Research on voltage stability and control strategy of power system considering grid connected charging of electric vehicles

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Abstract. The development of new energy vehicles is an important measure to deal with the growing energy demand and climate change. Especially in recent years, with the support of national policies and the maturity of electric vehicles (EVs) related technologies, the number of EVs has increased explosively, and the situation is very good. However, it also means that a large number of charging loads will be connected to the power grid, which will put great pressure on the safe and stable operation of the power grid. Although there have been many studies on the impact of EVs integration into modern power grid, most of the EVs load models are based on probability function and lack accuracy. Therefore, starting with the actual operation data of EVs charging station, this paper studies the influence of a large number of EVs charging loads on the static voltage stability of power grid. It is found that the charging load of large-scale EVs is added to the power grid, which significantly reduces the stability of power grid voltage, especially at the place connected to the EVs load and far away from the balance node. In addition, when the charging station adopts the time-of-use (TOU) price strategy, it can effectively improve the voltage stability of the whole network.

1. Introduction
In recent years, the rapid development of society has also brought a series of problems, such as the shortage of fossil energy, global warming and excessive emission of pollutants, which has brought great challenges to the development of modern society [1]. As a promising element of sustainable development and environment-friendly means of transportation, EVs have attracted extensive attention [2]. However, the rapid development of EVs has also brought various challenges to the growing charging demand of the power grid [3]. Nowadays, power systems are forced to operate closer to safety limits [4-6]. As a mobile random load, grid connected charging of large-scale EVs will increase the burden of the power grid and pose a potential threat to the voltage stability of the power grid, especially cluster charging, which may cause regional power grid collapse in serious cases [7-8]. Voltage is one of the important indexes to evaluate the stability of power system [9-10]. It is very important to evaluate the voltage stability of power system to ensure the safe operation of the system. In this paper, the existing actual charging station data are processed, and the influence of EVs charging load on power grid voltage stability is studied by comparing and analyzing the value of voltage stability index L of each node of power grid under the three conditions of only basic load, disorderly charging of EVs and TOU price strategy.
2. Data processing of EVs charging station

The charging of EVs connected to the power grid will impose relatively large load demand, and the load characteristics of EVs are different from other traditional system loads. The start and duration of charging and the actual power consumption of EVs load can not be simply predicted [11]. Therefore, starting with the real EVs charging data, the experiment is closer to the actual situation. The data comes from a charging station in Fuzhou. The station is a comprehensive charging station, with a total of five charging piles, each pile has two charging ports, all of which are DC fast charging. We analyzed the data of two months when the charging station adopted different pricing strategies, namely December 2020 and April 2021. The pricing strategy adopted in December 2020 is 0.8 ¥/kWꞏh for a whole day; In April 2021, the time-sharing pricing strategy was adopted from 6:00 to 23:00, it was 1.23 ¥/kWꞏh, and from 23:00 to 6:00, it was 0.88 ¥/kWꞏh.

We analyze and process the original message data, and extract the field information such as time, charging stake number, charging socket number. The time interval of each data is 7 seconds. Here, we take the voltage and current data appearing for the first time in each minute as the data at that minute, and multiply the voltage and current to be the power at that time. We then add the power of each charging port of each charging pile at the same time to obtain the overall power of the charging station for each minute. As shown in table 1, the power of the charging station for four minutes is given.

| Time             | Power(W) |
|------------------|----------|
| 2021-04-02 00:00:00 | 144360.72 |
| 2021-04-02 00:01:00 | 84066.20  |
| 2021-04-02 00:02:00 | 135400.46 |
| 2021-04-02 00:03:00 | 135863.94 |
| ...              | ...      |

In this way, the daily charging load curve of the charging station can be drawn. Considering the worst situation, we select the day with the largest peak valley difference in a month as the representative data of that month. They are the daily peak valley difference of load in December 2020 and April 2021, respectively. It is obvious that December 20, 2020 and April 13, 2021 are the days with the largest load peak valley difference in two months respectively, so we select the data of these two days for the experiment, as shown in figure 1 and figure 2.
3. Simulation example calculation

3.1. Calculation of voltage stability index

In [12], the formula of load bus voltage stability load index is given by using voltage equation. This technique uses the measured values of bus voltage phasor and no-load voltage to calculate the voltage stability index. This index gives the distance from the bus to the voltage stability limit. The voltage stability index is given by the following equation:

\[ L = \frac{4[V_0 V_1 \cos(\theta_0 - \theta_1) - V_1^2 \cos(\theta_0 - \theta_1)]}{V_0^2} \]  

(1)

Where \( V_0 \) and \( \theta_0 \) is the no-load bus voltage and phase angle respectively. \( V_1 \) and \( \theta_1 \) is the voltage and phase angle of the bus after the EVs is connected to the power grid and the superposition of the original load. When the value of \( L \) at every load bus in the system is less than 1.0, the system is voltage stable. As the value of \( L \) approaches 1.0 at any bus, the system approaches its stability limit and becomes unstable when \( L \) exceeds 1.0 at the referred bus.

3.2. Power flow calculation

PSASP software is selected for the simulation platform, and WSCC-9 node system is used for the test. As shown in figure 3, the reference capacity is 100mva, bus 1 is a balance node with unlimited output, bus 2 and bus 3 are PV nodes, and other buses are PQ nodes.

