

# The impact of quick charge on power quality of high-voltage grid

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**Abstract.** With the continuous development of electric vehicles, a large number of electric vehicles have connected to the grid. This impacts the security and economic operation of power systems deeply. When large-scale electric vehicles are charging, it will bring the problem of electricity load growth and cause the peak-valley difference of power grid. The paper analyzes the impact of electric vehicles quick charge on power quality. According to Monte Carlo method, the daily load curve of quick charging mode in Beijing in 2030 is set up. Newton Raphson method and forward-backward substitution method are used to analyze the voltage deviation and power loss of each node in the typical power system.

## 1. Introduction

Electric vehicles charging mode is divided into conventional charging mode, quick charging mode and mechanical charging mode [1]. Due to the quick charging mode has characteristics like charging time is short, long battery life, without memory and so on [2], in this paper, we study the quick charging mode. Electric vehicles quick charge will produce very big power load and high harmonic in a short time, which can produce great influence to power grid electric energy quality. The factors that affect the quality of the electric energy include the fluctuation and the flicker of voltage, the voltage deviation, frequency deviation, harmonics and three-phase voltage unbalance [3]. Electric vehicles will produce a lot of harmonic while charging. Harmonic pollution will have a negative impact on the power quality of the power supply system [4]. Therefore, it is significant to study the effect of power quality on electric vehicles quick charge and propose the corresponding strategies.

## 2. Electric vehicles charging load model and realization method

### 2.1. Total charge power calculation model

The total charge load curve is the sum of each electric vehicle charging load curve. The charging load is calculated with the day as the unit, the time is accurate to every minute, a total of 1440 minutes per day. The total charge power for the first  $i$  minutes is the sum of the charging load of all the electric vehicles which are being charging at the first  $i$  time. Equation (1) for the total charge power formula:

$$L_i = \sum_{n=1}^N P_{n,i} \quad i=1,2,\dots,1440 \quad (1)$$

Among them:  $L_i$  is the total charge power for the first  $i$  minutes;  $N$  is the sum of the electric vehicles;  $P_{n,i}$  is the charging power of the first  $N$  vehicle in the first  $i$  minutes.



## 2.2. Load model for electric vehicles quick charge

In the quick charging mode, the power of the charger is very large. The charging current is much higher than the normal current, which can improve the battery SOC in a very short period of time. The number of electric vehicles that set one day quick charging mode is  $N$ ,  $S_1$  is the initial SOC, which obeys  $N(\mu_1, \sigma_1^2)$ ;  $S_2$  is the end charge SOC, which obeys  $N(\mu_2, \sigma_2^2)$ ,  $S_1 < S_2 \leq 1$ . Set current charging with 1C, charging power is  $P$ , which obeys the uniform distribution in the 20~30kW range. It is assumed that the quick charge time of the electric vehicles is uniform distribution, and the distribution probability function can be obtained by the equation (2).

$$f_t(x) = \begin{cases} \alpha, & x \in T_a \\ \beta, & x \in T_b \\ \gamma, & x \in T_c \end{cases} \quad (2)$$

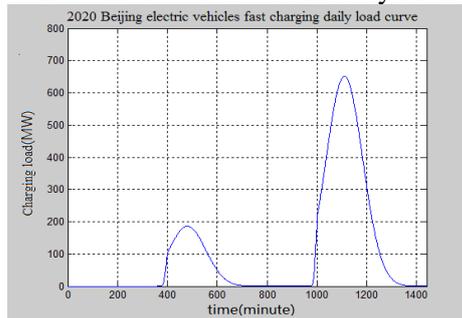
Among them:  $T_a$ ,  $T_b$  and  $T_c$  represent the different time periods.

Electric vehicles charging duration can be expressed by equation (3) [5].

