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能源互联微电网的商业模式分析

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摘要：随着能源互联网概念的快速发展，对能源互联网各细分领域的顶层设计已经成为能源领域研究的重要一环。针对能源互联网交易特点和商业模式的讨论已深入到能源经济学领域和技术领域。基于能源互联网是由多层次系统组成的理念，出现了能源互联微电网的概念。回顾了能源互联微电网的基本框架，提出了能源互联微电网的交易特点和商业管理模式。配网公司、个人投资者和子微电网是能源互联微电网运营过程中的三个重要组成部分，分析了这三者的角色、权利和责任，讨论了运行原则、政府角色以及能源互联微电网的优点。提出的能源互联微电网商业管理模式和运营模式建议有助于能源互联网的设计和实施。

关键词：能源互联网；能源互联微电网；交易特点；商业管理模式；运营模式；运行原则

Business Mode Analysis of Energy Internet Based Microgrids

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Abstract: As the concept of energy internet develops rapidly, the top – level design in different areas of energy internet has become one of the important tasks among energy field research. The discussion aiming at the transaction characteristics and business management modes of energy internet has been led to economical and technical fields of energy economics. Based on the idea that energy internet consists of multi-level systems, the concept of EIBM (energy internet based microgrid) has been proposed. This paper reviews the basic frame of EIBM, and proposes its transaction characteristics and business management modes. Distribution company, individual investors, sub-microgrids are the three main parts in EIBM operation, and their roles, rights and responsibilities are analized specifically in operation mode of EIBM. Operation principle, government role and advantages of EIBM are discussed respectively in detail. The suggestions on EIBM business management mode and operation mode are helpful to the design and construction of energy internet.

Key words: energy internet; energy internet based microgrid; transaction characteristic; business management mode; operation mode; operation principle

0 Introduction

With the rapid development of power system planning, the concept of energy internet has experienced a rapid development stage and is currently still under heat discussion. It is proposed that the development of energy internet will be based on the integration of energy infrastructure and information appliance[1]. Basic characteristics of energy internet include renewability, distributivity, inter-connectivity, openness and compatibility[2]. More importantly, it is widely accepted that energy internet is a new multi-energy system, consists of multi-level microgrids and sub-systems, optimization objectives including power flow, information exchange efficiency, information processing methodologies, transportation flow and systematic planning strategies etc. In energy internet, electricity is the main resources and power grid is the main carri-

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ers[2 – 3]. The technical difficulties of energy internet include solid transformer design and optimization, energy transfer efficiency enhancement (especially P2G techniques, i. e. power-to-gas), wide area distributed devices coordination, wide area load control, multi-directional secured information transmission, energy storage system design as well as system planning and promotion[2 – 5].

Aiming at the suggestion that energy internet is composed of multi-level sub-systems, EIBM (energy internet based microgrid) is proposed to resolve the difficulties at distribution side which includes high speed and accurate information processing, unbalance of energy consumption and generation on time scale, and helps the end of the whole energy internet system—the consumers—to participate in the energy system. This paper briefly introduces the design of EIBM, analyzes the transaction characteristics, and proposes the business management mode, operation mode and operation principle of commercial EIBM, and analyzes their different roles in EIBM operation.

1 General review of energy internet based microgrids

1.1 Basic concept

Different from energy internet, EIBM is concluded as a power and information center designed on the level of distribution side of power system, which is shown at Fig. 1[1]. The energy internet system is WAN (wide area network), which consists of transportation system, information system, cloud network control platform and MC (main carrier). MC is just the conventional electricity network, includes power generation, transmission and distribution. Compared to the WAN and MC, EIBM system includes information exchange and processing devices, control system, power generation such as PV generators and small scale power plant, power transfer devices such as P2G devices and fuel cells, which is much similar to the Energy internet system. The microgrids connect all energy consumers including business consumers, household consumers and industrial consumers. The aim to develop EIBM is to further enhance the reliability, sharing and openness, accessibility and compatibility of plug-and-play functions. It can obviously increase the participation of the consumers in the whole process of energy use, from generation to distribution, from control system to ends, from profit to cost.

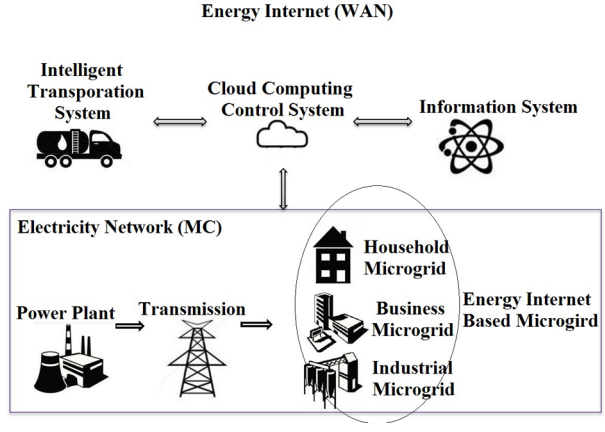

Fig. 1 Relationship among energy internet, electricity network and EIBM

In general design, control system, distribution devices and power processing elements are three main parts of EIBM. Power processing elements normally include PV generator, solid state transformer, gas furnace, gas turbine, fuel cell, heat exchanger, P2G devices[4], etc. During the power processing stage, power can be generated, transmitted, transferred, stored or consumed. Electricity can be generated by the small power plant or through PV generator. It also can be transferred to other energy carriers such as gas or heat. Smart meter is the main device used in the distribution part of EIBM to monitor, store, process, and forecast the power flow of different energy carriers at each customer end[6].

