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Harmonic measurement of power system based on artificial neural unit network

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Abstract. The purpose is to study the harmonic measurement method of power system based on artificial neural network. Based on the previous harmonic measurement method, the harmonic measurement method based on neural network is studied. The application of adaptive neural network in harmonic measurement is explored. WATLAB simulation software is used to simulate and validate the algorithm. For adaptive neural networks, a single neuron-based network architecture is used. The results show that the method is of higher adaptability and accuracy for the unknown power network with harmonic source. However, for changing harmonic sources, it has poor real-time performance. Therefore, it can be concluded that the proposed method is only suitable for the power systems with unknown harmonic sources.

Key words. Neural network, harmonic measurement, simulation verification.

1. Introduction

With the development of power electronics technology, the wide application of power electronic devices has brought serious harmonic pollution to the power system [1]. In the transportation, metallurgy, chemical and other industrial transportation fields, all kinds of power electronic equipment are widely used, which makes the harmonic problems in the power grid become increasingly serious. Many power electronic devices with low power factor bring extra burden to the grid, which affects the quality of the power supply. Harmonic pollution of power electronic devices has become a major obstacle to the development of power electronic technology. The problem of harmonic measurement and control is imminent [2]. Therefore, the research of harmonic measurement is an important work in power system analysis

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and control. It is an important prerequisite for relay protection, fault location and fault types. It is a meaningful work to study the method of harmonic measurement. At present, in the power system, the harmonic measurement methods are Fourier transform, instantaneous reactive power, neural network and wavelet transform. By collecting data, the previous harmonic measurement method is analyzed and summarized. Aiming at the shortcomings of these methods, a harmonic measurement method based on neural network is proposed. Then, MATLAB simulation software is used to simulate and analyze different neural network algorithms [3].

2. State of the art

The neural networks have been studied for thirty years. As early as 1957, F. Rosenblatt proposed and designed the famous perceptron concept for the first time. It consists of threshold neurons, which attempt to simulate the perception and learning functions of animals and humans [4]. In 1991, P. Saratchandran proposed a neural network method based on BP algorithm. However, this method requires a large number of samples to train learning weights. The speed of convergence and the various situations of different constraints are not discussed. It just gives the general situation of the algorithm. The improved algorithm has been pursued by many scientists [5]. In 1989, Moody and Darken proposed the neural network algorithm of RBF, which brought new life to the research and application of neural networks. In addition to the breakthroughs and advances in neuroscience research, the main reason is the need for the development of computer science and artificial intelligence [6]. From the point of view of artificial neural networks, a unified and complete theoretical system has not yet been formed. The formation, construction, design and performance evaluation of various network models and algorithms are only specific analysis of specific problems, which mainly rely on the results of computer simulation. It cannot give a strict and scientific general law and method. On the basis of analyzing the basic principle of harmonic measurement device, an adaptive neural network is used to measure the harmonics, and a network and algorithm based on adaptive harmonic measurement are constructed [7]. Then, the validity of the network is verified by simulation software. The radial basis function neural network is used to measure the harmonics. Through the determination of the algorithm, an example is selected for simulation analysis [8].

3. Methodology

3.1. Neural network model

The basic unit of the neural network is neurons. It is widely interconnected by a large number of neurons [9]. Artificial neural network is the simplification and simulation of biological neurons, which is the basic processing unit of neural network. It is a nonlinear component with multi-input and single output. Its input-output relation can be described as

$$I_j = \sum_{n}^{j=1} w_j x_j - \theta_j \, , \tag{1}$$

$$y_i = f(I_i) \, . \tag{2}$$

Here, $x_j, \ j = 1, 2, \ldots, n$ is an input signal from other cells. Symbol θ_j denotes the bias (threshold) of the neuron unit, and w_j represents the connection weight from cell j to cell i. Symbol n denotes the number of input signals, y_i is the neuron output, and t is the time. Function F is a transfer function, which is sometimes called an incentive function. It often employs 0 and 1, two-valued functions, or S type functions. The transfer function can be a linear function, but it is usually a nonlinear function like a step function or a S-shaped curve. The commonly used neuron nonlinear functions are as follows:

