Market-Oriented Consumption Model Based on the Joint Tracking of Renewable Energy Generation Curve of "Shared Energy Storage & Demand Side Resources"

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Abstract. The fluctuation of renewable energy output brings many challenges to the operation of power system, which also indirectly affects the consumption of renewable energy. This paper proposes a market-oriented consumption model based on "shared energy storage and demand side resources" to track renewable energy generation curve. This paper combs the benefits of each party when participating in the transaction, and gives an example to illustrate how the parties benefit from the transaction. The market transaction mode proposed in this paper can enhance the user's adaptability to renewable energy output by using energy storage equipment; additionally, it can avoid the risk of building energy storage facilities due to participation in the transaction. This provides a feasible idea for further improving the capacity of renewable energy consumption in China.

1. Introduction

"Shared energy storage demand side resources" is a market-oriented consumption mode that jointly tracks the generation curve of renewable energy, and encourages users with demand response resources and renewable energy producers in the province to trade in the electricity market [1]. Figure 1 shows the basic flow of the transaction pattern.

By reaching an agreement, the precise consumption of renewable energy on the user side can be realized [2]. The contract mainly stipulates the specific scheme for the user to track the renewable energy generation curve and the preferential electricity price for the user to absorb this part of abandoned electricity. After the contract is signed, it will be transmitted to the power dispatching center for security audit. According to the contract, users can actively track the curve of renewable energy abandonment to ensure that all the abandoned electricity is consumed. In this process, users will get the renewable energy quota index corresponding to the consumption amount. On the settlement day, both parties of the transaction shall settle the relevant expenses according to the actual consumption amount. In order to avoid the risk of default, users and renewable energy generators should strictly abide by the contract. When the expected deviation may occur, the user can sign a service contract with the investor of shared energy storage equipment. Both parties agree on the use
scheme of power and capacity of energy storage equipment. Investors of energy storage equipment earn income and return on investment by providing the right to use energy storage equipment for these two types of users.

Figure 1. "Shared Energy Storage & Demand Side Resources" Jointly Tracking the Market-Oriented Consumption Trading Mode of Renewable Energy Generation Curve

2. Economic benefit analysis of all parties

2.1. Benefit analysis of renewable energy power producers

In order to ensure the security of national power grid, renewable energy can not be fully absorbed, which leads to a considerable proportion of waste. According to industry statistics, in the first half of 2019, the wind power curtailment in China reached 10.5 billion kWh, which is equivalent to one tenth of Beijing's total power consumption in 2019 [3]. The fixed cost of renewable energy power generation is high and the variable cost is small, so the unit marginal contribution is large. If this part of the abandoned electricity is further absorbed by the market, it can make up for its fixed cost and even generate excess income. It is assumed that through this transaction mode, the electricity consumption of abandoned wind, light and water can reach $N_1$, $N_2$, $N_3$, kWh; the unit marginal contribution is $\mu_1$, $\mu_2$, $\mu_3$, yuan / kWh; and the energy storage cost is $C_1$, $C_2$, $C_3$, yuan. Then the excess income of renewable energy producers can be calculated according to the formula (1).

$$ M = \sum_{i=1}^{3} \mu_i N_i - C_i $$

2.2. User benefit analysis

The revenue of users participating in the transaction of tracking renewable energy generation curve consists of two parts. One part comes from the difference between the contract negotiation quotation and the market price or catalog price; the other part comes from the sales of excess renewable energy quota. Then the daily income that users can get from participating in this transaction can be calculated according to the following formula.

$$ R_m = (P_1 - P_2) \cdot Q_m + R^* - C_{ESN} $$

Where $P_1$ is the directory price of a certain user, $P_2$ is the contract price of participating in tracking renewable energy generation curve transaction, yuan / kWh. In order to simplify the problem analysis, it is assumed that both $P_1$ and $P_2$ have included the transmission and distribution tariff and corresponding government funds and surcharges. $Q_m$ is the daily consumption, kWh. $R^*$ is the
income from the transfer of excess renewable energy quota, yuan. $C_{ESN}$ is the user's energy storage cost, yuan.

2.3. Benefit analysis of energy storage equipment investors

Energy storage industry is an important link to realize energy Internet and the last kilometer to promote the development of renewable energy. It has broad application prospects in power generation, transmission and distribution, power demand side, auxiliary services, renewable energy access and other fields [4-6]. However, the investment in energy storage facilities is large and the return period is long. When there is no clear market return mode, the risk of investment is high. Therefore, the market has an obvious wait-and-see attitude. In order to improve the return of energy storage equipment investors, the first problem to be solved is to improve the utilization of energy storage equipment. Shared energy storage is profitable by providing energy storage charging and discharging services to energy storage users and charging usage fees, which improves the equipment utilization rate and makes up for the fixed cost [7]. Under the market consumption mode of joint tracking, the income of energy storage equipment investors comes from two parts. One is the equipment use fee paid by renewable energy power generation companies, the other is the equipment use fee paid by users. That is the sum of $C_{REC}$ and $C_{ESN}$.

