The Virtual Power Plant for the Management and Control of Distributed Generation - Review

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***Abstract*—*The significant increase in the insertion of distributed generation in the electric power systems when carried out in a disorderly manner can cause disruption to the electric power system. In this sense, Virtual Power Plants (VPP) are presented as a solution to ensure, through a power management system, the best control actions to integrate the generation and demand pattern of each generating unit. Thus, this paper presents a literature review on VPP, introducing concepts, definitions, topologies, communication technologies used, and finally presenting the advantages and disadvantages on this topic*.

***Keywords*—Virtual Power Plant, Renewable Energy, Microgrid, Distributed Generation.**

I. INTRODUCTION

Distributed generation is seen by many as a solution to meet the growing demand for electricity. However, the insertion of distributed energy resources in the electrical system, when carried out in a disorderly way can cause some complications, for example: increase in power losses in the network, unreliable operation of protection devices, undesired voltage profile and an imbalance between actual energy consumption and production [1]. In this sense, one way to avoid such complications is through the management of distributed generation units.

This management requires a robust control system since the distributed generation units are configured in a topology so that the Electrical System "sees" this set as a single entity. This configuration is called Virtual Power Plant. This topology results in operational changes in the electric power system, where the network ceases to act as purely passive (unidirectional energy flow - from high to low voltage) and acts as an active network (with multidirectional energy flow) [2]. The generation and demand management activities are carried out by an Energy Management System - EMS, and its activities are performed by sending signals that control the generation and demand pattern for each generating unit, consumption unit or any other assets belonging to the network, such as reclosers and LTCs (Load Tap Changers) [3].

This paper aims to carry out a literature review on VPP, presenting definitions, concepts, topologies, technologies used in its implementation, benefits to the electric system among other factors relevant to the topic.

To carry out the bibliographic survey for the paper, the ProKnow-C methodology was used, analyzing the Scopus and Web of Science databases, for the survey of papers the key words were used: “Virtual power plant”, “Review”, “Framework”, “Decentralized Energy Management System”, “Distributed Energy Management System”, “Distributed Generation”, “Renewable Energy Resources”, “Power Energy Resources” e “Microgrid”, the combination of keywords in search engines resulted in 2191 papers, when selected we obtained a portfolio of 35 to elaborate this document.

II. VIRTUAL POWER PLANT (VPP)

A. Definition of Virtual Power Plant

Because it is an element of recent implementation and still in the development stage, VPP does not have a literary definition yet, which is why some definitions found in the literature are presented below.

In [4], the author defines VPP as systems that use load management software and energy storage systems. They are groups composed of distributed generators, where the generation is carried out mainly by sustainable sources, battery systems and "active" consumers that use load

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management systems. He also says that the group should be controlled remotely by an EMS which manages the system ideally, depending on the energy demand, weather situation and storage capacity.

The VPP is also defined as a flexible representation of a portfolio of DER . It not only aggregates the capacity of several DERs, but also creates from a composition of parameters characteristic of each DER a unique operational profile, although it is composed of several technologies and several operational standards [2].

In [5] VPP is defined as the combination of different types of energy generation, renewable and non-renewable and storage devices, so as to appear in the energy market as a generating plant with a defined hourly output.

It is possible to notice that, although there are differences between the presented definitions, there is a consensus that a VPP is a group of DERs with different technologies in order to operate as a virtual power generation plant capable of controlling the aggregate units, managing the flow of electricity between them and obtaining the best operation for the system [1].

B. Concept of Virtual Power Plant

Formally, a VPP can be conceptualized as a group of distributed generators, flexible loads, and energy storage equipment that are grouped together for the purpose of operating as a single entity, as presented in Fig. 1: Virtual Power Plan Concept [6].

