Neural Network Approach of Harmonics Detection

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Abstract

This paper describes a novel approach of harmonics detection in power system which can be used as an alternative to the conventional approaches. The proposed approach uses the multilayer feed forward neural network to determine the components of harmonic in a six-pulse bridge converter. In this paper the detection of 5th, 7th, and 11th harmonic components from the distorted waves has been verified by means of the computer simulation. It is found that once trained by the learning algorithm, the neural network can determine each harmonic components very effectively and efficiently.

1. Introduction

The increasing use of power electronics load such as converters and solid state switching devices has created significant problems for power utilities. The current waveforms drawn by these loads contain high levels of harmonics leading to unwelcome losses in lines and equipment[1-3]. Harmonics influence power line to be distorted wave and degrade the voltage waveform enough such that the operation of other electrical apparatus may be impaired.

Consequently, an effective and efficient measures must be devised to detect each harmonic components separately in order to provide quality of the delivered energy. To provide quality of the delivered energy, there is a need to know the harmonic parameters such as magnitude and phase. This knowledge would make it possible to compensate for the harmonic components by injecting the corresponding portion of them into the power system. In conventional approaches, the detection of harmonics is done by using either FFT(Fast Fourier Transform) technique or by using appropriate electronics filter[4-6].

In FFT technique[6] the distorted wave is first sampled, then digitized and later processed by using Fast Fourier Transformation to detect each harmonic components separately. But this process of harmonic detection takes time and also computer memory and it is difficult to provide on line estimation.

In the second approach, special electronics filters separating the harmonic components are built and estimation of the parameters of the individual sinusoids can be easily provided by using standard measurement techniques. Isolation of the undistorted sinusoids can be done in real time using, for example, adaptive filters[5] consisting of a cascade of IIR biquadratic notch filters. This method is encouraging but its implementation is however complicated by specialized and sophisticated hardware.

This paper applies Multilayer Perceptron(MLP) neural network[7], which is well known for its learning ability and high speed recognition, to detect each harmonic component from distorted waves. To demonstrate the effectiveness of neural network, 5th, 7th, and 11th harmonics detection are done in a six-pulse bridge converter. From the simulation result it is seen that this

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method detects harmonic with mean squared error of 0.01. The principal advantage of this method is that it is possible to detect harmonics in real time.

2. Harmonics

A harmonic is defined as a sinusoidal component of a periodic wave having a frequency that is an integral multiple of the fundamental frequency. The theoretical maximum amplitude of each harmonic current produced by a converter is equal to that of the fundamental component divided by that harmonic order. For example, the 5th harmonic is equal to 20 percent of the load current; and the 7th harmonic is equal to 14.3 percent; and so on.

The commonest sources of harmonics and harmonic problems in power system is almost certainly the three-phase graetz bridge[3]. This is widely used in motor drives of all types as well as in HVDC transmission and such equipment as uninterruptible power supplies(UPS). This type of bridge is known as a six-pulse bridge, there being six pulses or ripples on the DC side voltage per period of the AC fundamental.

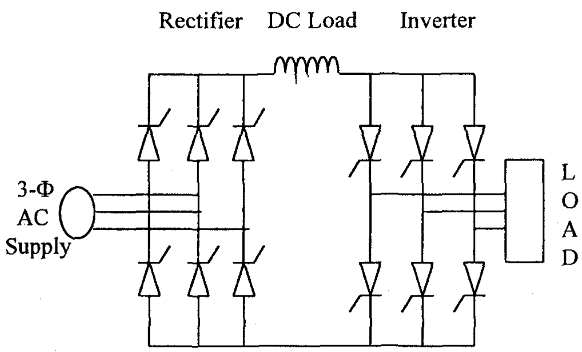

Figure 1: Six-pulse Bridge Converter connected to three-phase load

The static power converter generates harmonic currents the order of which is given by

$$n = kp \pm 1$$

where

n order of the harmonic

k an integer 1,2,3 ...

p number of pulses of the converter system

A six-pulse converter, as shown in Figure1 would generate harmonic currents of the order 5th, 7th, 11th, 13th, 17th, 19th, 23rd, 25th, etc. In the simulation six-pulse bridge converter is assumed as the harmonic load.

