Virtual Power Plants: Power Plants of the Future in India

Shivali Dwivedi
ICF Consulting India Pvt. Ltd.
New Delhi, India

Pramod Kumar Singh
ICF Consulting India Pvt. Ltd.
New Delhi, India

***Abstract*—Growing penetration of Distributed Energy Resources (DERs) and Renewable Energy (RE) in the Indian network is leading to several changes in the system operation. Due to these changes, coordinating operation of the entire power system has become complex. A Virtual Power Plant (VPP) can be one of the effective solutions to manage this transformation. VPP is a portfolio of DERs, which are connected by a control system based on Information and Communication Technology (ICT)** [1]**. A VPP aggregates the capacity of many diverse DERs and creates a single operating profile from grid's perspective. This paper will describe the usefulness and opportunities of VPP in India. In addition to discussing the definition and types of VPP existing across the globe, the paper will also highlight the general benefits of VPP for different entities across the electricity supply chain. The paper is segmented into four sections: (i) Defining VPP and its type, (ii) Relevance and plausible schemes of VPP in India, (iii) Example illustrating an opportunity for VPP in India, and (iv) Recommendations and way forward for the Indian market to adopt VPP technology.**

The objective of the paper is to give an insight to the readers about this concept and to provide a perspective to the Indian stakeholders for considering the implementation of VPP.

Keywords – Virtual Power Plant (VPP), Distributed Energy Resources (DERs), Deviation Settlement Mechanism (DSM), Qualified Coordinating Agency (QCA)

I. INTRODUCTION

The power system in India is evolving. Currently, the flow of energy is mainly one-directional, and the system architecture corresponds to a "top-down" structure. However, India is now rapidly shifting towards decentralized system architecture with more and more deployment of Distributed Energy Resources (DERs). The country plans to add 40 GW of distributed solar by 2022 which will cover the residential, commercial, and industrial sector. The Indian government recently introduced Phase-II of Grid Connected Rooftop Solar Programme, focusing on the adoption of solar rooftop in the residential sector. Recently, the Indian government also launched KUSUM (Kisan Urja Suraksha evam Uhaan Mahaabhiyan) scheme with the aim to add 25 GW of solar by 2022 in the agricultural sector. Launch of FAME-II (Faster Adoption and Manufacturing of (Hybrid &) Electric Vehicles) scheme reflects the interest of Government to pave way for the increased penetration of Electric Vehicles in the Indian market.

Such initiatives are leading to the massive adoption of DERs, which in turn is triggering various technical and economic challenges in the power system. Varying power quality, grid congestion, inaccuracy in forecasting, and no market visibility of the DER owners are some of the issues arising due to increase in RE and DER. Across the globe, new technologies like energy storage systems (ESS), network security management systems (NSM), and virtual power plants are being introduced to address these challenges. This paper will focus on VPP and will evaluate its opportunity and relevance in India.

II. VIRTUAL POWER PLANT – DEFINITIONS AND TYPES

A. Defining VPPs (Literature review)

Virtual Power Plant is a developing technology which is still in the evolving stage. Various institutes have coined different definitions for this technology. In [1], Virtual Power Plant is defined as *"A portfolio of Distributed Energy Resources (DERs), which are connected by a control system based on information and communication technology (ICT). The VPP acts as a single visible entity in the power system, is always grid-tied and can be either static or dynamic.*" In [2], VPP is defined as an aggregation of different type of distributed resources which may be dispersed in different points of medium voltage distribution network. A broadly accepted definition in [3] determines a VPP as "*flexible representation of a portfolio of DER. A VPP not only aggregates the capacity of many diverse DER, it also creates a single operating profile from a composite of the parameters characterizing each DER and incorporates spatial (i.e. network) constraints.*" While the above definitions focus on aggregating only renewables, [4] defines VPP as "*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."* On the other hand, [5] defines VPP as a software-based system relying upon "*software systems to remotely and automatically dispatch and optimize generation - or demand side or storage resources in a single, secure web-connected system.*"

B. Types of VPP (Literature review)

Similar to the definitions of VPP, different sources classify VPP differently.

