage, or mobile energy storage (electric vehicle). Prosumers, together with other market participants, can come together in communities (energy clusters, energy communities, prosumer cooperatives) to form a local energy market, which is then connected to the public electricity grid joining the global energy market.

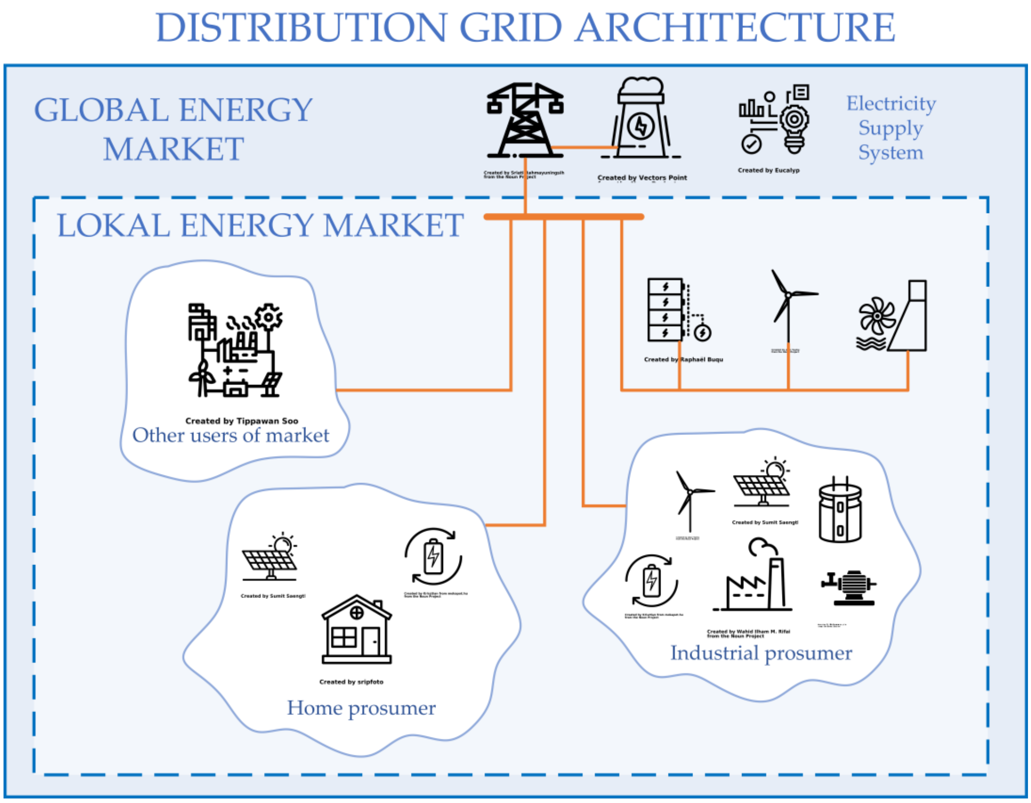

Figure 4. Modern architecture of distribution grids detailing users and the concept of participation in the local and global energy market.

For the effective operation of individual users in the local and global energy market, correlated operation on several layers of the network is essential. The entire system consists of a physical (hardware) layer, a communications layer, an interoperability control and security layer, an energy market management layer, and an energy exchange money market (Figure 5).

The current research is going in the directions listed in Table 1. The most popular is to operate according to the idea of an energy community and the equality of all entities constituting such a community, i.e., a peer-to-peer (P2P) cooperation model [6]. The articles describe models of cooperation between prosumers and consumers in energy communities or energy clusters, forming a local energy market. The goal set for such a market is to maximize the consumption of energy produced from renewable energy sources, minimize costs and maximize profits when exchanging energy with the global energy market. The capacities and parameters of the individual devices that make up prosumer installations are selected [7]. PV and BME operation are optimized for the individual prosumer and the housing cooperative [8]. Many works use game theory to predict the prosumer's actions [9,10]. The concept of virtual energy storage is emerging, as well as the exchange of energy between participants in the local energy market using bidding and energy trading.

