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Aggregation of Composite Virtual Power Plant - Application Possibilities and Limitations in Serbia

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Highlights

- A detailed review of the literature on virtual power plants, an overview of concepts and particular solutions is given
- Considered energy sources, methods of aggregation and technical potential for establishing a virtual power plant
- Proposed composite virtual power plant concept, estimated costs, benefits, legal restrictions

Abstract

Serbian power industry increasingly faces the challenges of the future. Electricity generation is based mostly on low-caloric lignite. Its deteriorating quality causes a decline in the level of safety, reliability, and efficiency of thermal power plants, increasing pollution. Beside their revitalization, there are huge investments in new, expensive systems for reduction of pollutants' emissions. With the announced introduction of carbon taxes, which will grow rapidly in the future, the profitability of these power sources and the market competitiveness of the price of electricity obtained from them become extremely questionable and uncertain. In inevitable decarbonization process, a strategic question arises for Serbian experts – how to compensate significant basic (thermal) capacities, which will be probably shut down?

At the other end of the system, the problem is inefficient use of electricity, unacceptably high level of its losses, including those due to its theft. At the same time, the technical possibilities for load management and for the application of a larger number of tariffs were not used sufficiently, to provide the desired demand response.

In such circumstances, the key question is - what investment strategy to choose? This paper proposes a solution that would have a positive impact on both ends of the system and its actors, but also on the networks between them and their operators. "Electric Power Industry of Serbia" could use the announced introduction of aggregator, as a new participant in the electricity market, for a kind of joint venture with its end-users, to establish a composite virtual power plant. It would represent a new, replacement capacity for the power industry, and a source of savings and even income for customers. Such a power plant would include various, dispersed renewable sources, both of electricity and heat, energy storage systems, chargers for electric vehicles, controllable customer load and various demand response programs. By increasing the volume of such aggregation, a composite virtual power plant would enable the aggregator to provide ancillary services to the transmission system operator, which would be an additional benefit. In synergy with other necessary, strategic steps, such a concept could provide Serbia more secure energy future.

Keywords

Aggregation, Ancillary Services, Decarbonization, Demand Response, Distributed Generation, Load Management, Virtual Power Plant

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1. INTRODUCTION

1.1 Energy issue context in Serbia

Beside functional and organizational unbundling during the previous period of the deregulation process, to the effects of which it is still adapting, the entire electric power sector of Serbia is increasingly facing new, threatening challenges of the future. The primary problem is relying on mostly lignite-based electricity generation over decades. The lignite quality (calorific value) recorded significant deterioration, and its available quantities are questionable. Multiple consequences are reflected firstly in power plants' safety, reliability, and efficiency level decrease, then in additional wear of equipment, and finally in increased air pollution. Thermal power plants (TPPs) are extremely old and therefore demand huge investments not only in rehabilitation but also in the construction of new and expensive (according to investments and exploitation) support systems in the function of environmental protection. Summing up these costs with announced carbon fees which will experience rapid growth in the future, the cost-effectiveness of these sources and the market competitiveness of the electricity price from these sources become very uncertain. Under conditions of inevitable decarbonization in Serbia, there is also an emerging question – which replacement capacities would be used instead of basic (thermal) capacities which are threatened by decommissioning for one or another reason?

Renewable Energy Sources (RES) in the transmission system will compensate a part of the electricity after decommissioning of thermal capacities. Significant integration of variable RES (V-RES) will cause new problems. V-RES have a lower capacity exploitation rate than coal-fired TPPs. For compensation of electricity generated by a coal-fired TPP over a year, it is necessary to build RES of significantly higher installed power, which may cause congestion in the existing transmission network or may limit connecting of new RES. V-RES integration will also condition increased necessary balancing reserve for system balancing in real time, and the system balance creation will also become a problem due to deviation between generation and consumption on a longer, seasonal level.

On the other end of the system, there are also no less of problem represents electricity inefficient use, inacceptable high level of losses, including also the losses due to its unauthorized use. At the same time, technical possibilities for load management or use of potentially larger number of tariff rates for the purpose of desired demand response that are already available are not exploited at all. Interests of supplier and operators of distribution and transmission systems are not necessarily the same, [1]; the supplier tends to sell as much electricity as possible, with as much profit as possible, while the latter strives to maintain a stable system, i.e. not to have the system elements overloaded.

Under such circumstances, long-term planners and creators of development of the power system (PS), as a whole, face a question – which direction to follow, which investment strategy to choose?

This paper suggests a solution to think about that would have a favourable impact on the technical aspect of the system (on both of its ends), and also on its actors, but also on the networks between them and on their operators. Instead of huge investments in the thermal sector of questionable perspective and profitability, the Joint Stock Company "Elektroprivreda Srbije" (Electric Power Industry of Serbia, EPS) could make use of the announced introduction of aggregator as a new participant in the electricity market, [2], for a kind of joint venture with its end-users – electricity customers, to establish multi-energy, composite (i.e. collaborative, cooperative) virtual power plant, [3]-[5]. For EPS, it would actually represent a new replacement capacity, while being a source of savings and potential revenues for customers. Such power plant would include different, dispersed, manageable and non-manageable, renewable sources of, not only electric, but also thermal energy (for example solar collectors for water heating), energy storage systems, chargers for electric vehicles, manageable customers load (ETS heaters, electric water heaters, and boilers) and different programs for demand response. By extension of the volume of such aggregation – through a kind of "capacity improvement" and its flexibility improvement – a composite virtual power plant would enable EPS as an Aggregator to additionally provide ancillary system services to the transmission system operator, such as participation in frequency regulation, as well as providing services to the distribution system operator, which would – within appropriate regulatory framework – represent another source of income for EPS. Synergy of such concept with other actions that are required, as harder reliance on hydro capacities, could provide a safer future to Serbia in terms of energy.

1.2 Virtual power plants – review of bibliography and experiences

1.2.1 Definitions and functions of virtual power plant. The basic motive to create and develop the virtual power plant concept in the world is an increasing share of V-RES. Namely, due to the uncertain and discontinuous (i.e. variable) nature of renewable energy sources such as sun and wind, they may cause problems in the operation of the power system implying system balancing and balance creation problems, power quality problems, efficiency, stability, and reliability problems. The virtual power plant (VPP) concept is designed to facilitate V-RES integration, without menacing system operation stability and reliability, with many other technical and economic benefits. What is actually virtual power plant? In [6] it is defined as a "concept consolidating a diversity of distributed electricity sources, manageable load, and electricity storages for the purpose of participation in dispatching and managing electricity market and network operation in the form of another special power plant." The second definition says that "VPP is a structure of ICT (information and communication technologies – *author's comment*) integrating different types of distributed energy sources, flexible consumers and energy storages, mutually and with other market segments, in real time, through the intelligent (smart) network", [3]. Name of "new teleinformatic system enabling energy resources management" is used in [7]. Thus, VPPs perform the task of flexible management of V-RES consolidation, electricity effective storing, and distribution, in variable scales when necessary.

Researches and modeling of endless possibilities of supplying smart cities using VPP technology are numerous, as well as possibilities of preserving environmental eco-system and energy savings. "Smart cities" represent a model of future city planning and urban development, integrating ICT solutions, as well as mechanisms of energy conservation and struggle against climate change with basic technology known as the Internet of Things (IoT). Since it is based on ICT and (most often) IoT, VPP is the most efficient means of energy distribution for smart cities, [8].

1.2.2 Users, carriers, and methods of aggregation. Another question is who may develop and apply the VPP concept and under which circumstances? VPP concept may be developed by many types of entities / energy entities, for example, distribution system operators, electricity producers, and energy clusters, [7]. There are many solutions due to the very wide range of possible applications, and the possibility of building a system based on modules enables the system to adapt to the needs of users, to change easier, and to integrate into larger systems. Regulations are passed and concepts are applied that enable the development of renewable energy sources, including prosumers and so-called active consumers, and also enable active participation of energy consumers in the energy market. Additionally, more severe requirements for energy production and consumption balancing are introduced which demand higher accuracy of balancing, [7]. Further, we will provide an overview of various solutions that can be found in the relevant bibliography references bellow.

Ref. [9] shows the structures, types, architecture, and operation of VPPs, as well as the situation regarding their application worldwide. VPP types are detailed, with optimization algorithms used for each of them. VPP is connected with most of the components of the power system, such as Distributed Generation (DG), prosumers, Transmission System Operator (TSO) and Distribution System Operator (DSO), and network services including fault elimination, reactive power management, while using communication, management and optimization technologies. The article provides a comprehensive insight into microgrid transformation towards VPP, which may be useful to researchers, consumers, prosumers, and system operators. The essence of the approach used in [9] is that the microgrid with optimization, communication ability, and with an application of artificial intelligence methods, becomes VPP. Automation of microgrids is implied as a precondition of generation and consumption manageability and optimization of the costs of its operation.

Paper [10] provides VPP concepts from the studies of various researchers as well as detailed explanations. Some typical VPP projects around the world are presented. Additionally, some potential challenges and advice for the future development in VPP studies are shown. Three types of VPP users are identified: Standalone, Energy buying, and Energy selling. Independent Power System Operator (IPSO) is a key player, "midfielder", between the external market, with whom it exchanges load forecast data and market information, and the decision-making center, to whom it reports price strategy and from whom it receives results of activities.

