Research on Harmonic Analysis in Power Systems Based on Neural Network

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Abstract. A new harmonic analysis method for electric power systems based on triangle basis functions neural network was presented, the convergence theorem of the algorithm was proposed, and a window function and interpolation algorithm were employed to correct the frequency of fundamental waves. This approach does not require synchronized sampling and integer period truncation, and can obtain directly the frequencies, amplitudes and phases of fundamental waves and harmonics. The result of computer simulations has shown that the algorithm is an ideal analysis method with high precision, small amount of calculation and speedy convergence.

Introduction

With the development of power electronics technology, power system harmonic pollution is worsening, which poses a potential threat to the power system security, stability, economic operation and greatly affects the surrounding electrical environment. Therefore, it is significant to monitor the power system harmonics real-timely, exactly control the status of the power system harmonic, prevent harmonic harm and maintain safe operation of power system[1].

The power system harmonic measurement usually using fast Fourier transform (FFT) to realize. However, the power system frequency is not necessarily rated frequency. It is unable to guarantee the sampling frequency is an integer multiple of the actual operating frequency. Thus, there exists a fence effect and leakage phenomenon, which make the calculated signal parameters, namely the frequency, amplitude and phase, incorrect, especially the phase error is large, which can not meet the harmonic measurement requirements. This paper presents a new method adapted to the power system harmonic analysis based on a triangular basis functions neural network algorithm. The neural network algorithm convergence theorem is proposed and proved. The simulation indicates that the method of calculating harmonic measurements is of high precision, small amount of calculation, fast convergence, so the algorithm has a higher electric system harmonic measurement application value [2,3].

The extraction of power system fundamental frequency

A periodic signal having a respective harmonic can be expressed as:

$$y(t) = \sum_{n=0}^{N} A_n \sin\left(2\pi f_n t + \varphi_n\right) \tag{1}$$

Where f_n represents the frequency of n harmonic; A_n and φ_n respectively represent the amplitude and phase of n harmonic; N represents highest harmonic frequency.

The signal is sampled at a sampling frequency f_s, when the sampling frequency f_s is not an integer multiple of the fundamental frequency f_0, the fundamental frequency can be expressed as:

$$f_0 = (K_0 + \Delta K_0) f_s / M \tag{2}$$

Where K_0 is integer; ΔK_0 is decimal; M is sampling points number.

According to the relevant literature, the correction equation of fundamental frequency combined with short form windowed interpolation algorithm can be obtained.

$$\Delta K_0 = \begin{cases} \dfrac{Y(K_0+1)}{Y(K_0)+Y(K_0+1)}, & Y(K_0+1) \geq Y(K_0-1) \\ \dfrac{Y(K_0-1)}{Y(K_0)+Y(K_0-1)}, & Y(K_0+1) < Y(K_0-1) \end{cases} \tag{3}$$

And the correction equation of fundamental frequency combined with Hanning window interpolation algorithm can also be obtained.

$$\Delta K_0 = \begin{cases} \dfrac{2Y_w(K_0+1)-Y_w(K_0)}{Y_w(K_0)+Y_w(K_0+1)}, & Y_w(K_0+1) \geq Y_w(K_0-1) \\ \dfrac{Y_w(K_0)-2Y_w(K_0-1)}{Y_w(K_0)+Y_w(K_0-1)}, & Y_w(K_0+1) < Y_w(K_0-1) \end{cases} \tag{4}$$

Where $Y_w(K_0)$ represents the windowed discrete Fourier transform.

Thus, the Hanning window correction fundamental frequency can be obtained from Eq. (2).

Power system harmonic analysis based on triangle basis neural network

In the power system, Eq. (1) can be further expressed as:

$$y(m) = A_0 + \sum_{j=1}^{N} \left[A_j \sin \varphi_j \cos(jw_0 mT_s) + A_j \cos \varphi_j \sin(jw_0 mT_s) \right] \tag{5}$$

Where w_0 is the fundamental angular frequency of the power system, $w_0 = 2\pi f_0$; j is the number of harmonic; A_0 is the DC component.

