Charging station quantity planning model based on neural network and electric load forecasting model

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ABSTRACT

A large quantity of electric vehicle (EV) charging station loads connected to the power grid will aggravate the peak-valley difference and reduce the stability of the power system and the economic benefits of operation. The connection of EV charging station loads will also inject a large quantity of harmonics into the power grid, further aggravating the risk of power supply equipment failure. EV can also be regarded as distributed energy storage devices. Under special circumstances, EV can feed back electric energy to the power grid through power conversion devices and participate in frequency modulation of the power grid. In order to reduce the idle rate of charging stations and promote the distributed photovoltaic absorption capacity of the system, this paper proposes an electric load forecasting model based on particle swarm optimization neural network (PSO-NN). The charging and discharging power of EV cluster and energy storage equipment are solved in turn by PSO algorithm, and when the regulation capacity of EV cluster is insufficient or limited, it is supplemented by energy storage equipment. The simulation results show that with the increase of the quantity of experiments, the accuracy of this algorithm is stable at about 95%, and the real-time wavelength tends to be stable. Therefore, the scheduling strategy can effectively improve the safety and economic performance of power grid and the capacity of transportation system, which is conducive to improving the operational performance of power grid and transportation network and providing algorithm and technical support for the construction of charging station number planning model.

Keywords: Electric vehicle; electric load; charging station; neural network

1. INTRODUCTION

The electric power industry is not only the foundation of the sustainable development of China's national economy, but also the guarantee of people's happy life. Power load forecasting is to predict the power consumption of the power grid in the future for a period of time, which can provide the basis for the power company to formulate the power consumption plan and arrange the operation mode of the power system. Therefore, the load forecasting of the power system is of great significance to the safe and stable operation of the power grid [1]. EV have the advantages of energy conservation and environmental protection, high energy utilization, faster power acceleration and more flexible control [2]. In addition to the strong support of national policies, the quantity of EV in the country has increased year by year [3]. Without regulating the load of the EV charging station, the load curve of the EV charging station has a similar trend with the load curve of the distribution network [4]. How to efficiently and reasonably arrange the orderly charging of EV, transform the EV load into a tool to make the power system benefit, and improve the stability and operation economy of the power system, the key is to accurately predict the load of the EV charging station [5-6].

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The governments of China and other developed countries in the world have vigorously supported the development of the EV industry and promoted the effective application of EV, but a large quantity of EV are bound to have an impact on the power grid and transportation system. In terms of power grid, the charging load of EV connected to the power grid will cause voltage deviation and power grid energy loss. In terms of transportation, the large-scale use of EV will cause road congestion and inconvenience to people's lives [7]. Although the amount of power grid data is increasing, which provides sufficient data support for short-term power load forecasting, it also increases the difficulty of forecasting [8]. At the same time, the power load data are all from the database of the power consumption information acquisition system. The data abnormality is inevitable. If it is not eliminated, it will inevitably interfere with the power load forecasting accuracy [9]. EV charging scheduling is not comprehensive whether it is based solely on the traffic conditions or the operation of the power grid. The comprehensive traffic and power grid conditions as the basis of EV charging path can ensure the safe and reliable operation of the power grid, and shorten the waiting time for charging, so as to optimize the overall performance of the system on the premise of ensuring that the EV can reach the charging station reliably for charging [10]. In this paper, an electric load forecasting model based on PSO-NN is proposed. The charging and discharging power of EV cluster and energy storage equipment is solved by PSO algorithm in turn. When the regulating capacity of EV cluster is insufficient or limited, the energy storage equipment is used for supplementary adjustment, thus providing algorithm and technical support for the construction of charging station quantity planning model.