1.2.3 Architecture, concepts, and models of VPP. In [11], the concept and the experimental results of a microgrid named District Power Plant, designed to operate as an active element in the local distribution network, capable of providing services such as demand response (DR), active supply, and advanced metering, are presented. Stable operation of both island and reconnection modes of operation of such system is presented, as well as good power quality in both modes of operation.

Paper [12] suggests a new system of the city VPP integrating distributed generation units, systems for energy storing, and controllable load. It applies advanced technologies for communication and coordinated management in order to implement the overall regulation and management of different types of distributed energy and load. Thus the challenges created due to the great share of random and variable distributed generation in power network operation and dispatching are mitigated and the imbalance between supply and demand is reduced. The paper illustrates the suggested architecture of the city VPP system and shows its resources on the side of users.

Efficient management and dispatching are also the subject of the paper [6]. For the purpose of efficient dispatching and management of large number of demand response resources (such as thermally controllable load capacities), this paper studies energy efficiency management system on the basis of a concept grounded on demand response technology and VPP theory and efficiently uses temperature management system. By collecting and controlling the parameters of capacity of resources for load management, making complete use of potential for load reduction on the consumption side, appropriate shifting of peak electrical load is achieved, suitable for mitigation of deviations between supply (electricity generation) and demand and for ensuring safe and stable operation of power grid.

VPP and components of "smart" energy, grid, system, and city are shown and compiled in the article [13]. It presents VPP and appropriate components of "smart" grid that are its integral parts. "Smart" energy structure consisting of subgroups of low-carbon production, efficient distribution and electricity consumption optimization is laid down.

A platform for the integration of different types of Distributed Energy Resources (DER) is presented in research [14]. Various domains of knowledge were necessary to plan and build this platform – telecommunication, electrical engineering, mechanics, automation, informatics, architecture, and sociology. The key thing was defining the scope of the project, harmonizing the specifications, and mutual understanding between the partners (including contractors and subcontractors), as well as defining the common language for efficient cooperation. Besides, it is highlighted that users/hosts have to be as informed as possible during the installation phase and connected to the project during its operational phase. They also want to understand the purpose of intervention and to be aware of when the installed devices are in operation. The criticality of integration of different technologies and standards is emphasized: authorization of http-clients, SSL certificates, web services, Common Information Models (CIM), Smart Energy Profiles (SEM), etc. Under the platform of such an integrated management center subjected to the Aggregator, it is possible to consolidate different users and their devices and dispersed sources; residential (thermal storages and heat pumps, photovoltaic panels, batteries for storage of electricity surpluses, load management), adjustable public lighting, industrial users (production from thermal solar collectors, cold storages), housing and business premises (solar thermal storages, load management), [14].

The notion of Energy Market of Things (EMoT) is introduced, [15]. DER is the historical chance for energy traders which may bring numerous advantages, for example, the possibility to open an abundant offer of flexibility on the side of supply at low and medium voltage, consisting of energy communities, and even small farms of PV panels and batteries. Access to behind-the-meter data which may be used for fine settings of trading and forecasting algorithms is necessary. Devices, starting from heat pumps up to the chargers for electrical vehicles (EV), DER, and power plants and facilities, may now collect and exchange the data (i.e. communicate) and be connected to any type of electricity market.

EMoT enables the networking of physical devices related to electricity, for a small volume of its generation, storing, and electricity flexible consumption, [15]. These "things" have built-in sensors, and dispose of software and other technologies to connect and exchange data with other devices and any type of electricity market – whether it is about local flexibility markets, energy balancing platforms or classic exchanges such as EPEX SPOT, Nord Pool and HUPX. These devices' variation range goes from simple household items to large commercial or industrial devices.

1.2.4 VPP as network or system of cooperation. Ref. [3] presents VPP as a cooperation network. It emphasizes that although VPP is one of the types of virtual organizations, VPP definitions are primarily directed toward its technical aspect while insufficient attention is paid to the management aspect and, particularly, the business model. Therefore, in [3], the legal background for VPP establishment is presented, as well as legal possibilities and threats for VPP creation in Poland. It is emphasized that legal analysis is the starting point for every practical project. Legal regulations related to prosumers and supporting energy micro-clusters are presented. These issues require the creation of new products, e.g., VPP. Then a review of business models is made in order to select an adequate model, [3]. Mainly three types of models are identified; the first model is mainly a characteristic of the relationship between customers, clients, partners, and suppliers; the second model emphasizes the importance of the company's resources which can be expanded and used, and potential sources of future economic benefits; the third model represents a combination of the first two and combines the key resources and key relationships important for VPP (this corresponds to system approach). Based on the selected model, the VPP is structured as a network of cooperation between different types of energy entities. At the same time, the segmentation of possible users of VPP is carried out according to two criteria – according to the type of market and according to the type of product [3].

The trend of convergence of VPP towards collaborative networks is also confirmed in [4,5]. Namely, it is claimed therein that according to its composition, VPP forms a kind of collaborative business ecosystem with a high degree of interaction and interdependence among interested parties. Research [4,5] is focused on analysing the trends and identifying the areas of convergence between the discipline of Collaborative Networks (CN) and the concept of VPP, as well as the development, using prior knowledge from the CN domain. The results show that various strategic and dynamic cooperative alliances are formed within VPP, such as goal-oriented networks, Virtual Organizations Breeding Environment (VBE), opportunity-driven networks, and continuous production-driven networks. Various basic functional principles of VPP are similar to those of CN: creation, operation, and dissolution of virtual organization, negotiations, brokerage services, VBE administrator services, virtual organization planner and coordinator services, and partner search and selection processes, [4,5]. DER share in the energy market is ensured through VPP aggregation, [4]. It includes multiple interested parties: markets/customers, distribution service operators, DER/prosumers/controllers of prosumers, energy management systems, service providers, energy communities and energy cooperation, and regulatory bodies, [4].

Authors of [4,5] developed and discussed in [16], the concept of a collaborative virtual power plant ecosystem (Collaborative/Cooperative/Composite VPP Ecosystem, CVPP-E). It contributes to the efficient organization of Renewable Energy Communities (REC) in such a manner that they can act as a VPP or exhibit its attributes. This concept is derived by merging or integrating the principles of organizational structures and mechanisms from the CN domain into the VPP area. It is expected that, if the actors in REC engage in collaborative actions, it will enable REC to perform functions similar to VPP. Conceptually, CVPP-E consists of a management community, a shared community energy storage system, consumers owning a combination of photovoltaic and battery storage systems, and passive consumers, all connected to the power network. A key attribute of this proposed ecosystem is that its members are engaged in collective actions or collaborative ventures based on a common goal, aimed at achieving sustainable power production, consumption, and sales. Study [16] gives a high-level model for the aspects of cooperation in CVPP-E. This includes the framework of compatible (common) goals, sharing framework, and a framework of collective actions. These frameworks serve as the backbone of CVPP-E and play a vital role in CVPP-E modelling. To evaluate the proposed model, different simulation scenarios were used in [16].

1.2.5 Components of VPP and optimization models. Components that may be covered by the concept of composite VPP, and CVPP are very diverse. Balancing the fleet of wind generators with the portfolio of flexible assets – biogas power plants and capacitor banks – was considered in [17]. The original purpose of the biogas power plants considered in VPP was to make money in the stock market, primarily on the day-ahead market. When these assets become a part of VPP, their task transforms into the maximization of electricity sales profit while ensuring the balancing the fleet of wind generators, which also results in participation in the intraday market. This task is challenging in terms of methods of optimization and price forecasting. In [17], two aspects are considered: optimization and price forecasting. The first one is mixed-integer optimization and sophisticated decomposition methods were developed. As for the latter one, several forecasting methods based on machine learning (ML) are implemented, to maximize the resulting cumulative revenue. Commercial forecasts are also used and the method from [17] recorded competitiveness compared to these forecasts in terms of the resulting cumulative revenue. Special attention is also paid to the robustness of VPP to handle the large amounts of assets it covers. In addition, Robust Model Predictive Control (RPMC) is used to take into consideration many scenarios during decision-making.

CVPP concept possibilities are not limited only to the increase of system flexibility by the combination of different, compatible energy sources. Thus, in [18], in addition to promoting multi-energy complementarity, with the aim of low carbonization, an optimal model for planning the operation of a VPP with carbon capture and waste incineration is proposed, taking into account the coordination of electricity and gas. By introducing a collaborative framework for using a gas plant system for carbon capture – "electricity to gas" (power-to-gas, P2G), the captured CO_2 can be used as a feedstock for P2G, to produce natural gas that is supplied to the gas unit. Additionally, energy consumption for carbon capture and flue gas treatment can be transferred through joint dispatching to mitigate V-RES output power fluctuations, so that electricity obtained from wind and photovoltaic panels can be indirectly dispatchable and used in flexible manner. Considering the high dimensional nonlinearity of the proposed optimization model and the difficulty in solving it, a new Gaussian complex differential evolutionary algorithm was designed in [18] to solve this model. Simulation results show that the proposed model and method can provide peak load shifting capacity and improve the consumption of renewable energy, while effectively reducing the price and VPP carbon emission.