3. Harmonics Detection by Neural Network

3.1. Algorithm for Harmonic Detection

In order to detect each harmonic components in real time the pattern recognition ability of neural network is applied. The harmonic detection process is shown in Figure 2. In this

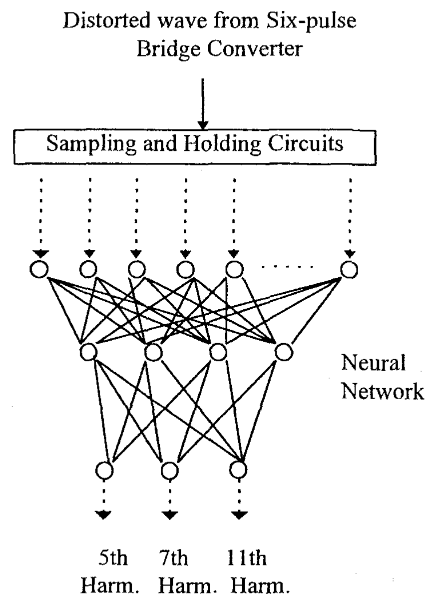

Figure 2 : Harmonic detection process

approach, the half cycle of the distorted wave is used as the input signal. This half cycle of the distorted wave is first sampled at 90 different points with regular interval of time axis. These sampled values are used as input signals of the multilayer feed forward neural network without any pre-processing. Multilayer perceptron(MLP) neural network for harmonic detection consists of three layer-Input layer, Hidden layer and Output layer. Input layer consists of 90 units, and units in the hidden layer are varied to get best performance of the network. Best performance of the network is obtained when 20 units are used in the hidden layer. The output layer of the network consists of units according to each order of harmonic to be detected. Since 5th, 7th, and 11th harmonics are detected, the output layer consists of 3 units. The outputs of the three units in the output layer represent the contents of 5th, 7th, and 11th harmonic components present in the original distorted wave.

3.2. Multilayer Perceptron(MLP) Network

Consider the multilayer perceptron network as shown in Figure 3[7].

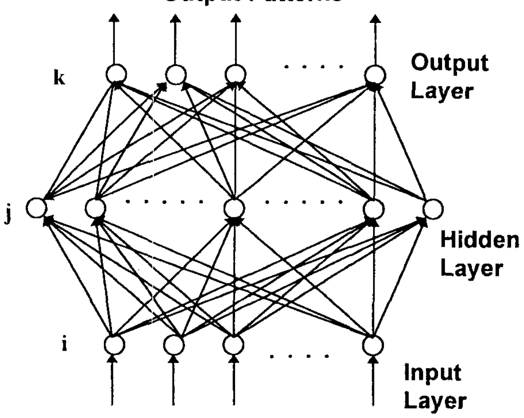

Figure 3 : A Multilayer Perceptron Neural Network

For each neuron j in the hidden layer and each neuron k in the output layer, the net inputs are given by

$$net_j = \sum_{i=1}^{NI} w_{ij} o_i \qquad j=1, 2, ..., NJ \qquad (1)$$

and

$$net_k = \sum_{j=1}^{NJ} w_{jk} o_j \qquad k=1, 2, ..., NK \qquad (2)$$

respectively. NI, NJ, NK represent number of nodes in the input layer, hidden layer, and output layer respectively. The neuron outputs are given by

$$o_i = net_i \qquad (3)$$

$$o_j = \frac{1}{1+e^{-(net_j, \theta_j)}} = f_j(net_j, \theta_j) \qquad (4)$$

$$o_k = \frac{1}{1+e^{-(net_k, \theta_k)}} = f_k(net_k, \theta_k) \qquad (5)$$

where net_i is the input signal from the external sources to node i in the input layer.

The MLP uses a gradient search technique to find the network weights that minimize a criterion function. The criterion function to be minimized is the Sum-of-Squared-Error criterion function:

$$J(w) = \sum_{p=1}^{P} J_p(w) \qquad (6)$$

where P is the number of training patterns, $J_p(w)$ is the total squared error for the pth pattern:

$$Jp(w) = \frac{1}{2} \sum_{k=1}^{NK} (t_{pk}-o_{pk})^2 \qquad (7)$$

where t_{pk} and o_{pk} are target output and generated output respectively at output node k for pth training pattern.

The connection weights between hidden unit j and output unit k are updated by using the following equations[7]

$$\Delta w_{jk}(p) = \mu\, \delta_{pk}\, o_{pj} + \alpha\, \Delta w_{jk}(p-1) \qquad (8)$$

where

$$\delta_{pk} = (t_{pk}-o_{pk})\, f'_k(net_{pk}) \qquad (9)$$

The learning rate(μ) and the momentum rate(α) give the relative weights for the present error and the error in the previous presentation. These factors affect the convergence rate of the learning process to a great extent. The connection weights between input unit i and hidden unit j can be updated by using similar equations:

$$\Delta w_{ij}(p) = \mu\, \delta_{pj}\, o_{pi} + \alpha\, \Delta w_{ij}(p-1) \qquad (10)$$

where

$$\delta_{pj} = f_j'(net_{pj}) \sum_{k=1}^{NK} \delta_{pk} w_{jk} \qquad (11)$$

The threshold θ is also updated in the learning process by using an equation similar to equation(10).

