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Virtual Instrument of Harmonics Detection Based on Neural Network Adaptive Filters

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Abstract

This study investigated the adaptive detection principle based on a single artificial neuron, and constructed a method for detecting harmonics using the artificial neural network technique. Based on the established method, and by comprehensively processing the obtained harmonics data using the LabVIEW software-developing environment of the virtual instrument, the harmonic waves were detected and analyzed. Finally, the analysis of current ball crusher harmonics verified that the designed system was effective.

Keywords: *Harmonics Detection, Neural Network, Virtual Instruments*

1. Introduction

With the wide application of all kinds of nonlinear power electronic devices, harmonic pollution has become increasingly serious in power networks, resulting in the frequent occurrence of various faults and accidents caused by harmonics occur. To intensify the treatment, management and charge for harmonic pollution, the research on the power harmonics monitoring systems, which are capable of doing real-time, accurate and continuous measures of power harmonics, is of great theoretical and engineering practical significance [1].

2. Detection method for power harmonics based on artificial neural network

Harmonics detection is a key technique of active power filter and harmonic monitoring systems. Only when harmonic currents are accurately detected in real time can they be effectively analyzed, compensated, and inhibited. Existing power harmonics detection includes those methods based on notch filters or bandpass analog filters, Fryze time domain power definition, fast Fourier transforms, the instantaneous reactive power theory of three-phase circuits, simultaneous detection, wavelet transforms, and adaptive filters [2]-[3].

To effectively monitor and eliminate power harmonics and therefore reduce the damage of power harmonics, harmonics detection methods are supposed to present the advantages of low computation amounts, real-time well, high accuracy and reliability, ease of realization, and strong adoptive ability. With these advantages, the fundamental active current, fundamental reactive current, total harmonic current, and the content of each harmonic can be detected simultaneously, which benefits the compensation and analysis of power harmonics. By considering the above requirements and comparing multiple detection methods, the power harmonics detection method based on an adaptive filter was applied in the research. This method not only shows high detection accuracy, but also can perform tracking measurements. Additionally, it exhibits a strong adaptive ability. Therefore, this method presents the best effects, strongest adaptive ability and broadest prospects among the aforementioned power harmonics detection methods [4]-[5].

A multi-channel adaptive filter is supposed to be easily realized and should also be able to perform real-time detection for power harmonics. Because of its simple structure and certain adaption and self-learning ability, only a single artificial neuron is used to build a multi-channel adaptive filter. The structure is demonstrated in Figure 1.

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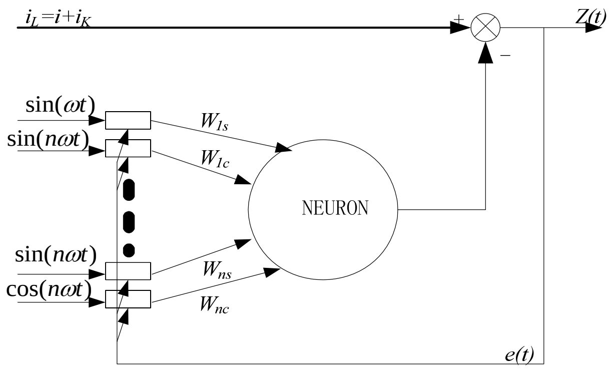

Figure 1. Detection principle for power harmonics based on signal neuron

When the power voltage us of the single-phase circuit passes through the lock-phase circuit, $\sin(\omega t)$ and $\cos(\omega t)$ are obtained. Then by increasing the frequency doubling, the sine and cosine signals in the number (2~N) are acquired, which are used as the reference input signals of the single artificial neuron. These linear combinations of the sine and cosine signals are the net inputs of the signal artificial neuron [6]-[7].

