Simulation Analysis of Harmonic Suppression for AC Charging Pile of Electric Vehicle

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Abstract. The nonlinear load of electric vehicle AC charging pile brings harmonic pollution to the power system, which seriously affects the safe and stable operation of the power system. In this paper, the AC charging pile of an electric vehicle is taken as the research object, and the system simulation and harmonic analysis are carried out. And APF is used to compensate and suppress the harmonic of the simulation model of electric vehicle charging. The simulation results show that the charger mainly increases the 5th and 7th harmonics to the power grid. After adding APF to the power grid side, the harmonics of the power grid side are suppressed, and the influence of the charging pile on the DC power grid is greatly reduced.

1. Introduction
At present, the power system in the trend of rapid development has entered a new era of smart grids. In the development and popularization of electric vehicles, a large number of charging piles have been built. As the charging pile produces harmonics, the existence of harmonics will affect the power quality of the microgrid [1-4]. Therefore, while actively developing the microgrid, effective harmonic suppression technology should be developed [5].

This paper first analyzes the causes and harm of harmonic problems in the power system and introduces Active Power Filter (APF) circuit structure to suppress the harmonic. Through the modeling and simulation analysis of the electric vehicle charging pile, it shows that the charger mainly increases the 5th and 7th harmonics to the power grid. Adding APF to the power grid side can suppress the harmonics of the power grid side and reduce the impact of the charging pile on the DC power grid.

2. Electric vehicle charging system modeling

2.1. Electric vehicle charging system topology
The general structure of the on-board charger is shown in figure 1.
The accurate modeling of the power converter is rather complicated and computationally expensive, and it is not conducive to observing the change of electric current during the entire charging process, so it is envisaged to approximate it, as shown in figure 1. Compared with the power frequency cycle, the charging time of an electric vehicle is about six hours. It can be considered that the output of the charger is constant in several continuous power frequency cycles, which is equivalent to the power converter working in a constant power state in these power frequency cycles. Because the power of the charger is very small, the equivalent input impedance of the charger power conversion circuit can be approximated by nonlinear resistance. In the charging process, it is divided into two stages, the first is constant current charging, when the voltage reaches a certain value, constant voltage charging is adopted, and the output of the power conversion circuit changes in different stages. Therefore, the power of the actual equivalent nonlinear resistance is also variable, based on the analysis of the harmonics in the charging process in this paper, it is reasonable to simulate the input impedance of the power conversion circuit working in a certain or even several power frequency cycles by setting different resistance power values. According to the above analysis, the equivalent topology of the electric vehicle charger is shown in figure 2.

### 2.2. Charger modeling analysis

In the power supply system, it is expected that the AC voltage and AC current will be sinusoidal. Sine wave voltage can be expressed as equation (1).

\[
u(t) = \sqrt{2}U\sin(wt + \varphi)
\]  

(1)

Where \(U\) represents the effective value of voltage, \(w\) represents angular frequency, \(w = 2\pi f = 2\pi/T\), \(\varphi\) represents initial phase angle, \(f\) represents frequency, \(T\) represents the period.

The \(n\)th harmonic current content is expressed by \(HRI\) in equation (2).

\[
HRI = \frac{I_n}{I_1} \times 100(\%)
\]  

(2)
Where $I_n$ represents the effective value of the $n$th current, $I_1$ represents the effective value of the fundamental current.

The total content of harmonic current $I_H$ is expressed by equation (3).

$$I_H = \sqrt{\sum_{n=2}^{\infty} I_n^2}$$

(3)

The total harmonic distortion rate of current is expressed by equation (4).

$$THD = \frac{I_H}{I_1} \times 100(\%)$$

(4)

By analyzing the topological structure of the charger in figure 2, the approximate expression (5) of AC phase $a$ current can be obtained through its working principle.

$$i(t) = \sum_{m=1}^{\infty} \sqrt{2} I \sin (m\omega t + \varphi)$$

(5)

Where $m=6k \pm 1$, $k=0, 1, 2...$, $I$ represents the effective value of current.

