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Transformation of microgrid to virtual power plant – a comprehensive review

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Abstract: To provide continuity of balancing demand and generation, renewable sources will be more active than today in near future due to the tendency of massive investment on renewable energy sources (RESs) by countries. However, due to the uncertain and intermittent nature of RESs, RESs would create problems on power system operations such as power quality, efficiency, stability and reliability. Owing to having problems with RESs integration, virtual power plant (VPP) has introduced to make this integration smooth without compromising the grid stability and reliability along with offering many other techno-economic benefits. This study reviews structures, types, architecture and operations of VPP along with the status of present implementations worldwide. The types of VPP are introduced in details with the optimisation algorithm used with each type. In addition, VPP is linked with the most of the components in power systems such as distributed generation, active prosumers, transmission system operator and distribution system operator, grid services such as fault ride through, reactive power control as well as with the help of technology such as communications, control and optimisations. This study gives a comprehensive outline of transforming microgrid to VPP that is useful for researchers, consumers, prosumers and utility operators.

1 Introduction

The continued strong development of distributed energy resources (DERs) provides a great opportunity for renewable energy investors around the world. The worldwide DERs integration grows the average rate of 20% by the end of the 20th Century [1]. Owing to priorities on carbon footprint reduction and harnessing energy from alternative sources than fossil fuel, DERs integration with existing power grid will be kept to increase more for the time to come. While these growths provide many advantages, it creates new challenges to manage the grid in an effective way. From the experiences of transmission system operator (TSO) and distribution system operator (DSO), some problems occur while integrating the DERs with an existing grid such as transmission congestion, voltage and frequency stabilities and reliability problems due to uncertain and intermittency natures of DERs.

A microgrid is a localised group of energy sources and loads that may operate at grid connected or islanded modes. The concept of microgrid is getting popular since last decade and there are many microgrids actively operating in different parts of the globe. The major investment in a microgrid is on its DERs. In many microgrids, the operators have to handle problems coming up with DERs; otherwise, green energy should be thrown away instead of being utilised. These problems create a new research area to seek solutions for integration of DERs without creating grid stability and reliability problems. One of the new solutions of eliminating of DERs negative impacts is through the transformation of microgrid to VPP. VPP coordinates all DERs as in a single agent to integrate them into the grid without compromising the grid stability and reliability, adding many other additional benefits and opportunities to consumers, prosumers and grid operators [2].

With the gain experienced from smart grid concept, has been studied on decades, VPP can be implemented easily and successfully which has already been tested in some country. Some of the smart grid technologies that may help to integrate VPP are intelligence algorithm, i.e. power generation, transmission and distribution, and demand response by using customer participation with the usage of advanced communications such as Internet protocols. Web to Energy project [3] is one of the biggest developments on smart grid that can easily adapted to VPP concepts. Communication of network of physical devices has enabled project of the Internet of things (IoT) [4]. IoT allows different devices to be sensed, communicate with each other and also controllable from remote locations. This method is applied for direct integration between intelligent devices with computer-based software offering advanced connectivity among the devices. Similar to IoT, VPP combines, communicates and behaves such as a neural network for each different DERs agents. Fig. 1 demonstrates simply how householders share their energy within a VPP. This system aggregates all DERs and other units inside the system. Fig. 2 shows how units are clustered and connected with centralised VPP. These clusters interact with each other in order to behave as just as one unit. The localised control centre emerges as a self-organised intelligent solution. To obtain a self-intelligent system and make a decision, there are many optimisation algorithms that have been developed. A detailed review study by comparing these optimisation algorithms is discussed in [5]. How the payment of energy will be dispatched among generation, transmission and distribution companies is getting complicated with increased integration of DERs into the grid. However, with the usage of VPP, monitoring and coordination of DERs will be much easier that helps to put market prices out easily. Hooshmand *et al. and* Shabanzadeh *et al.* in [6, 7] show how to investigate event-based scheduling and calculation of stochastic market price in the distribution network.

VPP also helps to reduce the losses on the network. Conveying the load along a long path causes large losses, but with VPP technology, the consumer can be fed by the closest distributed generation (DG) that provides minimising line losses, prevents overloading the system, and delivers electricity to consumers at a cheaper price. Recently, consumers have become active in production by using DERs named as prosumer that means consumers also produce. By being active in production makes generation forecast complicated due to uncertainty inside the DERs. Authors in [3] investigate all units (DERs, batteries, flexible loads etc.) in a comprehensive way to see the effect of uncertainties on forecasting. These uncertanities can be solved by using complex equations and computer programmes to make predictions more accurate. In a study [8], Wei *et al.* offered that the consumption statistics can be forecasted with artificial intelligence (AI) software that will be highly used in VPP in near future.

Available review papers found in the literature summarises advantages and disadvantages of VPP. Paper [5] describes the general structure and optimisation of VPPs. Different implementation techniques and scheduling of VPPs have been discussed in [9, 10]. There are very limited technical review papers that have been published related to architecture and advancements of VPP and none of them comprehensively mentioned technical problems highlighted above which triggered the authors to this work.

All kinds of power engineering applications (in point of VPP) and how these applications affect traditional grid systems are discussed in this technical review paper. In particular, technical articles, which contain practise and optimisation-oriented studies, have been examined and different popular theoretical approaches are compared in tabular form. In addition, well known optimisation algorithms are explained from different aspects and discussed effects of AI on optimisation methods.

In addition to all these, the ambiguity of VPP and microgrid terms have been clarified and explained the differences between these two technologies. The steps of converting microgrid technology to VPP, which is a higher-level implementation, are mentioned.

The rest of this paper is organised as follows: Section 2 begins with a classification of VPP based on technical and commercial types. Section 3 specifies the relationship between DERs and VPP. Section 4 presents an overview of prosumer in VPP. Then, the transmission and DSO's relationship with VPP is introduced in Section 5. Section 6 summarises how VPP helps for grid ancillary services, whereas Section 7 represents worldwide case studies related to VPP. Section 8 provides the comparison of a microgrid with VPP. Finally, this paper ends with conclusions in Section 9.

