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Power Quality Improvement in Distribution System using ANN Based Shunt Active Power Filter

Jarupula Somlal, Venu Gopala Rao.Mannam, Narsimha Rao.Vutlapalli
Departement of Electrical and Electronics Engineering, K L University, Guntur, INDIA

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ABSTRACT

This paper focuses on an Artificial Neural Network (ANN) controller based Shunt Active Power Filter (SAPF) for mitigating the harmonics of the distribution system. To increase the performance of the conventional controller and take advantage of smart controllers, a feed forward-type (trained by a back propagation algorithm) ANN-based technique is implemented in shunt active power filters for producing the controlled pulses required for IGBT inverter. The proposed approach mainly work on the principle of capacitor energy to maintain the DC link voltage of a shunt connected filter and thus reduces the transient response time when there is abrupt variation in the load. The entire power system block set model of the proposed scheme has been developed in MATLAB environment. Simulations are carried out by using MATLAB, it is noticed that the %THD is reduced to 2.27% from 29.71% by ANN controlled filter. The simulated experimental results also show that the novel control method is not only easy to be computed and implemented, but also very successful in reducing harmonics.

Corresponding Author:

Jarupula Somlal,
Departement of Electrical and Electronics Engineering,
K L University,
Green Fields, Vaddeswaram, Guntur District, Andhra Pradesh, INDIA.
Email: jarupulasomu@kluniversity.in

1. INTRODUCTION

In recent years with the expansion of power semiconductor technology, power electronics based devices such as adjustable-speed drives, arc furnace, switched-mode power supply, uninterruptible power supply etc are employed in various fields [1], [5]-[7]. Some of these converters not only increase reactive currents, but also produce harmonics in the source current. Due to the harmonics, there many losses in the power system. To mitigate the harmonics, there are different solutions are proposed and used by researchers in literature such as line conditioners, passive filters, active filter, etc., Firstly, conventional passive filter are used for elimination of the harmonics; but these passive filter having some disadvantages; such as large in size ,fixed harmonic compensation, weight and resonance occurrence. The above drawbacks of passive filter can be overcome by the concept of active power filter approach. Shunt-type active power filter (SAPF) is used to eliminate the current harmonics. The SAPF topology is connected in parallel for current harmonic compensation. The shunt active power filter has the capability to maintain the mains current balanced and sinusoidal after compensation regardless of whether the load is non-linear and unbalanced or balanced. Recent technological developments of switching devices and availability of inexpensive controlling devices, e.g., DSP-field-programmable-gate-array-centered system, accomplish an active power line conditioner, a natural option to compensate for harmonics. The controller is the heart or primary component of the SAPF system. Conventional PI and PID controllers are used to extract the fundamental component of the load current thus facilitating reduction of harmonics and simultaneously controlling dc-side capacitor voltage of the voltage source inverter. Recently, different AI techniques controllers are used for shunt active power filters.

The major research works are related with control circuit design .The target is to obtain reliability control algorithms of the reference current and a quick response procedure to get the control signal and simultaneously quick controlling dc-side capacitor voltage of the voltage source inverter. The Artificial Neural Networks (ANNs) have been systematically applied to electrical engineering [2-3]. This method is considered as a new tool to design SAPF control circuits. The ANN presents two principal characteristics .It's not necessary to establish specific input-output relationships but they are formulated through a learning process. Moreover, the parallel computing architecture increases the system speed and reliability [4].

In this paper, a new SAPF control method based on ANNs will be presented. Load voltages and currents are sensed, the control blocks calculates the power circuit control signals from the reference compensation currents , and the power circuit injects the compensation current to power system. The article is primilary focused on a system which uses the ANN system and the results for the same are discussed. In this paper, a shunt APF with a hysteresis band control is utilized to compensate the non-linear loads.

2. CONFIGURATION OF SHUNT ACTIVE POWER FILTER(SAPF) AND ESTIMATION OF COMPENSATING CURRENT

Figure 1 shows a shunt active power filter, it consists of the 3-phase source, universal bridge, load along with active filters. A SAPF is to produce the compensation current. The non-linear load is the sum of source current and the harmonic current.The objective is to get the balanced supply current with out harmonic and reactive components.The suitable current is injected by the SAPF corresponding to the load current. The SAPF is designed with ANN controller. The proposed controller, accounts for THD and DC voltage control, the controller have rapid dynamic response in case of load current deviation. The proper operation of the controller results in the generation of gate signals for 3-phase inverter which in turn is responsible for generating compensating currents. These compensating currents on injection through the 3-phase inverter results in harmonic compensation of source currents and improvement of power quality on the connected power system [9].