Eq. (5) can be further expressed as:

$$y(m) = w_0 + \sum_{j=1}^{N} w_j \cos(jw_0 mT_s) + \sum_{j=N+1}^{2N} w_j \sin[(j-N)w_0 mT_s] \tag{6}$$

Where m represents the m th sampling point, $m = 0,1,\cdots,M-1$; T_s represents the sampling period.

According to Eq. (6), the BP neural network model based on triangular basis function can be established. Wherein the input layer neurons is 1, the weight value of the hidden layer neurons is

w_j, and the excitation function is c_j, namely:

$$w_j = \cos(jw_0 mT_s), \quad j = 0,1,2\cdots,N \tag{7}$$

$$c_j = \sin[(j-N)w_0 mT_s], \quad j = N+1, N+2, \cdots, 2N \tag{8}$$

The weight matrix is defined as:

$$W = [w_0, w_1, \cdots, w_{2N}]^T$$

The excitation matrix is defined as:

$$C = (c_0, c_1, \cdots, c_{2N})$$

Thus, the output of neural network is obtained:

$$y_d(m) = \sum_{j=0}^{2N} w_j c_j = W^T C \tag{9}$$

The error function:

$$e(m) = y(m) - y_d(m), \quad m = 0,1,2,\cdots, M-1 \tag{10}$$

The performance index:

$$J = \frac{1}{2} \sum_{m=0}^{M} e^2(m) \tag{11}$$

The weight adjustment:

$$W(m+1) = W(m) + \eta_e(m)C(m) \tag{12}$$

Where, η represents the learning rate, and $0 < \eta < 1$.

In order to ensure the convergence of neural networks, we propose a convergence theorem:

Set η as the learning rate, when $0 < \eta < 2/(N+1)$, the neural network is of convergence, where $2N+1$ is the number of hidden layer neurons.

According to the above neural network algorithm, through neural network training, the weigh value of neural network W can be obtained, and the amplitude and the phase of each harmonic can be obtained by using the weigh value W and the following equation.

Fundamental amplitude: $A_1 = \sqrt{w_1^2 + w_{N+1}^2}$.

Fundamental phase: $\varphi_1 = \arctan(w_1/w_{N+1})$.

n th harmonic amplitude: $A_n = \sqrt{w_n^2 + w_{N+n}^2}$.

n th harmonic phase: $\varphi_n = \arctan(w_n/w_{N+n})$.

Simulation example

In order to verify the neural network algorithm proposed in this paper, take simulation harmonic

analysis to the following signal:

$$y(k) = \sum_{n=1}^{11} A_n \sin(2\pi f_n kT_s + \varphi_n) + 0.01 A_1 \cdot rand(k)$$

Where the fundamental frequency is 50.2Hz. The harmonic frequency of each other is the integer multiples of the fundamental frequency. The sampling frequency is 1500Hz and the sampling points is 1024 points. The fundamental, the harmonic amplitudes (a unit-value) and phase are shown in Table. 1.

Table. 1 Components of the simulated harmonic signal

Simulation signal	Fundamental	Harmonic number									
		2	3	4	5	6	7	8	9	10	11
Amplitude	1	0.02	0.1	0.01	0.05	0.05	0.04	0	0.03	0	0.02
Phase	0	10	20	30	40	50	60	-	80	-	100

In order to simulate the actual digital signal, the white noise signal whose amplitude is the 1% of the fundamental amplitude is added in the simulation signal. At first, obtain the fundamental frequency, through using the windowed interpolation algorithm described earlier, and regard this fundamental frequency as the one used in neural network algorithm. Put the sampling value (30 points) of the previous fundamental period into the neural network to train. After six iterations, the neural network is of convergence, namely, the amplitude and phase of the fundamental harmonic and other harmonic can be obtained with one-time. Table. 2 is the result of proposed neural network algorithm with rectangle-windowed interpolation algorithm. Table. 3 is the result of proposed neural network algorithm with Hanning-windowed interpolation algorithm. For comparison, we use adaptive artificial neural network algorithm for harmonic analysis of this signal, the analysis results are shown in Table. 4.

