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Market Mechanism Demonstration Review of Distributed Energy Resources and Market-oriented Construction Solution

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ABSTRACT

The energy low-carbon transformation strategy aimed at efficient energy utilization and energy structure optimization is continuously deepening globally, and the proliferation of distributed energy resources (DER) in distribution network attracts much attention from many sectors. However, DER are usually deployed on small scale, dispersed locations, and diverse in types. It has great difficulties to achieve market-oriented operation in electricity markets in various countries. In order to explore the effective construction path of DER market operation, the article analyzes typical worldwide demonstration cases of DER participating in electricity market, and summarizes the characteristics of two different market-oriented operation modes. Moreover, based on China's electricity market reform and the DER development status, it points out the phased construction goals and specific construction contents for DER participating in the electricity market and serving energy internet development in China. Through a comprehensive review of existing projects and the proposal of DER market-oriented construction, it provides a necessary reference for the DER development and energy internet construction.

Key words: Distributed energy resources, electricity market mechanism, energy internet construction

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1. INTRODUCTION

The rapid development of distributed energy resources (DER) on the distribution network accelerates the transformation of energy efficient supply and optimizes energy structure. The revenues associated with the expansion of DER capacity will likely reach about $650 billion in 2028 at a compounded annual growth rate of 15.9% [1]. However, the limited customer awareness, a fragmented value chain and costly communications infrastructure have become the market barriers of the DER development. Therefore, devoting to the study of a reasonable market mechanism is of great significance to the sustainable and healthy development of DER. The market-oriented operation of DER is conductive to improving the revenue of DERoperators or owners, increasing the investment enthusiasm of distributed energy markets, and accelerating the pace of electricity market reforms, thereby further promoting the rapid development of energy efficient transformation. Therefore, the DER market-oriented constructioncan be regarded as anactivator for the optimized energy structure. The illustration of the concept is given in Fig. 1.

In terms of the DER market-oriented operation, many previous studies give out a lot of theoretical research foundations in tendering for distributed energy trading technology anddistributed market trading algorithms. [2] discusses the decentralized transactive energy system infrastructure and proposes peer-to-peer transactive energy exchange technology in local energy market. [3] proposes a decentralized market mechanism which allows the distribution system operator to manage local demand by incentivizing the prosumer to provide flexible services. A well-defined strategic bidding mechanism is proposed to maximize the prosumers' operation revenue which are constructed with distributed energy resources in distribution-side retail electricity market [4]. [5] presents a double-side auction market clearing mechanism for renewable generation units in the distribution system. It gives out a solution even renewable energy with zero marginal costs participate in the bidding, the proposed clearing mechanism is still effective. An innovative economic and engineering coupled framework is proposed to encourage typical flexible load or load aggregator to participate directly in the real-time retail electricity market. Not only the electricity retailers but power system operators can benefit from the market mechanism [6].

However, the existing research still lacks comprehensive analysis of technical verification and experience based on the typical distributed market operation mechanism demonstration projects around the world, and cannot give relevant sectors or related industries an instructive development direction and construction path. This research conducts a review of the developed or under-development DER market-oriented operation cases. The market operation of DER is divided into two patterns. One is the market operation means in which distributed resources and conventional energy directly bid on the same platform. Another one is the market operation means in which the wholesale marketor ancillary service market, and the distribution network market with DER participantsoperate independently and are coupled through price signals.Through the analysis of typical cases in turn, it summarized the construction experience of DER participating in electricity market, including participation modes, trading mechanisms and technical characteristics. Besides that, it analyses the status of China's energy internet construction, based on China' electricity market reform requirements and national energy strategy, discusses the development solution and construction path of DER participating in the market and serving the energy internet.

