Artificial Neural Network Controller for Single-Phase Active Power Filter

Juwairiah Mohd Janggi, Wahyu Mulyo Utomo, Mohd Abdul Talib Mat Yusoh, Mohd Ezwan Mahadan,
Shamsul Aizam Zulkifli, Jumadril JN
Faculty of Electrical and Electronic Engineering, University Tun Hussein Onn Malaysia,
Johor, Malaysia
juwaijanggi@gmail.com

***Abstract*— This paper shows the conception and simulation of a single-phase shunt active power filter for harmonics and power factor compensation of uncontrolled rectifier with battery load. The objectives of this project are to minimize the harmonic distortion and intensity the power factor of the single-phase system with battery charger load. The design of shunt active power filter is verified using the simulations in Matlab/Simulink. Shunt active harmonic filter was controlled by the neural network method where it applied the proportional and integral method in order to adjust the direct current link voltage and the hysteresis current controller is employed to generate signals for switching the voltage source inverter. The error signal has been compensated using the controllers. The reference filter currents signal is obtained by subtracting the line current with the compensated signal from the controller. This reference current is fed to the hysteresis current controller and compare with the sensed filter currents to obtain the switching signal for active power filter. Simulation results are acquired with the conventional PI controller and ANN controller.**

Keywords*— *Shunt APF; PI controller; ANN controller; Total Harmonic Distortion (THD); Voltage Source Inverter(VSI);

I. INTRODUCTION

In recent years, the widely used by electronic devices such as personal computer, smart phones, tablet, or even electric vehicle leads to employment of battery chargers. The battery charger is a device used to store energy in a battery by forcing current through it. In general, it consists of one diode to convert AC source to DC source. A diode is a nonlinear device which generates harmonic in the power source. The presence of harmonics in the system leads to various problems and poor power quality. The application of passive filter to overcome this problem causes a few problems such as it is large in size and has fixed compensation characteristics and they may fall in series resonance with the source impedance [1].

Active power filter (APF) offers a better solution for harmonic problems over passive filter. The performance of the filter depends on the topology and the type of inverter [2]. The topology of the APF can be in shunt connected or in series connected.

Generally shunt APF is designed to reduce the total harmonic distortion which eliminate the majority of the harmonic current orders and improve the power factor closed into the unity. Based on standard IEEE 1159-1995, definition of harmonic source are the frequencies of voltages or currents are multiples with the frequency of the source system [3]. Thus the APF in shunt connected uses a power electronic device to produce current with 180 degree phase shift to the harmonic current to eliminate the harmonic current distortion.

This study has been focused on minimize the total harmonic distortion (THD) and improving power factor on the AC supply side of the single-phase system with nonlinear load. The APF be made up of voltage source inverter (VSI), inductor filter and the DC link capacitor. Voltage control loop (VCL) and current control loop (CCL) are two main of controller used to design the shunt active power filter. For VCL, the ANN controller is used to maintain the voltage of the capacitor instead of classical PI controller to produce harmonic current compensation and reactive power to the nonlinear load. The filter more effective if applied the intelligent controller to conduct the DC bus capacitor. In the CCL, hysteresis current control has been used to generate switching signals for the inverter. Hysteresis control technique is the most popular one for APF applications. Trends and prospects in the system are presented and simulation results are carried out by using MATLAB/Simulink software.

II. SINGLE PHASE SHUNT ACTIVE POWER FILTER

The single phase shunt APF has been applied, where it consists of a capacitor, the bridge power switches and series inductor line shows in the Fig.1. The basic operation of the filter is providing the harmonic compensation current with the same magnitude but opposite in phase to the system [4]. Hence the harmonics generated by the load is canceled out by the compensation current from the filter. This cause the source is forced to be in its original current form with reduced harmonic distortions.

The objective of APF with shunt connection is to provide a harmonic compensation current, i_f using the relationship as given in (1), where i_s is the current source which it in phase with the source voltage at the fundamental frequency while i_L is the load current which it has a harmonic current.

