Araştırma Makalesi / Research Article

HARMONIC DETECTION USING FEED FORWARD ARTIFICIAL NEURAL NETWORKS

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ABSTRACT

In this study, the method to apply the feed forward neural networks with two different numbers of hidden layers for harmonic detection process in active filter are described. We have simulated the distorted wave including 5th, 7th, 11th, 13th harmonics and used them for training of the neural networks. The distorted wave including up to 25th harmonics were prepared for testing of the neural networks. Feed forward neural networks have been used to recognize each harmonic. The results show that these neural networks are applicable to detect each harmonic effectively. The results of the neural network with two hidden layers are better than that of the other.

Keywords: Feed forward artificial neural networks, active filter, harmonic detection, hidden layer.

İLERİ BESLEMELİ YAPAY SİNİR AĞLARI KULLANARAK HARMONİK TANIMA

ÖZET

Bu çalışmada, aktif filtre işlemlerinde harmonikleri tanıma için iki farklı gizli katman ile ileri beslemeli yapay sinir ağları metodu tanımlanmıştır. Distorsiyonlu dalga içerisinden 5.,7.,11. ve 13. harmoniklerin simülasyonu yapıldı ve bunlar sinir ağlarının eğitimi için kullanıldı. Sinir ağının testi için distorsiyonlu dalga içerisinden 25. harmoniğe kadar hazırlandı. İleri beslemeli sinir ağları harmoniklerin her birini tanımak için kullanılmıştır. Sonuçlar yapay sinir ağlarının harmonikleri tanımada etkili bir şekilde kullanılabileceğini göstermektedir. Sonuç olarak iki gizli katmanlı sinir ağı diğerinden daha iyidir.

Anahtar Sözcükler: İleri beslemeli yapay sinir ağları, Aktif filtre, Harmonik tanıma, Gizli katman.

1. INTRODUCTION

Power quality has received increased attention in recent years with the widespread application of nonlinear loads employed in advanced solid-state power switching devices in a multitude of industrial and commercial applications. These devices draw non-sinusoidal load currents consisting primarily of lower-order 5th, 7th, 11th, and 13th harmonics that distort the system power quality. [1,2]. With the widespread use of harmonic-generating devices, the control of harmonic currents to maintain a high level of power quality is becoming increasingly important. Harmonic

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standards (e.g. IEEE 519 and IEC 555) have been developed to address limits of allowable harmonics [3].

An effective way for harmonic elimination is the harmonic compensation by using active power filter. Active power filter detect harmonic current from distorted wave in power line, then generates negative phase current as same as detected harmonic to cancel out the harmonic in power system. Using the feed forward neural networks (FFNNs) is one of the methods for harmonic detection [4-6]. In this study, the methods to apply the feed forward neural networks with two different numbers of hidden layers for harmonic detection process in active filter are described. The feed forward neural networks were also used for comparison. The distorted wave including 5th, 7th, 11th and 13th harmonics are used to be input signals for these neural networks at the training state. The output layer of network is consisted of 4 units in according to each order of harmonic. By effect of learning representative data, each component of harmonic is detected to each according unit. That means neural network structures can decompose each order of harmonic and detect only harmonic without fundamental wave in the same time. Since fourier transformation very intensive to concerned expression mathematics, have been used Artificial Neural Network.

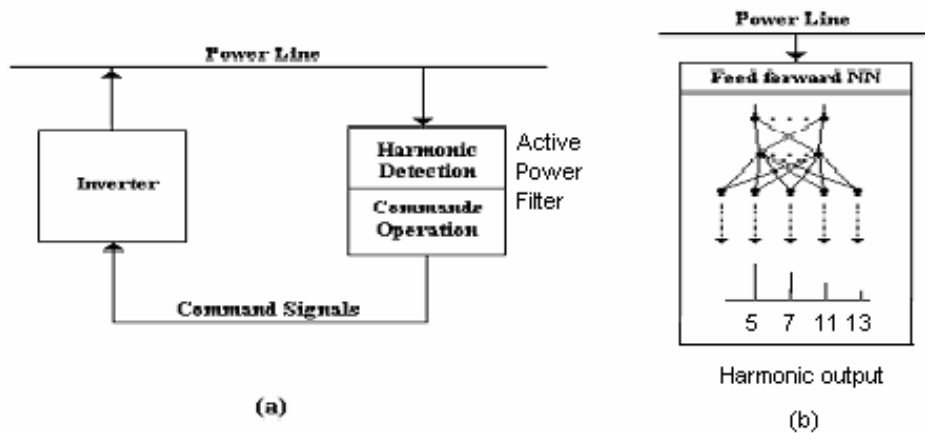## 2. FEED FORWARD NEURAL NETWORKS FOR HARMONIC DETECTION