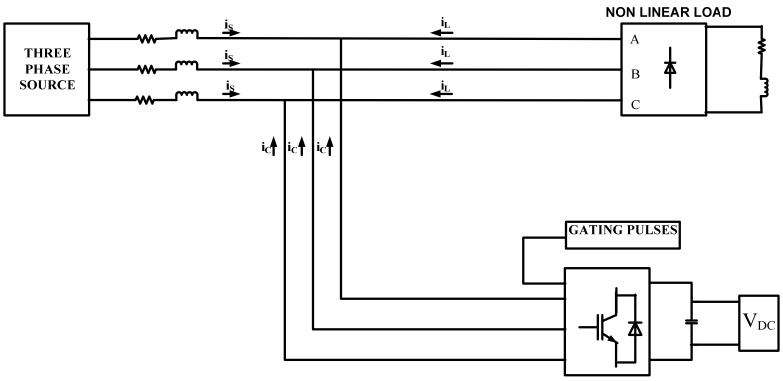

Figure 1. Configuration of Shunt Active Power Filter

A general formulation for the load current corresponding to Figure 1 is:

$$i_L(t) = i_{\alpha 1}(t) + i_{\beta 1}(t) + i_h(t) \quad (1)$$

$i_{\alpha 1}$ and $i_{\beta 1}$ are the in-phase and quadrature components of the phase current at the fundamental frequency respectively. All other harmonics are included in i_h. The per-phase source voltage and the corresponding in-phase component of the load current may be conveyed as:

$$v_s(t) = V_m \cos \omega t \quad (2)$$

$$i_{\alpha 1}(t) = I_{\alpha 1} \cos \omega t \quad (3)$$

Assuming that harmonics can be eliminated by the APF, the compensating current becomes:

$$i_L(t) = i_L(t) - i_{\alpha 1}(t) = i_L(t) - I_{\alpha 1}\cos\omega t \quad (4)$$

Where $i_{\alpha 1}$ is the peak magnitude of the in-phase current that the mains should supply and therefore needs to be assessed Once $i_{\alpha 1}$ assessment is over, the reference current for the active power filter may easily be fixed as per (4). i_L may be measured using current sensors.

3. PROPOSED CONTROL STRATEGIES

3.1. Reference Current Calculation:

For reference current calculation, instantaneous abc_to_dq0 transformation has been applied. The abc_to_dq0 transformation block calculates the d-axis, q-axis, and zero sequence quantities in a two-axis rotating reference frame for a 3- Φ sinusoidal signal. Equation (5), (6) and (7) are used for reference current calculation,

$$I_d = \frac{2}{3}(I_a \sin(\omega t) + I_b \sin(\omega t - \frac{2\Pi}{3}) + I_C \sin(\omega t + \frac{2\Pi}{3})) \quad (5)$$

$$I_q = \frac{2}{3}(I_a \cos(\omega t) + I_b \cos(\omega t - \frac{2\Pi}{3}) + I_C \cos(\omega t + \frac{2\Pi}{3})) \quad (6)$$

$$I_o = \frac{1}{3}(I_a + I_b + I_c) \quad (7)$$

Where ω = rotation speed (rad/s) of the rotating frame

3.2. Design of ANN Controller

An Artificial neural network (ANN), is a model (mathematical) inspired by biological neural networks. An ANN consists of an interlinked collection of artificial neurons, and it develops information using a connectionist method to calculation. It resembles the brain in two facets: 1) The data is accumulated by the network through the learning process and, 2) Interneuron connection strengths are employed to store the data. These networks are categorized by their topology, the manner in which they communicate with their surroundings, the manner in which they are guided, and their capability to process information. ANNs are applied to solve artificial intelligence problems without necessarily creating a model of a real dynamic system.

The rapid spotting of the disturbance signal with high accuracy, fast processing of the reference signal, and high dynamic response of the controller are the prime prerequisites for desired compensation in case of APF. The conventional controller fails to achieve satisfactorily under parameter variations nonlinearity load disturbance, and so forth

For improving the performance of the suggested Shunt Active Power filter, single layer feed forward network (trained by the back propagation algorithm) is seen. This network consists of two layers and their corresponding neuron interconnections. '2' neurons in input layer to receive the inputs. Hidden layer comprises of 21 neurons to which each of the processed input is fed. The output layer comprises of '1' neuron whose output is to be calculated as P_{loss}. Activation functions are assigned for each of the layers in order to train them. Input layer is given the Tan-Sigmoidal function as activation function and the output layer is being given the Pos-Linear activation function as activation function.