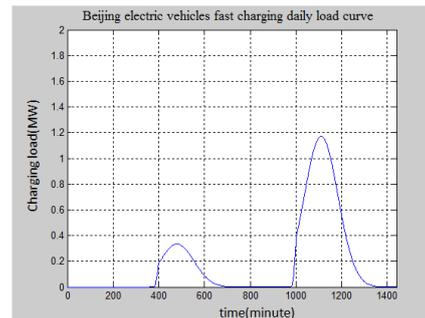
$$T = \frac{(s_2 - s_1)C}{P} \quad (3)$$

## 2.3. Method for realizing the quick charge load model of electric vehicles

According to the quick charge load model of the electric vehicles, the daily load curve of quick charge for electric vehicle can be obtained by Monte Carlo simulation method.



**Figure 1.** 2020 Beijing electric vehicles quick charge daily load curve.



**Figure 2.** 2030 Beijing electric vehicles quick charge daily load curve.

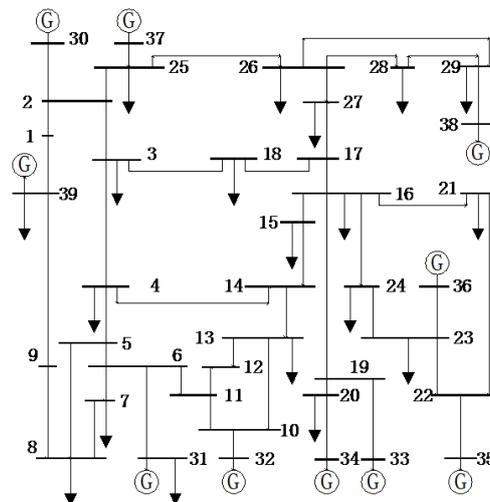
From the figure 1 and 2 we can learn that the daily load of the two peak values have a big difference between 2020 and 2030. The value of charging load can affect the running state of power system, and its power quality. Therefore, it is very important to control the charging load in a certain range and reduce the effect on the power quality.

## 3. The effect of quick charge on power quality of high-voltage grid

### 3.1. Voltage deviation of high voltage power network during quick charge

Using the Typical network topology data of 10 machines 39 nodes. We calculate the voltage deviation when the electric vehicles are quick charged according to the Newton Raphson power flow calculation method. By analyzing the voltage deviation, we can study on the effect of electric vehicles on power quality while they are being quick charged [6].

The network topology structure of 10 machines 39 nodes includes 10 generators, 39 nodes, 12 transformers, 34 lines. The system reference power is 100MVA, the reference voltage is 345kV. Figure 3 is a network topology structure connection diagram of 10 machines 39 nodes.



**Figure 3.** Network topology structure of 10 machines 39 nodes.

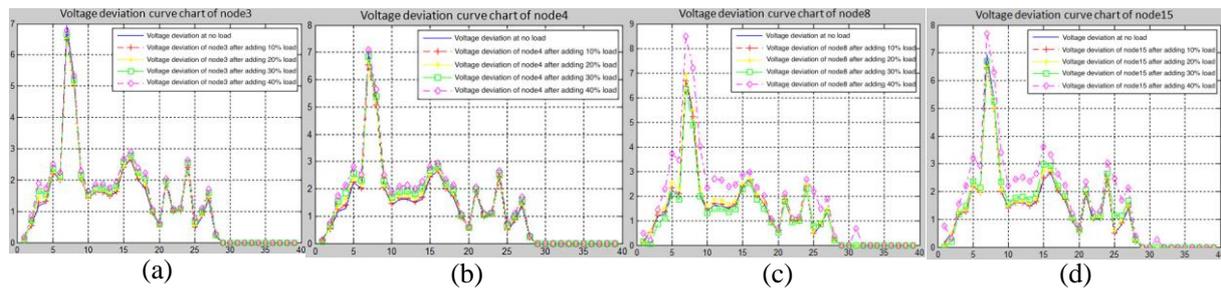
When the reactive power load is added to the system nodes, the system can get the voltage value of each node in the actual operation by the Newton Raphson method for power flow. Through the calculation formula of the voltage deviation, the voltage deviation of each node is obtained eventually [7]. When the electric vehicles quick charging daily load curve data of 2030 is added to the system nodes, we can calculate the voltage deviation of the system. In 2030, the daily load peak was 1172MW, and the power load was added to the single node of the system according to the 10%, 20%, 30%, 40% of the permeability respectively for calculating the voltage deviation of the system. After adding the power load, the voltage deviation variation of 6 nodes in the system is obvious. We select the 6 feature nodes to analyze the voltage deviation.

