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(RESEARCH ARTICLE)

The influence of electric vehicles charging and discharging on power grid stability

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Abstract

As a new type of transportation, electric vehicles (EVs) occupy significant advantages in terms of environmental protection, energy conservation and emission reduction, and renewable energy consumption. With the development of new energy grid integration technologies and the reduction of the production cost of electric vehicles, the ownership of electric vehicles has increased dramatically, at the same time, the charging and discharging process of electric vehicles will bring a series of impacts on the stability of the power grid. This paper analyzes the influence of the two operating modes of electric vehicle charging and discharging on the power grid stability.

Keywords: Electric vehicles (EVs); Charging and discharging; Power grid stability; Renewable energy

1. Introduction

With the development of time and economy, the problems of fossil energy shortage, environmental pollution and the greenhouse effect are becoming more and more prominent. Over the past few decades, these issues have gradually received extensive attention and focus worldwide. In order to alleviate and solve these problems, the exploration of alternative energy sources and research on sustainable energy development is a top priority, and electricity has become the focus of research in many countries because of its cleanliness and renewability. As a new generation of transport vehicles, electric vehicles (EVs) have the incomparable advantages of traditional vehicles in terms of energy conservation and emission reduction, and reducing human dependence on traditional fossil energy. EVs can be used as a mobile distributed power supply to access the power grid, not only for grid peak shaving, energy backup has an important role, but also EVs can be used as a distributed power supply, the ability to improve the flexibility and reliability of the grid power supply at the same time help to improve the efficiency of the energy use, and to slow down the investment in the construction of the power grid [1,2]. EV charging is equivalent to a load from the grid to obtain electricity, but with the large-scale development and popularization of EVs, large-scale load access to the grid makes the charging peak in the proportion of the load of the whole network gradually increased, and EV charging has the spatial uncertainty and the randomness of time, which causes disordered high-power load fluctuations for the power grid and poses challenges to the power grid stability [3].

2. Factors affecting the grid from EVs

The influence of EVs on the grid is determined by EV ownership, EV charging mode and charging time, and EV type.

2.1. EV ownership

The magnitude of the impact on the grid varies with the penetration of EVs. When the penetration of EVs is low, their charging has a small impact on the grid, and can even be considered a negligible perturbation of the power grid. And when EV penetration is high, its impact on the grid cannot be ignored.

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EV owners are influenced by most manufacturers, chief among them being the development of EV technology. As the technology becomes more sophisticated, the cost of building electric cars will come down. According to statistics, it is known that by the ten and twenty year span of 2020, 2030 and 2050 [4], the number of EVs in the United States will account for 35 percent, 51 percent and 62 percent of the total U.S. automotive industry, respectively. As China's economic development accelerates, awareness of environmental protection grows, and the energy crisis deepens, the number of EVs in China will approach the level of the United States. In addition, EV ownership is simultaneously dependent on government policy. This is because the market share of EVs depends on government subsidies. Eventually, the market for electric cars will grow dramatically when all of their costs are relatively equal to or less than those of conventional internal combustion engine vehicles. Large-scale grid-connected charging of EVs will bring a series of impacts on the power grid, such as load growth, increased difficulty in optimizing and controlling grid operation, and degradation of power quality, which will make power grid stability and control technology more difficult, and in severe cases, will cause system instability.

2.2. Charging mode and charging time of EVs

According to the technical and usage characteristics of EV power battery packs, there are three main modes: conventional charging (slow charging), fast charging and mechanical charging [5].

Slow charging is usually associated with overnight charging. Slow charging usually takes 6 to 8 hours to fully charge and is often found in homes and charging stations. The advantages of choosing slow charging are that it does not require much in the way of power supply, it has little impact on the battery and it is cheap to install. More importantly, night-time charging can help to balance loads through "valley filling" and "peak shifting". With the gradual increase in the number of EVs, it is highly likely that at some point in the future, centralized slow charging will result in charging loads superimposed on the original loads on the grid. "Peak-on-peak" or "Valley-on-valley" will result in the load on the grid exceeding the maximum capacity of the grid, and the worst-case scenario may be a repeat of the 1987 Tokyo voltage collapse and widespread blackouts in Japan.

