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RESEARCH ON OPTIMIZATION SCHEDULING STRATEGY OF DISTRIBUTION NETWORK CONGESTION WITH ELECTRIC VEHICLES

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ABSTRACT

Large-scale centralized charging of electric vehicles is likely to cause congestion phenomena such as line overload and voltage drop. A scheduling optimization scheduling strategy for distribution network congestion management considering electric vehicles charging load is proposed. Establish a multi-objective optimization model of three stakeholders including grid center, electric vehicle aggregator and electric vehicle user, and design the objective function according to their actual operating conditions. The non-dominated sorting genetic algorithm-II (NSGA-II) is used to solve the Pareto non-dominated solution set, and the Topsis method is used to determine the optimal solution. The case analysis part of the article proves that the proposed strategy can eliminate congestion by comparing the response results before and after optimization. The cost-benefit analysis proves that the strategy can reduce the running cost and increase the profit to some extent.

Keywords: electric vehicle, distribution network congestion, multi-objective optimization, NSGA-II, Topsis

1. INTRODUCTION

With the increasing environmental and energy problems, electric vehicles as a new type of green transportation are increasingly valued by society. When electric vehicles are introduced to the market on a large scale and most electric vehicle users have similar travel time, it will lead to a high charging peak in some periods, and result in problems such as distribution line and transformer overload. In severe cases, network congestion will occur. Most of the existing researches use electricity prices as an incentive to guide users to make electricity plans rationally. Literature [1] proposes an active distribution network congestion scheduling model that takes into account the charging/discharging service fee adjustment. Literature [2] considers the interruptible load participating in the congestion management and constructs the DC optimal flow model of coordinated unit output adjustment and interruptible load scheduling. In [3], the optimization of the operating cost of the active distribution network with large-scale electric vehicle and the minimization of the variance of the load curve are taken as the optimization objectives, and the multi-objective optimal scheduling model of the active distribution network is constructed.

Based on the above research, this paper constructs a distribution network congestion optimization-scheduling model, and optimizes the power consumption by adjusting the charging load of electric vehicles in different periods. At the same time, the article introduces congestion price as an economic means, and imposes certain penalties on the power consumers that cause congestion in the distribution network to further regulate the charging behavior of electric vehicle loads.

2. DISTRIBUTION NETWORK CONGESTION SCHEDULING MODEL

2.1 Objection function

In the actual distribution network, in order to reduce the network congestion caused by the disorderly charging of large-scale electric vehicles, the grid center needs to formulate the operation plan in advance, and ensure the safety and economy of the distribution network. The current distribution network generally adopts the three-level control architecture scheme of the grid center-load aggregator-electricity user. This paper adopts a similar control scheme, considering the three stakeholders of the grid center, electric vehicle aggregator, and electric vehicle user to maximize their benefits. The objective functions are designed as follows.

2.1.1 Grid center

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The grid center hopes to minimize its integrated operating costs. The comprehensive operating cost consists of three parts: the network loss cost f_{Loss}, the electricity purchase cost f_{Gen}, the electricity sales revenue and the subsidy cost of dispatching the electric vehicle aggregator to participate in the optimization of the distribution network operation f_{EVPop}. The cost of purchasing electricity can be divided into the cost of purchasing electricity from the upper power grid f_{Grid} and DG f_{DG}.

$$\min f_{\mathrm{Net}}(t)=\sum_{t=1}^{N_{\mathrm{d}}}(f_{\mathrm{Grid}}(t)+f_{\mathrm{DG}}(t)+f_{\mathrm{Loss}}(t)+f_{\mathrm{EVPop}}(t))$$
$$f_{\mathrm{Grid}}(t)=C_{\mathrm{Grid}}(t)P_{\mathrm{Grid}}(t)\Delta t$$
$$f_{\mathrm{DG}}(t)=C_{\mathrm{DG}}(t)P_{\mathrm{DG}}(t)\Delta t \quad (1)$$
$$f_{\mathrm{Loss}}(t)=C_{\mathrm{Grid}}(t)P_{\mathrm{Loss}}(t)\Delta t$$
$$f_{\mathrm{EVPop}}(t)=\sum_{i=1}^{N}C_{\mathrm{Sub},i}(t)\Delta P_{\mathrm{Pop},i}(t)-C_{\mathrm{C},i}(t)P_{\mathrm{Pop},i}(t)$$