Figure 2 shows the internal blocks of proposed neural network [10]. The large data of the DC-link voltage for 'n' and 'n-1' intervals from the conventional method are gathered and are stored in the MATLAB workspace. This data is used for training the ANN. The data stored in workspace is being retrieved using the training algorithm used. The neurons in the input and output layers is almost a fixed quantity to obtain the provided input. The accuracy of the ANN operation is mostly depends on the number of hidden neurons.

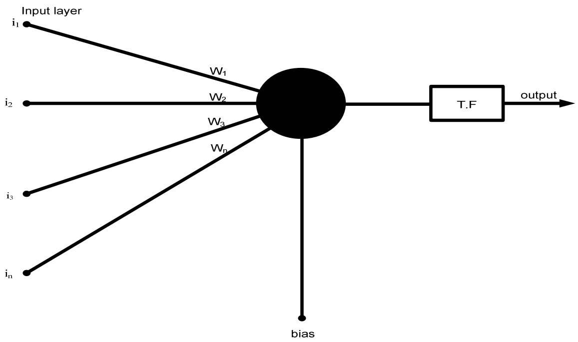

Figure 2. Internal blocks of proposed neural network

$$y = \sum_{n=1}^{21} w_n . i_n + b \tag{8}$$

3.2.1. Algorithm for ANN

Step 1: Normalize the inputs and outputs with respect to their maximum values. It is shown that the neural networks work better if the inputs and outputs lie between 0-1. There are two inputs given by $\{P\}_{2X20}$ and one output $\{O\}_{1X20}$ in a normalized form.
Step 2: Enter the number of inputs for a fed network.
Step 3: Enter the number of layers.
Step 4: Create a new feed forward network with ‘tansig and poslin’ transfer functions.
Step 5: Train the network with a learning rate 0.02.
Step 6: Enter the number of epochs.
Step 7: Enter the goal.
Step 8: Train the network for given input and targeted output.
Step 9: Generate simulation of the given network with a command ‘gensim’

The Neural Network is created with the set number of neurons in the each layer using the above algorithm. At each training session, 500 iterations are done and 6 such a validation checks are taken out in order to minimize the scope of error occurrence. The main aim of this is to bring the performance to zero. The Learning rate is the major consideration in the training of the Artificial Neural Network (change of interconnection weights). It should not be too low that the training gets too delayed. It should not be excessively because the oscillations occur about the target values and the time needed to converge is too high and the training gets delayed. For the considered controller, Neural Network is trained at a learning rate of 0.02. The compensator output depends on the input and its evolution.

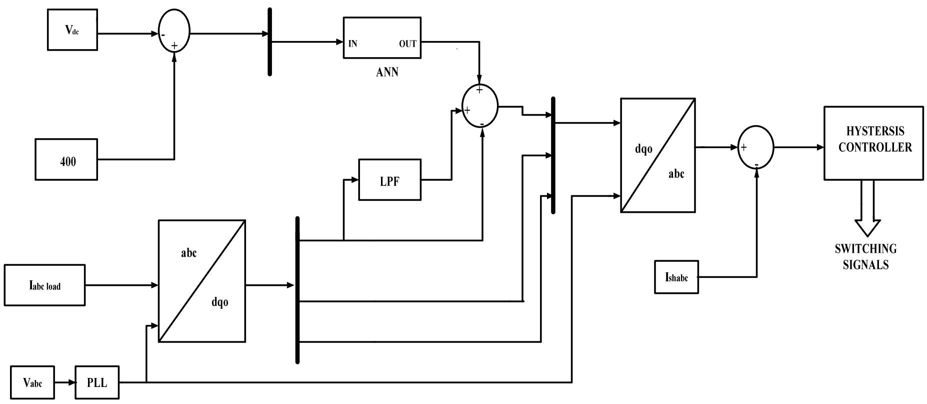

Figure 3. Control scheme for ANN controller

Figure 3 shows proposed control scheme for ANN, in which the load currents, PCC voltages and DC bus voltage of shunt active filter are sensed. The constant DC voltage is maintained by the DC voltage loop. The input of ANN controller is the difference between V_{DC} and a reference value. The output of ANN is responsible for harmonic mitigation. A phase-locked loop (PLL) synchronizes on the positive-sequence component of the current I. The output of the PLL (angle $\theta = \omega t$) is used to compute the direct-axis and quadrature-axis components of the three-phase currents [11]. The output signals of ANN controller and direct axis component of current from d-q-o transformation are compared which produces direct axis component of reference signal. The signals from d-q-o frame are again converted to a-b-c frame are compared with a filter current (I_{shabc}), which results in generation of reference compensation current, which is given as input to the hysteresis controller.

