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Harmonic Measurement Method Based on Artificial Neural Network

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Abstract: With the development of industry 4.0, new energy generation, electric vehicles and high-speed railways, the harmonic pollution problem of power grid has become more and more serious. The comprehensive treatment, responsibility division and cause analysis of power grid harmonics have become extremely urgent. This paper mainly studies a kind of artificial harmonic measurement method. In this paper, linear neural network is introduced into harmonic detection of power system because of its simple structure and small computation. A method based on the approximation of the 5, 7, 11 and 13 harmonics of CVT and neural network is studied to predict the transfer coefficients of each harmonics of CVT in the field. Simulation results show that the detection effect of the proposed method is superior.

1. Introduction

With the rapid development of power system, the interconnection of large-scale intermittent renewable energy and the complexity and diversity of power load itself, the existing power grid is facing new challenges and problems. The resulting power quality problems, especially harmonic pollution, are becoming more and more serious. It has seriously affected the safety and economic operation of the power grid system itself and the user equipment. How to accurately and effectively carry out harmonic measurement is an important prerequisite and basis for improving the power quality level of the power grid [1-2]. In power system, for accurate measurement of voltage, it is indispensable to the number of basic physical parameters. Due to the disadvantages of electromagnetic Voltage transformers, such as easy ferroresonance with distributed capacitors on the line, high insulation requirements, large volume and high cost, voltage measurement in the high-voltage power grid is often replaced by Capacitor Voltage Transformer (CVT) []3. CVT has the advantages of high insulation strength, small size and light weight, no ferroresonance with the system, low cost, and the coupling capacitor contained in CVT can also be used for power line carrier communication, so in the high voltage level range of 110kV and above, CVT is often used as the voltage signal measurement equipment. But due to the inherent structure of the CVT transmission characteristics, make compensation reactor unit equivalent inductance and capacitance pressure equivalent capacitive reactance of the impedance characteristics of LC series circuit, composed of changes with the change of frequency, has resulted in a working point of the series resonance circuit produces deviation, at the moment of CVT transmission ratio and the load presented correlation, As a result, the voltage error at each frequency of measurement is large [4-5].

At present, most studies on capacitive voltage transformers focus on the selection of component parameters of each component of CVT and the analysis of transient process [6]. The research on CVT harmonic voltage measurement and correction technology started relatively late in China, and most of them qualitatively believe that the use of CVT for harmonic voltage measurement will produce large errors, resulting in the lack of in-depth research on quantitative analysis and relevant physical experiments [7]. In the past two years, with the development of high-power and high-voltage harmonic disturbance devices, a group of scientific researchers and some universities have been born to carry out quantitative practical experimental research []8. Some scholars built an equivalent circuit model based on the structure of CVT itself, and the equivalent models constructed were basically similar, and analyzed the related factors causing errors in the transfer ratio of CVT [9]. Some circuit models built by scholars do not consider some parameters of the intermediate transformer, so it is impossible to accurately know how these parameters affect the harmonic transmission characteristics of CVT [10]. Foreign research on transformers started relatively early. Photoelectric transformers have been gradually used because of their advantages of small size, light weight, simple insulation structure and high measurement accuracy [11]. However, in recent decades, due to the limitations of equipment technology and economic benefits, photoelectric transformers can not be widely used and well developed. Therefore, the current main research direction is CVT, and the dielectric materials of capacitive voltage dividers in CVT are studied. How to better improve CVT measurement accuracy and specific analysis of transient process under power frequency [12]?

The existing methods of reading harmonic voltage measurement results directly by CVT have great shortcomings, and the harmonic measurement results are not completely reliable. It is urgent to put forward an effective method of harmonic measurement by CVT.

2. Harmonic Measurement of Power Network Based on BP Neural Network

2.1. Existing Harmonic Detection Methods

(1) Time domain analysis

The harmonic measurement method based on the principle of analog filtering adopts a series of different center frequencies (f0, 2f0, 3f0, ... hf0), the analog bandpass filter extracts harmonic components of specific natural frequencies. Although the spectrum information of power grid signals can be obtained to a certain extent, it is limited by the tuning frequency value of its analog filter. When the system power frequency fluctuates, large measurement errors are easy to occur, and with the increase of the measured frequency order, the circuit structure of the corresponding measuring device is more complex and the operating power consumption increases [13]. Therefore, a new harmonic detection method based on instantaneous reactive power is added. This method uses p-q theory to obtain the corresponding fundamental wave and total harmonic reactive current parameter values through coordinate transformation under the condition of three-phase circuit symmetry. However, this method is only applicable to three-phase symmetric circuit due to the influence of its operating conditions. Moreover, the specific spectrum information of each harmonic signal can not be analyzed and obtained. And harmonic detection method based on time domain synchronous is the accuracy of measurement in time domain analysis method, a detection method is the most representative is obtained by numerical integration of the sampling sequence synchronization after multiple iterative approximation of original signal sequence, then the signal is fast Fourier transform to calculate the corresponding every harmonic signal amplitude, phase and frequency, Although this method can obtain relatively accurate spectrum information of power grid harmonic signals, the computational complexity of the signal quasi-synchronization process is high, which requires repeated integration of the original signal sequence for many times, occupies large CPU resources, and has poor real-time performance, so it is not feasible in practical applications [14-15].