Fig. 1 *Household energy sharing scheme in a VPP*

2 VPP classifications

The VPP can be classified into two different categories. First one is commercial VPP (CVPP), the second one is technical VPP (TVPP) [11]. One of the main problems is that it is not clear how participants can interact among themselves and with the DSO that has all grid infrastructures. VPPs generate their own electricity and transfer this energy by using transmission line that does not belong

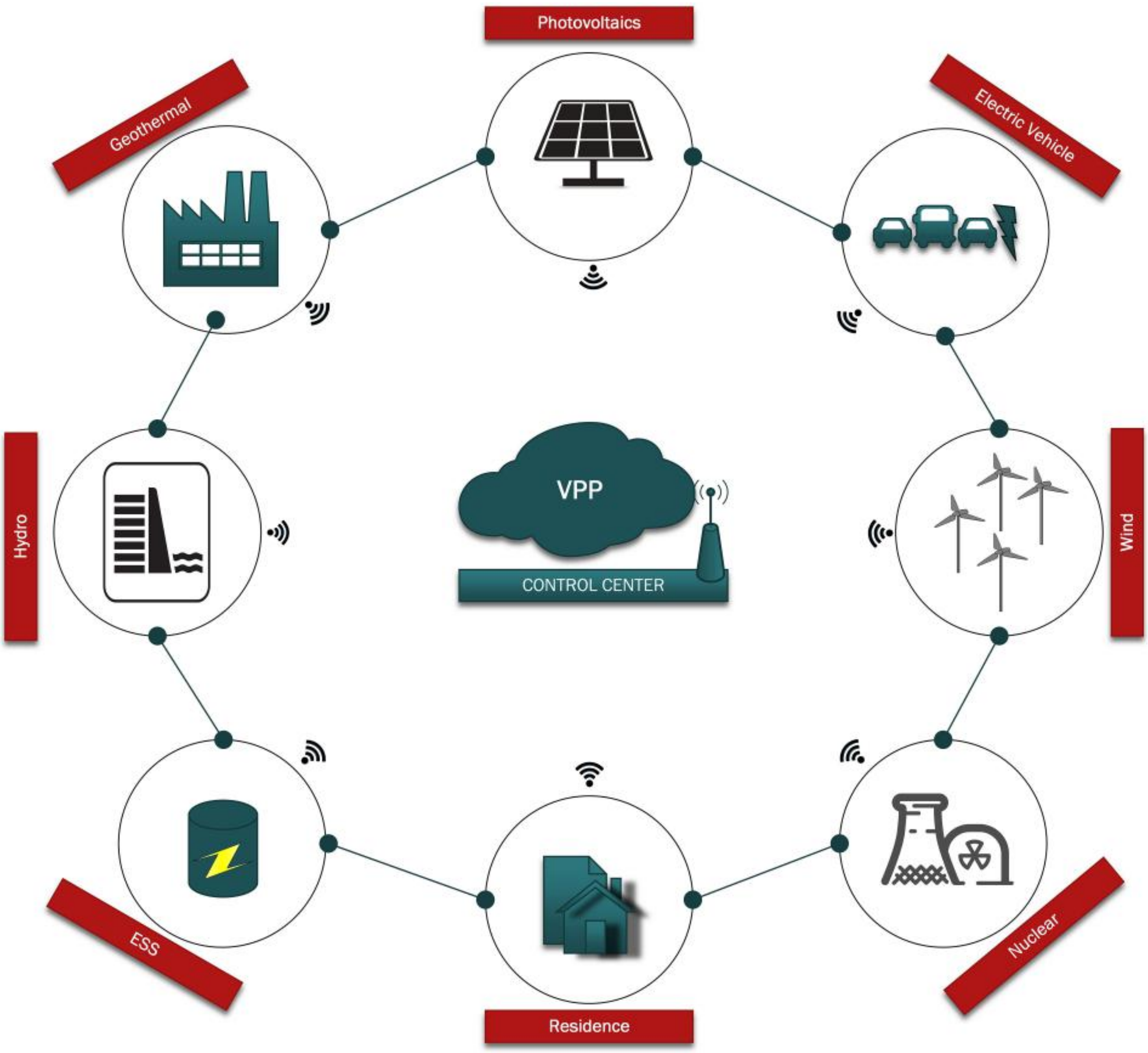

Fig. 2 *Centralised VPP*

to VPP owners, so the cost of this energy transfer needs to take into account as well. This topic requires innovative research itself to decide what kind of billing system is required to solve this chaos. Another technical aspect of the implementation of VPP is that whether the system is currently used as microgrid (islanded mode) or grid-connected mode that effects hardness level and cost of implementation and dispatching bills among participants.

2.1 Commercial VPP

The main purpose of CVPP is an economic optimisation. It includes financial risks: cost, optimised revenue for exchange energy, combine economical paradigms with intelligent grid services and represents bid-offer tables. In general, studies in this area are based on risk-management methodologies. Developed models include how VPP users have agreed with each other, partnership agreements with distribution companies, also mutual agreements between different VPP groups and energy marketing issues. Thus, different mathematical methods and computer algorithms have been developed for solving such complex situations. The fundamental of most studies is relying on stochastic or deterministic approximations. However, some programmes may become unsuccessful due to the variable and flexible nature of the results by using deterministic approximate methods. It is found that recently the researchers have the tendency to focus on stochastic methods. A detailed description of these topics is given in [12], where stochastic approximation methods and solutions are also discussed for CVPP.

2.2 Technical VPP

As the name suggests, TVPP defines comprehensively about complex calculations, technical applications, storage and optimisation. Mostly financial issue, monitoring and fault detection schemes are the topic of interest. This classification deals with power flow optimisation, communication protocols within smart grids, technical feasibility solutions and some fuzzy algorithms about generation and consumption. In addition, security is one of the main challenges, because VPP has to keep personal information in private. One of the most troublesome problems of an intelligent system is the hostile cyber attacks and viruses. For example, consumer's personal information has to be preserved in case of any cyber attack, so TVPP deals with this situation, and because of these features it becomes significant in communication system [13].

2.3 Highlights of TVPP and CVPP

Two different types of VPP can be characterised by the following [14]:

- Energy management systems (EMSs) offer different tariffs for consumers. Authors demonstrate calculation and implementation of these tariffs [15] (TVPP).
- Demand forecasting process deals effectively with complex commercial proposals since nowadays energy market has become such as the stock market (TVPP) [16].
- Tariffs have to be updated by manufacturers and inform to customers about new tariffs and energy rates [17] (CVPP).
- New tariffs should be updated, so tariff updater officer has to be responsible [14] (CVPP).
- Communication of VPP units occurs between each other. An implementation technique based on information and communication technology (ICT) is proposed [18] (TVPP).
- Safety and reliability parameter (TVPP).
- Generation and consumption control, optimisation process and stability control (TVPP).
- Grid imbalance has to be overcome (TVPP).
- Different weather situations are foreseen. Photovoltaic (PV) and wind generators depend on weather, so the producer has to deal with it by using different software, complex algorithms and using satellite images (TVPP). Some forecasting applications are demonstrated by using stochastic simulation methods [14, 19, 20] (TVPP).
- Storage control and optimisation are for all units. Energy storage system (ESS) linkage application affects grid balance and change energy markets, (TVPP).

3 DERs linkage with VPP

The centralised control unit of DER's clusters plays a key role in VPP. Distribution grid management application and ICTs are considered to be the most important applications for VPP with DERs linkage.

3.1 Optimal sizing

Optimal sizing is one of the highly investigated topics where the most economical cost, technically applicable and most efficient devices have been chosen. To deal with the optimal sizing problem, there are many algorithms that have been developed and used many optimisation algorithms as well. EMS is one of the most important applications of VPP related to optimal sizing problem [21].