A. Reference Compensations Current

Generally, the performance of shunt active power filter depends on many factors, such as the system configuration and overall control system design, but most importantly is the selected reference generation scheme [5]. If the voltage supply, V_{in} for this system is an ideal sinusoidal waveform, the value of the instantaneous voltage can be illustrated as in (2).

$$i_f = i_L - i_s \tag{1}$$

$$V_{in} = V_s sin(wt) \tag{2}$$

$$u(t) = \frac{V_{in}}{V_s} \tag{3}$$

$$i_s^*(t) = i_{dc} * u(t) \tag{4}$$

$$i_f^*(t) = i_s^*(t) - i_L(t) \tag{5}$$

Assume the unit vector for line supply voltage at the fundamental frequency, ***u(t)*** replace with ***sin(wt)*** then generated as in (3).This system uses the sine multiplication as a harmonic detection method, to achieve the instantaneous value of active current supply, $\boldsymbol{i_s*(t)}$ has multiplied the peak value of reference supply current, $\boldsymbol{i_{dc}}$ with a unity sinusoidal signal, ***u(t)*** as in (4). Lastly, the difference between the instantaneous value of the active current supply to the load current will produce the reference compensation current of the active filter,$\boldsymbol{i_f*(t)}$ shown as in (5).

B. *Hysteresis current controller*

For shunt APF, the CCL used to generate the switching signal for the voltage source inverter (VSI) [6]. The hysteresis current control technique applied in this system where is obtained by comparing between the error filter current with a fixed width hysteresis band. Switching signal occurs when the error filter current more than the hysteresis band. The outputs of the comparator are switching gating signals for VSI in the APF [7]. This control scheme is shown in Fig.2. The hysteresis band consists of reference current, $\boldsymbol{i_f*}$, the actual compensation current, $\boldsymbol{i_f}$, upper band, ***+H/2*** and lower band, ***-H/2*** [8].

C. *Proposed DC voltage Control*

The VCL used to provide the peak value of reference supply current, $\boldsymbol{i_{dc}}$ by regulating the DC bus capacitor. It must be maintained to an appropriate constant value. If the performance of VCL is improper, the reference of supply current will cause distortion and lapse of the sinusoidal waveform. There have two types of VCL will be discussed and compared their performance. The VCL being used for this project are proportional-integral (PI) controller and artificial neural network (ANN) controller [9].

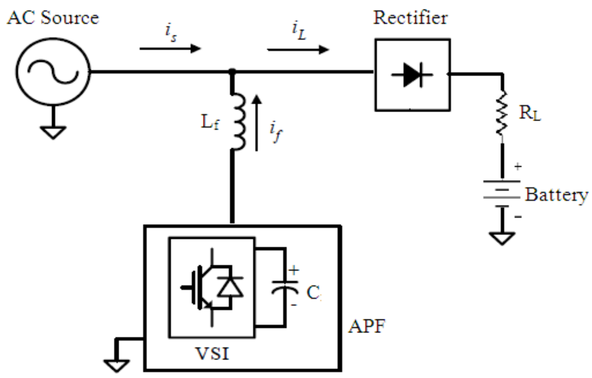

Fig. 1. The single phase shunt active power filter.

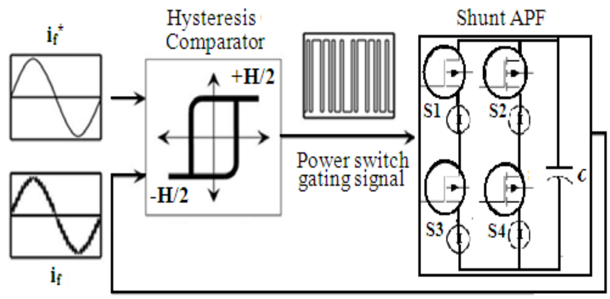

Fig. 2. The hysteresis control technique.

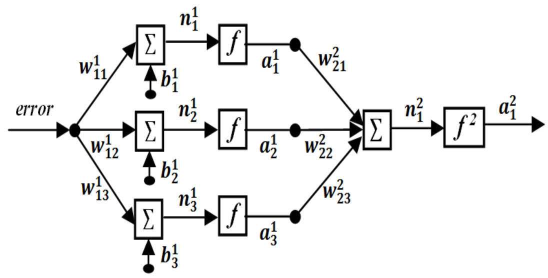

Fig. 3. The proposed ANN controller algorithm.