Table. 2 The result of proposed neural network algorithm with rectangle-windowed interpolation algorithm

Harmonic number	Harmonic frequency		Harmonic amplitude		Harmonic phase	
	Frequency	Relative error	Amplitude	Relative error	Phase	Relative error
1	50.1996035	-0.0007894	1.00000333	0.01033	0.00118116	0.0006562
2	100.3992070	-0.0007894	0.01999150	0.042500	10.01175094	0.1175094
3	150.5988105	-0.0007894	0.09999463	-0.005370	20.00670294	0.0335174
4	200.7944140	-0.0007894	0.00999567	-0.043300	30.03567769	0.1189256
5	250.9980175	-0.0007894	0.04999686	-0.006280	40.01318266	0.0329567
6	301.1976210	-0.0007894	0.00499773	-0.045400	50.07577618	-0.1515524
7	351.3942245	-0.0007894	0.03999794	-0.005150	60.01820710	0.0303452
9	451.7964315	-0.0007894	0.02999893	-0.003567	80.02506330	0.0313166
11	552.1956385	-0.0007894	0.02000029	0.001450	100.03820892	0.0382089

Table. 3 The result of proposed neural network algorithm with Hanning-windowed interpolation algorithm

Harmonic number	Harmonic frequency		Harmonic amplitude		Harmonic phase	
	Frequency	Relative error	Amplitude	Relative error	Phase	Relative error
1	50.2001517	0.0003022	1.00000720	0.000720	-0.00118767	-0.0006598
2	100.4003034	0.0003022	0.02000011	0.000550	9.98068456	-0.1931544
3	150.6004551	0.0003022	0.09999896	-0.001040	19.99566769	-0.0216616
4	200.8006068	0.0003022	0.00999794	-0.020600	29.97587054	-0.0804315
5	251.0007585	0.0003022	0.04999709	-0.005820	39.99421845	-0.0144539
6	301.2009102	0.0003022	0.00499651	-0.069800	49.97821918	-0.0435616
7	351.4010619	0.0003022	0.03999644	-0.008900	59.99594266	-0.0067623
9	451.8013653	0.0003022	0.02999711	-0.009633	80.00045400	0.0005675
11	552.2016687	0.0003022	0.01999984	-0.000800	100.01210024	0.0121002

Table. 4 The result of adaptive artificial neural network algorithm

Harmonic number	Harmonic frequency		Harmonic amplitude		Harmonic phase	
	Frequency	Relative error	Amplitude	Relative error	Phase	Relative error
1	50	-0.3984	0.99854	-0.146	0.08584	0.2384
2	100	-0.3984	0.01675	-16.250	23.0349	130.3490
3	150	-0.3984	0.09833	-1.670	24.0217	20.1085
4	200	-0.3984	0.00961	-3.900	52.8324	76.1080
5	250	-0.3984	0.04982	-0.360	46.9546	17.3865
6	300	-0.3984	0.00595	19.000	82.3320	64.6640
7	350	-0.3984	0.04043	1.075	68.2527	13.7545
9	450	-0.3984	0.03061	2.033	89.2676	11.5845
11	550	-0.3984	0.02023	1.150	100.9942	0.9942

As can be seen from the simulation results, the proposed method of measuring harmonic frequency fluctuation has better adaptability, by the white noise signal interference, the precision for each harmonic amplitude and phase angle is high.

Conclusions

This paper presents a novel triangular basis function neural network algorithm and its convergence theorem. Combined with windowed function interpolation algorithm, we make a harmonic analysis of power system. The above simulation simulation calculations indicates that, in the non-synchronous sampling and the case of non-integral period truncation and white noise, etc., the proposed method is of high accuracy for harmonic measurement. The neural network algorithm requires small amount of data (only one fundamental cycle sample data), and is fast convergence (the above example only 6th iteration can converge). Therefore, the algorithm has a higher value in the power system harmonic measurement.

References

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