A Novel Intelligent Charging-Ordered Strategy Based On The Optimization Electric Vehicle Charging Load

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Abstract. This paper proposes a new optimization based on charging load and the conditions of line loss minimum as the objective function of the orderly intelligent charging control strategy, the charging control strategy using the Monte Carlo simulation method to simulate the user demand, permeability at the same time considering the electric car users in a variety of scenarios, from several aspects, such as load, power loss and voltage electric vehicle charging to the influence of the distribution network are analyzed. Based on this, puts forward a based on the optimal charging load and line loss minimum as the objective function of the intelligent orderly charging methods, this method can meet the demand of the electric car charge, according to the trend of short-term load, in each period of rechargeable power optimization, to achieve steady load, reduce the energy loss and improve the voltage quality goals.

1. Introduction

The disordered charging of the large-scale electric vehicles is bound to have a great impact on the structural operation of the existing distribution network. One of the most main point is to bring a new round of load growth, especially in rush hour charging electric cars will leads to further peak and valley difference of network load, which may ends up with a series of problems like distribution network line’s overload, voltage drop [1] [2], the increased distribution network loss [3] [4], distribution transformer’s overload [5] [6], etc. Electric cars, on the other hand, as a new type of moving load, the charging behavior has strong uncertainty of time and space, a large amount of electric vehicles’ widely access and disorderly electricity penetration will increase the difficulty to control the power grid operation. Therefore, control charging electric vehicles orderly is of great importance to reduce the risk of power grid operation and improve the efficiency and reliability of power grid operation.

This paper fully studied the influence of conventional charging mode of electric vehicle on distribution network. It selectively analyzed the electric vehicle’s permeability which means the specific value of electric vehicle charging load and the maximum load, in order to better illustrate the electric car charging effect on the distribution network, this paper, taking a 10 KV life line of a city as the object, analyzes the influence of the distribution network caused by user’s random charging behavior under all kinds of electric cars permeability. For enormous pressure caused by the user’s uncontrollable charging behavior under high permeability to the power distribution network, this paper proposes an orderly intelligent charging control strategy based on the objective function which is
based on the optimization of charging load and the minimum line loss, in order to realize the mutual benefit of power grid and the users.

2. The influence of disordered charging on distribution network of electric vehicle

2.1 Influence on distribution network load

In the case of no economic interests or policy guidance, the owner’s charging behavior tends to be random, generally owners began to charge after they come home from work, such as starting around 18:00, ended at 24:00, charging time lasts about 6 h [7-10]. This kind of uncontrollable charging behavior of users is easy to create new load peaks with the original load peak, which can cause great pressure on the power grid operation. In this paper, a 10KV life line in a city is used to analyze the influence of EV charging on the distribution network under the permeability of various electric vehicles. The analysis of this paper is based on the assumption that if the three-phase power supply is balanced, the electric vehicle charging load is evenly distributed in each of the distribution zones. For the convenience to analyze, conventional charging mode is adopted, namely, the charging voltage of ev is 220V, the charging current is 10A, the charging power is 2KW, and the normal charging time is about 6h[12]. At the same time, we use the circuit in a certain city’s living areas, including a total of 89 line, 90 nodes which has one source, 39 load node, with a total distribution transform capacity of 16.5 MVA. We made a real-time record of the line load of the random is charging behavior of electric vehicle users in the living area. The graph is shown in figure 1 below.

![Figure 1](image1.png)

In the figure 1, 0 represents there is no charging load of EV. As can be seen from the figure, the original load ratio of the line is not high, the maximum load ratio is 43.31%, the minimum is 7.92%, the peak load appears at 19:00~22:00, 22:00-7:00, the load is relatively low, and the load at 8:00-18:00 is relatively stable. When the electric vehicle is connected to the power grid, it will stack with the original load peak to form a new load peak. When the penetration ratio of electric vehicle is 100%, the maximum load ratio is high as 86.62%, and the peak valley difference is large, which is unfavorable to the economic operation of the power grid.

2.2 The influence of network loss

FIG. 2 shows the 24h loss ratio and its distribution in random charging under various electric vehicle penetration ratios.

![Figure 2](image2.png)
In the Fig. 2, when there is no electric vehicle charging access the line, the line’s average load loss ratio is low, which cause the low line load loss ratio, and the transformer no-load loss ratio is on the high side, line loss ratio is relatively high.

3. Orderly charging control strategy

3.1 Principle of intelligent orderly charging algorithm

From figure 2, when there is no electric vehicle connected to charge, the load rate of the line is low, the highest is 43.31%, and the lowest is only 17.29%. If the charging power can be reasonably distributed according to the driving rules of the owner and the load rate of the line, the optimal charging power of the electric vehicle will be realized. Smart orderly charge means in the condition of meeting the demand of electric vehicle charging, aim at minimizing the total loss in different time period and the sum of crossing the line voltage, use the optimal algorithm to calculate the electric car rechargeable power of each period in order to achieve the goal of stable power grid load, reducing loss, improving the voltage quality of power grid. The intelligent orderly charging method in this paper optimizes the off-line charging load of electric vehicles based on the short-term load prediction data of 24 hours. At present, the short-term load prediction error is about 5%, which is of high accuracy, and can provide data support for the intelligent orderly charging method. In order to improve the controllability of lines and economy, the charging conditions set in this paper are: the rechargeable time is from 18:00 to 7:00, and when the load rate is less than 40% electric vehicles are allowed to connect to the power grid for charging. When 50% of electric cars are charged, the optimized line load rate is less than 50%. When 100% electric vehicles are charged, the optimized line load rate is less than 65%. After the above charging conditions are set, flexible control over the rechargeable period can be carried out, rather than just limited to a fixed period of time. After adopting ordered intelligent charging method, load curve will become more smooth, the influence affected by the electric vehicle charging to the grid will also reduce, which is advantageous to the owners reasonably arrange charging plan, and realize the power grid and the user's mutual benefit.