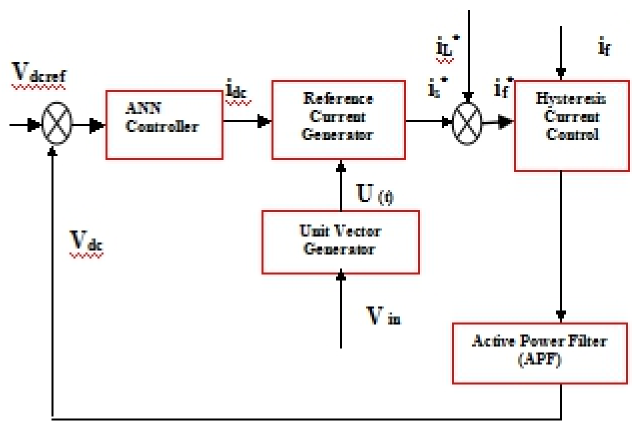

Fig. 4. The complete block diagram of proposed ANN for shunt APF.

Classically, PI controller has been applied widely to control the shunt APF. The disadvantage of PI controller is difficult to obtain accurate values of linear mathematical model. Its performance also fails to support under the variety of parameter, nonlinearity, and load disturbances [10].

To intensify the achievement of VCL, the classical PI controller has been replaced with the ANN controller. To construct the ANN control some knowledge about the plant is needed. Essentially, the numbers of input and output neuron in each layer are equal to the number of input and output signals of the system respectively. Farther, the number of hidden layers and the total neurons is depended on the complexity of the system and the required training accuracy [11]. Based on the type of the task to be performed, the structure of the proposed controller is equally presented in Fig. 3.

The controller consists of an input layer, hidden layer and output layer. Based on a number of the neuron in the layers, the ANN controller is defined as a ***1-3-1*** network structure. The first neuron of the output layer is used as a voltage reference signal ($a^1_2 = m_f$). The connections weight parameter between j^{th} and i^{th} neuron at m^{th} layer is given by w^m_{ij}, while bias parameter of this layer at i^{th} neuron is given by b^m_i. Transfer function of the network at i^{th} neuron in m^{th} layer is defined by [12]:

$$n_i^m = \sum_{j=1}^{S^{m-1}} w_{ij}^m a_j^{m-1} + b_i^m \tag{6}$$

The output function of neuron at m^{th} layer is given by:

$$a_i^m = f^m (n_i^m) \tag{7}$$

Where, f is activation function of the neuron. In this design the activation function of the output layer is unity and for the hidden layer is a tangent hyperbolic function given by:

$$f^m (n_i^m) = \frac{2}{1 + e^{-2n_i^m}} - 1 \tag{8}$$

Updating of the connection weight and bias parameters are given by:

$$w_{ij}^m (k+1) = w_{ij}^m (k) - \alpha \frac{\partial F(k)}{\partial w_{ij}^m} \tag{9}$$

$$b_i^m (k+1) = b_i^m (k) - \alpha \frac{\partial F(k)}{\partial b_i^m} \tag{10}$$

Where k is sampling time, α is learning rate, and F performance index function of the network.

After the neural network architecture is modeled, the next stage defines the learning model to update network parameters. Generally, in learning mode of the neural network controller a sufficient training data input-output mapping data of a plant are required. Since the shunt APF parameters vary with DC voltage, the online learning Back propagation algorithm is developed. Fig. 4 shows the complete block diagram of proposed ANN for shunt APF.

III. SIMULATION RESULTS

The verification of proposed single phase shunt active power filter was simulated by Matlab/Simulink. The simulation results obtain as follows, two conditions, the system with PI controller and the system with ANN controller respectively. Table I shown the list of parameters used for the system. The performance of the distribution system under the compensation of a shunt APF between two controllers will be compared and described.

Fig. 5 shows the waveform of voltage and current source of the system with uncontrolled rectifier without connecting the shunt APF system. Based on Fig. 5, the waveform of current source has harmonic distortion where the shape of waveform in non sinusoidal form. This happens because the system carried the rectifier as a nonlinear load and creates a distortion current at the system.

