Distributed Energy System Feasibility and Supportive Energy Internet Technologies

Xun Dong*

Tongji Architectural Design (Group) Co., Ltd, Shanghai, China

*Corresponding author: tm5djw@tjad.cn

Abstract. The increasing demands of renewable energy lead to upgrading and iterating on current centralized grid system. Depends on the unique characteristics of green energies, such as photovoltaic power, wind power and so forth, the wide range of geographical allocation, power uncertainty and near to end-users has become the crucial consideration factors for next era energy system. Distributed energy system (DES) as a new emerging energy management method, it shows large numbers of similarities with renewable energy and it has been deemed as a potential reasonable way to solve the above issues. In order to illustrate whether DES have the ability to provide citizen with a sustainable, reliable and efficient grid system, this paper try to evaluate it from DES applications in different scopes and possible supportive energy internet technologies. Through discussing DES in regional and community scale, the physical limitations have been pointed out. Furthermore, micro-grid, blockchain technology and Virtual Power Plant (VPP) has been elected as potential methods to solve DES existing problems, such as data loads, inter communications between energy provider and consumer and energy trading mechanism. Since DES could not reach the optimal working status without other technologies support, how to integrate and combine different new emerging technologies into this energy system could be a further research direction. This significance of this paper is evaluating possibility of creating an autonomous, reliable, highly efficient and tradable energy system based on DES.

Keywords: distributed energy system, micro-grid, blockchain technology, Virtual Power Plant, energy internet.

1. Introduction

Thanks to the increasing awareness of environment friendly and sustainable energy, an increasing number of attentions have been focusing on researching renewable energies and green energies. However, the generation resources modification lead to an urgent updating and iterating on traditional electricity grid and system design. Considering of these new requirements on integrating and constructing new city grid system, DES could be a suitable development choice. In terms of the grid physical design, DES as a new emerging electricity management system, it is built on bottom-to-up design mode which takes user's demand, supply energy storage methods and power dispatching controlling into consideration. DES do not have an accurate definition, but it can be generally illustrated as a typical electricity system which is consisted of near terminal-users distributed small generator, energy storage system, energy management system, transmission and loads [1, 2]. Besides, DES also show remarkable potential on energy internet construction. The future energy system could not only be able to provide and transmit energy, also provide managers with the ability to control and analyze energy usage in visualization way [3]. Since DES is a bottom-to-up grid system, it could endow user with the power to participate in both of future energy production and consumption parts. In order to realize this function, various energy internet technologies could be adopted. From this point, DES can be regarded as a sustainable, lucrative and social and environment friendly grid system.

Previous researches and reviews on DES are focused on single distributed energy generator, including generating skill, generating efficiency, cost estimation, lifetime cycle and other technical aspects. Another discussing point of DES is the renewable energy characteristics, which has been evaluated from wide range of geographical allocation, generation uncertainty and multiple participators. However, grid system work as a comprehensive network and various scales, it needs to discussed and evaluated through multiple scopes. Although there have a certain number of researches related to energy internet skills recently, a thorough discussing on these new emerging technologies' advantages and disadvantages need to explore to illustrate whether they are positive for creating an efficient distributed energy network system. Comparing with other researches and reviews, this paper also shows efforts on integrating and combining various energy internet technologies and issue solving methods to evaluate ultimate form of energy trading and communication form.

This paper mainly focuses on two parts, which are DES feasibility on different scales and supportive energy internet technologies. Firstly, the DES working performances on regional and community scope will be discussed. Secondly, energy internet as a crucial supportive part of DES, three main technologies, which are micro-grid, blockchain technology and Virtual Power Plant technology will be evaluated on their functions during cooperating with DES.

2. DES application scopes

As DES is a new energy generation and supply method, distinctive attempts have been tested to verify whether DES could have an opportunity to create a more sustainable energy system. In the duration of past two decades, projects related to centralized grid system combined with distributed energy generations and centralized grid system combined with renewable energy generations in single building scale, community scale and urban scale have been implemented. According to the how-to design guide published by National Renewable Energy Laboratory [4], it concludes majority parts of applications could combine with DES. As shown in the Table 1, not only renewable energies could work with DES, traditional energies also have possibility to work combined with decentralized grid network. In order to explore whether DES can provide a more sustainable energy system, in the following sections, the advantages and disadvantages of DES are summarized by analyzing practical scenarios at different scales, regional aspect and single building and community aspect.