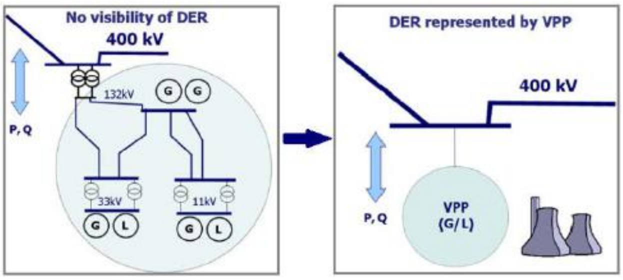

Fig. 1: Virtual Power Plan Concept [6].

Generating units in the VPP may use fossil or renewable energy sources. The objective of a VPP is to coordinate the production of the units that compose it in order to maximize its the performance [7]. In this sense, [8] states that the main part of a VPP is the EMS, which is responsible for coordinating the flow of energy from the plants, as well as the management of controllable loads and batteries. In this way, with the active network, the VPP not only receives information of the current state of each unit connected to it, but also sends control signals to these units [9].

The exchange of information between the EMS, the generating units and the plants (mainly the intermittent ones, wind and photovoltaic), allows the EMS to operate according to specific objectives. For example, by acting on power flow control you can: Minimize operating costs, Increased reliability of power supply, Minimize losses caused by technical errors, Demand control and Planning, operation and supervision of the energy distribution process.

In addition, in order to obtain a process of optimization of the operation, information about the probable points of network overload is essential. This set of information allows the EMS to define the optimal mode of operation for each particular system [9].

In some countries the VPP is in operation, for example: Germany, Denmark, Spain and England are participants of the Fenix Project started in 2006 [10], the Netherlands has been running the City Zen Project in the city of Amsterdam since 2016 [11], France [12][13] and China[14].

III. STUDY OF THE TECHNOLOGIES - VPP

According to [1] [9] [8] and [15] the VPP can be divided into three technological components, being these: (i) Distributed generation, (ii) Energy Storage Systems and (iii) Information and communication technology. This chapter will now detail this division.

C. Distributed Generation

There are several considerations regarding the definition of distributed generation, so that those presented in the literature are not consistent [16], however, the authors usually agree that "Distributed Generation is a generation plant directly connected to the grid at the distribution voltage level or at the client side"[17].

The input of distributed generation into the system represents, depending on the system, considerable positive impacts on power flow and voltage levels. For example [16]: Loss reduction; Increased system reliability; Investments in new transmission and distribution infrastructure are dispensable; Quick and easy installation of standardized and pre-fabricated components and Reduced costs, since high-voltage power transmission over long distances is avoided. The Table 1. Most used technologies in GD [18].

The Table 1 shows the most commonly used technologies in distributed generation (DG) are presented and their typical power per module [18].

Table 1. Most used technologies in GD [18].

Technology	Power available per module
Combined Cycle Gas Turbine	35 - 400 MW
Internal combustion engines	5 kW - 10 MW
Turbine combustion	1 - 250 MW
Micro-Turbines	35 kW - 1 MW
Fuel Cells, Phosphoric Acid	200 kW - 2 MW
Fuel cells, Molten Carbonate	250 kW - 2 MW
Fuel cells, Proton Exchange	1 - 250 kW
Fuel cells, Solid Oxide	250 kW - 5 MW
Battery Storage	500 kW - 5 MW
Small Hydro	1 - 100 MW
Micro Hydro	25 kW - 1 MW
Wind turbine	200 W - 3 MW
Photovoltaic Arrays (PV Arrays)	20 W - 100 kW
Solar thermal, Central Receiver	1 - 10 MW
Solar thermal, Lutz System	10 - 80 MW
Biomass Gasification	100 kW - 20 MW
Geothermal	5 - 100 MW
Ocean Energy	100 kW - 5 MW

The generation units can be divided into 2 groups [9]: (i) Distributed Home Generator (DHG): They are the generation units intended for use by individual users, such as households, businesses or industries. In this case, excess energy can be injected into the grid [9]; (ii) Public Distributed Generator (PDG): It distinguishes itself from the DHG, since they are generators whose purpose is to inject the energy produced in the network, and do not have an individual owner [9].