From figure 4, it can be seen that the voltage deviation of the nodes after adding the 40% of the power load is bigger than that with no power load. This can be known, the user charging behavior will affect the size of the power load, while the power load will affect the index of the voltage deviation in power quality. Therefore, the reasonable range of the power load to the nodes of the grid can make the normal operation of the network. If exceeding a reasonable range, the voltage deviation in the power grid will be greater and the power quality will also be seriously affected.

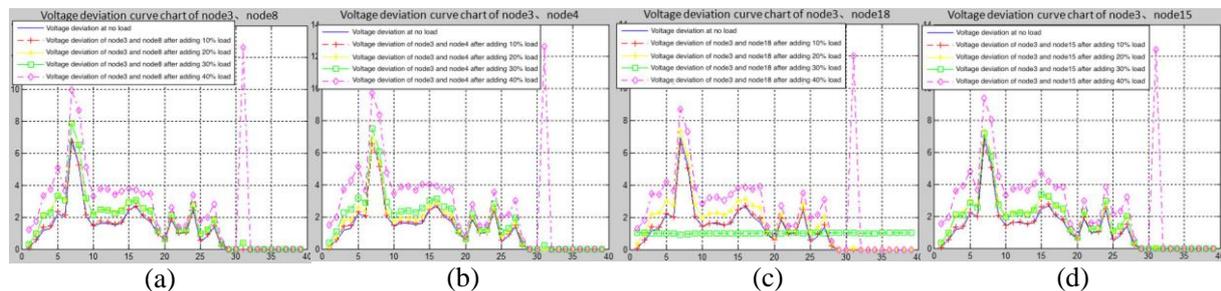
The above is the result of voltage deviation by adding the power load to the single node. In real life, electric vehicles charging will select multiple nodes at the same time in the power grid. Then we will select two nodes to add the 10%, 20%, 30% and 40% of the power load, and study their voltage deviation variation [8].

After according to the voltage deviation variation of the single feature node adding power load, we select any two nodes in the feature node.

Voltage deviation is an important index in power quality. According to the provisions mentioned above concerning the voltage deviation standard for power supply (GB/T 12325-2003), the voltage deviation of the supply voltage higher than 35kV shouldn't exceed 10%. The reference voltage of the power grid is 345kV. It can be seen from figure 5, the deviation of the voltage deviation from the load without power load is increasing with the increase of the power load. After any two feature nodes adding 40% of the power load, most of the value of the voltage deviation exceed the standard range of voltage deviation, reaching 11%~12%. The voltage deviation exceeding the standard range will increase the loss of line in the grid system and increase the power consumption of the grid. It's also has a bad impact on the power grid [9].



**Figure 4.** Voltage deviation of single feature node comparison chart.



**Figure 5.** Voltage deviation of two feature nodes comparison chart.

### 3.2. The influence of voltage deviation on power quality in high voltage power grid

The large voltage deviation will affect the quality of power directly, which shows the increase of line loss and the decrease of power factor in power grid. The reactive power loss and the active power loss of the power grid increase with the low voltage operation, which increases the cost of power consumption and affects the economic operation of the power grid. In addition, voltage deviation is too large will make the operation of the power system is not stable and easy to cause damage to electrical equipment easily [10]. In this paper, reactive power loss, active power loss and reactive power factor of the power grid are analyzed to study the influence of voltage deviation on the power quality of the electric vehicles charging at multiple nodes simultaneously.

