Application of an improved harmonic detection algorithm in harmonic control of charging station

Zhang Kunfeng*
Datang Central-China Electric Power Test Research Institute, 450000 Henan Zhengzhou, China

*Corresponding author: 819832203@qq.com

Abstract. With the rapid prosperity of the electric vehicle industry, the demand for charging stations providing charging services has become increasingly strong, which followed by serious power quality problems. Because the current level of the charging station changes gradually with time, the harmonic current generated by the charging station will also change gradually with time. The influence of the low-pass filter leads to the slow start-up and tracking speed of harmonic current detection method based on $\text{ip-iq}$ algorithm, which cannot meet the need of harmonic control in charging station. In this paper, the harmonic characteristics and basic structure of six-pulse rectifier charging pile are analyzed in detail, and the charging station model based on six-pulse rectifier charging pile is established. At the same time, in order to meet the need of harmonic suppression, a harmonic current detection algorithm based on variable step size LMS/LMF algorithm is proposed and analyzed comprehensively. The simulation and experimental results show that compared with the traditional harmonic detection algorithm, the improved harmonic detection algorithm has obvious advantages in many aspects, such as start-up and tracking speed, and has good engineering application prospects.

1. Introduction

With the continuous depletion of traditional petroleum fossil resources and the increasingly serious haze problem, the advantages of electric vehicles have gradually emerged, and their development has been strongly supported by the government[1]. The rapid development of electric vehicles will inevitably increase the demand for their charging stations. Which can convert AC to DC to charge the electric vehicles. Therefore, the application of a large number of power electronic semiconductor devices makes it becoming a typical non-linear load, which has a great impact on the safe and orderly operation of the power grid, and its harmonic problem is quite serious. At present, the most common way to effectively reduce the harmonic impact of charging station on power grid is the passive compensation method, that is, to compensate it by adding harmonic compensation equipment. The structure of the existing charging device can be unchanged and it is more flexible, so it has been widely used. Through the research and improvement of harmonic detection algorithm of harmonic compensation equipment, this paper realizes the harmonic detection and control of charging station. Firstly, the harmonic characteristics of charging station are analysed, and the structure and harmonic situation of charging pile based on six-pulse rectifier topology are analysed. On this basis, the harmonic model of the charging station composed of six charging piles is established. Based on the
analysis of the present situation and application of existing adaptive filtering algorithms, an improved adaptive filter based on variable step size LMS/LMF algorithm is proposed [2-3]. The algorithm can gradually adjust the proportion of step factor and LMS/LMF algorithm according to the actual situation to achieve the reliability of detection speed and accuracy, and give full play to the advantages of different algorithms in convergence and steady-state performance. The simulation result shows that the algorithm is remarkable in the speed and accuracy of dynamic response, and it is suitable for the harmonic control in grid-connected charging stations.

2. Charging pile and charging station model

2.1. Charging pile model

Because of the extensive use of power semiconductor devices, the harmonic problem of charging piles is quite serious while realizing reliable and effective charging of charging vehicles. Generally, the charging pile structure is mainly composed of four parts: rectifier circuit, RLC filter circuit, DC-DC power conversion circuit and output filter circuit [4]. There are many kinds of charging piles, the charging piles based on three-phase six-pulse rectifier topology are widely used because of their simple structure and low cost, but their harmonic problems are particularly serious. This paper focuses on the harmonics of this kind of charging pile and the charging station composed of it. The model of a single charging pile is shown in Fig. 1.

Figure 1. The model of a single charging pile.

Three-phase AC from the grid side is converted into DC through rectifier circuit. After filtering by RLC filter circuit, it is supplied to DC-DC circuit. DC-DC circuit can convert it into DC output power with controllable size according to need, and then through the final filter circuit, the reliable charging of electric vehicles can be realized.

The charging of electric vehicles is a rather slow process. Therefore, in a very short period of time, the equivalent input resistance of charging pile can be simulated by non-linear resistance to approximately replace its harmonic impact on the power grid. On the basis of measuring the equivalent resistance of charging pile in the actual charging process of electric vehicle, the equivalent resistance curve of charging pile is fitted by simulation software.

Fig. 2 is an equivalent model of six-pulse rectifier charging pile. The filter inductance L=1.5mH, capacitance C = 2215 uF, resistance R = 0.014Ω, and Rd is non-linear resistor [5-6].

Figure 2. An equivalent model of six-pulse rectifier charging pile.

2.2. Charging station model

Charging station is usually composed of several charging piles. In order to simulate the impact of charging station on power grid, this paper establishes a harmonic model of charging station composed of six charging piles, as shown in Fig. 3.
3. Harmonic detection algorithm

3.1. The traditional harmonic detection algorithm

The three-phase instantaneous reactive power theory was put forward by Hirofumi Akagi of Japan in 1990s. The harmonic detection algorithm based on instantaneous reactive power theory is very suitable for harmonic detection in APF, which greatly improves its speed and accuracy, and strongly promotes the development of active power filter. The principle is shown in Fig. 4.

