Residential Demand Response Potential Evaluation in Shandong Province

Bo Xu*, Fuqiang Zhang
State Grid Energy Research Institute Co., Ltd., Beijing, China
*Corresponding author’s e-mail: xubo@sgeri.sgcc.com.cn

Abstract. Demand response can promote the stable operation of power system and reduce the operation costs. With the aid of demand response, we can reduce the peak load of power system, slow down power grid investment, and improve power system operation efficiency. Based on the investigation of load characteristics and demand response implementation status in Shandong province, this paper proposes a method to evaluate the demand response potential of residential air conditioning loads. In the case study, the demand response potential of residential air conditioning loads in the future is evaluated, which can clarify the scale and source of expected demand response resources in Shandong province.

1. Introduction
In recent years, how to accelerate the development of clean energy, improve energy efficiency and optimize energy structure has become the focus of the world [1]. As the main carrier of energy resources, power system plays an important role in achieving optimal energy allocation. In an increasingly competitive electricity market, improving the operation efficiency of power system has become an important problem in China. In Shandong province, the contradiction between power supply and demand is becoming acute increasingly. Implementation of demand response will become an important breakthrough to ease the contradiction between power supply and demand.

Demand response means that consumers can change their electricity consumption behaviors based on price signals or incentives to reduce (increase) power consumption. By implementing demand response, the peak load of power system can be shaved. The development of the smart grid and power internet of things has realized the sharing of multi-source data and provided a large amount of data resources for analyzing characteristics of consumer behaviors. Demand response potential refers to the resources that can use technical means to achieve control and management goals. A lot of research has been done on demand response potential evaluation. Li Yaping proposed potential evaluation methods for different types of demand response projects [2]. Pan Fan studied the demand response potential in Guangdong province by considering traditional demand side management, user interaction and electric vehicle [3]. Wang Jingmin calculated the demand response potential of various industries in Hebei province [4]. Generally speaking, how to evaluate the demand response potential is still under constant exploration.

In this paper, based on the investigation of the power load characteristics in Shandong province and the current status of demand response, we focus on the demand response potential of residential users, and evaluate future demand response potential in Shandong province. This paper is composed of six sections. In Section 2, some domestic demand response practices in China are reviewed. In Section 3, demand response potential evaluation scope in this paper is given. In Section 4, demand response potential evaluation method is proposed. In Section 5, the proposed method is applied to Shandong
province. The paper concludes in Section 6.

2. Domestic demand response practices review
According to statistics, since 2014, peak-shaving demand response has been successively implemented in Shanghai, Beijing, Jiangsu, Zhejiang and other provinces in China. The scale of the response load accounted for 4% of the peak load.

On July 9, 2014, Shanghai became the first city in China to implement demand response, with a response load of approximately 55,000 kilowatts.

On August 12, 2015, Beijing’s load integrators and power users were mobilized to participate in the project implementation, reducing the total power load by about 70,000 kilowatts, accounting for 0.4% of the peak load on the day.

On July 21-22, 2017, Zhejiang province successfully implemented the first demand response with a cumulative response time of 4 hours. Some cement production enterprises actually responded to a load of 51,000 kilowatts, and transferred a total of about 204,000 kilowatt-hours, effectively guaranteeing residents’ air-conditioning electricity consumption.

3. Demand response potential evaluation scope
According to different response time, demand response can be divided into interruptible load management and direct load control management [5-7]. Among them, the interruptible load management is usually for industrial users, with the advantages of relatively concentrated execution objects and large execution capacity per user. Direct load control management is applicable to residential users and commercial users. It mainly controls devices such as air conditioners and refrigerators that do not seriously affect the quality of power supply due to short-term power outages. This paper evaluates the demand response potential of residential users in Shandong province. Residential users can participate in demand response through household appliances such as refrigerators, air conditioners, and electric water heaters. In this paper, we mainly focus on air conditioners. In reality, the direct load control management of air conditioners for a single user is generally less than 30 minutes, which has almost no impact on human comfort.

4. Demand response potential evaluation method
In the literature, the current demand response potential evaluation methods mainly consist of bottom-up method, electricity consumption process analysis method and price elasticity coefficient method [6-7]. Among them, the bottom-up method uses typical user load curves as samples to evaluate the demand response potential. The demand response potential is summarized from the bottom up, and the evaluation process is roughly divided into the following three steps.

4.1 Peak load forecast
In order to forecast the peak load of the whole society, firstly, we collect typical sample users to investigate the load characteristics of the whole society. And then, we compute the average daily load rate of different users based on the load rate of each typical sample user. Finally, based on the annual total electricity consumption of the whole society, the peak load of the whole society in the future years can be computed as

\[ P_{all}^t = \frac{E_{all}^t}{8760K_{all,p}^t} \]  

Where \( t \) represents the future year, \( P_{all}^t \) represents peak load of the whole society in year \( t \). \( E_{all}^t \) represents total electricity consumption in year \( t \), which can be predicted using regression analysis based on historical data. \( K_{all,p}^t \) represents the average daily load rate of the whole society.

