The impact of electric vehicle charging on grid reliability

WANG Yanfei , SU Haifeng , WANG Wenhao And ZHU Yunjing
North China Electric Power University, School of Electrical Engineering, Baoding Hebei, 071003, China
e-mail: 969742950@qq.com

Abstract: After the large-scale electric vehicles are connected to the distribution network, the load on the distribution network is increased and the power quality of the distribution network is affected. In this paper, in line with various factors related to the demand for charging power, the charging power of electric vehicles is modeled according to the travel rules of electric vehicle users, and the load changes of the original distribution network caused by different sizes of electric vehicles connected to the distribution network are simulated. This paper uses Monte Carlo method to evaluate the reliability of the power grid. Taking the IEEE-RBTS Bus2 power distribution system as an example, the paper analyzes and calculates the reliability index of each load point, and studies the influence of different scale electric vehicles accessing the distribution network on the reliability index of the distribution network.

1. Introduction
In recent years, electric vehicles, as a new energy vehicle, have been rapidly developed due to their low carbon and environmental protection, low cost and low noise. Governments are also paying more and more attention to the development of electric vehicles. In 2015, the production and sales volume of new energy vehicles in China has reached 500,000 units. It is estimated that by 2030, the number of electric vehicles in China will reach 60 million, and the total power consumption will reach $1.35 \times 10^{11}$ kWh, which is estimated to account for 1.3% of the national electricity consumption. At the same time, in terms of the power grid, the State Grid plans to cover the suburban counties of major cities by 2020. Therefore, electric vehicles will become more and more popular in our daily life.

If a large number of electric vehicles are connected to the grid without control, the operation and planning of the power system will be affected by the non-negligible. These effects mainly include the increase of load, the difficulty of optimization of power grid operation control, affecting power quality, and put forward new requirements for distribution network planning [1]. Therefore, it is of practical significance to study the impact of large-scale electric vehicle grid connection on distribution network reliability. At present, the reliability assessment methods of distribution networks commonly used in engineering are divided into two major categories: simulation and analytical methods [5]. Monte Carlo method has been widely used in reliability evaluation [6]. Zhou Jiaqi [3] studied the influence of electric vehicles connected to the grid on the reliability of the grid under time-sharing electricity price, indicating that the reliability of the grid under controlled charging mode is higher than that of the uncontrolled method.

The above literature analyzes the impact of electric vehicles on the reliability of distribution systems after they are connected to the distribution network in different charging modes, and the main evaluation method is Monte Carlo method. This paper analyzes the impact of electric vehicle charging
on the same scale on grid reliability. According to the failure rate of components, Monte Carlo simulation method is used to analyze the reliability of distribution network.

2. Electric vehicle charging model

2.1. Electric vehicle charging load model

The load demand model of electric vehicles is closely related to the charging power of electric vehicles, the type of electric vehicles, driving characteristics, and charging duration. Among them, the types of electric vehicles can be classified into different types such as electric official vehicles, electric private cars, and electric taxis according to their driving characteristics. In actual situations, electric vehicles are charged at a constant power for most of the time when charging. Therefore, in the construction of the charging demand model, this paper takes a private car as an example to simulate, the charging power of which is constant power in order to facilitate the simulation.

Private cars are mainly used for daily activities such as commuting. Because the car owners have different car habits, their charging behavior is very random. The charging mode of a private car is generally slow charging, and its charging power is relatively small, and the charging time is generally 6-9 hours. In this paper, we make reasonable assumptions about private cars by referring to some performance parameters of BYD e6 electric vehicles:

① Battery capacity is 57kWh; endurance capacity 316km.
② The battery is charged at a constant power of 8.1 Kw.
③ The electric car is charged immediately after the last return.
④ Charge the battery to the fullest each time it is charged.
⑤ The battery charge chef SOC, the charging start time is a random variable independent of each other.

2.2. Travel demand model of electric vehicle

The survey found that 14% of private cars were not used during the day, so this part of the car did not charge during the day. Assuming that the remaining private car returns home and immediately recharge until full, and the evening traffic peak is about 17:00-18:00. According to statistics, the return time of the electric vehicle owner vehicle meets the normal distribution, and its probability density function is

\[
f_{t}(x) = \begin{cases} 
\frac{1}{\sigma_{t}\sqrt{2\pi}} \exp\left(-\frac{(x - \mu_{t})^2}{2\sigma_{t}^2}\right) & (\mu_{t} - 12) < x \leq 24 \\
\frac{1}{\sigma_{t}\sqrt{2\pi}} \exp\left(-\frac{(x + 24 - \mu_{t})^2}{2\sigma_{t}^2}\right) & 0 < x \leq (\mu_{t} - 12)
\end{cases}
\]

Assuming that the private car is charged immediately until it is full, and the average value is 18, and the standard deviation is 1. The driving mileage of private cars is relatively random, and the daily mileage is subject to a lognormal distribution, and its probability density function is

\[
f_{D}(x) = \frac{1}{x\sigma_{D}\sqrt{2\pi}} \exp\left[-\frac{(\ln x - \mu_{D})^2}{2\sigma_{D}^2}\right]
\]

The mean value is 3.2 and the standard deviation is 0.88.