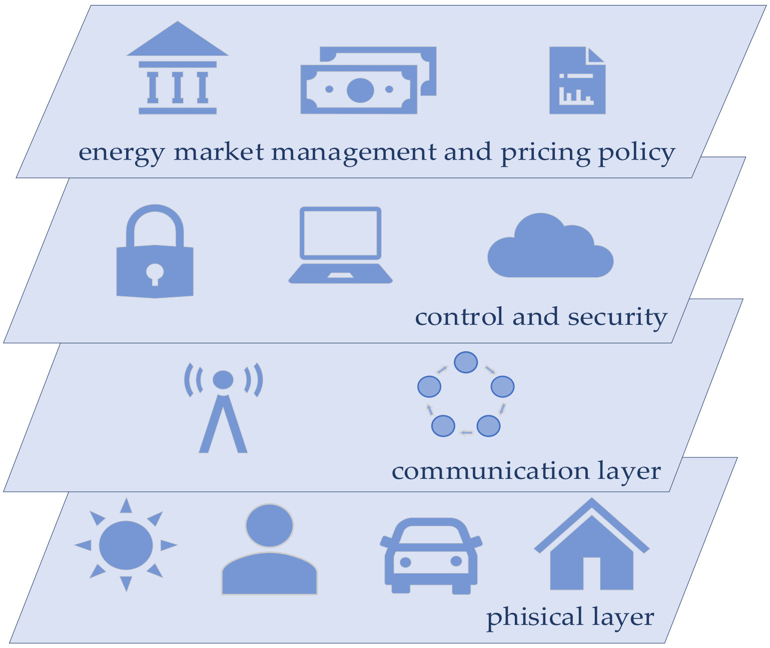

Figure 5. Concept of several layers of the command and control system of modern power grids.

Another popular topic of research is devices that are able to increase the flexibility of the power grid [11]. Battery energy storage is an object that is rated as the most flexible element of the microgrid, both in terms of storing as a collection or giving back energy as a source [12,13]. Using algorithms, grid models with storage are optimized so that the prosumer gains as much energy as possible or can store energy so that it can be sold at higher prices through price arbitrage. A special case of prosumer energy storage is the electric vehicle, which is mobile energy storage connected as vehicle-to-grid (V2G) [14] or vehicle-to-home (V2H) [15]. Both energy storage facilities and the offtakes themselves may be subject to an operating schedule, as discussed in subsequent works. A special case here is the receivers, which are generally fixed (not flexible) in home installations. Their contribution to flexibility is realized through forecasting [16], scheduling [17], and load shifting [18]. The least developed topic is the use of photovoltaic inverters. The operation of inverters appears in only seven papers over a three-year period, and only one indicates the possibility of using a PV inverter as a source of regulation for frequency [19].

A topic related to the relationship between the local and global energy market is energy trading and transactive energy [20]—that is, describing the prosumer as an active participant in the energy market [18]. Articles point to a number of solutions for energy trading in the market and pricing policies related to energy flows [21]. The cashless settlement with energy storage in virtual energy storage [14] and cash settlements on the basis of auctions, dynamic tariffs, or monetary stimulus are considered [22]. Market mechanisms are used in energy management so as to achieve the NPS goal of providing energy continuously and uninterruptedly, and for this, it needs to encourage the prosumer to become its own regulator. In addition, the NPS aims to maintain appropriate power quality parameters, which is also considered in publications—what is the impact of distributed energy on the distribution network and power quality [23,24]?

The last topic, related to the layer of structure, control, and protection, is blockchain, security [25], and the Internet of things [26]. Authors of related works solve problems related to the protection of the personal data of prosumers providing in the energy market and the collection, transmission, and processing of data to manage the electricity system [27].

Sporadically covered topics in works in the area of power grid flexibility are hybrid installations, which include wind turbines [4], pumped-storage power plants [28], supercapacitors [29], kinetic energy storage [19], and fuel cells [5].

The end goal of the existence and development of prosumer installations is zero carbon and decarbonization. Intermediate goals that achieve the end goal or go hand in hand with it can be for the prosumer and the NPS: minimizing and optimizing energy consumption and minimizing costs. The future development of the topic of increasing the flexibility of the electricity grid is heading in this direction.

For the local energy market, it is planned to develop and improve the control of prosumer plant components through load forecasting, load shifting and virtual energy storage in the local energy community. There is increasing interest in the use of electric vehicles as energy storage [30] due to the reduction in the production of combustion cars. At the same time, algorithms are being developed to optimize the use of secondary batteries so as to preserve or increase their lifetime.