where $C_{\mathrm{Grid}}(t)$ and $C_{\mathrm{DG}}(t)$ represent the electricity price from the grid and from the DG, respectively; $P_{\mathrm{Loss}}(t)$ $P_{\mathrm{Grid}}(t)$ and $P_{\mathrm{DG}}(t)$ respectively represent the network loss of the distribution network, the power purchased from the grid and from the DG, and N_{d} represents the number of schedulable periods, Δt represents the simulation interval . For the meaning of each symbol in f_{EVPop}, please refer to 2.1.2.

2.1.2 Electric vehicle aggregator

On the one hand, electric vehicle aggregators purchase electricity from the grid center; on the other hand, aggregators accept dispatching from grid center to provide auxiliary services for distribution network. In order to increase the enthusiasm of aggregators, the grid center must pay subsidies to the aggregators, which are profitable parts for them. Similarly, aggregators should pay a certain amount of compensation to electric vehicle users. Therefore, the objective function of the electric vehicle aggregators are designed as follows:

$$\max f_{\mathrm{Pop}}=\sum_{i=1}^{N}\sum_{t=1}^{N_{\mathrm{d}}}\left(\begin{array}{l}\left(C_{\mathrm{Sub},i}(t)-C_{\mathrm{sub},i}(t)\right)\Delta P_{\mathrm{Pop},i}(t)+\\\left(\beta(t)-\beta^{'}(t)\right)P_{\mathrm{Pop},i}(t)-C_{\mathrm{con},i}(t)\end{array}\right)\Delta t \quad (2)$$

where N is the number of aggregators. $\Delta P_{\mathrm{Pop},i}(t)$ represents the charging power adjustment amount of the *i*-th aggregator at time *t*, which can be obtained by formula (3). $P_{\mathrm{Pop},i}(t)$ is the power that the *i*-th aggregator actually purchases from the grid at time *t*. $C_{\mathrm{Sub},i}(t)$ is the subsidy price of the grid to the *i*-th aggregator; $C_{\mathrm{sub},i}(t)$ is the subsidy price for the *i*-th aggregator to the electric vehicle users in its jurisdiction; $\beta(t)$, $\beta^{'}(t)$ are the electricity price of the user's and aggregator' s, and $C_{\mathrm{con},i}(t)$ is the blocking price, indicating that the grid center punishes the aggregator that causes the distribution network to block.

$$\Delta P_{\mathrm{Pop},i}(t)=P_{\mathrm{Pop},i}(t)-P_{\mathrm{Pop},i}^{'}(t) \quad (3)$$

2.1.3 Electric vehicle users

Electric vehicle users need to purchase electricity from the electric vehicle aggregator to meet their own travel needs, and users accept the dispatch of the aggregators in their leisure time, and they should also be paid subsidies. At the same time, for the sake of their own needs, the users expect that the amount of adjustment is minimized while accepting the scheduling, thereby ensuring the least impact on the user's travel demand. Therefore, the electric vehicle users have the objective function of minimizing their own travel costs, which can be expressed as follows:

$$\min f_{\mathrm{EV}}=\sum_{i=1}^{N_{\mathrm{EV}}}\beta(t)P_i+C_{\mathrm{sub}}(t)(P_i-P_i^{'}) \quad (4)$$

where, $P_i^{'}$ and P_i are the charging power before and after adjustment of the *i*-th electric vehicle user, and N_{EV} is the number of electric vehicle users.

The second term represents the subsidy paid by the aggregator to the user. Considering that the user wants the minimum adjustment amount, the negative sign is changed to the plus sign.