2. METHODOLOGY

2.1 Planning and analysis of EV charging station

The governments of China and other developed countries in the world strongly support the development of EV industry and promote the effective application of EV. However, a large quantity of EV are bound to have an impact on the power grid and transportation system. The load forecasting of EV charging station is influenced by many factors, and there are many similarities between the influencing factors of EV charging station and the traditional influencing factors of electric power load [11]. Because the load of EV has many unique load characteristics, there are many differences between the load influencing factors of EV charging station and the traditional power load influencing factors. In addition to considering the user's charging demand, the number planning of charging stations should also fully analyze the construction and operation economy of charging stations, optimize the power of charging stations as much as possible under the premise of ensuring the user's charging demand, reduce the quantity of charging stations, reduce the construction and operation costs, effectively enhance the participation of operators and users, and ensure the normal development of the charging market [12]. The load of EV charging station is closely related to the energy consumption of EV. It is the premise of accurate load forecasting of EV charging station to analyze the travel habits and energy consumption of EV users. At the same time, the state of charging equipment and EV battery in EV charging station also has great influence on the load of charging station. Therefore, it is necessary to understand various charging modes of EV and analyze the basic principle of EV battery.

In the regional power grid, an energy management system collects the state information of EV parked in the parking lot in real time, and optimizes the dispatching according to the state information of energy storage device, distributed photovoltaic output and basic load, and feeds it back to the energy storage device and parking lot management system to control the charging and discharging state of energy storage device and the connection state of EV and charging station. Conventional charging stations generally use 220V alternating current, the charging current is generally about 10-15A, and the maximum charging power is 3.3kW. Conventional charging stations generally exist in conventional EV charging stations or large parking lots [13]. The conventional EV charging station can generally charge 20-40 EV, and the conventional EV charging station adopts the charging mode of low voltage and low current.

According to the charging station information and the actual electric special vehicle information, the charging station layout scheme is randomly generated, wherein the charging station information includes information such as the quantity of charging stations and the construction location, and the electric special vehicle information includes information such as the remaining power, average working hours and corresponding seats of all electric special vehicles when they leave. The behavior habit of users driving EV is random, which plays a key role in the temporal and spatial distribution characteristics of EV charging load. For example, the choice of driving route, charging mode and stopping time of EV. The driving operation of users also has a great influence on the energy consumption of EV. During use, some users may choose to accelerate, and during the acceleration process, emergency stops and starts may occur, which undoubtedly increases the energy consumption of electric vehicles.

2.2 Planning model of charging station number based on PSO-NN

The intelligent development of power industry can realize real-time monitoring and recording of power load data, but due to human factors or mechanical equipment failures, some values of power load data are easy to be abnormal and missing. Load forecasting data directly obtained from EV charging equipment and other intelligent detection equipment can not be directly used to analyze and train forecasting models [14]. Because there are inevitably some missing data, repeated records and abnormal data in the process of data collection, in order to ensure that the prediction model can extract features accurately and quickly, it is necessary to preprocess the collected data to eliminate the adverse effects of missing data, repeated records and abnormal data on the prediction model. The analysis of load characteristics can clarify the relationship between various influencing factors and load, which is beneficial to the rational use of relevant data in the forecasting model, thus improving the accuracy of load forecasting.

In the load forecasting based on neural network, the time scale of day-ahead load forecasting is typical, which is conducive to the initial establishment of effective load-related input data sets and provides a basis for further ultra-short-term load forecasting. Figure 1 shows the PSO-NN process in the number planning of charging stations.

