Multi-objective Optimization Charging Strategy for Plug-in Electric Vehicles Based on Dynamic Time-of-use Price

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Abstract: With the increase of plug-in electric vehicles (PEV), the uncontrolled charging of them may pose a wide pressure on the operation of regional distribution network. In order to reduce adverse impacts of PEVs, an intelligent charging strategy for a cluster of PEVs is proposed. Considering several constraints such as the charger's maximum charging power, a multi-objective optimization scheduling model is proposed with the objectives of minimizing the total charging cost and minimizing load variance basing on dynamic time-of-use (TOU) price. The Non-dominated Sorting Genetic Algorithm II (NSGA-Ⅱ) is adopted to solve the optimization problem, and the MATLAB calculation results prove the feasibility and effectiveness of the proposed strategy. Factors such as the number of PEVs, the TOU price and the length of time-window are also analyzed to further study PEV charging load's characteristics.

1. Introduction

High permeability electric vehicle is a load that can not be ignored for power grid. Its impact on the grid must be taken into account.[1] A large number of literature research shows that a large number of electric vehicles disorderly charging will have a bad impact on the safe and stable operation of power system. This includes further increasing the peak load [2][3], reducing transformer life[4], influencing voltage quality[5], increasing the loss of network and so on[6]. In order to reduce the impact of electric vehicle load on distribution network, an intelligent scheduling strategy for electric vehicles based on realistic scenarios has become an important research topic. Reasonable electric vehicle coordinated charging strategy can better meet the interests of electric vehicle users. It is beneficial to the popularization of electric vehicles, to alleviate the environmental pollution caused by a large number of fuel oil. At the same time, it

also can stabilize the peak and off peak difference of the distribution network, and play the purpose of reducing the peak and filling the low points [7].

This paper analyzes the factors that affect the model of coordinated charging for electric vehicles. The advantages and disadvantages of the existing electric vehicle charging strategies are analyzed. At the same time, in view of some problems[8] existing in the current electric vehicle coordinated charging strategy model, the corresponding improvement measures are put forward combined with the characteristics of the real scene[9].

2. Optimal Charging Strategy for Electric Vehicles

2.1 Overview of Coordinated Charging Methods for Electric Vehicles

Whenever a new electric vehicle customers access the charging station i (i=1,2... n) charger, a charging station control system should achieve the coordinated charging station of electric vehicles in accordance with the following 3 steps.

1) Getting charging demand for electric vehicles. Through the battery management system on the electric vehicle, the charging station gets the battery capacity of the electric vehicle B_i, and the state of charge (SOC) of the battery, $S_{i,A}$,(the ratio of the current battery capacity to the total battery capacity of an electric vehicle).

2) According to the charging demand and the system running state, the time of use tariff is formulated. Electric vehicle charging station aims to realize peak shaving and off peak filling, and to meet customer charging demand and charging station transformer not overloaded as constraints. The dynamic TOU pricing for this user is formulated.

3) The interaction information between controller and power grid is mainly to obtain load forecasting information. After the controller collects the information, the charging power of each electric vehicle is obtained at each time step by optimization calculation.

2.2 Method for Formulating Time-of-use Price of User

Supposing that the rated charging power of charger i(i=1,2,…,N) in charging station is Pi, and the system changes the charging state every hour. In 1 hour, the charging characteristics of lithium batteries are considered [11]. The number of charging time needed for charging the electric vehicle with charger No. i in charge station is J_i.The parking time of the electric vehicle is T_i, calculated as follows:

$$J_i = \left\lceil \frac{\left(S_{i,desire} - S_{i,departure}\right) \times B_i}{p_i \times \Delta t \times \mu} \right\rceil$$

(1)

$$T_i = \left\lfloor t_i \Big/ \Delta t \right\rfloor$$

(2)

In the form: Δt is the length of a period of time (taking 1 hour in this article) ； μ is the

charging efficiency of the charger.

The electric vehicle charging corresponding to the required number of time period J_i, the number of parking time T_i, the charging load margin of the system in T_i time periods from the current period to the departure of the vehicle M_t (t=1,2,…,T_i) are firstly calculated:

$$M_t = A_i S_T \gamma$$

(3)

In the equation, the γ is the power factor of the charge load. If $M_t \geq P_i$ in the corresponding time period, it shows that the electric vehicle can be charged at this time. Otherwise, the electric vehicle can not be charged at this time. The greater the value of M_t, the greater the charge load margin of the corresponding period.

