Three Phase Series Active Power Filter Based Adaptive Linear Neuron (ADALINE) To Overcome Voltage Harmonics In Power Systems

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Abstract

Voltage harmonics in the power system can interfere with the work of equipment and reduce the quality of electrical power. This is overcome by using a Series Active Power Filter which is a three-phase Voltage Source Inverter (VSI). The artificial neural network compensation method is used as the control circuit of the Series Active Power Filter to generate a reference voltage from the harmonic distorted and unbalanced source voltage. The artificial neural network determines the amplitude of the sine and cosine components of the reference voltage. Computer simulation results show that the three-phase Series Active Power Filter with artificial neural network compensation method is effectively able to remove harmonics and produce a sinusoidal and balanced three-phase voltage that will be received by the load..

Keywords: *Series Active Power Filter, Harmonics and Artificial Neural Networks.*

I. INTRODUCTION

Ideally, the generated AC voltage waveform is a smooth sinusoidal wave. However, facts in the field show that the voltage waveform is not as smooth as desired. There are three-phase voltages that are distorted by harmonics and also unbalanced. This will reduce the quality of electrical power because the load will receive a voltage that is not ideal. Equipment operation will also be disrupted or damaged.One way to reduce harmonics from the source is to use a filter. To make a filter, passive components (R, L, C) or active components (transistors) can be used. The use of passive filters to solve the problem of harmonics has many disadvantages, including that it can only be used to filter one harmonic frequency (single tune). This means that it requires a number of filters to overcome a number of harmonics. This filter is not flexible in dynamic conditions and can cause parallel resonance in the power system, has the characteristics of an L-C filter which is strongly influenced by the system impedance which is difficult to know exactly because it can change against the configuration of the power system.

Difficult to know exactly because it can change against the network configuration. To overcome the weaknesses caused by Passive Power Filter [1][2][3][4][5], the Active Power Filter (APF) is used. There are 2 types of APF, namely series type and parallel type [6][7][8][9]. The series type works to compensate the voltage while the parallel type to compensate the current. Therefore, to overcome the problem of voltage harmonics from the source, the use of Series Active Power Filter will be investigated.There are many compensation methods used to control APF [10][11][12][13]. It is expected that the method used can help generate an appropriate anti-harmonic voltage or current to be injected into the disturbed system. Nowadays, artificial intelligence techniques, especially artificial neural network techniques [14][15] are being applied to detect harmonics. Therefore, this paper will discuss the application of a three-phase APF Series that works by compensating the harmonic voltage and also the unbalance of the three-phase source in the power system with the artificial neural network (JST) method so that the load receives a sinusoidal and balanced voltage source.

II. ACTIVE POWER CIRCUIT CONFIGURATION FILTER

Series APF is an inverter that is connected in series between the power source and the load with the help of matching transformers so that it can compensate for harmonic voltage distortion (Figure 1). The inverter used is a Voltage Source Inverter (VSI) consisting of 6 IGBTs with anti-parallel diodes. On the DC side a capacitor is installed and on the AC side an L-C configuration is installed as a high-pass filter [6].

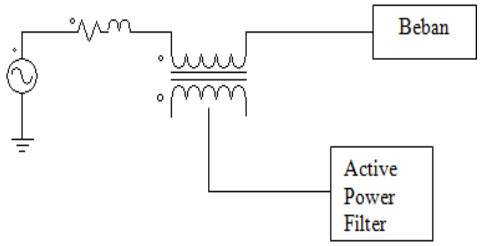

Fig 1. Series APF circuit

The VSI is operated by controlling the output voltage in such a way that it matches the desired reference voltage. To see if the output voltage of the inverter is equal to the reference voltage, a voltage sensor is installed on the output (AC) side of the VSI. The output of the voltage sensor is compared with the reference voltage. If the inverter voltage is equal to the reference voltage then the error is zero. The error signal is summed with the reference voltage and then compared with the triangular carrier signal to produce a Pulse Width Modulation (PWM) signal to continue triggering the IGBT.The reference voltage which is the harmonic component is obtained from the difference between the distorted source voltage and the fundamental voltage. The process starts from detecting the three-phase source voltage that contains harmonics and is also unbalanced using a voltage sensor. This voltage is then processed to separate The fundamental component and the harmonic component using the JST method. The output of the JST is the fundamental voltage.This harmonic component is used to control the output voltage of the VSI. Thus the VSI produces an anti-harmonic voltage that opposes the harmonic voltage generated by the source so that the voltage supplied to the load becomes sinusoidal. Series APF diagram configuration can be seen in Figure 2.

