Architecture Conception of Energy Internet and Technical Challenges

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***Abstract*—This paper presents a new management system for energy internet based on hierarchical and independent principle. Every point connects each other and has its own scheduling rights. In previous work, we have analyzed the features, structure and technology system for energy internet, and put forward the architecture conception based on Multi-agent system. Compared to current energy system, Multi-agent operation method can perform high efficiency. We also provide the functional detail of management system and point out the research direction of the key technologies to implement the function of multi-agent system.**

***Index Terms*—management system, energy internet, architecture conception, multi-agent**

I. Introduction

Energy is the foundation for the survival and development of modern society. In recent years, under the dual pressures of energy crisis and environmental protection, actively research on new energy technologies is developed around the world. Solar, wind and other renewable energy resources [1] are inexhaustible and clean, has received special attention all around the word. EU, U.S. and China have respectively proposed to reach the target renewables account for 100%, 80%, and 60-70% of the energy supply until 2050.

Electric power has occupied an important position in the current energy system because of high energy transfer efficiency and has formed a large-scale power transmission network. The main energy style of the future management structure must be electrical energy. Despite the prominent advantages of renewable energy, but there are also geographically dispersed, intermittent, random, and uncontrollable volatility and other issues. A large number of decentralized, diverse, different performance of renewable energy connected directly into electricity grid will impact the traditional grid and users, and adversely affect power quality, reliability of system protection and operation. Resolving connection problems is one of the driving force behind the development of the smart grid. Smart grid is the main direction of modern grid, but now, different countries has different definitions in meanings, the specific path of implementation and the standard of the technology are not uniform.

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In 2008, the U.S. National Science Foundation project "The future of renewable electric energy transmission and management system" (The Future Renewable Electric Energy Delivery and Management system, FREEDM system) first proposed the concept of the energy internet [2], [3]. Different from traditional solutions, the Energy Internet adopts Internet development concepts, methods and techniques to achieve major change on energy infrastructure architecture itself. The construction of a new information fusion energy network can solve many problems in the current grid. Broadly considered, energy internet is another form of smart grid. Purdue University, the University of California at Berkeley, the Swiss Federal Institute of Technology researchers have conducted studies of energy internet, but the energy of the Internet is not a formal model of development and future energy solutions until the United States home Jeremy Rifkin's "The Third Industrial Revolution" was published, which caused widespread concern in economics. He believed that "Internet technology and renewable energy are combined to form the Energy Internet, which will be an effective model to achieve a distributed energy supply".

Based on the summary of the energy characteristics and basic content of the target analysis, we proposed the architecture in the perspective of wide area: Based on the existing power grid skeleton, for hierarchical management, we adopt multi-agent system [4]-[7] to dispatch the control system of energy Internet. At last, analyzing the technical challenges currently and pointing out the key technical requirements of the internet architecture.

II. Features of Energy Internet

Comprehensive studies show that the energy internet can be understood as an internet-based development concept, the integration of advanced power electronics technology, information technology and intelligent management techniques [8], [9], which is consisting of a large number of distributed energy generation devices, distributed energy storage devices and various types of load to achieve a two-way flow between energy terminal unit, as the same as information exchange and sharing of network.

Although there is currently no one uniform definition on energy internet, but the researchers reach an agreement on that new internet meets energy future

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development of production and consumption. From this perspective, the energy Internet has the following key features [10]:

High penetration of renewable and clean energy: global warming, energy pressure, and the increase of ecological consciousness of civilization makes the system highly dependent on fossil fuels energy unsustainable, renewable and clean energy will gradually become the Internet's main energy supply sources. With intermittent volatility, a large amount of renewable energy's access to large-scale grid will impact the stability, thus contributing to the revolution of traditional energy networks to the energy Internet.

Decentralized collection and local consumption: As traditional energy production system is centralized and consumption is decentralized, energy efficiency is low; while renewable energy has a low energy density and geographical dispersion characteristics, in order to maximize the efficiency of the collection and using of renewable energy, energy system can follow the client's energy collection, storage and consumption in the spot through cascade utilization.

Two-way flow and network sharing: As decentralized collection of energy and local consumption, energy network users who are also dual roles of producers and consumers, with great dynamic freedom. Energy Internet should be an energy sharing networks with peer and flat two-way flow. Power generation equipment, energy storage and load can "plug and play". According to interoperability standards, no one is more important than the other nodes in the independent access and energy exchange process.