To solve a large number of discrete clusters of different distributed energy resources in rural areas, in [19] an Electricity Retailer (ER) is set as an agent of these clusters through VPP, that is, an ER is integrated with a virtual power plant (VPP-ER). Further, [19] discusses the collaborative mode of "electricity-carbon" transactions and the optimal model of purchase-sale transactions, at two levels. The higher-level model applies the Conditional Value-at-Risk (CVaR) method to establish a coordinated electricity-carbon transaction model for rural VPP-ER. The lower-level model applies the robust optimization theory to measure the risk of wind farm (WF) or solar PV power plant output power uncertainty, to establish the optimal dispatching model for VPP. Thirdly, the model is converted to Karush–Kuhn–Tucker (KKT) optimality conditions to solve the two-stage purchase-sale transaction model. Using the example of an industrial cluster (Henan Lankao), the results show also that the proposed two-stage model can establish a coordinated optimal electricity and carbon trading scheme. The conclusion of the study [19] is that its findings could provide an effective decision-making tool for rural VPP-ER in Chinese electricity market.

Participation of electric power industry in carbon and green certificates trading is an effective, market-based approach to address the negative external effects of electricity generation. In this regard, VPP also proves to be an effective tool. Thus, in [20] VPP is taken as an aggregator for coordination and optimization of carbon and green certificates trading between the electricity purchasers and the final sale of electricity, in order to achieve the goal of maximizing the comprehensive benefit of VPP. First, the mode of operation of VPP that aggregates different types of distributed energy and different users participating in green certificates market and carbon emissions market is analyzed. Second, a two-stage collaborative optimization model of VPP participating in electricity purchase and sale transaction and green certificate transaction is constructed. On the one hand, the costs of electricity purchase and green certificate obtaining are minimized by combining different types of resources for electricity generation in the end purchase of electricity, and on the other hand, the purchased energy is distributed among different types of users when selling electricity, in order to maximize incomes from electricity and green certificates sales, respectively. On that basis, VPP as a whole participates in the electricity market, the carbon emission market and the green certificate market in order to maximize the overall revenue. Finally, VPP was taken as an example to verify the cost-effectiveness and efficiency of the model proposed in [20].

1.3 Content, contribution and structure of the article

Concept of CVPP which - apart from electricity - would also include other types of energy, as proposed by the authors of this article, is presented in Chapter 2. It is based on the vertical concept of the Industrial Internet of Things (IIoT), [21-23], taking into account its advantages both from the aspect of data and information management and processing, and from the aspect of distributed realization and cyber security. Apart from a very wide range of types of distributed resources for energy production and its consumers, the concept proposed in this article considers the position and role of CVPP in a wider environment and also remains open to include individual larger production units or energy storages. When it comes to distributed resources, under the conditions common for Serbia, the most significant and potentially the most effective is the establishment of management functionality over the preparation of sanitary hot water. Additionally, the emphasis was placed on possible contributions to the optimization of operation and flexibility of the system, which would be provided by functional connection and subsuming under the CVPP concept of thermal storages (distributed, both smaller and larger, purpose-built) and potential energy storages (such as water towers) and their management.

Beside technical and technological connecting of various components, on which the CVPP concept is otherwise based, in the event that EPS would appear as an Aggregator, its power generation portfolio management function (so-called "Trade") could, by concluding long-term contracts on electricity supply (Long Term Power Purchase Agreement, LT PPA) with private wind and solar farms' investors, by offering balancing services, contribute to CVPP model proposed herein. Thus, this part of "green" energy would also become one of the components of the proposed EPS concept and portfolio, that energy would be kept in Serbia and made available for optimization of operation and increase of flexibility of the system.

In the manners described above, CVPP would gain additional performance as a tool for optimization of the operation of the system and use of electricity and thermal energy, produced and stored not only within the capacities of EPS and its end users but also of other energy and business entities. All of this, certainly, does not limit independent energy entities from being independent aggregators on the market (offering their services and developing their own VPP concepts), subject to accepted European practice and regulations.

Chapter 3 of this article shows the ways of aggregation of distributed production of prosumers and their consumption. Chapter 4 provides a rough estimate of the effects that could be achieved by introducing and implementing the concept of a composite virtual power plant. In the example shown, only the effects that would be obtained from aggregation of storage tanks for the preparation of sanitary hot water, equipped with remotely controlled thermostats and "smart" switches, were calculated and presented. Chapter 5 provides an overview of the legal framework and current restrictions in Serbia for further development of this concept. At the end of the paper, appropriate conclusions are given.

2. ORGANIZATIONAL STRUCTURE AND TECHNICAL POTENTIAL FOR INTRODUCTION OF COMPOSITE VURTUAL POWER PLANT

The authors of the article recognized three key questions to be answered before investment planning and practical implementation of virtual power plant. The first question refers to production and consumption processes' control and management, the second question refers to technological aspects of different electricity sources and consumption and the third one is of organizational nature, as the spatial dispersion of sources and consumption has to be harmonized, i.e., they have to create a unique network.

2.1 Vertical and hybrid conception of control and management

Application of modern concepts of control, data processing, management, and decision-making implies that many decision-making processes are transferred from the operational level to higher hierarchical levels. The main goal of modern control, management, and decision-making concepts is to reduce operational costs and shorten the time of data analysis and processing. A VPP represents an extremely complex system with a large number of subsystems. Starting from the advantages of vertical concepts of control, management, and processing of data and information, which have become one of the reliable and acceptable solutions of IIoT-based concepts [21-23], Figure 1 shows the proposed structure of EPS future VPP.

Today, new technologies enable fast and cheap two-way communication between customers and energy companies. "Smart" metering devices with the possibility of remote control can monitor, analyse, forward, and/or store data on the consumption of various forms of energy with high selecting frequencies. The availability of hundreds of thousands of time profiles of the load of different consumer groups creates the possibility of applying artificial intelligence (AI) algorithms to group consumers with similar consumption patterns.

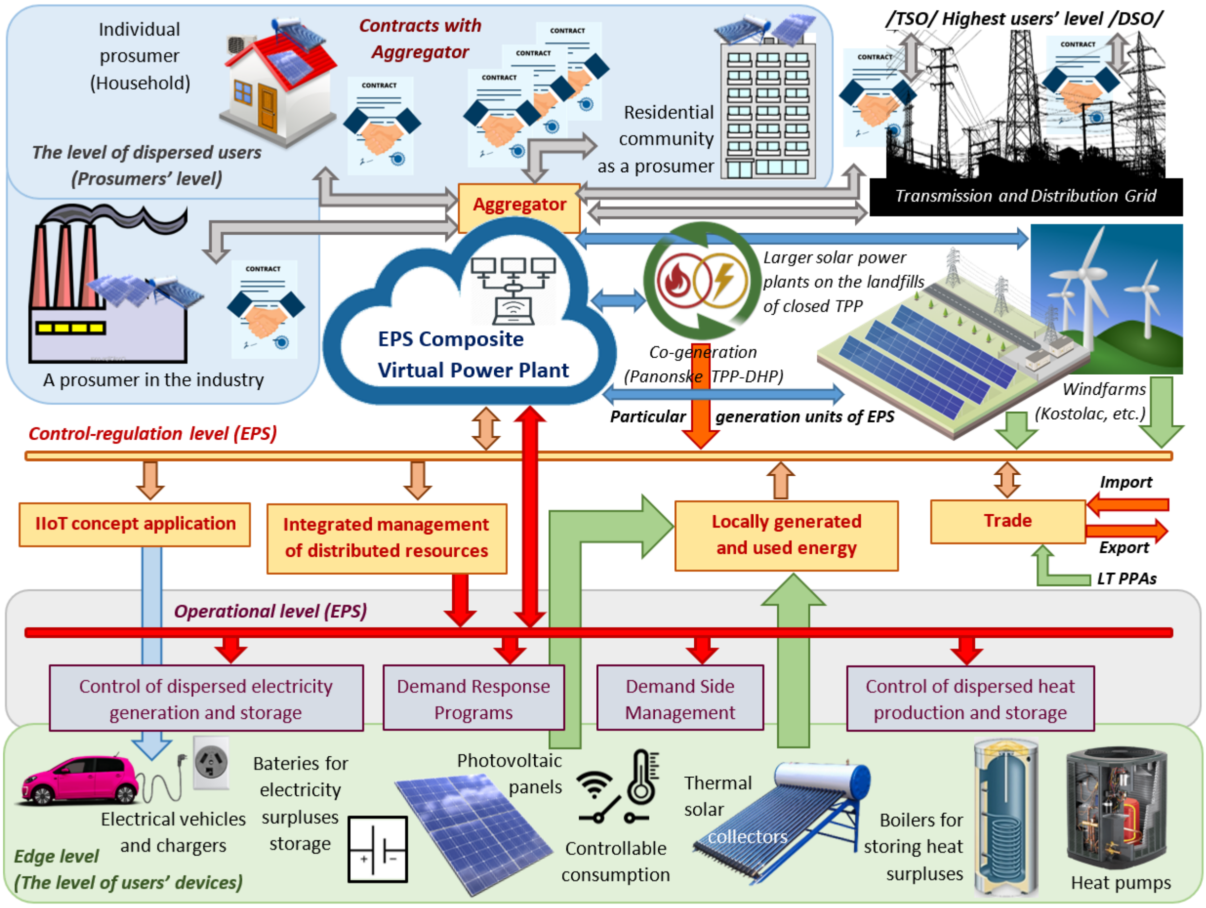
Big Data Analytics (BDA) significantly changed business practices in different industries. Large online shopping platforms (Alibaba, Amazon, etc.), that rely heavily on BDA and data on users' previous purchases and behavioural analysis based on browsing history and internet activity, are maybe the most prominent examples [24].