Figure 1. Concept of active power filter (a), process of harmonic detection in active power filter using feed forward neural networks (b)

Figure 1.a depicts the concept of active power filter. Figure 1.b shows the process of the harmonic detection in the active power filter using the FFNNs. Because of non-sinusoidal load currents consisting primarily of lower-order 5th, 7th, 11th, and 13th harmonics that distort the system power quality, we consider detection 5th, 7th, 11th, and 13th harmonics. We used the FFNNs as shown in Figure 2. These networks are multilayer networks (input layer, hidden layers, and output layer). The hidden layer neurons and the output layer neurons used are nonlinear sigmoid activation functions. Equations which are used in the neural network model are given in equations (1), (2), and (3).
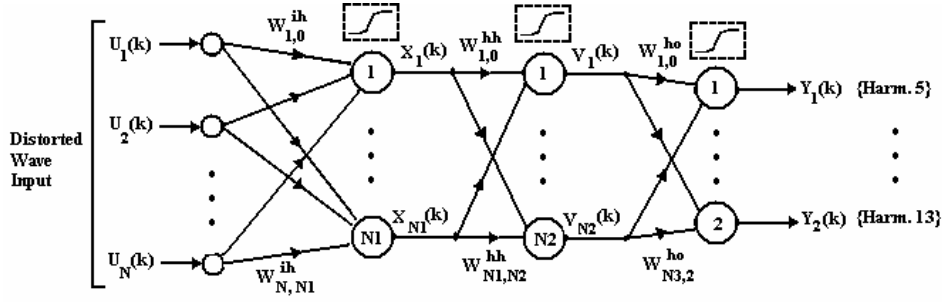
Figure 2. Feed forward neural network structures with two hidden layer for harmonics detection

Outputs of the first hidden layer neurons are,

$$X_j(n) = 1 \bigg/ \left(1 + \exp\left(b_j^{ih}(n) + \sum_{i=1}^{N} W_{ij}^{ih}(n)U_i(n)\right)\right) \tag{1}$$

Outputs of the second hidden layer neurons are,

$$V_j(n) = 1 \bigg/ \left(1 + \exp\left(b_j^{hh}(n) + \sum_{i=1}^{N1} W_{ij}^{hh}(n)X_i(n)\right)\right) \tag{2}$$

Outputs of the network are,

$$Y_l(n) = 1 \bigg/ \left(1 + \exp\left(b_l^{o}(n) + \sum_{j=1}^{N2} W_{jl}^{ho}(n)V_j(n)\right)\right) \tag{3}$$

where $b_j^{ih}(n)$ are the biases of the first hidden layer neurons, $b_j^{hh}(n)$ are the biases of the second hidden layer neurons, $b_l^{o}(n)$ are the biases of the output layer neurons, $W_{ij}^{ih}(n)$ are the weights from the input to the first hidden layer, $W_{ij}^{hh}(n)$ are the weights from the first hidden layer to the second hidden layer, $W_{jl}^{ho}(n)$ are the weights from the second hidden layer to the output layer, $U_j(n)$, $i = 1$ to N are the sensor inputs, and $Y_l(n)$, $l = 1$ to $N3$ are outputs for concentrations. In this study, 128 is used as N, 4 is used as N3, and five different values which are 10, 20, 30, 60, and 90 are used as N1 and N2. The network with one hidden layer was also used for comparison.

3. TRAINING OF THE NETWORKS

In this paper, BP learning rules with momentum and adaptive learning rate are used to adjust the weights and biases of networks to minimize the sum-squared error of the network [7].

In order to make neural network enable to detect harmonics from distorted wave, it is necessary to use some representative distorted waves for learning. These distorted waves are made by mixing the component of the 5th, 7th, 11th, and 13th harmonics in fundamental wave. For this purpose, 5th harmonic up to 70%, 7th harmonic up to 40%, 11th harmonic up to 10% and 13th harmonic up to 5% were used and approximately 2500 representative distorted waves were generated for training process.

