Virtual Power Plant Basic Requirements for Integration of Distributed Energy Resources, Driven by Industry 4.0.

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Abstract

The real-time biggest challenges in energy balance and delivery by Virtual Power Plant System stems from the complex nature of the system, barriers associated with the integration of Distributed Energy Resources (DER) multiple sites, demand-side responses, regulatory tools, Market economics, logical and physical standards, networking, technical, models' proliferation and the dynamics of current technologies; requiring the service of a higher digitization level.

Industry 4.0 as the key driver of both the horizontal and vertical integration maintains real-time optimal energy operations, distributions, scheduling, forecasts, pricing and demand responses for enterprises, which performance is also constrained by cybersecurity, information networks, and protocols, maintenance, technical and economic.

To satisfy these requirements for real-time energy balance, reliability, flexibility, resiliency and sustainability, the operational and functional systems in order to perform require automated intelligent distributed technologies and control interfaces, data information techniques, protocols and cloud platforms.

This paper, therefore considers the technical and operational requirements of VPP supported by industry 4.0 for interoperability and integration of DERs, optimization of Supply and Demand-side energy management, standards and protocols, best emerging management practices; and control strategies to mitigate system cyber security as integration tools to support and maximize DER benefits for the Stakeholders.

Keywords
Industry 4.0, Distributed Energy Resources, Operational Requirements, Process, Virtual Power Plant.

1. Introduction

The need for cleaner, flexible, reliable and sustainable energy compels enterprises to leverage on intelligent systems to provide intelligent energy management solutions. Maintenance of this balance from multiple generation sites to load consumption side resulted in the emergence and aggregation functioning of Virtual Power Plant (VPP). This complex process compensates for the depletion and cost escalation of conventional generated (fossil) fuels when designed appropriately, especially now that the traditional (conventional) energy production of centralized power increasingly is shifting towards DERs management (Bosch, 2015); which system operation cannot possibly be executed without basic requirements both from the system and DERs (Ahmed, Amin, and Aftab, 2015).

DERs generation Sources include renewable energy resources (non-dispatchable); Solar, Wind, Combined Heat and Power (CHP), biomass, Distributed energy storage (DES), energy hybrid Vehicles (EHV). Other components of VPP include the Demand Response (DR), Energy trading (ET) and Grid Stabilization (GS) (Bosch, 2015). Notably, the DERs are uncertain and stochastic in nature with small generation outputs. However, integration of DES, DR, ET, DER either in the near and spatially located platform and other Operational subsets: planning, and scheduling, operational capacities and maintenance is enhanced by industry 4.0 for operation and delivery (Abdelaziz, Hegazy, El-Khattam, and Othmam, 2013). This intelligent system uses the necessary architectures, standards, and norms in its horizontal and vertical integration to consider the life cycle and the value stream chain of this complex energy-balance process in making an intelligent decision (Marko and Peter, 2011).

Backed by real-time and historical information, the supply network is characterized of four capabilities; interconnectivity, visibility, an autonomous and predictive analysis that effectively manages the upstream vendor, and supplier arrangements, responding faster to unforeseen events within the network. Reconfiguring the supply network for more competitive advantage through preventive maintenance presents a more agile and resilient one that shortens time to customer delivery; enhance, generate better customer experiences, greater savings and high performance. The current data capture processes boost the throughput, increases the efficiency, and accuracy while asses to customers' service level expectations through the interconnectivity process enhance the degree of transparency while adhering to the minimal standards, (Howell, et al, 2017).

The Demand response network changes the emphasis towards customization that defines the supply chain target. To achieve the systems goal of prioritisation of critical loads, power cost saving, energy efficiency and peak load reduction, the network through advanced communication and control technologies employs a load-dependent pricing policy, more efficient energy consumption scheduling, and interchangeably power scheduling to activate load control, demand responses, and price adjustment (Oracle,2012). The core strategy of consumers' involvement to reduce supply-demand imbalance and to prioritize energy utilization constitutes the main driver of the demand network. However, the availability of service is a function of the data center, its backup and maintenance capability, energy theft, threats and resilient robust design, (Oracle, 2012).

2. Literature Review

VPP as a seamlessly digital, complex and self-conscious system is linked not to any single technology supplier or technical solution but integrated to other complex entities that uses logistics and information and operates on digital convergence in its process, utilising data to function and integrate across multiple supply chains and product life cycles, (Ravichandran, Ananthraj, Sivakumar, Sivakarthik, and Vijay, 2017).

2.1. Overview, Definitions, and Operations of Virtual Power Plant

There is the need to offer the highest possible interoperability for optimal real-time energy distribution. These needs necessitated for the high integration of decentralized and intermittent renewable energy into the distribution grid are consequences of induction and intermittency infeed of renewable energy resources, voltage drop, and fluctuation of real and reactive power, harmonics, and resonance. Facilitation and integration, therefore, becomes necessary for generation, distribution, load consumption, energy market and the resynchronization process to create the energy balance through demand response (Etherden and Vyatkin, 2014).

This heterogeneous entity concept was developed from the legacy grid of conventional centralized generation control, microgrid (decentralized), smart grid '2.0' and '3.0' and their market pricing systems based on electrical standards of interconnectivity and interoperability. However, Ma, Billanes, and Jørgensen (2017) describe virtual grid as the aggregation of distributed energy resources, energy storage, and load, that balances production and consumption of energy to provide a larger size of the energy market. These group of dynamic grids performs its control and operational functions through sensors, actuators (devices), device software management (gateways) to cloud data hosting; allowing for timing and synchronization to maintain the whole distributed updates and provides the solution to deploy the control system to fulfil the protection requirements of the plant (Industrial Internet Consortium, 2017).

