# Virtual Power Plant (VPP), Definition, Concept, Components and Types

[1] H .Saboori, Student Member, IEEE, [2] M. Mohammadi, and [2 & 3] R. Taghe

[1]Center of Excellence for Power System Automation and Operation, Iran University of Science and Technology (IUST), Tehran-Iran
[2] Islamic Azad University, Borujerd Branch, Borujerd, Iran
[3] Bisotoun Power Generation Management Company, Kermanshah, Iran

*Abstract*— **Along with the rising energy consumption in the world, new technologies will influence the way we generate, distribute and consume energy. Alongside others, distributed energy generation becomes a major trend in many countries. The fast upward penetration of Distributed Energy Resources (DER) and the ongoing trend towards a more competitive electricity market requires new technologies and policies to handle both emerging technical and economic issues. In order to handle distributed generation and to intensify its visibility within power markets, the idea of virtual power plant (VPP) has emerged and is used by many researchers. It is composed of combining various small size distributed generating units to form a "single virtual generating unit" that can act as a conventional one and capable of being visible or manageable on an individual basis. Present paper tries to sheds light on main issues related to the idea of the VPP. The paper will review various definitions and primary concept of VPP, its main components, and finally two principal VPP types namely commercial VPP (CVPP) and technical VPP (TVPP).**

**Keywords-Commercial VPP (CVPP); Distributed Energy Resources (DER); Technical VPP (TVPP); Virtual Power Plant (VPP).**

## I. INTRODUCTION

The penetration of Distributed Energy Resources (DER) is rising fast worldwide, which is mainly associated with the requirement of a sustainable energy system with less environmental problems, more diversified energy resources and enhanced energy efficiency [1]. In the meanwhile, the continuing process of liberalization of the electricity market, i.e. the changeover from the monopoly system to competitive market structures, also attracts more and more attention [2]. In the context of these two tendencies, running a great number of DER units under market conditions is inevitable, which yet poses new challenges that have to be addressed including:

• Taking part in market: Considered as small, modular power sources, storage technologies and controllable loads [3], DER is generally prohibited from entering the current electricity market [4].

• Intermittent nature: As many DER technologies like solar cells and wind turbines are weather dependent, their fluctuating output is therefore considered non-dispatchable which not only limits their contribution to grid operation, but also causes economic penalties associated with unexpected unbalances.

• Stand alone: Many DER units are working isolated due to their different ownerships. Cooperation and communication often lack between neighboring DER units, thus the capability of DER is restricted to satisfy the local needs rather than the whole grid.

One way to address these issues is to aggregate a number of DER units in a so-called Virtual Power Plant (VPP). In this construction, the group of DER units will have the same visibility, controllability and market functionality as the conventional transmission-connected power plants [5]-[10].

The remainder of paper is as follow: in section II various VPP definitions introduced in literature and general concept of it has presented. Section III states the main VPP components. Then, section IV explains the terms technical VPP (TVPP) and commercial VPP (CVPP). Finally, section V mentions the conclusion remarks.

## II. VPP DEFINITION AND CONCEPT

### A. Definition (Literature Review)

Actually, VPP is still in hypothesis stage and there is not a unique definition for the framework of VPP in the literature. In [11] VPP is defined the same as an autonomous micro-grid. In [7], VPP is defined as an aggregation of different type of distributed resources which may be dispersed in different points of medium voltage distribution network. In [15], VPP is composed of a number of various technologies with various operating patterns and availability which they can connect to different point of distribution network. In [14] VPP defines as a multi-technology and multi-site heterogeneous entity. In the FENIX project concept of VPP is defined as: "A Virtual Power Plant (VPP) aggregates the capacity of many diverse DERs, it creates a single operating profile from a composite of the parameters characterizing each DERs and can incorporate the impact of the network on aggregate DERs output. A VPP is a flexible representation of a portfolio of DERs that can be used to make contracts in the wholesale market and to offer services to the system operator [15]."

