Evaluation of Social and Economic Benefits of Demand Response

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Abstract. The rapid development of demand response has realized the transformation of power system operation from isolated decision to interconnected communication, which is of great significance for improving power network flexibility, security and reliability. Also, by introducing demand response, power network investment for satisfying peak load could be delayed, while renewable energy consumption and power network economic operation could be promoted simultaneously. Based on the practice of demand response in China as well as to further encourage the application of demand response, this paper proposes a social and economic benefit evaluation model for demand response. Combined with the reality of China's electric power system operation, social and economic benefits of demand response are scientifically evaluated. Also, capital requirements for China to promote the application of demand response is analysed and practical measures for demand response application are put forward.

1. Application of demand response around the world

Exploration of demand response originated from EU and US in last century. According to different guiding mechanisms, demand response could be divided into price-based demand response (PBDR) and incentive-based demand response (IBDR). PBDR refers to power users’ behaviour change under the influence of electricity price, while IBDR is mainly influenced by economic incentive.

Despite of different reaction methods, the development of demand response needs to coordinate with the progress of power market. In the beginning of demand response, both EU and US have strict restrictions on users’ participation in demand response. For example, PJM requires industrial users with a minimum capacity of 1MW. Also, UK POOL requires industrial users with a minimum capacity of 3MW to participate. With the gradual maturity of demand response mechanism, the participation requirements for demand response in EU and US have been significantly reduced, and the market participants have become more diversified, as shown in Table 1 [1]. In particular, third-party agencies such as service providers and electricity selling companies are allowed to aggregate small and medium-sized residents to participate in demand response, which effectively expands the scope of participation in demand response.

| Power market | Demand response program | Participants | Requirements |
|--------------|-------------------------|--------------|--------------|
| PJM          | Emergency demand response program | Self-owned power plants, large power users, curtailment service providers | Minimum 100 kW capacity and the ability to react on time |
CAISO Demand alleviation program for large power users, curtailment service providers Minimum 1 MW capacity

NYISO Emergency demand response program for large power users, electricity retail companies Minimum 100 kW capacity and the ability to react on time

UK POOL Ancillary services bidding for large power users Minimum 10 MW capacity

UK NETA Reserve capacity bidding for large power users, load aggregators Minimum 100 kW capacity

Also, the compensation mechanism of demand response should match with the progress of market development, which applied fixed rate compensation as the main method and diversified electricity price mechanism as the supplement. For example, PJM mainly conducts emergency demand response and economic demand response programs. Emergency demand response program is mainly based on fixed rate compensation, and the economic benefits of market players depend on fixed compensation rate and actual demand response volume. Economic demand response program regards the demand response participants as "negative power supply unit". Instead of fixed rate compensation, the compensation price of economic demand response is determined by centralized bidding and clearing [2]. In EU, demand response is mainly based on IBDR. Electricity retail companies encourage power users to independently optimize electricity consumption behaviours through the guiding of price packages such as TOU price, peak and valley price, critical peak price, et al [3].

The sources of compensation for demand response include government subsidies, incorporation of electricity price mechanism, establishment of capacity market and participation in ancillary service market. At present, 18 states in US have established system benefit charging mechanism, which is specially used for demand response compensation by adding 1%-3% charging in electricity price. Take California as an example, the system benefit charging mechanism accounts for 2%-3% of the electricity charging income, about $218 million [4]. In France, capacity market is applied, which requires electricity retail companies to purchase enough capacity certificates from generation companies, which guarantees the power supply of electricity users in peak periods. In UK, demand response is encouraged to participate in regulation and reserve ancillary services [5].

2. Progress and Challenge of Demand Response in China
At present, the state and some provinces have issued a series of policy documents leading the development of demand response, promoting standardized operation and encouraging the exploration of demand response. In September 26th of 2017, National Development and Reform Commission, National Energy Agency and other six national ministries jointly issued “Notice on Further Promoting Supply-side Structural Reform and Improving DSM Progress under New Circumstances”, which revised and published new version of “Demand Side Management Method”.

Besides state policy, provincial governments like Tianjin, Shandong, Shanghai, Zhejiang, Jiangsu, Henan, Jiangxi and Chongqing carry out support policies and implementation programs. According to Table 2, the provincial policies provide monetary support for application of demand response based on provincial social circumstances as well as power balance conditions.

| Province | Compensation standards |
|----------|------------------------|
| Tianjin  | Peak-shaving price is 2¥/kWh, while valley-filling price is 1.2¥/kWh |
| Shandong | Compensation prices are determined through centralized bidding and clearing. Fixed rate is calculated as 80% of centralized clearing results. |
| Shanghai | Baseline for peak-shaving is 3¥/kWh, while valley-filling is 1.2¥/kWh. In addition, a factor with maximum value of 3 could be multiplied. |
| Jiangsu  | Industrial peak-shaving is 10¥/kW. Air-condition peak-shaving is 30¥/kW. Utility peak-shaving is 5¥/kW. |
| Zhejiang | Peak-shaving price is 2¥/kWh, while valley-filling price is 1.2¥/kWh. |
Although the specific source of demand response compensation may vary in different provinces, almost the entire compensation fund of demand response in China originates from government support. According to statistical data, China provincial governments provide 39.3, 70.5 and 110.5 million to support the development of demand response in 2017, 2018 and 2019, respectively.