Table 1. Applications with DES [4].

Technology	Application				
	Standby Power	Low-cost Energy	Stand-alone System	Combined Heat& power	Peak Shaving
Diesel Energy	√	√	√	√	√
Natural Gas	√	√	√	√	√
Dual Fuel	√	√	√	√	√
Micro turbine	√		√	√	√
Combustion	√	√	√	√	√
Fuel Cell			√	√	
Photovoltaic			√		√
Wind			√		

2.1. DES in regional scale

The primary difference between centralized electricity grid systems and the DES was the characteristic presence of distributed energy generators in the latter. In term of this point, DES could be a more suitable choice for renewable energy than the centralized grid system, such as solar energy, wind energy and so forth. Comparing with traditional energy resources and grid system, these renewable energies served with DES could provide with a more sustainable, more efficiency and potential lower cost grid system. In terms of the sustainable of renewable energy with DES, it shows superiority on both of the generation and energy supply aspects. According to Alanne and Saari's research [2], the sustainability of an energy system can be discussed from affordable costing, dependable and environmental friendly. Through the comparison of DES and centralized grid system, DES electricity generators are more nearby to the consumers and more generator nodes are designed. Thanks to the special working pattern of DES, the energy demands of each consumer, communities and districts are well monitored. According to Somma's team work in 2015 [5], they have pointed out that based on DES under optimized operation the energy generation cost can be reduced significantly and energy efficiency also show remarkable increase. In terms of the cost affordable, there is no recent papers related with this part. The past decade works are not able to present the current situation of DES construction cost and social cost and benefits. As mentioned in Wen and his team work [1], more attention of DES economic on regional level has been focused on pipeline network. Furthermore, both of Somma and Allan [5] indicated that although the investment cost of DES are relative high, the construction cost shows possibilities to look forward to decrease with the technological advancement.

However, renewable energy with distributed system still facing some remarkable issues which lead to relative low social acceptance as the main electricity generation way, such as the unstable energy supply and new grid system design [6]. In terms of the uncertainty of renewable energy supply with DES, it could consist with two parts, inherent natural uncertainty and lack of real time energy demand data [7]. Furthermore, another main drawback of renewable energy needs to be discussed is the maximum energy consumption. Compared with traditional energy, renewable energy is difficult to respond and provide external energy when there has risk of energy hazards [2]. The majority of natural uncertainty in renewable energy is determined by weather and the environment, as a consequence, this part is unavoidable in the process of relying on sustainable energy sources to generate electricity. In terms of the new grid system design, both of advantages and disadvantages are existed. Since DES is consisted with large amounts of nodes in energy system, the data and information sharing and transformation is crucial for analyzing energy demands and dispatching. To some extent, the diversity nodes are able to monitor energy usage and provide accurate energy consumption. This kind of flexibility system could lead to cumbersome calculations and extreme demands for information integration [2].

To sum up, comparing with the traditional centralized gird system, renewable energy with DES shows remarkable potential to be a more sustainable energy system based on energy costing and efficiency. However, the drawbacks of this energy system are also not able to be ignored. For energy generation aspect, the uncertainty of energy source and the maximum load lead to DES difficult to suit for large population district. Furthermore, the inner-network data and information sharing and management issues could induce to energy supply disturbance.

2.2. DES in single building and community scale

Although renewable energy with DES in single building and community scope shows similar to some extent, the differences between them are existed. These can be concluded to less energy demands for each distributed energy generator, less mutual energy consumption data. Consequently, an increasing number of researches and papers focus on the technology of renewable energy generation and energy sharing management on this scope. Regarding to the technology aspect, house with photovoltaic (PV) and multiple kinds of storage batteries are the mainstream. Wen et al [1] indicated that PV cell has been used in large number of cases in the interest of high energy efficiency, flexible scales and low carbon dioxide emission. Besides of the PV cell, fuel cell shows attractive possibility on energy storage with home cooling and heating power system. Furthermore, the technology of building- integrated photovoltaic (BIPV) and building- applied photovoltaic (BAPV) are discussed in recent decade. Both of these two solar energy generation technologies are suitable for various character buildings on roofs, building facades and wall coverage. The different sorts of BIPV have been analyzed by Vasilliev [8], the energy harvesting efficiency, influence on city and building and the system aesthetics of non-transparent PV and transparency PV have been discussed. In community scale, more attentions have been relayed on the building cluster design reflecting on improving energy efficiency. Dissimilar from DES at the regional scale, there is strict spatial requirements to install renewable energy generation and distribution systems at the community range. Therefore, how to achieve higher energy reception and distribution efficiency needs to be explored. Perera [9] presented a comprehensive study on different type of community clusters influences on the cost and efficiency of DES. He indicated that community morphology has a notable impact on energy performance related to geometrical and volumetric factors.