D. *Energy Storage System (ESS)*

Considering that the component generating units of a VPP are mostly renewable energy sources, energy storage systems contribute to attenuate the fluctuation of the frequency caused by the intermittent generation of sources, aiming at the delivery of high quality energy , controlling frequency, improving transmission line capacity, attenuating voltage fluctuations and improving power quality [19] [20].

Energy storage systems are classified based on the use of energy in a specific form, and can be categorized into [19]: Mechanical, Eletrochemical, Chemical, Electric, Thermal and Hybrid.

In addition, two criteria are used to determine the type of storage system for each application: the nominal power of the system and the discharge time of the rated power. According to these criteria the ESS can be used for three applications [21]: (i) Energy quality: According to [21], the ESS are used for a short period of time, within a few seconds, so the most used technologies are supercapacitors, energy storage in magnetic superconductors and some battery types; (ii) Briding Power: This application is used in the exchange of generation technologies, having as main objective to ensure the continuity of the energy supply. The most commonly used ESSs are supercapacitors and some battery technologies [21] and (iii) Power management: When used for this purpose the technologies that make up ESSs have high storage capacity, so the most appropriate technologies for this application are compressed air storage systems, hydrogen technologies and some types of batteries [21]. Some storage technologies are presented in [19].

Table 2. ESS, life cycle and efficiency [9].

Storage System	Life (cycles)	Efficiency (%)
Hydroelectric with pumping	75 years	70-80
Compressed air	40 years	-
Flow Batteries	1500 – 2500	75 – 85
Metal Oxide Batteries	100 – 200	50
Sodium sulfide battery	2000 – 3000	89
Other advanced batteries	500 – 1500	90 – 95
Lead Acid Batteries	300 – 1500	60 – 95
Supercapacitors	10000 – 1000000	93 - 98

E. *Information and Communication Technology*

As discussed earlier, when implemented a VPP involves the participation of several DERs in simultaneous operation, so the EMS, through bidirectional communication, requires the data of all the RSDs in real time, allowing the execution of actions to guarantee the reliability and stability to the members of the network. Therefore, information and communication technology is one of the main components in the design of a VPP, making necessary the analysis of some aspects that impact on the development, such as [22]: (i) Type and configuration of equipment in the system: since different equipment may require responses at different times, so that different communication and interface configurations are set up together with the bandwidth of

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each communication channel; (ii) Type of connection required: It is determined by the number of DERs in the system and their physical location, directly influencing the volume of data traffic and system maintenance costs; and (iii) Type of control to be used: it can be centralized or decentralized and directly designates the communication structure of the system. Opting for a centralized system guarantees the system a unification and simplification of its components, since all the processes are executed by a single software, without significant complications with respect to operating conflicts. Decentralized communication systems guarantee the system a high rate of redundancy, since it allows the independent operation of each equipment.

It is noteworthy that although the VPP technology is recent, it uses consolidated communication technologies in automation systems and even power systems [22]. The communication infrastructure used takes into account the value available to the project and the location of the DERs. A basic division of the communication system defines two types of technologies that can be used: wired and wireless. Tab. 3 shows some technologies already used in the functioning VPP.

Table 3. Communication technologies used in VPP [22].

Wired	Wireless
Power Line Communication (PLC)	Satellite Communication
Twisted pair	Wireless Communication
Optical fiber	Cellular Communication

Wired technologies can be trivially distinguished, however wireless technologies require a more detailed approach to a more consolidated understanding of the subject. The following will present some of them.

Satellite Communication: is the transmission of signals between two points (transmitter and receiver) through satellites. In the process of data transmission is considered the modulation of the signal and sending from the transmitter, the signal is then received by the satellite, amplified and sent to the receiver on the ground. This technology is used for monitoring and remote control of substations [23].

Wireless Communication: There are several technologies, wireless for VPP applications, these technologies are divided into short or long range. Some examples of technologies that can be used in VPP are : ZigBee, Wireless Local Area Network (WLAN), Wireless Mesh e Z-Wave [23]. The Table 4 it is possible to distinguish these technologies and the most recommended ones for each distance.

Table 4. Wireless technologies for VPP [23].