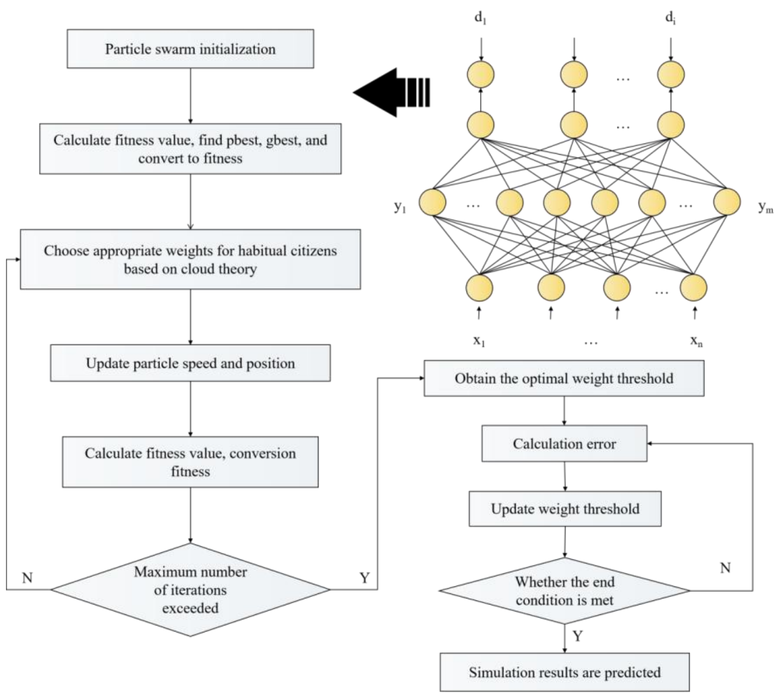

Figure 1. PSO algorithm flow

After many convolution pooling operations, the final output matrix is connected to the fully connected neural network after dimensionality reduction. The dimensionality reduction operation transforms the high-dimensional data after convolution pooling into one-dimensional data, and each element in the one-dimensional data is treated as a neuron. The neuron is connected with each neuron in the fully connected network, and all neurons in each layer are connected with all neurons in its adjacent layer, and no connection relationship is formed between neurons in the same layer, so that each input unit has a certain relationship with each output unit.

When the amount of data is large and the proportion of abnormal data in the total data is small, the direct deletion method can be used to delete abnormal data and retrain the model. In order to keep all the characteristics of training samples as much as possible, the abnormal data are replaced by the same method according to the same principle of date type as the missing data filling method.

As a special load, EV's energy demand is influenced by the user's travel rules. Assuming that there are n EV in the area, divide the day into J segments at the time interval Δt, and establish the EV charging state set according to the user's travel rules:

$$C_j(i) = \begin{cases} 1, i \in T_{v,j} \\ 0, other \end{cases} \tag{1}$$

Where $C_j(i)$ is the charging state of the j EV at the i time. When $C_j(i)=1$, the j EV can be charged at the i time. When $C_j(i)=0$, the j EV is out at the CC time.

Assuming that the power required by the i EV on that day is Q_j, the quantity of charging stations is m and the rated charging power is $P_{e\max}$, in order to meet the charging demand of EV, the following formula should be satisfied:

$$\sum_{i=1}^{J} P_e(i) = \sum_{j=1}^{n} Q_j \tag{2}$$

$$N = \min\left[m, \sum_{j=1}^{n} C_j(i) \right] \tag{3}$$

Where: $P_e(i)$ is the sum of the charging powers of all EV at the i moment; N takes the minimum value of the quantity of EV that can be charged and discharged in the charging station and the quantity of charging stations.

3. RESULT ANALYSIS AND DISCUSSION

The evaluation indexes of EV charging load are complex and diverse, and the dimensions and orders of magnitude of various types of data are usually quite different, and the values of various types of data are quite different. If the original value of data is directly used for load forecasting analysis, the role of forecasting indicators with larger values will often be highlighted and the role of forecasting indicators with lower values will be relatively weakened in the comprehensive analysis of load forecasting of EV charging stations. It is inevitable that the data recorded by various intelligent terminals of EV have some defective values, abnormal data and repeated records. These bad data will not only increase the calculation amount of training models and lengthen the training time of models, but also reduce the quasi-efficiency of the prediction results of EV charging load. There are great differences in the dimensions and orders of different types of data in the data set, which leads to the fact that the data with large orders of magnitude have great influence on the prediction model, while the data with small orders of magnitude have little influence on the prediction model. Therefore, before training the model, it is necessary to preprocess the training data. The deviation curve of the main abnormal characteristics of the number planning of charging stations is shown in Figure 2.