The air conditioning loads can be estimated according to the number of air conditioners of residents.
The peak load of air conditioners is formulated as

\[ P_{ac} = \sum_{i=t}^{2} \frac{N_{1_{i_{ac}}}^{i_{i_{0}}} \psi_{i_{1_{ac}}}^{i_{i_{ac}}} (1+\rho_{i_{1_{ac}}})^{i_{i_{0}}}}{i_{i_{ac}}} P_{ac} \]  

(2)

Where \( N_{1_{i_{ac}}}^{i_{i_{0}}} \) represents the number of city residents in year \( t_{0} \). \( N_{2_{i_{ac}}}^{i_{i_{0}}} \) represents the number of rural residents in year \( t_{0} \). \( \rho_{i_{1_{ac}}} \) is the growth rate of the number of residents. \( \psi_{i_{1_{ac}}}^{i_{i_{ac}}} \) represents the household air conditioner percentage in year \( t_{i} \). \( P_{ac} \) is the average load of an air conditioner.

4.2 Evaluate load curtailing effect

The user load curtailing effect refers to the average load curtailing rate \( f_{ac} \) during the peak period when some residential users perform demand response, and is expressed as the ratio of the user’s load curtailing amount to the peak load. Through evaluation of typical sample users, the average load curtailing effect of typical sample users is used to represent the load curtailing effect of all the residents.

4.3 Evaluate the demand response potential

The demand response potential of residential users is also related to their participation rates. Factors that affect the demand response participation rates include smart meter installation rates and incentive measures. The user’s participation has the characteristics of stage development, and gradually improves with the continuous improvement of technology and market mechanism. Demand response potential of residential users is formulated as

\[ F = P_{ac} \cdot f_{ac} \cdot \alpha_{ac}^{i_{i_{ac}}} \]  

(3)

Where \( F \) represents demand response potential of residential users. \( \alpha_{ac}^{i_{i_{ac}}} \) represents the residential user participation rate in year \( t_{i} \).

5. Case studies

Demand response mainly depends on the effect of user load curtailing. In recent years, Shandong province has launched a series of demand response projects and gained some experience in the implementation of demand response. For residential users, air conditioners participate in the demand response by increasing the operating temperature. According to our investigation, when the air conditioning temperature is increased by 1 \( ^{\circ} \)C, the average power of a single air conditioner will decrease by 10%. Thus, assume that the load curtailing rate of residential users is 10%.

As demand response potential depends on user participation rate, this paper combines domestic and foreign practices to estimate the participation rate of residential users. It is assumed that the participation rate will gradually increase from 2020 to 2035. Table 1 shows the evaluation of demand response participation rate of residential users.

| Residential users | 2025 | 2035 |
|-------------------|------|------|
|                   | 25%  | 40%  |

We obtain the historical power consumption data during year 2011-2018 (Fig.1 and Fig.2). Based on regression analysis, the electricity consumption of the whole society from 2020 to 2030 is predicted, and then the peak load can be computed using equation (1).
Also, we obtain the historical data of household air conditioner percentage in Shandong province which can be seen in Fig. 2. By predicting future air conditioner percentage, the peak load can be computed using equation (2).

Using equation (3), the demand response potential of residential users in 2025 and 2035 are evaluated. The evaluation results are shown in Table 2. It can be seen that without considering demand response, the peak load of Shandong power grid will exceed 138000 MW in 2025. Through demand response, 3040 MW load can be reduced, accounting for 2.2% of the peak load. By 2035, the potential of demand response is expected to be further increased to 6900 MW, accounting for 4.1% of the peak load.

| Year | Peak load / MW | Demand response potential / MW | Peak load cut ratio /% |
|------|----------------|-------------------------------|-----------------------|
| 2025 | 138000         | 3040                          | 2.2%                  |
| 2035 | 168000         | 6900                          | 4.1%                  |

6. Conclusions
In Shandong province, demand response potential of residential users is very huge. However, Shandong still has some challenges in the implementation of demand response. In the future, we need to focus on the following aspects:
(1) Establish demand response special funds. Demand response requires a large investment in the early stage, and it is necessary to establish a stable source of special funds for the implementation of demand response.

(2) Encourage all parties to participate in demand response. In order to increase demand response participation, we should improve relevant policies and regulations to further improve the legal status of demand response. Improve demand response subsidy reward mechanism and build a long-term implementation mechanism of demand response based on market demand.

Acknowledgments
This work is supported by State Grid Corporation of China Project (SGSDJY00GPJS1900179).

References
[1] Sun Hongbin, Guo Qinglai, Pan Zhaoguang, et al. Energy internet: driving force, review and outlook[J]. Automation of Electric Power Systems, 2015, 39(11): 3005-3013.
[2] Li Yaping, Wang Ke, Guo Xiaorui, et al. Demand response potential based on multi-scenarios assessment in regional power system[J]. Power System and Clean Energy, 2015, 31(7): 1-7.
[3] Pan Fan, Jia Wenzhao, Xu Baiting, et al. Analysis on demand side response potential of Guangdong power grid[J]. Electric Power, 2011, 44(12): 21-25.
[4] Wang Jingmin, Wen Yuqian, Chen Lin. The potential analysis and measures research of Hebei electric power load management[J]. Power Demand Side Management, 2009, 11(1): 32-34.
[5] Kong Xiangyu, Yang Qun, Mu Yunfei, et al. Analysis method for customers demand response in time of using price[J]. Proceedings of the CSU-EPSA, 2015, 27(10): 75-80.
[6] Yang Xuying, Zhou Ming, Li Gengyin. Survey on demand response mechanism and modeling in smart grid[J]. Power System Technology, 2016, 40(1): 220-226.
[7] Zeng Ming, Li Na, Wang Tao, et al. Load forecasting compatible with demand-side resources[J]. Electric Power Automation Equipment, 2013, 33(10): 59-62, 73.