IOP Conference Series: Materials Science and Engineering

PAPER • OPEN ACCESS

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IOP Conf. Series: Materials Science and Engineering **486** (2019) 012139 doi:10.1088/1757-899X/486/1/012139

Analysis of Impact of Electric Vehicle Charging Load on City Grid

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Abstract. With the rapid development of electric vehicles, increasing electric vehicle charging load will have extensive impacts on the power grid. This paper innovatively analyzed the impact of charging load on the urban power grid by taking the power grid of a large city as an example. Firstly, the scale of electric vehicles is predicted. Secondly, considering the travelling characteristics of electric vehicles, the charging load characteristics of electric vehicles in different functional areas of the city were analyzed. Finally, the impact of unordered charging of electric vehicles on urban power grid is quantitatively analyzed from four aspects, including load structure, on-peak and off-peak difference of system, distribution network utilization rate, charging facilities and supporting network construction. Electric vehicle charging will change the load structure of the power grid, reduce the utilization rate of distribution network and investment efficiency, increase the on-peak and off-peak difference of system etc.

1. Introduction

With the rapid development of electric vehicles, increasing charging load is connected to the power grid, which has a certain impact on the operation of the distribution network. At present, domestic and foreign scholars have analysed the impact of charging load on the distribution network from different perspectives including the following aspects.

Influence on power quality of distribution network. The impact of charging load of electric vehicles on power quality of distribution network mainly includes voltage deviation, three-phase unbalance and harmonic pollution. Literature [1] analyzed and studied the influence of electric vehicle charging piles on power quality. When electric vehicle users choose to charge late at night, this will be the main cause of voltage deviation distortion. At the same time, harmonic pollution caused by charging load will also have adverse effects on transformers, relay protection devices and cables. Literature [2] analyzed the voltage flicker problem caused by rapid charging stations. Literature [3] studied the influence of different permeability conditions of electric vehicles on low-voltage feeder and found that the influence on three-phase node voltage of distribution network is not the same, also proposed to use three-phase distribution power flow model for specific analysis.

Influence on the economy of distribution network. The influence of electric vehicle charging load on distribution network economy is mainly reflected in the change of distribution network loss when charging load is connected or not connected and the influence on transformer service life. Literature[4] analyzed the influence of electric vehicle access on distribution network loss under different permeability conditions. Literature [5] studied the influence of charging load of electric vehicles on the service life of transformers. The results show that the service life of the transformer will be greatly reduced if the charging load of the electric vehicles is not optimally controlled.

Influence on environment. Electric vehicles have the advantage of low emissions compared with fuel vehicles. When electric vehicles are gradually popularized, carbon dioxide emission will be effectively reduced. Literature [6] studied and analyzed the relationship between electric vehicle access and carbon dioxide emissions in different scenarios. Simulation results show that carbon dioxide emissions are reduced to some extent in each scenario. Literature [7] and [8] established emission model to analyze the impact of electric vehicle access on emissions. The calculation results show that the emission can be effectively reduced by controlling the load of electric vehicles and coordinating the new energy access.

Influence on the planning and construction of distribution network. The increase in the number of electric vehicles is bound to require the corresponding charging equipment. In the planning and construction of distribution network, the space-time distribution of charging load of electric vehicles should be fully considered, and the number and address of charging facilities should be reasonably selected. Literature [9] divides the service area of a charging station according to Voronoi diagram theory, and determines the configuration of the charger with the maximum queuing waiting time, so as to determine the address and quantity of the charging station and minimize the construction investment cost, operation cost and time cost of the charging station for users.

However, few studies focus on the impact of electric vehicle development on urban power grid. Electric vehicle scale prediction model, electric vehicle load characteristic model and load impact of electric vehicles on the city power grid model are established in this paper. Based on actual data of electric vehicles and power grids in a large city, this paper predicts the development scale electric vehicles. Considering the travel characteristics of electric vehicle users, this paper analyzes load characteristics of electric vehicles and quantitatively analyzes multi-level impact on the city power grid of the electric vehicle load. At last, this paper summarizes the corresponding conclusions and put forward suggestions.