However, three challenges still exist for the further development of demand response.
(a) Constrained by the progress of electricity market development, the market based trading mechanisms of demand response are difficult to be applied.
(b) Confined by current subsidy standards, market participants have limited participation willingness.
(c) The source of compensation is limited, current compensation fund is not sufficient to support the long-term development of demand response.

3. Social and Economic Benefit Evaluation of Demand Response
To evaluate social and economic benefit of demand response, an ability assessment of demand response is required. Based on its function to maintain power balance in peak period, the reaction ability of demand response is presumed to satisfy a certain proportion of power system’s peak load. Take China as an example, National Development and Reform Commission proposes that by the end of 2025, the ability of demand response in China should be able to cover 5% of the peak load, which could significantly increase the security and reliability of power system in peak period. According to the proposal of National Development and Reform Commission, the reaction capacity of demand response could be calculated by Equation (1).

\[ C_{dr} = L_{max} \times a \]  

Where \( C_{dr} \) and \( L_{max} \) represent the ability of demand response and the maximum peak load, while \( a \) represents the coefficient of demand response ability to satisfy peak load.

Based on the evaluation of demand response reaction ability, the social and economic benefit of demand response could be quantitatively analysed.

3.1. Benefit of demand response in saving power system investment
With the rapid development of social economy, more and more electric equipment has been deployed in daily life. As a result, the peak load of power system continues to grow, which demonstrates the importance of maintaining power system balance. In order to satisfy peak load demand, two options could be adopted, i.e. to invest new power transmission and distribution facilities or to introduce demand response. Compared with the high investment and low utilization rate of new power facilities, it is more economical and practical to carry out demand response to improve system operation flexibility. Thus, the benefit of demand response in saving power system investment could be defined as equation (2).

\[ M_i = C_{dr} \times b \]  

Where \( M_i \) represents the quantitative benefit of demand response in saving power system investment, while \( b \) refers to the coefficient between power facility investment and power capacity. To determine coefficient \( b \), historical annual investment and its corresponding capacity increment of power facility should be calculated.

3.2. Benefit of demand response in promoting renewable energy consumption
Through introducing demand response, the utilization of renewable energy could be significantly improved, which could alleviate the pressure of thermal power plant in peak load regulation. Also, the flexibility of demand response could incorporate the uncertainty of renewable energy, which contributes to the operation security of power system. The increment value of renewable energy consumption through demand response could be calculated as equation (3).

\[ Q_{re} = C_{dr} \times T \]
3.3. Benefit of demand response in energy conservation and emission reduction

The energy conservation and emission reduction benefits of demand response are mainly reflected in two aspects. First, the benefits brought by saving investment and construction of power facilities. Second, the equivalent benefits of energy conservation and emission reduction brought by renewable energy consumption. The above two benefits could be calculated as equation (4) and (5).

\[ E_i = M_i \times c \]  
\[ E_{re} = Q_{re} \times d \]  

Where \( E_i \) and \( E_{re} \) refer to the energy conservation and emission reduction benefit brought by demand response. Parameters \( M_i \) and \( Q_{re} \) could be calculated by equation (2) and (3) respectively. Coefficients \( c \) and \( d \) are the emission reduction factor determined from historical statistics.

4. Case Study and Conclusions

Based on the proposed social and economic evaluation methods of demand response, this article simulates the application benefit of demand response in China. Under the direction of National Development and Reform Commission, this article proposes three different cases in the simulation, i.e. the reaction ability of demand response to satisfy 1%, 3%, 5% of peak load. According to the parameters in three different cases, the social and economic benefit of demand response could be calculated as follows.

According to historical statistics of power facility investment in different provinces of China, the average coefficient \( b \) is nearly 8.9 million/MWh. Under different reaction ability cases, the benefits of demand response in saving power system investment are 79.4, 238.3 and 397.2 billion when demand response reaction ability is able to satisfy 1%, 3% and 5% of the peak load. Specifically, the provinces with better economic foundation and greater adjustable potential will bring greater social and economic benefits from demand response, and the benefits of the eastern region are significantly higher than those of the central and western regions.

Based on the operation situation of demand response in pilot provinces like Shanghai, Zhejiang, Shandong, et al, the annual typical available hours of demand response \( T \) is 20 hours. Thus, the benefits of demand response in promoting renewable energy consumption are 0.18, 0.54 and 0.89 billion kWh under different reaction ability cases. Take the renewable energy curtailment volume of China in 2019 as an example, the deployment of demand response could help reduce nearly 5% of renewable energy curtailment.

For the benefit of demand response in energy conservation and emission reduction, emission reduction factors \( c \) and \( d \) are 132 ton of carbon dioxide per million Yuan and 335.7 gram of carbon dioxide per kWh according to historical statistics. As a result, the reduced carbon dioxide emissions are 11.09, 33.27 and 55.42 million tons, which could effectively contribute to the low-carbon transition of China.

As a conclusion, the deployment of demand response in China not only demonstrates economic profit for power system, but also has tremendous effect on environment protection. As a key to low-carbon transition of China and an effective method to improve the operation security and flexibility of power system, the technology of demand response deserves wide application and further research.

Acknowledgments
The work described in this paper was supported by Science and technology project of State Grid Energy Research Institute “Research on economic and technological evaluation and risk control system of virtual power plant project” (SGNY202007015).
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