Research on Power System Comprehensive Load Modeling Considering Electric Vehicle Charging Loads

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Abstract. In this paper the principle of all kinds of load models are analyzed. A construction method of comprehensive load model was put forward based on statistical probability theory and Monte Carlo simulation. On the basis of the previous research, a time sequence probability model and simulation algorithm for electric vehicle load was put forward based on Monte Carlo simulation, which can consider the influence of the electric vehicle charging load in the comprehensive load model. Taking the historical load data of some certain area as illustration, comprehensive load model was constructed and analyzed, which verifies the availability of the method. The research results have practical guiding significance for the power system planning, operation and simulation analysis.

1. Introduction
In recent years, along with the increasing of load type, the adjusting of industrial structure, the development of new energy, and the requiring of simulation accuracy, load model has become more and more important in the field of power system operation and planning analysis. However, the research on the time variation and changing of the load structure parameters in the load model has been neglected. Fixed load structural parameters are usually used to analyse and simulate the power system behavior. The simulation results obtained have greater error in accuracy, even in some important operation. The research on the modeling and simulation of all kinds of loads was very necessary and has practical significance.

With the changing of elements and structure characteristics in power grid loads, complex diversity of power system operation decided the scheduling requirements of load parameters. The existing industrial load structure cannot meet the needs of power system simulation and there are some problems in the following aspects:

(1) The social and economic development can lead to changes in load structure. If the calculation of load structure parameters cannot be timely changed and developed, it will lead to inaccuracy for simulation conclusion.

(2) Large-scale new energy load is given priority to electric vehicle load. With the gradual increase of electric vehicle load, the system operating characteristics will also change. However, it is the key problem on how to analyse and solve the load structure of power grid including the electric cars.
(3) Load equivalent and load structure will be a larger influence on the system simulation analysis, the rules and characteristics between the simulation results and load model are in urgent need to explore and practice.

The electric car is about to enter large-scale application period, which will have a big impact on the power grid operation, bring new challenges for electric power industry. Electric vehicle charging mass load will trigger a new load growth [1,2]. In recent years, international experts have done a lot of research in electric vehicle load.

The daily load curve and the historical daily load curve of the electric vehicle are superimposed in [3-5], and the influence of the electric vehicle on the daily load curve is obtained under certain conditions. In [6-7,12-13] different kinds of electric vehicle charging characteristics and charging time are analyzed and classification is carried out in the modeling. Based on the analysis of the actual statistical data, in paper [7-11], the time distribution of electric vehicle charging was analyzed.

All of the above studies are based on the fixed load structure parameters, thus to make the inaccuracy simulation results. In this paper the principle of all kinds of load models were analysed, a construction method of comprehensive load model was put forward based on statistical probability theory and Monte Carlo simulation. The specific implementation steps were also given in the paper. On the basis of the previous research, a time sequence probability model and simulation algorithm for electric vehicle load was put forward based on Monte Carlo simulation, which can consider the influence of the electric vehicle charging load in the comprehensive load model. Taking the historical load data of some certain area as illustration, comprehensive load model was constructed and analyzed, which verifies the Validity of the method. The research results have practical guiding significance for the power system planning, operation and simulation analysis.

2. Comprehensive load modeling for power grid

2.1. Statistical synthesis of load structure

A lot of research work has been carried out on load modeling, the modeling method in general can be divided into two categories: "distinguishes the overall test method" and "statistical synthesis method ".Due to the difference of the different incentive identified model ,the mechanism and algorithm of load model synthesis are not mature today and application has great limitations. And the purpose of modeling is to use, in order to truly reflect the simulation of load characteristics in power system, to improve the accuracy of the simulation, the above problem can only use comprehensive statistics to solve.

The method is mainly based on statistical principle, through the user (industry) power situation investigation and statistics, you can get a comprehensive load model in the dynamic and static ratio.

\[
\alpha_i = \sum_{j=1}^{n} \alpha_{ij} p_{ij} \left( \sum_{j=1}^{n} p_{ij} \right)^{-1}
\]  

The structure parameters of \( \alpha_{ij} \) represent the \( i \)th industry \( j \)th typical users, \( p_{ij} \) represent the typical user capacity of conventional load of \( i \)th industry \( j \)th typical users; \( \alpha_i \) is load structure parameters for the \( i \)th industry. According to the sum method of average weighted volume, the dynamic load ratio can be concluded within a day.

2.2. Model of electric vehicle load

2.2.1. Time sequence based probability model

The charging load of electric vehicle depends on the user's behavior, so it is random and uncontrollable. There are many factors which affect the timing distribution of the electric vehicle charging load.
Daily mileage, vehicle charging, charging frequency, charging mode, start charging time, battery charging state and charging time are the factors which affect the timing distribution of the electric vehicle charging load. This project is mainly considering the two main factors of the start charging time and battery charged state when starting.

The premise to predict the electric car charging load includes characteristics analysis of the electric car load, making sure the probability models of all kinds of loads in different times. In this project, through the analysis of operation area and charging habits of four kinds of electric vehicles sequential probability model is derived for electric vehicle loads. According to the results shown in the survey, you can clearly see the probability model of various models. According to the starting time of the distribution of the mean $\mu_t$ and standard deviation of $\sigma_t$, the Gaussian distribution model fitting start charging time is as follows:

$$f(T) = \frac{1}{\sigma_t \sqrt{2\pi}} \exp\left[ -\frac{(T - \mu_t)^2}{2\sigma_t^2} \right]$$ \hspace{1cm} (2)

Similarly, according to the starting state of charge $\mu_o$ of average and the standard deviation sigma $\sigma_o$, the Gaussian distribution model is adopted to simulate the starting charged state

$$SOC = \frac{1}{\sigma_o \sqrt{2\pi}} \exp\left[ -\frac{(T - \mu_o)^2}{2\sigma_o^2} \right]$$ \hspace{1cm} (3)

According to the start charging time and battery charged state of starting time, it can be concluded that the charging time is long (the project is not to consider the battery temperature, voltage change and other factors)

$$T_c = \frac{1 - SOC}{P_c} \times C \times 60 \hspace{1cm} (4)$$

In the formula, $T_c$ is the charging time, $C$ is the battery capacity, $P_c$ is the charging power and they are all decided by electric vehicle category and the charging mode.