Another factor worth to be discussed in single building and community scope is data sharing and energy trade off system. In consideration of DES is a consumer-based grid system, introducing enormous number of users to participate in the entire power system will improve the controllability of DES [10]. The DES sharing economy could provide benefits to both of consumers and community. For consumers, Alanne and Saari pointed out that through dealing surplus energy to main grid or other users will suffice their income [2]. Besides, the energy sharing scheme also has a positive effect on stimulating users' willing on participating in excess energy storage and DES utilization [10]. In terms of community benefit, the DES sharing economy could lead to ultimate energy autonomy [9]. Meanwhile, it also shows notable encouragement on social sustainability development. The co-ownership consciousness promotes an increasing number of user to join the new energy scheme proactively [11].

According to the above researches, the feasibility of DES in single building and community scope are relatively high. This new energy system could not only make renewable energy are possible used as primary and secondary energy, also show significant promoting on citizens' awareness of using and storing renewable energy and community sharing economy development. Although the drawbacks papers are not mentioned in the above content, it is remarkable that demands of reliable skills and managements on sharing economy network are crucial.

3. DES energy internet technologies

As a new energy generation and supply mode, DES relies heavily on new energy dispatch and integration technologies. The next era of energy can be concluded as distributed, stochastic, collaborative, involved and tradable [12]. Thanks to the rapid digital information technologies development and improvement, energy internet shows unique competent with this new electricity grid system. Similar with DES, energy internet aims to enable more green energy to be used in urban power grids. Meanwhile, energy internet also is comparable with DES on user-centrist and energy autonomy. Through creating an open digital platform for energy users, energy internet is able to allow users participate in future energy sharing and trading system and balance energy demand and dispatch to achieve higher energy efficiency. Besides, energy internet are able to authorize additional users and generators into the existing network which could eventually expand to a comprehensive intelligent energy management system [13]. The Fig. 1 has shown the possible working pattern of multiple functions energy internet. The DES energy internet will focus on three technologies, micro-grid, blockchain technology and VPP, will be indicated how to achieve an optimal DES energy internet and what aspects will these three technologies be able to support and promote.

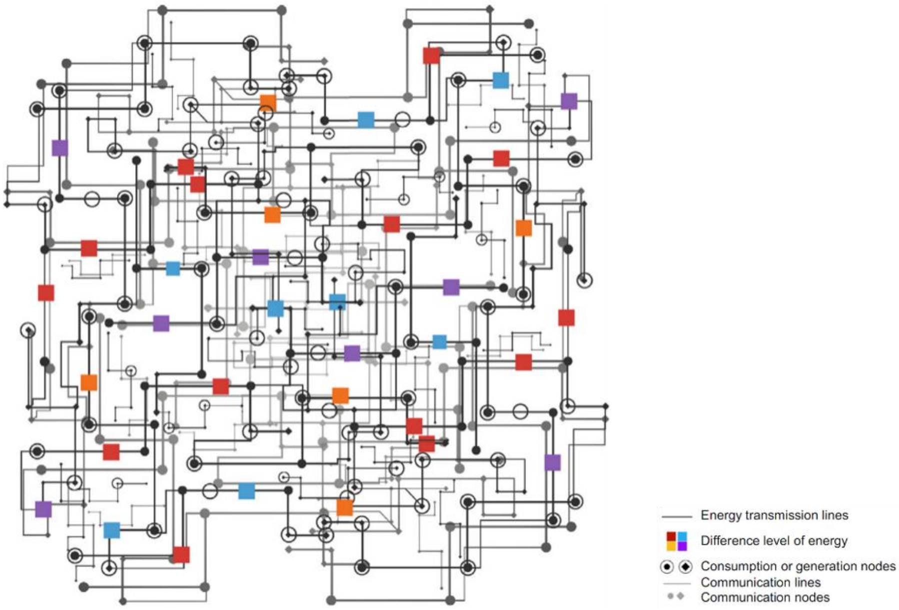

Figure 1. Working pattern of energy internet [13].