3.2 Use of optimisation algorithms in VPP

Increased penetrations of DERs and renewable energy sources (RESs) require the appropriate communication by using general architecture, as an example, the smart grid architecture model (SGAM) [13] can be referred that offers simplicity for any proposed smart grid architecture. The SmarterEMC2 project [22] which is used as SGAM, aims to devise new business model, increases RES usage and links ICT tools between DER and VPP.

Optimisation can be applied to the very large area that is based on a mathematical model, the computational power of process and application. The main idea is to find maximum and/or minimum results that depend on objective functions for highly complex problems. It is specifically used as giving input values, provides what output values would be suitable for a given system. In short, it tries to find optimum results. In power system, optimisation algorithms are widely used in optimum power flow, loss minimisation, generation cost reduction etc. As VPP involves parties such as DGs, DSO, ESS and loads, there are numerous applications of optimisation algorithms within VPP framework such as reducing unbalanced power flow, capacity factor, system interruption, forecasting of load and generations, sizing of RES and ESS elements and profit maximisation [23]. Besides advantages of VPP technology, people have faced many problems based on optimisation issue. There have been too many optimisation techniques that can be used for different purposes with the pros and cons, so Table 1 below summarises the most popular algorithms used in power system with their objectives and similarities.

3.3 Communication features

Recently, significant progresses in electronic and communication technologies have been carried on automation applications in the electricity sector. Manufacturers have produced devices with different working prescriptions and various machine-oriented languages and algorithms were developed as well. However, these developments put forward the problem of interoperability of intelligent electronic devices belonging to different manufacturers in a centralised system. The main reason for this problem is that each manufacturer's devices have their own communication protocol that makes global information transfer system complicated.

The International Electro Technical Commission (IEC) 61850 has developed electric power substation's communication standard [44]. Detail of IEC 61850 standard and its applications are presented in [45]. Application of IEC 61850 in VPP grid services is demonstrated in [46]. Although IEC 61850 is common communication standard and easily applied to communicate with different branches, there are some issues that need to be solved. To surpass these issues, service oriented architecture (SOA) method is used as discussed in [47]. On the other hand, object linking and embedding for process control (OPC) refers to the software standards that enable the connection of the machines for systems and devices in different manufacturers and transfer of data. Servers based on the OPC standard allow devices in any two different systems to connect without the need for an additional application. In [48], SOA Technologies, devices profile for web services (DPWS) and OPC Unified Architecture have been used for VPP application. OPC UA and DPWS both provide significant benefits for features on smart grid implemented based on VPP technologies. Also, some data models such as RESTful [49] can be used for IEC 61850 as shown in [27]. IEC 61850 data model can be mapped easily to uniform resource locator format by using RESTful services [31].

4 VPP as active prosumer

4.1 Gateway and smart metering

Smart metering (SM) is a device for not only recording the electricity consumption, but also provides billing, monitoring and selection of tariffs for consumers. These advanced metering devices include software, hardware and communication infrastructure. Smart meters also have the ability to transfer bidirectional communications of data. Recently, IoT is commonly used by data transfer between smart meters and meter data management systems [50]. Smart meters include IoT community as well. They have got Internet communication ability, sending and receiving electrical consumption data's, and consumers can monitor all actions on their electricity usage [51]. Lei and Huang [52] explain the communication feature used in smart meters. It also explains wide area network and the ability of router that would act as a bridge between different protocols. *Gateway*' can be used as that bridge.

A gateway is networking that provides the transmission of data frames between two computer networks that are using different network protocols. In other words, when two networks that cannot speak in the same language, at this point 'gateway' serves as an interpreter [53].

SM gateway (SMGW) provides not only communication between cloud and local area, but also security against foreign intervention. To achieve sustainable and secure data transfer, SMGW is being used. For detailed comprehension, a gateway model is presented in Fig. 3. SMGW model interaction with sensors and its differences from conventional metering can briefly be explained in [22–24]. Smart meter system has included different types of sensors to identify usage of electricity and allows bidirectional communications between customer and grid service provider. Thus, SM will play a significant role in future technology. The smart meter features with details are provided in [53] for developing countries.

4.2 Smart consumer

In the developing world, VPP brings new features and change consumers' behaviour. Prosumer is a new term, which actually has the close meaning of smart consumer who is serving as both producer and consumer [26, 27]. Today's power systems are going to be transformed from centralised generation to decentralised and

Table 1 Applications of modern optimisation algorithms in VPP framework

Algorithm	Objective	Remarks	Other similar studies
geographic routine algorithm based on ant colony optimisation	denser network does not mean more efficient and improved grid performance [14]	simulation results demonstrate that the denser network becomes the better performance occurs up to the saturation limit	[15, 16]
mixed linear integer method based on maximising or minimising an equation anyone can find theoretically background on it from	forecasting wind speed and solar radiation [17]	detected the occurred faults by using a prediction algorithms	[18–22]
genetic algorithm is an adaptive heuristic search algorithm (based on the evolutionary idea of natural selection)	multiple DER's reliability problem solving [23]	method is based on the intelligent process of random search used to solve optimisation problem. Authors proposed optimal sizing with genetic algorithm	[24–26]
firefly algorithms (FFA, are inspired by firefly that creates a mathematical equation of these behaviours, the method explained in)	this algorithm used for optimisation of power flow, transmission and distribution lines. To understand which line is most effective, create a flexible loading and find the most sustainable system solution [27, 28]	author proposed a power system based on FFA to understand which line is most effective	[29, 30]
artificial bee colony (ABC, is an optimisation tool which is inspired by bee's behaviour to find a food source. They fly randomly multidimensional directions and if one of them found the nearest source it forgets the previous one	DER placement and sizing process [31]	In the power system, this algorithm is mostly used for DER placement and sizing process	[32–34]
CPLEX (IBM Log Optimisation Studio) program**me** based on mixed integer linear programming	results of real-time integration of DER into VPP [35]	results demonstrate that optimal real-time integration of VPP enhances economic feasibility and also yields reliable and functional energy. On the other hand, many researchers still investigate how grid extension and the network could effect on feasibility and performance.availability ↑%5.3interruption↓ %65.47;capacity factor ↑%45	[36]
quantum PSO (MSC quantum particle swarm optimisation (QPSO), based on quantum behaviour)	to change updating strategy and obtain high searching accuracy [37]	authors proposed an improved model of traditional PSO	[38, 39]
particle swarm algorithm (PSA, ABC and FFA algorithms are based on a similar idea)	considering the uncertainty in the optimal energy management	paper proposed a new probabilistic framework for management of microgrid [40]	[41–43]

interactive generation. In a decentralised network, prosumers may participate in the energy market. In these markets, energy prices always are traded as time-varying quantities. These prices go up and down depending on many factors such as consumption and demand response. Fig. 4 presents the concept of consumer and prosumer.

They are also part of the EMS that they are aware of the consumption and generations. Many kinds of management system and sparsity tariffs that smart consumer is involved have been used in present days. With the utilisation of ICT, widespread application has become easily accessible and popular. As more technology is introduced in the power system, well-equipped smart houses will be more popular in near future.