To make the learning process converge more rapidly than the conventional method the momentum rate is also updated after each iteration [8] using the following adaptation rule:

$$\begin{aligned} \alpha(n+1) &= 1.01\,\alpha(n) \quad ; \Delta Jn > 0 \\ &= 0.99\,\alpha(n) \quad ; \text{otherwise} \end{aligned} \qquad (12)$$

where $\alpha(n)$ is momentum rate at iteration n, and $\Delta J(n)= J(n-1)-J(n)$ with $J(n)$ being the sum of squared error at the end of nth iteration. This was done to expedite the convergence process so that the connection weights moved in the right direction.

3.3. Learning and Generalization

To make neural network enable to detect harmonics, it is required to use some representative distorted waves for learning. These distorted waves for learning are made by mixing the components of 5th, 7th, 11th harmonics in the fundamental component. In the distorted waves, the phase of the 5th and 11th harmonic components are kept same as that of the fundamental where as the phase of the 7th harmonic component are 180° out of phase of the fundamental. During learning process, 80 different input patterns of distorted wave are used. The content of each harmonic used in learning process is shown in Figure 4. The content of each harmonic component is used as the supervisor. In the learning process, neural network adjusts its structure such that it enables to produce the output as same as the supervisor. The learning is repeated until the difference between the network output and the supervisor is low enough. The difference is known as learning error which was set 0.01 in the computer simulation..

When the learning process is completed, it is desirable that the network should perform well on the actual problem which is not used in learning. The network is tested by using the data which was not used in learning process. As a result of generalization, the output signal of each output unit means the content of each harmonic present in the actual distorted wave.

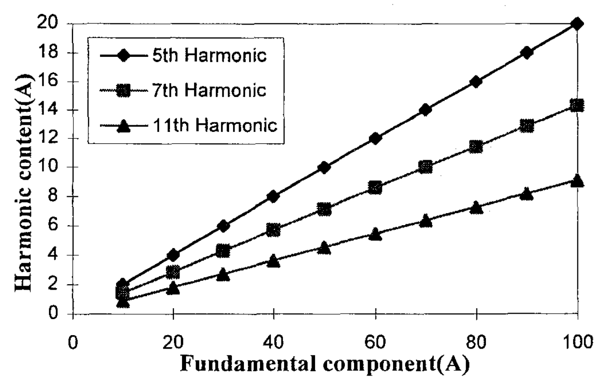

Figure 4 : Variation of harmonic contents with fundamental in learning process

4. Testing Results

At first 5th and 7th harmonic components, major harmonic components present in the six-pulse bridge converter, are simulated. At this time the network is learned by using the distorted wave consists of 5th, 7th harmonic components and fundamentals. 80 different input patterns of distorted wave are used during learning. During testing 25 different patterns are used which are completely different than those of the patterns used during learning process. Figure 5 represents the output of the 5th and 7th harmonic components for different hidden units in the hidden layer. From the result it is evident that though the expected outputs are approximately equal to the generated outputs , we have best performance when the number of hidden unit is 20. The network can determine the harmonic contents when the fundamental load current is between 0 to 100 Amp. The variation of Mean Squared Error(MSE) is also shown on Figure 6 .

Later the network is trained by using the distorted waves formed by the combination of 5th, 7th, 11th and fundamental. At this time the output unit is consisted of three units in order to detect 5th ,7th, and 11th harmonic component separately. The 25 testing patterns used in testing the network is quite different from the patterns used in learning the network. The output of the 5th, 7th, 11th harmonic contents are presented on Figure 7 . From Figure 7 it is absolutely obvious that the network can detect the harmonic in a six-pulse bridge converter when the fundamental load current varies between 0 and 100 Amp.