As an independent complex entity of no-one definition and requirements, VPP (a cluster of Microgrids in spatially located sites) is defined by many authors differently. The cause of this according to Wei, Hong, and Alam (2016) is the diversified nature of the DER technologies, developers need and aggregation methods and models. Encorp. (2015) views it as a means of using ICT technologies to manage a cluster of generation assets. In Bosman, Bakker, Molderink, Hurink, Smit, (2014), it is the aggregation of Distributed Generations (DG) units of different enabling technologies involving integration, interconnection, and interface of systems of systems. Rekika, Chtouroua, Mitton Z, Atiehca, (2016) summarize it as concourse of dispatchable and non-dispatchable DGs, energy storage elements and controllable loads accompanied by information and communication technologies forming single imaginary power plant that plans, monitors the operation, and coordinates the power flows between its component to minimize the generation costs, minimize the production of greenhouse gases, maximize the profits, and enhance the trade inside the electricity market, These authors agree that VPP has a common conceptual purpose and technical standards. To operate as a powerful entity and for better operation of the system, it has the ability to control the aggregated units and to manage the electrical energy flow between these units, (Wei, et al, 2016). Differing from its subset of microgrid, VPP disregards physical locations of generations and loads empowered, provides ancillary and capacity reserves for larger, more acceptable power market size, (Industrial Internet Consortium. 2017; Perera, et al., 2016; Wanga, Parkinson, Miao, Jia, Crawford, Djilali, 2012). Wei, et al, (2016) claim that VPP functions as Energy Management System (EMS) are an independent power producer based on the aggregation and energy supplier and prosumer aggregation respectively. Using EMS, it establishes the link between DER and energy system operations from centralized to decentralized control structures. However, there is not enough available literature of the integration of Virtual Power Plant value stream chain and the functional elements, delivered by industry 4.0 (Rekika, et al, 2016).

Categorizing VPP, in terms of functions and needs, Wei, et al (2016) further grouped it as an aggregation of commercial and technical; controller and information agent; structure and strategy; and Media and Direction. Similarly, Lukovic, Kaitovic, and Bondi (2015) structured it into three levels (figure 1): Market level, Information Technology (ICT) and the power flow. In contrary, Encorp. (2015) insist that as EMS, VPP is rather classified into components of dispatch center, Remote generation sites and communication processor module. Saliba (2015) describes VPP as the bid balancing power market for stable operation between power generation and consumption that interact dynamically; primary balancing, secondary balancing and minute reserve with a pre-qualification requirement from Transmission system operators (TSO). As a unique entity, the dispatchable units compensate for the DERs intermittency.

The intermittent nature of some DERs, poses serious problems to the Transmission System Operator (TSO), as such VPP through it power network lowers the loads, shares more power among the participants reducing long-distance power transmission creating one alternative either energy is eliminated or minimized, (Mehta, 2017).

Nevertheless, a notable issue in VPP is the ability to identify gaps and enabling technologies integrating the control and management systems in field operations and distribution sites, and also identifying the interactive functions of the controllers, (Lins, Jose da Silva, Augusto, and Oliveira, 2016). An advanced digital VPP identifies all the system components and sends signals in microseconds, delivering peak load electricity or load-aware power generation at short notice. The controversy of communication devices among the various products, however, still exist.

Remotely and automatically through an Industry 4.0 software, VPP dispatches and optimizes generation, demand-side or storage resources in a single, secure web-connected system. The distributed energy sources, energy conversion units, and consumers are connected to a Decentralised Energy Management System (DEMS) with two-way data communication capability to optimize the operation of the DERs, (figure 1). The DEMS enables the DERs through the different applications: modeling, forecasting, scheduling, real-time optimization to be operated under different operating regimes to achieve certain objectives by the regulators (Perera, 2016).

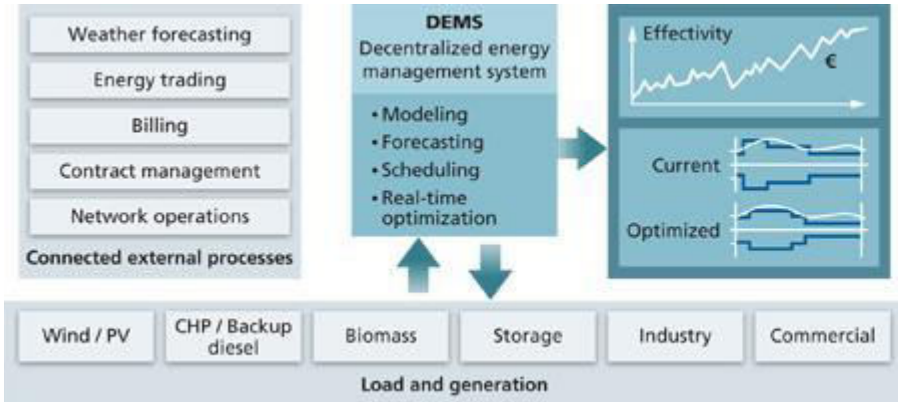

Figure 1. VPP Operation System (**Source**: Lukovic, Kaitovic, and Bondi, 2015)

Regulations and policies that form part of the market structure of VPP vary and inconsistent, as such not standardized. It is, therefore, the derivative based on the utility ownership and state. Though it performs a bilateral contract with the DG units and the customers, production, consumption, scheduling is based on demand profiles and weather forecasting, (Hahn, 2016, Lins, et al, 2016; Pérez-Arriaga, and Knittel, 2016; Schlaepfer, and Koch, 2016).