Fast charging is a high-current method used in order to fully charge in a short period of time. Typically, the charging time is 10 to 30 minutes. Therefore, it is extremely efficient during peak hours and other time demand situations. However, the disadvantages of this method are: firstly, it gives a huge shock to the grid; secondly, it reduces the life of the battery. At a certain power level of the grid, large-scale EVs will draw significant currents from the grid, which will reduce the grid voltage, and in severe cases, will cause the voltage to deviate from the critical point of voltage stability leading to voltage instability and causing voltage collapse.

Mechanical charging is namely the rapid battery pack replacement system. Replacing the battery means replacing it with a fully charged battery inside an EV with a depleted battery. This method does not affect the cycle life of the battery. This method is easy to facilitate centralized management and can store the remaining power from the grid at night when the grid electricity load is low, and feed it back to the grid through inverter control at the peak of electricity consumption. Moreover, EVs can be used as distributed mobile power supply, which can be concentrated in areas with relatively large loads to provide back-up power and contribute to the safe operation of the power grid, and large-scale EVs will form a movable "power plant" when they are concentrated to provide power. Ideally, they can be supplemented wherever the load is too heavy.

In addition, wireless charging and mobile charging technologies are also developing rapidly.

2.3. Types of EVs

EVs can be classified according to the type of energy supply: pure EVs, hybrid vehicles, and fuel cell vehicles; according to the type of use: private EVs, electric buses, electric rental EVs. Due to the different energy supplies, the charging current and charging modes of EVs are also different. Literature [6,7] analyzed small EVs, medium-sized EVs, medium-sized multi-purpose EVs and large multi-purpose EVs, and came to an important conclusion: the larger the capacity of an EV, the longer its charging time, and the greater the impact on the power quality and voltage stability of the grid.

3. Influence Analysis of EV Access on Power grid stability

The increase in EVs will bring huge energy and environmental benefits to the power grid, but it will also make the issue of grid stability more acute. If the stability of the power grid is damaged, the consequences are unimaginable. The stability of the power grid lies in the power angle stability and voltage stability. And voltage stability is mainly studied in the power grid under normal operation and pre-set fault conditions, all nodes in the network can maintain the accepted voltage level, if a disturbance makes the power grid voltage continues to fall, and fall to the point where it cannot be controlled, this stage is the voltage collapse state [8].

The access of large-scale EVs constitutes a potential threat to the voltage stability of the power grid, i.e., once the load power constituted by EVs accessing the power grid is out of balance and gradually deteriorates the process of voltage instability, which propagates successively in the power grid and ultimately leads to the collapse of the entire power grid.

In this paper, we will analyze two modes of operation for grid-connected EVs: (1) EVs charging as loads and (2) EVs feeding energy back to the grid as mobile distributed power sources.

3.1. Impact of EV charging on power grid stability

3.1.1. Number and space for EVs

The voltage stability of the grid is reflected in the ability to maintain the load voltage within the specified operating limits. EVs exist as an important form of load when charging, and due to the number of EVs, the types of EVs, the charging methods of EVs and the charging frequency, the EVs as a load charging time randomness and spatial uncertainty. The uncertainty of the time and geography of EV access to the grid will not only cause local overloading of the system, but also bring impacts on the power grid in terms of power quality, energy loss, peak-to-valley difference and stability of the grid [9]. In time, the random and disorderly charging of large-scale EVs will increase the peak load of the grid, especially the peak load at midday is significantly higher, exceeding the capacity of power distribution and supply. In space, discrete EVs connected to the grid will cause a three-phase imbalance in the grid. Disorderly large-scale EV access to the grid increases the network loss in the distribution network and also deteriorates the power quality, seriously affecting the security and stability of the power grid.