3.2 Mathematical model of algorithm

The mathematical model of intelligent sequential charging algorithm can be described as follows.

(1) Objective function

In this paper, the optimal objective is to minimize the sum of total loss and voltage across the power grid in multiple time periods:

$$\min \sum_{t=1}^{N_{ch}} [P_t(t) + \lambda \max_i (\Delta V_i(t))^2] \quad (1)$$

Where: $P_t(t)$ is the system loss of time period $t$; $\Delta V_i(t)$ is the voltage offset of the time period $t$ node $i$; $N_{ch}$ is the number of rechargeable time periods within 1 day; $\lambda$ is the voltage across the boundary penalty coefficient.

(2) Equality constraint

During all rechargeable periods, the battery must be fully charged to meet the vehicle owner's driving needs, i.e.

$$\sum_{t=1}^{N_{ch}} (P(t)\Delta t) = P_{EV}T_{cd} \quad (2)$$

Where: $P(t)$ is the rechargeable power of the time period $t$; $\Delta t$ is the charging period, which is set as 1h. $P_{EV}$ is the charging power for electric vehicle batteries; $T_{cd}$ is the charging time. In this paper, the load flow equation is used to calculate the node voltage and line loss, so the constraint condition of load flow must be met.

(3) Inequality constraint

In order to improve the controllability and economy of the line, the optimizing of the line load rate before and after charging should meet the following conditions:
A. The load rate of the line should be satisfied with \( L_i \leq L' \).

B. After optimizing charging, the load rate of the line should be satisfied with \( L_i \leq L' \) and \( L' \) can be set according to the actual operation requirements.

C. Meet the time constraint as after work like: \( t \in (18:00 - 07:00) \)

### 3.3 Algorithm scheme

The algorithm process is as follows:

Step 1: the dispatching center makes short-term load prediction for 24h;

Step 2: the owner will submit the information like next day's drive arrangements, charging plan and whether to participate in scheduling to the service provider, after summary the provider would report to dispatching center, and according to the report data the dispatch center will predict the electric vehicle charging load in 24h and adjust the short-term load forecasting results;

Step 3: owners of electric vehicles participate in unified dispatching through service providers, avoiding blind unordered charging behaviors, and at the same time will gain economic benefits.

Step 4: according to the result of the short-term load forecasting, in the case of meeting the demand of electric vehicle charging, ordered intelligent charging optimization will be calculated, to get electric vehicle's optimum charging power at all time period;

Step 5: the dispatching center sends the data of electricity price in each period and optimal charging power to the service providers, and the service providers send charging scheduling arrangements to the electric vehicles within their jurisdiction. The owner adjusts their respective charging plans according to the charging schedule, so as to achieve the optimal charging. It is a process demanding response for electric vehicle to adjust charging plan according to the dispatching instruction. All kinds of information (such as charging plan and scheduling arrangement) between the dispatching center, service provider and electric vehicle will be transmitted through the Advanced Metering Infrastructure (AMI) to achieve two-way communication. The service provider not only provides service for the charging and discharging of electric vehicle, but also participates in the online activities of distributed generation.

### 4. Simulation Result

According with the algorithm scheme and process (above 3.3), Figure 3 shows the daily load curve of the line at 50% and 100% EV penetration.

![Load loss vs. time](attachment:image.png)

**Fig 3.** 50% and 100% permeability ratio vs daily load loss

From Fig.3, at the 50% permeability ratio, the new load peak is not formed due to the reasonable allocation of charging load in each period by the intelligent ordered charging method. When 100% permeability, due to the electric vehicle charging load is bigger, although the ordered intelligent charging method also formed the new peak load, compared with other methods, ordered intelligent charging method’s peak valley load difference is small, the curve is relatively smooth, the effects on
the grid is relatively small. Figure 4 shows the total loss rate of the line at 50% and 100% permeability.

From Fig.4, for the total loss rate of the line, the intelligent ordered charging method is less than the time period charging method, and less than the random charging method. Therefore, the intelligent ordered charging method can achieve the goal of loss reduction and energy saving.

5. Conclusion
The random charging method will superimpose the original peak load to form a new peak load, which will bring great pressure to the operation of the power grid. Although timely charging method to a certain extent, improve the load curve, but in the large-scale electric vehicle charging, it’s mechanical chooses to off-peak still cannot meet the needs of the safe and economic operation of power grid. Ordered intelligent charging method takes various time period’s minimum total loss for the optimal target, sets rechargeable power in each period dynamically, overcome the time charging method’s mechanism, able to adapt to the more flexible requirement of the operation, guide the optimal charge plan to owners, thus reduce the influence of large-scale electric vehicle charging to power grid, achieve win-win situation between the grid and the owner. The construction of intelligent distribution network will provide very favorable conditions for the optimal charging and network access of electric vehicles and promote the better development of electric vehicles.

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