Finally, VPP employs the same concept as the microgrid but with major functions of using advanced technologies for control DER market participation, optimization and status coordination. The needs of VPP are broadly grouped into 2: the technical and commercial needs established to boost operational efficiency of DER and those of autonomous commercial actors on the open energy Market (Lukovic, Kaitovic, and Bondi, 2015). These issues and many more constraints evident in the operation of VPP are confronted by Industry 4.0.

2.2. Influence of Industry 4.0 Concept on VPP Operation

Industry 4.0 is the 4^{th} level total automation of cloud data bus, expected to enhance global competitiveness, and open domestic energy production trend, (Salam, Mohamed, and Hannan, 2008). It is integrated technology infrastructure via a software service that connects, monitors, predicts, schedules, analyses, and optimizes any system to produce real value for efficient DER software, (Basso, Chakraborty, Hoke, and Coddington, 2015; Wei, Hong, and Alam, 2016; Mehta, 2017; Pérez-Arriaga, and Knittel, 2016; Saliba, 2015). Its major constituent systems includes Sensing and measurement devices; Data networking (LAN and WAN); Embedded computing (enables cost-effective local control and automated operation of physical systems); Cloud computing (a scalable platform for software for optimization, and control); Big data analytics (discern useful information from massive amounts of sensory and working data); Multi-physics and model-based systems engineering, (the cost-effective design, verification, and validation of highly complex large-scale systems); and Adaptive and predictive control algorithms (dynamically optimize system operation subject to safety, performance, and other constraints), (Etherden, and Vyatkin, 2014; Mehta, 2017; Perera, Ciufo, and Perera, 2016; Pérez-Arriaga, and Knittel, 2016) . Its distinctive features include its adaptability to any network and data demands, explicit interface management (combines many software modules and team coordination capability); source selectivity (finds and delivers exactly the right data at the right place and time); and uses no server, (Lua, Wanga, and Guo, 2016).

The software server forms the key drivers to the whole range of predictions and continually monitors and shares information of the current energy stock level, detect problems and changes demand levels with a coordinated process and delivers supply; ensuring quality market and purchase, (Saliba, 2015). These embedded electronics, sensors and connectivity interfaces digitally, connect with one another forming an integrated platform for speedy and deep data analytics that provides richer decision-making insight currently possible. The Internet of Things (IoT), Communication machine-to-machine (M2M) and Cyber-Physical Systems (CPS), data historians are essential for the implementation of Industry 4.0, while the Software Defined Networks (SDN), (in figure 2) is a new concept that can help in communicating devices that are part of the network propelling VPP digitization, (Kaur, Nonnemacher, and Coimbra, 2016; Mehta, 2017; Schlaepfer, and Koch, 2016).

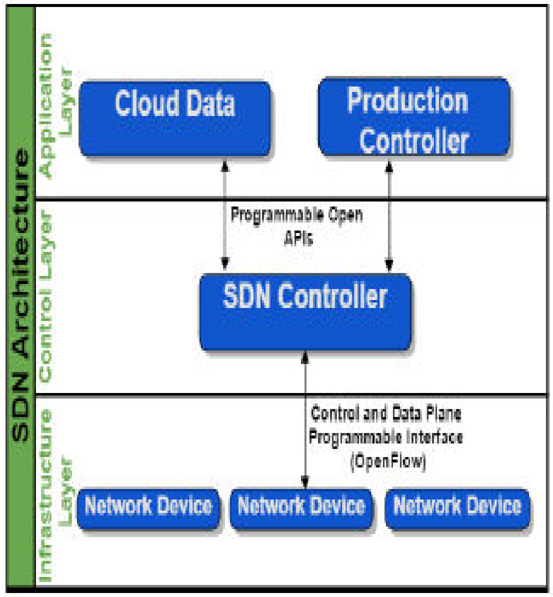

Figure 2. SDN Architecture with the Production Controller (**Source**: Lins, et al., 2016)

SDN network enables the advancement of Industry 4.0 communicating devices to form a gateway stack with DER network devices and the cloud. However, over 70% of these devices contain vulnerabilities, insufficient data breach response, operator-side data leakage, and insecure data transfer. With adaptability as its major feature, it is limited to a centralized control. This created an opportunity for a distributed network controller, (Kaur, Nonnemacher, and Coimbra, 2016). This high technological strategy cyber-physical system enables the connection of operation of the physical reality with computing and communication infrastructures that networks several devices for collection and exchange of information, from the physical to the application layers amongst the communication layers, (Abdelaziz, Hegazy, El-Khattam, and Othman, 2013; Basso, and DeBlasio, 2016; Wei, Hong, and Alam, 2016). Communication is extremely critical for optimizing system value and essential for penetration efficiency. Applicability of the various connectivity standards rests on the application protocol, especially for wired industrial. Hypertext Transfer Protocol (HTTP) is applied for IP-based smart objects. This allows interoperability with a large number of external systems relative to wireless - a Constrained Application Protocol (CoAP) for small power sensors and components remotely supervised, (Abdelaziz, Hegazy, El-Khattam, and Othmam, 2013).