Figure 1 illustrates the classification of VPP as defined in various projects.

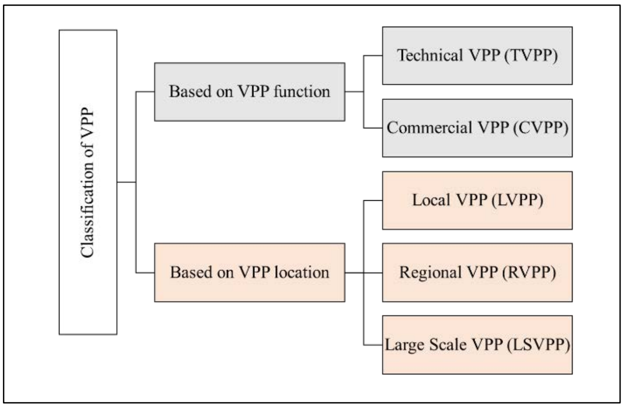

Figure 1: Classification of Virtual Power Plant

1) *Classification based on VPP function*

FENIX ("Flexible Electricity Network to Integrate the eXpected energy evolution") project [6] in Europe classifies VPP as Technical VPP (TVPP) and Commercial VPP (CVPP). TVPP focuses on connecting decentralized energy plants at the grid level for supporting the grid [3]. Services and functions from a TVPP include managing a local system for distribution system operators and providing balancing and ancillary services for a transmission system operator [7]. Contrary to this, functions of a CVPP include trading aggregated DER in the wholesale energy market, balancing of trading portfolios and provision of services (through submission of bids and offers) to the system operator [7].

2) *Classification based on VPP location*

Ref. [8] classifies VPP as Local VPP (LVPP), Regional VPP (RVPP) and Large Scale VPP (LSVPP). Operation of a LVPP is done by a local energy company with the focus on providing network support and balancing services from local DER. LVPP can help aggregate local DER and provide them the transparency to trade in the energy market. LVPPs are aggregated to form a RVPP, with the focus of managing power flow in a regional distribution network. RVPPs are operated by the distribution system operator (DSO) or other commercial parties. Pooling of these RVPPs form a LSVPP, which is operated at the transmission level and is, therefore, the responsibility of the transmission system operator (TSO).

North America, China, Australia, and Europe are the front runners in the deployment of VPP. VPPs in North America focus on energy management in the Industrial and Commercial sector. The objective of the VPPs in North America is a cost-effective operation of integrated assets in these sectors [9]. China claims to have the largest operational VPP (owned by State Grid Jiangsu Electric Power Co.). The aim of the Jiangsu VPP is to contain integrated controllable loads with a power of around 10 GW by 2020 [10]. In Australia, the focus of VPP is on the residential sector with the aim of saving cost for end customers and providing system services [11]. Europe is hosting VPP projects like FENIX [12], REstable [13], Regenerative Combined Power Plant 2 project [14], SolVer project [15], and Regio: VK project [16] which focus on DER aggregation for providing various ancillary services.

III. Relevance and Plausible Schemes of VPP in India

Market and technological developments happening in India are demanding a strengthened and modernized grid. In terms of regulatory development, India is striving towards a stricter Deviation Settlement Mechanism (DSM) and sub-15-minute markets. Figure 2 illustrates the evolution happening in the Indian power system. Adapting to these changes requires a highly sophisticated, flexible, and accurate system, which can suitably be met by a virtual power plant.

Figure 2: Developments transpiring in the Indian power sector

Depending on the connectivity to the grid and customer type catered, plausible configurations of VPP in India have been identified in this section, supported with their suitable end-uses. The configurations identified here depend on factors such as VPP's location in the grid (generator side, transmission side, distribution side, or off-grid), resources utilized (flexible loads, EVs, solar rooftop, energy storage, etc.), and beneficiary involved (Prosumers, Customers, Gencos, Transcos, and Discoms).

Figure 3 illustrates different plausible configurations of VPP in India.