4.3 Energy forecasting and power of artificial intelligence

Accurate calculation of energy production and consumption is one of the most important steps in order to sustain and balance demands and generations. There are many surveys that have been conducted to get real consumption statistics to improve prediction accuracy. Why energy demand prediction is very important for producers? The answer is bringing prices down and to get more sustainable and balanced power flow. Energy production and consumption example is demonstrated in [8]. Prices are varying as demand changes on installed power. The other most significant goals are to equalise demands and generations. To achieve that, AI-based algorithm is getting popular which can be expressed using Fig. 5.

Besides demand forecasting, production and price forecasting issues are also in the point of interest. Price forecasting comes into prominence at energy market. The main point is differences between the cost of production and demand.

The relationship between production and demand costs is demonstrated in [38]. Renewable energy resources such as PV and wind depend on weather conditions. Thus, we need to use advanced mathematical methods, physics and some specialised software algorithms to forecast them accurately. Table 2 summarises energy forecasting algorithms and their usage in VPP. All the algorithms shown in Table 2 are highly used as a mathematical model for optimisation and forecasting in a power system. When the status of power system changes (which may include a new power supply), then optimisation and forecasting algorithms are updated by the developer. In some cases, the developer will have completely irrelevant consequences and will have to go through a completely different algorithm. Instead of evaluating the problems and the situation on the background with a single solution method and approximation, it is required to simulate the system by using AI that can exhibit flexible behaviour and give correct results adopting same flexibility by examining the behaviour as case varies.

As shown in Fig. 6, the algorithm should be able to act flexibly as state changes, using flexible tree by taking all possible states as input.

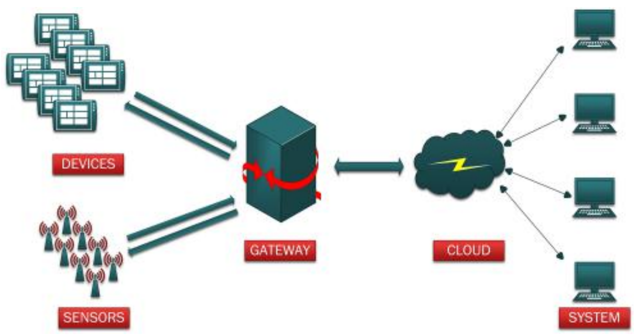

Fig. 3 *Gateways's position in the IoT ecosystem*

5 VPP linkage with TSO/DSO

DSOs and TSOs consider operational actions on linkage with VPP. From a practical viewpoint, TVPP undertakes this mission. Centralised control of DERs is a good solution for harnessing RES since the irregular schedule of RES can cause serious problems for the TSO. For example, wind and PV resources are dependent on weather conditions. The uncertainty in weather condition may cause scheduling problem, hence, TSO's main role is to provide load–demand balance. The DSO handles the last stage of transmission of power flow delivering it to the end user.

TSO and DSO are incharge of maintaining security, data exchange, grid planning and quality. TSO and DSO need to cooperate closely for providing sustainable and flexible electricity. VPP helps to engage DERs and end users with the DSO, so that VPP, DSO and TSO remain interlinked with each other. Integration of the VPP system would not violate the existing local network. Furthermore, it provides more flexibility and prevents conflict in overload situation. In [71], real system is used to demonstrate *'managing synergies and conflict between TSO&DSO control objectives'*. The result of this paper shows that the VPP application will not violate local network.

5.1 Real-time energy pricing

The main purpose of real-time pricing application is to regulate the usage of energy by targeting consumption habits. In real-time pricing, consumers are billed for hourly prices for all day and the impact of energy profit is monitored. Results show that the introduction of real-time pricing can decrease the amount of bill and provide annual energy savings.