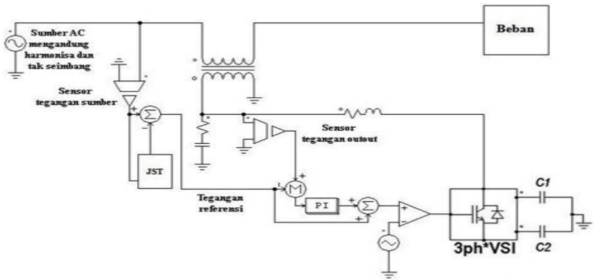

Fig 2. Series Active Power Filter Configuration

In order for the circuit to work stably and the compensation to work properly, the DC side voltage of the VSI must be greater than the peak-to-peak voltage on the AC side. The voltage on the DC side must be maintained constant using PI (Proportional Integral) control. Otherwise, the losses in the circuit will cause the DC-bus voltage to decrease [6].

III. HARMONIC COMPENSATION WITH ARTIFICIAL NEURAL NETWORK METHODS

3.1. Basic Principles of Artificial Neural Network Control

Some periodic signals can be described as the sum of sine and cosine components. This concept is the basis for designing the JST architecture in estimating the harmonic and unbalance components in the three-phase voltage source. The source that generates voltage harmonics can be described as:

$$V(t) = \sum (a_n \sin(n\omega t) + b_n \cos(n\omega t)) \quad (1)$$

Where an and bn are the amplitudes of the sine and cosine components of the source voltage harmonics. The source voltage harmonics can be expressed by the equation:

$$V(t) = W \cdot X(t) \quad (2)$$

where is the weight matrix:

$$W = [a_1, b_1, a_2, b_2 ... a_n, b_n]$$

Based on "equation (4)", the architecture of the compensation artificial neural network can be described as follows:

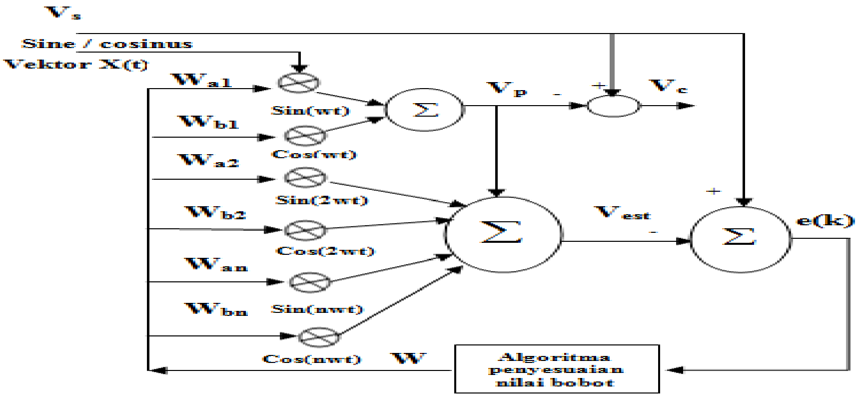

Fig 3. Artificial Neural Network Architecture

Basically, the JST architecture as shown in Figure 2 is the ADALINE (Adaptive Linear Neuron) artificial neural network developed by Widrow and Marcian Hoff using a Single Layer Network consisting of one input layer and one output layer.Figure 2 shows a JST that has n pairs of voltage inputs consisting of sine and cosine inputs and divided into fundamental and harmonic components. The weight (W) of each input is set such that it resembles the amplitude of the fundamental voltage and harmonic voltage.With repeated adjustments to the weight values, the JST undergoes a learning process. At each learning, the voltage input (VS) will be processed and the estimated voltage output (Vest) will be produced. The difference between the network output (Vest) and the target (Vs) is the error e (k) that occurs. The network will modify the weights according to the error. Thus, when e(k) has become zero, the estimated voltage resembles the input voltage.The output of the JST is the fundamental voltage (VP). From the output of the JST, the reference voltage Vc can be determined to be injected into the Series Active Power Filter which is obtained from the reduction of the harmonic source voltage Vs with the estimated fundamental voltage VP.