Industry 4.0 is a guideline built on a revolutionary step that requires lean setups to leverage an existing technology that results to interdependence, efficiency, increased capacity, and productivity, and improved organizational and process performance, (Ravichandran, Ananthraj, Sivakumar, Sivakarthik, and Vijay, 2017). However, serious challenges abound in Industry 4.0 in VPP digitization which includes interoperability and standards, cybersecurity, reliability, availability, and latency requirements for mission-critical intelligent infrastructure systems which requirements are different for general business or consumer applications, (Wanga, Parkinson, Miao, Jia, Crawford and Djilali, 2012). A notable issue is the security of data and update of storage servers at all time.

3. Systems' Functions, Requirements, and Processes

Rekika, et al., (2016) and Rekika, et al., (2016) describe VPP as a multidisciplinary, multifunctional and multitasking system, that interacts and integrates network controls capabilities which enable the distributed generations in the performance of three main functions: network support control, balancing and trading energy flow. In Industrial Internet Consortium (2017), DG is grouped according to the type of primary energy source, Capacity, ownership, and nature of the operation.

Distributed energy storage system (energy or power supply) bridges the gap between the generation and demand; storing energy off-peak periods to feed the peak periods demand, (Wei, Hong, and Alam, 2016; Schlaepfer, and Koch, 2016; Wanga et al, 2012).

The Energy Management System (EMS) (figure 3) as the control center relies on the information and communication system, which are characterized by prediction and experience; managing the energy storage off-peak periods to feed the peak periods energy demand. Amongst the major functions are the reduction of operation, energy minimization, profit maximization, reduction of environmental CO_2 and power quality enhancement, and performance of real-time energy forecasting, energy storage and loads control, (Wanga, Parkinson, Miao, Jia, Crawford, Djilali, 2012; Wei, et al., 2016).

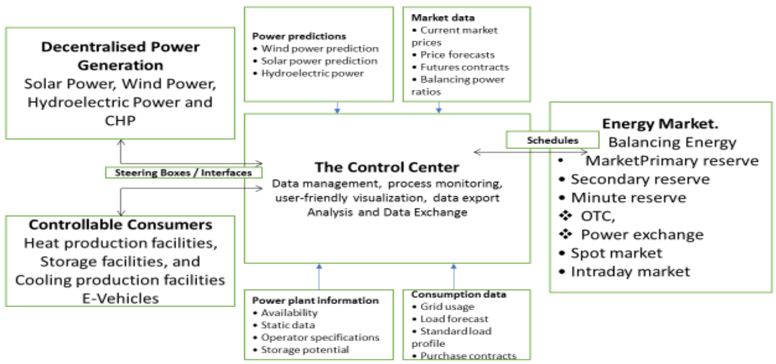

Figure 3. VPP Integrational Composites (**Source**: Adapted from Industrial Internet Consortium, 2017)

Lins, Jose da Silva, Augusto, and Oliveira, (2016) enlisted four functionalities of this system which its interoperability depends on energy service interfaces (ESIs), flexible and extensible. It further supports a resource-oriented architecture adopting plug-and-play of DER devices, loads, and other functionalities, abstracting energy components as its resources (Lins, et al, 2016). The following therefore constitutes the functional requirements (refer to figure 3): Data forecast, analysis, and transmission could describe the quantity and type of fuel available at specific locations and time to power energy systems. These requirements are based on deterministic generation, stochastic generation, deterministic load, stochastic load and energy storage systems, (Industrial Internet Consortium, 2017). The data analysis provides insights into DERs characteristics, market optimizations, and the load. These are utilized to adjust the short-term forecast, event detection, local demand response and the optimization models for better performances, (Industrial Internet Consortium, 2017; Lins, et al., 2016; Pérez-Arriaga, and Knittel, 2016) whilst, transmission data provides data visualization, archiving, rated line capacities, impedance, and line ratings. These functions are performed through the hardware vendor and network protocols. These protocols, further assess the energy demand (load profile) of the area, and how quickly energy demand changes; determines the size, location, and timing of electricity demand and the demographics of economic activities and population, (Wanga, Parkinson, Miao, Jia, Crawford, Djilali, 2012).

VPP does not only control the supply and energy flow within the cluster but exchanges energy with the main grid, (Lins, et al., 2016). Based on application of needs and dispatch criteria, Rekika, et al, (2016) argue that due to its user-friendly interfaces, dispatches to a virtual site are focused on a specific need of the user as influenced by the software prescheduling interface, (Industrial Internet Consortium, 2017; Schlaepfer, and Koch, 2016). The authors' further list these applications dispatch needs as Regional Dispatch, Fuel Type Dispatch, Economic Dispatch, Substation Feeders, Site Priority Dispatch, Remote Scheduled Dispatch and Load Reduction Dispatch. Predominantly, two Major types of VPP exist technical virtual power plant (TVPP) which primary function apart from its balancing nature, is to avoid network problems of local system management for the Distribution system operator, DSO. It ensures the location of DG units and loads, location, and capacity of the storage units, the control strategy for the loads and voltage controls.

The commercial virtual power plant (CVPP) exploits business opportunities of optimization, wholesale trading, portfolio management, system balancing and ancillary services and a mixture of the above, (Kaur, et al., 2016). These two VPP types operate together to achieve its functions using Information and Communication Technology (ICT) infrastructure, Smart metering and control devices installed at the customer sites. Monitor, control, and Software applications are the tools to forecast VPP power generation, (Abdelaziz, et al., 2013; Basso, et al., 2015;

Perera, et al., 2016). Network operation constraints are not considered by CVPP. Rather, it uploads the results of the optimal schedules to TVPP. This constraint of centralized dispatch can only be avoided by the use of Software and EMS that controls a multitude of DERs.