In the global energy market, energy trading solutions are being improved to suit the nature of production while taking into account the flexibility of prosumer installations and the possibility of prosumers' participation as active members of the energy market.

Studies are planned to develop the concept of working an energy cluster/cooperative into an island separated from the NPS [31], working in the face of a black-out due to an outage or shortage of energy supply. In parallel, work is underway on a solution for the provision of regulation services by prosumers with, for example, energy storage facilities so that the prosumer is itself a regulator of the voltage in the grid [32] while maintaining the rigor of power quality and encouraging skeptical consumers to become prosumers despite the investment risk [33].

An important direction increasingly discussed is the sphere of cyber-security in an IoT-based structure pursuing the tasks of the interoperability of the electric power system and the concern for prosumers' energy data transmitted in the system, which necessitates the development of the previously discussed topics. This is the field of developing blockchain and similar solutions [34,35].

The reason for the narrow interest in the possibility of using a photovoltaic installation as a controllable source may be due to the fact of the number of restrictions introduced by grid codes for this type of source, but most importantly, the high variability in the available generated power dependent on weather conditions. The EN50549 standard introduces recommendations for the use of regulation to support the maintenance of voltage levels, which in extreme cases, with a high concentration of photovoltaic installations, results in their cyclic activation for the purpose of limiting the increase in voltage. However, it seems that the use of weather prediction in combination with flexible power factor regulation could effectively contribute to the prevention of switching on photovoltaic installations arising from the voltage rise limiting rule. Thus defined, the activities conducted in the direction of power factor reduction involve a temporal limitation of the generated active energy in favor of reactive energy regulation. This requires consideration of the rules for the provision of grid flexibility services by photovoltaic installations, including issues of formulation of the contract for the provision of flexibility services.

4. Discussion and Conclusions

In the face of the expansion of the distribution grid with more photovoltaic sources, it will be necessary to use all possible regulatory resources, including the use of regulatory resources of photovoltaic inverters themselves. The photovoltaic inverter, thanks to its built-in control modes, is able to change the balance of active and reactive power for a specific purpose depending on the selected mode and thus affect the parameters of voltage.

As a first step, weigh the possible control modes available when considering a photovoltaic installation as an active flexibility resource. In existing installations, inverters can be set to operate with a power factor of cosφ fixed at a preset level, most often cosφ = 1. Current regulations related to the introduction of the network code described by EU Regulation 2016/631 and subsequently included in the EN 50549-1:2019 standard introduce two regulation modes of the reactive power: Q(U) and cosφ(P). The mentioned current method limits the flexibility potential of the photovoltaic installations to control voltage.

The first method formulates the output of the reactive power of the PV inverter, in both directions generated and absorbed, in dependence on the measured voltage at the point of the common coupling. The realization follows the fixed characteristic, Q(U), defined in the grid code. The second method does not use a measurement of voltage; however, it constitutes the contribution of absorbed reactive power in the function of generated active power. The method uses a fixed characteristic of variable cosφ(P). Both mentioned current methods use local parameters of voltage or generated power, do not consider distributed control data collected within the microgrid, and finally, due to standard recommendation, the method implements a narrow range of reactive power regulation up to cosφ(P) = 0.9. However, it seems that in the future, in order to achieve full utilization of the inverter's flexibility resources, strategies based on distributed regulation through the use of remote access of the grid operator or aggregator of microgrid flexibility resources to the inverter should be considered. In the case of active access to the inverter's regulation resources, the current volume of active and reactive power share would depend on the current flexibility target formulated by the microgrid flexibility aggregator, which considers technical limitations. Applied and prospective methods for managing inverter control resources are shown in Figure 6.

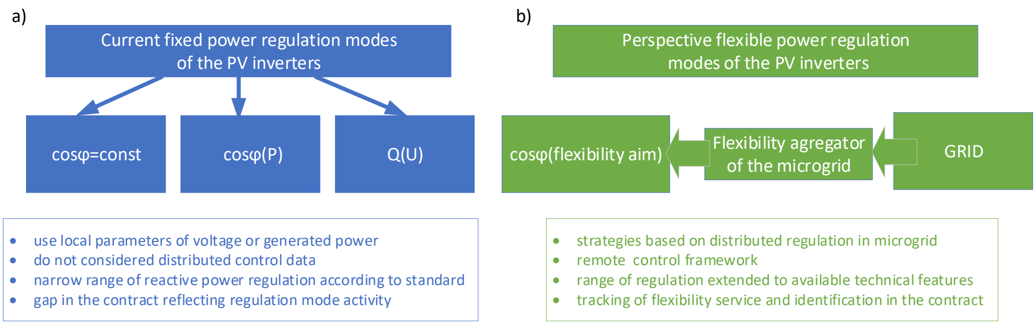

Figure 6. Current (**a**) and prospective (**b**) methods for managing inverter control resources for flexibility purposes.