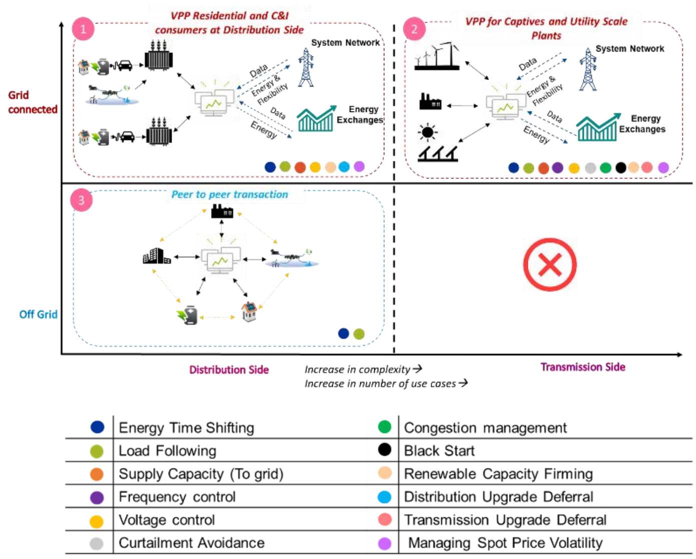

Figure 3: Plausible configurations of VPP suitable for India along with plausible use cases

Table I gives a brief overview of each VPP configuration illustrated in Figure 3.

TABLE I. CUSTOMER AND CONNECTIVITY TYPE FOR EACH VPP CONFIGURATION

	Configuration-1	***Configuration-2***	***Configuration-3***
Connectivity Type	Grid Connected	Grid Connected	Off-Grid
Customer Type	Customers (operational at 230V, 400V, 11kV or 33kV) having DERs, flexible loads at distribution side and EVs; and grid-connected microgrids.	Large captives and large customers (operational at 66kV, 132kV or 220kV) having DERs, RE Generating Companies, and Utility-Scale RE Plants	Off-grid customers having DERs and off-grid microgrids

Each configuration identified here aims to benefit different grid participants. Table II summarizes the potential benefits that could be gained by different grid participants in different VPP configurations.

TABLE II. BENEFIT TO GRID PARTICIPANTS FROM THE PLAUSIBLE VPP CONFIGURATIONS

	Off – Grid consumers with DER	**Grid Connected Consumers with DER**	**Utility scale RE Plants, Captives**	**Load Dispatch Centers**	**Transmission Company**	**Distribution Company**
Configuration-1	NA	• Improved supply capacity to grid • Flexible Generation and improved dispatchability • Improved Service Reliability • Improved market visibility	NA	NA	**Indirect Benefits:** Relief in the transmission congestion and transmission upgrade deferral	• Accurate forecasting of net load and planning of power purchase • Reduction in the quantum of power purchase with aggregated DER generation available • Improving Grid Services (Power Quality, Voltage Control, Congestion management)
Configuration- 2	NA	NA	• Improved dispatchability of RE Plants • Transparent to Energy Market/ Capacity Markets • Bill savings due to deferred T&D upgrade • Reduced or Zero Energy Curtailment • Better forecasting and scheduling→ reduced DSM charges	• Improved scheduling of RE plants • Automated network monitoring • Accurate accounting of electricity transmitted • Improved Grid Services (Power Quality, Voltage Control, Congestion management, Black Start)	• Transmission upgrade deferral (controlling single power source is easier than many smaller ones) • Reduced congestion	**Indirect Benefits:** Distribution upgrade deferral
Configuration-3	• Better utilization of assets • Peak Load Management • Peer-to- Peer transaction	NA	NA	NA	NA	**Indirect benefits:** Reduction in the burden on distribution grid and grid congestion

IV. EXAMPLE ILLUSTRATING AN OPPORTUNITY FOR VPP IN INDIA

While the previous section illustrates the plausible configurations of VPP that can be potentially implemented in India, this section demonstrates the available opportunity taking Deviation Settlement Mechanism (DSM) as an example. Under DSM, wind/solar energy generators are required to pay huge penalties for variability in RE generation. It is worthwhile mentioning that the purpose of this section is not to present the techno-economic feasibility of a VPP, rather, presenting an example to highlight an available opportunity for VPP and conditions affecting the deployment of VPP solution.