Higher quality requirements for energy supply: digital society put forward higher requirements for the reliability and quality of energy supply. There is a large number of sensitive power loads in modern society, the load has almost demanded for high quality power. On the one hand the energy internet need to accept the impact of large-scale renewable energy access, but also to ensure a higher quality of power supply, which makes very advanced technical requirements for the realization.

III. Architecture and Key Technologies of Energy Internet

A. Architecture of Energy Internet

The internet is designed to provide the energy platform with green energy efficient, reliable and high quality access and consumption. Building energy transmission architecture and design optimization of the whole network scheduling strategy to meet its target feature is the first problem to be solved. According to the implementation feasibility and economics, making best use of existing energy infrastructure is a factor that must be considered. Based on these considerations, we get the following energy Internet architecture shown in Fig. 1.

The architecture takes the large-scaled grid as "backbone" and the smart grid distribution micro-grid as "local area network". According to hierarchical peer multi-agent system [11]-[16] and dispatching control system, make dynamic energy decentralized balance and bi-demand mobility. The architecture maximizes the use of existing energy infrastructure. It can integrate different sizes of micro-grids into internet simply by transforming terminal side of distribution network, and found a distributed grid scheduling architecture at the same time.

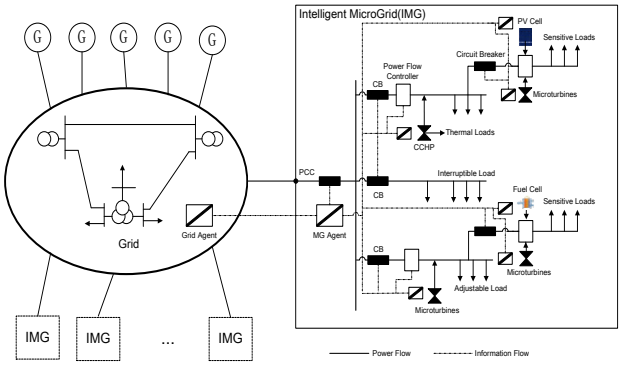

Figure 1. The architecture of energy internet

Energy Internet takes the large grid as "backbone". Electric power has occupied an important position in the current energy system by its unparalleled transmission efficiency, and has formed a large-scale power transmission network. It interconnects dispersed smart micro-grids efficiently throuth large grid, which greatly improving the internal micro-grid power quality and reliability, while also providing a foundation platform for distributed energy market transactions.

Energy Internet consists of Intelligent Micro-Grids (IMG) [16]-[18] which took as energy source "LAN". Micro-grid is to coordinate the conflicts between grid and distributed power, make fully use for the value and benefits of distributed energy. Micro-grid can be seen as an integration of distributed power system, load, energy storage and control devices. It is shown as a single controllable unit which can respond to the central control signal. The micro-grid distributed power sources are mostly small generator unit contain the power electronics interface, the sources are generally connected to the user side. Micro-grid can run depend on the power grid, but also separated from the main grid when the grid fails or needs to run independently. It also has a dual role: to the grid, it can be considered as controlled micro-grid cells, the cells may be used as a simple and controllable, scheduling load, which can make response in a few seconds to meet system needs; To the user, micro-grid can be used as a customizable power to meet the diverse needs of users, for example, to enhance local reliability, reduce feeder loss, support the local voltage, waste heat utilization by improving energy efficiency, voltage sag correction, provide uninterrupted power supply. Therefore, micro-grid is a superior mode to achieve power network, which form an interactive intermediate layer between grid and distributed energy supply system, effectively reducing the adverse effects when large numbers of discrete intermittent access to the grid, improve the coordination of grid operation, power quality and reliability levels.

Energy Internet adopts hierarchical and peer Multi-Agent System (MAS) scheduling system. Energy Internet

contains features include high penetration of renewable clean energy, energy consumption in situ collection and dispersion, two-way flow and network sharing, smart micro-grid is the basic networking of its "LAN". The distributed nature of micro-power, control large amounts of data, and flexible control features, which all make previous uniform judged by the dispatch center, centralized control difficult to achieve flexible scheduling for effective operation. Meanwhile, the two-way flow energy will continue to strengthen the participation of independent power producers, market-oriented energy systems will be increasingly high, in the case, the system control center not only undertake the traditional power economic and technical tasks, but also adds a lot of work with the electricity market and the transaction, which makes operation and control tasks more complex and onerous. Single processing for various control information in the control center computer will become very difficult.