2. Prediction of electric vehicle scale

Considering the functional uses, electric vehicles are divided into four categories, namely bus, taxi, freight logistics, and private cars for scale prediction. The scale of bus and taxi is predicted according to the relevant total quantity planning and the process of electrification. The scale forecast of freight logistics increases with the city and population scale and partly is electrified. The prediction of private car scale mainly takes into account urban license plate policies, etc. The prediction results of electric vehicle scale are shown in table 1.

Table 1. Prediction of electric vehicle scale.

	2018	2020	2025	2030	2035
Number of electric vehicle stock	23	57	82	102	112
Electric vehicle stock/vehicle stock	2.8%	9.3%	13.0%	15.8%	17.1%

3. Characteristic of electric vehicle charging load

3.1. Analysis method

In this paper, the space-time distribution model of electric vehicle travel based on travel chain and the charging load model of electric vehicle charging station based on Monte Carlo simulation are adopted. Considering the characteristics of the electric vehicle travel, including travel time, travel destination, distance, parking time, etc., a city could be divided into residential areas, work areas, commercial areas according to the functional characteristics. By analyzing the characteristics of the electric vehicle travel in different function areas and electric vehicle charging load characteristics, then the paper analyzes the multi-level influence of the electric vehicle charging load to the urban power grid.

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3.2. Characteristic of electric vehicle trip

3.2.1. Trip modes of electric private cars. The main parking places for electric private cars are the parking lots in residential areas, working companies and shopping malls and other commercial entertainment areas. According to the statistics of Beijing Traffic Development Research Center, the peak time for car owners to go to work is 7:30-8:30, and to arrive at company is 8:30-9:30. The peak time for car owners to get off work is 17:00-18:30, and to go back home is 17:30-19:00. If the car owner needs to go shopping or go for fun after work, it can be assumed that the time to get home is 21:00-22:30.

3.2.2. Departure time. The daily driving needs and personal habits of the owners of electric private cars determine the departure time. According to the statistical data of the traffic department of family users, the departure time follows the normal distribution. Due to work, shopping and other reasons, the departure time of users is mainly 7.30-8.30 as Figure 1.

*3.2.3. Parking time distribution.*Parking needs in different functional areas vary. During the day, as factories work, shopping malls and office buildings start to operate, a large number of cars drive into such areas, and the working areas, industrial and commercial areas and other areas are in the parking peak. In the evening, with the closing of factories, shopping malls and offices, users drive away from office areas and business districts, therefore residential areas are in the parking peak. The demand fitting results of weekday parking in residential areas, offices, commercial areas and other areas of a city obtained from the survey are shown in the Figure 2-4.

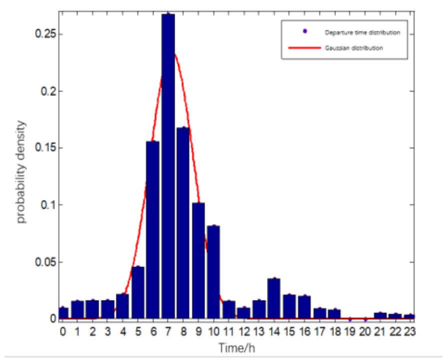

Figure 1. Electric vehicle daily departure time distribution.

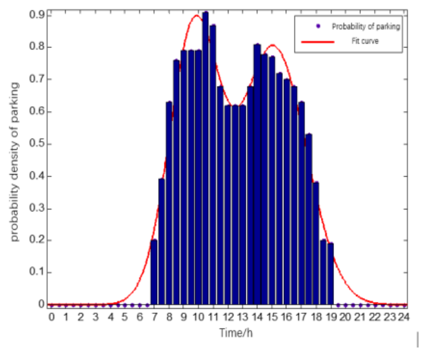

Figure 2. Electric vehicle daily parking distribution of residential area.

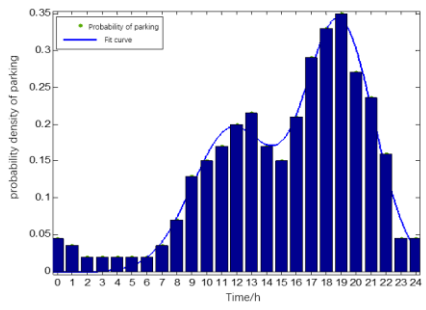

Figure 3. Electric vehicle daily parking distribution of commercial area.