Figure 4 shows operating principle of hysteresis band controller is to produce triggering signals required for switching ON/OFF of IGBT's of shunt active filter. The objective of this controller is to control the compensation currents by forcing it to follow the reference ones. The switching strategies of the three-phase inverter will keep the currents into the hysteresis band. The real load currents are sensed and their non active components are compared with the reference compensation currents. The hysteresis comparator outputs signals are used to turn on the inverter power switches.

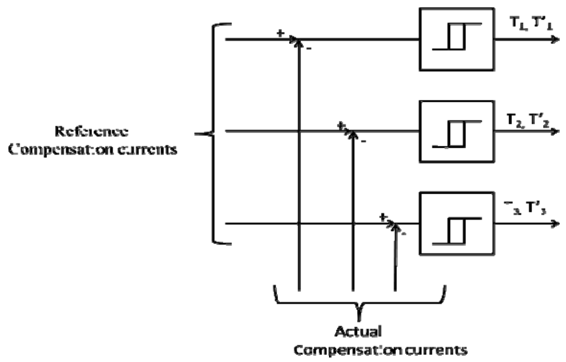

Figure 4. Operating principle of hysteresis band controller

4. RESULTS AND DISCUSSIONS

4.1. For Uncompensated System

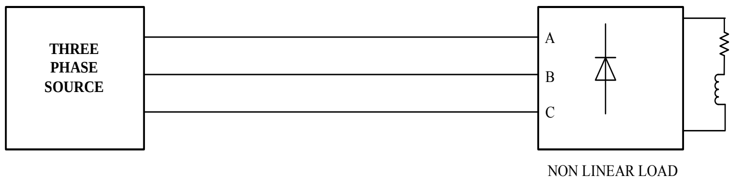

Figure 5. Uncompensated system

Figure 5 shows the simulation circuit for 3-phase 3-wire distribution system with a 3-phase voltage source connected to non linear load. Table 1 shows the various parameters of the considered system. Figure 6 shows Wave forms of source current and load current of uncompensated system. It can be observed from Figure 6 that instead of the actual sinusoidal waveform, a huge distortion in the source current can be observed. A delay can be observed in the output wave form, it is caused due to an inductor because an inductor opposes the sudden change in the current, though the supply wave form changes instantaneously it takes time for the inductor causing the delay in the wave form. Figure 7 shows the FFT analysis of source current. From the FFT analysis of the output waveform without filter shown in Figure 7, the %THD is about 29.71.

Table 1. System parameters

System parameters	*Values Used*
Source Impedance	L=0.01e-3 mH
Load	R=10Ω,L=30e-3 mH
Active filter	*R=0.1* Ω,L=3e-3 mH