Hierarchical distributed multi-agent coordination control system can effectively solve the above problems. Control-rights are dispersed into each backbone grid, micro grid and the internal component. Intelligent agent of dispersed component in all levels strengthen collaboration through real-time communication with each other, and change the running status according to their scheduling requirements, then achieve stable and efficient operation of the grid. The proposed scheduling control system broadly divided into three levels, namely the grid layer Agent, smart micro-grid layer Agent, component layers Agent, shown in Fig. 2.

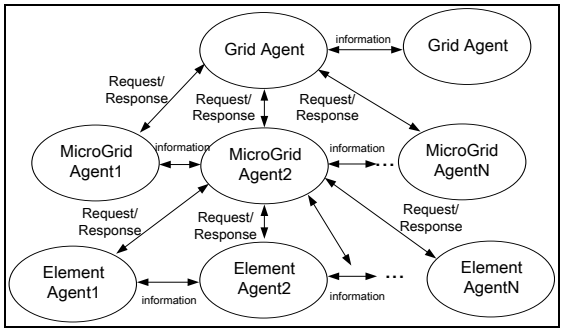

Figure 2. Scheduling architecture based on hierarchical peer multi-agent system

Grid layer agent is in charge of stable operation of the backbone network and support system-level power market trading, also completes scheduling coordination between the Agents and consolidate the relevant information in the lower micro-grid Agent to make major decisions, then notifying lower micro-grid agent to execute by the request/response approach. Tasks Division and shared resources between micro-grid agent and the higher level agent are solved by communication. Micro-grid layer agent manage the agent of the underlying components and receive information, make appropriate control strategies based on the operating state of distributed power, then send to components agent for execution. The components in the bottom including various types of distributed power generation and load which are running as independent Agent.

B. Key Technology

Previously put forward internet architecture that taking existed large grid as "backbone" and the smart grid distribution micro-grid as "local area network", using hierarchical peer multi-agent system to Schedule the Control System. While researchers have in-depth research work on smart grid, distributed generation and micro-grids, even Involve in EV [19]-[21] and other more technical fields, but there are still a number of critical technical issues yet to be resolved.

1) Micro-Grids areas

a) Micro-Grid computing and simulation technology

Micro-grid computing is the foundation of making micro network planning, operational control, power generation, scheduling and protection setting. Compared with the current computing and simulation technology, micro-grid computing and simulation need consider a variety of factors include distributed energy access, short circuit calculation model's uncertainty of power electronic devices and CCHP (Combined Cooling Heating and Power). The original grid computing and simulation analysis methods are difficult to adapt to the requirements of micro-grid. Due to these characteristics, need the study of new calculation method to form complete theory of micro-grid computing and simulation, techniques and tools.

b) Micro network planning and design technology

Rational planning, designing for micro-network can effectively improve the utilization efficiency of distributed energy, improve external network security, reliability and economy of micro-grid operation. In particular, need to consider a coordinated operation, reasonable power structure, independent operation capacity for the energy style contains power and micro-grid heat and other forms of energy, the size and rational distribution.

c) Micro-Power technology within the network

There is no communication in the context of distributed power among themselves, micro-grid operation make the appropriate response within the network disturbance in a few milliseconds according to the local voltage and current signals. Control functions include regulating flow calculation on feeders, interface voltage of distributed power and ensure that the power supply can quickly share their load and networks. To achieve the above functions, it requires not only a basic distributed power control of active and reactive powers, also requires sharing the load, interference suppression.

d) Micro-Grid energy storage technology

The introduction of small generating capacity inverter and distributed generation reduce the inertia of the micro-grid, which is not conducive to stable operation. Distributed generation of renewable energy has the characteristics of uncertainty and randomness, as power generation units connected into operation or removal, as well as fluctuations in the load, all of these factors will cause voltage and frequency fluctuations in the process of micro network. Energy storage unit has an irreplaceable

role in improving the economic system, increase system inertia, transient fluctuations buffer system, smooth response time and support node voltages and so on. Currently economically viable large-scale energy storage is still technical difficulties. Efficiency, charge and discharge times, cost, capacity and other issues are still to be resolved.

