Simulation of Electric Vehicle Charging Station and Harmonic Treatment

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***Abstract*—Because of less pollution and low consumption, electric vehicles play an important role in solving the energy shortage and environmental degradation problems. But harmonics will be generated during the charging process of electric vehicles because of the existence of nonlinear equipments, it will affect the power quality and system operating seriously. In this paper, the simulation model of electric vehicle charging station is built and the characteristic of harmonics generated during charging process are analyzed, then passive filters are added to the model.**

Keywords-electric vehicle charging station; current harmonics; single-turned filters

I. INTRODUCTION

Because of less pollution and low consumption, electric vehicles will play an important role in solving the energy shortage and environmental degradation problems. Electric vehicles are becoming an ecologically attractive to gasoline driven cars, which is strongly pressed by the car manufactures need of sales of zero emission vehicles. The energy conservation is very impressive because the electric vehicles offer about 60 percent greater mileage from the same amount of primary energy [1]. The development of electric vehicles can contribute to optimizing energy structure, saving energy and reducing emission.

With the development of society, there will be more and more electric vehicles enter ordinary families, lots of electric vehicle charging stations must be built at the same time. Electric vehicles can be charged conveniently in the charging station or even at home. Electric vehicles can be charged during the valley load, frequently after midnight, which will lower the peak load and improve the valley load, improving the efficiency of the power grid.

However, due to the presence of nonlinear devices, large amounts of harmonic will be generated during the charging process of electric vehicles, if the harmonic is not properly handled, it may do great harm to the utility grid [2]-[7]. Because the existence of the harmonic current great damage may be brought to the power grid, large amounts of harmonic may increase the line loss of the network, aggravate the electric equipment heating problem, make the control equipment misoperation, cause the production or operation interrupt, and may even cause large scale blackout [8]-[10]. So the study of the harmonic characteristic and the corresponding control program will be necessary.

The paper is organized as follow. In Section II, The simulation model of electric vehicles charging station is built. In Section III, the characteristic of harmonic is analyzed. In Section IV, the fifth and seventh single-tuned filters are added to the model of electric vehicle charging station, and the filtering result is fine. In Section V, the conclusion is given.

II. THE MODEL OF ELECTRIC CHARGING STATION

A. The model of the electric vehicle charger

The general architecture of electric vehicle charger is shown in figure 1. Three-phase bridge diode rectifier circuit, small resistance (R_f), inductance (L_f), and DC/DC converter are included. DC power can be provided by the charter for battery.

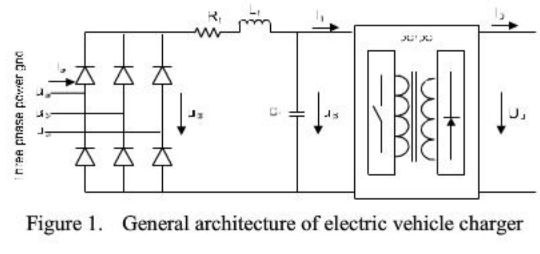

Figure 1. General architecture of electric vehicle charger

Compared to the charging process (4-6h), frequency cycle (0.02s) is very short, so I_0 and U_0 can be considered to be a constant value within one or several cycles, which means the charger works on a constant power state. The DC/DC converter can be simulated approximately by a nonlinear resistance (R_C) at every minute.

$$R_C = \frac{U_B}{I_1} = \frac{U_B^2}{P_1(t)} = \frac{\eta U_B^2}{P_0(t)} \tag{1}$$

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The output power of the electric vehicle charger is:

$$P_0(t)=\begin{cases}0.79P_{0\max}t^{0.048}, 0<t\le 150\\ P_{0\max}e^{-0.021\times(t-150)}, 150<t\le 270\end{cases} \quad (2)$$

where, $P_0(t)$ is the output power of the electric vehicle charger, minute is used as time unit; $P_{0\max}$ is the maximum output power.

The curve of nonlinear resistance (R_C) can be plotted due to (1) and (2), shown in figure 2:

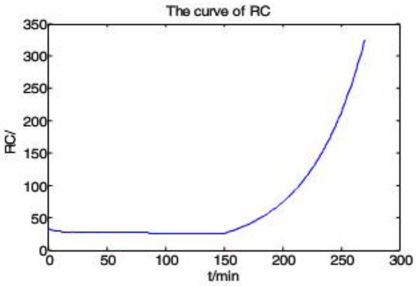

Figure 2. The curve of nonlinear resistance (R_C)

In order to simplify the calculation and simulation, discretization method is adopted: choose a sampling point every 15 minutes during the charging process (270min), then 18 sampling points are selected shown in figure 3.