The reference input vector $X(t)$, net input $s(t)$, and output $y(t)$ of the signal artificial neuron are:

$$X(t) = [\sin \omega t, \cos \omega t; \cdots, \sin(n\omega t), \cos(n\omega t)] \quad (1)$$

$$s(t) = \sum_{i=1}^{2n} w_i(t) x_i(t) - \theta(t) \quad (2)$$

$$y(t) = f[s(t)] \quad (3)$$

As $y(t)$ can be obtained by the linear combination of the reference input, the action function of the artificial neuron is $f(x) = x$. Because the alternating current (AC) transmission bus does not contain direct current (DC) components, $\theta(t)$ is zero. Under this condition:

$$y(t) = \sum_{i=1}^{2n} w_i(t) x_i(t) \quad (4)$$

The least mean square (LMS) algorithm [8] was adopted in the learning rule of the neuron. As the algorithm applies the estimations of the relevant functions of input vectors in the estimation of the instant gradient vectors, the convergence rate is distinctly faster than found in the typical LMS algorithm, with slight computation complexity.

Next, the error feedback signal $e(t)$ is used to adjust the weight $w_i(t)$

$$w_i(t+1) = w_i(t) + \eta e(t) x_i(t) + \beta [w_i(t) - w_i(t-1)] \quad (5)$$

Where η is the learning rate $0 < \eta < 1$, β is the damping coefficient, which accelerates learning rate and reduces vibration $0 < \beta < 1$.

The concrete procedures are as follows:

1) Initialization. The convergence factor $\mu (0 < \mu < 1)$ and constant α are set. The initial value of weight vector W_n is random, and its dimension depends on the number of harmonics and interharmonics.

2) The iteration number is set and the output error is computed by:

$$e_n = y_n - (W_n^{q-1})^H X_N ; n = 0,1,2\cdots, N-1 \quad (6)$$

Where $(W_n^{q-1})^H$ is the transposed matrix of the qth learning result of the weight vector matrix.

According to the learning rule of the artificial neuron, the weight approaches the optimal value by several iterations. Under this condition, $E[e^2(t)]$ approaches the minimum value, which indicates that in the least mean square, the output $y(t)$ of the neuron optimally approximates the noise interference current $i(t)$, while the output $z(t)$ of the system optimally approximates the signal $i_k(t)$ to be detected. Furthermore, it proves that the weights of each subcircuit adaptive filter optimally approximate the peak values of the sine or cosine signals that correspond to the subcircuit in the noise interference current i(t) [9]-[10]. Therefore, the power harmonics can be detected using the output $z(t)$ of the system or the weight of each sub circuit of the artificial neuron based on the real situation [11].

After obtaining the data of each harmonic, the power network parameters are calculated using the following formulae:

1) The effective value of the nth harmonic: $I_n = \sqrt{(\omega_{ns}^2 + \omega_{nc}^2)/2}$

2) The phase angle of the nth harmonic: $j_n = arctg(W_{nc} / W_{ns})$

3) Fundamental active power: $P_1 = UI_1 \cos\phi_1$

4) Fundamental reactive power: $Q_1 = U_1 \sin\phi_1$

5) The content of the nth harmonic: $HRI_n = I_n / I_1 \times 100\%$

6) Harmonic content: $I_H = \sqrt{\sum_{n=2}^{\infty} I_n^2}$

7) Total harmonic distortion: $THD_i = I_H / I_1 \times 100\%$

3. System design and implementation

3.1. Overall structure of the system

The data acquisition circuit is designed as shown in Figure 2. In the figure, DHPT and DHCT are the micro high-accuracy voltage and current sensors, respectively, and have been designed to perform AC measurements for any voltage below 1000V, current in the range of 1mA to 100A, and frequency in the range of 40 to1000Hz.AD620, as a high-accuracy instrumentation amplifier, has a wide voltage range and good output linearity, and meets the system requirements for input signals by adjusting backward resistors and bias resistors.

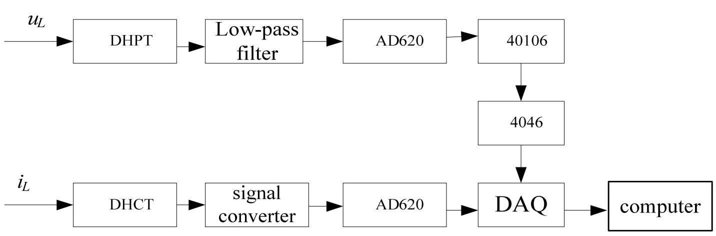

Figure 2. Structure of system hardware

The module 40106 is a Schmitt trigger, which eliminates and shapes the peaks of sine signals. The module 4046 is the phase-locked loop of monolithic integration, which maintains the conformity of the output signals and input signals by automatically tracking the frequency variation of input signals in a certain scope.