The relationship between these control functions and VPP are interlinked. Though, this link is enabled by the big data bus, (Etherden and Vyatkin, (2014), the major challenge experience in VPP is the standardizing of interoperability, interfaces to Cloud Servers and heterogeneity of Sensors. Using the same basics as a microgrid, it employs same functional assignment at the DG units. These control functions mapped into blocks from the device of the DG units to the grid level (shown in table 1) uses multi-agent network system of both intelligent agents (computational Cyber Process) and physical (interaction) processes to form a network. The resulting network consists of microcontrollers that decides generator set points.

Table 1. Control functional Blocks (**Source**: Etherden, and Vyatkin, 2014)

Function Assignments to Blocks	
Block 4	**Grid-Interactive Control Functions** Area EPS Control, Markets, DMS, Distribution SCADA
Block 3	**Supervisory Control Functions** Forecasting, Data Management and Visualization, Optimization (e.g., Volt/VAR, Economic Dispatch), Dispatch, State Estimation, Emergency Handling, Generation Smoothing, Spinning Reserve, Topology Change Management, Black Start, Protection Coordination
Block 2	**Local Area Control Functions** Sequence Logic/Status Control, Load Management, Building Energy Management, Plant Controller, AGC, Fast Load Shedding, Resynchronization, Disturbance Recording
Block 1	**Device-Level Control Functions** Voltage/Frequency Control, Reactive Power Control, Electric Vehicle Control, Energy Storage Control, Load Control, Generation Control, Islanding Detection, Fault Protection

Due to the complexity of centralized dispatch, this distributed decentralized multi-agent triad controllers of power, load and price optimize VPP energy schedule to cope with the micro sources generation uncertainties. These agents are interactive: The power agent attached to DER determines real power to be constrained to stay within the operational level; the price agent computes shadow price that assists the power agent to coordinate the selection of the respective individual requests. The load agent monitors power quality and dispatches power level to the price agents.

Industry 4.0 among its functions is the robust integration of additive manufacturing throughout the supply chain, both for the producers and consumers of energy in a customized way within the value chain. The data generating nature of industry 4.0 supply chain produce in real time with incredible speed and precision with instant capacity access and visibility balances the demands through its Cloud technology. It continues to improve enterprise in the deployment of data management and functionality providing the necessary agility for the supply chain of the next generation within the virtual power plant boundaries. Using its in-memory databases it handles ad-hoc optimization and analytics to maximize virtual power plant storage and agility. Both Virtual power plant operation and Industry 4.0 are not only technology based but involve process and people integrating informational technology vertically and horizontally facilitated by the systems operational enablers and inhibitors.

4. System Barriers and Enablers

These are the operational systems directly or indirectly that support or delay performance during the lifecycle of both the Virtual power plant and industry 4.0 functions. These barriers range from institutional, regulatory and policies to the deployment of DERs.

4.1. Standards: Networking and Communication

Standard 1547 forms the foundational document for the interconnection of DERs with the grid, as stipulated by The Institute of Electrical and Electronics Engineers (IEEE). These standard forms the provision of mandatory functional technical requirements and specifications, as well as flexibility and choices, for equipment and operating details, (Basso, et al., 2015; Kaur, et al., 2016; Mehta, 2017). Providing the modern solutions for enhanced integration of DER and loads with the grid Intelligence is based on IEEE 2030 that states the grid interoperability for further realization of greater implementation and visualization of communications information technologies, (Rekika, et al., 2016). Due to the proliferation of connectivity models, most protocols developed by different service providers are not adaptive to each other, where they do, it proves expensive and cyber security is predominant. The general interoperability Standards are summarized (table 2) as follows:

Table 2: Interoperability Standards (**Source**: Author)

CODE	DESCRIPTION
IEEE 1547	Requirement for DER grid interconnection and interoperability
IEEE 1547.1	Test Procedure for conformance to 1547
IEEE 1547.4	Guide for Design, Operation, and integration of Distributed Resource Islanded systems with Electric Power System
IEEE 1547.7	Draft Guide to Conducting Distribution Impact Studies for Distributed Resource Interconnection
IEEE 1547. 8	Draft Recommended Practice for Establishing Methods and procedures that provide Supplemental support for implementation Strategies for expanded use of IEEE154
IEEE 2030	Smart Grid Interoperability Standards and Transportation Infrastructure
IEEE P2030.2	Guide for the interoperability of energy Storage systems integrated with the electronic power infrastructure
IEEE 2030.3	Standards for Test Procedure for Electric Energy Storage Equipment and systems for Electric Power Systems Application
IEEE2030.7	The standard for Specifications of microgrid controllers. The microgrid control System functions classification (SCADA)
IEEE 2030.8	The standard for Testing Microgrid Controllers
IEEE 2040	Connected and Automated Intelligent Vehicles
IEEE 802.1 / 802.3/802.15.4	Interface identifiers that offer the highest interoperability, control of power, Exchange of information from and between components.
IEC 61850	Automation Architecture requirement for utility subsystems, enabling communication and semantic interoperability among multi-vendor equipment, communication Networking, Communication Front End for Network D
IEC 61850-7-2	Abstract Communication Service interface (ACSI) as a paradigm used for vertical and horizontal communication among IEC61850
IEC 61970/ 61968/62325	Based information integration and software frame of EMS for EMS for Multi-Distributed Generation Microgrid system and common Information model
IEC 61970-5-101/104	Tele Control and management system applicability conformance Standard, Mapping between different information, control and Monitoring.
IEC 62351	Communication Security Requirement
ISO/IEC 141	Defines various components of IIoT reference Model and ref. Architecture Model
IEC 62264	Hierarchy level
IEC 62890	Life cycle and Value Stream
IEC 62443/ ISA99	Cyber Security and Risks Control

4.2. Policy Framework

A key target in energy policies centres on issues of negative environmental impact and sustainability resulting from energy generation, and transmission; pollution and climate change but most importantly on economic efficiency that emphasis on increased security of supply, low prices integration of flexible DER, empowerment of customers and industrial competitiveness, (SWECO, 2015). Figure 5 shows the cascading nature of the policy framework from policy target to the centricity of the consumers and prosumers.