In the simulation, the spectrum of harmonic current source is shown in Fig. 6. From the graph, it can be observed that the higher of magnitude harmonics current occurs in low-order harmonics. The result of total harmonic distortion (THD) current ratio a battery charger load has been measured as 60.44% and the power factor is 0.8558 (11).

A. Hysteresis current controller

The operation of the hysteresis current controller is depicted in the Fig.7. (a). Switching signals for S1 and S4 are generated when the compensation current is greater than the hysteresis band as shown in Fig.7. (b). When the compensation current is lower than the hysteresis band, switching signals for S2 and S3 are generated as shown in Fig.7. (c). If the compensation current within the hysteresis band the switching signals will not generate by the controller. Fig.8 and Fig.9 shows the reference currents and measurement currents result that fed into hysteresis block based PI controller and ANN controller.

B. System with PI controller

From Fig.10 to Fig.12 show the simulation results of the system with filter by using the shunt APF with the PI controller scheme. Based on the results, the waveform of current source nearly in sinusoidal form and it improved based on the percentage of THD as shown in Fig. 10 compare with Fig. 5. In the Fig. 11, the THD ratio of current sources is reduced from 60.44% to 6.84%. Hence, this type of shunt APF of PI controller is quite effective to reduce the THD. The values of power factor also increase from 0.8558 to 0.9977.

By using PI controller, DC capacitor is maintained at reference value. However, there is a small overshoot and swell on the dynamic response before it obtain steady state conditions as shown in Fig.12.

TABLE I. CIRCUIT PARAMETERS OF SYSTEM

Parameters	Values
Source voltage	240 V
Source frequency	50 Hz
DC bus capacitor	6000 *uf*
DC bus reference voltage	680 V
Filter inductance	0.052 mH
Hysteresis band	0.1
Load resistor	2.5 Ω
Load battery capacity	240 V

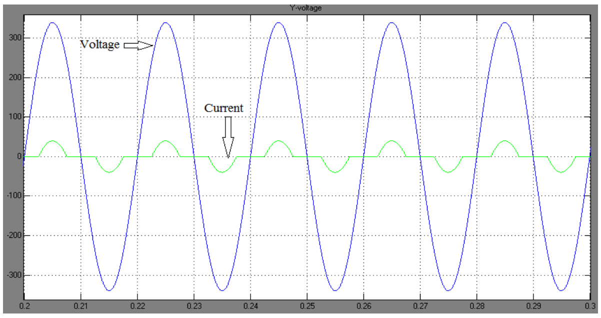

Fig. 5. Voltage source and current source without shunt APF.

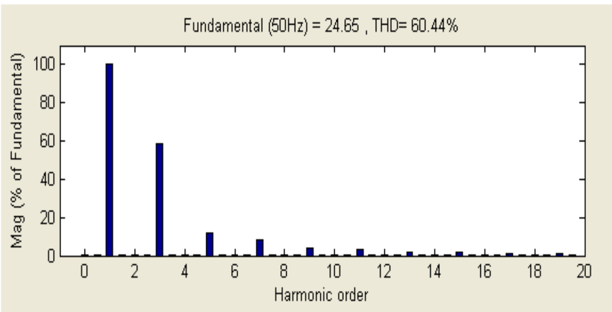

Fig. 6. The THD spectrum of current source without shunt APF.

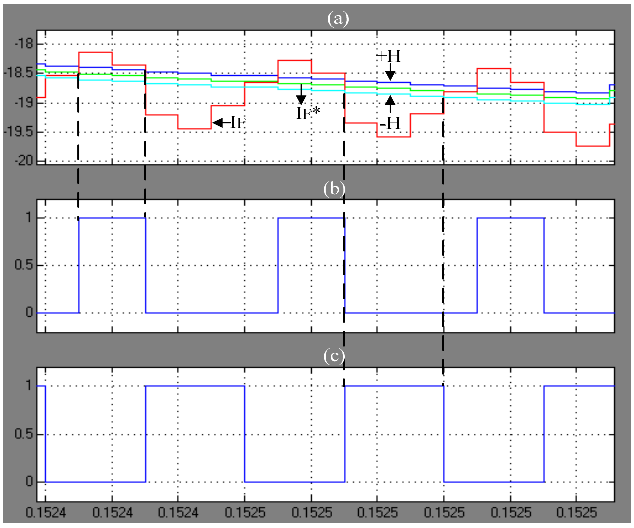

Fig. 7. (a) Hysteresis current control performance, (b) Switching signal for S1 and S4, (c) Switching signal for S2 and S3.