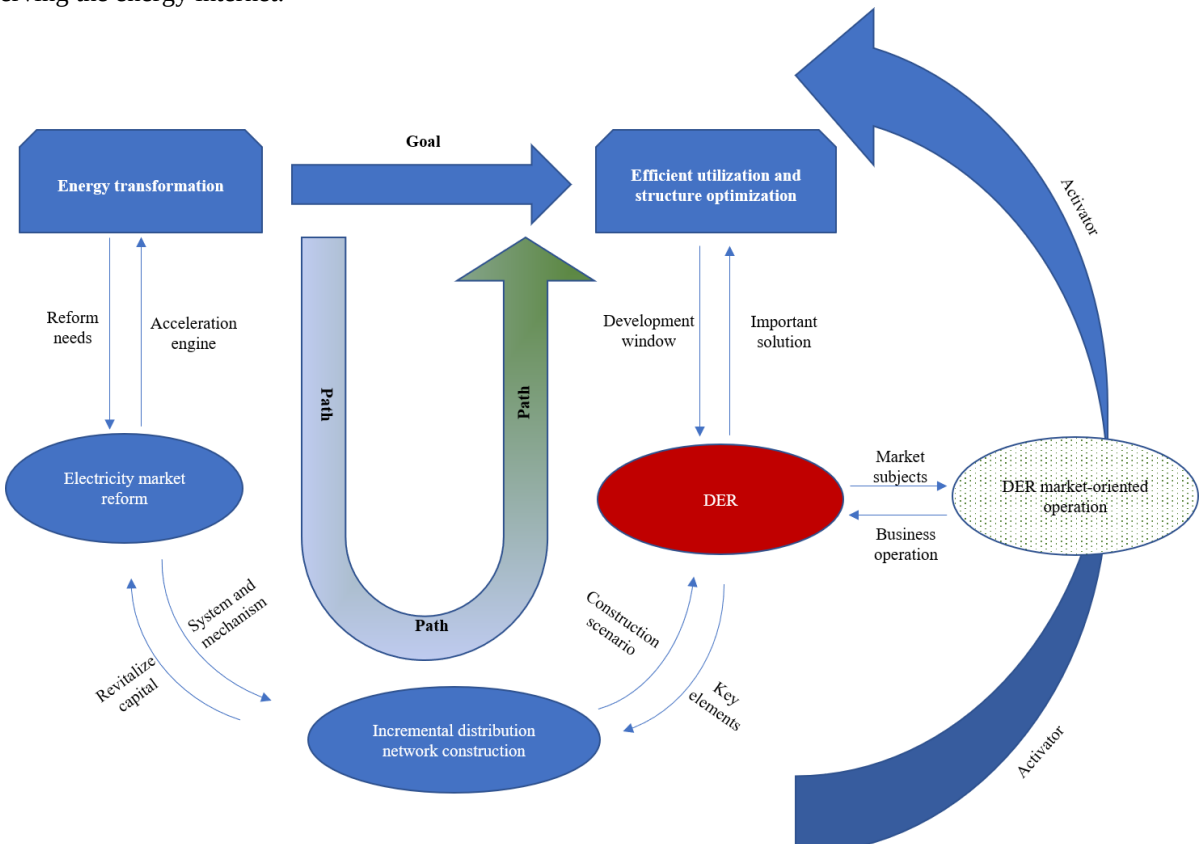

Fig. 1 Illustration of Market-oriented Operation of DER for Accelerating Energy Transformation

2. DEMONSTRATION PROJECTS REVIEWAND ANALYSIS

Generally, DER has three obvious characteristics: 1) the installed capacity is small and the number is enormous; 2) the location is dispersed and mostly in the distribution network; 3) the operational uncertainty is high due to many DER composed of renewable energy and its operation relies on DER owners' decision-making. For system operators, dispatching enormous DER can improve the flexibility of power system operation, but the cost of interactive communication is high, and it is difficult to bring about scale impact. For market operators, the participation of enormous demand-side resources in electricity market can introduce competition, meet the individual needs of electricity users, and promote the clean energy development. However, the existing DER are difficult to meet the market access requirements. For DER owners, participating in the electricity market can increase revenue and meet their own flexible needs of energy utilization, which is conducive to guiding investment in distributed resources and promoting the DER development. Therefore, it is of profound significance to carry out research on the business operation mode of DER participating in the electricity market. In accordance with the investigation of existing demonstration projects of DER market-oriented operation around the world, the review is implemented from the view of participation approaches. One is the market operation mode in which DER are aggregated and directly compete with conventional energy in the same market. Another one is the market operation mode in which the wholesale market, and the regional market with DER are coupled and coordinated.