## B. General Concept

A virtual power plant is a cluster of dispersed generator units, controllable loads and storages systems, aggregated in order to operate as a unique power plant. The generators can use both fossil and renewable energy source. The heart of a VPP is an energy management system (EMS) which coordinates the power flows coming from the generators, controllable loads and storages. The communication is bidirectional, so that the VPP can not only receive information about the current status of each unit, but it can also send the signals to control the objects [16, 21].
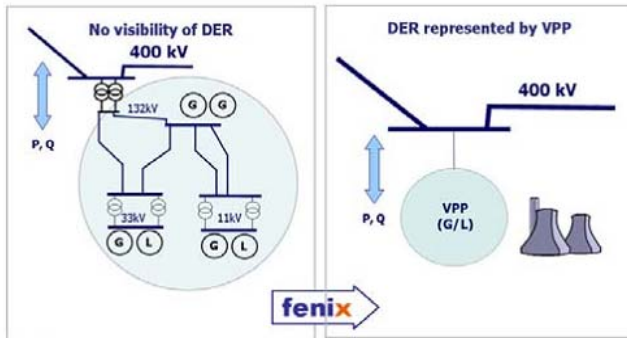


Figure 1. VPP Concept in FENIX [21]

The mentioned Energy Management System (EMS) can operate according to its targets which can be, for example, the minimization of the generation costs, minimization of production of green house gasses (GHG) and maximization of the profits. In order to achieve such targets the EMS needs to receive information about the status of each unit on the one hand, and on the other hand forecast - especially for renewable units like wind and photovoltaic (PV). Furthermore, the information about the possible bottlenecks in the grid plays a relevant role in the optimization process of the VPP operation. In this way the EMS can choose the optimal "modus operandi". Due to the fluctuating nature of renewable energy sources, the prediction of the energy production is not an easy procedure. Actually, for Wind Park, the day ahead forecasting errors are between 9 and 19 %. Due to such errors, power networks with a high penetration of renewable energy sources, can easily have bottleneck and balancing problems. These problems can be faced either by using ESS or NSM. Although ESS and NSM are the most used instruments, in some cases alternative solutions can be also used. For example, in regions poor of fresh water, desalination plants that are driven by the electricity surplus can be an optimal solution to face bottleneck situations [16].

## III. VPP COMPONENTS

The ideal Virtual Power Plant consists of three main parts including:

### A. Generation Technology

The DG specification is useful to broadly mention the range of capabilities for various technologies, generally falling under the distributed generation category. DER considered for integration in VPP:

- CHP (Combined Heat and Power)

- Biomass and biogas

- Small power plants (gas turbines, diesels, etc.)

- Small Hydro-plants

- Wind based energy generation

- Solar production

- Flexible consumption (controllable/dispatchable loads)

In this respect all of DGs can be classified into two categories which are defined in following [13].

*1)* Domestic Distributed Generator (DDG), it is a small DG unit which serves individual consumer for residential, commercial or industrial parts. The surplus power production of a DDG owner may be injected to the grid as well as its shortage may be compensated by the grid.

*2)* Public Distributed Generator (PDG), it is a DG unit which does not belong to an individual consumer and its primary aim is to inject its power production to the grid. Generally, both DDG and PDG can be equipped with energy storage. DDG is referred to a generator with a load and probably an energy storage which is usually connected to low voltage distribution network. On the other hand, PDG is referred to a generator and probably an energy storage which can only be connected to the medium voltage distribution network. The distinctions of DDGs and PDGs are as follow:

1. The aim of the owners of DDGs is to provide economically their electrical and probably heating needs as well as to promote probably their services reliability. They are uninformed of the power business rules. On the other hand, the aim of the owners of PDGs is to sell their power production to the network customers.

2. Generally, the capacities of DDGs generation are small in comparison with PDGs. So, a DDG is never being able to participate in the power market independently as an individual participant, but a PDG may test its chance in the power market.

Some PDGs or DDGs have stochastic nature, e.g. wind and photovoltaic units which are not equipped by energy storages. But some others, e.g. fuel cells and micro turbines, are dispatchable that is; they are capable to vary their regime of operation almost quickly. In this respect, both PDGs and DDGs can be subdivided into two categories, i.e. Dispatchable PDGs (DPDGs) and Stochastic PDGs (SPDGs) for the former and also Dispatchable DDGs (DDDGs) and Stochastic DDGs (SDDGs) for the later.

### B. Energy Storage Technologies

Energy storage systems can be considered today as a new mean to adapt the variations of the power demand to the given level of power generation. In context of use renewable generation, can be used also as additional sources or as energy buffers in the case of non-dispatchable or stochastic generation, e.g. wind turbines or PV technologies especially in weak networks.ESS considered for integration in VPP:

- hydraulic Pumped Energy Storage (HPES)

- compressed air energy storage (CAES)

- flywheel energy storage (FWES)

- super conductor magnetic energy storage (SMES)

- battery energy storage system (BESS)

- supercapacitor energy storage (SCES)

- hydrogen along with fuel cell (FC)

### C. Information Communication Technology (ICT)

The important requirement for VPP is communication technologies and infrastructure. In many different communications, media technologies can be considered for communications in Energy Management Systems (EMS), Supervisory Control and Data Acquisition (SCADA) and Distribution Dispatching Center (DCC).