In order to identify the technical limitations associated with the maximum regulation capabilities of the share of active and reactive power, the authors of this paper analyzed the technical capabilities of the power factor regulation range in a group of 11 selected photovoltaic inverters. The identified maximum regulation capabilities based on the technical documentation of the 11 analyzed inverters are shown in Figure 7. The analysis presented shows that the range of regulation that the inverter is able to achieve based on the built-in hardware of the device, given in the power factor cosφ values, is at least from 0.8cap to 0.8ind, verified for the TD of the 11 photovoltaic inverters with a power of 3–6 kW. This is a range higher than current DSO requirements, and for 2 of the 11 devices, the producer declares a flexibility of 0.7cap to 0.7ind.

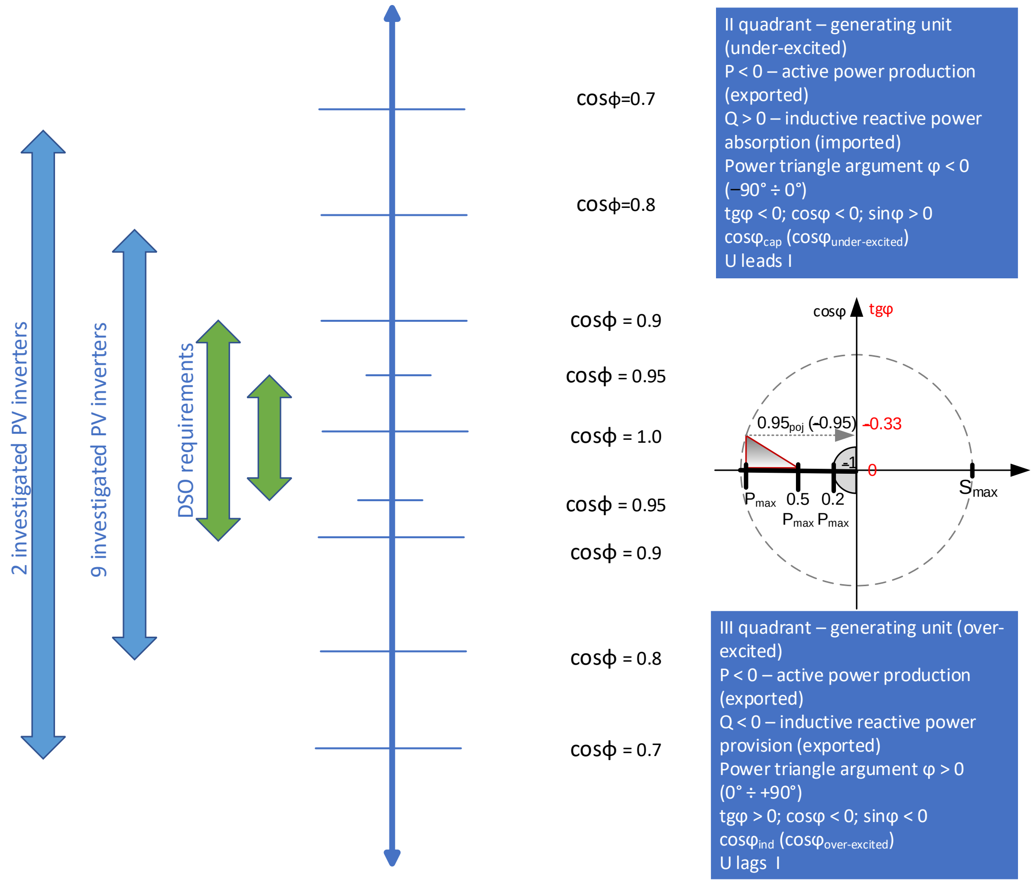

Figure 7. Identification of the maximum regulation capacity based on the technical data of the 11 analyzed inverters.