$$\text{Power factor(PF)} = \sqrt{\frac{1}{1+(\text{THD})^2}} \tag{11}$$

C. System with ANN controller

From Fig.13 to Fig.15 show the results simulation of the proposed shunt APF based on the ANN controller. In the Fig.13, the current source waveform was compensated and the configuration of current sources is sinusoidal form. From the Fig.14, the THD ratio of source current is reduced from 60.44% to 2.35%. It can be understood that the current source of this controller is better than PI controller.

By the simulation result, the THD of the distorted line current source for the system based on ANN controller is more beneficial than the system based on PI controller. By comparing the charts shown in Fig.5 and Fig.13, the condition of the current source waveforms had improved approximately 58% based on the percentage of THD. The values of power factor also increase from 0.8558 to 0.9997. The DC link voltage has achieved at steady state in approximately 0.1s as illustrate in Fig.15. From this simulation result, it can be picked up the DC link capacitor voltage is maintained at a reference value without overshoot and good dynamic response before it achieved steady state conditions. This result verifies that the system based on ANN controller perform more intelligence comparable to the system based on PI controller.

Table II expressed the comparison results of the system between with shunt APF and without shunt APF. On the basis of results, the system with shunt APF based on ANN controller are well implemented because it produces the minimal of THD and the good enhancement of power factor compare with PI controller.

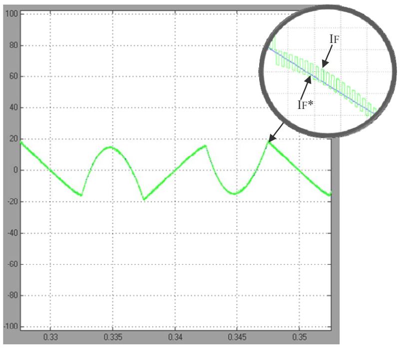

Fig. 8. Reference current filter (i_F*) and compensation current filter(i_F) of shunt APF by PI.

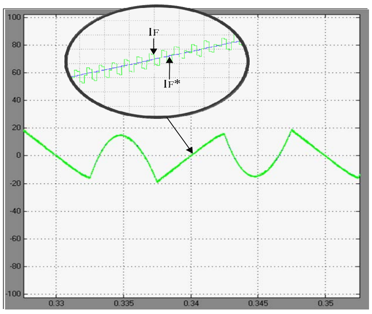

Fig. 9. Reference current filter(i_F*) and compensation current filter (i_F) of shunt APF by ANN.

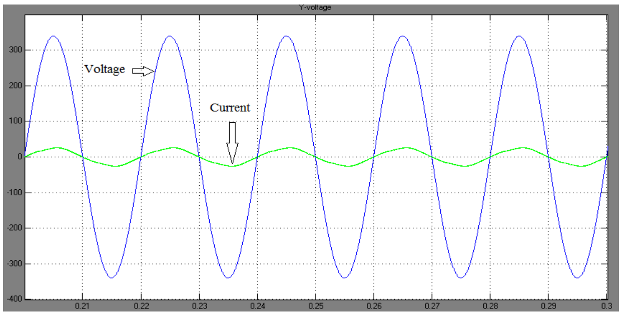

Fig. 10. The waveform of voltage and current source with shunt APF by PI controller.