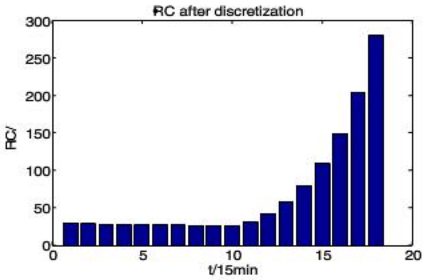

Figure 3. R_C after discretization

The values of R_C for the sampling points are shown in table I.

TABLE I. THE VALUE OF R_C

t/min	15	30	45	60	75	90
R_C/Ω	29.91	28.43	27.76	27.32	26.99	26.74
t/min	105	120	135	150	165	180
R_C/Ω	26.52	26.34	26.19	26.05	30.89	42.33
t/min	195	210	225	240	255	270
R_C/Ω	58.00	79.47	100.9	149.22	204.47	280.17

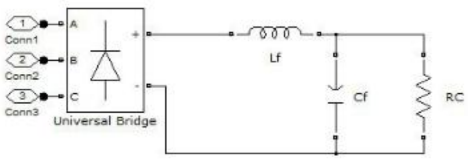

Figure 4. Simplified model of electric vehicle charger

So, the model of the electric vehicle charger can be simplified as figure 4.

B. *The model of the electric vehicle charging station*

Electric vehicle charging station is composed by the following elements: three-phase power, ammeter, voltmeter, oscilloscope, transformer, and several electric vehicle chargers. Dyn11 connection manner is used in the distribution transformer, which can prevent the three times and integer multiples of three times harmonics flow into the utility grid. Under the three-phase balance condition, only the voltage and current of phase-a are analyzed in this paper, and the conclusion of the other two phases will be the same. The voltage and current of high voltage side (grid side) of the transformer are measured in this model.

The simulation model of the electric vehicle charging station is shown in figure 5.

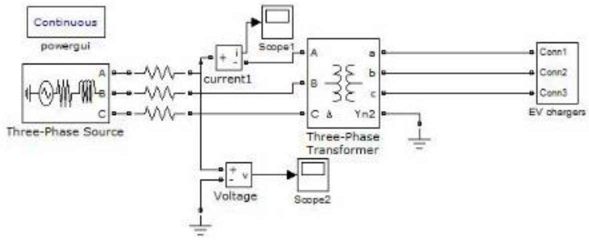

Figure 5. The simulation model of electric vehicle charging station

On the right side of the model there are several paralleled electric vehicle chargers, shown in figure 6.

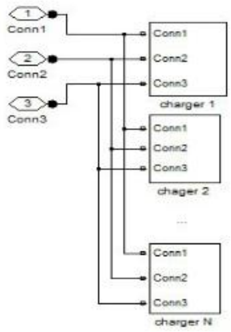

Figure 6. N paralleled electric vehicle chargers in the charging station

III. HRMONIC ANALYSIS

A. *Harmonic voltage analysis*

In this study the harmonic voltage analysis is conducted under the supply voltage 10kV.

TABLE II. DISTORTION RATE OF HARMONIC VOLTAGE FOR DIFFERENT NUMBER OF VEHICLES

N	1	3	5	8	9	10	15
THD_u	0.01%	0.03%	0.05%	0.08%	0.08%	0.09%	0.12%

N is the number of vehicles charging in the station at the same time.

From table II, it is clearly shown that voltage distortion rate is far less than the permissible value 4%. Generally, the influence of the harmonic voltage bought to the power grid can be ignored in the electric vehicle charging station.

B. *Harmonic current analysis*

1) The characteristic of harmonic current

In order to get the characteristic of the harmonic generated by the vehicles during the charging progress, fast Fourier transform (FFT) method is used.

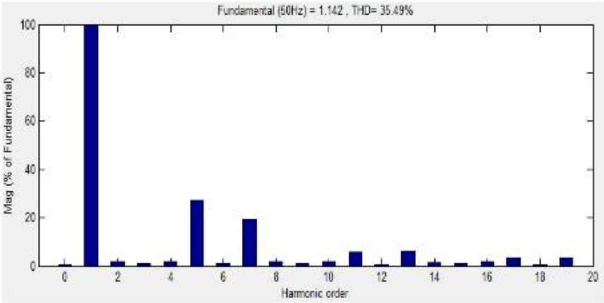

Figure 7. FFT analysis of current in the charging station

It is clearly shown that the main order of the harmonic currents is 5, 7, 11, 13…, while the fifth-order and seventh-order take the largest part.