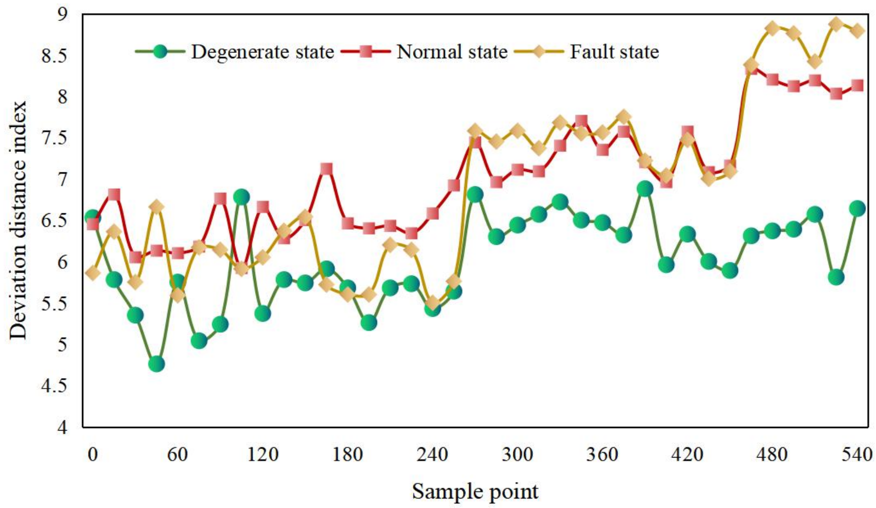

Figure 2. Selection of abnormal characteristic deviation curve

Considering that the intelligent monitoring equipment may produce missing data, duplicate data and abnormal data due to factors such as failure, power failure or man-made destruction. The F1 situation of the charging station number planning model based on PSO-NN is shown in Figure 3.

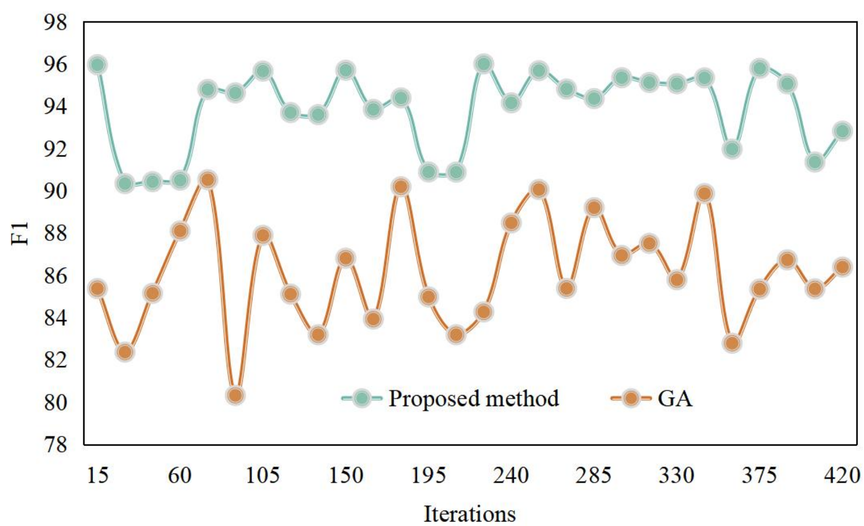

Figure 3. F1 comparison of different algorithms

In the process of load prediction for charging stations, modeling the time space matrix of the charging station load can effectively maintain the load of the charging station. Conduct in-depth analysis on the load characteristics and influencing factors of electric vehicle charging stations, collect load prediction data for electric vehicle charging plants, and handle missing, duplicate, and abnormal records in the original data. Figure 4 shows the comparison of simulation time between various algorithms.