Demonstration Projects for DER Directly Participate in Electricity Market

Lessons from CAISO (USA)-In June 2016, FERC approved a framework for DER aggregations to participate in CAISO's real-time and day-ahead wholesale energy markets and ancillary services markets [7]. Under CAISO's amended MST, the DER aggregations are regarded as a novel kind of market participants which is similar to traditional facilities. There are no restrictions on the number of individual DER that can be aggregated. The aggregated DER can be composed of different types of sources, and also located in different pricing nodes. The requirement of minimum aggregated capacity is 0.5 MW, and the maximum aggregated capacity is 20 MW if the DER located at different pricing nodes, or there is no maximum size limitation for the DER located at the same price node. The qualified DER aggregators become the wholesale market participants after executing agreements and implementing trail operation. Like other conventional market participants, DER aggregator may bid into the wholesale energy market through a scheduling coordinator, or elect to be a scheduling coordinator itself. Different roles have different bidding mechanisms. When the DER aggregator is a scheduling coordinator, the scheduling coordinator should fulfil the bidding obligations as it does for other participants. The unique difference is that the bidding information should include the generation distribution factors which can reflect the share of DER at each pricing node. When the DER aggregator retains another scheduling coordinator, the aggregated DER are treated as a single source no matter where it is located. The DER aggregator receives the dispatch instructions issued by the CAISO, and is responsible for disaggregating the instructions to the DER. The aggregated DER must provide a net response at the bidding pricing node which is consistent with dispatch instructions. The settlement is based on the LMP, or a weighted LMP when the DER spans on different pricing nodes.

Lessons from NEM (Australia)–The Australian Energy Market Operator (AEMO) proposes an open energy network project to achieve the goal of facilitating and managing the ever-increasing levels of DER within the distribution network. In AEMO, the small DER units can be aggregated to participate in all the eight ancillary service markets and wholesale market [8]. DER aggregators or retailers agenting DER submit bids and offers to the market platform. AEMO assesses the bids and offers, and conducts the optimal dispatch considering transmission-level and distribution-level constraints. Then the dispatch instructions are sent out to DER via aggregator or respective retailer. Moreover, the DSO provides the operating envelopes based on forecast and network constraints to accommodate the DER dispatch. Finally, the aggregators or retailers integrate different DER and provide their aggregated output to fulfil the dispatch instructions issued by AEMO. The advanced ICT system contributes to measuring the amount of each DER in the aggregator or retailer in real time, and the aggregated amount must be measured within 4s. In the NEM market framework, DSO maintains its technical function to manage and communicate distribution network constraints, and the AEMO manages a market platform that optimizes the DER for multi-types market services.

Summary: 1) Mechanism characteristics: According to market access requirements, it needs to introduce aggregation technologies, such as virtual power plant, as DER aggregators to realize effective aggregation of multiple subjects. Aggregators are responsible for agenting the DER to participate in the wholesale market and realize the revenue allocation. 2) Technical difficulties: It is necessary to consider the output characteristics and response characteristics of DER, conduct the research on integration method with existing wholesale market on the bidding mechanism, clearing mechanism, settlement mechanism and assessment mechanism. Its realization also needs to change existing market trading rules and has great requirements for the market mechanism development, market starting and implementation.