(2) Frequency domain analysis

The harmonic measurement methods of frequency domain analysis mainly include DFT and its improved algorithm, modern spectral estimation method and other detection algorithms. Although the DFT based harmonic measurement method is simple to calculate, the resolution of this method is limited, and the estimation accuracy of peak frequency parameters between two adjacent rational frequency points is limited [16]. Put forward based on window interpolation FFT harmonics measurement algorithm, through the introduction of real symmetric window function to weighted truncation of original signal, and according to the selected window function in the time domain expression to choose the appropriate interpolation algorithm (single line interpolation algorithm, double spectral lines interpolation algorithm, three line interpolation algorithm) for every harmonic peak spectral lines interpolation correction, However, with the complexity of the time-domain expression of the window function, it is difficult to solve the analytical expression of the corresponding correction formula, leading to the difficulty of further improving the measurement accuracy [17]. To this, the researcher according to the model of power grid harmonic signal harmonic measurement method based on the modern spectral estimation theory, the method is based on a priori knowledge about the sampling process or some assumptions, using the signal part of the observational data or the statistics include signal parameter equation, the accurate estimate signal parameters is obtained by solving the equation, Although these methods can be part of the sample data for every harmonic component of amplitude, frequency and phase information, but with the diversification of the power grid structure, its corresponding grid signal model is also becoming complicated, direct signal parameters in the equation, to implement more difficult, the corresponding calculation process is also more complex [18].

2.2. Construction of Harmonic Neural Network

In this paper, a neural network for predicting CVT harmonic transfer coefficients is constructed, and the approximate values of the four harmonic transfer coefficients are taken as the input values of the neural network, that is, the five eigenvalues, because the voltage transfer coefficients of CVT5, 7, 11 and 13 harmonics can basically characterize a complete CVT amplitude-frequency curve.

For CVT in field operation, except stray capacitance parameters are not known due to environmental reasons and the magnitude of other circuit main parameters of CVT can be obtained through test debugging or measurement. The established CVT transfer function model is used to simulate and analyze the frequency characteristics. In order to obtain the multi-band frequency characteristic curve, the stray capacitance parameter can be changed. The appropriate neural network model was selected, and then the network was repeatedly trained by using the self-measured and corrected 2-25 harmonic voltage values of CVT and PT, the main circuit parameters of CVT except stray capacitance, and the amplitude-frequency characteristic curve of CVT obtained in the laboratory. The purpose is to obtain a neural network model with high accuracy of CVT prediction and recognition. With the help of this neural network model, the laboratory can predict the amplitudefrequency characteristic curve of CVT (containing CVT2-25 harmonic transfer coefficients) that best matches the five eigenvalues of CVT5, 7, 11 and 13 harmonic transfer coefficients obtained in the field. The transfer coefficients of CVT2-25 harmonics can be obtained from the amplitude-frequency characteristic curves. According to the above analysis, the construction of a complete and stable neural network with high accuracy of CVT is helpful to better predict the harmonic voltage transfer coefficient of CVT in the field.

BP neural network (BP neural network) is also a multi-layer forward network, and its training algorithm uses the back propagation algorithm, BP algorithm, which is easy to implement and simple in structure. The theory has shown that when the hidden layers of BP neural network are set as three layers, it can approach any nonlinear function describing the characteristics of sample data. BP neural network algorithm is widely used, such as pattern recognition, function approximation and classification, the main reason is its strong adaptability.

When building the neural network, the number of hidden layer nodes is calculated as 3-12 according to the following empirical formula.

$$H=\sqrt{n+m}+\alpha;(\alpha=1-10) \tag{1}$$

Where H is the number of neurons in the hidden layer, m is the number of neurons in the input layer, and n is the number of neurons in the output layer.

The excitation function is g(x) and the sigmoid function is taken. In the form of:

$$g(x)=\frac{1}{1+e^{-x}} \tag{2}$$

A certain type of CVT was selected, and 40 sets of data were collected using the aforementioned method, which all included the 2-25 harmonic voltage values measured by PT and CVT, the main circuit parameters of CVT except stray capacitance, and the amplitude-frequency characteristic curve. With the value of stray capacitance as a variable, different amplitude-frequency characteristic curves of CVT can be obtained, and different installation conditions can be simulated on site. The number of training groups is selected as 40.