e) Operation and control technology of micro-grid

In normal conditions the basic operation of micro-network can rely only on distributed power, but when in an emergency, recovery, switch transition and critical stable state, it needs to predict and analyze the operation of the system by the global, prior information. The main technical requirements in terms of operational control as follows: micro-network structure and the automatic control system, seamless switching between micro-grid connection and independently running modes, automatic generation/frequency/voltage control, fast stabilizing stable system and black-start technology.

f) Protection technology of micro-grid

Micro-grid protection system has a great difference with the traditional protection, typically expressed as: two-way flow calculation, connecting the grid/independent status, fault transition needs, allowing not to exit with non-selective, which makes short-circuit current flow and the size varies greatly in different circumstances, the protection of external distribution network also requires a coordinated network based on micro-operation. Meanwhile, need to establish the appropriate protection and control strategies to ensure the survival when the next catastrophic accident comes. Micro-network protection has two main aspects: 1) how to extract fault feature; 2) how to provide adequate protection for micro-grid in different modes, different failure points.

g) Power quality of micro-grid

Distributed generation close to the user, which caused power quality changes will be directly reflected in the client, while micro-grid covers smaller geographical scope, disturbances will spread rapidly in tiny micro-network, even evolve to be stability matters, especially independent operation. It is important to address the following issues: micro-grid power quality problems with particularity, the mechanism of generation and diffusion, power interaction and communication between micro-grid with high penetration and distribution network, power quality detection and analysis techniques in micro-grid and distribution network contains micro-grids, power quality control and management technology based on inverter type distributed generation.

2) Areas of large-scaled grid

Energy Internet proposed higher requirements on power grid, mainly in lower transmission and distribution losses and the wider connection. In the energy internet, renewable energy is the main source of energy, decentralized energy collection and local consumption is the most important way, in the interconnected grid it need to further reduce power transmission losses. Renewable energy has a high penetration in energy internet, how to ensure supply reliability and power quality with the consumption of renewable energy is a problem that must be addressed. It is a potential solution for the consumption of massive access of renewable energy by a broader intercontinental interconnected, global coordination to reach the complementary energy. America's "superconducting grid" is the best carrier of the energy Internet backbone, but has yet no mature technologies.

3) Areas of scheduling

a) Management and control technology of distributed energy

As the power network coupling level is very high, stability control is primary consideration. We must ensure the realization of energy optimization control in a stable situation. The control architecture of peer hierarchical multi-agent system has no control center, energy control mainly include autonomic collaboration and cooperation between energy LAN by a dynamic control structure. Because the peer control structure has more complexity, more interfaces, so the response rate is relatively slower than centralized control, need to explore a quick, efficient global optimization without compromising the interests of another single LAN in the processing of distributed energy management and collaborative control.

b) Corresponding technology of auto-demand

Demand Response (DR) refers to power users' participation behavior which changes consumption patterns due to the market price signals and Incentives. For the lack of energy storage capacity, we can implement multi-scale power generation forecast, load forecasting to develop automated demand response measures, and found virtual buffer in the generation side and user side. Effective management of energy uncertainty and consumption is greatly improving the stability of the grid.

c) Technology of information and communication

Two-way communication architecture is the foundation supporting energy internet. Operational control, energy optimization, demand-side response, advanced applications and economic dispatch all need to rely on two-way communication technology. Internet information and communication technology have the following needs:

Open: open network architecture provides "plug and play" platform which securely connects various types of network devices, allowing interoperability and collaboration between them;

Standard: The main component of the communication infrastructure as well as interactive style with each other must be clear norms;

Ample: communication architecture must have enough bandwidth to support the current and future capabilities;

Robust: As energy control and management of the Internet are usually highly automated with no artificial feedback, so that the communication architecture must be with a high manageability and reliability.

IV. Conclusion

Currently, the energy crisis and environmental pressures driving profound global energy revolution. Its basic feature is that renewable and clean energy gradually replace fossil energy. In order to solve the outstanding problems in the transformation, energy internet achieve widely attending by national researchers. This paper analyzes the basic content and summarizes the features about the internet, and puts forward that take large grid as "backbone" and smart micro-grid as "LAN (Local area network)", schedule the energy control system with hierarchical peer multi-agent principle. Through analyzing the key technologies and proposing the current technical challenges, we expect the paper to provide a reference for the future research.

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