This can be achieved by calculating the system, from the current period of time in the parking period of the vehicle, the number H_i that charging load margin M_t (t=1,2,…,T_i) is greater than P_i:

$$H_i = |A_i|, A_i = \{t | M_t \geq P_i, t = 1, 2, \cdots, T_i\}$$

(4)

In the equation, $|A_i|$ is the number of a set of A_i elements.

Specifically, the system should follow the following expression to calculate the initial period of the peak price:

$$t_i^s = \min\left\{ \underset{t_i^s \in [i, T_i - J_i + 1], t_i^s \in N}{\arg\max} \left(\sum_{t=t_i^s}^{t_i^s + J_i - 1} M_t \right) \right\}$$

(5)

2.3 Optimal Scheduling Model

In order to comprehensively consider the impact of electric vehicle load on power grid and charging economy and to optimize the charging problem, a multi-objective optimization model is established in this paper. The two objective functions used are: the minimum total charge fee and the minimum load variance. This is conducive to the operation of power grid, so as to realize the win-win of power grid and electric vehicle owners.

2.3.1 Objective Functions

1）objective function 2: minimum charge of the total charge fee
Under the mode of TOU price, the lowest total cost of electric vehicles gives full

consideration to the user's economy. This allows the users to respond positively, so that electric vehicles are charged at a low price period, so as to achieve the purpose of peak shaving and off peak filling for the power grid.

The expression of the function:

$$\min F_1 = \min \left(\sum_{i=1}^{n} \sum_{k=1}^{t+m-1} C_k \cdot P_{i,k} \cdot \Delta t \right)$$

(6)

In the equation, n is the total number of electric vehicle charging station access. That is the total number of chargers in the charging station; m is a time window of rolling optimization, which contains several periods. C_k is the TOU price in the above scheduling period k; $P_{i,k}$ is the charging power of the i electric vehicle in the period k; t is the number of the current scheduling periods; Δt is the length of time each time, which is set to 1 hour in this paper.

2) objective function 2: the minimum variance of the total load

If the charging load of electric vehicles in the off peak is large enough, a new load peak may be formed during the low load period of the power grid. In order to prevent this from happening, second objective functions are proposed in this paper: minimum load variance. Through minimum variance in each period of the total load of electric vehicle after charging load superimposed on grid load, the load curve can be smoothed, and spinning reserve capacity units can be reduced. As for the actual system, to minimize the variance of the load will cause a loss to minimize. [10]

The expression of the objective function is expressed as follows:

$$\min F_2 = \frac{1}{m} \sum_{k=t}^{t+m-1} \left[\left(P_{1,k} + \sum_{t=1}^{n} P_{i,k} \right) - \frac{1}{m} \sum_{s=t}^{t+m-1} \left(P_{1,s} + \sum_{i=1}^{n} P_{i,s} \right) \right]^2$$

(7)

In the equation, $P_{i,k}$ is the predicted value of grid load in the K period.

3. Example Analysis

3.1 Research Objects and Basic Data

In order to verify the feasibility and effectiveness of the proposed strategy, a parking lot charging station is calculated as an example. The probability distribution curve of the running time of electric vehicles is normal distribution. The driving time of electric vehicles in working days in literature [11] is used to model. The probability density curve of the driving time is a normal distribution with a mean value of 9 and a variance of 1.2. The initial SOC level is set to a continuous random number between 0.2~0.6. Parking time is set to the random number between 1~8 H[12]. The charging efficiency of the charger is taken as 0.9. Maximum charging power uses Level 2 charging mode of maximum power (that is, "insert and charge") , the charging mode of which can provide 7.68 kW power. Due to the role of power electronic devices, the power provided by it can also be lower than this value. That is, the $P_{\max}$ in the constraint is 7.68 kW.