Technology	Protocol	Theoretical maximum transfer rate	Range of coverage
ZigBee	ZigBee	250 kbps	Up to 100 meters
	ZigBee Pro		Up to 1600 meters
WLAN	802.11x	2 - 600 Mbps	Up to 100 meters
Wireless mesh	Many (802.11, 802.15, 802.16)	Depends on protocol selected	Depends on the type of deployment
Z-Wave	Z-Wave	40 kbps	Up to 30 meters
WiMAX	802.16	75 Mbps	Up to 31 miles
Cellular	2G	14.4 kbps	Up to 31 miles
	2.5G	144 kbps	
	3G	2 Mbps	
	3.5G	14 Mbps	
	4G	100 Mbps	
Satellite	Internet satellite	1 Mbps	62 - 3728 miles

Cellular Communication: technology based on radio networks and therefore has a large number of transmitters, taking advantage of the frequency of radio waves to increase coverage and data transmission capacity. The division of cellular communication technology is available in the Table 4, as well as the transmission capacity and coverage area.

IV. TOPOLOGY OF CONTROL

Given the concept and defined the technologies used in VPP, it is possible to analyze the VPP with greater understanding. The Figure 2 presented a VPP scheme is presented, where it is possible to notice that all forms of energy are connected to VPP, by which they will also be controlled, so that specific control topologies are required for each level of freedom of the DER.

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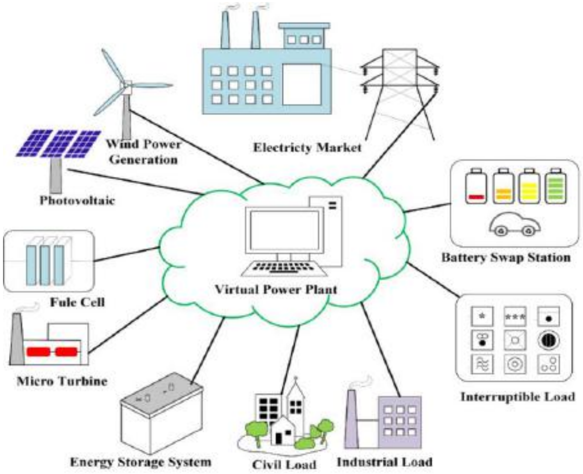

Fig. 2: Basic Elements in a Virtual Power Plant [24]

In [9], [8] and [15] two control topologies for VPP are pointed out: centralized and decentralized. However, it is also possible to find in the literature a third hierarchical control topology. All of these topologies will be explained below.

F. Virtual Power Plant – Centralized

In this VPP topology the DERs are controlled by a Control Coordination Center (CCC), which is strategically installed in the center of the DERs. This center is responsible for receiving, analyzing and processing the load signals, after which it transfers the power request to each distributed generation controller (DGC), so that the requested power is delivered as required [9], as shown in Fig. 3.

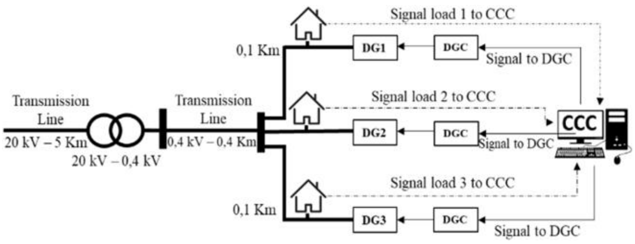

Fig. 3: Centralized Virtual Power Plant. Source [9]

Moreover, in this topology the control logic is the responsibility of the VPP and the planning of market and production are performed separately from the DER, this being an advantage given that the VPP can use the DERs to meet market demand [25]. The topology of this structure is shown in Fig. 4.

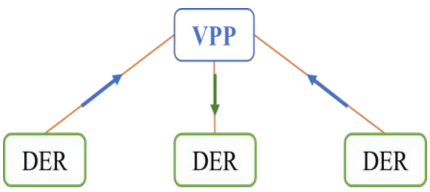

Fig. 4: VPP with Centralized Control [25]

G. Decentralized Virtual Power Plant

In this topology the active energy produced by the DER is controlled by the DGC which is controlled by a local controller (LC). Each DER has a dedicated LC that are connected to each other in the ring topology, thus ensuring a synchronized signal exchange, being treated as a single control center, as can be seen in Fig. 5.