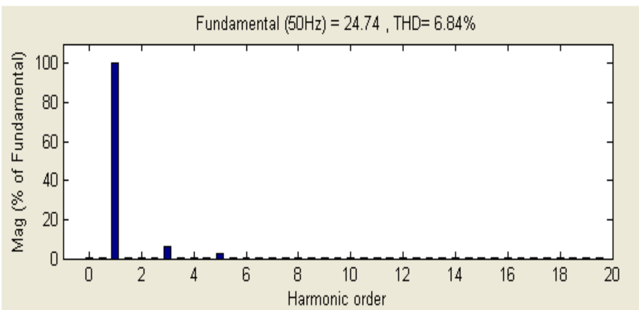

Fig. 11. The THD spectrum of current source with shunt APF by PI controller

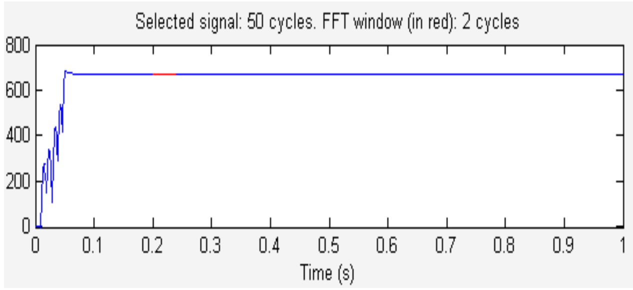

Fig. 12. The DC link voltage with PI controller.

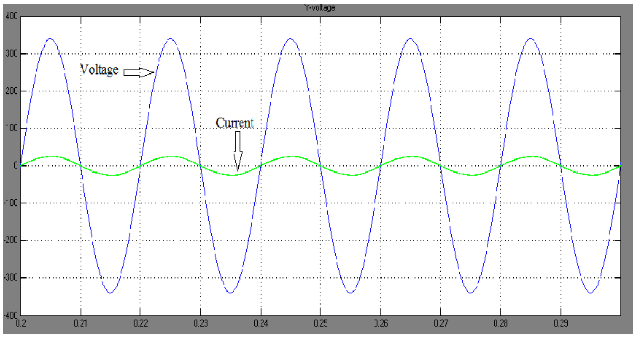

Fig. 13. The waveform of voltage and current source with shunt APF by ANN controller

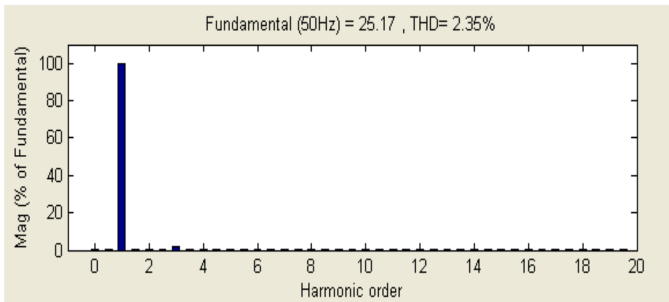

Fig. 14. The THD spectrum of current source with shunt APF by ANN controller.

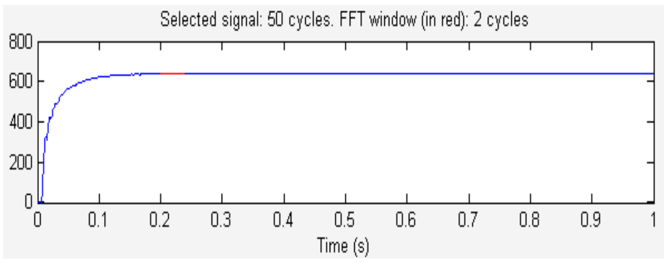

Fig. 15. The DC link voltage with ANN controller.

TABLE II. THE TOTAL HARMONIC DISTORTION AND POWER FACTOR VALUES OF APF .

Parameters	Without controller	PI controller	ANN controller
THD	60.44%	6.84%	2.35%
Power factor	0.8558	0.9977	0.9997

IV. CONCLUSION

At the final stage, the single phase shunt APF has been designed and the proposed controller methods have been introduced. This project has been attached with nonlinear load and a single-phase shunt APF has been developed using Matlab/Simulink for verify of proposed control technique. The effectiveness of the system has been successfully tested for different controller (PI controller and ANN controller). The results show that the ANN controller based on the shunt APF has more quality manifestation which has reduced harmonic and improve system performance compared to the use of PI controller. As a conclusion, applied the shunt APF to the system, harmonic distortion can be reduced. Thus the power factor of the supply system has improved as well.

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