2.2.2. Simulation of time sequence based probability model

This project adopts Monte Carlo simulation. Combining with all kinds of electric load forecasting parameters, the start charging time and battery charging state of starting time as random variables are set to simulate the electric vehicle charging behavior. Matlab software is used. The charging behavior of electric vehicles is not controlled by the power grid, so we assumes that automobile charging immediately after being connected to the electricity grid. Monte Carlo simulation calculation process is as follows:

1) The input of the original information includes total electric car sets, all kinds of charging mode corresponding proportion and power, start charging time probability distribution and the corresponding time, battery charging state of starting time, the charging time constraints, etc.

2) To extract the starting charging time, determine the vehicle charging mode.

3) To extract the starting state of charging soc, calculate the charge mode corresponding to the charge time $T_c$.

4) Calculate the charging load, cumulative charge curve, until the number of vehicles $n$ reaching a given value of $N$.

The number of simulation is 1000 times, the convergence precision is 10-4. When the vehicle number reaches a given value, it needs to determine whether the calculation results meet the convergence accuracy. If the calculation results meet the accuracy of convergence, it comes to calculate the output curves; if the calculation result does not satisfy the convergence precision, the
process of the calculation should be carried out until the calculation results meet the convergence precision.

\[ P = \sum_{i=1}^{1440} \left( \sum_{j=1}^{N_a} P_{a_i} + \sum_{j=1}^{N_b} P_{b_i} + \sum_{n=1}^{N_c} P_{c_n} + \sum_{n=1}^{N_d} P_{d_n} \right) \] (5)

After calculating the charging load of the four kinds of electric vehicles, total electric vehicle charging load is the sum of the single electric car charging power, as shown in formula (5), in the formula: \( P \) is total load of electric vehicle charging in a given area; \( N_a, N_b, N_c, N_d \) is respectively the number of taxi, bus, transit, official car and private car in this area; \( P_a, P_b, P_c, P_d \) is charging power of single electric car.

Operation and charging habits, electric vehicle charging power, the proportion of charging mode, charging time probability distribution and battery charging state were got by researching the existing electric vehicles in a given area.

2.3. Comprehensive load model with electric vehicle

2.3.1. Adjustment variables

Along with the economic and social development and the change of industrial structure, the combination of all kinds of loads is also experiencing great change. In the consideration of the adjustment of industrial structure, we define load adjustment variables: \( p_i(n) \), in which \( i \) is on behalf of various industries, \( n \) is on behalf of time for power grid plan. The load adjustment variables on the formula (6) are the form of comprehensive capacity weight coefficient correction.

Define energy saving technology adjustment variables and the solution model of this variable, as shown in the formula (6).

\[ e_i(n) = \frac{\sum_{n} \left[ p_i^n \lambda_i^n \left( G_i^n - S_i^n \right) / \left( S_i^n + 1 \right) \right]}{p_i^n} \] (6)

Among them:

\( e_i(n) \) is the factor of the \( i \) industry in the \( n \) year, which is used to correct the influence of the new technology energy load.

\( t_0 \) is the starting year for planning; \( n \) is the end year for planning;

\( G_i^n \) is the economy increase rate of the \( i \) industry in \( n \) year;

\( S_i^n \) is power increase of the \( i \) industry in the \( n \) year;

\( \lambda_i^n \) is output growth and energy consumption growth in the total amount of energy saving factors of the \( i \) industry in the \( n \) year;

2.3.2. Comprehensive load model with electric vehicle

As shown in formula (7), we define the Comprehensive load model with electric vehicle.

\[ \rho_i(t) = \frac{\sum_{n=1}^{n} \left( e_i(n) \alpha_i \right) F_{pi} \left( t \right) p_i \left( n \right)}{\sum_{j=1}^{j} F_{pi} \left( t \right) p_i \left( n \right)} \] (7)

Where \( F_{pi} \) is the probability model; \( \alpha_i \) is the structure parameters of the \( ith \) industry;
According to the time sequence probability model of sub industry, by Monte Carlo simulation method, load characteristic curve with electric car can be achieved by statistical weighted synthesis.

3. Case analysis
By using the time sequence model of electric vehicle load, the load characteristic curves of different models are obtained.

3.1. Solution of comprehensive load model with electric vehicle
Based on the above parameters and model, Monte Carlo simulation was used to solve the problem. The load data come from the northeast region of China.

The above parameters and model are on the basis of using the Monte Carlo simulation.

4. The conclusion
In this paper the principle of all kinds of load models are analysed. A construction method of comprehensive load model was put forward based on statistical probability theory and Monte Carlo simulation. The specific implementation steps were also given in the paper. On the basis of the previous research, a time sequence probability model and simulation algorithm for electric vehicle load were put forward based on Monte Carlo simulation, which can consider the influence of the electric vehicle charging load in the comprehensive load model. Taking the historical load data of some certain area as illustration, comprehensive load model was constructed and analyzed, which
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