For [25] this topology is named "VPP with fully distributed control", where each DER acts independently, reacting under its responsibility to the different states of the market or the energy system. This topology can be seen in Fig. 6.

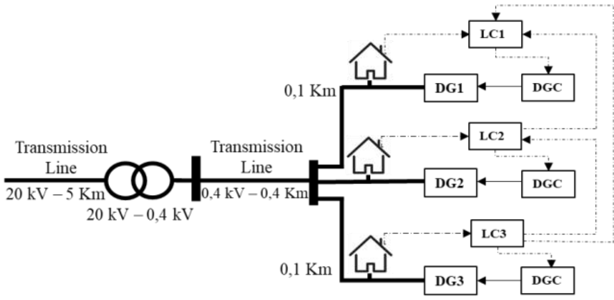

Fig. 5: Decentralized Virtual Power Plant [9].

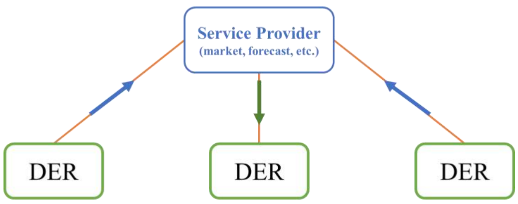

Fig. 6: VPP with fully distributed control [25]

H. Virtual Power Plant with Distributed Control

According to [25] there are levels of hierarchy, such that the coordination and supervision of DERs is performed by a local VPP (low level of control), while decisions are made by the VPP of high level of control. This simplifies the responsibilities and communication of each VPP [25]. The Fig. 7 shows the topology with distributed control.

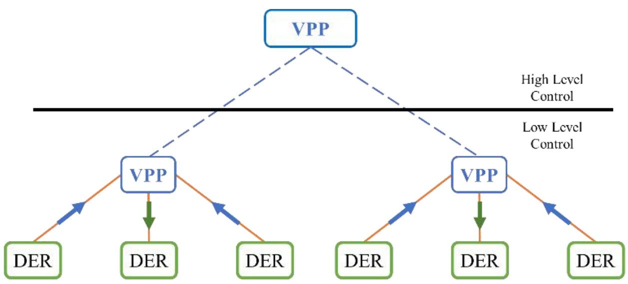

Fig. 7: VPP with distributed control [25]

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V. TYPES OF VIRTUAL POWER PLANT

The different control topologies presented earlier, as well as the technologies employed in VPP, contribute to the VPP's responsibility to control the power supply and manage the flow between the VPP and the power grid in order to contribute to the quality of electric power. Therefore, according to [1] in order for VPP to fulfill these functions, it is necessary to have some tools, such as: Applications for control and monitoring; Intelligent metering and control of equipment installed in customers' homes; Software that guarantee the predictability of the generation of DERs and Communication Infrastructure

Thus, it is possible for VPP to perform its activities in order to guarantee the best results in connection with the system. To this end, VPP assumes two distinct roles: Technical Virtual Plant (TVPP) and Commercial Virtual Plant (CVPP). It is worth noting that both operate together and the role of each will be presented below.

I. Technical Virtual Power Plant (TVPP)

TVPP is composed of the generating units of the same geographic region, being responsible for the operation of these and the storage systems of each one, besides resolving technological restrictions and mainly the communication of the VPP with the distribution network [1], [26]. In the attributions of a TVPP is the control of the energy flow within the group of DERs, realization of continuous monitoring, management of financial issues, detection of faults and its location, besides the execution of auxiliary services to the system [1], [27]. To that end, CVPP is responsible for providing contractual information and controllable loads, this information must contain [1]: Maximum generation capacity and the commitment of each generating unit; Generation and consumption forecast; Physical location of generating units and loads; Location of storage system and capacity and Possible control strategy for controllable loads throughout the day in accordance with the contractual obligations between VPP and loads.