![Figure 4](image)

**Figure 4.** The harmonic detection algorithm based on instantaneous reactive power theory.

The above is the basic theory of harmonic detection of ip-iq algorithm based on instantaneous reactive power theory. Because of the influence of low-pass filter, the starting speed of harmonic detection is slow. At the same time, when the load situation changes, it can not track its changing state well, which leads to the poor detection speed and accuracy of the algorithm, and thus greatly affects the accurate operation of APF. In the process of grid-connected charging station, the load of charging pile is time-varying. Especially when constant current charging changes to constant voltage charging, the current and impedance of the load have changed greatly. Therefore, the traditional harmonic detection algorithm based on ip-iq algorithm can not be well used to deal with the harmonic detection problem in grid-connected charging station. It is necessary to find a more rapid and accurate harmonic detection algorithm applied to APF.

3.2. The improved harmonic detection algorithm

In order to reduce the influence of low-pass filter, an adaptive filter based on LMS/LMF algorithm is proposed to improve the detection speed of traditional harmonic detection algorithm. Taking the principle of adaptive filter based on LMS algorithm as an example, its basic principle is to continuously adjust the weight coefficients according to the difference between the output signal and the expected signal in order to achieve the consistency between the output signal and the expected signal. Generally, LMS algorithm is a fixed step size. Fig. 5 is the basic principle of adaptive filter based on LMS algorithm[7-8].

![Figure 5](image)
In the Fig. 5, $i(n)$ is the input signal, $e(n)$ is the difference between the output signal and the input signal, $x_k(n)$ is the reference input signal, $w_k(n)$ is the weight coefficient, and $y(n)$ is the output signal. Therefore, the output of the filter is $y(n) = w_k(n)x_k(n)$. The error signal $e(n) = i(n) - y(n) = i(n) - w_k(n)x_k(n)[9]$. Therefore, the adaptive filter based on LMS algorithm means that the weight coefficient $w_k(n)$ is adjusted by the principle of minimum mean square of error signal[10].

On this basis, a variable step size LMS/LMF algorithm is proposed. The adaptive filter based on LMF algorithm has better dynamic response speed, while the adaptive filter based on LMS algorithm has better detection accuracy. Therefore, the two algorithms are combined to achieve fast and accurate tracking speed by adjusting the step factor and the proportion of LMS/LMF algorithm.

Set the function is:

$$J_n = (1 - r_n)E[e_n^2] + r_nE[e_n^4]$$

When $m = 0$, the performance function is the LMS algorithm, and when $m = 1$, the performance function is the LMF algorithm. The weight coefficient $w_k(n)$ is updated in a gradient manner, and a momentum term is added in the process of adjusting the weight coefficient.

$$w_k(n + 1) = w_k(n) - u(n) \frac{\partial J_n}{\partial w_n} + k[w_k(n) - w_k(n - 1)]$$

In the formula, $k$ is the dynamic coefficient. The momentum term $k\left[ W_k(n) - W_k(n - 1) \right]$ is added to the iteration formula of the weight coefficient to accelerate the convergence of the adaptive process. If the change of weight coefficient is large, the correction of weight coefficient will increase, and the gradient will decrease, so that the mean value of weight coefficient converges faster and more smoothly, thus improving the whole algorithm. The weight update formula is as follows:

$$w_k(n + 1) = w_k(n) - 2u(n)[(1 - r_n) + 2r_ne_n^2]e_nx_k(n) + k[w_k(n) - w_k(n - 1)]$$

The step size factor is adjusted by hyperbolic tangent function:

$$u(n + 1) = \beta(n)[1 - \frac{m + 1}{m + \exp(a_1q(n))}]$$

$$\beta(n + 1) = \xi\beta(n) + \eta q^2(n)$$

The bottom waveform of hyperbolic tangent function changes rapidly, which makes the error signal change greatly when it approaches zero. The introduction of coefficient $m$ can make the error signal become very smooth when it approaches zero, and can effectively improve the bottom waveform of function. The coefficient beta determines the range of the function. The updating of the proportion factor $m$ is as follows:

$$r_n = a_1p_n^2 + a_2r_{n+1}$$

$$p_{n+1} = \beta p_n + t(1 - \beta) \frac{e(n)e(n-1)}{|i(n)|i(n-1)}$$

In the formula, $a_1$, $a_2$, $\beta$ and $t$ are all memory factors, showing the influence of past error factors on current adjustment factors. The longer is the time, the smaller is the influence of adjustment factors. When the original signal of the filter is the sudden change of current, the whole system mainly adopts LMF algorithm to improve the dynamic response speed. When the original signal of the filter, i.e. the
current, tends to be stable, the whole system adopts LMS algorithm to maintain a good detection accuracy. The above formulas (1) to (8) constitute a new adaptive filter based on LMS/LMF algorithm. The necessary condition for convergence of the algorithm is $|k| < 1$. Considering the stability of the algorithm, the values of $u(n)$ and $r_n$ are limited.