2.2 Congestion price adjustment strategy

Assume that a line *k* with transmission limit $P_k^{\max}$ in the distribution network has a blocking phenomenon at time *t* and the transmission power of this line is $P_{k,t}$, so the minimum power reduction $P_{k,t}^{\mathrm{cut,min}}$ of the line is calculated as follows:

$$P_{k,t}^{\mathrm{cut,min}}=P_{k,t}-P_k^{\max} \quad (5)$$

The power flow tracking technology is used to obtain the distribution of the power demand of the electric vehicle aggregator for the line, that is, the power distribution factor of the line to the *N* electric vehicle aggregators $\lambda_{1,t},\lambda_{2,t},\ldots,\lambda_{N,t}$. The larger the power distribution factor of an electric vehicle aggregator, it means that the more power the aggregator receives from the line, the greater the responsibility for the line blockage, and the more severe the grid center should punish.

The grid center should sign a contract with each electric vehicle aggregator in advance and stipulate that the penalty price per unit of the power of the over-limit part is δ, then the congestion cost of the *i*-th electric vehicle aggregator is calculated as follows:

$$C_{\text{con},i} = \lambda_{i,t} \cdot P_{k,t}^{\text{cut,min}} \cdot \delta \tag{6}$$

2.3 Restrictions

2.3.1 System power balance constraint

$$P_{\text{DG}}(t) + P_{\text{Grid}}(t) = P_{\text{Base}}(t) + P_{\text{EV}}(t) + P_{\text{Loss}}(t) \tag{7}$$

where $P_{\text{Base}}(t)$ indicates the base load of the distribution network, that is the original load when the electric vehicle is not connected to the grid.

2.3.2 Electric vehicle charging power constraint

$$P_{\text{EV},i}^{\min} \le P_{\text{EV},i} \le P_{\text{EV},i}^{\max} \tag{8}$$

where $P_{\text{EV},i}^{\max}$ and $P_{\text{EV},i}^{\min}$ represent the upper and lower limits of the charging power adjustment of the *i*-th electric vehicle aggregator, respectively.

2.3.3 Line transmission power constraint

$$L_{m,n}^{\min} \le L_{m,n} \le L_{m,n}^{\max} \tag{9}$$

where $L_{m,n}^{\max}$ and $L_{m,n}^{\min}$ represent the upper and lower transmission power limits of the line between node *m* and node *n*, respectively.

2.3.4 Node voltage constraint

$$V_k^{\min} \le V_k \le V_k^{\max} \tag{10}$$

where $V_k^{\max}$ and $V_k^{\min}$ represent the maximum and minimum values of the voltage amplitude of node *k*, respectively.

2.3.5 Safety constraint

A primary device in the distribution network can be allowed to operate within a certain time range, and beyond this time range, the safe operation of the device can be adversely affected.

$$T_{k,t} < T_{\text{Limit},k} \tag{11}$$

where $T_{k,t}$ is the time that the line *k* is blocked for the duration, and $T_{\text{Limit},k}$ is the maximum allowable time for the line *k* to run beyond the limit.

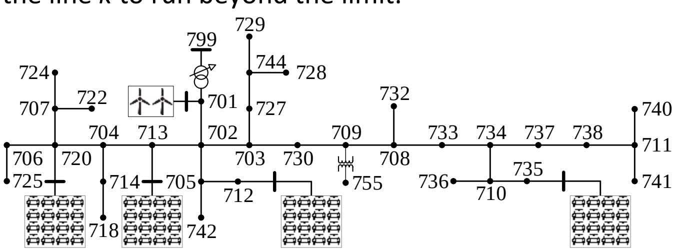

Fig 1 Modified IEEE 37 Node System

2.4 Optimization model solving method

In this paper, the non-dominated sorting genetic algorithm-II (NSGA-II) is used to solve the multi-objective optimization model and obtain the Pareto non-dominated solution set. In order to find the optimal solution, this paper uses the Topsis method to determine the optimal solution from the Pareto solution. For detailed steps, please refer to the literature [4]. In addition, this paper uses the electric vehicle cluster response strategy in [5].

3. CASE STUDY

The case uses the IEEE37 node system to verify the effectiveness of the optimization strategy. In this paper, four electric vehicle groups are set up, which are connected to 712, 713, 720, and 735 nodes, as shown in Fig 1. A wind farm is connected to the 701 node. The simulation time is from 6 am to 6 am the next day, and the simulation interval is 15 minutes. For the initialization parameters of electric vehicles, please refer to the literature [5]. Fig 2 shows the time-of-use electricity price. The population size of the genetic algorithm is 100. The number of evolution is 500. The probability of crossover and variation is 0.9 and 0.1.