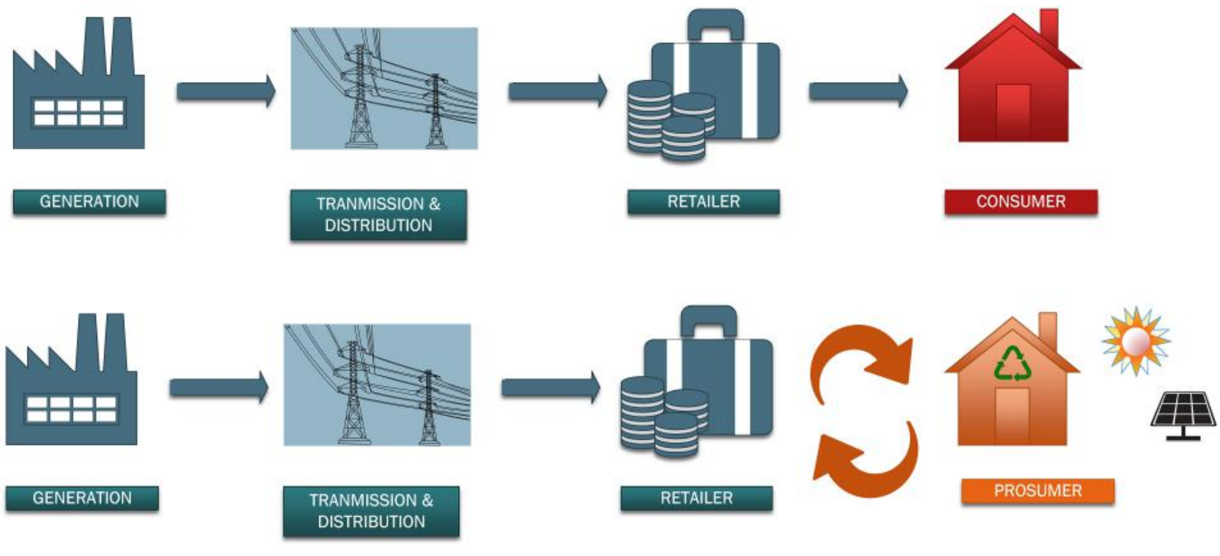

Fig. 4 *Consumer and prosumer concept in VPP framework*

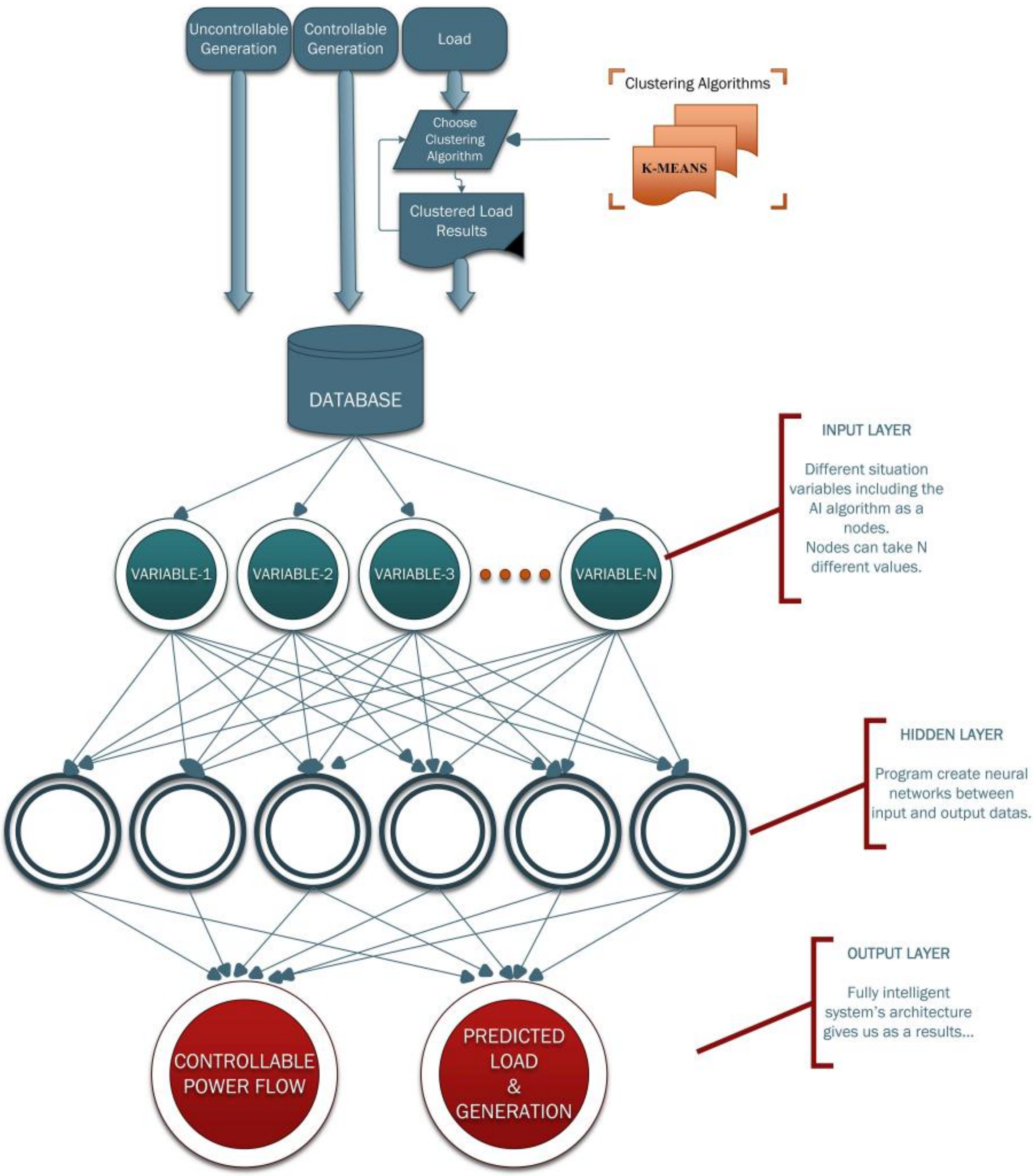

Fig. 5 *AI-based control*

Yan *et al.* [72] represent an application for small householders in Spain who used real-time pricing. Consumers can monitor the price hourly for all day by using the web and smart meters. Results show that potential economic impact cannot be neglected. Another implementation of real-time pricing is integrated as a home EMS. With the usage of VPP, variations on real-time prices could be reduced by generating and sharing data with intelligent control systems. However, there are too many compatibility issues that are to be solved to handle that. It is very difficult to get a real-time price on the basis of the energy since the user may use energy from the nearest and the most suitable place and the energy price can change based on the distance. However, a cloud-based system with advanced computers can overcome this burden. In addition to this, it is very difficult to make billing correctly and to offer package descriptions (kind of special tariffs) for variable energy flow. Fig. 7 shows three different prosumers connected with each other. The storage unit of home # 3 is almost empty and estimating algorithms predict that the home user will keep consuming. However, the real problem is that: Will home # 3 get the energy from number 1 or number 2? Home # 2 is closer than #1 so if the system can decide the most efficient energy transfer cheaper energy will be obtained.

What if there are thousand homes and hundred-generation units, it would be very hard to solve this complex situation. Thus, one of the optimal solutions is to choose AI algorithms to handle this, and hence AI is one of the most appropriate and dominant algorithms for VPP technology.

5.2 Energy trading

Consumers can be enabled to trade their energy by using VPP technology. This feature changes the consumer's usage habits and so they become active in energy trading. Application of neural networks in VPP framework enables peer-to-peer energy trading. People can generate, share and trade their own energy with factories, officers and even dwellings. Some successful energy trading projects worldwide are shown in Table 3. Detailed comparison and explication about these projects can be found in [77].

5.3 Transactive energy management

Energy transfer system, transactive energy management (TEM) systems, may involve demand response information exchange

Table 2 Applications of prediction algorithms in VPP framework

Algorithm	Objective	Results	Other studies by using the same algorithm
energy management strategy-based model	to improve the prediction accuracy [54]	energy management strategy-based on model prediction control by changing time scale, so that prediction accuracy significantly improved	[55–58]
fuzzy logic algorithm has been demonstrated for increased prediction accuracy	this method has been used especially in wind energy processes [59]	proposed stochastic model used for renewables and their market price	[60–62]
Monte Carlo simulation method (method based on repeated random sampling to obtain numerical results when physical and mathematical problem solving methods are difficult to solve the problem)	to solve PV radiation prediction [51]	simulation results demonstrate that prediction accuracy increased	[52, 63]
stochastic hybrid ıntelligent algorithm	mathematical model was developed for prediction of energy storage units level [64]	thus balanced energy and cheaper priced electricity have been obtained	[65, 66]
empirical mode and artificial neural network (ANN) decomposition (based on TurbSim, FAST and Simulink)	combination of traditional algorithms used for the fault diagnosis of wind turbine [67]	forecasting results have been improved by comparison with conventional methods	—
ANN is mostly used for an interconnected system which somehow they have a relationship between together	how would it effect selected hidden layers randomly and weight of output layer [68]	it improves computing efficiency and predictions are more precise	[69, 70]

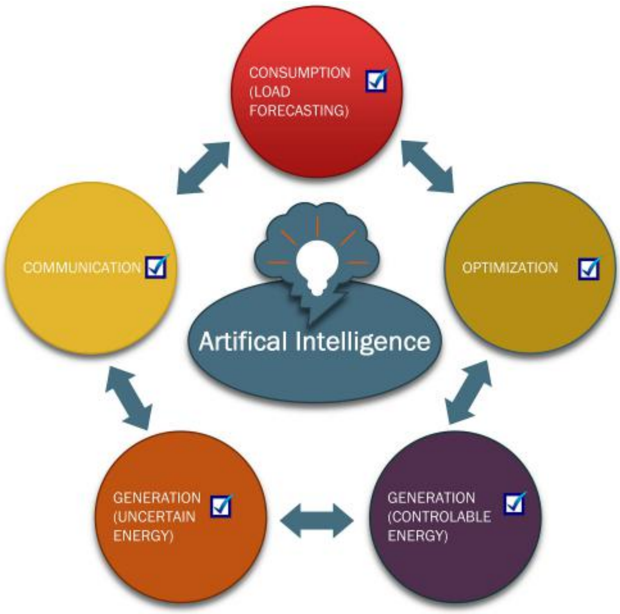

Fig. 6 *AI cope with power system's equipment*

between grid services, DERs, ESSs, customer's behaviours, service providers and markets. Numerous transactive EMSs have been developed for the wholesale and retail energy market.