3.2. Widrow-Hoff Training Algorithm for Artificial Neural Network in Series Active Power FilterThe learning process performed using the Widrow-Hoff algorithm aims to minimise the magnitude of the error e(k) between the source voltage Vs(t) and the estimated voltage Vest, where e(k) can be expressed by the equation below:

$$e(k) = V_S - V_{est}$$

The reference voltage Vc(t) of the Active Power Filter will be obtained based on the results of the weight calculation. The basic principle of weight calculation with JST algorithm can be described as follows:

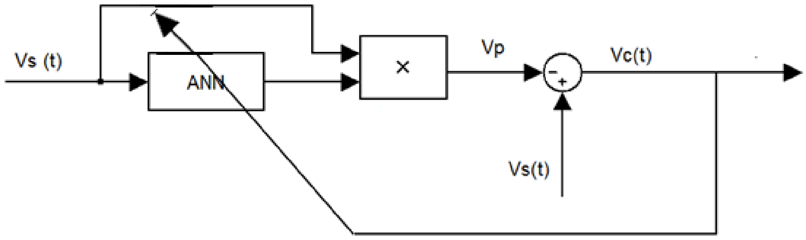

Fig 4. Artificial Neural Network Weight Calculation

The artificial neural network in Figure 4 consists of a neuron, where the neuron weight is expressed as W. The input of the system is the generated source voltage Vs(t), while the output is the fundamental voltage VP(t) and the output of the system is the reference voltage Vc(t).

Based on the Widrow-Hoff algorithm, "equation (6)" is used to update the weights.

$$W(n) = W(n-1) + \eta V_{cr} V(n-1) \qquad (6)$$

where :

$\eta V_{cr} V(n-1)$ = voltage change

η = *learning rate*, $0 < \eta < 1$

$V_{cr}(n) = V_S(n) - W(n) V_S(n)$

The learning process of the JST network with the Widrow-Hoff method is used to obtain the value of the weights with a certain learning rate. Finally, the reference voltage of the filter can be calculated using "equation (7)"

$$V_C(t) = V_S(t) - WV(t) \quad (7)$$

Based on "equation (6)" and "equation (7)", the control circuit modelling in Matlab Simulink to obtain the weight value W with Widrow-Hoff algorithm can be illustrated in Figure 5.

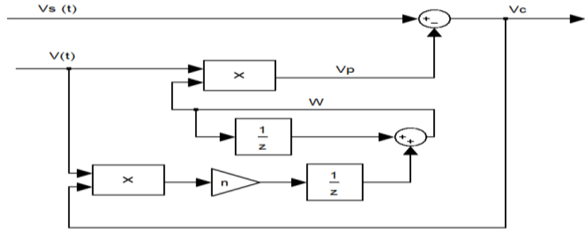

Fig 5. Compensation circuit VC(t)

IV. RESULTS AND DISCUSSION

To prove the working of Series Active Power Filter with JST compensation method, the circuit is simulated using a combination of PSIM and Matlab Simulink software. The source, load and inverter circuits are modelled in PSIM while the compensation control uses Matlab Simulink. The source containing harmonics and unbalance can be seen in Figure 6 and Figure 7.

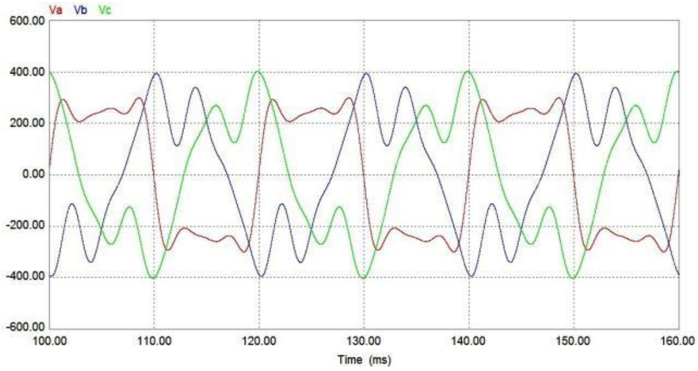

Fig 6. A three-phase unbalanced source generating harmonics

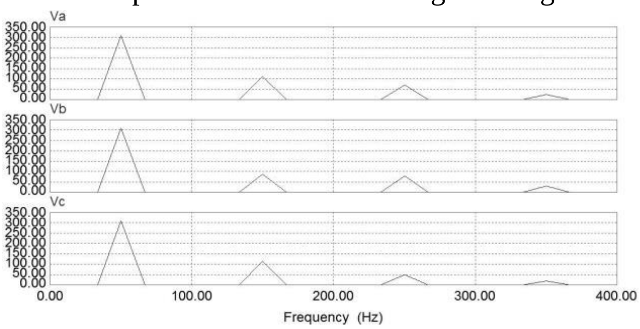

Fig 7. Harmonic spectrum of a three-phase source

Figure 8 shows the signal reading by Matlab Simulink for the input of the harmonic voltage source (VS) phase A that enters the JST system:

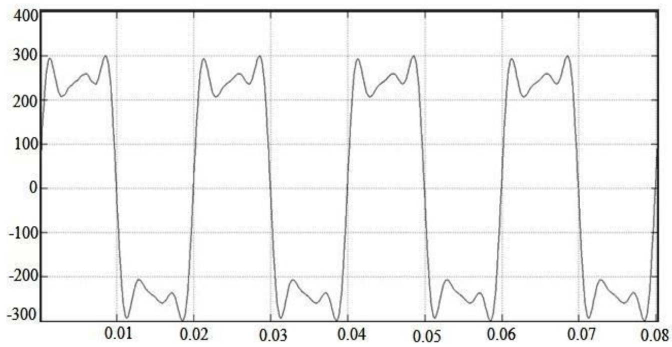

Fig 8. Input voltage source harmonics phase A

The estimated voltage is the total voltage of the sine and cosine signals generated by the JST circuit which is expected to produce the same voltage as the input harmonic voltage source with a gain (learning rate) of 0.2 (Figure 9).

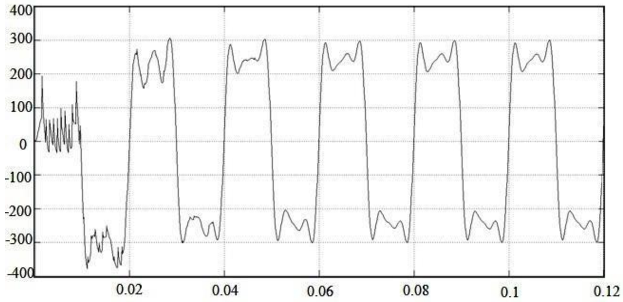

Fig 9. Voltage estimation (Vest) generated by the artificial neural network

Figure 9 shows the output of the JST learning process. It takes about 0.05 seconds to produce an estimated voltage that is in steady state and resemble the input voltage of the harmonic source (Vs). By looking at Figure 6 and Figure 7, Figure 10 shows the error resulting from the comparison of Vs and Vest:

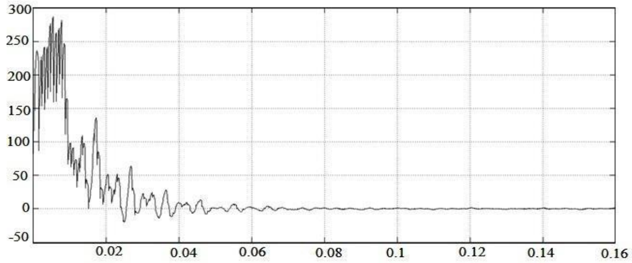

Fig 10. Error e(k)

The simulation produces an error with a fairly high ripple from t = 0 seconds to t = 0.04 seconds, but after that the error is getting closer to zero due to the learning process. Since the estimated voltage already resembles the phase A harmonics voltage input, the fundamental voltage output which is the JST output can be determined as shown in Figure 11:

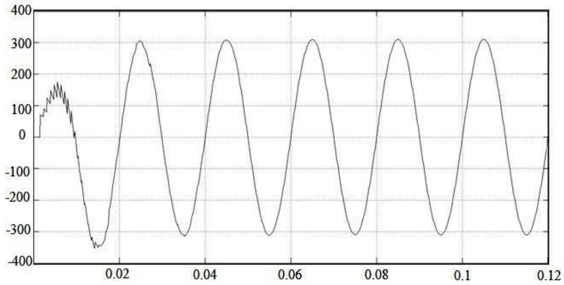

Fig 11. Fundamental voltage (VP)

The fundamental voltage is identical to the fundamental voltage of phase A generated in the power grid system with Vrms = 219.4 Volts and Vpeak = 310.48 Volts.The next process is to determine the reference voltage for VSI which is the harmonic voltage through the comparison between the three-phase voltage source containing harmonics and unbalanced with the fundamental voltage generated by the JST can be seen in Figure 12.