3.1. Micro-gird

Micro-grid is a relatively small power generation and distribution system that integrates distributed power sources, loads, energy storage devices, conversion equipment, control systems and protection devices. From the aspects of working status, micro-grid can be classified as two main categories, which are isolated island mode and grid- connected mode. Meanwhile, all of these items are able to operate in controllable and coordinated way in each mode [14]. The increasing driving force of micro-grid can be concluded from two factors. Firstly, an increasing trend of renewable energy usage lead to each country's future energy development attention. However, as the traditional centralized grid are not able to accept distinctive green energy in one comprehensive energy system [15]. Secondly, more reliable, resilient, predictable and user-oriented energy system has been pursued in the recent decade. Both of these two issues lead to further micro-grid development and research.

Micro-grid shows remarkable variations comparing with traditional grid not only in grid physical design methods, also the energy internet system needs various improvements and redesigns. In order to investigate how to solve communications among each factor in micro-grid and multiple micro-girds and guarantee reliability and cost efficiency in energy internet, different efforts have been tested in multiple methods. As one of the main issues of renewable energy is the environmental uncertainty, the energy storage system in micro-grid is crucial. According to Wu's opinion [16], the energy storage system could certain controllable and foreseeable power generation and load performing consistently well. It could consider as the secondary frequency modulation which is able to adjust the node currency, voltage and active power into rated value of micro-gird. This section guarantees the flexibility of micro-grid. Besides, the HOMER (Hybrid Optimization Model for Multiple Energy Resources) software which is developed by the National Renewable Energy Laboratory also focusing on solving power quality issue and connecting different end-user devices to achieve optimal operation status of micro-gird [14].

Another pursuit direction to reach micro-grid stability is from energy management. In order to find a better method to analyze efficient operate micro-grid system, centralized, decentralized and hierarchical management structures have been discussed [17]. Through the comprehensive analysis by Elmouatamid et al, predictive control under hierarchical management shows well behavior on uncertainty and power smoothing issues in micro-gird system and enable coordinating multiple micro-grids under same control strategy [17]. Another prediction method in early energy supply decision making stage is relayed on potential game. As proposed by Jun et al [18], this method is possible on integrating energy generations, storage and loads interactions in isolated micro-gird. Yang et al [19] focused on the flexibility property of micro-grid, investigating how the flexible interconnection device (FID) could help optimize coordinating among multiple different micro-grid. Through the research, FID shows positive effective on controlling power flow, maintaining energy storage larger capacity and enabling high effective generator working status. In accordance with the idea of quality-of-service in electricity (QoSE), Huang et al [20] pointed out that it is crucial to achieve the efficient operation status through matching energy demands. Based on Lyapunov optimization method and virtual queue, it is possible to schedule energy usage, reduce micro-grid operation cost and remain high efficiency of whole energy system. There has a new direction attempt on real-time energy demand monitoring and supply method is based on Internet of Thing (IoT) and Big Data. According to Elmouatamid et al [21], they proved that it is useful to reach high effectiveness energy system through real-time monitoring energy demand and response based on these two new technologies.

Consumer participation as one main characteristic of DES, however, micro-grid could improve less in this aspect. In terms of the physical design, micro-grid are aiming to create a grid which can control energy supply and loads, enable smart plug- and- play and accomplish autonomy [13]. However, it requires additional software technology to achieve the ability of interacting with users. The software DEEP and MOD-DR developed by Berkeley Lab could endow micro-gird with this ability. According to Feng et al [14], this supportive software enable micro-grid to be an independent third party to trade energy between centralized grid and consumers.

To conclude, micro-grid's novel physical designs are possible to support DES becoming an effective, reliable and flexible alternative grid scheme in the future. Nonetheless, the drawbacks are conspicuous. The standardization of micro-grid interconnection and inter-operation are inadequate and failing, which bring enormous difficulties for future integration. Besides, the complex energy scheduling brings additional computational hardship on energy internet system. Thirdly, since energy is the vital living resources, the micro-grid requires safer cyber-security to maintain whole energy system would not shut down suddenly.