Threshold type function: when y_i takes values 0 or 1, $f(x)$ is a step function.

$$f(x) = \begin{cases} 1, & x \geq 0, \\ 0, & x < 0. \end{cases} \tag{3}$$

The S-curve is usually a monotonically differentiable function of continuous values within (0,1) or (-1,1). It is commonly used index or tangent and other types of S-shaped curve to represent, such as

$$f(x) = \frac{1}{1 + \exp(-\beta x)}, \ \beta > 0 \tag{4}$$

or

$$f(x) = \tanh(x) \, . \tag{5}$$

In the neural network composed of RBF (Radial Basis Function), the structure of neurons can be described by Gaussian function

$$y_i = \exp\left[-\frac{1}{2\sigma_i^2} \sum_j (w_i - w_{jt})^2\right] \, . \tag{6}$$

Here, σ_i^2 is a standardized parameter.

The neural network is the nerve structure, which consists of many neurons interconnected together. The neural network model can be obtained by mathematically modeling the relationship between neurons. The application of neural network in harmonic measurement mainly involves the following aspects. The problems are the input method, the construction of the network structure, the determination of the input layer and the determination of the hidden layer [10]. These are the problems that must be considered in the application of neural network theory to harmonic measurement. It will directly affect the speed of convergence. That is to say, it will affect the real-time measurement of harmonics and the accuracy of harmonic measurement. Theoretically, to make the harmonic measurement circuit has a certain accuracy, the measurement should be aimed at different targets [11]. according to the actual waveform distortion of collecting training samples, the harmonic measuring circuit can suitable for measuring a (or several) generated by the nonlinear load harmonic distortion wave component. However, the distortion waveforms in the power system are different from each other, and the harmonic components are different. It is impossible to collect all types of distortion waveforms. Therefore, the training samples should be extracted theoretically [12]. At the same time, in selecting the learning algorithm of the network, the method of higher efficiency and accuracy should be considered, in order to meet the real-time and high precision requirements of harmonic measurement. The construction of neural network has a direct influence on the speed of convergence. Therefore, on the basis of convergence, the network structure should be chosen as simple as possible. By using this method, the real-time requirement of harmonic measurement can be satisfied [13].

3.2. The adaptive noise canceling technology

The adaptive noise cancellation method is a kind of signal detection method proposed by Widrow in the United States. It can separate a signal from additive noise. The principle shown in Fig. 1.