The relative phase shifts of harmonics will vary with system conditions. So, the relative phase shifts must be taken according to system. For the recognition of full range relative phase

shifts, 360^0. phase shift range must be used for the neural network training. For this purpose, neural network structures must be modified using additional four output neurons which will be used to recognize the relative phase shifts of the 5th, 7th, 11th, and 13th harmonics. This recognition also requires additional training data. That is, as an example, if 5^0. step is used for phase shift training, 72 data ($360/5 = 72$) must be used per harmonic. So for 5th, 7th, 11th, and 13th harmonics, approximately 25 million ($72 \times 72 \times 72 \times 72$) data combination must be taken in the full range training and this data must be combined with harmonic coefficient data (2500×25 million). This enormous data will increase the neural network training time. Fortunately, estimation time will not increase because this data is used for only network wight updates during training process. For decreasing the neural network training time, coefficients ranges and relative phase shift ranges of the harmonics can be selected according to the system. This decrease the required data size and time for training[8].

During the training process, the distorted waves were used for recognition. As the result of recognition, output signal from each output unit means the coefficient of each harmonic which is included in the input distorted wave and these harmonics are eliminated from the distorted wave. Equations which used in the elimination process are shown in (4), and (5).

$$V_f(t) = V_d(t) - \sum_h V_h(t) \tag{4}$$

$$V_h(t) = A_h Sin(2\pi h f t + \theta) \tag{5}$$

where, $V_f(t)$ is active filtered wave, $V_d(t)$ is distorted wave, $h = 5,7,11,13$, A_h are coefficients of lower-order 5th, 7th, 11th, and 13th harmonics, $f = 50$ Hz, θ is phase angle and equal to zero in this study.

4. THE QUALITY OF POWER SYSTEM WAVES

The common index used to determine the quality of power system currents and voltages are total harmonic distortion (*THD*) [1,10], which is defined as

$$\mathrm{THD} = \sqrt{\frac{\sum_2^\infty V_h^2}{V_1^2}} \tag{6}$$

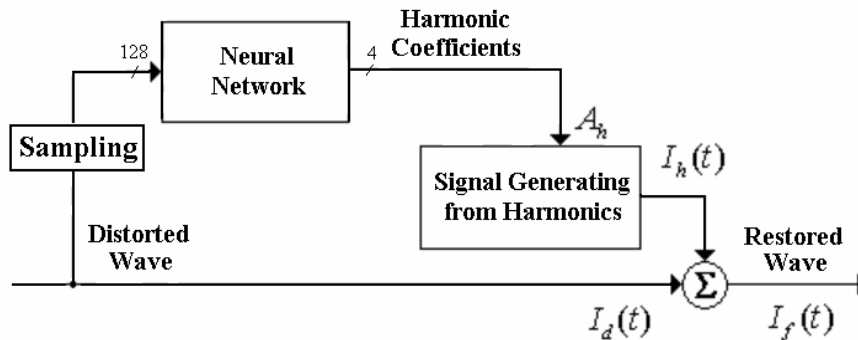where, V_h represents the individual harmonics and V_1 is the fundamental component of load wave.

Figure 3. Process for restoring wave

Input Artificial Neural Network 128 sample signals have been given and output Artificial Neural Network 5th, 7th, 11th and 13th harmonics existed. With distorted wave, 5th, 7th, 11th and 13th harmonics have been mixed and by Artificial neural network distorted wave have been detected.

5. RESULTS AND CONCLUSIONS

The non sinusoidal load currents also consist at higher order harmonics such as 17th, 19th, etc., but they do not carry any significant current [1]. So, for the performance evaluation of the neural network structures, 5th harmonic up to 70%, 7th harmonic up to 40%, 11th harmonic up to 10% and 13th harmonic up to 5%, 17th harmonic up to 5%, 19th harmonic up to 2.5%, 23rd harmonic up to 2.5%, 25th harmonic up to 2% were used [9] and approximately 250 representative distorted waves were generated as a test set.

For the training and test processes, input signals of the neural networks are the amplitudes of one period of distorted wave. The amplitudes are taken 128 point at regular interval of time axis. The amplitudes are used to be input signals of the neural networks without any pre processing. At the training phase, the higher order harmonics such as 17th, 19th, etc., are ignored for *THD* calculations.