In [80], TEM architecture has been proposed, addressing the solution frameworks. TEM system is a good solution (in case of adding a new grid) to provide the network balance, optimum power flow and to see wholesale energy market variations. For example, there has been presented four different transactive energy models for microgrid clusters, in [81]. Role of transactive energy involves free communication and information services in order to energy trading and data exchange. In terms of changing consumer's consuming habits to prosumer, transactive energy (TE) and VPP show similarities. To obtain efficient and reliable power flow, TE techniques are used. TE engage producers and customers. It helps to formulate objective function for optimisation problem, so TE promotes digital grid architecture by using DERs instead of the traditional hierarchical grid structure.

5.4 Peak demand reduction

Peak demand is the highest electricity usage when the demand is at peak. This causes serious problems unless grid operators take precautions. There are two most common ways to reduce the peak demand. The first one is conscious consumers and the second one is through finding some technical solutions. Conscious consumers are so-called 'prosumers'. Consumers have to know low-cost off-peak times and high-cost peak times, so they can manage their energy usage for different billed hours.

Another way of technical solutions has been proposed such as: VPP, different optimisation algorithms, intelligent systems and SM applications. These technologies provide the reduction of peak demand in a different way. Fig. 8 represents how the VPP is used to reduce the peak demand. When VPP provides reduction for the overloaded system, consumers use self-energy or energy is being transferred from the ESS of nearest neighbour through VPP management [82].

5.5 Spinning reserve

In a generation unit, when the system load suddenly increases, another system unit tries to keep up with the load within a few seconds. These units are generally sitting in idling state and known as spinning reserve. Sources used for these purposes are hydro or steam generation units. Main purposes of having spinning reserve are providing frequency and grid supports. Spinning reserve cost allocation and spin rate are demonstrated in [83].

Today, many electrical power systems have capacitors and ESSs acting as power control units. To keep demand in balance and provide peak demand reduction, spinning reserve is one of the most preferred system units. Although these favourite units are in good solution, there are many novel ideas and solutions that have been represented instead in [84]. One of the newest solutions is VPP technology usage, which can maintain power balance as well as reducing peak demands. In comparison to other methods, VPPs are more profitable in financial terms. If it looks deeper, for implementation of spinning reserve, need some turbines that are also in idle states. That means spending money, waste of time and wastage of labour just to keep grid balance during unexpected peaks. The market integration of responsive load as a spinning reserve has been simulated and discussed in [81].

6 VPP grid services

There are six grid services that have been identified, which could be enhanced in a VPP framework [85]:

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- *Localised clean energy:* Clean energy production is being provided because of the search for new methods and technologies that are linked to global warming and pollution. Integrated VPP unit is a good way to achieve that point.
- *Virtual capacity:* There are some mysterious assumptions to ensure that the total resource sufficiency is determined and regulated.
- *Real-time demand response*: To provide real-time demand response, neural network linkage with RES is a good solution. VPP technology brings the features that all resources interact with each other and try to keep the system in balance by using the software.
- *Fast frequency regulation:* Conventional grids are still slow for sudden changes. VPP provides fast frequency response in an effective way. Since power flow may be controlled instead of taking a long path, it reduces the peak demand while drawing energy from the nearest neighbours' sources.
- *Smart voltage control:* As long as the smarter devices in the power system evolve, profitability rises.
- *Big data from small source:* Management of big data accuracy may achieve a high yield from digital grid utility transformation.

6.1 Reactive power control

Reactive power control is one of the most challenging processes. In power system, current may lag/lead voltages because of capacitive/inductive nature of the transmission network. That means, it can increase/decrease reactive power, but optimally, voltage and current should be in phase.

To control reactive power, there are many researches that have been implemented [84]. Improperly shared reactive power can be due to line impedance mismatch. A method proposed to use line impedance mismatch is decreasing load sharing errors and correcting voltage drop characteristic [86]. Simulation results demonstrate that centralised DG unit can control ideal active and reactive power sharing with appropriate speed and accuracy under different operation conditions.

Also, there is an effective method of decentralised optimal reactive power control used of holonic architecture features. Simulation analysis is conducted and the proposed method has been compared with some other methods and it has been proved that the proposed method exploits fully reactive power and exhibit great potential to reduce active power [87]. Furthermore, reactive power control for RES is another challenging process. An iterative algorithm can be proposed for a wind power generator to control reactive power. The control strategy is developed in five different operating modes: rotor current, rotor voltage, real power, reactive power and stator current [88]. In another survey demonstrated for PV generators, where a three-phase grid-tied controller system has been proposed using direct power controller and a sliding mode controller. Experimental results show that the proposed system is suitable for active and reactive power controls [89].