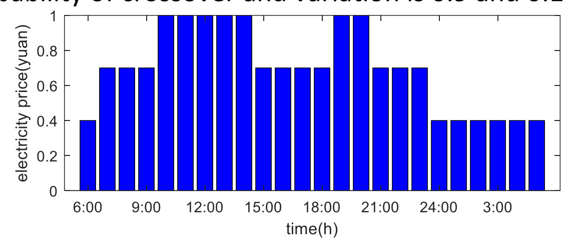

Fig 2 Time-of-use electricity price

The simulation results and analysis are as follows.

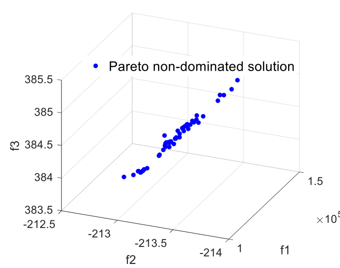

Fig 3 Pareto solution set

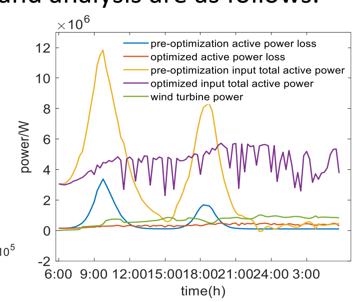

Fig 4 Line power information

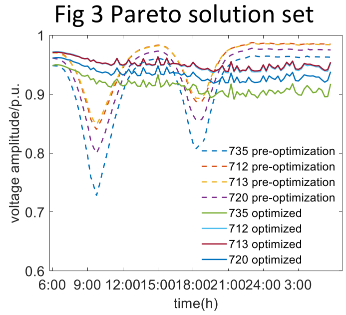

Fig 5 Node voltage information

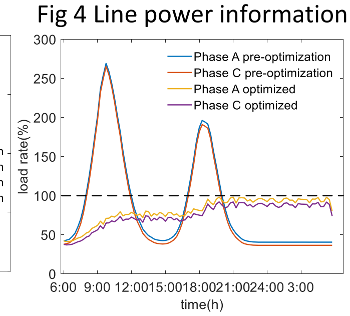

Fig 6 Load rate of line 701702

At a certain moment, the Pareto non-dominated solution set is shown in Fig 2. The power flow and the voltage of load node is shown in Fig 4 and Fig 5. Fig 3 indicates the load rate of phase A and phase C of Line701702 before and after optimization.

Fig 7 represents the charge curve of 4 aggregators before and after optimization. It can be seen that compared with the pre-optimization charging curve, the charge peak of the aggregator is eliminated after optimization and the charging curve can accurately track the target power curve. The optimization result of the strategy is better.