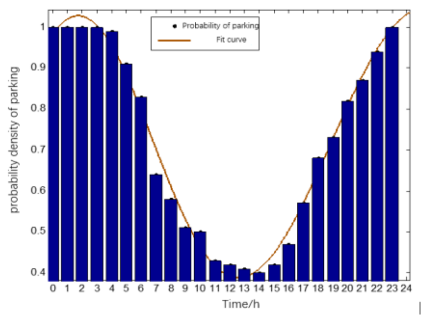

Figure 4. Electric vehicle daily parking distribution of residential area.

3.3. Characteristic of electric vehicle load

Charging modes of different functional areas are different. Assuming that slow charging mode is selected in residential areas and fast charging mode is adopted in working areas and commercial areas, the charging behavior of 90,000 electric vehicles is simulated as Figure 5-6.

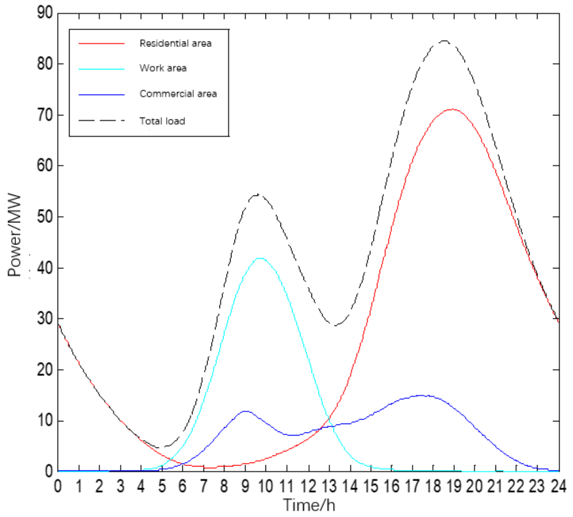

Figure 5. Daily load curve of workday.

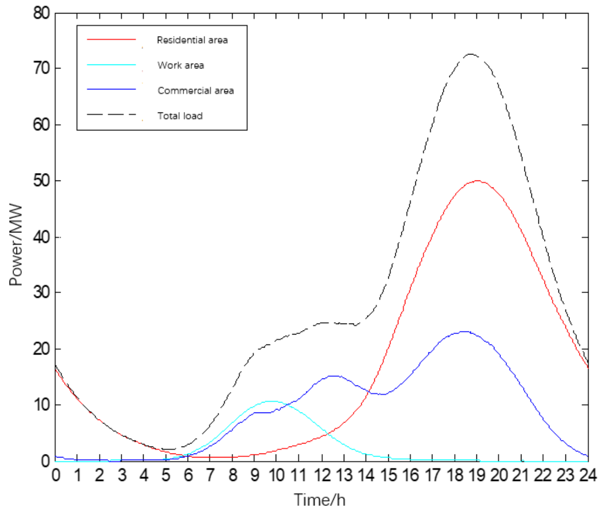

Figure 6. Daily load curve of weekend.

The charging load of electric vehicles has the following characteristics:

In general, the total charging load reaches its maximum at 18:00-19:00 in the evening. With the increase of electric vehicle load penetration, the on peak and off-peak difference of the overall load gradually increases.

The daily load curve characteristics of different functional areas are different. The charging load in residential areas is mainly concentrated in the evening, and reaches the maximum at 18:00-20:00, which is the peak time for residents to go home, and reaches the minimum at 7:00-9:00, which is the peak time to leave home. The charging load in work area is mainly concentrated at 7:00-13:00, and reaches the highest at 9:00-10:00. The charging load in the commercial area mainly concentrate in the daytime and before 24:00 at night. The charging loads reach the highest level at 17:00-18:00. In workday, charging load in the work area is obviously greater than that in commercial area during the daytime. Moreover, the peak load appears at different times, and the commercial area has two peak load charges in a day.