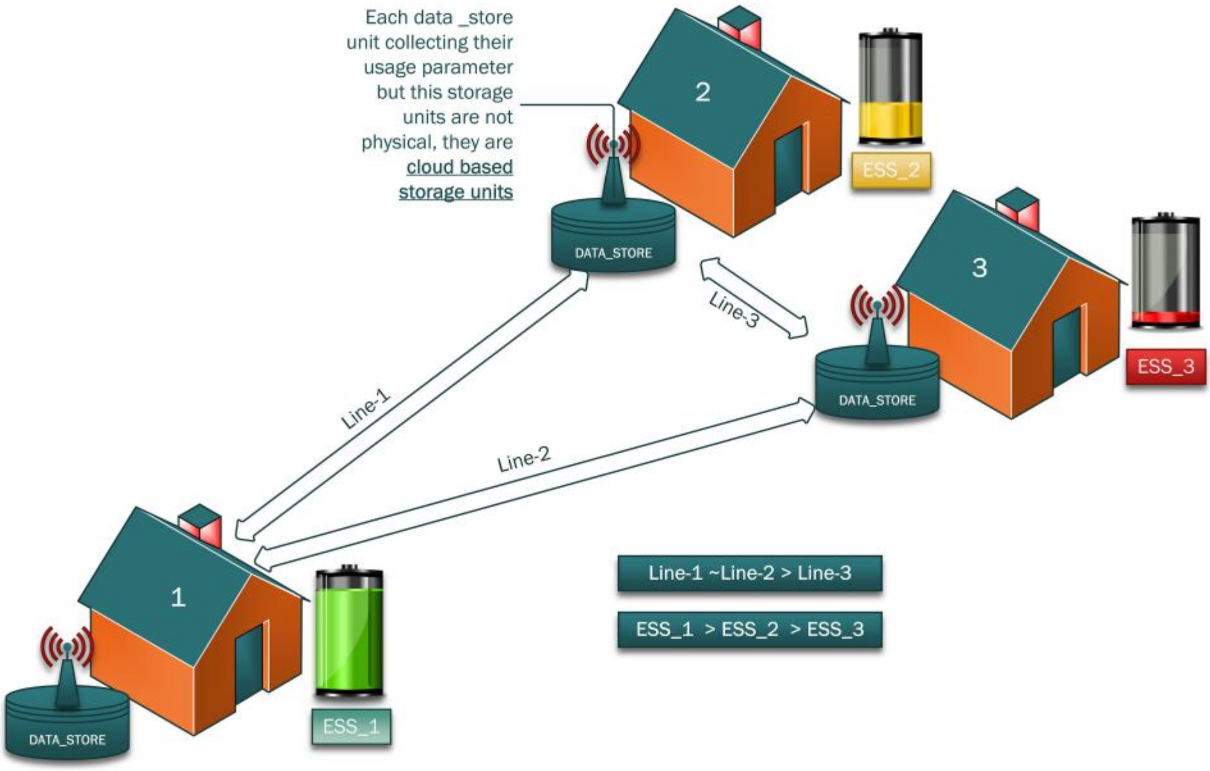

Fig. 7 *Real-time energy sharing scheme determining the best transaction*

Table 3 Energy trading strategies

Project name	Trading strategy
smart watt [73]	modern ICT was used to achieve cost-effectiveness
vandebron [74]	consumers can select the generator and buy the electricity
transactive grid [75]	consumers can buy and sell energy via highly modern software and hardware ICT tools
sonnen community [76]	who can share and sell self-produced energy to others
peer energy cloud project [77]	developed in order to forecasting procedure and record data within microgrid. Also, use cloud-based technology has been used
Yeloha and Mosaic [78, 79]	they give opportunity for trading to anyone who is interested and wants to be a participant such as householders etc.

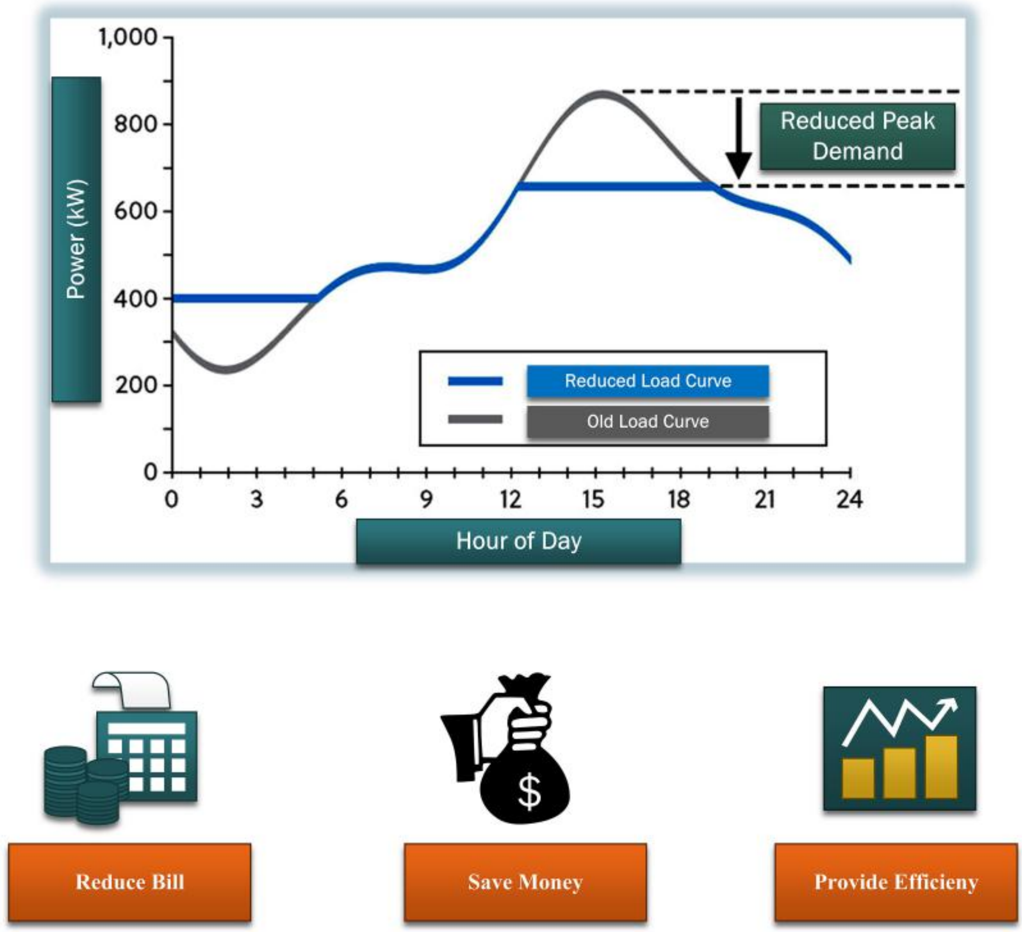

Fig. 8 *Peak demand reduction using VPP concept*

6.2 Fault ride through

Fault-ride-through (FRT) is defined as the ability of wind turbines to remain on the network after the failure of the grid, which may result in voltage drop, and to support the network until the fault is over and normal operating conditions are restored. Alternative energy sources are today's fastest growing industry. These alternative energy resources have been included in the growing number of power systems in recent years. However, some failures can occur while using these kinds of alternative energy sources such as voltage drop so that the network exposes to losses. So, as to prevent a short circuit at a low- or high-voltage level defined as FRT and especially used in wind turbines network failure, until the network returns to normal operating conditions [58, 59].

RESs are weather-dependent sources, so to obtain efficient, sustainable and balanced power source we need to use some kind of meta-heuristic algorithms. Numerous surveys have been prepared for solving FTR problem in RESs. Here are some elaborative studies: vector control algorithm was used to achieve higher efficiency in [90]. PSCAD and MATLAB simulation related to FTR-based techniques is developed in [91].

Overall, the effect of VPP on FRT problem is significant. There is a very limited study about VPP effect on FRT, but VPP technology can be used to limit adverse effects by minimising connected grids to make grid balance.

6.3 Frequency control support

In the electrical grid, all generators are supposed to deliver the synchronised power flow. Whenever load level increases on the generator, rotor of synchronous generator slows down, so the frequency of the grid slows down and reduction occurs in the frequency. However, the power system will be in balance when demand and generation are equal and then the frequency will be maintained at around 50 Hz (or 60 Hz depends on the countries). Frequency has to be balanced; otherwise, generator would try to bring back frequency to the normal value. Certain fluxional frequencies can harm important equipment in the power system or at end user end that has to be in control. To achieve this control, many studies have been revealed [51, 62].