EIBM normally can be a neighborhood, a building, a factory, a district or even a house, as long as the microgrid is equipped with essential facilities such as control element and transformer.

1.2 Control sub-system

The functions and requirements of EIBM control system are not limited to power flow control and information process. Customized demand management and network maintenance are also essential for EIBM to

meet the demands of customers and enhance the reliability of microgrid. Here the network maintenance includes access identification, remote control of management strategies, abnormal condition recognition and processing, important data import and analysis [5, 7], etc.

Here the control system of EIBM is designed based on energy router, which was proposed in FREEDM (future renewable electric energy delivery and management) system [8]. As electronic control elements are combined to energy router, it has the basic function of information exchange among power generation, transmission, distribution and control systems [9]. The integration of information process unit and energy router can be used to control the power processing devices and communicate with the smart meter at the ends [4]. Energy processing control methodologies are designed based on the theoretical tool of energy hub, which is commonly introduced to analyze power flow inside a system with multi-energy carriers [10].

2 Energy transaction characteristics of energy internet based microgrids

With the implementation of EIBM, the energy trading, especially between customers and distribution companies, will change dramatically.

Firstly, energy price is floating price [11]. Floating price can truly reflect the real cost of energy generation, and this is regarded as trading foundation of EIBM.

Secondly, consumers' participation increases during the whole process of power generation, transmission, processing and consumption. As the process becomes increasingly open, consumers' supervision shows great benefits on microgrid performance, especially in aspects of positive competition among distribution companies, efficiency enhancement of information transmission, cost control and system planning.

Thirdly, trading market becomes extremely more complicated than ever before. This includes the expansion of trading subjects, multi-level customers and great varieties of energy commodities [12]. With the openness of distribution market, energy interfaces within microgrids will provide multi-functional services and energies. Here the services include multi-directional power consumption and generation, information consultation, operation status supervision, etc. As the power flow has multiple directions, the roles of energy consumers and energy providers may exchange in different situations. Customers are divided into different levels based on demands of energy use, like household system, low-demand consumer, and industrial system, high-demand consumer, which is shown in Fig. 2. Here black arrows, grey arrows and white arrows mean that power flows out of systems, into systems and internally within systems.

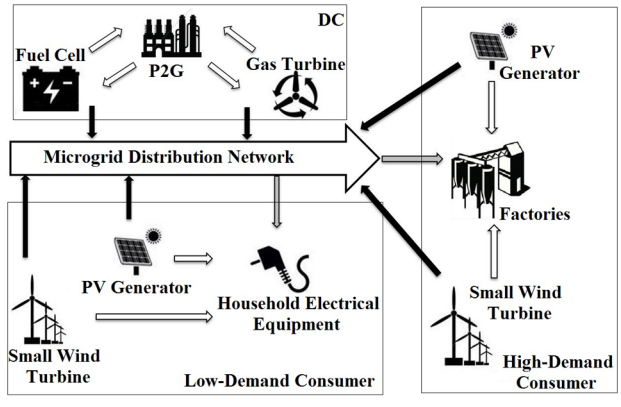

Fig. 2　Power flow direction inside EIBM

3 Commercial planning

3.1 Business management mode

Supplier and supporter is the main role of the power grid company to microgrids. It is hard for private capital and individuals to participate in the whole power system, due to the technical factors, security and policy. The main grid company should gradually become responsible, technically professional and low-profit organization, organized by government or state-owned enterprises. The responsibilities of grid company are mainly on power generation, security supervision and technical support for the public. In terms of the microgrids, although some are equipped with power generation facilities, it is still hard for them to meet

all energy demand of consumers. The main grid provides all microgrids with electricity and gas. EIBMs buy energy from the grid and transfer, store or transmit the energy by the control system and the power flow is calculated by optimization algorithms. As EIBMs have equipment of energy transfer and storage, they can trade the energy to each other to reach the balance of trading in energy market. This finally helps peak load to shift among the whole grid.

In terms of business management mode among microgrids, customers' participation, crowd-funding and microgrids varieties are three main characteristics.

Customer's participation includes customer-participated operation, management and supervision. Customer-participated operation promotes competition among energy distribution companies. This not only increases the participation of private capital in energy market, but also makes energy providers and system controller improve their service. Customer-participated management and supervision leads to persistent improvements on operation of the whole microgrid system. Crowd-funding and private capital participation effectively reduces the investment difficulties of constructing EIBM. As microgrids are interconnected to each other and can be constructed on different ranges including buildings, factories or even districts, consumers have large range of selections on energy providers and energy carriers. The wide area multi-selections lead to the commercial balance on cost, profit and price among different energy providers and microgrids.