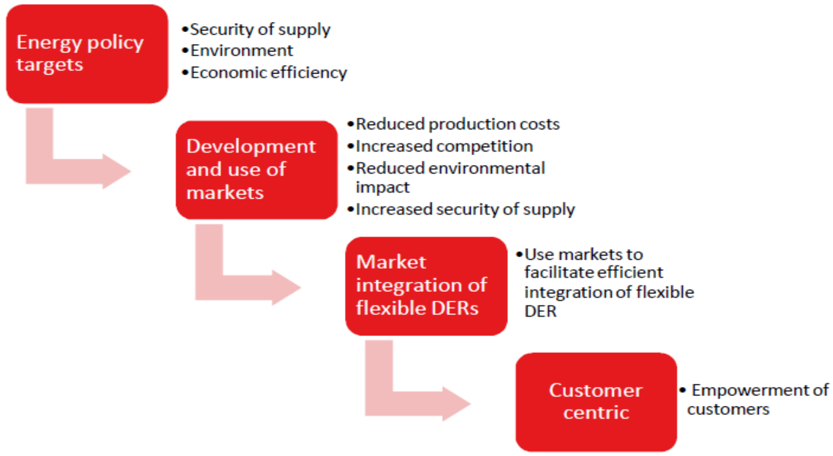

Figure 5 Cascade Policy Framework (**Source**: SWECO, 2015)

4.3. Safety and Cyber Security

Byres, (2017) enlists the prominent network threats (figure 6): Control interfaces to the internet, compromise of intranet and extranet connected to the cloud, intranet and internet infiltration of malware, intrusion through remote access, human error, phishing and Social Engineering.

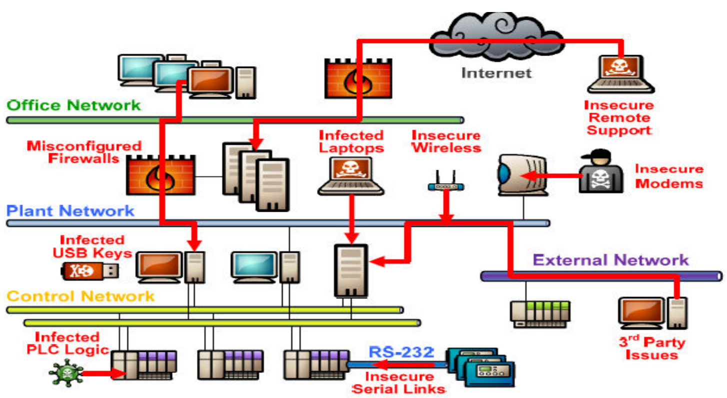

Figure 6. Possible Pathways of Proliferation on the Control System (**Source**: Byres, 2017)

To improve control, according to Byres, (2017), the security functional requirements, process, and procedures as stipulated in IEC 62443 becomes necessary. This provides a logic and physical framework that contends the network security threats both from 'productivity push' and 'Stuxnet worm' due to multiple points of entries, proliferation of soft targets and weak network segmentation (internal), (Bosman, et al., 2014).

ISA 99 tools (with level 3.5 DMZ later included) are used as modeling in designing control systems and Supervisory control and data acquisition systems, having 5 levels commencing from level 0 to level 5 representing instrumentation to internet interfacing network respectively. Each level based on functional requirement supports a specific SCADA component. A buffer network (firewall) terminates IP communication originating from any untrusted network from outside SCADA (level 2) and control system networks. There is no direct access to inside devices within the SCADA network that can communicate externally even to level 5. SCADA system is only used when the automated processes are geographically or spatially located sites, VPP in multiple sites is a good example. Contrarily, the Distributed Control System (DCS) which automate the flow of data with all components at one platform and at one geographic location (Mostafa, Hooshmand, and Gholipour, 2016).

4.4. Maintenance

This defines the roles, responsibilities and set of skills required in operating and managing VPP. Related faults and failures are localized and defined irrespective of distance, (Schlaepfer and Koch, 2016). Maintenance propels linear supply chain to dynamic network increasing digital connectivity and technological capabilities through predictive analytics and personnel. Intelligent operation of Virtual power plant does not only involve the process and technology but also people. A major application of Industry 4.0 in the operation of VPP is predictive maintenance. This forms the framework to the overall strategy and uptime performance necessary for the capital-intensive VPP; a reassuring asset performance to the standards and technology required to achieve the business of energy flexibility and reliability. Maintenance assures regulatory compliance, quality programs, asset management, develops strategy, manage change, and vision through its review process, enabling the value chain prioritization.