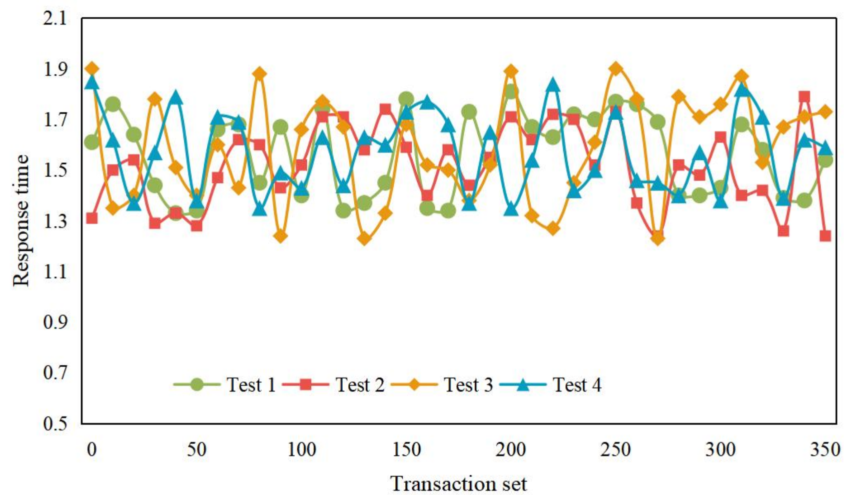

Figure 4. Comparison of Four Algorithms in Operation

These edge data centers distributed in different regions will be integrated and connected with greater bandwidth. Therefore, there is an urgent need for a comprehensive distributed edge data center scheduling platform to manage and schedule it in real-time and efficiently. Figure 5 shows the accuracy comparison between different algorithms.

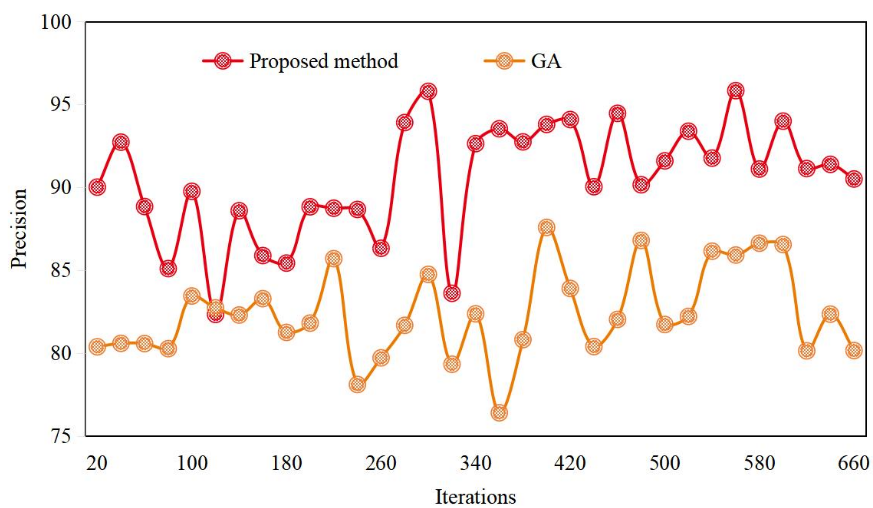

Figure 5. Accuracy comparison of the algorithm

From Figures 3, 4, and 5, it can be seen that the charging station number planning model proposed in this article has significant improvements overall compared to conventional genetic algorithms. After the application of cloud computing technology, an architecture was established through systematic management, enabling data to be efficiently organized and processed conveniently. Accurately predicting the load of charging piles can provide decision-making basis for the rational use, reasonable use, and reasonable use of charging piles, and is of great significance for ensuring the safe, stable, and reliable operation of charging piles.

The configuration of EV charging piles, the battery loss caused by EV and energy storage equipment participating in photovoltaic consumption will all produce certain economic costs. In the planning of the quantity of charging piles, if the above economic costs can be reduced on the premise of meeting the demand of EV charging and promoting the consumption of photovoltaic output, the participation of operators and users can be improved and the development of EV industry can be promoted.