3.2. Blockchain technology

The core of blockchain is a decentralized and distributed ledger technology, which could store various transaction data on the chain. Thanks to the unique technology of blockchain, the distinction properties of blockchain can be concluded as following points, indelible, global readable, rule-based right and transaction traceable. In a broad sense, the blockchain could be considered as not only a technology, also a cogitation. When it links with the energy internet, it shows obvious improvements on system construction. Firstly, as discussed in last chapter, the micro-gird-based DES has a plug-and-play characteristic which show great potential on coordinating with blockchain fully open system. Under this circumstance, users and energy providers could join the network conveniently and archive sharing economy. Furthermore, the equal right of each node in blockchain could enhance the reliability of DES. With the evolution of blockchain research, smart contract has been recognized as a possible alternative choice of third party in current world financial system. It is a code-based automatic execution programme and no human intervention are permitted. Blockchain technology indicates similar characteristics with DES and it could use as a supportive way to enhance energy internet network creation to reach the ultimate goal of DES.

Firstly, blockchain could improve the peer to peer (P2P) trading mechanism in distributed energy internet system. As Akter et al mentioned in [22], the P2P energy trading platform based on blockchain technology has been accepted by virtue of its capacity on managing different kind of energy portfolios and providing price bidding function. In order to accomplish a better energy trader platform, the real-time energy recording and price auction system is crucial. As the explanation provided by Mylrea et al [23], blockchain is able to record real time energy net loads, real time exchange data and residual energy data. Digital Grid is a concept proposed by Abe et al and it is an energy management tool for small power producers and consumers. This blockchain technology platform is focused on providing bidding service based on forecast energy demands and generation in real time electricity market [24]. The most attractive point of this platform is the automatic pricing power for different kind of energies.

The ultimate blockchain technology is not to provide an energy trading platform based on a third party, but reacting a system could endow users with right to decide energy purchasing and selling price. Li [25] indicated that the blockchain-based distributed micro-grid are designed for end users to participate in energy pricing role and promote more vigor in energy market. From another point of view, it could enable an automated energy trading and monitoring platform in DES and abandon third party through coordinating with the blockchain smart contract technology. Smart contract can act as a role for balancing demand and energy generation, auction instrument and information recording and exchange [25]. Coordinating with micro-gird, a reasonable and flexible pricing mechanism based on real time energy consumption and supply could be implemented [26]. Furthermore, the smart contract based on Ethereum and proof of authority mechanism could integrate with multiple micro-grids to work efficiently [27]. In addition, smart contract can use as an energy consuming monitor to enact a unique reward and punishment mechanism [25, 28]. Under this circumstance, a fair and balanced energy trading environment between consumers and suppliers will be created.

Another improvement of blockchain technology bring to distributed energy internet trading system is enhancing security. Thanks to the four main principles of blockchain technology mentioned above, the consensus structure and the unique key-less signature infrastructure (KSI), it is safer than other encryption technologies. As Kumar explained in article, the distributed ledger and time stamping could maintain a secured data exchange among energy consumption, emission calculator and system operating and management [29]. Kavousi-Fard et al analyzed whether blockchain based energy internet system could work in common situation under malicious attack from the consensus aspect. According to their team work, the distributed calculation consensus mechanism could protect and maintain the whole system in normal working condition through rejecting conflicted data and the attack success possibility is approximate zero [30]. Mylrea et al in article proved blockchain technology could enhance fidelity of data , data verification and real time energy trading based on the cryptographic signing program [23].

To sum up, blockchain technology show noticeable improvements on distributed energy P2P trading system construction from both of energy exchanging services among users and providers and system security condition. However, the drawbacks of this technology are still not able to neglected. The most important issues is the low throughput and inadequate IoT technology, which can expend to low frequency transaction and dispatching of blockchain and the lack of smart monitoring equipment technology [12].

3.3. Virtual Power Plant

When DES works in isolated status, the drawbacks, such as low generation capacity, non-negligible uncertainty, volatility and intermittency cannot be avoided. VPP as an effective management method, it can integrate distinctive distributed energies, energy storage devices and controllable loads into a comprehensive energy system. The framework of VPP has been shown in Fig. 2. In general, VPP is consisted of electricity generation system, energy storage system and communication system. In terms of the functional aspect, VPP is classified as commercial VPP (CVPP) and technical VPP (TVPP), which is shown in Fig. 3 [31, 32]. CVPP is focused on predicting energy generation and consumption balance through combining multiple distributed energies. TVPP is aimed on optimizing distributed energies working status in real time and providing visualized information for managers. In terms of the information flow transmission control structure, VPP can be classified as centralized controlled VPP (CCVPP), distributed controlled VPP (DCVPP) and fully distributed controlled VPP (FDCVPP). From CCVPP to FDCVPP, a decreasing number of control and coordination centers are needed. For the sake of better scalability and openness, FDCVPP is the most suitable choice for electricity market. In order to investigate whether VPP is a possible choice for improving DES, it will be analyzed through VPP power flow and information flow both directions.