For the purpose of demonstration, this stylized example is based on an analysis of the expected vs. actual generation from a 40 MW wind plant hypothetically located in Gujarat. The regulation for DSM in Gujarat exempts individual wind energy generator/pooling station from paying the penalty for forecasting error up to 12%. Beyond 12%, the plants are charged a penalty which increases with the increase in error range. Figure 4 illustrates the number of time blocks when deviation penalty is applicable for the wind energy plant due to the difference between the expected and actual injection. As per the DSM regulation of the state [17], authors estimate the annual penalty to be paid by the wind plant on account of forecasting error to be ~INR 60 Lakhs.

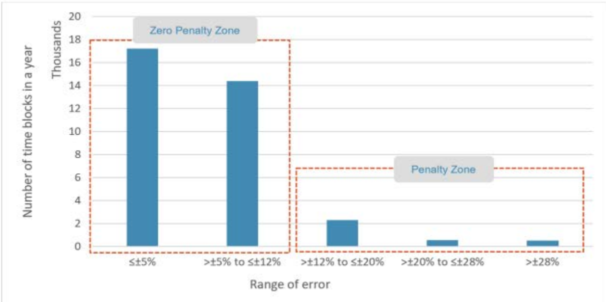

Figure 4: General forecasting and scheduling scenario for a Wind Energy Plant in Gujarat [17]

The penalty incurred by a single plant can be considered as the available opportunity for deployment of VPP. VPP can help improve the forecasting of a wind plant. It can also be used to manage a pool of different wind plants to collectively improve the forecasting error, thereby leading to a reduction in the penalty to be paid by all plants in the pool.

It may be possible that VPP is able to eliminate the penalty, completely or partially, depending on the accuracy of the forecasting modules used in VPP.

A study of the German VPP market shows that a medium-sized VPP solution costs in the range of USD 20,000 (INR 14 Lakhs equivalent) to USD 300,000 (~INR 2 Crores equivalent). Since the VPP to be set up for this scenario requires accurate forecasting, optimizing tools, and high-end communication technology, the cost of VPP here has been assumed as USD 300,000 at the higher end of the cost range. Also, it has been assumed that this VPP can manage up to 6 similar-sized wind plants.

Figure 5 summarizes the discussion and illustrates the simple payback period for VPP based on the assumption that an annual penalty of INR 60 lakhs is paid by a single wind plant. Hence, opportunity available for a VPP will increase proportionally with increase in the number of participants or MW size, i.e. INR 120 lakhs for 2 wind plants assuming each of 40 MW, INR 180 lakhs for 3 wind plants, and so on. The figure illustrates that for a VPP having 3 participants (wind plants), the simple payback period is 1 year for a scenario in which penalty is eliminated completely, i.e. the VPP is able to perform highly accurate forecasting and scheduling to bring the forecasting error within the exempted error range (less than 12%). In a scenario where the same VPP (having 3 participants) is able to eliminate the penalty partially, let's say by 50%, then the simple payback period increases to 2 years. Similarly, for a VPP having 6 participants, the payback is reduced to 1 year even if the VPP is reducing the penalty by 50%.