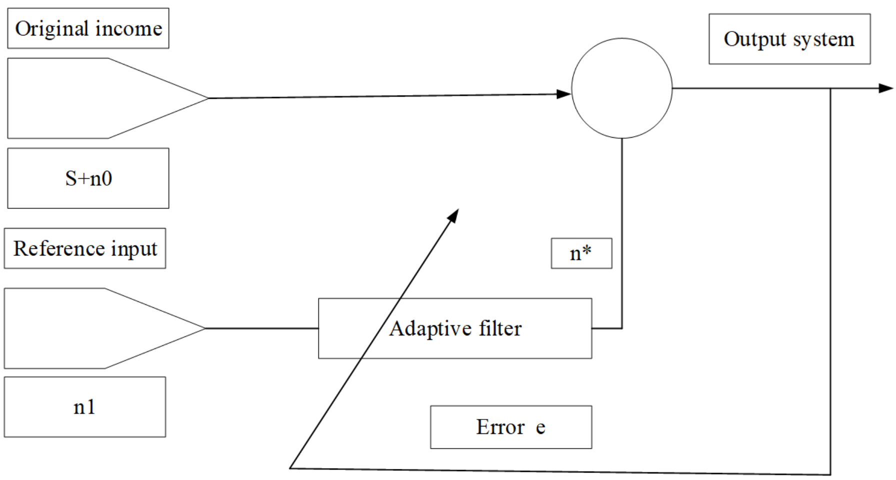

Fig. 1. Adaptive cancellation scheme

The detection system has two inputs. They are the original input $s + n_0$ and the reference input n_1. The symbols s and n_0 are irrelevant, and s and n_1 are not related. However, n_1 and n_0 are related to noise interference. The function of the reference channel is to detect interference. The output n_1 is adjusted by the adaptive filter, so that it is closest to the main channel n_0 in the sense of minimum mean square error. Here, the system output y is also used as the error signal e to adjust the parameters of the adaptive filter. This method requires little or no need for a priori knowledge of signals and noise. The n_0 can be estimated by an adaptive filter, so that the output of the system is s.

3.3. The harmonic measurement principle based on adaptive filtering

Taking single-phase circuit as an example, this paper expounds the principle of applying adaptive filter to harmonic measurement, and it is also suitable for three-phase circuit. Assuming that the single-phase voltage is $U_{\mathrm{N}}(t) = U_{\mathrm{N}} \sin \omega t$, the non-linear load of the non-sinusoidal current can be expressed as Fourier series in the form

$$I_1(t) = I_1 \sin(\omega t + \phi_1) + \sum_{n=2}^{\infty} I_n \sin(\omega t + \phi_n) = i_i(t) + \sum_{n=2}^{\infty} i_n(t) \,. \tag{7}$$

$$I_n(t) = I_n \cos \phi_n \sin n\omega t + I_n \sin \phi_n \cos n\omega t = i_{ns}(t) + i_{nc}(t),\ n > 1 \,. \tag{8}$$

In the above formulas, i_1 and i_n are the fundamental active current and fundamental reactive current, respectively. Symbols i_{ns} and i_{nc} denote the sine and cosine components of the nth harmonic, respectively. The adaptive noise cancellation method is used for harmonic measurements. Quantity i_1 is used as the original input. If $i = i_1 + i_2 + ... + i_n$ is taken as the "noise interference" current, then the other higher harmonics of the total current i need to detect the "signal". Quantity i is not related to i_n. Taking the fundamental sine and cosine signal $\sin \omega t \cos \omega t$ and their $2, 3, ..., n$ multiples of the frequency harmonic as a reference input, they are related to the sine and cosine components corresponding to the "noise interference" current i, but are not related to other higher harmonic currents i_h. Thus, the components of the "noise interference" current I and the approximation values in the sense of the minimum mean square error of the "signal" i_h can be obtained by the multi-channel adaptive filter [14].

3.4. Realization of adaptive filter with neurons

The individual neurons have a certain degree of adaptive and self-learning ability, and the circuit structure is simple. Therefore, a single neuron circuit can be used to implement an adaptive filter to construct an adaptive neural network for harmonic measurement, so that the output can be approximated by the "mean" error to the "signal" to be detected [15]. The sine and cosine signals $\sin \omega t \cos \omega t$ and their $2, 3, ..., n$ multiples are taken as the input of a single neuron, so the input vector $x(t)$ of the neuron is

$$X(t) = [\sin \omega t \cos \omega t, \sin 2\omega t \cos 2\omega t, ..., \sin n\omega t \cos n\omega t] \,. \tag{9}$$