The frequency control system has been classified in the following ways [55]:

- *Primary control*: Automatic control and response time in seconds. This proportional controller (P controller) maintains the balance between generation and load for unaffected generator load level growth. Some grids detect the frequency level increases or decreases and change it until obtaining stable frequency again by using frequency sensors.
- *Secondary control*: Automatic control and response time in minutes. This method is known as an integral controller (IC) in control theory. If the generation is less or larger than the nominal value, it needs to be added or stopped with some generation capacities. Therefore, IC is used to achieve reducing the integrated time errors.
- *Tertiary control*: On the basis of manually activated and response time in 10–15 min. This method is used as a manual controller and switching speed is lower than primary and secondary systems.

There are some other methods available in power system literature about frequency controls. In [92], the virtual ESS (VESS) is used for frequency control and simulation results show that VESS provides more controllable and adjustable frequency. In fact, VESS and VPP systems show similar features. VPP can also be linked with frequency control. VPP-integrated system supports frequency response that contributes to the reduction of power unbalanced. Besides, MATLAB-based VPP simulation and frequency response have been investigated in [93]. Results show that the VPP-based system indicates more and easy controllable

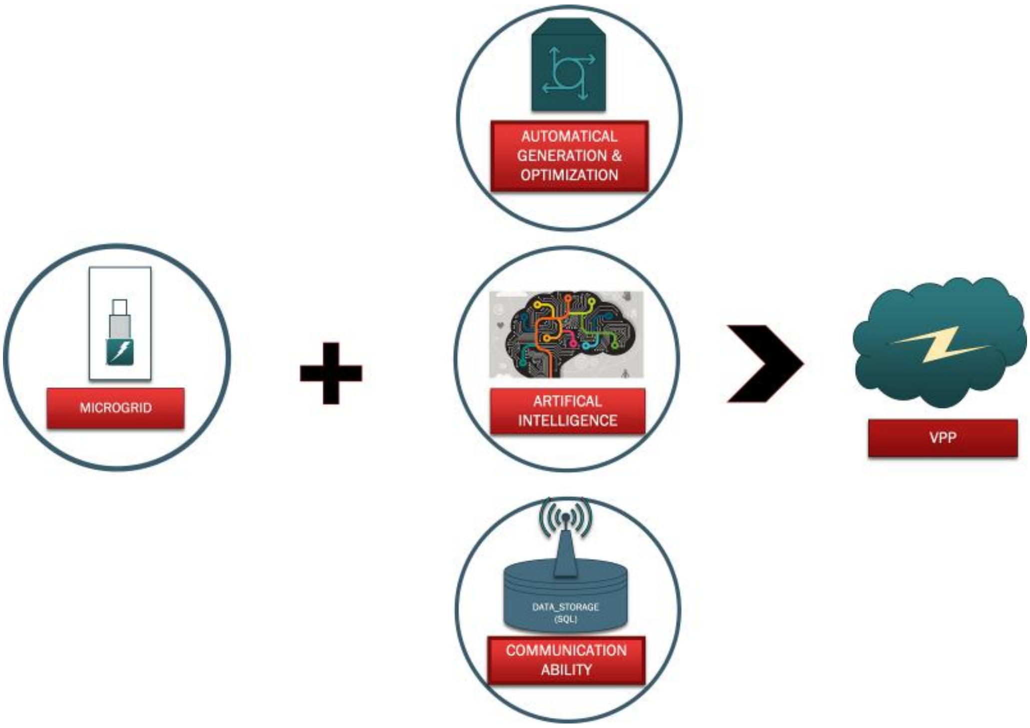

Fig. 9 *Transformation of the microgrid to VPP*

Table 4 VPP-microgrid projects in the world

	Project name	Country	Project detail
1	Fenix Project [97]	Spain	project aim is to gather all the aggregating large number of DER units by using VPP
2	EcoGrid Project [98]	Denmark	project's main purpose is put and the end user at the centre of power market, so that provide the most cost-effective system solutions
3	EU's fifth framework programme [80]	EU	develop a VPP concept and demonstrate tests, result analises.31 residential fuel-cell system has been installed. Each DER unit system communicated by the centralised control unit. Total cost of project is €13.8 million
4	Edison Project [99]	Island of Bornholm	52 DER units located in island and 35 of them are wind powers. Projects' main purpose is how electric vehicles effect on grids
5	Konwers2010[100]Piclo [101]	UK	project has been created for lack of power in the power network and unpredictable power generation problems.Consumers can select the generator and buy the electricity
6	BlueGen project cited different implemented countries [102–106]	Australia	Australian-based Ceramic Fuel Cell Ltd. has sold BlueGen systems for VPP implementation projects on Netherland, UK, Belgium and Germany

features. Therefore, the VPP-based frequency control system provides improved grid performance.

Furthermore, some computational based frequency control methods are: particle swarm optimisation (PSO) used and simulated on MATLAB [94], non-linear benchmark method has been presented on MATLAB/Simulink for wind farms in [95], a novel narrowband noise and vibration control algorithm is proposed and results verify robustness and effectiveness of the algorithm [96].

7 Comparison of microgrid with VPP

First of all, to summarise the differences between microgrid and VPP, in fact, VPP and microgrid are not structures separated by sharp lines from each other. Thus, it is impossible to draw a clear line, but they show some structural differences from one to another in terms of the services they offer. The VPP model that the combination of a different technology is shown in Fig. 9. The differences between them are listed below:

- The failure of a single user in microgrid affects all connected sub-elements connected in this microgrid.
- While a microgrid can work in island mode, VPP is not equipped to island from the grid, so the cooperation will result in much greater profitability.
- Microgrid technology often uses ESSs, but VPP does not have to use storage as much as microgrid. VPP, therefore, offers a solution that is more consistent and cheaper to implement.
- While VPP is a technology that can be implemented all over the country, the microgrid is used for smaller diameter settlements. Therefore, a new technology that can address wide geography will be obtained.
- Microgrid technology uses intensive and very complex optimisation algorithms. However, usage of AI-based algorithms into VPP can provide simpler solutions for more complex problems while automatically controlling production and consumption.

VPP-integrated DER projects have been presented in Table 4. Most significant and the biggest priced projects are listed with project details and that of countries applied.

8 Conclusion

The power system is one of the biggest devices that have been developed by a human being. A number of DER units have been integrated into the grid over time, and then operation procedures changed. More complex algorithms and high-level computers are used for weather-dependent consumption prediction. VPP is a relatively new and attractive framework for providing balanced, sustainable, efficient and cheaper energy. Furthermore, the operation of VPP provides less complex algorithms and secures more financial profit for consumers and producers.

In this paper, the essential elements of the VPP are introduced such as VPP classifications (TVPP and CVPP), DER–TSO–DSO linkage through VPP, grid services and worldwide case studies of VPP projects have been reviewed in a comprehensive way. Furthermore, features of VPP on power systems such as communication, different optimisation algorithms and forecasting methods both of production and consumption, FRT, reactive power control, gateway technology and frequency control were described.

Finally, how AI technologies will be compliant with the architecture of VPP is identified and then an attempt is made in comparing microgrid with VPP, and the superiority of VPP is highlighted as well. This research shows that VPP will be highly adopted in near future for most of the utilities due to its valuable contributions in grid operations.

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