The daily load curve of workday is different from that of weekend. The shape of charging load curve in residential areas on weekend is similar to that in weekdays, but the peak value is slightly smaller. The shape of charging load curve in work areas on rest days is similar to that on weekdays too, but the peak value decreases obviously. On weekend, the charging load in commercial area is much larger than that of weekday, reaching the peak from 18:00 to 19:00. Compared with weekdays, the on-peak and off-peak difference of total load in rest days of all areas are different, and the peak load is lower.

4. Impacts of electric vehicle charging load on city grids

Electric vehicle charging has the characteristics of randomness and mobility, with large on-peak and off-peak difference and low utilization hours, which are superimposed with double peaks of grid load. Disorderly charging of electric vehicles has a profound impact on load structure, on-peak and off-peak difference of system, distribution network utilization rate, charging facilities and supporting network construction. Based on the actual data of a large city A, this paper analyzes the impact of electric vehicle load on the distribution network.

4.1. Impact of electric vehicle load on grid load
Electric vehicle charging load changes the grid load structure. It is estimated that the maximum charging load of grid in city A will take up more than 15% of the maximum electricity load in 2030, reaching the peak. The charging power of single pile in private, public and specialized fields is estimated as 7 kw, 60 kw and 100 kw respectively. In 2035, the maximum charging load of electric vehicles in city A will reach 6.3 million kw, accounting for 14% of the maximum load of the power grid and half of the air conditioning load, which becomes one of the main power consumers during the city peak load. It is estimated that the proportion of the maximum charging load in the maximum load of the power grid will reach a peak of 15% in 2030. From 2020 to 2035, the average annual growth rate of electric vehicles charging load is as high as 4.2%, 1.9 percentage points higher than the growth rate of total electric load as Table 2.

4.2. Impact of electric vehicle load on grid use ratio
The maximum load utilization hours of electric vehicles are lower than the power grid load, which reduces the utilization rate of distribution network and investment efficiency. It is estimated that in 2030, the annual maximum load utilization hours of grid base load in urban A will be 5,500 hours, but the electric vehicle load will only be 1,900 hours. Considering the capacity increase and transformation of the distribution network based on 30% reserve, the capacity utilization rate of the charging distribution network of electric vehicles is only 15%, which is 26 percentage points lower than the new distribution network of conventional load, and the investment benefit of the supporting distribution network of charging facilities is low.

4.3. Impact of electric vehicle load on on-peak and off-peak difference
Electric vehicle charging increases on-peak and off-peak difference of system as shown in Table 3. In 2030, the on -peak and off-peak differential rate of power grid in city A will increase by 6.3 percentage points to reach the peak, which puts forward higher requirements for the power grid's peak regulation capacity. The charging peak of electric vehicles overlaps with the peak load of electricity, which pushes up the peak load and peak-valley differential rate of the system and makes the peak regulation of the power grid more prominent. In city A, the time periods of 13:00-14:00 and 20:00-22:00 are the charging load peaks of electric vehicles, which are superimposed with the peak load periods of the power grid. Influenced by electric vehicle charging, it is estimated that in 2030, the maximum load of grid in city A will increase by about 4.8 million kw, an increase of 13%, and the on-peak and off-peak differential rate will increase by 6.3 percentage points, to 52%. It will cost about 24 billion yuan to build a new peak regulation power supply.

4.4. Impact of electric vehicle load on grid investment and construction
With the increasing demand for charging infrastructure, it is increasingly difficult to build charging facilities and supporting power grids. In 2035, the total demand for charging piles in the public, specialized and private sectors of city A will be 244,000, 37,000 and 694,000 respectively. A total of 10.88 million kva and 6.8 billion yuan of investment are needed to build new substation capacity for the distribution network. The construction land demand for charging facilities in the public sector is 2.83 million square meters, making it more difficult to locate charging stations and supporting power grids.

Table 2. Prediction of electric vehicle charging load.

	2017	2020	2025	2030	2035
Maximum grid load (10MW)	2263	3117	3638	4128	4477
Maximum electric vehicle charging load (10MW)	64	340	446	609	630
Maximum electric vehicle charging load/ maximum grid load (%)	3	11	12	15	14

Table 3. Impact of electric vehicle load on grid load.