2) Harmonic currents compared with their permissible value

The harmonic content generated during the charging process must meet the national standards GB/T 14549-1993 *Quality of electric energy supply, Harmonic in public supply network.*

The permissible value of harmonic current feeding into the common connection point (PCC) is shown in table III.

TABLE III. PERMISSIBLE VALUE OF HARMONIC CURRENT FEEDING INTO PCC

Nominal voltage	Reference short-circuit Capacity	Permissible value of each order harmonic current(A)					
		5	7	11	13	17	19
10kV	100MVA	20	15	9.3	4.3	6.0	5.4

The harmonic current feeding in to the common connection point (PPC) of all the users should not exceed the permissible value.

When the minimum short-circuit capacity of the power grid PPC is different from the reference short-circuit capacity, correct the harmonic current permissible value follow (3):

$$I_h = \frac{S_{K1}}{S_{K2}} I_{hp} \tag{3}$$

In the forum, S_{K1} is the minimum short-circuit capacity of PCC, MVA; S_{K2} is reference short-circuit capacity, MVA; I_{hp} is permissible value of the h-order harmonic current in table III, A; I_h is permissible value of the h-order harmonic current when $S_{K1}$is the minimum short-circuit capacity.

When there are many users connected to PCC, the permissible value of the h order harmonic current of the user (I_{hi}) can be calculated according to (4).

$$I_{hi} = I_h \times (\frac{S_i}{S_t})^{1/\alpha} \tag{4}$$

In the forum, S_i is Electricity agreement capacity of the user i, MVA; S_t is the Supply capacity of PCC, MVA; α is phase superposition coefficient.

The fifth and seventh harmonic currents take the largest part of the harmonic currents, so in table IV only the fifth and the seventh harmonic currents are analyzed. The value of the fifth and the seventh harmonic currents and their permissible values are shown in table IV.

TABLE IV. HARMONIC CURRENTS COMPARED WITH THEIR PERMISSIBLE VALUE

Voltage	Harmonic order	Permissible value(A)	Harmonic generated by different number of vehicles(A)					
			1	3	5	6	8	9
10kV	5	*1.28*	0.23	0.67	1.08	**1.29**	1.67	1.85
	7	*0.78*	0.15	0.39	0.57	0.64	0.77	**0.84**

From table IV, it is clearly shown that the fifth and seventh harmonic currents will exceed the state standards when the number of vehicles charging in the station is over 9.

Conclusion: the influence of the harmonic current bought to the power grid cannot be ignored, and harmonic suppression must be considered in the electric vehicle charging station.

IV. HARMONIC SUPPRESSION

There are many ways to restrain the harmonics, among which the equipment of the filter at the harmonic source is widely used. The filter can be divided into two kinds: active filter and passive filter. Although the filtering result of the active source is better, its capacity is small, and the cost is high, so the low cost and more easily realized passive filter is adopted in the practical project. In this study, single-turned filters are designed.

The principle of the passive filter is that the combined use of the reactance and the capacitor create a low resistance channel for some order harmonic [11]-[13]. The channel can let the harmonic enter and become short-circuit.

A. *The parameter calculation of single-tuned filters*

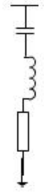

Figure 8. Schematic diagram of the single-tuned passive filter

The total impedance of the single-tuned filter branch is:

$$Z = R + j[\omega_n L - \frac{1}{\omega_n C}] \quad (5)$$

$$\omega_n = n\omega_s = n2\pi f_s = 100n\pi \quad (6)$$

In the formula, R is filter resistance; L is filter inductance; C is filter capacitance; ω_n is harmonic angle frequency; ω_s is fundamental wave angle frequency; n is harmonic order; f_s is network fundamental frequency.

The parameter of the single-tuned filter is:

$$C = \frac{n^2 - 1}{n^2 \omega_s U_F} Q_F \quad (7)$$

$$L = \frac{1}{n^2 \omega_s C} = \frac{U_F^2}{(n^2 - 1)\omega_s Q_F} \quad (8)$$

$$Q = \frac{X_n}{R} \quad (9)$$

$$R = \frac{n U_F^2}{(n^2 - 1) Q Q_F} \quad (10)$$

In the formula, Q_F is reactive power of the single-tuned filter; U_F is terminal voltage of the single-tuned filter; Q is quality factor, $30 < Q < 60$.