The net input $S(t)$ of the neuron is

$$S(t) = \sum_{i=1}^{n} w_i x_i(t) - \theta_i \,. \tag{10}$$

In the formula, w_i is the connection weight and θ_i is the neuron threshold. The output of the neuron $y(t)$ is

$$y(t) = f\left[s(t)\right] . \tag{11}$$

In the formula, $f(x)$ is the activation function. From (8) and (9), it can be seen that the fundamental and harmonic components are linear combinations of their sine and cosine signals. Thus, the activation function $f(x)$ takes the linear function $f(x) = x$. In addition, since the power system transmission bus does not contain the DC component, the neuron threshold value θ_i is zero. The current sampling value is taken as the target value of the neural network, that is, the difference between the current sampling value $iL(t)$ and the output value $y(r)$ of the neuron is taken as an error $iL(t) - y(t)$. Function $e(t)$ is used to constantly adjust the input weights of neurons. According to the learning rules of neurons, each weight can get the optimal value, so that its mean square error is the smallest. Let the output $y(t)$ of the neuron approach the "noise interference" current i, the error approximates the "signal" i_h, thus, the function of the adaptive filter for harmonic measurements is realized [16].

4. Result analysis and discussion

The algorithm of power harmonic detection based on adaptive neural network is simulated by Matlab software. In the simulation study, the neural network is used to measure the fundamental and 3, 5, 7, 11 harmonic components [17]. Therefore, the reference inputs are $\sin\omega t$, $\cos\omega t$, $\sin 3\omega t$, $\cos 3\omega t$,.......,$\sin 11\omega t$, $\cos 11\omega t$, 10 input vectors, respectively. The LMS algorithm is used to study the network online [18]. The simulation flow chart is shown in Fig. 2.

From the simulation results, it can be seen that the network has good real-time performance [19]. Under the simulation conditions in this paper, the upper target value can be tracked in about two cycles. At the same time, in order to analyze the measurement accuracy of the circuit, Fig. 3 lists the fundamental frequencies at the end of 1 cycle and 2 cycles at the end of the harmonic value of the measurement error [20].

Figure 4 lists the fundamental frequency at the end of the two cycles and three cycles (extended 100 times) at the end of the harmonic phase angle of the measurement error.

As can be seen from the Fig. 4, at the end of the 2 cycles, the accuracy of each harmonic amplitude measured by the circuit is higher, and they are not less than 1 %. The phase angle measurement accuracy is slightly lower, the maximum is 12.27 %. However, the accuracy of the phase angle at the end of the third cycle is also high, and it reaches 0.005 %. Therefore, it can be said, that it exhibits high measurement accuracy simultaneously.

The harmonic measurement circuit is constructed by using adaptive neural network. The circuit detection method for measuring arbitrary harmonics is given, and the network with 3, 5, 7 and 11 harmonics is simulated by MATLAB. The simulation results show that the circuit has good real-time performance, measurement accuracy and adaptability when using adaptive neural network for harmonic