It should be recognized that the scope of regulation of photovoltaic inverter power is broader than the requirements of network codes, and the number of prosumer installations means that the potential volume of energy available for flexibility purposes could be significant. This creates a new research perspective, the purpose of which could be to define rules for the use of control resources of a photovoltaic installation, especially one that does not have energy storage in its infrastructure and the required investment does not allow the use of BME. The use of an inverter operating in regulation modes alone does not require additional financial outlays from the prosumer. Instead, the challenge is to develop a path and a way to implement this solution in the local energy market, directed at profits and no losses, and in the DSO billing area, assuming that the prosumer would provide a flexible service. From this point of view, selected prospective works include:

- Developing the principles of a business model for the provision of photovoltaic regulatory resources for the provision of flexibility services to local power grids, including the interaction of local user groups within a microgrid or energy communities.
- Developing a trusted communication technology to implement regulation and track the path of energy resources used in the process of providing flexibility services.
- Development of an IT system to support the billing system for flexibility services provided using prosumer installations.
- Use of computational intelligence methods to automate the management of flexible energy resources inside a microgrid or energy community, including the introduction of a peer-to-peer billing model and techniques for predicting available energy volume for flexibility services.

Funding: This research was funded from subsidies for financial resources for the maintenance and development of the didactic and research potential of the Faculty of Electrical Engineering of the Wroclaw University of Science and Technology (no. 8211104160, year 2022).

Data Availability Statement: Not applicable.

Conflicts of Interest: The authors declare no conflict of interest.

Abbreviations

BES	Battery energy storage
cosφ	Power factor
DSO	Distribution system operator
ESS	Electricity supply system
GW	Gigawatt (power unit)
IoT	Internet of things
LV	Low-voltage
P	Electric power
P2P	Peer-to-peer
NPS/PPS	National/Polish Power System
PV	Photovoltaic (installation)
Q	Reactive power
RES	Renewable energy source
NC RfG	Network Codes Requirements for Generators
TD	Technical documentation
U	Supply voltage
V2G, V2H	Vehicle-to-grid, vehicle-to-home

References

1. Mikołajuk, H.; Zatorska, M.; Stępniak, E.; Wrońska, I.; Gawlewski, K. Statistical Information on Electricity No. 9 (345)—September 2022. 2022. Available online: https://www.are.waw.pl/badania-statystyczne/wynikowe-informacje-statystyczne/publikacje-miesieczne (accessed on 23 November 2022).
2. *CENELEC European Standards EN50549-1:2019*; Requirements for Generating Plants to Be Connected in Parallel with Distribution Networks—Part 1: Connection to a LV Distribution Network—Generating Plants up to and Including Type B. CENELEC: Brussels, Belgium, 2019.
3. Daneshvar, M.; Mohammadi-Ivatloo, B.; Zare, K.; Anvari-Moghaddam, A. Optimal Stochastic Water-Energy Nexus Management for Cooperative Prosumers in Modern Multi-Energy Networks. In Proceedings of the 2022 IEEE International Conference on Environment and Electrical Engineering and 2022 IEEE Industrial and Commercial Power Systems Europe, EEEIC/I and CPS Europe 2022, Prague, Czech Republic, 28 June–1 July 2022.
4. Laoharojanaphand, V.; Ongsakul, W. Virtual Battery Storage Service Using Hydropower Plant with Co-Located Floating Solar and Wind Generation. *Sustain. Energy Technol. Assess.* **2021**, *47*, 101531. [CrossRef]
5. Luta, D.N.; Raji, A.K. A 2 MW Grid-Tied Fuel Cell Inverter under a Single Loop Control Scheme. In Proceedings of the Proceedings—30th Southern African Universities Power Engineering Conference, SAUPEC 2022, Durban, South Africa, 25–27 January 2022.
6. Soto, E.A.; Bosman, L.B.; Wollega, E.; Leon-Salas, W.D. Peer-to-Peer Energy Trading: A Review of the Literature. *Appl. Energy* **2021**, *283*, 116268. [CrossRef]
7. Andresen, C.A.; Sale, H.; Degefa, M.Z. Sizing Electric Battery Storage System for Prosumer Villas. In Proceedings of the SEST 2020—3rd International Conference on Smart Energy Systems and Technologies, Istanbul, Turkey, 7–9 September 2020.
8. Brecl, K.; Topic, M. Photovoltaics (PV) System Energy Forecast on the Basis of the Local Weather Forecast: Problems, Uncertainties and Solutions. *Energies* **2018**, *11*, 1143. [CrossRef]
9. Lee, W.-P.; Han, D.; Won, D. Grid-Oriented Coordination Strategy of Prosumers Using Game-Theoretic Peer-to-Peer Trading Framework in Energy Community. *Appl. Energy* **2022**, *326*, 119980. [CrossRef]
10. Henn, S.; Wenzel, T.; Osterhage, T.; Müller, D. A Game Theory Based Optimal Operation Strategy for Neighborhoods. In Proceedings of the ECOS 2021—34th International Conference on Efficency, Cost, Optimization, Simulation and Environmental Impact of Energy Systems, Taormina, Italy, 4–6 July 2021; pp. 299–309.
11. Gough, M.; Santos, S.F.; Javadi, M.; Castro, R.; Catalão, J.P.S. Prosumer Flexibility: A Comprehensive State-of-the-Art Review and Scientometric Analysis. *Energies* **2020**, *13*, 2710. [CrossRef]
12. Guedes, W.; Deotti, L.; Dias, B.; Soares, T.; de Oliveira, L.W. Community Energy Markets with Battery Energy Storage Systems: A General Modeling with Applications. *Energies* **2022**, *15*, 7714. [CrossRef]