$$u(n) = \begin{cases} u_{\text{max}} & u > u_{\text{max}} \\ u & \text{else} \\ u_{\text{min}} & u < u_{\text{min}} \end{cases}$$  \hspace{1cm} (9)$$

$$r_n = \begin{cases} r_{\text{max}} & r_n > r_{\text{max}} \\ r_n & \text{else} \\ r_{\text{min}} & r_n < r_{\text{min}} \end{cases}$$  \hspace{1cm} (10)$$

4. Simulation and experimental verification

The charging station is composed of several charging piles, whose harmonic phase is similar or even identical when starting at the same time. The harmonic situation of these charging piles composes the harmonic problem of the whole charging station. In summary, this paper establishes a small charging station consisting of six chargers, analyses the load and harmonic current changes, and uses the charging station model to realize the simulation and verification of the improved harmonic detection algorithm. Fig. 6 shows the current waveform of the charging station for about 150 minutes. The figure shows that the harmonic current distortion of charging station is quite serious.

Figure 6. The current waveform of charging station at about 150min.

The above half of Fig. 7 is the harmonic detection results based on the traditional harmonic detection algorithm. The dynamic performance of the detection results is poor. When the current suddenly changes, it can not meet the harmonic detection requirements of charging stations, especially large charging stations. The last half is the harmonic current detection results based on the improved harmonic detection algorithm. The figure shows that compared with the traditional harmonic detection algorithm, the detection speed is greatly improved. Considering the time-varying harmonics of charging stations, the proposed algorithm can effectively solve the harmonic control requirements of charging stations, especially large charging stations.

Figure 7. The contrasting harmonic current detection results.
In order to verify the effectiveness of the proposed harmonic detection algorithm, a test platform based on DSP and FPGA is established. The test platform uses the improved harmonic detection algorithm. Fig. 8 is the waveform of phase A current before compensation. Fig. 9 is the phase A harmonic current waveform. Fig. 10 is the compensated phase A current waveform. The improved harmonic detection algorithm can quickly track the changes of harmonics and achieve ideal results.

5. Conclusion
With the popularity of electric vehicles, the dynamic response speed and tracking speed of the traditional harmonic detection algorithm cannot meet the time-varying needs of the harmonic situation in the charging station of electric vehicles. Based on the analysis of the basic structure and harmonic effects of charging piles, a small charging station model based on six charging piles is established, and an improved harmonic detection algorithm based on variable step size LMS/LMF is proposed. The method and its algorithm are explained concretely. It has good dynamic response speed and detection accuracy. The results of simulation and experiment show that the harmonic detection algorithm for harmonic control of charging station discussed in this paper has good performance and can realize fast and real-time detection of harmonic current, which has good engineering practical value.

6. References
[1] Zhu Yu. Current Technological Progress and Market Development of Global Electric Vehicle Market. *Electricity and Energy*, 2013, 34 (4): 376-380.
[2] Puri A, Modak S V, Gupta K. Modal filtered-x LMS algorithm for global active noise control in a vibro-acoustic cavity. *Mechanical Systems & Signal Processing*, 2018, 110:540-555.
[3] Mahi H, Farhi N, Labed K. Remotely Sensed Data Clustering Using K-Harmonic Means Algorithm and Cluster Validity Index. IFIP Advances in Information & Communication Technology, 2018, 456:105-116.

[4] Wuhong Zhang L C. High-harmonic-generation-inspired preparation of optical vortex arrays with arbitrary-order topological charges. Chinese Optics Letters, 2018, 16(3).

[5] LÜ Zibo, Chushan L I, Yan D, et al. A Harmonic Detection Method by Separated Sequence and Order Suitable for Novel Direct AC-AC Based Active Power Filters. Journal of Chinese Electrical Engineering Science, 2015(6).

[6] Du Y, Zhou X, Bai S, et al. Review of non-isolated bi-directional DC-DC converters for plug-in hybrid electric vehicle charge station application at municipal parking decks// Applied Power Electronics Conference & Exposition. IEEE, 2010.

[7] Wu X L, Tan Z Z, Gao L. A New Variable Step Size LMS Adaptive Filtering Algorithm and its Simulations. Applied Mechanics and Materials, 2014, 513-517:3736-3739.

[8] Wang Y, Bao M. A variable step-size LMS algorithm of harmonic current detection based on fuzzy inference// International Conference on Computer & Automation Engineering. IEEE, 2010.

[9] Chuanlin L, Kaipei L. On Instantaneous Characteristic of Adaptive Harmonic Detection Based on LMS// Power & Energy Engineering Conference. IEEE, 2010.

[10] Pereira R R, Silva C H D, Silva L E B D, et al. Harmonic detection with LMS adaptive notch filter and transient detection// Power Electronics Conference (COBEP), 2011 Brazilian. IEEE, 2011.