## IV. TECHNICAL VPP (TVPP) & COMERCIAL VPP (CVPP)

### A. Technical VPP (TVPP)

The TVPP consists of DER from the same geographic location. The TVPP includes the real-time influence of the local network on DER aggregated profile as well as representing the cost and operating characteristics of the portfolio. Services and functions from a TVPP include local system management for Distribution System Operator (DSO), as well as providing Transmission System Operator (TSO) system balancing and ancillary services. The operator of a TVPP requires detailed information on the local network; typically this will be the DSO" [17]. The TVPP enables [21]:

- Visibility of DER units to the system operator(s)

- Contribution of DER units to system management

- Optimal use of the capacity of DER units to provide ancillary services incorporating local network constraints

This allows small units to provide ancillary services and reduces unavailability risks by diversifying portfolios and capacity compared to stand-alone DER units. A comprehensive overview of the technological control capabilities of distributed generators and the resulting possibilities of providing ancillary services are analyzed in [18] and [19]. The technological potential is investigated by application of a new assessment approach that considers the grid-coupling converter separately with its particular capabilities. An enormous technological potential is identified. DSOs that use the TVPP concept can also be considered as Active Distribution Network (ADN) operators [20]. An ADN operator can use ancillary services offered by DER units to optimize their network operation. On the other hand, an ADN operator can also provide ancillary services to other system operators. A hierarchical or parallel structure of ADNs may exist where the TVPP concept is applied, for instance according to different voltage levels or different network regions. Many examples of ADNs can be found in the Active Network Deployment Register [21]. Some of the functionalities that have to be performed by TVPP are:

- Continuous condition monitoring - retrieval of equipment historical loadings

- Asset management - supported by statistical data

- Self-identification/self-description of system components

- Fault location - automatically integrated with outage management

- Facilitated maintenance

- Statistical analysis and project portfolio optimization

### B. Commercial VPP(CVPP)

A CVPP has an aggregated profile and output which represents the cost and operating characteristics for the DER portfolio. The impact of the distribution network is not considered in the aggregated CVPP profile. Services or functions from a CVPP include trading in the wholesale energy market, balancing of trading portfolios and provision of services (through submission of bids and offers) to the [transmission] system operator. The operator of a CVPP can be any third party aggregator or a Balancing Responsible Party (BRP) with market access; e.g. an energy supplier" [17]. The CVPP enables [21]:

- Visibility of DER units in energy markets

- Participation of DER units in the energy markets

- Maximization of value from participation of DER units in the energy markets

This allows market access of small units and reduces the risk of imbalance by portfolio diversity and capacity compared to stand-alone DER units. CVPPs perform commercial aggregation and do not take into consideration any network operation aspects that active distribution networks have to consider for stable operation [3]. The aggregated DER units are not necessarily constrained by location but can be distributed throughout different distribution and transmission grids. Hence, a single distribution network region may have more than one CVPP aggregating DER units in its region.

Basic CVPP functionalities would be optimization and scheduling of production based on predicted consumers' demand and generation potential. When actual needs differ from predicted ones, DRRs (Demand Response Resources) are introduced to fill the gap between production and real consumption. In general, CVPP functions should also include:

- Maintenance and submission of DERs' characteristics

- Production and consumption forecast

- ODM (Outage Demand management)

- Building DER bids

- Bids submissions to the market

- Daily optimization and generation scheduling

- Selling energy provider by DERs to the Market

## V. CONCLUSION

Through the VPP concept Individual DERs can gain access and visibility across all energy markets, and benefit from VPP market intelligence to optimize their position and maximize revenue opportunities. System operation can benefit from optimal use of all available capacity and increased efficiency of operation. Benefits from the Virtual Power Plant concept have been identified for different stakeholders [21]:

Main benefits for owners of DER units:

- Capture the value of flexibility
- Increasing value of assets through the markets
- Reduced financial risk through aggregation
- Improved ability to negotiate commercial conditions

Main benefits for DSOs and TSOs:

- Increased visibility of DER units for consideration in network operation
- Using control flexibility of DER units for network management
- Improved use of grid investments
- Improved co-ordination between DSO and TSO
- Mitigate the complexity of operation caused by the growth of inflexible distributed generation

Main benefits for Policy Makers:

- Cost effective large-scale integration of renewable energies while maintaining system security
- Open the energy markets to small-scale participants
- Increasing the global efficiency of the electrical power system by capturing flexibility of DER units
- Facilitate the targets for renewable energy deployment and reduction of CO2 emissions
- Improve consumer choice
- New employment opportunities

Main benefits for suppliers and aggregators:

- New offers for consumers and DER units
- Mitigating commercial risk
- New business opportunities

## REFERENCES

[1] ENIRDGnet: Concepts and opportunities of Distributed Gneration: The Driving European Forces and Trend., ENIRDGnet Project deliverable D3, 2003

[2] J.O. Wara: Current status and Evaluation of Electricity market liberalization in Japan, USA and Europe. IEE 391st regular research session, May 2005.