The input neurons of the neural network during training are the approximation values of the transfer coefficients of the 5th, 7th, 11th and 13th harmonics of CVT. The number of neurons in the input layer is 5, which is the five eigenvalues of CVT. The output of the neural network is the amplitude-frequency characteristic curve that best matches the five eigenvalues of CVT, which contains the transfer coefficients of 2-25 harmonics.

3. Simulation Experiment

In the simulation experiment, in order to effectively prove the method of this paper, for different power system harmonic signals to carry out. Assuming that there are harmonics with multiple frequency components in the harmonic signal, the fundamental wave of the research object and the frequency, amplitude and phase of each harmonic are given in Table 1 below. According to the above, we set the fundamental frequency as 50Hz, and the period obtained is 0.03s. In one cycle, set the sampling frequency as 50 times and the sampling frequency as 2500Hz. In this way, the basic requirements of sampling theorem are satisfied. In this harmonic signal, the frequency of the highest harmonic is 600Hz, and the number of harmonics is 4. According to the above situation, we can set the number of output nodes as 4.

Table 1. The fundamental wave and its amplitude, frequency, and phase

	5	7	11	13
Frequency	200	300	500	600
Amplitude	1/5	1/7	1/11	1/13
Phase	50	70	110	130

4. Analysis of Simulation Results

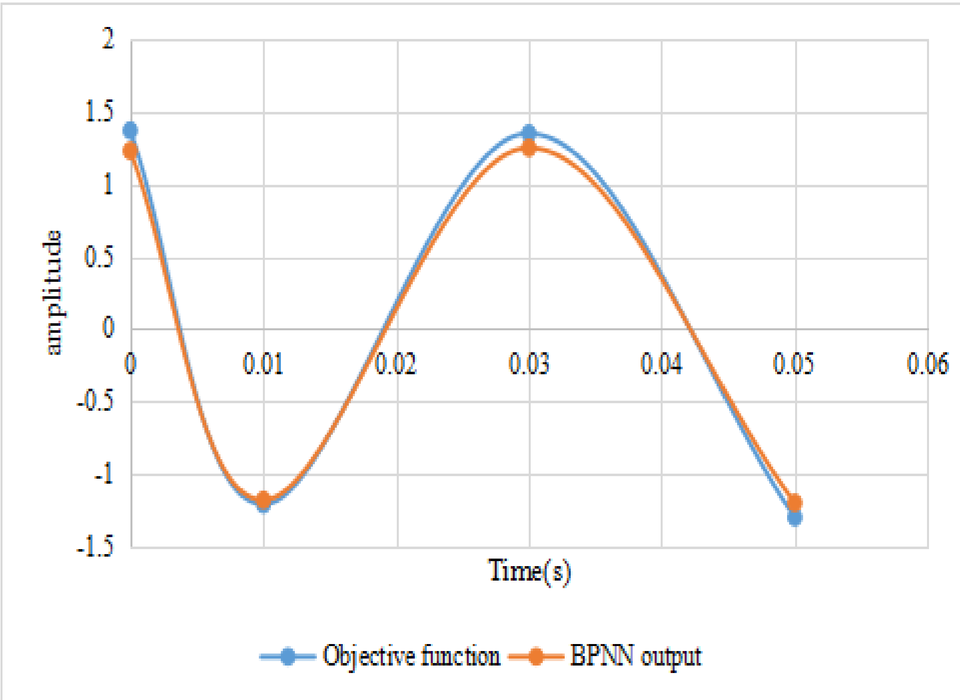

Figure 1. The output result of BPNN is compared with the objective function

The orange dotted line in Figure 1 is the result obtained after the signal to be detected is detected by BPNN, from which it can be seen that the BP neural network algorithm can approximate the target signal.