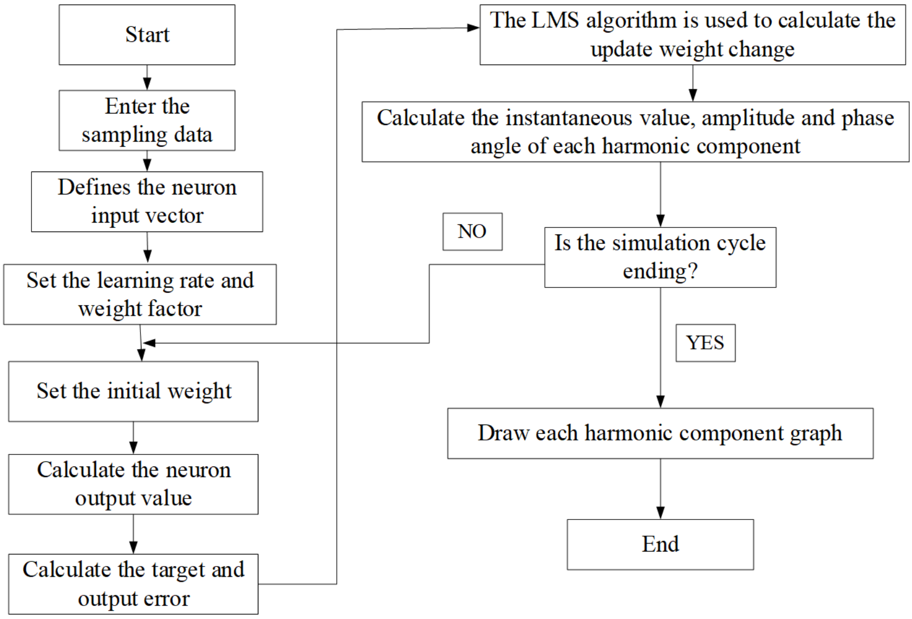

Fig. 2. Simulation flow figure

Fig. 3. Measurement error of the amplitude of each harmonic wave at the end of 1 cycle and at the end of two cycles

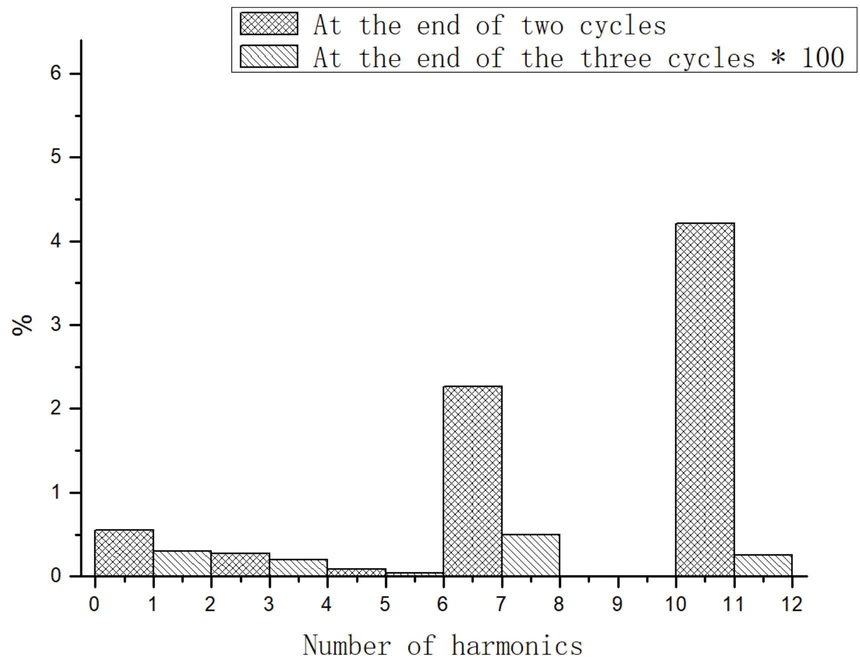

Fig. 4. Two cycles and three cycles (extended 100 times) at the end of the harmonic phase angle of the measurement error

measurement. Adaptive neural network based on single neuron structure is a good method for power network with unknown harmonic source. It is not only simple in structure, but also has certain adaptive ability. For power systems with large load variation, the real-time performance of this method needs further improvement. At last, the simulation test of random distortion current shows that the network has the longest tracking time, and it reaches about 0.08 s.

5. Conclusion

The adaptive neural network based on a single neuron has the characteristics of simple structure and strong network adaptability. For the measured power network, it does not require pre-training. The results show that the proposed method is not only simple in circuit structure, but also has better real-time performance and higher accuracy for power network with unknown harmonic source. However, there is a real-time difference in the large harmonic source, which requires a tracking time of 0.06 to 0.08 s. Therefore, the method is suitable for harmonic sources in unknown power systems. In order to better meet the real-time and measurement accuracy of harmonic measurement, a method based on multilayer feedforward neural network for harmonic measurement is further studied. In the future, the harmonic measurement algorithms should be developed from simple function analysis methods to complex numerical analysis and signal processing. At the same time, these algorithms should be intelligent. Therefore, it is urgent to establish a general power theory and apply the new theory to harmonic measurement. In this way, harmonic measurement can achieve a breakthrough in real-time and accuracy.

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