Demonstration Projects for Multi-Market Coupling Operation with DER

Lessons from Ecogrid EU (Denmark)– The EU Smart Eco Grid (EcogridEU) project is a smart grid pilot project of the EU's Seventh Framework Program (PF7) [9-10]. This project aims to use flexible resources and smart grid technology to balance the supply and demand in real time, and ensure the safe, stable and reliable operation of the power system connected with high penetration renewable energy. The focus of the EcogridEU is that it allows DER and end-users to participate in the operation of the electricity market and power system. This project establishes a real-time power balance market for small/medium-sized users and DER, coupling with the existing power regulation market, to maintain the supply-demand balance of power system. It supports the provision of balance services required by the system in a shorter time. The specific mechanism is as follows: When the transmission and distribution network exist congestion or the unbalance of supply and demand, the real-time power balance market operator sets real-time electricity prices based on the unbalance needs. DER and end-users can receive the real-time electricity price issued by it, and adjust their own generation and consumption according to the real-time electricity price signal to respond to the market instructions. Transmission system operators have the ability to monitor thebehavior of market participants to ensure the supply-demand supply in the coupled operation of real-time power balance market power and existing power regulation market. This proposed market eliminates the structural problem faced by the DER, such as minimum market access requirement, online monitoring or market bidding. Its function not only provides better match in real-time system operation, but also bring DER the possibility of obtaining economic profits.

Lessons from Peer Energy Cloud (Germany)- Peer Energy Cloud project is a peer-to-peer (P2P) energy trading system developed in Germany[11-12]. Its basic goal is to establish a regional electricity market for DER to achieve a balance of power generation and consumption within a certain area. The project platform manages more than 500 smart homes and multiple distributed photovoltaic generation systems. The energy utilization in smart homes can be measured and

transmitted in real time through smart terminals, which can be used to predict energy demand and power generation. Moreover, in terms of data processing and integration, and dealing with uncertainties, the project devotes a lot of work to achieve accurate forecast of DER and end user behavior. The specific mechanism is summarized as follows: First, the system collects data from user calendars, weather prediction departments and smart terminals. The data is preprocessed and integrated to provide accurate power supply forecast, energy demand forecast, and interruptible load forecast. The forecast information is used as the basic information for agents to access the regional electricity market, together with the location and transactive capacity of each DER and end users. Then, the regional market operator organizes the agents to conduct direct P2P energy transaction. Through the construction of regional electricity market, the power supply won't be controlled any more centrally, and instead the DER and end users can obtain cheaper electricity price and more flexible supply by energy trading locally.

Lessons from Piclo (UK)-Piclo project is a P2P clean energy trading platform developed by the UK [12-13]. Its power suppliers include a variety of energy types, such as wind power, hydropower and photovoltaic generation. Its electricity users contain commercial users and residential users. The project focuses on establishment of a regional electricity market, to provide personalized and customizable power supply services and to promote the local consumption of renewable energy. The specific mechanism is given as follows: For the power suppliers, the Piclo platform can make the power purchase agreement according to their generation capacity, power quality and technology level in which the electricity price is clarified. For the electricity users, they are required to sign a contract with the retailer who supports Piclo services, and its data will be sent to the Piclo platform including its location, demand and energy preference. Then, the platform discloses user information in a targeted manner. For the generation-side users, its location and DER type are disclosed, and for demand-side users, its location and energy preference are disclosed. Moreover, the platform collects transactive energy of each DER at the current, and the electricity demand in 30 minutes by using smart meters. Finally, the platform conducts P2P matching according to the supply-demand distance, electricity price and energy preference. The imbalance energy is compensated by the Good Energy with renewable energy. Reasonable market mechanism for the DER can benefit each participant, be helpful to solve the problem of local consumption of renewable energy, promote the active coordination of DER and load in the distribution network.

Lessons from TransActiveGrid (USA)- The TransActiveGrid project is located in New York, USA, and is developed by the LO3 Energy Company [14]. It is a distributed energy trading platform based on the microgrids. Its objective is to realize the local supply-demand balance, thereby reduces the proportion of dispatch, transmission and distribution cost paid by users and improve the utilization efficiency of power system. The project introduces blockchain technology to realize P2P trading between users through the advantages of decentralization, open transactions and transparent settlement. The specific mechanism is proposed as follows: Residents participating in the project can choose to charge the surplus photovoltaic energy into energy storage equipment or sell to the other electricity users. The surplus energy can be recorded in the platform account in the form of digital currency. Moreover, the user can use the account balance to directly deduct electricity consumption or conduct trading with other users, which determine the energy trading amount and price independently. The smart contract on the blockchain automatically trigger the transaction by judging the SELL and BUY condition. It effectively improves the efficiency of electricity market trading and energy utilization.