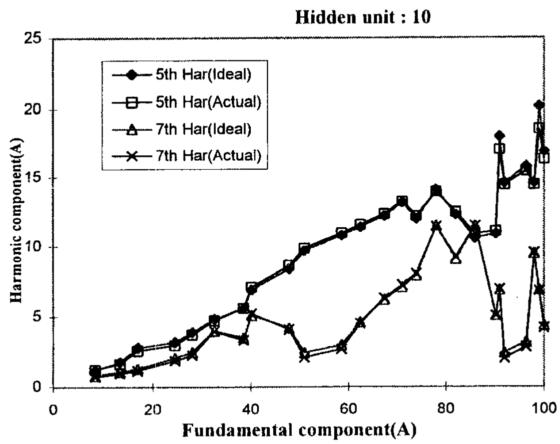

Figure 5(a) : 5th and 7th Harmonic Detection

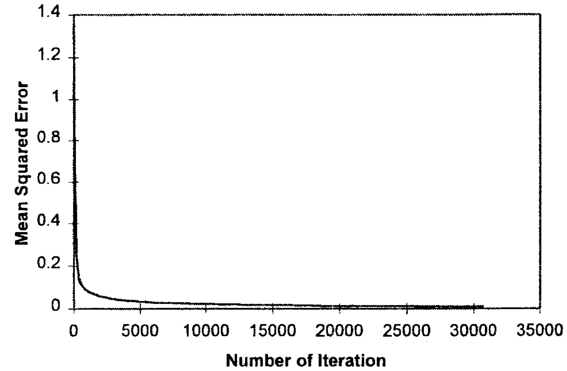

Figure 6 : Variation of Mean Squared Error with Iteration

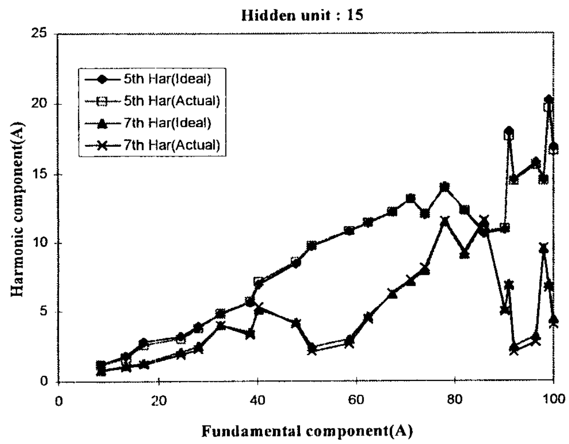

Figure 5(b) : 5th and 7th Harmonic Detection

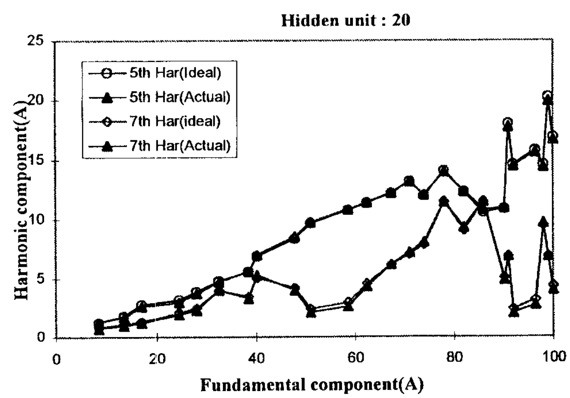

Figure 5(c): 5th and 7th Harmonic Detection

5. Digital computer analysis

A digital computer program has been developed to learn and test the Multilayer Perceptron Network(MLP) for harmonic detection. Calculations are done using an IBM PC compatible with following system configuration:

Processor type: 80486-DX4

Numeric coprocessor: 80487

Basic memory size: 640 Kbytes

Extended memory size: 7168 Kbytes

Hard drive: C: 341 Mbytes

Clock speed: 66 MHz

6. Conclusions

This paper has used the neural network approach of the detection of harmonic components in a six-pulse bridge converter. In neural network approach only half cycle of the distorted wave is used as the input signal whereas in the conventional approach more than two cycles of the input signal is required to detect component of harmonics. Therefore, it is possible to determine the harmonic components 4 times faster than the conventional approach. Though the complexity of the circuit is directly proportional to the number of samples of the input signal, neural network is an effective

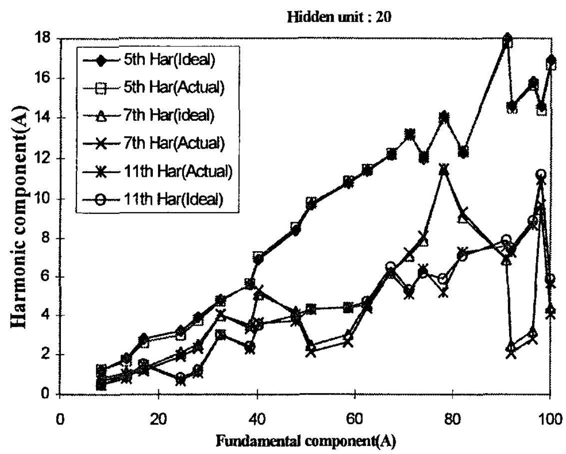

Figure 7: Detection of 5th, 7th, and 11th Harmonics

method where high speed of estimation is required.

The detection of 5th, 7th, 11th harmonics has been verified by means of the simulation. To have the best performance of the network number of units in the hidden layer is varied. From the simulation result it is seen that, the network has good generalization which means that it performs well on the actual problem outside the training data. For on-line estimation of harmonic components, neural network is an effective, efficient and simple method.

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