After the load voltage u_L has been transformed by DHPT and filtered by a low-pass filter, the obtained sine signal is amplified using AD620; afterwards, it is shaped using 40206. The signal is then sent into the phase-locked control circuit 4046 to generate an interruption of the rectangular signal, which is synchronous with u_L. Therefore, when u_L frequency changes, the calculating step size is adjusted correspondingly. It is worth mentioning that the external component of 4046 was designed based on the 50 Hz of the center frequency of the voltage-controlled oscillator.

The load current i_L is transformed to AC voltage using DHCT and the signal converter. After being amplified and biased, the AC voltage signal changes from bipolar to unipolar. When it satisfies the requirements of the acquisition equipment, the signal is applied as the one to be detected to extract harmonics data, which will be processed using a computer.

3.2. Software implementation of the system

Software is the core of a virtual instrument. To reduce development efforts and improve the designed system's universality and expansion capabilities, the most successful and widely used software development environment, LabVIEW 2010,was used to comp print statement, rehensively process the collected data. This allowed for the development of an integrated and intelligent detection system for power harmonics, implementing multiple functions, such as real-time detection, display, analysis, prediction, alarm, and protection. The functions are described in detail below:

1) Data acquisition, including the actuation and initialization of data acquisition cards, and the acceptance of acquired data.

2) The realization of adaptive filtering. This refers to using a computer to perform adaptive filtering of the acquired data in order to calculate each harmonic datum in the signal.

3) The display, storage and backup of the data.

4) An exceeding-limit alarm and protection for the data.

5) Data queries, statistics, and print statement.

Because LabVIEW does not have the neural network function, among its functions, the concrete computation of adaptive filtering is realized by CIN nodes, or by MATLAB using the MATLAB interface.

The structure of system software is illustrated in Figure 3.

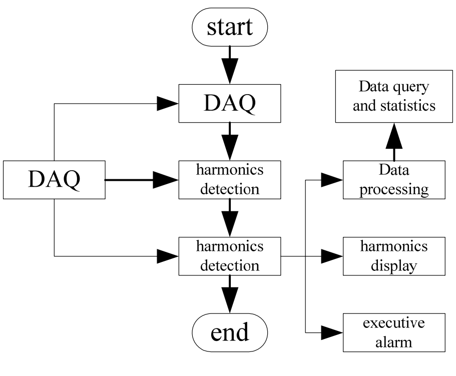

Figure 3. Structure of system software

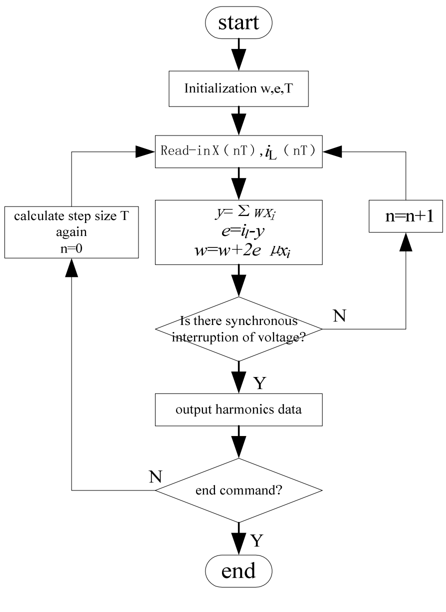

Figure 4. Flow chart of intelligent detection of harmonics

Among the aforementioned functions, harmonics detection and analysis show highest requirements and the largest computation amounts and real-time levels, which are the main parts of the software. First of all, harmonics detection was performed for the acquired data using the above adaptive filter algorithm, obtaining the data of each harmonic, as displayed in Figure 4. Afterwards, based on the received harmonic weight, the power network parameters, including the effective value of the nth harmonic, phase angle, fundamental active power and fundamental reactive power, content of the nth harmonic, the harmonic content, and total harmonic distortion were analyzed and displayed using display module. Considering the necessary legibility and intuition characteristics of the data, harmonics data are usually displayed in the form of graphs. Therefore, the LabVIEW software's Waveform Graph control was used to show the effective value and content of harmonics. The prototype waveform, fundamental waveform, harmonic waveform, fundamental active power, fundamental reactive power, and total harmonic distortion were displayed using the Waveform Chart control, and the effective value and content of harmonics were presented using a histogram while other data were displayed using linetypes.