3. Example

Suppose a user has two kinds of adjustable resources: central air conditioning and electric vehicle. The adjustable range of central air conditioning system is 1500kW-2200kW. The working hours of electric vehicles are 7:00-9:30 and 17:30-19:30, and the rest of the time can be charged. The total daily demand of electric vehicles is 12000 kWh. Assuming that the market power price is 1 yuan / kWh, the contract price is 0.7 yuan / kWh. The best tracking scheme can be calculated based on the principle of maximizing the user's income. Table 1 shows the best scheme for a certain user to track the wind power curve on a certain day.

| Time | Wind power generation | Central air-conditioning | Electric vehicle | Energy storage | Time | Wind power generation | Central air-conditioning | Electric vehicle | Energy storage |
|------|-----------------------|--------------------------|------------------|----------------|------|-----------------------|--------------------------|------------------|----------------|
| 1    | 1726                  | 0                        | 2000             | -274           | 13   | 2204                  | 1620                     | 0                | 584            |
| 2    | 2589                  | 0                        | 2000             | 589            | 14   | 1596                  | 2100                     | 0                | -504           |
| 3    | 1138                  | 0                        | 2000             | -862           | 15   | 1505                  | 1520                     | 0                | -15            |
| 4    | 809                   | 0                        | 2000             | -1191          | 16   | 1890                  | 1520                     | 0                | 370            |
| 5    | 397                   | 0                        | 0                | 397            | 17   | 2759                  | 1720                     | 0                | 1039           |
| 6    | 821                   | 0                        | 0                | 821            | 18   | 2103                  | 2120                     | 0                | -17            |
| 7    | 370                   | 0                        | 0                | 370            | 19   | 1621                  | 0                        | 0                | 1621           |
| 8    | 2101                  | 2200                     | 0                | -99            | 20   | 793                   | 0                        | 0                | 793            |
| 9    | 964                   | 2140                     | 0                | -1176          | 21   | 931                   | 0                        | 0                | 931            |
| 10   | 1785                  | 2200                     | 0                | -415           | 22   | 342                   | 0                        | 0                | 342            |
| 11   | 1011                  | 1620                     | 0                | -609           | 23   | 1276                  | 0                        | 2000             | -724           |
| 12   | 1009                  | 1720                     | 0                | -711           | 24   | 740                   | 0                        | 2000             | -1260          |

From the assumptions and the data in Table 1, the following conclusions can be drawn.

(1) Through this transaction, wind power companies sold 32480 kWh of abandoned electricity and obtained a profit of 22736 yuan.

(2) Through this transaction, users saved 7063 yuan of electricity charges. According to the catalogue price, the user should have paid 32480 yuan. However, by consuming the abandoned wind power, users get preferential electricity price. Although users pay 2681 yuan for energy storage equipment, they still benefit.
(3) Through this transaction, the investor of energy storage equipment gains 2681 yuan, which comes from the use fee of energy storage equipment paid by users.

(4) Through this transaction, all the participants have gained profits, which can prove the feasibility of the model.

4. Conclusion
The market-oriented consumption model proposed in this paper can fully tap the regulatory potential of demand side resources, and optimize the allocation combined with shared energy storage. The model provides a solution to realize the instant response to renewable energy output. Through the model benefit analysis, we can see that the market-oriented consumption model can mobilize the enthusiasm of all parties to participate, so as to promote renewable source consumption. In order to promote the development of the model, this paper discusses the related problems in its promotion.

(1) Requirements for participating users. First, users should actively grasp their own electricity demand, carry out the statistics, analysis and prediction of their own load data as soon as possible, so as to provide data support for participating in tracking curve trading. Second, users should comprehensively analyse the characteristics of demand side resources, master their adjustment ability and safe use range, and give full play to their role in curve tracking.

(2) Areas suitable for this model. At present, the mode is suitable for developing in regions with large renewable energy power generation capacity, which can fully guarantee the market trading capacity and activity, and provide the market basis for the development of the mode. At the same time, the mode is suitable for carrying out nearby, that is, encouraging the local consumption of renewable energy or trading with surrounding provinces and cities. Long distance transmission is short of response speed and transaction convenience, which is not conducive to the full consumption of renewable energy. With the continuous construction and improvement of the power system and the gradual development of the power market, the long-distance curve tracking transaction can be carried out gradually.

Acknowledgment
This paper is supported by project named "Research and Application of Key Technologies for Interactive Trading among Renewable Energy, Power Users and Energy Storage Business" of "State Grid Corporation Headquarters Science and Technology Project".

References
[1] Fabian S., Robert B., Robert S., Russell M., Thomas B. (2020) Competition between simultaneous demand-side flexibility options: the case of community electricity storage systems. Applied Energy,269.
[2] Luka P., Tomislav C., Hrvoje P., Marko D. (2017) Integration of Renewable Energy Sources in Southeast Europe: A Review of Incentive Mechanisms and Feasibility of Investments. Renewable and Sustainable Energy Reviews.
[3] Song M., Gao C., Su W. (2016) Air conditioning load modeling and control for demand response applications. Automation of Power Systems,40 (14): 158-167
[4] Hao M., Zhang W., Dong Q., et al. (2020) Optimization of multi-user shared energy storage system under complex factors. Information and Control,49 (02): 242-248
[5] Sun X., Chen L., Qiu X., et al. (2019) Generation side shared energy storage planning model based on cooperative game. Journal of Global Energy Interconnection, 2 (04): 360-366
[6] Sun X., Zheng T., Chen L., et al. (2020) Study on shared energy storage mechanism based on combinatorial double auction. Power System Technology, 44 (05): 1732-1739
[7] Yang J., Xia Y., Wang Y., et al. (2020) Clearing model and pricing method of energy storage right in electricity market environment. Power System Technology, 2020,44 (05): 1750-1759