Based on this information TVPP ensures that the system will be operated safely and in an optimized way [1]. Furthermore, according to [1], TVPP will perform the following functions: (i) Manage the local system for the distribution system operator; (ii) Ensure balance, network management and execution of ancillary services; (iii) Allow the visibility of the DERs in the distribution network to the system operator, in order to allow the distributed generation to contribute to the demand of the distribution system; (iv) Observe the operation of the DER according to the information obtained with CVPP; (v) Continuously monitor equipment condition; (vi) Asset management based on statistical data; (vii) Auto identification of system components; (viii) Determine missing places; (ix) Facilitate maintenance and (x) Optimize project portfolio and statistical analysis. The Fig. 8 shows in a summarized way the necessary inputs and outputs that characterize the activity of a TVPP.

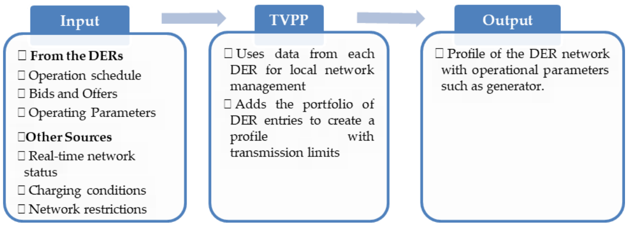

Fig. 8: Synthesis of inputs and outputs of a TVPP [2].

J. VPP Commercial (CVPP)

According to [26] CVPP is responsible for the VPP business in the energy market, managing the business portfolio and providing services to the system operator. The operator of a CVPP is usually a third party aggregator or a party responsible for maintaining the balance between the VPP and the market, for example, an electric utility. It is a representation of a set of DERs that can be used to participate in the energy market in the same way as a centrally generated plant, this mode of operation reduces to the associated DER the risks that would be exposed in a particular operation in the energy market, in addition to providing the benefits of resource diversity and increasing generation capacity through cooperation with other generating units [2].

CVPP optimizes the use of VPP in the energy market, generating bilateral contracts between DERs and other customers. These contracts are sent to TVPP where they are analyzed and considered in the planning and predictability of generation, once the unit will have another contractual generation [1].

CVPP allows small generating units to enter the electric power market, since these are not allowed when acting in a solitary way, since their production is not enough, and can have consequences in the face of non-guarantee of service to demand. The features of a CVPP are listed in [1], as follows: (i) Schedule production based on customer need forecast; (ii) Negotiate throughout the electricity market; (iii) Manage the business portfolio; (iv) Provide services to the system operator; (v) Send features and maintenance costs of DER; (vi) Forecast production and demand based on weather forecast and consumption profile; (vii) Elaborate proposals for DER

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and sending to the energy market, (viii) Schedule generation and daily optimization and (ix) Sell energy from the DER in the energy market .

Still according to [1], to achieve the above objectives, CVPP interacts with the following entities: (i) DER: Its main function is to fill the gap between demand and production. The production requirement of the DER should be planned with anticipation this planning should be sent to TVPP for scheduling; (ii) Party Responsible for the Balance (PRB): It is an electric energy business entity whose purpose is to prepare its own energy consumption / production plan in such a way that it is used by TVPP and (iii) TVPP: Receives the information of the CVPP considering them during the optimization of the operation of the VPP and its interaction with the main network .

Unlike TVPPs, the CVPP can represent DERs from several different locations in systems that allow unrestricted access to the energy market, however in regions where energy resources are critical the CVPP will be restricted to include only DER from the same locality[2].

The possibility of the CVPP representing DERs from any part allows the generating units to choose which CVPP will represent it in the electricity market [2]. The Fig. 9 shows the synthesis of inputs and outputs of a CVPP.