4. Operation test

After finishing the design, operation tests were conducted for the power utilization of a micro-powder plant. The major load in the tests was a ball crusher that was 2.2m in diameter; its sampling frequency was 4.8 kHz, and the sampling lasted for 100mS, which lasted for about 5 fundamental wave periods. The above LMS algorithm was used for learning; the forgetting factor was $u = 0.99$, and the constant was $\delta = 0.01$.

By using the online monitoring system for power quality, the a-phase current waveform of the ball crusher in normal operation was obtained, as demonstrated in Figure 5 and Figure 6.

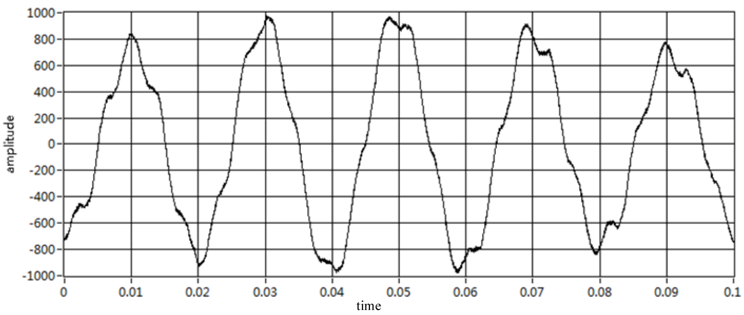

Figure 5. Current waveform of the ball crusher

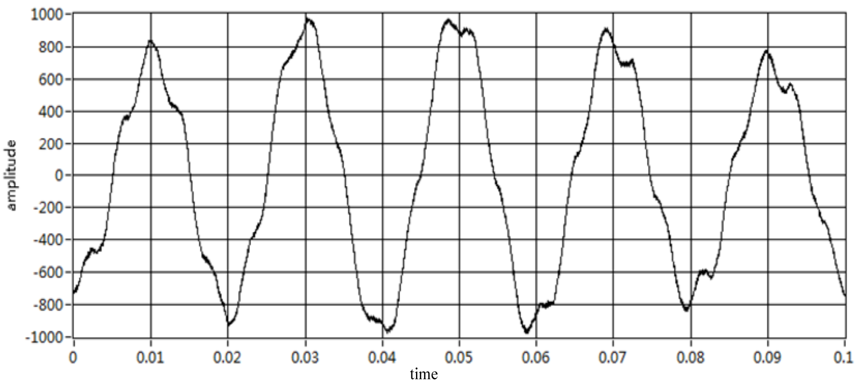

Figure 6. Current fitting waveform of the ball crusher

By using the above method, 19 sine components were acquired in the current signal of the ball crusher; the estimations of the current parameters of the ball crusher are displayed in Table 1.

Table 1 Estimated results of current harmonics of the ball crusher

Serial number	Frequency /Hz	Amplitude	Phase	Harmonic rate
1	41.303	97.564	83.313	11.977%
2	49.878	814.572	271.263	100%
3	59.236	95.708	146.998	11.749%
4	149.732	8.890	16.413	1.091%
5	238.726	9.782	309.335	1.201%
6	254.550	10.076	264.416	1.237%
7	340.723	8.943	135.366	1.098%
8	355.901	3.560	44.655	0.437%
9	537.143	3.696	229.369	0.454%
10	636.855	3.620	24.271	0.444%
11	830.039	5.400	59.590	0.663%
12	923.974	5.774	95.024	0.709%
13	940.699	4.102	235.142	0.504%
14	1121.311	2.154	343.700	0.264%
15	1223.168	2.624	255.472	0.322%
16	1784.413	0.244	239.325	0.030%
17	1859.637	0.503	36.540	0.062%
18	1930.749	0.255	128.600	0.031%
19	2076.858	0.288	46.854	0.035%
THD				16.989%

Limited by screen space, Figure 7 shows specific data of 10 harmonics with their minimum frequencies, which were directly displayed on the user interface, while the others were printed in a statement.