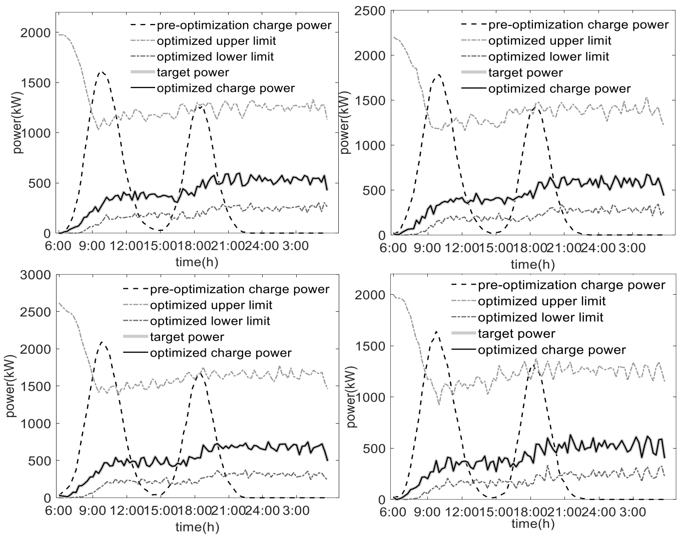

Fig 7 Charging curve of aggregators before/after optimization

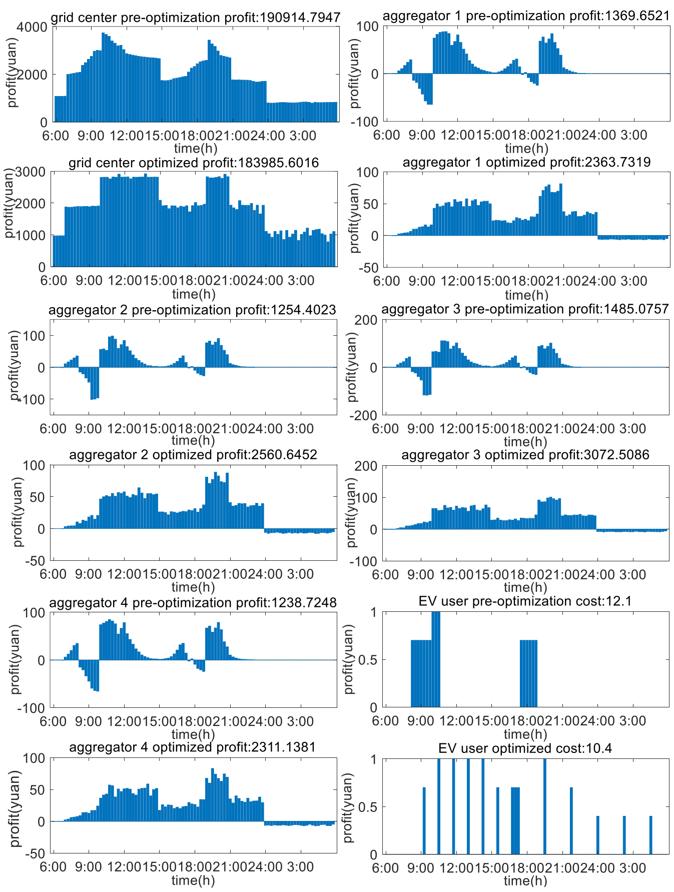

Fig 8 Cost/profit of all stakeholders before/after optimization

Fig 8 shows the profit or cost of all stakeholders in the distribution network before and after optimization. The optimized profit of grid center decreases compared with pre-optimization. There are two reasons. On the one hand, due to the existence of congestion, the profitability of the grid center is high. On the other hand, the grid center has to pay a certain fee to the load aggregator, resulting in an increase in its cost after optimization. The optimized profit significantly increases and the cost of user is reduced after optimization.

4. CONCLUSION

In this paper, a multi-objective optimal dispatching strategy based on electric vehicle load is proposed. The example in the paper shows that the strategy can reduce the charging peak of electric vehicles and raise the voltage level of the distribution network, thus effectively eliminating the congestion. The final cost-benefit analysis of the example shows that the strategy can improve the economics of various stakeholders. This strategy can provide a reference for large-scale electric vehicles to participate in the optimal dispatching of distribution network.

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REFERENCE

[1] Sun Hui, Shen Zhonghao, Zhou Wei et al. Congestion dispatch research of active distribution network with electric vehicle group response[J]. Proceedings of the CSEE. 2017, 37(19):5549-5559.

[2] Shi Quansheng, Li Shidong. Congestion management model and characteristics analysis with participation of interruptible load[J]. Proceedings of the CSU-EPSA. 2015, 27(7):48-53.

[3] Xiao Hao, Pei Wei, Kong Li. Multi-objective optimization scheduling method for active distribution network with large scale electric vehicles[J]. Transactions of China electrotechnical society. 2017, 32(2):179-189.

[4] Qian Wuyong, Dang Yaoguo, Xiong Pingping, et al. Topsis based on grey correlation method and its application[J]. Systems Engineering.2009, 27(8):124-126.

[5] Wang Dan, Sun Dongdong, Hu Qing'e, et al. Research of demand response of electric vehicles based on optimal energy status regulation and its impact on distribution network[J]. Electric Power Construction. 2018, 39(5):91-99.