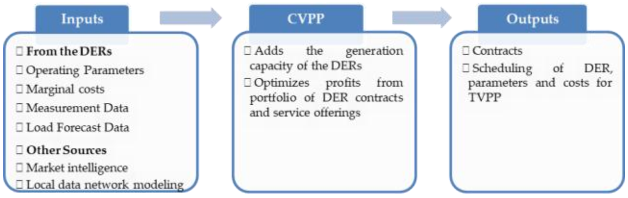

Fig. 9: Synthesis of inputs and outputs of a CVPP [2].

K. Advantages and Disadvantages of VPP

Although there are a limited number of VPP and research projects related to the subject so far, it is possible to find some references of advantages and disadvantages of implementing this topology (Table 5), which will be presented below, according to [9] e [25].

Table 5. Advantages and disadvantages of VPP [9] [25].

Advantages	Disadvantages
- Optimization of the units of distributed generation to provide services to the distribution network. Reduction of losses in transmission and distribution. - Decrease in the emission of greenhouse gases, since sustainable sources are used to generate energy by DER. - Economic benefits to members of distributed generation units. Slows the need for the construction of new plants by concessionaires. - Provides services such as network disturbance filtering and reactive power compensation. - It allows concessionaires to provide customized energy delivery services to individual consumers while simultaneously optimizing the production and distribution of electricity at costs much lower than those practiced in the current system. - Through the CVPP facilitates the access of the RSD to the electricity market.	- Climate dependence of generation resources. - Need for a robust cyber security system to control VPP. - Uncertainty of the dynamic response to the system. - Indispensable of an information technology system for the automated control of generating units.

L. Rules and regulations

In Brazil, the regulation that most closely approximates VPP is Normative Resolution n° 482/2012, which presents the shared generation, such as the characterization of the meeting of consumers within the same concession area or permission, through a consortium or cooperative, composed of individual or legal entity. However, it does not provide for the control of the generating units by a third party or the possibility of the sale of energy to the concessionaire. In Brazil the energy produced by GD is offset in the energy consumed by the property where GD is installed, this credit will remain available for the property for the period of 60 months.

VI. CONCLUSION

This article reviews Virtual Power Plants (VPP). Its different definitions and possible questions generated to the reader are due to the fact that the concept is relatively new and, therefore, research about this is scarce. On the other hand, although the concept is new, it shows itself in line with the current needs of the evolution of the energy market and evolution of the increase in demand. The concept of CVPP facilitates and encourages

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entrepreneurship and it is hoped that more people will enter the energy market through cooperatives or consortia. TVPP has the greatest benefit in controlling distributed units and the predictability of generation.

In Brazil, to date we do not have information about installed VPPs and few research works on the subject, therefore, this work helps future researchers to understand the concept and the main aspects regarding VPP.

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REFERENCES

[1] M. M. Othman, A. Y. Abdelaziz, and Y. G. Hegazy, "A Review of Virtual power plant Definitions , Components , Framework and Optimization A Review of Virtual power plant Definitions , Components , Framework and Optimization," vol. 6, no. February 2016, 2015.

[2] D. Pudjianto, D. Pudjianto, C. Ramsay, C. Ramsay, G. Strbac, and G. Strbac, "Virtual power plant and system integration of distributed energy resources," Renew. Power Gener. IET, vol. 1, no. 1, pp. 10–16, 2007.

[3] P. Lombardi, M. Powalko, and K. Rudion, "Optimal operation of a virtual power plant," IEEE Power Energy Soc. Gen. Meet., pp. 1–6, 2009.

[4] P. Lombardi, "Multi Criteria Optimization of an Autonomous Virtual Power Plant with a High Degree of Renewable Energy Sources," Proc. 17th PSCC, 2011.

[5] G. Koeppel, "Distributed Generation - Literature Review and Outline of the Swiss Situation," no. November, pp. 1–19, 2003.

[6] M. Braun, "Virtual Power Plants in Real Applications Pilot Demonstrations in Spain and England as part of the European project FENIX," Int. ETG-Kongress, no. August, pp. 3–8, 2009.

[7] J. M. Morales, A. J. Conejo, H. Madsen, and M. Zugno, Integrating Renewables in Electricity Market - Operational Problems. New york: Springer, 2014.