From the table 1 we can see that, after two feature nodes are added at 30% and 40% of the power load, the reactive power loss is higher than that are added at 10% and 20% of the power load. Therefore, the increase of voltage deviation will directly affect the reactive power loss of the power grid. After adding 40% of power load, the reactive power loss rate is 4%~6% in Table 1, the loss of reactive power is larger. The line loss rate in the power grid is mainly the reactive power loss. Therefore, it can be explained that the voltage deviation will affect the line loss rate of the power grid, thus affecting the power quality [11].

The cause of the voltage deviation is reactive power compensation is excessive, the transmission distance is too long, excessive overloading and lack of reactive power [12], the reactive power shortage is major cause of the voltage deviation. Because of the lack of reactive power is generated due to the reactive power factor is low. The following will mainly analyze the reactive power factor of the two feature nodes after adding power load and study the reasons for the shortage of reactive power.

From table 2 indicates that part of the power factor is reduced to 0.8 after two feature nodes of the grid system adding to 30% and 40% power load. The low power factor of power system causes insufficient reactive power.

We charge with the power load of 10%, 20%, 30% and 40% on the single node or two feature nodes. It can be seen that the voltage deviation is within the standard range after the power load is added to the single feature node. As the power load increases, the deviation of voltage deviation from the original voltage deviation is getting larger and larger. Therefore, we should add the reasonable

power load at the nodes, avoiding the voltage deviation exceeding limit. After two feature nodes are added to 20%, 30% and 40% of the power load, part of the voltage deviation is greater than 10%. Lead to voltage deviation exceeding the limit, resulting in line loss and the reactive power shortage. After node 4 and node 15 are added 20% of the power load at the same time, the voltage deviation exceeds the limit. We need to avoid adding too much power load on these two nodes at the same time. When electric vehicles quick charge in the two nodes, the number of electric vehicle charging needs to be restricted, avoid grid voltage deviation is too large, which can affect the power quality.

**Table 1.** The power loss after two nodes added the power load.

| node             | 10% load<br>reactive<br>power loss | 10% load<br>active<br>power loss | 20% load<br>reactive<br>power loss | 20% load<br>active<br>power loss | 30% load<br>reactive<br>power loss | 30% load<br>active<br>power loss | 40% load<br>reactive<br>power loss | 40% load<br>active<br>power loss |
|------------------|------------------------------------|----------------------------------|------------------------------------|----------------------------------|------------------------------------|----------------------------------|------------------------------------|----------------------------------|
| node 3, node 4   | 0.489                              | 0.484                            | 1.188                              | 0.520                            | 2.419                              | 0.587                            | 6.604                              | 0.832                            |
| node 3, node 8   | 0.520                              | 0.486                            | 2.389                              | 0.582                            | 2.344                              | 0.581                            | 6.166                              | 0.800                            |
| node 3, node 15  | 0.431                              | 0.480                            | 2.349                              | 0.582                            | 2.364                              | 0.587                            | 6.781                              | 0.851                            |
| node 3, node 18  | 0.451                              | 0.481                            | 2.362                              | 0.582                            | 2.439                              | 0.590                            | 5.512                              | 0.768                            |
| node 3, node 27  | 0.418                              | 0.473                            | 2.275                              | 0.569                            | 2.355                              | 0.576                            | 4.266                              | 0.690                            |
| node 4, node 8   | 0.591                              | 0.488                            | 2.389                              | 0.582                            | 2.735                              | 0.597                            | 4.762                              | 0.716                            |
| node 4, node 15  | 0.485                              | 0.482                            | 4.038                              | 0.674                            | 2.581                              | 0.593                            | 4.619                              | 0.713                            |
| node 4, node 18  | 0.487                              | 0.482                            | 1.206                              | 0.517                            | 5.582                              | 0.772                            | 4.391                              | 0.695                            |
| node 4, node 27  | 0.457                              | 0.474                            | 1.158                              | 0.505                            | 5.431                              | 0.758                            | 4.336                              | 0.686                            |
| node 8, node 15  | 0.517                              | 0.483                            | 1.248                              | 0.519                            | 2.524                              | 0.588                            | 4.440                              | 0.699                            |
| node 8, node 18  | 0.519                              | 0.483                            | 2.345                              | 0.577                            | 5.286                              | 0.750                            | 4.192                              | 0.681                            |
| node 8, node 27  | 0.491                              | 0.476                            | 2.293                              | 0.568                            | 2.371                              | 0.569                            | 4.159                              | 0.672                            |
| node 15, node 18 | 0.442                              | 0.479                            | 1.184                              | 0.517                            | 5.736                              | 0.787                            | 4.643                              | 0.720                            |
| node 15, node 27 | 0.415                              | 0.471                            | 2.433                              | 0.583                            | 2.535                              | 0.590                            | 4.659                              | 0.723                            |
| node 18, node 27 | 0.431                              | 0.472                            | 1.176                              | 0.509                            | 2.562                              | 0.590                            | 4.678                              | 0.722                            |