3. Operating State Model of components in Distribution Network

3.1. Facility outage model

The facility outage model is the key to the reliability assessment of medium voltage distribution networks. Different outage models have a greater impact on the assessment. The facility outage model is mainly divided into independent operation and related outage. In dependent outages can be further
classified into fault outages (forced outages) and pre-arranged outages depending on the nature of the outage. According to the reasons for the outage, the related outages can be divided into common cause outages, environment dependent failures, etc. Their common feature is that one outage state contains multiple facilities failures, such as lightning strikes causing the same tower double return overhead line to fail. Related outages are often associated with independent outages, and independent outages are the basis for related outages. Due to the complexity of the reliability evaluation and the difficulty in obtaining the reliability parameters, the two-state model mainly considers the operating state of the facility and the fault outage state, and simulates through the state transition diagram of the steady-state “run-fail-out”.

3.2. Component repair model
The repair probability \( G(t) \) of the component is the probability that the component will be repaired if the initial state of the component is faulty within \((0, t] \) time. The repair rate \( m(t) \) is the probability that the component will be repaired in unit time after the time \( t \) from the initial state to the fault time \( t \). Assuming \( m(t) \) is a constant value \( \mu \), the relationship between \( G(t) \) and \( \mu \) is derived from the conditional probability formula, as shown in equation (3).

\[
G(t) = 1 - e^{-\mu t}
\]  

(3)

In general, the average repair time (MTTR) of a component is known. The relationship between component repair time (MTTR) and repair rate is as in (4).

\[
MTTR = \frac{1}{\mu}
\]  

(4)

4. Distribution network reliability assessment
4.1. Reliability index calculation
The reliability of distribution network reflects the ability of distribution system to supply power continuously, and it is also an important factor to check the quality of power, which plays an important role in the development of national economy and the whole country. At present, in the reliable assessment, the reliability evaluation indicators of the medium-voltage low distribution network are divided into load point indicators and system indicators.

The load point indicator is used to describe the reliability level of power supply at a single load point, mainly the expected value of the power failure rate at the load point \( \lambda_{LP}(\text{time/y}) \), the expected value of the power failure rate at the load point \( \lambda_{LP}^{P}(\text{time/y}) \), the expected value of the power failure time at the load point \( u_{LP}(\text{h/y}) \), the expected value of the reliability of the power supply at the load point (ASAI-LP), and the expected value of the power supply at the load point [ENS-LP(kW/y)] , etc.

The distribution network system indicator is used to describe the reliability level of the whole system. The system reliability index can generally be calculated by the load point reliability index. The main system has the average power outage frequency expectation value SAIFI (time/house/y), and the system average power outage time. Expected value SAIDI (h/house • y), average power supply reliability expectation value ASAI, system power shortage expected value ENS (kWh), etc.

4.2. Assessment method
At present, Monte Carlo has occupied an important position in the reliability evaluation of large power grids due to its flexibility. The Monte Carlo method is based on the failure rate of components. The failure rate of components is simulated at random, and the state of components is represented by the random numbers generated by computer. When the simulation time is long enough, the error caused by this randomness can be ignored. In practical application, this method can be improved in order to improve the calculation efficiency.
5. Calculation examples and analysis

In this paper, the IEEE-RBTS Bus2 power distribution system is taken as an example for analysis. The system has 4 feeders, 4 circuit breakers, 22 load points, 22 transformers, 22 fuses, 36 lines, and 3 isolation switches. The system structure is shown in Fig.1. Lines and user data are detailed in [6] and the transformer capacity data are in reference [7].

Fig.1 Structure of IEEE-RBTS Bus2

Some parameters of this paper refer to the literature [6], and the reliability parameters of the line and transformer are shown in Table 1.

| Component   | Failure Rate       | Repair Time /h |
|-------------|--------------------|----------------|
| Circuit     | 0.065 times/(km·yr) | 5              |
| Transformer | 0.015 times/(set·yr) | 200           |
| Switch      | 0.06 times/(set·yr)  | 4.5            |

This article takes a private electric car as an example. The selected charging mode is conventional charging, and the relevant parameters refer to the above model. In order to analyze the impact of electric vehicles on grid reliability, this paper compares and analyzes the following three cases in the IEEE-RBTS Bus2 system:

Case 1: Not connected to electric cars;
Case 2: Connected to 300 electric vehicles;
Case 3: Connected to 500 electric cars.

This section takes the daily load curve of a certain day in this area as an example. According to the above model, the influence of different numbers of electric vehicles on the daily load curve of the area after accessing the distribution network is analyzed. The simulation results are shown in Fig. 2. It can be seen from the figure that when the electric vehicle is disorderly charged, the peak load period overlaps with the original load, causing a peak on the peak. The load increase during this period will affect the reliability of the distribution network.
Table 2 shows the calculation results of the system reliability index in Case1-Case3. It can be seen from the above that in the residential area charging the electric vehicle, the system load increases, resulting in an increase in the ENS index of the residential area. That is, as the access volume of electric vehicles increases, the reliability of the power grid decreases; the access of electric vehicles leads to an increase in distribution network load, and has no effect on SAIFI, SAIDI, and ASAI indicators.

6. Conclusion
Taking the IEEE-RBTS Bus2 system as an example, this paper analyzes the reliability of the distribution network after analyzing the impact of electric vehicles on the reliability of the distribution network under different scales. And it has been verified by an example. The reliability index of distribution network calculated by this method is closer to the actual situation. It is practical to provide real-time data for optimal operation and distribution network planning.

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