Combined with the typical daily load curve given in reference [13], it is taken as the basic load at bus 6. In addition, the charging loads of EVs under the guidance of disordered and time of use pricing strategies are added respectively. The EVs load power factor is set to 0.95, Suppose there are 100 similar charging stations in the region. Other buses are the original conventional load of the system. The voltage and phase angle of each bus are calculated by power flow. As shown in table 2, the voltage amplitude and phase angle of each bus under no-load condition. Then calculate the voltage amplitude and phase angle under other loads, and bring it into equation (1) to obtain the value of voltage stability index \( L \) of each bus under different loads.

Figure 3. WSCC-9 node system.
Table 2. Voltage amplitude and phase angle of each bus under no-load condition.

| Bus name | Voltage amplitude | Voltage phase angle |
|----------|-------------------|---------------------|
| Bus 1    | 1.04              | 0                   |
| Bus 2    | 1.02506           | 30.64294            |
| Bus 3    | 1.02502           | 25.43784            |
| Bus 4    | 1.02559           | 7.27665             |
| Bus 5    | 1.02918           | 13.36107            |
| Bus 6    | 1.03812           | 12.57936            |
| Bus 7    | 1.04583           | 25.18871            |
| Bus 8    | 1.05453           | 24.13246            |
| Bus 9    | 1.04822           | 22.78013            |

4. Results and discussion

As shown in figure 4 and figure 5, the L index of each bus when the time-of-use tariff strategy is adopted by the charging station and the charging station respectively. We can see that since bus 4 is closest to the balance node and the L index at bus 4 remains at a very small value, the voltage stability at bus 4 closest to the balance node is the highest. Bus 8 is far away from the balance node, its L value is large and its voltage stability is low. The load at bus 6 is the heaviest, and the L value at bus 6 is also high, with large fluctuation range and unstable voltage. Next, we compare the L index values of buses 6 and 8 under the conditions of only basic load, disordered charging and TOU price, as shown in figure 6 and figure 7.

It can be seen that after the EVs charging load is connected, the L index value at the bus increases obviously and the voltage stability decreases. Compared with the situation after disordered charging and charging stations adopt TOU price strategy, generally speaking, the L index value decreases and the voltage stability improves. However, with the time of use price strategy, the L index value increases significantly in the valley price period, resulting in the reduction of voltage stability in this period.

Figure 4. L index of each bus during disordered charging.

Figure 5. L index of each bus during TOU price charging.
5. Conclusion
Research shows:
- When the electric vehicle charging load is connected to the power grid, it will reduce the stability of the power grid voltage, especially at the bus added to the electric vehicle load and the bus away from the balance node.
- The time of use pricing strategy can effectively improve the voltage stability of the power grid at the whole time, but it will reduce the voltage stability during the valley price period. Therefore, it is necessary to formulate the charging price strategy in a planned way according to the local load characteristics, so that the power grid can operate within a safe range without transforming the existing lines.

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References
[1] Lv J B, Song H., Liu Y , et al. Study on the influence of EVs charging on the voltage quality of distribution network [J]. Electrical measurement and instrumentation, 2018, 55 (22): 33-40
[2] Notice of the State Council on printing and distributing the development plan of energy saving and new energy vehicle industry (2012-2020) [J]. Bulletin of the State Council of the people's Republic of China, 2012 (20): 26-31
[3] Kadurek P, Ioakimidis CS, et al. EVs and their impact to the electric grid in S. Miguel. In: Proceedings of international Conference on power engin.
[4] Chendur Kumaran R, Venkatesh TG, Swarup KS. Voltage stability – case study of saddle node bifurcation with stochastic load dynamics. Int J Electr Power Energy Syst 2011;33:1384–8.
[5] Tiwari R, Niazi KR, Gupta V. Line collapse proximity index for prediction of voltage collapse in power systems. Int J Electr Power Energy Syst 2012;41:105–11.
[6] Khani D, Sadeghi Yazdankhah A, Madadi Kojabadi H. Impacts of distributed generations on power system transient and voltage stability. Int J Electr Power Energy Syst 2012;43:488–500.

[7] Wu X, Hu X, et al. Stochastic control of smart energy management with plug-in EVs battery energy storage and photovoltaic array. J. Power Sour 2016;333:203e12.

[8] Dickerman L, Harrison J. A new car, a new grid. IEEE Power Energy Mag 2010;8(2):55e61.

[9] Wang Z, Fan S, et al. Coordinated charging strategy of plug-in EVs for maximizing the distributed energy based on time and location. J Eng 2017;13:1740e4. 2017.

[10] Burchett S, Douglas D, et al. An optimal thevenin equivalent estimation method and its application to the voltage stability analysis of a wind hub. IEEE Trans Power Syst 2018;33(4):3644e52.

[11] Impact of EVs fast charging on power system voltage stability[J]. International Journal of Electrical Power & Energy Systems, 2014.

[12] T. K. Rahman, G. B. Jasmon, “A New Technique for Voltage Stability Analysis in a Power System and Improved Loadflow Algorithm for Distribution Network”, Proceedings of 1995 International Conference on Energy Management and Power Delivery, 1995. EMPD '95, Vol. 2, pp. 714 – 719.

[13] Li Meng, Cheng Haozhong, Yang Zonglin, et al. Improved forecasting method of typical daily load curve using fractal interpolation [J]. Journal of power system and automation, 2015