4.5. Enterprise

According to SWECO (2015), market integration because of the need to meet domestic resources is also expected to improve the security of supply as disturbances in the system and trade can largely alleviate problems. The author further insists that the transformation of the electricity system towards more DERs, will both increase the demand (need) for flexibility in the power system, and over time reduce the supply of flexibility from conventional generation sources. Wei, et al, (2016) indicate that one of the best ways for distributed resource allocation is the market-based control, which can be executed through the internal exchange, price signal controlled based and direct-controlled operation. Wei, et al, (2016) warn that incurred information flows and decision-making principles differentiate these 3 control schemes. Direct-controlled and price signal controlled requires simulation to obtain trading portfolios and optimized generation, unlike the internal exchange which is presently and globally in use that coordinate DER productions. Price signal controlled based is used to depict the working flow of Market-based. The biggest challenge is the relationship between the physical and financial models. DER as VPP Coalition member are managed according to its objectives of profit maximization, and risk minimization of profit variability (Industrial Internet Consortium, 2017). The major constraints evident in the market and resource analytics include the uncertainty of electricity price, stochastic nature of the power output and the power balance penalty and tariffs.

4.6. Technical

In the design, operation, and distribution of energy system, technical challenges abound especially on the flexibility gap while integrating DERs to the VPP. This gap ranges from Grid losses, reverse power flow, Voltage problems, and congestions.

5. Integration Strategy

Due to the complexity of the system, flexibility (value stream) as a concept in the integration process of VPP and DERs becomes necessary, based on scenarios in the formulation of strategies. Flexibility services either provide additional power as needed to maintain system balance or reduce the power availability in the system. Industry 4.0 facilitates how fast flexible resources can change demand or supply of power. Therefore, DERs impact depends on the characteristics of electricity demand and on the chosen scenario. These scenarios include the supply of energy on daily patterns, yearly dynamic ranges, yearly ramping ranges, day-ahead markets and demand based on timeframes (seconds and minutes). However, irrespective of the level, either local or system, through effective integration, VPP balances price vitality, Market value of flexibility, meeting peak demand, manages congestion, and ensures continuous equilibrium of demand and supply in the system. In lieu of this, two most important strategies were selected to illustrate the strategy.

5.1. Optimization

In order to reduce power loss and maintain flexibility, optimization forms a constituent part of the VPP to improve the voltage profile, utilize resource and operation of the power system and to enhance load control scheduling and reliability. Hence, it is a process based on objective and multi-objective functions of minimization and maximization considering the constraints of demand response, ramping rates, over and undersupply of energy, (Rekika, et al., 2016).

Inferring from the above, this process is categorized as that based on VPP operation and that subject to selecting VPP structure by optimizing its components. Whichever optimization path is taken, for a newly-established power system, VPP has the capability to choose the capacity and location of the DG units, energy storage systems, locations of the loads to be controlled and the appropriate control strategies and schedules deployed. On the other hand, for existing power systems, these options are limited to the DG units' location and size are pre-determined and done individually, Rekika, et al 2016; Saliba, 2015).

The main issue in the operation of VPP optimization is in the area of load scheduling. Based on energy demands and prices, its concern is to resolve problems of critical (uninterruptible or uncontrollable), Emergency (uninterruptible and controllable), Normal (interruptible and controllable) loads. This greatly helps to overcome power loss minimization, cost reduction, profit maximization and environmental emission reduction, (Cavalieri and Regalbuto, 2015).

5.2. The process of System Integration

The integrated solution provides an optimized operation of decentralized Distributed energy resources (DER) controller DER controller Equipment energy resources, load, and storage, that enables trading of energy flexibility at minimized risk (Siemens, 2013). Effective integration of Virtual Power Plant Operation delivered by industry 4.0 requires a simultaneous system of a systems framework to address the technical challenges, environmental, Business, information, regulations and operational management to achieve a sustainable solution to Stakeholders objectives hierarchy. In literature, no framework exists for both technical and non-technical issues for VPP, as such development and design of VPP for critical multiple sites is incomplete without these combinations (Saliba, 2015).

The complex VPP cyber-physical and hierarchical structure achieve a simultaneous balance, utilizing bidirectional network system distributed decision-making intelligence. The system employs a multi-agent and event-based approach using a common resource Strategy to harness exchange of information among the entities and delivery of electricity, (Salam, Mohamed, and Hannan, 2008; Saliba, 2015). To achieve integration, VPP uses industry 4.0 to optimize scheduling; intro and day-ahead forecast load, weather, generator profile and spot electricity prices in real time; fast communication, fast algorithms. This vertical networking of smart energy balance is underpinned by smart sensors and maintenance management; monitoring of wear and tear, breakdowns, production and supply fluctuations and resource logging are all pre-empted. The integration of the prosumers and other business partners generates new models for cooperation and completely business models.

External sub-Systems within the boundaries of the VPP also constitute integral functional requirements for its operation. Such systems include regulatory bodies, maintenance (technical and non-technical), environment and users (both critical and non-critical loads).

The following integrated domains (figure 6) forms the operational management of VPP their functionalities.