**Table 2.** Reactive power factor after two nodes added power load.

| node            | 10% no load<br>Power factor | 20% no load<br>Power factor | 30% no load<br>Power factor | 40% no load<br>Power factor |
|-----------------|-----------------------------|-----------------------------|-----------------------------|-----------------------------|
| node 3, node 4  | 0.9                         | 0.9                         | 0.9                         | 0.9                         |
| node 3, node 8  | 0.9                         | 0.9                         | 0.9                         | 0.8                         |
| node 3, node 15 | 0.9                         | 0.9                         | 0.9                         | 0.8                         |
| node 3, node 18 | 0.9                         | 0.9                         | 0.9                         | 0.8                         |
| node 3, node 27 | 0.9                         | 0.9                         | 0.9                         | 0.9                         |
| node 4, node 8  | 0.9                         | 0.9                         | 0.9                         | 0.8                         |
| node 4, node 15 | 0.9                         | 0.8                         | 0.8                         | 0.8                         |
| node 4, node 18 | 0.9                         | 0.9                         | 0.8                         | 0.8                         |

|                         |     |     |     |     |
|-------------------------|-----|-----|-----|-----|
| <b>node 4, node 27</b>  | 0.9 | 0.9 | 0.9 | 0.9 |
| <b>node 8, node 15</b>  | 0.9 | 0.9 | 0.9 | 0.8 |
| <b>node 8, node 18</b>  | 0.9 | 0.9 | 0.8 | 0.8 |
| <b>node 8, node 27</b>  | 0.9 | 0.9 | 0.9 | 0.8 |
| <b>node 15, node 18</b> | 0.9 | 0.9 | 0.9 | 0.9 |
| <b>node 15, node 27</b> | 0.9 | 0.9 | 0.9 | 0.9 |
| <b>node 18, node 27</b> | 0.9 | 0.9 | 0.9 | 0.9 |

#### 4. Conclusion

Based on the daily load curve of quick charge for electric vehicles in Beijing in 2030, this paper analyzes the influence of the electric vehicles quick charge on voltage deviation of high voltage power grid. Through the typical network topology data of 10 machines 39 nodes, using Newton Raphson method analysis the voltage deviation and loss, when a large number of electric vehicles quick charge on the high voltage power grid. And study its effect on power quality. Quick charging mode can generate a large charge power in a short time, which can meet the electric vehicles in a short time full of electricity requirements. However, it also causes the increase of voltage deviation, increases the line loss in the power grid system, and increases power consumption of the power grid. At the same time, it has a negative impact on the power grid, affecting the reliability of the distribution network operation. The calculation method of this paper can predict the future electric vehicles ownership. And the load model can also be used to study the impact of future electric vehicles charging on the power grid, which has certain practical value.

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