In terms of the power flow, VPP is able to control multiple distinctive energy generations and Energy Storage System (ESS). Meanwhile, VPP is considered as an effective energy management system, it shows ability on real time energy monitoring, controlling and scheduling regardless of geographical limitation [33]. In this article [32], through Bi-level multi-time scheduling method, it realizes electricity price bidding function with optimal energy allocation in upper level and stability of DES by controlling loads and energy output in lower level. Van Summeren and his colleges have analyzed the VPP working status in real world through three different CVPP case studies, Loenen, Gent and Tipperary. Although Gent is a VPP combined with centralized and decentralized control and Loene and Tipperary are centralized VPP, they share similar functions on optimizing energy supply and demand equilibrium, integrating diverse distributed energy resources and trading in energy market with dynamic price [34]. Currently, these three VPPs are centralized, but the providers and managers are considered of switching to decentralized working status. The reason can be concluded as decentralized VPP shows distinctive ability on responding speed and coordinating with large amount of distributed energy resources, meanwhile, it is also able to improve community ownership awareness and residence involvement in energy governance [34]. Besides, VPP as a new technology of energy dispatching and coordinating system, the decision-making variables need to be discussed in order to achieve optimized power flow. Since VPP is an energy pooling and planning system, it is crucial to consider it from a large scale, such as city scope. In the article written by Duan et al [35], through analyzing comprehensive land use site, they pointed out the most relevant factors as follow, average daily cost, load properties and degree of distributed generation and resource aggregation. According to this research, it provides city planners with a pointcut to think about VPP from urban planning view.

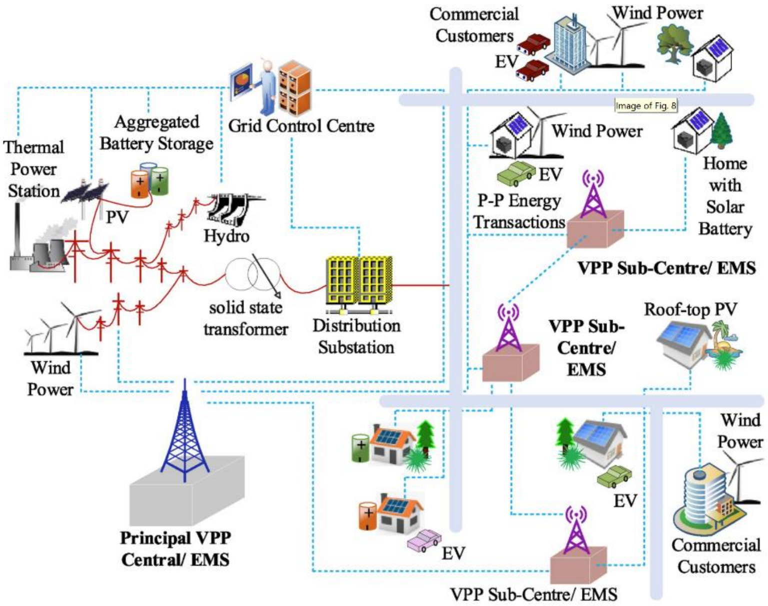

Figure 2. VPP framework among consumers and providers [36].