	2017	2020	2025	2030	2035
Increase of grid maximum load (10MW)	9	272	338	478	477
Percentage of increase of grid maximum load (%)	0.4	9	10	13	12
Increase of peak and off-peak load ratio (percentage)	2.1	4.7	5.0	6.3	5.8

5. Conclusion

With the rapid development of electric vehicles, increasing electric vehicle charging load will have extensive impacts on the power grid. At present, few studies focus on the impact of the charging load on the urban power grid. This paper innovatively analyzed the impact of charging load on the urban power grid by taking the power grid of a large city as an example. Firstly, the scale of electric vehicles is predicted by comprehensively considering urban development planning, traffic planning, policies and other factors. Secondly, considering the travelling characteristics of electric vehicles, the charging load characteristics of electric vehicles in different functional areas of the city were analyzed. Finally, the impact of unordered charging of electric vehicles on urban power grid is quantitatively analyzed from four aspects, including load structure, on-peak and off-peak difference of system, distribution network utilization rate, charging facilities and supporting network construction. It mainly includes: electric vehicle charging will change the load structure of the power grid; the maximum load utilization hours of electric vehicles are lower than the power grid load, which will reduce the utilization rate of distribution network and investment efficiency; electric vehicle charging will increase the on-peak and off-peak difference of the system; the development of electric vehicles has increased the demand for charging infrastructure construction, making it increasingly difficult to build charging facilities and supporting power grids. It is suggested to guide and participate in two-way interaction through incentive, price and market mechanism, which can effectively reduce the maximum charging load of electric vehicles, improve on-peak and off-peak difference, reduce the need for supporting power grid construction, and promote the consumption of clean energy.

Acknowledgments

This paper is supported by State Grid Corporation of China Technology Program “Study on Grid Load Characteristics and Load Prediction Considering User Behaviour and Electricity Characteristic of Industry” and State Grid Energy Research Institution Research Program “Research on the Impact of Electric Vehicle "Vehicle-Pile-Network" Development on Electric Network”

References

[1] Gao CW, Zhang L 2011 *A Survey of Influence of Electrics Vehicle Charging on Power Grid* vol 35, Power System Technology p 127

IOP Conf. Series: Materials Science and Engineering **486** (2019) 012139 doi:10.1088/1757-899X/486/1/012139

[2] Hu ZC, Song YH, Xu ZW, Luo ZW, Zhan KJ, Jia L 2012 *A Survey of Influence of Electrics Vehicle Charging on Power Grid* vol 35, Power System Technology p 127
[3] Hu ZC, Song YH, Xu ZW, Luo ZW, Zhan KJ, Jia L 2012 *Impacts and Utilization of Electric Vehicles Integration Into Power Systems* vol 32, Proceedings of the CSEE p 1
[4] Quinn C, Zimmerle D, Bradley T 2012 *An Evaluation of State-of-Charge Limitations and Actuation Signal Energy Content on Plug-in Hybrid Electric Vehicle, Vehicle-to-Grid Reliability, and Economics* vol 12, IEEE Transactions on Smart Grid. p 483-491
[5] Lin C, Yao C, Wu Q, Lin WX，Singh C 2014 *Evaluating Charging Service Reliability for Plug-In EVs From the Distribution Network Aspect* vol 5, IEEE Transactions on Sustainable Energy p1287
[6] Lin ZL 2013, *Operation Mode of Charging and Swapping Facilities for Electric Vehicles and their Impact on Power Grid*, South China University of Technology
[7] Tu Y 2013, *Charging Mode of Electric Vehicle and its Load Characteristics Analysis*, Nanjing University of Science and Technology
[8] Li QS 2014, *Research on Models and Strategies of Electric Energy Coordinated Consumption with Electric Vehicles Integrated in Power System*, North China Electric Power University
[9] Xue F, Lei XZ, Zhang YB, Liu HC, Gao CW 2012, *A Complex Network-Based Method to Evaluate Smart Charging and Swapping Network for Electric Vehicles* vol 36, Power System Technology p20