13. Zhang, Z.; Lehmal, C.; Hackl, P.; Schuerhuber, R.; Zuo, J. Study of the Dynamic Performance Boundaries of a Converter's Energy Storage Device. *Elektrotechnik Und Inf.* **2022**, *139*, 682–692. [CrossRef]
14. Hashemipour, N.; Crespo del Granado, P.; Aghaei, J. Dynamic Allocation of Peer-to-Peer Clusters in Virtual Local Electricity Markets: A Marketplace for EV Flexibility. *Energy* **2021**, *236*, 121428. [CrossRef]
15. Hernández, J.C.; Sanchez-Sutil, F.; Muñoz-Rodríguez, F.J.; Baier, C.R. Optimal Sizing and Management Strategy for PV Household-Prosumers with Self-Consumption/Sufficiency Enhancement and Provision of Frequency Containment Reserve. *Appl. Energy* **2020**, *277*, 115529. [CrossRef]
16. Saini, V.K.; Singh, R.; Mahto, D.K.; Kumar, R.; Mathur, A. Learning Approach for Energy Consumption Forecasting in Residential Microgrid. In Proceedings of the 2022 IEEE Kansas Power and Energy Conference, KPEC 2022, Manhattan, KS, USA, 25–26 April 2022.
17. Khorasany, M.; Najafi-Ghalelou, A.; Razzaghi, R. A Framework for Joint Scheduling and Power Trading of Prosumers in Transactive Markets. *IEEE Trans. Sustain. Energy* **2021**, *12*, 955–965. [CrossRef]
18. Nizami, M.S.H.; Hossain, M.J.; Amin, B.M.R.; Fernandez, E. A Residential Energy Management System with Bi-Level Optimization-Based Bidding Strategy for Day-Ahead Bi-Directional Electricity Trading. *Appl. Energy* **2020**, *261*, 114322. [CrossRef]
19. Ghaebi Panah, P.; Hooshmand, R.-A.; Gholipour, M.; Macana, C.A.; Guerrero, J.M.; Vasquez, J.C. A Cost-Effective Disturbance Governance Framework for Low-Inertia Autonomous Microgrids. *Sustain. Energy Technol. Assess.* **2021**, *48*, 101640. [CrossRef]
20. Nizami, S.; Tushar, W.; Hossain, M.J.; Yuen, C.; Saha, T.; Poor, H.V. Transactive Energy for Low Voltage Residential Networks: A Review. *Appl. Energy* **2022**, *323*, 119556. [CrossRef]
21. Saviuc, I.; Milis, K.; Peremans, H.; van Passel, S. A Cross-European Analysis of the Impact of Electricity Pricing on Battery Uptake in Residential Microgrids with Photovoltaic Units. *J. Sustain. Dev. Energy Water Environ. Syst.* **2021**, *9*, 1080368. [CrossRef]
22. Tsao, Y.-C.; Dedimas Beyene, T.; Gebeyehu, S.G.; Kuo, T.-C. Renewable Power Distribution Networks Considering Dynamic-Differential Pricing, Carbon Trading, and Solid Waste Recycling: A Fuzzy Programming Approach. *Int. J. Electr. Power Energy Syst.* **2023**, *144*, 108521. [CrossRef]
23. Plamanescu, R.; Dumitrescu, A.-M.; Albu, M.; Suryanarayanan, S. A Hybrid Hilbert-Huang Method for Monitoring Distorted Time-Varying Waveforms. *Energies* **2021**, *14*, 1864. [CrossRef]