[3] N.R. Friedman, "Distributed Energy Resources Interconnection Systems: Technology Review and Research Needs", National Renewable Energy Laboratory Report No. NREL/SR-560-32459, Sept 2002.

[4] S. Ropenus, and K. Skytte, "Regulatory Review and Barriers for the Electricity Supply System for Distributed Generation in the EU-15", International Journal of Distributed Energy Resources, vol. 3, pp. 243-257, 2007.

[5] European Virtual Fuel Cell Power Plant Management Summary Report, 2005.

[6] R. Caldon, A. Rossi, and R Turri, "Optimal Control of a Distribution System with a Virtual Power Plant", Bulk Power System Dynamics and Control-VI, Italy, Aug 2004.

[7] F. Bignucolo, R. Caldon, and V. Prandoni, "The Voltage Control on MV Distribution Networks with Aggregated DG Units (VPP), Proceedings of the 41st International, vol 1, pp. 187-192, Sep 2006.

[8] F.F. Wu, K. Moslehi, and A. Bose, "Power System Control Centers: Past, Present, and Future", Proceeding of IEE, vol.93, , pp.1890-1907, Nov 2005.

[9] I. Kamphuis, J. Kok, C. Wamer, and M. Hommelberg, "Massive Coordination of Residential Embedded Electricity Generation and Demand Response Using the PowerMatcher Approach", The 4th International Conference on Energy Efficincy in Domestic Appliances and Lighting- EEDAL06, 2007.

[10] R. Skovmark, and J. H. Jacobsen, " Analysis, Design and Development of a Generic Framework for Power Tradin, M.Sc thesis, available from Technical University of Denmark, 2007.

[11] H. Morais, P. Kadar, M. Cardoso, Z. Vale, and H. Khodr, "VPP operating in the isolated grid", IEEE Power and Energy Society General Meeting - Conversion and Delivery of Electrical Energy in the 21st Century, Pittsburgh (PA), pp.1-6. Jul 2008.

[12] D. Pudjianto, C. Ramsay, G. Strbac: "The FENIX vision: The Virtual Power Plant and system integration of distributed energy resources", FENIX Deliverable 1.4.0, 21 Dec 2006.

[13] E. Mashhour, and S.M. Moghaddas-Tafreshi, "The Opportunities for Future Virtual Power Plant in the Power Market, a View Point", 2009 International Conference on Clean Electrical Power, pp. 448 – 452, 2009.

[14] H. Morais, M. Cardoso, L. Castanheira, Z. Vale, and I. Praca, "A decision-support simulation tool for virtual power producers", IEEE International Conference on Future Power Systems, Amsterdam (Netherlands), pp.1-6, Nov 2005.

[15] D. Pudjianto, C. Ramsay, and G. Strbac, "Virtual power plant and system integration of distributed energy resources", IET Renewable Power Generation, vol 1, issue 1, pp. 10 - 16, Mar 2007.

[16] P. Lombardi, Z. A. Styczynski, and B. M. Buchholz, "Optimal operation of a distribution power system with renewable generators and desalination plants', GCC Power, pp. 10-12, Nov2008.

[17] C. Ramsay, "The Virtual Power Plant: Enabling Integration of distributed generation and demand", FENIX Bulletin 2, Jan 2008.

[18] M. Braun: "Provision of Ancillary Services by Distributed Generators – Technological and Economic Perspective", Renewable Energies and Energy Efficiency, vol. 10, 2009.

[19] M. Braun, "Technological Control Capabilities of DER to Provide Future Ancillary Services", International Journal of Distributed Energy Resources, 2007.

[20] M. Braun, and P. Strauss: "A Review on Aggregation Approaches of Controllable Distributed Energy Units in Electrical Power Systems", International Journal of Distributed Energy Resources, vol 4, issue 4, 2008.

[21] M. Braun, "Virtual Power Plants in Real Applications", Online Available at: http://www.iset.uni-kassel.de/abt/FB-A/publication/2009/2009_Braun_Etg_Fenix.pdf.