Figure 2 shows a possible BDA scheme applied to PS. The data collection process starts with different sources of information (Figure 2.a)), such as "smart" meters, the electricity market, weather forecasts, wind speed measuring sensors, etc. This data can be subject to the processing (Figure 2.b) and the application of advanced statistical methods and machine learning (ML) techniques (Figure 2.c)), such as time series analysis, clustering, and deep learning in order to generate information about the peculiarities of the entire system that can be applied for the purposes of estimating technical potential and predictive management of resources, [25]. Such information can be used for the benefit of energy companies, their users, and third parties involved in this process (Figure 2.d)).

2.2 Technical potential of end-users

Virtual power plant can integrate (aggregate) end-users in terms of manageable electricity consumption, and when it comes to prosumers, it can also aggregate manageable dispersed electricity generation. The idea advocated in this article is the integration of dispersed production and manageable consumption, and other forms of energy. At the same time, all considered types of energy are viewed in relation to electricity. The end-user can be a household or a business entity (see Figure 1, top left). Virtual power plant can provide and valorise two types of services, balancing and economic dispatch, and accordingly the technical potential of end-users who could increase the capacity of virtual power plants to provide the relevant services to system operators, as the highest rank users, was analysed (see Figure 1, up right).

End-users' electricity consumption is reduced to the conversion of electricity into another form of energy. Electricity is mostly converted into thermal energy, then



Legend: Contractual relationship; Inclusion of power plant into CVPP; Functional structuring of CVPP; Operational command, communication and data acquisition; Downward propagation of the IIoT concept; „Green“ energy; Electric power from conventional power plants and interconnection

Figure 1 Possible structure, functionality and environment of EPS composite virtual power plant

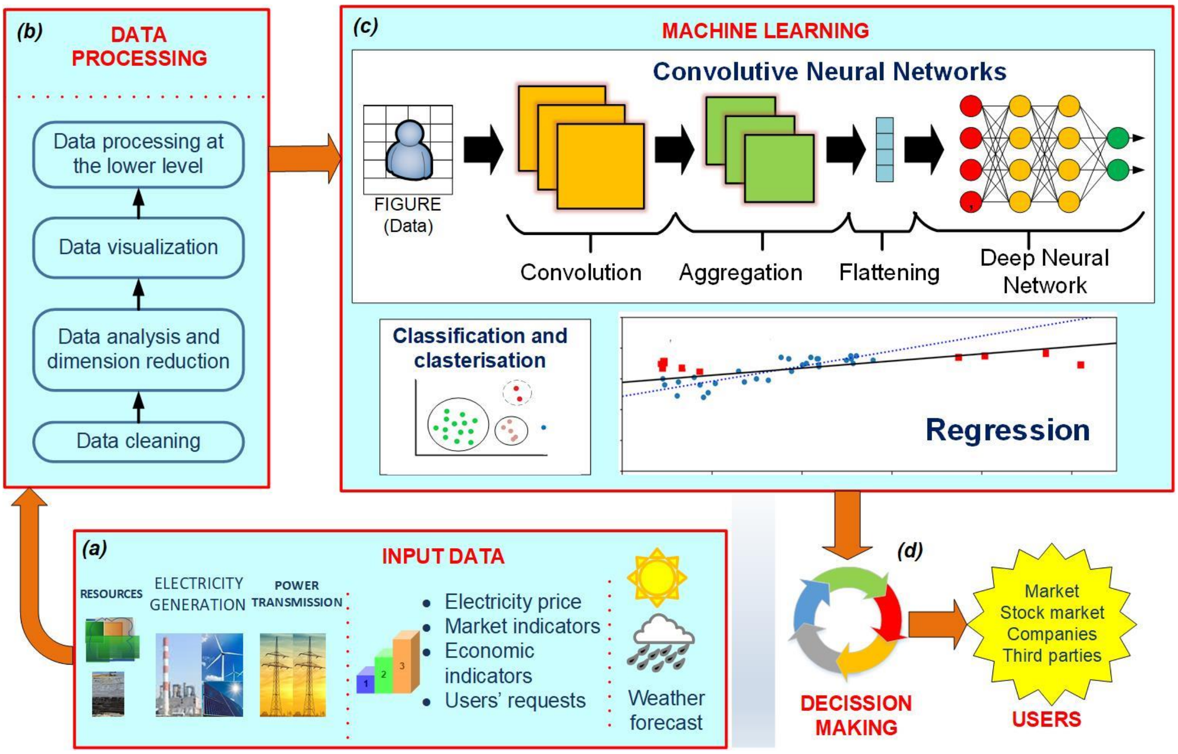


Figure 2 Possible scheme for BDA in EES

into chemical energy, into potential energy or other forms of energy. From the point of view of the virtual power plant, manageable consumption is important, as it has a certain type of energy stored in its technological process, without affecting the technological process of energy consumption. Technological processes consuming electricity, without possessing certain energy accumulations, will not be considered in this article.

Final energy is predominantly spent on heating and cooling processes. In EU28 countries, half of the final energy is converted into heat [26], and for countries that are at a lower level of economic development, that percentage is even higher. In the Republic of Serbia, a rough estimate is that approximately one-third of total electricity consumption in the winter period goes to space heating (average daily electricity consumption in May is around 80 GWh and around 120 GWh in January). With the low cost of heat accumulators, thermal energy consumption represents the most important resource of virtual power plants for both balancing services and economic dispatch. The use of electricity consumption for heat production for the purpose of system balancing is already applied. In Belarus, [27], for the purposes of system balancing, about 1200 MW of manageable electric water heaters were installed for the needs of district heating and preparation of hot water for citizens.

Electricity consumption for the purpose of converting it into chemical energy is most increasing. It's about batteries, and dominant growth is represented by electric car batteries. The direction of battery charger development is not in favour of manageable consumption. Manufacturers of electric cars invest considerable resources to reduce the charging time of batteries by increasing the power of chargers, hence the chargers reach powers of 400 kW, [28]. Electric car batteries during the charging process, in conjunction with "smart" chargers, can become a significant resource for consumption management in the near future.

Another form of conversion of electricity into chemical energy is the production of hydrogen or hydrogen products, which is becoming one of the main directions for energy sector development. At the end of 2021, the EU allocated funds in the amount of over EUR 500 billion for the development of projects for the use of hydrogen, which should be spent by 2030. Currently, the number of end-users who can produce hydrogen is limited to business entities that produce technical gases, but the goal of EU is to increase the use of hydrogen, primarily for transportation purposes. With adequate hydrogen tanks and hydrogen production facilities reaching a consumption change gradient of 10%/s, hydrogen production in the near future may become a significant resource for virtual power plants, for both balancing services and economic dispatch. The manifest problem of hydrogen storage is currently being solved in two directions, by obtaining methanol or ammonia.

Converting electrical energy into potential energy for end-consumers is also promising from the point of view of VPP. The end-users who perform this energy conversion are primarily public utility companies of waterworks and sewerage. Technological processes of water supply and sewerage removal involve processes of water pumping from or into water/sewerage storage areas and usually have a certain freedom regarding accumulation (reservoir) level. As such, they represent a significant potential for the aggregation of manageable consumption, especially from the point of view of grouping the end-users who are aggregated. It is not necessary to wait for the near or far future to develop resources for this type of consumption since they are already available now.

2.2.1 Energy sources. The most important energy sources of PS end-users, which are prospective for aggregation into virtual power plants, can be divided into groups according to manageability:

- Unmanageable energy sources:
  - solar panels,
  - solar collectors,
  - solar thermal panels (cooling of these panels warms up the water);
- Manageable energy sources, the application of which can be optimized (economic dispatch):
  - biomass and biogas (thermal energy),
  - fossil fuels (thermal energy),
  - heat pumps (source of thermal energy),
  - unmanageable sources with energy storage;
- Combined energy sources, the most promising from the point of view of the application in virtual power plant applications, with a significant number of variable states that need to be monitored:
  - cogeneration (they are mainly used by business entities whose production process requires the use of both electricity and thermal energy, possibly of the process steam, as well),
  - heat pumps in combination with heat storages (sources of thermal energy, the application of which increases the capacity of thermal storages),
  - low-temperature sources of thermal energy (sources that are under significant development, a combination of heat pumps and waste heat from industrial processes or heat generated by cooling the computer centers).

2.2.2 Manageable consumption and storing of energy. PS end-users' energy storages that are currently in use correspond to already mentioned forms of electricity transformation into another type of energy. Thermal energy storages (heat accumulators), chemical energy storages (mainly batteries), and energy storages in which electricity is stored as potential energy are the most common. Considering that they are currently widely available and that it is not necessary to wait for their development, only heat accumulators and potential energy storage will be considered in this article. Heat accumulators can be targeted, and the thermal capacities of other objects can be used as heat accumulators (for example the walls of the heated space). Manageable consumption in combination with energy storages expands the range of services that virtual power plant can provide to the system - system balancing and economic dispatch.