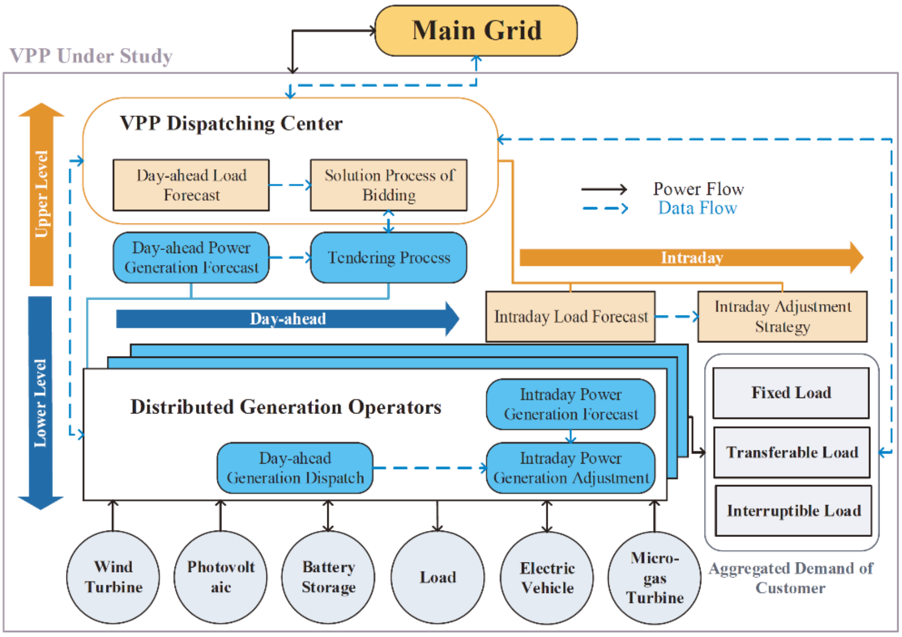

Figure 3. VPP working pattern in power flow and data flow [32].

Another aspect of VPP need to be analyzed is the information flow. In terms of this section, researches are focused on combing VPP with other emerging technologies to achieve an effective energy system's intercommunication. In order to solve the decentralization computing and data storage issues, edge intelligence has been used as a supportive method to handle it. Since edge computing can maintain a high bandwidth, low information delay and high communication quality, it can secure a competent decision making platform by improving responding speed and reducing computing load [37]. Similarly, edge intelligence technology has also been discussed in this article [31], it shows this technology could store data in regional cloud platform and complete data pre-processing individually, meanwhile, communicate with other devices in same layer seamlessly. Moreover, the flexible characteristics of edge computing are suitable for decentralized energy network since it can expand dynamically [38]. Secondly, concerning decreasing the operation cost of VPP, machine learning and artificial intelligence (AI) have been adopted. The remarkable method of reducing operation cost is to optimize energy forecasting and balancing. Based on Reinforcement Learning (RL), a subset of machine learning, and AI, VPP has been endowed the ability of offline training and online dispatching [38]. During offline mode, VPP could through analyzing data gathered from edge- devices to forecast energy demands and predict uncertainty of each distributed generators [31, 33]. Based on the offline training, VPP could behavior more accurate during real time energy dispatching. Thirdly, VPP also could cooperate with blockchain technology. Thanks to blockchain technology unique property, the blockchain-based VPP platform could enhance P2P trading function, meanwhile, maintain whole system security and without leaking of user's privacy [39].

Briefly, VPP as a comprehensive energy managing and integration platform, it shows strong connections with DES. Not only the decentralized and distributed control system, also the progressive awareness of sharing economy and energy autonomy. Through previous discussion, it is obvious that VPP still need distinctive new emerging technologies to support it to reach ultimate optimal operation status.

4. Conclusion

DES as a decentralized user-friendly energy system, it contributes to increase awareness of renewable energies usage and the trend of growing share of sustainable resources in energy market which could substitute fossil resources in the future. This paper discussed DES feasibility in regional scale and community scale and relevant energy internet technologies could cooperate with to build the next era city sustainable grid system. In terms of DES availability of implementation in regional and community scale, the advantages are low energy cost and high energy production and consumption efficiency, meanwhile, the potential of creating energy sharing economy and changing user's behaviour on energy consuming are obvious in community scale. With regard to the improvements on DES energy internet, it can be obtained from two directions, physical grid design and energy network design. Micro-grid could provide a solid foundation of DES in physical grid work, which show strength on integrating each community inner energy production, consuming and trading. VPP, blockchain technology and other issue solving methods as the software enhancement on connecting each micro-grids and centralized grid, these unique technologies could help secure user's privacy, whole trading system safety and enable data storage easily and convenient. Other supportive technologies, such as AI and RL, can realize energy system offline self-training. However, the drawbacks of each isolated solving method exist irreparable issues, such as coherent standards and regulatory concerns. The future work could enhance on multiple technologies combination in DES and lead it to an autonomous, high efficiency, accurate and expandable energy network. With the information technology renovation, other new suitable solving issues would emerge and also could take into further conditions.

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