4. CONCLUSIONS

In terms of power grid, the charging load of EV connected to the power grid causes voltage deviation and energy loss of the power grid. In terms of transportation, the large-scale use of EV will cause road congestion and bring inconvenience to people's lives. The uncertainty and mutual difference of users' needs and behaviors of EV make the charging load of large-scale EV in the future have the characteristics of randomness, intermittence and fluctuation in time and space, which will undoubtedly bring difficulties to the safe operation and optimal dispatch of power grid. In this paper, an electric load forecasting model based on PSO-NN is proposed. When the regulation capacity of EV cluster is insufficient or limited, it is supplemented by energy storage equipment, thus providing algorithm and technical support for the construction of charging station number planning model. Compared with the traditional genetic algorithm, the power load forecasting performance of the proposed charging station number planning model has been comprehensively improved. On the basis of the research in this paper, the real-time influence of different charging station locations, real-time regulation requirements of power grid and real-time location of EV on the charging and discharging service fees of charging stations can be further considered, and the commercial operation of vehicle-to-power grid technology can be realized by combining advanced artificial intelligence and blockchain technology.

REFERENCES

[1] Nishanthy, J., Charles Raja, S., Praveen, T., Jeslin Drusila Nesamalar, J., Venkatesh, P., Techno‐economic analysis of a hybrid solar wind electric vehicle charging station in highway roads. International Journal of Energy Research, 46(6), 7883-7903 (2022).

[2] Chen, X., Dong, X., Shi, L., Short-term power load forecasting based on I-GWO-KELM algorithm. MATEC Web of Conferences, vol. 336, no. 2/3, pp. 5021 (2021).

[3] Bang, Y. K., Lee, C. H., Daily Peak Electric Power Load Forecasting using LERP-based IT2TSK Fuzzy Prediction System. Transactions of the Korean Institute of Electrical Engineers, 69(5), pp. 688-697 (2020).

[4] Song, W., Cattani, C., Chi, C. H., Multifractional Brownian motion and quantum-behaved particle swarm optimization for short term power load forecasting: An integrated approach. Energy, vol. 2020, no. 3, pp. 194 (2020).

[5] Wen, L., Zhou, K., Yang, S., Lu, X., Optimal load dispatch of community microgrid with deep learning based solar power and load forecasting. Energy, 171(3), pp. 1053-1065 (2019).

[6] Panda, S. K., Ray, P., Analysis and evaluation of two short-term load forecasting techniques. International Journal of Emerging Electric Power Systems, 23(2), pp. 183-196 (2021).

[7] Xu, X., Niu, D., Li, Y., Sun, L., Optimal pricing strategy of electric vehicle charging station for promoting green behavior based on time and space dimensions. Journal of Advanced Transportation, pp.1-16 (2020).

[8] He, Y., Zheng, Y., Short-term power load probability density forecasting based on Yeo-Johnson transformation quantile regression and Gaussian kernel function. Energy, 154 (7), pp. 143-156 (2018).

[9] Monteiro, V., Lima, P., Sousa, T., et al., An Off-Board Multi-Functional Electric Vehicle Charging Station for Smart Homes: Analysis and Experimental Validation. Energies, 13(8), 1864 (2020).

[10] Liu, J. P., Zhang, T. X., Zhu, J., et al., Allocation Optimization of Electric Vehicle Charging Station (EVCS) Considering with Charging Satisfaction and Distributed Renewables Integration. Energy, 164(12), pp. 560-574 (2018).

[11] Syed Mohammed, A., Lodhi, A. S., Murtaza, Q., Techno‐economic feasibility of hydrogen based electric vehicle charging station: A case study. International Journal of Energy Research, 46(10), 14145-14160 (2022).

[12] Balasundar, C., Sundarabalan, C. K., Sharma, J., Srinath, N. S., Guerrero, J. M., Effect of fault ride through capability on electric vehicle charging station under critical voltage conditions. IEEE Transactions on Transportation Electrification, 8(2), 2469-2478 (2022).

[13] Guillet, M., Hiermann, G., Kröller, A., Schiffer, M., Electric vehicle charging station search in stochastic environments. Transportation Science, 56(2), 483-500 (2022).

[14] Ye, Z., Gao, Y., & Yu, N. (2022). Learning to operate an electric vehicle charging station considering vehicle-grid integration. IEEE Transactions on Smart Grid, 13(4), 3038-3048 (2022).