The concept of consumption management as a support for frequency regulation was mentioned more than forty years ago, [29], where in addition to the concept of "production follows consumption", the concept of "consumption follows production" was shown. In [29], a categorization was made into passive and active consumption management. Passive consumption management mainly refers to loads that naturally use the duty cycle and can be turned on/off temporarily without compromising the duty cycle and user's comfort. As the first candidates for manageable consumption, which do not require additional investments other than management, thermostatically controlled devices stand out, which inherently have thermal energy storing, and at the same time are large consumers in households as end-users, [30]. Such devices include air conditioners, electric water heaters, storage heaters, etc. In [29], authors presented possibilities for the use of a device that, based on the frequency measurement of the network to which it is connected, can turn on/off certain consumers. However, at that time there was no available infrastructure and technology that could support the rapid flow, storing, and processing of large amounts of information.

With the application of new technologies to old ideas, in [31] a prototype of remotely controlled switch of an electric water heater, based on the IIoT concept, with the possibility of reading the values from sensors measuring the water temperature, the consumption current and the network frequency is presented. In [31], statistical analysis of the operation of the electric water heater was performed and available changes in its power and energy were estimated - increases and decreases, depending on the current needs of the PS, but also on the expected customer requirements. Based on the obtained statistical indicators, a dynamic model of a large number of water heaters that are used in a similar way - a dynamic model of one cluster - was proposed. By analysing the possibility of working in secondary frequency regulation, it was shown that such system can achieve even better results in terms of response time, relieve the existing, conventional generation units and contribute to the stability of PS and the safe supply of customers. In addition to technical analyses, in [31], a simplified economic analysis of one such project was performed. It was pointed out that the investment would be returned to the user in about five months, and that the rate of annual income in the first year is approx. 270%.

Heat accumulators, as targeted energy storages, represent one of the cheapest forms of energy storage, with a price of less than 15 USD/kWh, [32], while according to [33], the price of large heat storages may range 15-50 EUR/m^3. Inexpensive heat accumulators most often accumulate the heat in water, and accumulators of 50 litres of water, up to seasonal heat accumulators with the capacity of over 500,000 m^3 of water, are in use [34]. In combination with a heat pump, which lowers the lower limit of usable water temperature to below 20 ^oC, heat accumulators represent an extremely elastic plant from the point of view of manageability of consumption.

If the thermal storage is zoned as to have two separate storages, the energy from warmer storage can be used directly for heating the space when the price of electricity is high, and in case of a favourable electricity price, the heat from colder storage can be used for heating the space after conversion via a heat pump. Heat sources are mainly solar collectors (as in Figures 1 and 3), but also waste heat from cogeneration or even the conversion of electricity into thermal energy. Large thermal energy storages can reach a capacity of over 40 GWh individually. In the areas where 27% of the final energy is spent on heating the space [26], they can represent an ideal solution for the annual balancing of V-RES electricity generation. Energy losses of seasonal thermal energy storages can be reduced by up to 10%.

Manageable consumption with storing the energy in the form of potential energy is present in technological processes in which the fluid is transferred from one place to another at a higher altitude. Examples of end-consumers of electricity that perform the described energy conversion are public utility companies of water supply and sewerage. In plain areas, it is common to maintain the water pressure in the water supply system by pumping the water into a water tower, the highest point of the settlement. A water tower is a water reservoir having a level gauge, with a maximum and minimum allowed value. Depending on the water consumption, the pumps of the water supply systems are manageable on an hourly basis, and the manageability depends on permitted minimum and maximum volumes of the water in the water tower. Sewage systems have collectors that also have permitted levels and pumps that are manageable, as in the case of water supply.

3. MANNERS OF AGGREGATION OF PRODUCTION AND CONSUMPTION

3.1 Active manner of aggregation – EPS as a possible Aggregator

Since EPS, among other things, performs the roles of electricity producer, trader, and supplier, during the optimization of the entire portfolio of EPS, different types of plans are made, for several time horizons. When creating medium-term (quarterly, monthly, and weekly) and short-term (day-ahead and intraday) electricity generation and trade plans, the goal is to optimize their production by making maximum use of the flexibility of power plants, so that the company achieves the highest possible profit. To achieve this, it is necessary to place the largest possible part of available energy in periods of the highest market prices, taking into account already contracted obligations/deliveries (supply and previously concluded trade contracts) and existing constraints (primarily technical characteristics of power plants, as well as maximum and minimum levels of reservoirs, and coal landfills). This is achieved by electricity trading so that in periods of low market prices power plants are "pushed" to technical or biological minimums, while the difference between demand (consumption) and production is compensated by purchases on the "spot" market, in which way most of the primary energy (coal, water) is transferred to periods of high prices. In this sense, in order to transfer as much of the primary energy as possible from the period of low to the period of high prices, it is necessary for the power plants to have as wide range as possible between nominal power and technical (or biological) minimums, i.e., to have as much flexibility as possible.

On the other hand, the same effect can be achieved by using the available range of manageable consumption, that is, by "shifting" a part of consumption from periods of higher prices to periods of lower prices (Demand Side Management - DSM). Nevertheless, the possibility of applying DSM is quite limited, because there is a relatively small number of large industrial/commercial consumers (customers) of electricity to whom their production process allows consumption management and where the cost of electricity represents a significant share in the price of final product (energy-intensive customers), so that they could be motivated by adequate price signals. Otherwise, there is a relatively large number of small customers and households where "shifting" of consumption is possible, but there is no adequate regulation, infrastructure, or price signals to enable it, yet. In addition, more significant effects of manageable consumption can only be achieved by aggregation (consolidation, grouping) of a large number of (mostly smaller) end-users of PS, which is one of the main reasons for the introduction of a new participant in the electricity market – the Aggregator.

The Aggregator can also consolidate smaller, distributed (dispersed) electricity producers, and most often those with controllable production, such as the example of a prosumer with the possibility of electricity storing, illustrated in Figure 3. It shows an energy "smart" house, as well as a radially fed distribution network to which a number of such, spatially distributed, houses are connected. From the perspective of consumers and "local green generation", the edge concept is presented, the main advantages of which are short data processing time (delay reduction) and simpler local production and consumption process management. Figure 3 shows a general case – a household that can produce and store both thermal energy and electricity. The aggregator can consolidate even fewer complex cases, as in [31].

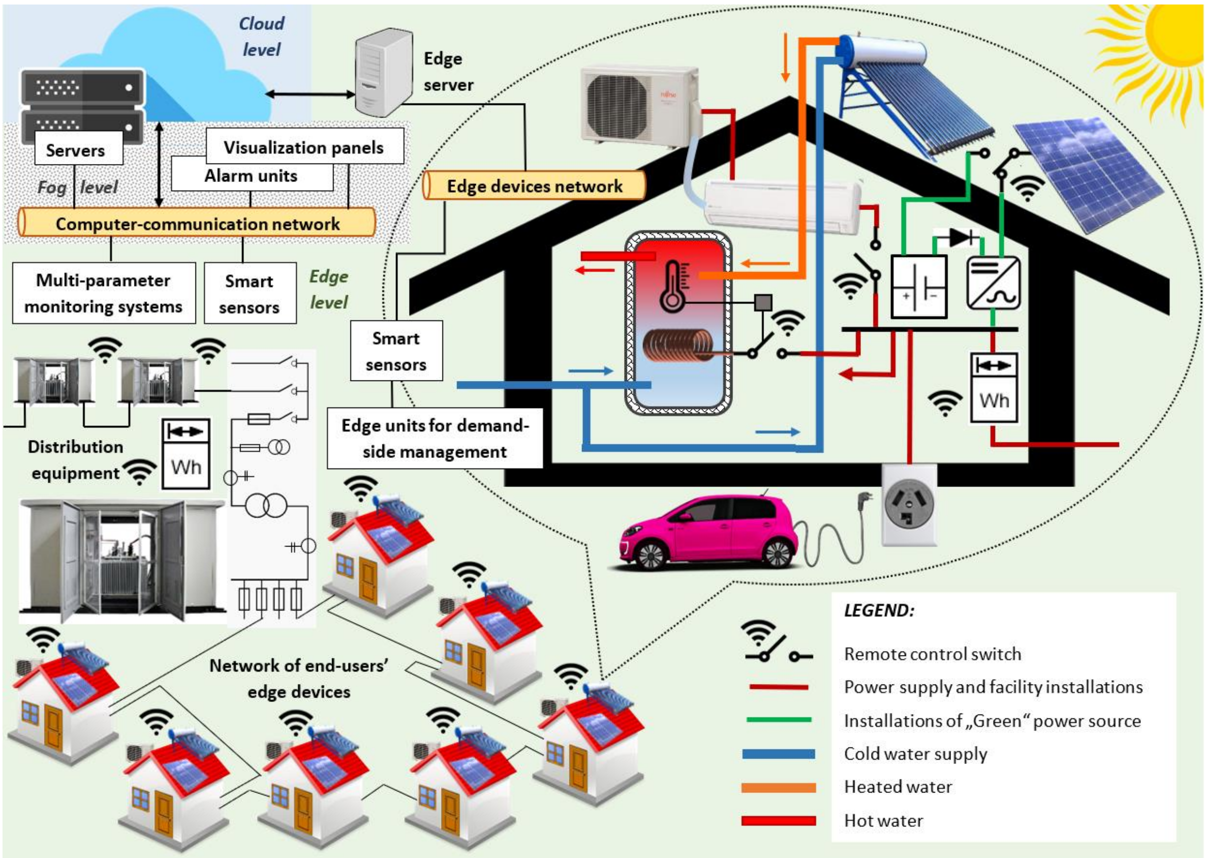


Figure 3 A hybrid IIoT concept for composite virtual power plant aggregation and management