3.2 Analysis of Optimization Results for Different Number of Electric Vehicle

Matlab programming is used to solve the optimization model. The parameters in NSGA- II algorithm are set as: the population number is 50, the maximum number of iterations is 200,the crossover rate is 0.8, the variation rate is 0.3.The total number of electric vehicles is set to 50, rolling optimization time window is set to 8.

By comparing the data in Figure1, we can see that, in the use of smart charging strategy, the peak electric vehicle load is effectively reduced. The impact of the electric vehicle load on the power grid is also reduced. Moreover, the charging strategy can also make the load of electric vehicles be allocated more in a longer time, so that the load fluctuation of the grid can be effectively stabilized.
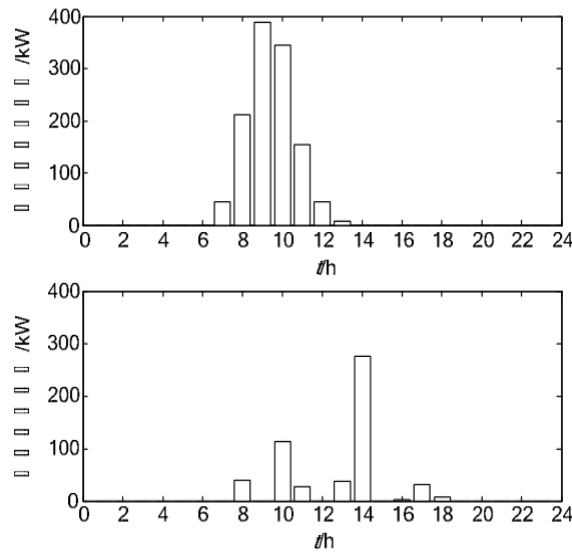

Figure 1 Uncontrolled and Controlled Charging Power Distribution of 100 Electric Vehicles

After the further analysis of three kinds of electric vehicles under controlled and uncontrolled, two cases of data after analysis, the total load standard deviation and charging cost are compared after the power grid load is superimposed on the electric vehicle load. At the same time, the calculation of the simulation time of the charging arrangement in the next time period is also recorded. They are used to verify the feasibility of the optimization model and the algorithm for practical application. The comparison results are shown in table 1.

Table 1 Optimal Dispatching Results of Electric Vehicles under the Charge of TOU

Vehicle quantity	Control Method	Standard Deviation of Load/kw	Charging Fees/Yuan	Computing Time/s
50	Uncontrolled	593.91	1023.74	39.98
	Controlled	592．13	592.53	
100	Uncontrolled	616.99	2280.98	40.32
	Controlled	603.89	820.09	
200	Uncontrolled	659.01	4499.26	41.31
	Controlled	607.94	1164.45	

By comparing the data in Table 1, we can see that ① The coordinated charging of electric vehicles will increase the standard deviation of equivalent load, which means to increase the fluctuation of power grid load. And with the increase in the number of electric vehicles, this has a more detrimental impact on the grid load. This shows that the disordered electric vehicle charging behavior will increase with the scale of electric vehicles increases the impact on the grid. ②After the charge strategy is taken, the dispatch results of three kinds of electric vehicles reduce the standard deviation of total load. And, the more number of electric vehicles scheduling, the total load decreases the greater the magnitude of standard deviation. It is reduced by 0.23%, 2.12% and 7.75% respectively. For a cluster of electric vehicles with a certain scale, this shows that the charging strategy has a significant effect on smoothing the load curve of the grid; ③ After comparing the charging fees of the two cases of uncontrolled and controlled, the charging costs of the three cases are reduced by 42.12%, 64.05% and 74.12% respectively after the charging strategy is adopted.

4. Conclusion

Aiming at the centralized charging optimization scheduling of the electric vehicle cluster, this paper establishes a mathematical model of multi-objective optimization based on dynamic pricing of electric vehicle charging time. Through the optimization of electric vehicle research on different number of calculation results, the feasibility and effectiveness of the optimization model is verified. If the proposed time interval pricing method can be adopted, the peak reducing and off peak filling of the electric vehicle charging load can be effectively realized on the basis of ensuring the charging demand of the customers and the overload of the transformer load of the system. The average cost of charging station and charging operation costs and the user can be significantly reduced. This makes the win-win situation between the grid, electric vehicle charging stations and users.

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