3.1.2. EV load characteristics

Among the multiple factors affecting the stability of the power grid, the most active, direct and critical are the load characteristics, which largely determine the process of voltage instability or even voltage collapse. When an EV is charging, its load has more complex characteristics under many factors. When the EV is charging, the load increase causes a rapid voltage drop or downward shift, and the operator and the automatic control system cannot stop this decay process, when the voltage drop characteristic may last for a few minutes or tens of minutes or even longer, and this situation may lead to the system disintegration. EVs, if utilized properly, can reduce the impact of EV charging loads on voltage and even improve the safe and stable operation of the grid.

Voltage stability is determined by the amount of load that can be accommodated in the transmission and distribution system, and the load usually plays an indispensable role in voltage stability analysis, so how to establish a large-scale EV charging load model will play an extremely important role in the study of voltage stability. The selection, establishment, and parameters of the load model for large-scale EVs will have an important impact on the results of the future large-scale grid interconnection test, and it is the key to determining the accuracy and credibility of the results of the grid stability study.

3.1.3. Power grid reactive power capacity

When the power delivered by the grid is insufficient to meet the power requirements of the integrated loads themselves, such as EVs, triggering a continuous reaction of system reactive power overruns, the load voltage drops. If large-scale EVs continue to connect to the grid to obtain power at this time, the power grid may be unstable, which in severe cases will lead to a collapse of the grid voltage, resulting in system disturbances and widespread blackouts, the losses of which are incalculable.

3.2. Impact of EV discharge on power grid stability

3.2.1. Trends and Benefits of EV Feedback Power

With the development of society and the rapid growth of China's economy, the great demand for electricity provides an excellent opportunity for the development of renewable energy in China. Distributed power generation and large power grid combined loop operation are an important trend in the development of power grids, and the two-way interaction technology between EVs and the smart grid based on V2G (Vehicle-to-Grid) is the most promising area of development for EVs [10,11].

EVs, as mobile distributed power supplies, have the characteristics of energy saving, environmental protection, small modularity, proximity to the load center, flexible mode of operation and small footprint, among which the most important aspect is that the power load is more efficient, economical and convenient to dispatch than centralized power supply during peak hours, and it can be high-voltage long-distance transmission capacity is insufficient to satisfy the requirements of the power grid [12].

3.2.2. Impact of EVs as distributed power sources

At present, due to the limitations of the technical level, large-scale geographically distributed EVs to the power grid power supply not only change the voltage distribution of the regional power grid, but also bring a series of problems to the power grid. The integration of EVs into the grid in the form of power supply will have an impact on the losses of the distribution grid, the power market and the reliability and transmission capacity of the power supply.

The grid connection of EVs as distributed power sources will change the steady state voltage distribution of the regional grid, which has a great impact on the voltage distribution of the distribution network due to its characteristics of diversity and randomness. If a large number of EVs supply power to the grid at the same time, the larger the output and the higher the penetration rate, the stronger the voltage support ability, and the higher the voltage level of the whole power grid.

As a distributed mobile power source connected to the grid, the EV's power generation capacity, access location and other factors will have an impact on the voltage stability of the grid, which in some cases may destabilise the voltage, or even produce a chain reaction causing the disintegration of the power grid.

4. Conclusion

At present, EVs have entered a period of rapid development, and the charging and discharging process of EVs has brought a greater impact on the power grid. Grid integration of EVs is a two-way mutually beneficial process, for EV users, charging the vehicle at night when the electricity load is low, and during the daytime when the electricity consumption is at its peak, the energy stored in the EV is fed back to the grid, which reduces the cost of using EVs while obtaining an economic subsidy.

For the grid, V2G-based EVs not only act as peak shapers and spinning back-ups, but also delay the investment spent on grid construction. It is important to seek suitable interactive and coordinated control methods with the grid during the development of large-scale EVs, so that EVs can become an effective means of promoting renewable energy.

Compliance with ethical standards

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Disclosure of conflict of interest

No conflict of interest to be disclsoed.

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