The aim is to provide as much flexibility as possible which Aggregator valorise subsequently on the electricity market. Depending on technical possibilities that the Aggregator disposes of within its portfolio, beside shifting of consumption/production, the latter realizes revenues from flexibility and on the markets of system services and balance energy. Accordingly, Aggregator makes a profit by offering its services (flexibility) to various interested parties (market participants):

- to other producers/suppliers for whom the flexibility is important for production/supply portfolio optimization, as well as for balance responsibility on the balance energy market,
- to transmission system operator, through system services (provision of secondary and tertiary reserve power), indirectly reducing the required level of reserve at the production side (and thus opportunity costs of production),

- to distribution system operator, bearing in mind the fact that due to the increasing number of connections of V-RES to distribution network there is a need for flexibility for the purpose of efficient and safe distribution network management, as well as possible investment costs reduction (in distribution network).

Taking into account the volume of EPS portfolio, business it performs, as well as potentials that the role of Aggregator brings along, a clear interest of EPS is to perform this role in order to complete the possibilities of portfolio of EPS and provide additional source of revenues. Considering the electricity supply function within EPS, and that, in [2], the possibility that, beside independent aggregators, suppliers also deal with aggregation in electricity market is reviewed, one of the options that should be explored in terms of feasibility is to register "EPS Snabdevanje" (EPS Supply) as Aggregator, as well.

In this regard, the business activities of a similar state-owned enterprise like GEN-I could serve as an exemplar. The above company plays the role of an aggregator-supplier in more than one country in central-eastern Europe. As far as aggregation is concerned, GEN-I also disposes of manageable consumption and distributed generation, as well. Their virtual power plant concept is based on development of unique platform consolidating aggregator portfolio management, access to different markets, e-mobility and advanced analytics. Such concept enables GEN-I to participate in an active manner in providing balancing services in Slovenia and Austria from virtual power plant, [35].

3.2 Passive manner of aggregation – dynamic pricing

Dynamic pricing, option usually offered by traditional electricity suppliers, is a type of supply contract containing variable part of price that partly or completely reflects price fluctuation on the wholesale electricity market. With such contract form, buyers are encouraged to react on price signals from the market and adjust their consumption according to price changes (i.e., tend to reduce electricity consumption during high price rate hours and to increase it during low price rate hours). This type of proactive approach of buyers may lead to electricity bill savings. However, it should be highlighted that such approach bears certain risks regarding sudden exposure to high prices in particular periods. Therefore, it is very important that the buyer is highly acquainted with all aspects and risks, review well possibility of managing own consumption and even maybe negotiate such contract that will contain some limitations that would protect him from sudden price change and its volatility in the short term.

Some of the examples of dynamic pricing from European practice, [36], are described below:

- *Octopus* supplier (Great Britain): offers a tariff named "A*gile*" with electricity price for customer changing each 30 minutes. On the website of the supplier, interactive presentation of exemplary buyer for whom such form of pricing is the most applicable is offered and a review and comparison with other static tariffs the supplier may offer are presented. Contract contains the limitation clause ("*price cap*"), i.e., the clause on the highest price that the customer may be exposed to.
- *easyEnergy* supplier (Netherlands): offers a tariff reflecting the price for end user as combination of variable part (hourly wholesale price) and fixed part (fixed fee defined on a monthly basis). There is no protection or alarm for the buyer that would indicate the high prices and hence sudden increase in electricity bill.

4. TECHNICAL AND ECONOMIC FEASIBILITY OF VPP IMPLEMENTATION

There are relatively small number of large industrial (commercial) electricity customers in Serbia to whom the generation process would allow consumption management and the electricity cost has a significant share in the price of final product. These are energy intensive customers that might be motivated by adequate price signals. The recent increase in electricity price for commercial customers further increased its share in final product for a large number of energy intensive customers, so that the interest of commercial customers in participating in possible consumption management programs should be examined.

Otherwise, there is relatively large number of small customers and households who have possibility of consumption "shifting" but without adequate infrastructure for implementation so far (for example "smart" meters, remotely controllable switches, etc.). Besides, the price for guaranteed supply is still significantly lower than the market price, thus there are relatively rare periods with possibility of motivating the households and small customers to change the manner and time of use of their electrical appliances. Namely, it is rare that the market price is lower than the price for guaranteed supply.

Due to the above mentioned reasons, and above all due to the lacking regulations (see Chapter 5) and actual inability for assets management related to the assets that does not belong to EPS (such as storage water heaters in example from [31]), EPS in the capacity of a supplier exclusively (when it comes to consumption) cannot make any savings on the account of the existing customers that it could have as an aggregator of a VPP and after providing technical conditions for such active approach. Cost estimation and estimation of possible benefits from VPP establishment is given in this chapter, but only for the component of manageable consumption based on remote controlled preparation of sanitary hot water.

4.1 VPP implementation costs – estimated costs of required hardware and software resources

Depending on the type of switches and a number of sensors (symbolically presented on the Figures 1 and 3, as far as manageable consumption is concerned), price of IIoT devices for acquisition with remote switch, with installation, amounts to 50÷300 EUR per consumer/switch. Total price per consumer depends on number and type of devices of an entity (for example household). Funds are also needed for the purchase or rent of server, as well as for software maintenance and development. Depending on the complexity and expected number of users, funds for software development are estimated in the range of 300,000 – 1,000,000 EUR. For the range of 10,000 – 100,000 users, software maintenance and server lease costs would be 30,000 – 60,000 EUR/year. Investment and exploitation cost estimation for 10,000 users, corresponding to the framework range of one 50 MW composite VPP are presented in Table I. It is important to notice that software development costs practically do not depend on number of users, thus their percentual share decreases as the number of users increases.

Table I Cost estimation for 50 MW VPP

10,000 users	cost	amount
CAPEX (EUR)	IIoT devices	1,000,000
	software development	500,000
	total CAPEX	1,500,000
OPEX (EUR/y)	server	40,000
	personnel costs	40,000
	total OPEX	80,000

4.2 Market opportunities for using virtual power plant and examples of benefits

Greater flexibility on the side of electricity consumption and distributed production, aggregated and managed through the virtual power plant concept, can lead to numerous benefits in terms of efficiency and operating costs of PS. The virtual power plant operator, depending on technical characteristics and the possibility of aggregated production and consumption, can use it for trading and optimizing its own portfolio on the wholesale market, as well as for providing the system services to transmission and distribution system operators.

In this context, the market value of a virtual power plant consisting of 50 MW of aggregated flexible consumption, managed by an independent aggregator, was considered as an example of the effects of introducing the virtual power plant concept. It is important to note that the mentioned 50 MW refer to the equivalent flexible part of consumption from the total consumer portfolio, which will be available and which the aggregator optimizes on the market. A proper assessment of this level of available flexible capacity to create a VPP offer is very important. Should the aggregator make a wrong assessment, i.e., overestimate the level of available flexible part of portfolio, it will be exposed to a higher financial risk in case of inability to provide the contracted services (for example imbalance on balancing market, penalties for not adequate level of reserve, etc.). Flexibility of aggregated consumption is presented through the option of possibility of intra-day "shifting" ("*Load Shifting*") up to the maximum of 4-hour duration. The described virtual power plant is modelled in commercial software tool for energy market simulations, PLEXOS, and optimized as market participant according to market conditions in Serbia recorded in 2021 (hourly profile of wholesale prices from SEEPEX, [37]). This optimization is illustrated under the Figure 4. Potential revenues for Aggregator that may be realized on wholesale market have been reviewed without considering further services that the virtual power plant could possibly provide. Such revenues are shown in Table II.

Table II Potential revenues of Aggregator for example of 50 MW VPP optimization, as per the Figure 4

Indicator	Unit	Value
Energy offtake	GWh/y	72.8
Delivered energy	GWh/y	72.8
Average purchase price	EUR/MWh	79.8
Average selling price	EUR/MWh	144.74
Average market price	EUR/MWh	114.02
Expenses for purchased energy	MEUR/y	5.80
Energy sales income	MEUR/y	10.54
Market profit	**MEUR/y**	**4.74**

The goal of the analysed example is to illustrate the market needs for sources of flexibility, i.e., possible income for one form of use of virtual power plant. Based on the conducted analysis (Figure 4, Table II), it can be concluded that there is a significant potential in terms of economic income from the virtual power plant management.