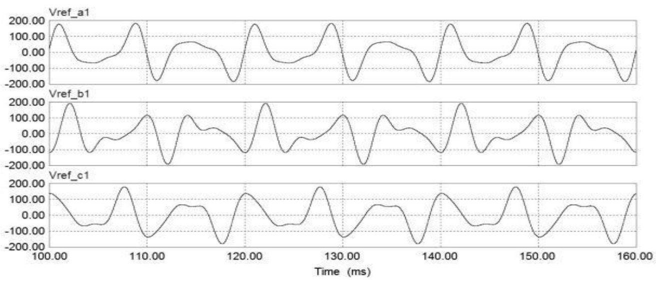

Fig 12. Three-phase reference voltage (Vc)

This reference voltage is compared to the triangle signal to generate a PWM to trigger the IGBT. This process continues until the VSI output voltage increasingly resembles the reference voltage. This output voltage is then injected into the system through a transformer connected in series with the system. Figure 13 shows the output voltage of the VSI. The voltage waveform resulting from Series APF compensation and its harmonic spectrum are shown in Figures 14 and 15. It can be seen that the load voltage is sinusoidal and balanced with Vrms = 218.9 Volts.

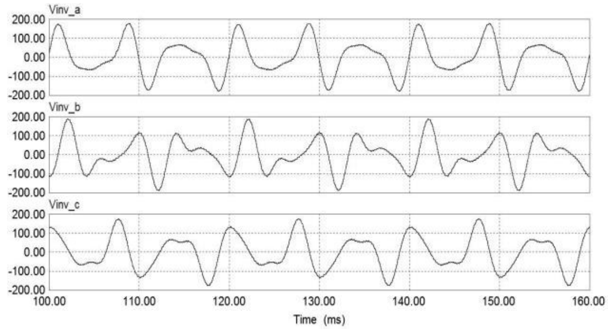

Fig 13. VSI output voltage injected into the syste

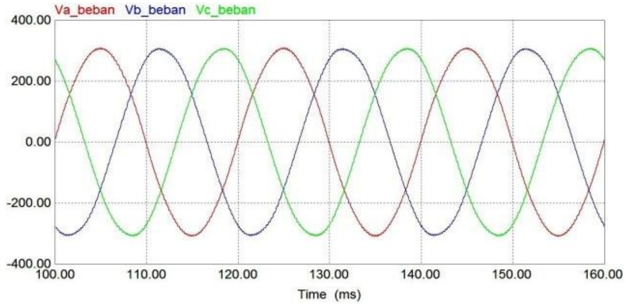

Fig 14. System voltage after compensation

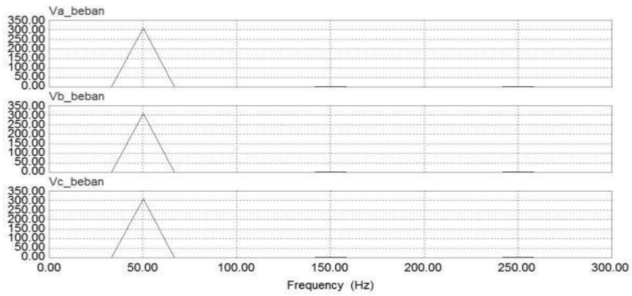

Fig 15. Harmonic spectrum after compensation

V. CONCLUSION

The components of the Artificial Neural Network (ANN) circuit both from the sine cosine input source and the learning rate, the parameters are determined manually, and when the harmonic source voltage is injected into the artificial neural network as a comparison, the artificial neural network flexibly adapts to the changes, through the learning process on the weights W. In addition, by adjusting the gain (learning rate), time delay, and amplitude of the input sine cosine V(t) affects the estimated voltage, with the right settings the estimated voltage resembles the harmonic source voltage.In addition, by adjusting the gain (learning rate), time delay, and amplitude of the sine cosine input V(t) affects the estimated voltage, with the right settings, the estimated voltage resembles the harmonic source voltage. The more the harmonic source voltage resembles, the smaller the resulting error and is expected to equal zero. When the error is equal to zero, the desired reference current (pure harmonic current) is obtained which will be injected into the VSI.Simulation results show that the three-phase Series Active Power Filter circuit with the Artificial Neural Network compensation method is effectively able to overcome the distorted and unbalanced three-phase voltage source harmonics.

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