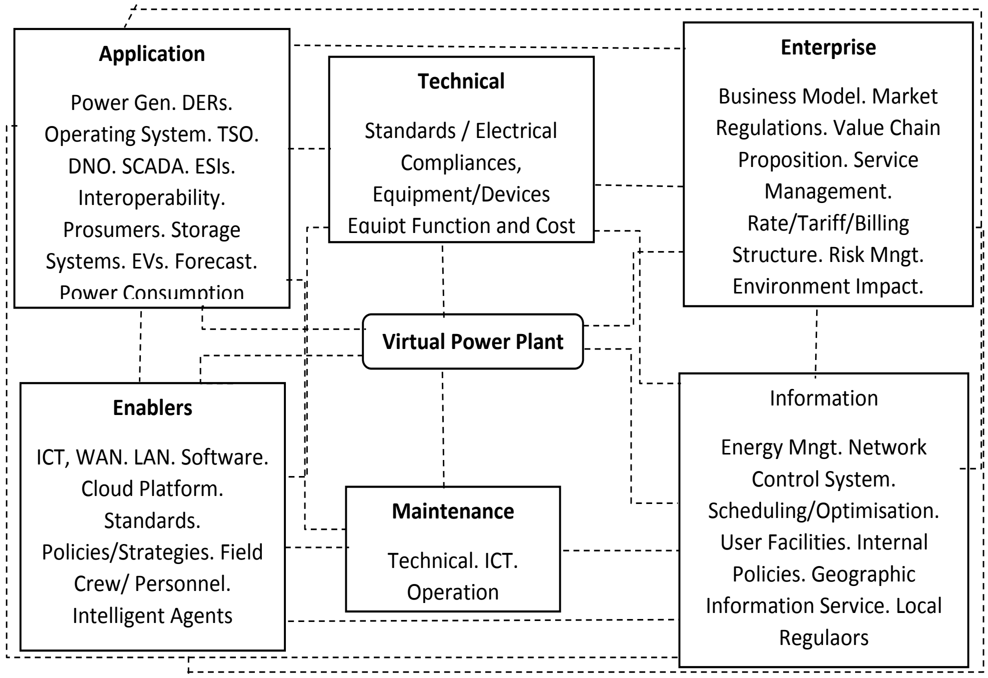

Figure 6. VPP Operational Functions Interactive Process (**Source**: Author)

The automated intelligence along with other enablers support predictive maintenance, pre-empting the enterprise resources (ERM) (figure 7.) to increase efficiency, harnessing the development of new models, reduce risks impacts, deliver timely, offering high level of flexibility and better optimization, encouraging inbound and outbound logistics and the ICT aiding the constant traceability of the process cycle, (Saliba, 2015).

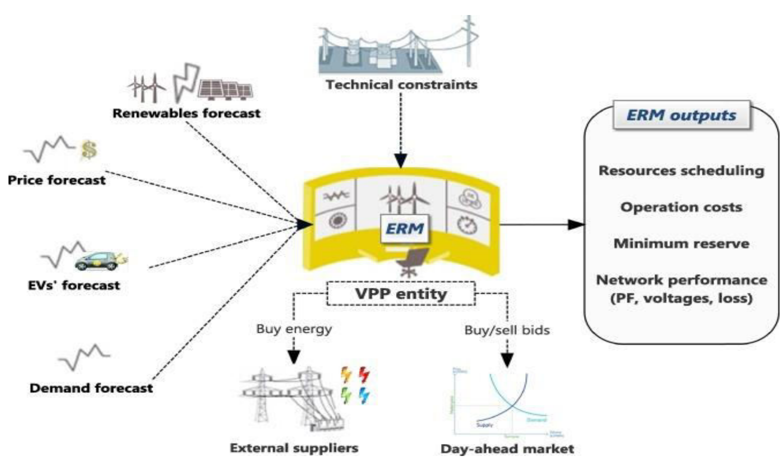

Figure 7. Multi-Objective Performance Model (**Source**: Soares, Ali, Ghazvini, Vale, Oliveira, 2016)

At the intersection of the development, design, manufacture of new products (including ICT, Software, Electrical), modification of the products, and installation and operation of the systems is technical, characterized by the enablers throughout the life cycle process of the Virtual Power Plant.

The artificial intelligence is noted for cost and time savings, individualized solutions and flexibility in the production, distribution, and consumption of energy allowing the stakeholders to make a choice on need and autonomy increasing the reliability of the supply chain.

Integration of the system performs at its best, governed by the System uptime, response speed, and accuracy, latency of communication and its ability to receive and respond consistently to dispatch signals. However, IEC 61724 describes few parameters for evaluating the performance of the systems through Weather forecast, Energy trading, Billing, and TSO/DSOs having data collection for a prescribed period in accordance with the standards, Via SCADA. This enables the execution of VPP major functions for managing energy and asset as well as local gateway agent, (Sharma, and Goel, 2017).

6. Conclusion

Virtual Power Plant complexity demands a concerted effort in the integration of the system, configuration, components variations, operational analysis and other control requirements. Critical technologies, analytical framework and architectural reference designs form a major tool for the integration of distributed resources. The integration of technical requirements, codes, applications, information, enterprise, exhibitors and enablers through industry 4.0 assures a value stream chain network to the Stakeholders. The use of these intelligent distributed technologies and control interfaces, gateways, networks, data information techniques, and wireless communications devices, protocols and cloud platforms to enable the flexibility and stability of future energy balance not only prompt good communication requirements of the VPP but also control strategies and deployment techniques especially in energy optimization.

7. Future Work and Recommendations

System integration forms the pivot of virtual power plant operational management. For energy flexibility, reliability and market pricing, emphasis shall be placed on Quality of Service, Maintenance, Critical Infrastructure. Impacts of cyber-attacks to the value chain, Scheduling, and Real-time analytics. Development of optimization module, Software technologies, the operational functions should be supported by standards and integrated frameworks. All distributed energy resources must automatically synchronize to allow schedule event simultaneously take place. Other necessary functionalities for energy mix shall include skill resource Limitations, Key Enablers, and inhibitors, Interoperability. Energy Trading, Billing, Weather forecasting, Network operations and Real-time automated optimization.

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