[8] H. Saboori, M. Mohammadi, and R. Taghe, "Virtual power plant (VPP), definition, concept, components and types," Asia-Pacific Power Energy Eng. Conf. APPEEC, 2011.

[9] T. K. V. Hernández, "Uma proposta de integração da geração distribuída, por meio das usinas virtuais, ao Sistema Elétrico do Estado de São Paulo," Diss. em Energ. do Inst. Energ. e Ambient. da Univ. São Paulo – USP, p. 152, 2015.

[10] A. van der Welle, C. Kolokathis, J. Jansen, C. Madina, and A. Diaz, "FENIX a step towards the future of electricity networks. Assessment of costs and benefits of FENIX: Final Report," Eur. Comm. Sixth Framew. Program. Res. Technol. Dev., p. 70, 2009.

[11] N. E. Rosman, "Impact Analysis of a Virtual Power Plant," 2017.

[12] M. Armstrong and A. Galli, "Impact of VPP on the Day-Ahead Market in France Accepted for publication in the Journal of Energy Markets," vol. 33, no. April, pp. 12–13, 2009.

[13] C. Tranchita, "France Pilots Virtual Power Plant," no. April, 2016.

[14] X. Wang et al., "Multi-Objective Virtual Power Plant Construction Model Based on Decision Area Division," Appl. Sci., vol. 8, no. 9, p. 1484, 2018.

[15] E. A. Setiawan, Concept and Controllability of Virtual Power Plant. 2007.

[16] V. S. Bhadoria, N. Singh, and V. Shrivastava, "A Review on Distributed Generation Definitions and DG Impacts on Distribution System," Int. Conf. Adv. Comput. Commun. Technol. (ICACCTTM - 2013), no. November, 2013.

[17] "Distributed Generation in Liberalised Electricity Markets," 2002.

[18] L. I. Dulău, M. Abrudean, and D. Bică, "Distributed Generation Technologies and Optimization," Procedia Technol., vol. 12, pp. 687–692, 2014.

[19] M. Faisal, M. A. Hannan, P. J. Ker, A. Hussain, M. Mansur, and F. Blaabjerg, "Review of energy storage system technologies in microgrid applications: Issues and challenges," IEEE Access, vol. 3536, no. 1, 2018.

[20] S. Koohi-Kamali, V. V. Tyagi, N. A. Rahim, N. L. Panwar, and H. Mokhlis, "Emergence of energy storage technologies as the solution for reliable operation of smart power systems: A review," Renew. Sustain. Energy Rev., vol. 25, pp. 135–165, 2013.

[21] P. Lombardi, T. Sokolnikova, Z. Styczynski, and N. Voropai, Virtual power plant management considering energy storage systems, vol. 8, no. PART 1. IFAC, 2012.

[22] O. Starynets, "PG Thesis-Communication in microgrids and virtual power plants," no. June, 2016.

[23] M. Kuzlu and M. Pipattanasomporn, "Assessment of communication technologies and network requirements for different smart grid applications," 2013 IEEE PES Innov. Smart Grid Technol. Conf. ISGT 2013, 2013.

[24] H. Bai, S. Miao, X. Ran, and C. Ye, "Optimal Dispatch Strategy of a Virtual Power Plant Containing Battery Switch Stations in a Unified Electricity Market," pp. 2268–2289, 2015.

[25] L. I. Dulau, M. Abrudean, and D. Bica, "Distributed generation and virtual power plants," 2014 49th Int. Univ. Power Eng. Conf., no. December, pp. 1–5, 2014.

[26] M. Thesis, S. Development, and T. Olejnczak, "Distributed Generation and Virtual Power Plants : Barriers and Solutions Energy and Resources," Integr. Vlsi J., no. 0357022, 2011.

[27] S. Ghavidel, L. Li, J. Aghaei, T. Yu, and J. Zhu, "A review on the virtual power plant: Components and operation systems," 2016 IEEE Int. Conf. Power Syst. Technol. POWERCON 2016, pp. 1–6, 2016.