As a first step, five different numbers of hidden layer neurons were used to determine the effects of hidden layer neurons. The comparative the training results of the feed forward neural networks with one hidden layer can be seen in Figure 4. Optimum number of hidden layer neurons for the feed forward neural networks is approximately 20 as seen in the same figure. For all comparisons, the numbers of iterations for training were taken as 50000.
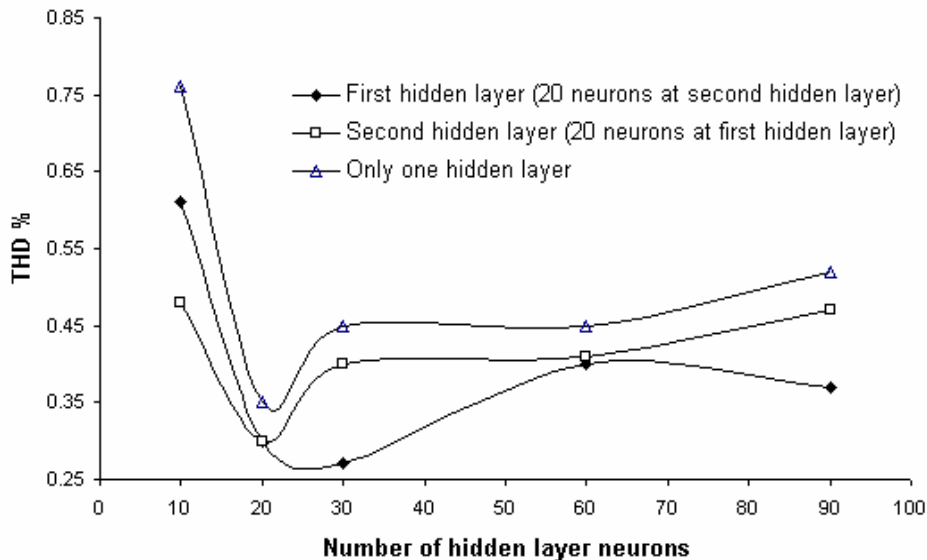

Figure 4. Training results of feed forward neural networks with one and two hidden layers

Figure 4 also shows the training results of all of the feed forward neural networks with two hidden layers. As seen in this figure, the results of FFNN with two hidden layers are better then that of FFNN with one hidden layer.

After the training process is completed, the general distorted waves (test set) were used for recognition. As the result of recognition, output signal from each output unit gives the

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coefficient of each harmonic which is included in the input distorted wave and these harmonics are eliminated from the distorted wave. Table 1 shows the average *THD* values of restored waves obtained by using the feed forward neural networks for the test set.

The recommendation IEEE 519 allows a total harmonic distortion (*THD*) of 5% in low-voltage grids [8]. As seen in the table 1, average *THD* value is 46.36% before compensation and obtained average *THD* values are less then 5% after compensation for all networks. These *THD* values are suitable to the recommendation IEEE 519. 3.65% of these *THD* values come from the higher order harmonics such as 17th, 19th, etc which are not used in the training. This shown that a further improvement is possible. The *THD* values obtained by using FFNN with two hidden layers are better than the *THD* values obtained by using FFNN with one hidden layer. The sample source wave and the restored waves are shown in Figure 5.

Table 1. Average *THD* values

Numbers of hidden layers	Numbers of neurons at first hidden layer	Numbers of neurons at second hidden layer	Average *THD* (%)
Before compensation			46.36
1	10	-	3.73
	20	-	3.66
	30	-	3.67
	60	-	3.67
	90	-	3.68
2	10		3.70
	20		3.66
	30	20	3.66
	60		3.67
	90		3.67
		10	3.68
		20	3.66
	20	30	3.68
		60	3.67
		90	3.67
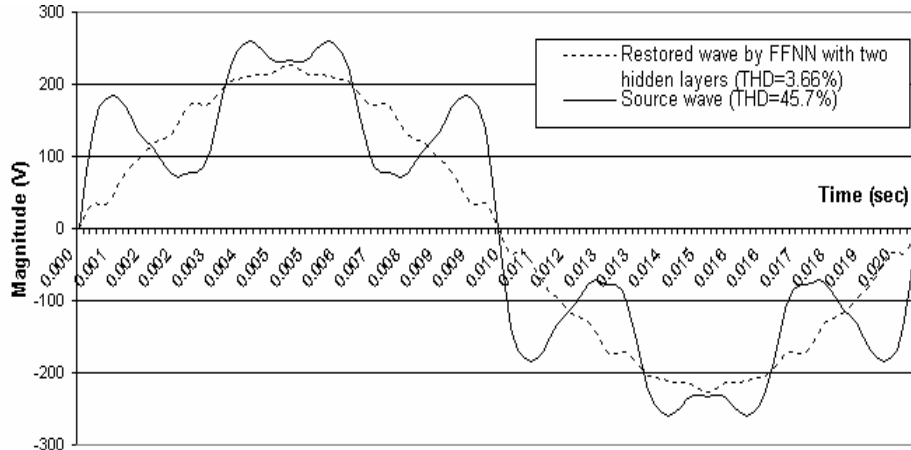
Figure 5. Sample source and restored waves (by FFNN with two hidden layers)

As the result, the possibility of the feed forward neural networks to detect harmonics is confirmed by compensating the distorted waves and it can be said that the feed forward neural networks are effective to use for active filter.

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