24. Plamanescu, R.; Dumitrescu, A.-M.; Albu, M.; Suryanarayanan, S. Monitoring LV Prosumers Operation Using Hilbert-Huang Method. In Proceedings of the UPEC 2020—2020 55th International Universities Power Engineering Conference, Torino, Italy, 1–4 September 2020.
25. Olivares-Rojas, J.C.; Reyes-Archundia, E.; Gutierrez-Gnecchi, J.A.; Molina-Moreno, I.; Cerda-Jacobo, J.; Mendez-Patino, A. A Transactive Energy Model for Smart Metering Systems Using Blockchain. *CSEE J. Power Energy Syst.* **2021**, *7*, 943–953. [CrossRef]
26. Neagu, B.C.; Grigoras, G. A Data-Mining-Based Methodology to Identify the Behavioural Characteristics of Prosumers within Active Distribution Networks. In Proceedings of the 2020 International Symposium on Fundamentals of Electrical Engineering, ISFEE 2020, Bucharest, Romania, 5–7 November 2020.
27. van Leeuwen, G.; AlSkaif, T.; Gibescu, M.; van Sark, W. An Integrated Blockchain-Based Energy Management Platform with Bilateral Trading for Microgrid Communities. *Appl. Energy* **2020**, *263*, 114613. [CrossRef]
28. Li, Z.; Zhang, Q.; Guo, Q.; Nojavan, S. Pumped Hydro Energy Storage Arbitrage in the Day-Ahead Market in Smart Grid Using Stochastic p-Robust Optimization Method. *Sustain. Cities Soc.* **2021**, *75*, 103274. [CrossRef]
29. Hernández, J.C.; Gomez-Gonzalez, M.; Sanchez-Sutil, F.; Jurado, F. Optimization of Battery/Supercapacitor-Based Photovoltaic Household-Prosumers Providing Self-Consumption and Frequency Containment Reserve as Influenced by Temporal Data Granularity. *J. Energy Storage* **2021**, *36*, 102366. [CrossRef]
30. Singh, K.; Singh, A. Behavioural Modelling for Personal and Societal Benefits of V2G/V2H Integration on EV Adoption. *Appl. Energy* **2022**, *319*, 119265. [CrossRef]
31. Mumbere, S.K.; Matsumoto, S.; Fukuhara, A.; Bedawy, A.; Sasaki, Y.; Zoka, Y.; Yorino, N.; Tanioka, Y. An Energy Management System for Disaster Resilience in Islanded Microgrid Networks. In Proceedings of the 2021 IEEE PES/IAS PowerAfrica, PowerAfrica 2021, Virtual, 23–27 August 2021.
32. Hou, P.; Yang, G.; Hu, J.; Douglass, P.J.; Xue, Y. A Distributed Transactive Energy Mechanism for Integrating PV and Storage Prosumers in Market Operation. *Engineering* **2022**, *12*, 171–182. [CrossRef]
33. Medved', D.; Kolcun, M.; Pavlík, M.; Beňa, L.; Mešter, M. Analysis of Prosumer Behavior in the Electrical Network. *Energies* **2021**, *14*, 8212. [CrossRef]
34. Huang, Q.; Amin, W.; Umer, K.; Gooi, H.B.; Eddy, F.Y.S.; Afzal, M.; Shahzadi, M.; Khan, A.A.; Ahmad, S.A. A Review of Transactive Energy Systems: Concept and Implementation. *Energy Rep.* **2021**, *7*, 7804–7824. [CrossRef]
35. Botelho, D.F.; Dias, B.H.; de Oliveira, L.W.; Soares, T.A.; Rezende, I.; Sousa, T. Innovative Business Models as Drivers for Prosumers Integration—Enablers and Barriers. *Renew. Sustain. Energy Rev.* **2021**, *144*, 111057. [CrossRef]