Summary: 1) Mechanism characteristics: It needs to develop a regional energy trading system, coupled with the existing other markets,facingwith the DERin the distribution networkthat have the characteristics of small in size, large in quantity, and diverse in types.2) Technical difficulties: It is necessary to study the regional market trading rules, organization method, and clearing and settlement mechanism. Besides that, it also needs to explore the coupled operation method and price signal transmission mechanism of different markets.

3. DER MARKET-ORIENTED CONSTRUCTION SOLUTION

In accordance with the review and analysis of the DER market operation demonstration projects around the world, this sector discuses the DER market-oriented construction path and solution. Through the proposed phased development suggestions, it provides an important reference for the distributed market which has a profound significance.

Market-developed Formation Forecast of Electricity Market containing DER

Early and Medium-Term: At this stage, the activeness of distributed energy market and its contribution to the balance of supply and demand at the distribution network will greatly increase. The regional power demand will be supplied by the local DER and generation from transmission grid equally. Moreover, in order to cope with the growth of DER integration, the distribution network system puts forward more dynamic and diversified requirements for the distributed energy trading market activities. In addition to energy market trading, a wider range of ancillary service products will be transferred to the distribution network level as well. Therefore, the broader market products and more active market activities will require the capability of dynamic operation of the market. For the effective distribution network management will require consideration of the fluctuation of renewable energy generation, the ancillary service demand of transmission-distribution two level network, and the ever-changing consumer demand.

Long-Term: At this stage, local DER can meet regional capacity needs, and the distribution network system will operate as an independent power system. At this time, the power generation from transmission only share a small part of electricity market in distribution network, and provide limited capacity service and ancillary services to ensure the safe

and reliable operation of power system. Under a community-led market structure, the regional distribution capacity service market will replace the conventional distribution network capacity service provided by the transmission network. The supply-demand balance is ensured by dispatching the DER. Moreover, the sufficient distributed energy service and complete regional ancillary service market ensure the reliability and safety of power supply.

Phased Construction Solution of DER Market-oriented Development

Early and Medium-Term: The primary construction goal of this stage is to achieve a full participation in the electricity market of a high proportion of DER, to realize efficient consumption of distributed energy through the interaction of supply and demand, and to enhance the competitiveness of distributed energy market. The distributed energy market will be oriented to multiple distribution network regions, and its core is to mobilize generation and users' resources outside the existing wholesale market, reintegrate and carry out market-oriented operation. The specific construction content is proposed as follows: 1) expand the market access scope, allow DER and end-users participate in market, and introduce diversified market entities; 2) establish a multi-market coupled market clearing mechanism to realize the effective transmission of price signal in the wholesale market; 3) establish a market clearing model of regional market to achieve priority consumption of renewable energy, and provide accurate price signal for all parties in the market through the adoption of distribution locational marginal price.

Long-Term: The main goal of this stage is to build a DER-based electricity market system with diverse trading varieties, comprehensive trading timing, and flexible trading forms to achieve multi-dimensional coordination and matching of regional resources. The specific construction content is proposed as follows: 1) create characteristic energy trading products facing with actual market needs, including conventional energy, capacity, ancillary services and climbing services, as well as some novel trading products for renewable energy consumption; 2) further refinement of incremental trading timing of clean energy and realize refined and market-oriented operation of DER.

4. CONCLUSION

The market-oriented operation of DER can effectively promote the development of distributed energy and accelerate the clean energy transformation of power system. First of all, this research conducts review and analysis on typical demonstration projects of DER participating in electricity market in the world, and summarizes two different modes of DER market-oriented operation, namely direct participation in existing market through aggregation technology and coupled operation of regional market containing DER and existing market. Besides that, it analyses the mechanism characteristics and technical difficulties of the two different modes, which provides a reference for the development of DER market-oriented operation. Secondly, based on the development status and trends of DER in the power system and electricity market, this research predicts the early-medium and long-term developed formation of power system and electricity market containing distributed energy. In accordance with different market developed formation, it puts forward targeted construction goals and cultivation content, which provides a clear development path and solution for the DER market-oriented operation. It is an important development basis for the economic operation of power system with a high penetration of DER.

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