2.3. Harmonic compensation and suppression circuit on grid side

At present, the methods of harmonic suppression are mainly divided into active control and passive control. Active control is to reduce the harmonic content directly by improving the circuit structure while passive control is to add passive filter or active filter on the line.

The nonlinear load is the main filter source, and the power supply is a three-phase AC power supply. The main circuit structure of the three-phase three-wire APF is shown in Figure 3. For a three-phase load without the neutral line, the active power filter with a three-phase three-wire structure can compensate the harmonics of the nonlinear load.

![Figure 3. Main circuit structure of three phase three wire APF](image)

3. System simulation

It is assumed that the output power of the power conversion circuit is constant in several power frequency cycles, and an equivalent impedance is used to replace the power conversion circuit. The simulation model of the system is established based on the charger model.

3.1. Simulation parameter setting

The resistance and inductance from the rectifier circuit to the power conversion circuit in the charger are very small, which can be ignored. According to the previous analysis, the power of the charger can be regarded as constant in several power frequency cycles, and different $R_c$ values are selected for different simulations to represent different periods of the charging process. After repeated debugging, the main parameters of the simulation are shown in Table 1.
Table 1. System simulation parameters

| Circuit parameters                                   | Set value          |
|------------------------------------------------------|--------------------|
| Maximum single phase voltage \( U \)                | 380V               |
| Power equivalent impedance \( R_e \)                | 10 Ω ~ 40 Ω        |
| Rectifier input side inductance \( L_i \)           | 0.001H             |
| Rectifier input side resistance \( R_1 \)           | 0.1 Ω              |
| Input side filter inductance of power conversion circuit \( L_f \) | 0.002H             |
| Input side filter capacitance of power conversion circuit \( C_f \) | 0.0215F            |
| Input side inductance of compensation circuit \( L_2 \) | 0.001H             |
| Input side resistance of compensation circuit \( R_2 \) | 0.1 Ω              |
| Output side capacitance of compensation circuit \( C_{ab} \) | 0.05F              |

3.2. Result analysis

The waveform comparison of the main parts of the system is shown in figure 4 and figure 5, and the FFT analysis and comparison of grid side current are shown in figure 6 and figure 7.

Figure 4. Waveform before compensation

Figure 5. Waveform of APF added to power grid side

Figure 6. Analysis of current harmonics in uncompensated grid side

Figure 7. Harmonic analysis on grid side after compensation
In figure 4, after the voltage and current of the charger are stable, the grid side current appears distortion. In figure 6, the harmonic analysis of the abnormal current is shown, mainly including 5th, 7th and 11th harmonic.

The APF compensation circuit is added. The waveform of APF is shown in figure 5, and the FFT analysis of harmonic at the grid side after compensation is shown in figure 7.

After adding APF circuit, the total harmonic distortion rate of grid side current is reduced from 36.7% to 14.8%. It can be seen from figure 4 and figure 5 that the harmonics are suppressed after the active compensation of the current waveform at the grid side. This result can also be obtained from the comparison between figure 6 and figure 7.

In the process of simulation, changing the value of $R_c$, the total harmonic distortion rate of current will change, and the harmonic suppression effect of grid side will also change. When the nonlinear loads $L_1$ and $C_1$ remain constant, $R_c$ only determines the impedance of the nonlinear load. When the resistance $R_c$ increases and the power of charger decreases, the nonlinear load will increase, and the total harmonic distortion rate of grid side current will increase. When the resistance $R_c$ is reduced and the charger power is increased, the total harmonic distortion rate of the grid side current is reduced, and the stability time is also reduced.

4. Conclusion
Through the modeling and simulation of electric vehicle charging pile, it shows that the charger mainly brings 5th and 7th harmonics to the power grid. In the process of building charging pile, APF should be added to the grid side to suppress the harmonic of the grid side and reduce the impact of the construction of charging pile on the DC power grid. This paper simulates the charging process of AC charger, which has a certain practical significance for the construction of charging pile and harmonic suppression of power grid.

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