B. Harmonic suppress model

The fifth and seventh harmonic take the most part of the harmonics, so in this study, the fifth and seventh single-tuned filters and a high-pass filter is added to the original charging station. Take the condition that 15 electric vehicles charging in the station.

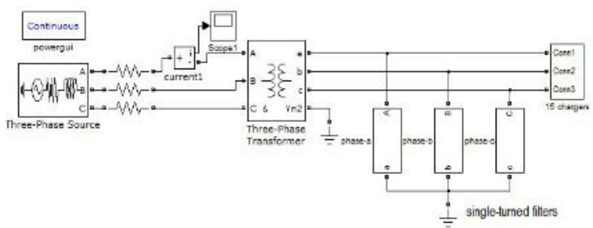

Figure 9. The model adding the fifth and the seventh single-turned filters

The main parameters of the single-turned filters are shown in table V.

TABLE V. PARAMETERS OF SINGLE-TURNED FILTERS

Parameter name	fifth single-turned filter	seventh single-turned filter
Reactive power Q_F/var	9000	4800
Capacitance C/F	2.273e-4	1.237e-4
Inductance L/H	1.8313e-3	1.672e-3
Resistance R/Ω	0.028	0.037
Quality factor Q	40	40

1) FFT analysis before filters added

Before filters added to the model, the current distort heavily. The main order of the harmonic current is 5, 7, 11, 13…, THD_i=37.25%, I_5=2.904A, I_7=1.162A.

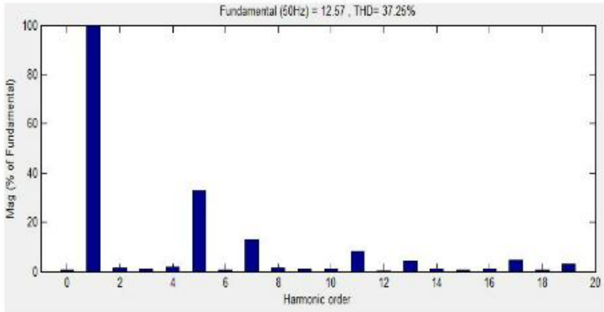

Figure 10. FFT analysis of current phase-a before adding filters

2) FFT analysis after the fifth and seventh single-turned filters added

It is clearly shown below that the filtering result is fine: the fifth and the seventh harmonics decreased to a very low level. THD_i=9.63%, I_5=0.082A, I_7=0.027A, far less than the permissible value.

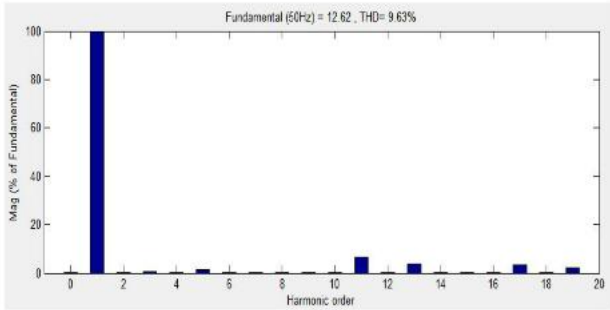

Figure 11. FFT analysis of current phase-a after single-turned filters added

C. Analyze

For small-size electric vehicle charging stations, no harmonic handle measure is needed. For medium-size vehicle charging stations only the fifth single-turned filter is needed sometimes. For large-size electric vehicle charging stations, make clear that which order of the harmonic exceed the state standards first, then proper filters should be added to the electric vehicle charging station.

V. CONCLUSION

Because of the existence of the power electronic elements, a large quantity of harmonic is generated in the process of charging of the electric vehicles. If the harmonic is not properly handled, it may do great harm to the utility grid. According to the research of the characteristic of the harmonic, the main order of the harmonic currents is 5, 7, 11, 13…, while the fifth and seventh-order take the largest part. In this study, the fifth and seventh single-tuned filters are added to the charging station, and the filtering result is fine. For small-size electric vehicle charging stations, no harmonic handle measure is needed sometimes. For the large and medium-size electric vehicle charging stations, make clear that which order of the harmonic current exceed the state standards first, then proper filters should be added to the electric vehicle charging station.

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