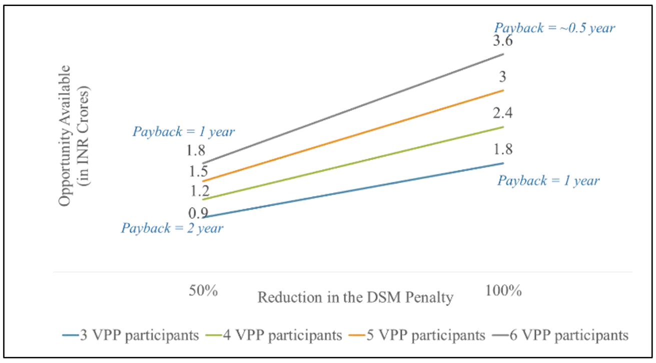

Figure 5: Illustrative opportunity cost and payback period for a VPP with varying number of participants

Thus, from this example, it can be inferred that a VPP solution depends broadly on the following four parameters:

Project or site-specific criteria:

- Level of deviation from the forecast

State regulation specific criteria:

- Exemption or tolerance for forecasting error
- Penalty levied on the wind energy generator for the deviation

Participants' specific criteria:

- Size of the generating plant
- Number of generating plants pooled

Efficacy of the solution deployed

- Improvement in Forecasting Error

While the example demonstrated the available opportunity in case of DSM, similar calculations can be made to assess the opportunities for other applications such as in case of demand response, aggregation of rooftop solar, peer to peer trading of electricity.

V. RECOMMENDATIONS AND WAY FORWARD

The energy system architecture of India is changing and there are clear opportunities to implement a solution like VPP to cater to the changes. Figure 6 proposes a few recommendations for the Indian market, which will help in increasing the penetration of VPP in India.

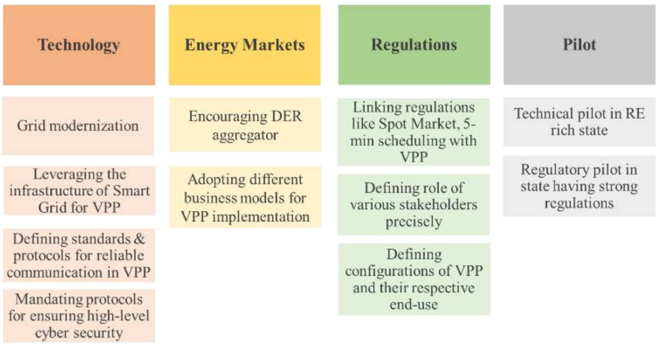

Figure 6: Recommendations for increasing uptake of VPP in India

To gain more confidence over this technology, India should begin with the implementation of pilots at various scale and at various locations. The proof of concept needs to be designed and implemented to weigh the feasibility and understand the system functionalities – both at the technical level and regulatory level.

Technical Pilots can be introduced in the RE rich states like Andhra Pradesh, Gujarat, Tamil Nadu, etc. to analyze the various technical concepts and benefits, which VPP may provide to the grid. The pilot can be used to study the impact of VPP in grid congestion, frequency and voltage management, etc. Similarly, **Regulatory Pilots** can be introduced in states which already have provisions that lay the groundwork for implementing VPPs. For instance, Uttar Pradesh's net metering policy already specifies the peer-to-peer transaction with proper accounting and billing mechanism. This will help in the implementation of VPP at a larger and faster pace in the state. Various configurations of VPP can be tested in such pilots, and feasibility of each configuration can then be identified. In few states like Tamil Nadu, Andhra Pradesh, and Gujarat, a precedent for VPPs have already been established with the requirement of a Qualified Coordinating Agency (QCA) in the state-level forecasting & scheduling regulations. QCAs can be involved in these pilots as VPP operator.

With the active participation of DER installers in regular network operation, the demand for defined end-use in the grid code will increase. Alongside, the role of each stakeholder will have to be defined precisely before deciding on a VPP configuration. In terms of technology, currently, there is no standard interface for communication between generators, pooling stations, substations, load dispatch centers, and loads in India. This poses several challenges in streamlining the connection between these elements and facilitating the free flow of information along the value chain. Hence, standards and protocols are required to facilitate reliable communication in a VPP, and for ensuring cybersecurity.

Remodeling of the energy market is also required to boost VPP implementation. DER aggregators need to increase and need to be responsible for coordinating between RE generator and Discoms/ Load Dispatch Centers/ Transcos. This is where the role of QCAs will come into effect. In addition, business models supporting various VPP configurations will have to be proposed for successful implementation of VPP.

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