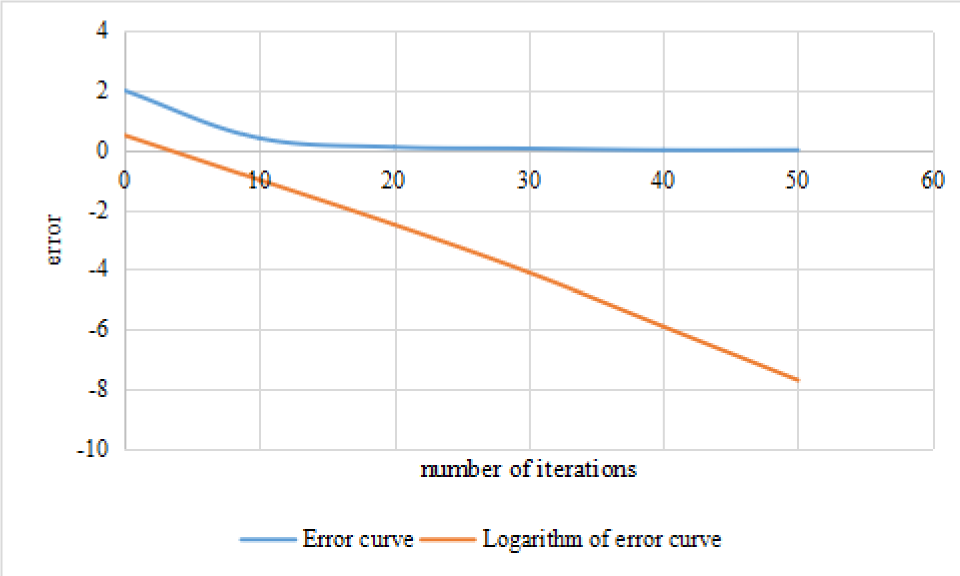

Figure 2. BPNN error curve

Figure 2 represents the iteration error curve. It is not difficult to see that with the increase of iteration times, the error decreases continuously and rapidly. At the same time, it can be seen that the decay rate is significantly reduced when it reaches 20 iterations.

Table 2. Spectrum detected by different methods

	5	7	11	13
FFT	200.14	299.53	501.07	600.98
BPNN	199.97	300.06	501.04	600.12
True value	200.00	300.00	500.00	600.00

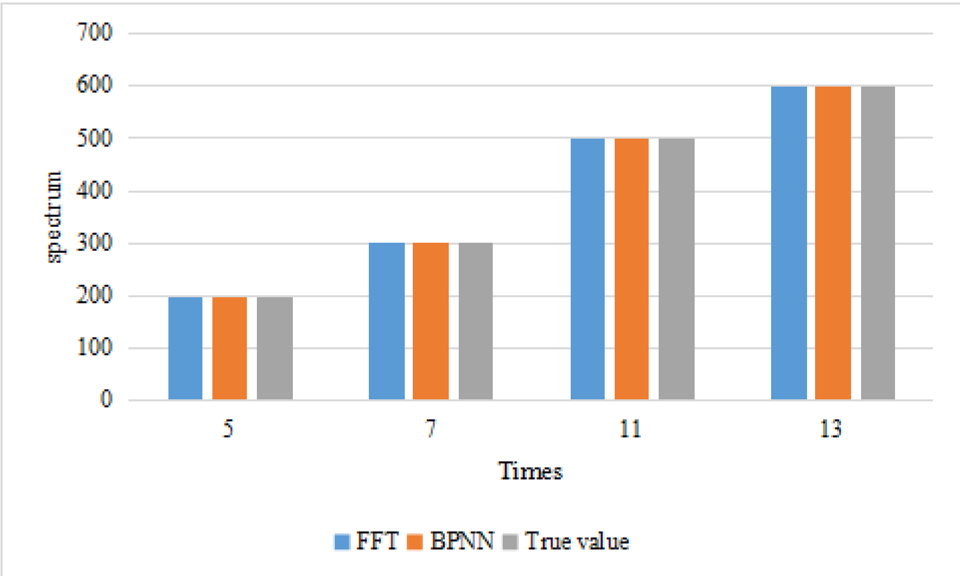

Figure 3. Spectrum comparison of different methods

As can be seen from Table 2 and Figure 3, compared with Fourier transform, the results detected by BP neural network are more accurate in terms of harmonic frequency, amplitude and phase, and the error can be controlled within 5%. The reason is that the corresponding training of neural network can suppress many false frequencies and improve the accuracy of detection.

5. Conclusion

With intelligent power grid construction, the new energy such as solar energy, wind energy of parallel operation, large uhv dc project put into use, power grid harmonic problems become more prominent, the harmonic effect on the normal operation of power grid is becoming more and more serious, accurate monitoring of the power grid harmonic content is becoming more and more necessary, CVT has been widely applied in the power grid, It is very important to study how to obtain accurate harmonic content in power grid by CVT. By combining the approximate values of the voltage transfer coefficients of the 5th, 7th, 11th and 13th harmonics of CVT with the God and network, the amplitude-frequency characteristic curves containing the voltage transfer coefficients of CVT2-25 harmonics that best match the eigenvalues are output to form the BP neural network to detect the harmonics of the power system. Simulation results show that the detection effect of the proposed method is superior.

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Data Availability

Data sharing is not applicable to this article as no new data were created or analysed in this study.

Conflict of Interest

The author states that this article has no conflict of interest.

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