3.2 Operation mode

In different stages of EIBM, the roles of distribution company, private investors and sub-microgrids are much different. Here their main roles are analyzed.

1) Distribution company or other third party is responsible for the public system of EIBM. Here the responsibilities include construction, maintenance and updates of infrastructure, control system and large power generation and transfer facilities. The infrastructure includes electricity network, gas pipelines and information channel. The algorithms and orders in control systems are essential for power flow in the microgrid. Although EIBMs can buy most energy from the main grid, some power generation and energy transfer facilities are still required during the peak demand period. These facilities also require companies to operate and maintain, not individuals.

2) Private capital can flow into affordable, threshold low, low technically required, easy-connected and public used systems or facilities. These include PV generators, small wind turbines, small-scale methane storage facilities or electric vehicles[13]. These facilities can be purchased or invested by private capital or individuals and they must be used for the whole EIBM only. Individuals or trust can choose to lease the facilities to EIBM or self-financially-operate. The profit or rental is paid by the operator of EIBM, i.e., the distribution company. However the facilities must be under control of EIBM main control system. Facilities owner is not responsible for the technical operation.

3) Sub-microgrid such as intelligent building or smart home system is compatible to be connected to EIBM. These systems may have their own control systems, power generation facilities and some infrastructure, hence they are not controlled by EIBM. Individuals or companies can buy such systems, which can be connected to the grid of EIBM, to decrease the energy cost by reducing energy waste, or increase energy income, by trading with EIBM. However, planning and load forecasting abilities of sub-microgrids are required. They also need to exchange all information, from power flow to estimated values, with the main control system. When processing the values collected from all parts of EIBM, EIBM-controlled parts have more calculation priorities on system stability, power flow and profits distribution than sub-microgrids.

Also, in some occasions, intelligence of individuals is also encouraged in the operation process of EIBM. These may include smart meter data collection and correction, improvements on control system algorithms and operation or supervision advise. If anyone who really helps the operation of the system from loss

or waste, profits should be provided as bonus.

3.3 Operation principle

Stability and safety are most important concerns in operating EIBM. Here stability refers to system stability in power generation, transfer, transmission and storage process. Safety refers to information safety, including information loss, hackers attack and information system breaks down, etc. Not only in the technical design stage, but also in operating stage, both stability and safety are always in the first priority to be considered.

UE (user experience) is the second important concern in energy commercialization. Except for submicrogrids which are controlled by particular algorithms and aim to reduce energy waste, EIBM should provide consumers all their energy demand whatever the cost is, as long as they pay for it[4]. Therefore, direct load control seems not feasible in EIBM.

Maximum profit is the object function in optimization calculation. As the public is encouraged to invest on EIBM infrastructure, capital gain must be guaranteed for investors. Profits are also the basic motivation of energy market investment.

Communication and information processing is also rather important in system improvements. As hardware in information system updates fast, information processing efficiency must be guaranteed and information among SCADA, EMS and BMS system must be transmitted smoothly[14]. As the information technologies develop, operating system of control platform, smart meter and other information processing system should be updated timely[5].

4 Government role

Government role is essential in EIBM construction and management. Policy must be adopted to dismantle monopolies in distribution side of power system and encourage the establishment of distribution companies. Crowd-funding platform should be built to attract private capital or finance from capital market. Regarding EIBM management, government should make regulations on market surveillance, responsibilities allocation and grid company support.

5 Advantages

Firstly, the permeability of renewable energies in energy consumption increases significantly. With the large investment on clean energy equipment, green energy generation will dramatically raise, especially in the distribution side of power system, due to economic benefits.

Secondly, the costs of power generation decrease in society range. Renewable energy generation decreases the cost in the distribution side of power system, while the control of power flow inside and outside EIBM finally achieves the goals of peak shifting and load balancing, which reduces the cost of energy generation in the whole grid obviously.

Thirdly, customers' participation helps lead technical and administrative innovation, based on abundant capital strength and enthusiasm of participation. Technical innovation includes energy transfer technologies, information exchange and processing, power system planning, plug-and-play interface design and charging point planning. Administrative innovation mainly focuses on system operation, system coordination and profit distribution.

In addition, capital flow and social participation promotes the development of economy. Also, responsibilities of grid companies and distribution companies will be changed.

6 Conclusion

EIBM is on the distribution level of power system. In addition to electricity distribution, different energies transfer, information process and communication, customized demand management are also the main characteristics of EIBM, compared to the conventional microgrid.

Floating energy price, customer-participated operation and complicated trading market are main transaction characteristics of EIBM. In addition, distribution company, individual investors and sub-micro grids are three main roles in energy transaction process. Distri-

bution companies work on infrastructure maintenance, technical support and control system operation. Private capital flows into public used facilities. Sub-microgrid trades energies with EIBM while power flow inside sub-microgrid is controlled by itself. Stability and safety, UE and maximum profit are the targets in operating EIBM, ordered from high to low priorities. Government should encourage the establishment of distribution companies, organize crowd- funding and make regulations on market surveillance and support.

As energy internet is the final target of developing power system, the authors hope that the analysis on EIBM operation mode will be helpful to energy internet development.

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