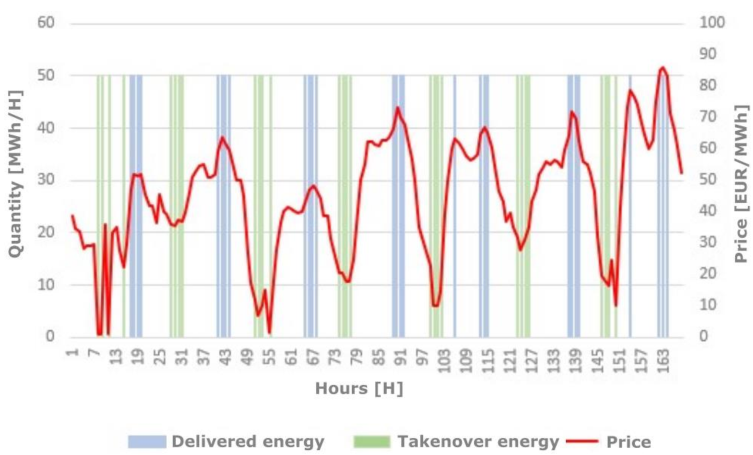


Figure 4 Example of 50 MW VPP optimization on the wholesale electricity market, on a week sample basis

We emphasize that for each potential business case of implementing a virtual power plant, it is necessary to analyse the costs and benefits in detail, i.e., to conduct a complete technological and economic analysis with an sensitivity analysis of the results to the changes in input parameters. This is especially important considering the last energy crisis and the enormous increase in electricity market prices (in this regard, it should be noted that the average prices in Table II are lower than those that occurred in the meantime).

It should be also emphasized that a prerequisite for the effective implementation of aggregation is the existence of a legal-regulatory framework with removed barriers for the appearance of aggregators in different markets, especially in terms of providing auxiliary services to transmission and distribution system operators. Namely, the profitability of implementation of such a concept will largely depend on adequate valuation of these services.

5. LEGAL FRAMEWORK AND CURRENT LIMITATIONS IN SERBIA

Amendments to the Energy Law (Official Gazette of RS, no. 40/2021, hereinafter referred to as: EL) introduce new electricity market participant – Aggregator, but its role, the same as its rights and obligations in the electricity market, has not been fully defined and elaborated in secondary legislation yet. Notion of aggregation is defined by Article 2 of EL as "*aggregation of electricity consumption and/or generation for the purpose of purchasing, selling or auctioning on electricity markets*", while Aggregator as one of the electricity market participants is defined as "*legal entity or natural person that provides the service of aggregating electricity consumption and/or generation for further sale, purchase or auctions in electricity markets*". The role of Aggregator is defined by Article 210b of EL as follows: "*Aggregator acts in electricity market on behalf and for the account of market participants for whom it provides the service of aggregating electricity consumption and/or generation*", and it shall:

1) act toward the market participant in a non-discriminatory manner;
2) publish the general conditions of the offer for contract conclusion, i.e., to inform market participants in a convenient way about the offered conditions;
3) provide all relevant data to the market participant free of charge at least once during the accounting period if the market participant requests it;
4) inform market participants about the aggregation function on its website or in any other convenient way.

Aggregators and market participants conclude contracts regulating mutual relations (see Figure 1, above).

Law on the Use of Renewable Energy Sources (Official Gazette of RS, no. 40/21, hereinafter referred to as: LoURES) indirectly also provides for an aggregator and a role of aggregator; Article 58 of LoURES defines that "*prosumer is entitled to <u>independently or by means of an aggregator</u> generate electricity for own consumption, store the electricity for own needs, deliver surpluses of generated electricity into transmission, distribution and/or closed distribution systems and may not use incentive measures in the form of market premium or fid-in tariffs, nor may it be entitled to guarantees of origin.*" Article 66 of LoURES also defines that "*aggregation of renewable energy sources, and/or legal entity established on a principle of open and voluntary participation of its members*"… "*has right of production, consumption, storage and sale of renewable energy and right of access to all energy markets, <u>directly or by means of an aggregator</u>, in a non-discriminatory manner, as well as other rights and obligations of producers under this law.*"

Although the above mentioned laws regulating energy sector in the Republic of Serbia foresee an aggregator as a market participant/system user and define aggregation activity, legal regulations in this part have not been fully completed. In particular, the fact that aggregation is not intended to be an energy activity must be taken into account, and therefore the aggregator (natural or legal entity that provides the service of consolidating electricity consumption and/or generation for resale, purchase or auctions in electricity markets) cannot obtain a license or other consent to provide this service.

Therefore, to further define the role of aggregator, it is necessary to amend national secondary legislation in accordance with the "Clean Energy Package" of the European Union, which entered into force in June 2019, and the guidelines from the *EU Directive 2019/944*. This package defines new participants in the market such as aggregators, i.e., independent aggregators, and more precisely defined energy activities such as aggregating and energy storing. According to the Directive, in general, each electricity market participant is obliged to regulate his balancing responsibility by contract; to transfer it to another electricity market participant, to sign a full supply contract or to register as a balance responsible party. By Article 17(3.d) of this Directive, not even the new market participant – the Aggregator is exempt from this obligation. In this sense, there is no essential difference between the Supplier and the Aggregator. Nevertheless, one of the main differences between these two market participants is that the Supplier manages consumption implicitly (the customer reacts to the Supplier's price signals from the bill, and the tendency is to move towards dynamic pricing with the introduction of "smart" meters), while the Aggregator has the ability to manage consumption explicitly (directly, actively). This should include defining/contracting the conditions under which the Aggregator manages the customer's consumption and at what price, within an individual contract or within the Supply Agreement. Consumption explicit management would enable the Aggregator to make a profit on the markets of system services and balance energy, but it requires, in addition to currently lacking regulations, adequate infrastructure which implies the mass use of appropriate "smart" meters, which is another obstacle that needs to be eliminated to fully implement the concept of Aggregator on the market of the Republic of Serbia.

Additional limitation and possible problem, primarily in regulating the relationship between Aggregator and DSO, is represented by the legislative provision that the management of renewable sources over 160 kW is responsibility of DSO, "Elektrodistribucija Srbije" (EDS).

The position of the authors of this article is that EDS should operate RES power plants of individual capacities higher than 160 kW only to ensure safe operation of the distribution system. In such terms, Aggregator should dispatch and control these assets, while EDS would have a possibility to change their power (including power curtailment) only when safety of the distribution system is endangered (so-called "*Re-dispatching*" – a measure of change in generation and/or consumption implemented by the system operator, changing physical power flows in the system to ensure the safety of the system and eliminate congestion in the system. Assets (RES power plants, manageable consumption, storages) re-dispatched by EDS (due to threatened system safety), should be financially compensated for the lost profit.

Practically, operating RES power plants of individual capacities higher than 160 kW by DSO (EDS) should be regulated based on similar technical and market principles as those when TSO (in Serbia: EMS JSC) operates power plants of higher capacities connected to the transmission system in the moments of compromised system safety.

6. CONCLUSION

On the side of end-users of PS, there is significant capacity in manageable consumption. With dispersed (distributed) electricity generation and its expected expansion, including "prosumers" that were put under legal framework in Serbia in 2021, the need, but also the interest, to effectively and efficiently manage consumption and generation will strengthen at the users' level. When you add to that the necessity of improving energy efficiency on the consumption side, as well as the fact that perhaps the greatest potential – both for savings and for manageability and flexibility – lies in water and space heating devices, the concept of aggregation into a multi-energy composite (cooperative, collaborative) virtual power plant is imposed as a possible solution. Investing in its creation, development, technical implementation and expansion can turn out to be a more favourable solution than investing in dilapidated thermal energy capacities whose production is based on low-caloric and less environmentally acceptable lignite. In this regard, the composite virtual power plant can facilitate the expected greater scope of V-RES integration and actually represents a replacement capacity in the PS of Serbia.

For the realization of a virtual power plant, it is first necessary to define a methodology based on which the technical conditions of manageability would be evaluated for end-users who want to be a part of the virtual power plant. The methodology would have to include an assessment of availability of the end-user's manageable consumption, storage and reserve capacities, as well as the maximum active power of the storage. A large number of end-users who would be involved in the realization of virtual power plant, would generate large administrative costs. Larger storages should be used primarily. First of all, it is necessary to take advantage of the manageability of significant users of PS. From the point of view of the utilization of storage capacities, the order in the strategy of investing in this component of the composite virtual power plant would be as follows:

- use existing thermal storages,
- use existing potential energy stores,
- investing in new thermal storages,
- when all options for the construction and application of thermal storages have been exhausted, include the battery-based and hydrogen-based storages in the implementation project.

It is clear that one of the prerequisites for the realization of virtual power plant is the application of modern, "smart" devices, such as remotely controlled switches, followed by the application of appropriate management and control software and appropriate protocols for two-way communication and data transmission. Regarding the complex structure of the virtual power plant system, the concept based on IIoT was evaluated as the most suitable to make an efficient system of control, data processing, management, and decision-making. Greater flexibility on the side of electricity consumption and distributed production, aggregated and managed through the concept of a virtual power plant designed in this way, can lead to numerous benefits in terms of efficiency and operating costs of PS.