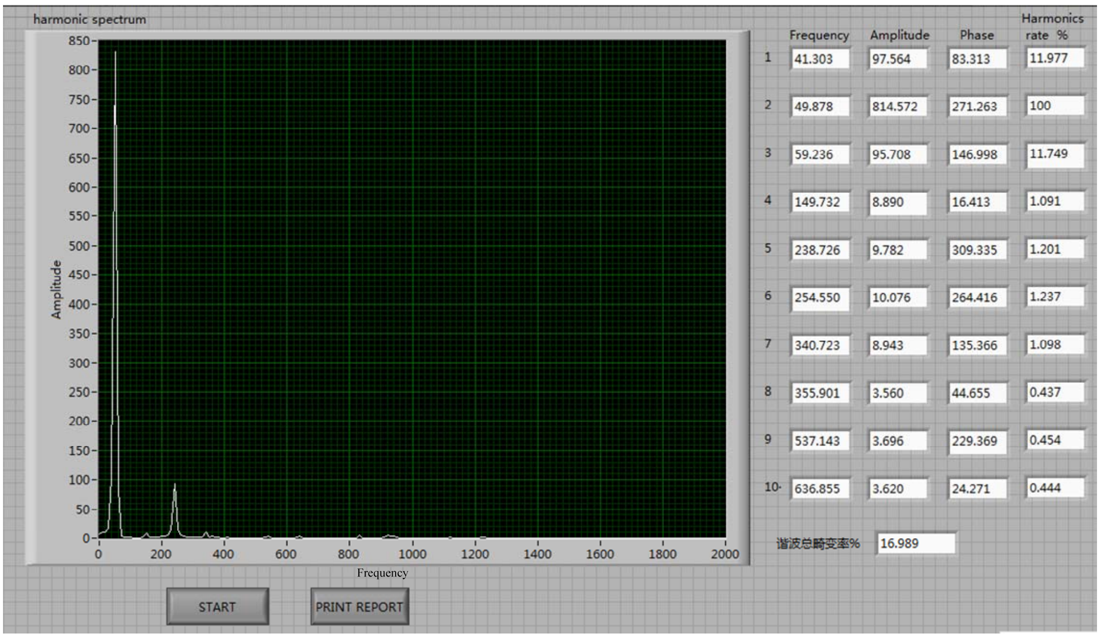

Figure 7. User interface of the comprehensive detection system for harmonics

Apart from the harmonics detection and analysis, the management for harmonics data is also very important. In the system, harmonics data management is realized by the software tool package SQL Toolkit, which supports real-time interactions with the database system. There are three steps for visiting the database using ODBC driving mode: assigning the data source, writing the operating command, and executing the command. Therefore, the database structure has to be determined first, based on which database and data source were established. Afterwards, the function nodes of SQL Toolkit were adopted to connect and operate the data source, thus effectively managing harmonics data.

According to the function requirements of the system, the constructed database contains five data tables that store the monitoring parameters, normal operation power network parameters, power network parameters before and after a fault, power network parameters before and after an alarm, and power network parameters before and after a trip. The last four instances apply the date (year, month, and day) as the primary key and index, which is convenient for the query, statistics, backup, clearing, and recovery of the database.

5. Conclusions

Test results verified that the system performed well, realizing all the functions in demand analysis and the expected design objective. Compared with most existing monitoring systems for power harmonics, the system developed in this paper exhibited the following advantages:

- It detected specified harmonic by changing parameters online;
- By adopting the adaptive power harmonics detection method based on a single artificial neuron, the system responded quickly with high detection accuracy and strong adaptive ability;
- The comprehensive monitoring system demonstrates strong functions, high flexibility, good openness and expandability through use of LabVIEW;
- Its cost is low and therefore can be popularized on a larger scale.
- In conclusion, the integrated and intelligent monitoring system for power harmonics designed in this paper presents broad application prospects.

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