Depending on technical characteristics and the possibility of aggregated generation and consumption, the Aggregator, i.e., the virtual power plant operator can use it for trading and optimizing its own portfolio on the wholesale market, as well as for providing the system services to transmission and distribution system operators.

It should be emphasized that a prerequisite for the effective implementation of aggregation is the existence of an appropriate legal-regulatory framework with removed barriers for the Aggregator's performance in various markets, including the market of ancillary services.

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BIOGRAPHIES

Vladimir M. Šiljkut was born in Belgrade in 1966. He graduated in 1994 and received his doctorate in 2015 at the Faculty of Electrical Engineering in Belgrade. He worked in "Elektrodistribucija Beograd" (1995-2013) on distribution network planning, development and exploring, he led the Laboratory for Electricity Meters and Center for Integrated Management System. In "Electric Power Industry of Serbia", he headed the Department for Trade and Relations with Tariff Customers (2013-2015). Further, (2015/16) he managed and coordinated projects on reducing the Distribution System Operator losses. From 2016 to 2022, he had been, and currently is, the Head of the Unit for preparation of new investments in power plants and renewable energy sources. From March 2022 to July 2023 he was the Advisor for business system to EPS General Manager. Over a period of more than a decade, he had been engaged as visiting lecturer for electricity distribution and retail and power plants and switchgears at the School of Electrical and Computer Engineering in Belgrade. He is a (co)author of more than 75 articles and papers (four articles in international journals), published and presented during numerous national, regional and international conferences. These papers' scope includes the load forecasting method, optimal network planning, electricity losses estimation, RES, load management, power transformers, metrology, etc. He is also a co-author of one practical book on electric power distribution and electricity retail, in Serbian. As a member of Serbian National Committee of CIRED, and its Executive Board, he is particularly engaged in the session 1 – Network Components (as a Chairman), session 2 – Electricity Quality (a member) and session 5 – Distribution Network Planning.

Nikola Georgijević was born in 1987 in Belgrade. After completion of his undergraduate studies, he obtained master's and doctorate diplomas in Electrical Engineering and Computing in 2011 and 2020 respectively, at the Faculty of Electrical Engineering in Belgrade. He worked in Nikola Tesla Institute (2011-2020), where he was engaged in exploring EES analysis and optimization. Since 2020, he has been employed in Electricity Coordinating Center as chief of the software development section. His fields of interest are computer programming, mathematical modelling, EES stability optimization and analysis, machine learning, and artificial intelligence. He managed and participated in technical projects in the regions of south-east Europe, the Near East, Africa, and South America.

Saša Milić was born on 11th July 1967 in Belgrade. He graduated in 1993 and received his master degree and doctorate in 2000 and 2008, respectively, at the Faculty of Electrical Engineering in Belgrade. He has been a science adviser since 2021. His areas of interests and fields of professional expertise are: electrical and magnetic measuring, laser measuring, laser technics, optoelectronics and infrared technics, fuzzy logic, machine learning and artificial intelligence, internet of things and industrial internet of things, risk analysis and assessment, development strategies and management and decision-making algorithms, monitoring systems and expert systems. He was the project manager in more than one science, expert and innovative projects. He published over 100 scientific papers in the country and abroad. He published 10 technical solutions and had several technical and scientific lectures in prominent scientific institutions. Since 1994, employed in Belgrade University Electrical Engineering Institute Nikola Tesla. He is a member of scientific and technical boards of conferences and magazines.

Aleksandar Latinović was born on 6th September 1986 in Bihać. He went to Zrenjanin gymnasium, then graduated and received master degree at the Faculty of Electrical Engineering, Energy Department, in Belgrade. He has been employed in EPS since 2010. Special interests of his are within the field of ancillary services in electric power industry, primarily turbine governors, and additionally digitalization in electric power industry as well as technical and legal regulations in the field of energy. During the period of education, he obtained the following success: the best student in his generation both in primary and secondary school, awards on local and national competitions in physics, awards on knowledge competition of "Elektrijada" and an average mark obtained during bachelor and master studies of 9,5. Employed in EPS, Aleksandar participated in several projects on development of the turbine governors implemented in EPS, and development of thermal power plants simulator.

Projects on improving technical quality of ancillary services and one of the largest digitalization projects in the Republic of Serbia, PROTIS project, are some of the projects he directly managed.

Dušan Vlaisavljević was born in 1988 in Belgrade.Graduated in 2012 as Master in Electrical Engineering and Computer Science from Faculty of Electrical Engineering, University of Belgrade. The main areas of professional engagement include electricity market modelling and analysis, power generation portfolio optimization, power system development planning, development of wholesale and balancing market mechanisms and procedures, as well cost-benefit and economic evaluations of power plants and transmission infrastructure projects. He was engaged in numerous regional and international projects for power utilities, transmission system operators and international institutions (World Bank, European Commission, USAID and Energy Community Secretariat) in regions of South East Europe, Central East & Central West Europe, Black Sea region, South Caucasus, South East Asia and Central Asia.

Radoš Čabarkapa was born on 1st May 1986 in Belgrade. He completed primary school “Petar Petrović Njegoš” as a holder of the diploma of Vuk Stefanović Karadzić and the best student in his generation. In the period from 2001 to 2005, he is a student of the Mathematical Gymnasium in Belgrade. Afterward, in 2005, he enrolls in electrical engineering studies at the Faculty of Electrical Engineering (electric power systems department) in Belgrade. He completed the above mentioned studies in 2009 and master studies at the same Faculty in 2012. Since 1st June 2010, he has been employed in the public enterprise Electric Power Industry of Serbia occupying different positions in Electricity Trading Department, and currently in the same company, he heads the section for support to the planning and analysis of the plan implementation in the Power Portfolio Management Affairs. Areas of interest and professional expertise are focused on electricity market analysis, software modeling in the energy field and challenges of RES transition. As a member of working groups of the Ministry of Mining and Energy, he participated in development of strategic documents, by-laws and Law on the use of Renewable Energy Sources.

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Agregacija kompozitne virtuelne elektrane – mogućnosti i ograničenja za primenu u Srbiji

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Kategorija rada: Pregledni članak

Ključne poruke

- Dat detaljni prikaz literature o virtuelnim elektranama, pregled koncepata i konkretnih rešenja
- Sagledani izvori energije, načini agregacije i tehnički potencijal za uspostavljanje virtuelne elektrane
- Predložen koncept kompozitne virtuelne elektrane, procenjeni troškovi, koristi, zakonska ograničenja

Kratak sadržaj

Elektroenergetski sektor Srbije se sve više suočava s izazovima budućnosti. Većina proizvodnje električne energije zasniva se na niskokaloričnom lignitu. Njegov sve lošiji kvalitet uzrokuje pad nivoa sigurnosti, pouzdanosti i efikasnosti termoelektrana, uz povećanje zagađenja. Osim značajnih sredstava namenjenih njihovoj revitalizaciji, velika su ulaganja u nove, skupe sisteme za smanjenje emisija štetnih materija. Uz najavljene ugljenične takse, čiji se rast očekuje u budućnosti, isplativost ovih izvora i tržišna konkurentnost cene električne energije dobijene iz njih, postaju krajnje upitni i neizvesni. U procesu neminovne dekarbonizacije, postavlja se i strateško pitanje pred srpske eksperte – čime nadomestiti znatne bazne (termo)kapacitete, koji će verovatno biti ugašeni?

Na drugom kraju sistema, problem predstavljaju neefikasno korišćenje električne energije, neprihvatljivo visok nivo njenih gubitaka, uključujući i one usled njenog neovlašćenog korišćenja. Pri tome, ni iz bliza nisu iskorišćene tehničke mogućnosti za upravljanje opterećenjem niti za primenu većeg broja tarifnih stavova, radi željenog odziva potrošnje.

U takvim okolnostima, ključno je pitanje – kakvu strategiju investiranja treba odabrati? Ovaj rad predlaže rešenje koje bi imalo pozitivan uticaj na oba kraja sistema i njegove aktere, ali i na mreže između njih i njihove operatore. „Elektroprivreda Srbije“ bi mogla da iskoristi najavljeno uvođenje agregatora, kao novog učesnika na tržištu električne energije, za svojevrsni zajednički poduhvat sa krajnjim korisnicima, za uspostavljanje kompozitne virtuelne elektrane. Ona bi za elektroprivredu predstavljala novi, zamenski kapacitet, a za kupce izvor ušteda i potencijalnog prihoda. Ovakva elektrana bi obuhvatila različite, dispergovane obnovljive izvore, kako električne energije, tako i toplotne, sisteme za skladištenje energije, punjače za električna vozila, upravljivo opterećenje kupaca i različite programe za odziv potrošnje. Povećanjem obima ovakve agregacije, kompozitna virtuelna elektrana bi agregatoru takođe omogućila pružanje pomoćnih sistemskih usluga operatoru prenosnog sistema, što bi predstavljalo dodatni benefit. U sinergiji s drugim neophodnim, strateškim koracima, predloženi koncept bi Srbiji mogao da obezbedi sigurniju energetsku budućnost.

Ključne reči

Agregacija, dekarbonizacija, distribuirana proizvodnja, pomoćne usluge, odziv potrošnje, upravljanje opterećenjem, virtuelna elektrana

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