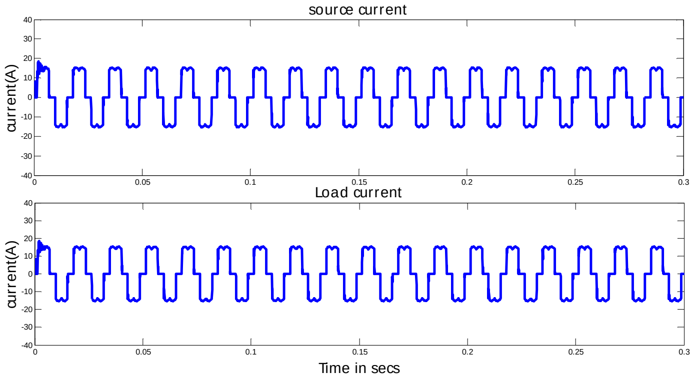

Figure 6. Wave forms of load current and source current of uncompensated system

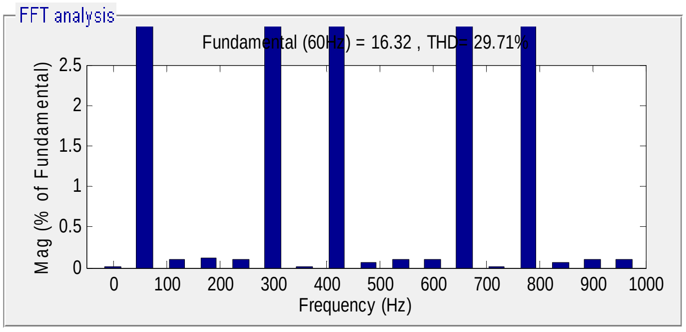

Figure 7. FFT analysis of source current

4.2. For Shunt Active Filter with ANN Controller

Figure 8 shows simulation circuit of Shunt Active Filter. Figure 9 shows the Simulation results of Shunt Active Filter with ANN Controller. From Figure 9, it can be observed that after Shunt Active Filter with ANN Controller runs, it reduces the much delay and waveform appears sinusoidally with fewer distortions when compared to uncompensated system and it also observed that the harmonics of the source current are eliminated by injecting the capacitor current which happens because of maintaining the capacitor voltage near to constant. Capacitor voltage takes 0.08sec to reach the steady state. Figure 10 shows FFT analysis of source current with ANN controller. From Figure 10, it can be seen that the current total harmonic distortion reduces to 2.27% from 29.71%.

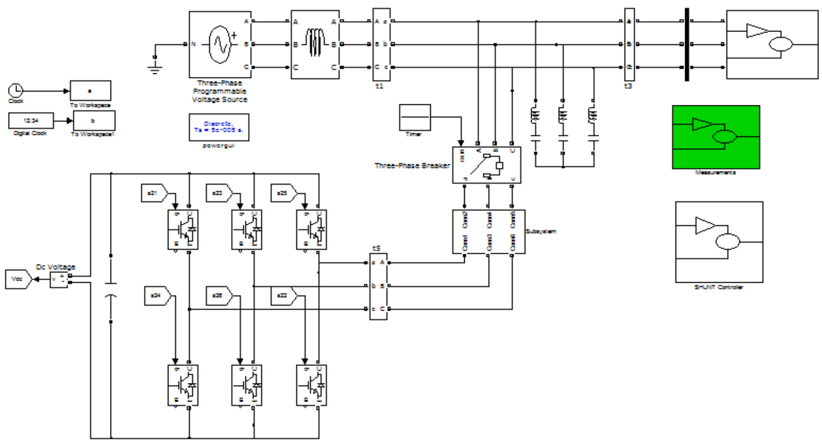

Figure 8. Simulation circuit of Shunt hybrid Active Filter

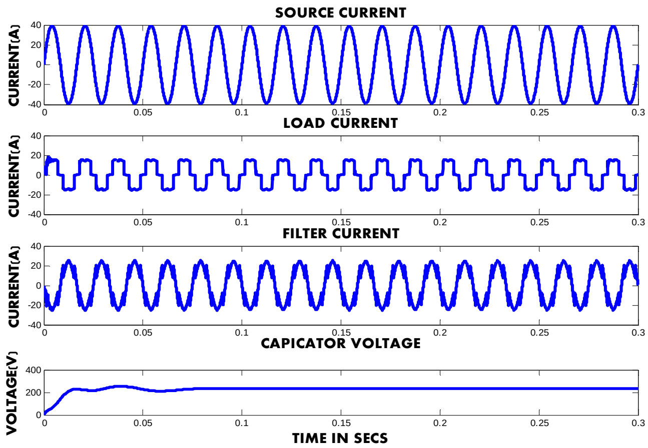

Figure 9. Simulation results of Shunt Active Filter with ANN Controller

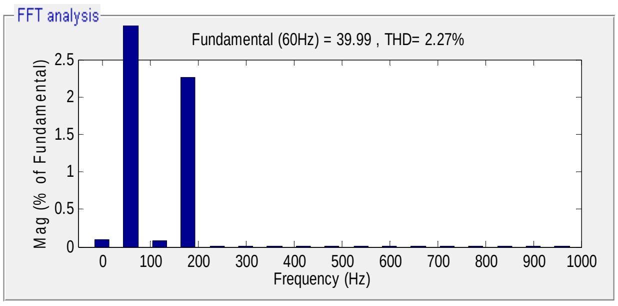

Figure 10. FFT analysis of source current with ANN controller

Table 2. Comparison of simulated results

	SIMULATED RESULTS APF	
	Uncompensated System	ANN
Settling Time (V_{DC}) in Sec.	--	0.08sec
%THD	29.71	2.27

5. CONCLUSION

In this paper, a detailed analysis of Shunt Active Power Filter with ANN controller has been proposed to mitigate harmonics of the three phase distribution system.

The obtained results show the simplicity and the effectiveness of the proposed intelligent controller under nonlinear load conditions. From the results, it can be observed that the current total harmonic distortion reduces better with ANN controlled active filter. The simulation and experimental results also show that the new control method is not only easy to be calculated and implemented, but also very effective in reducing harmonics

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BIOGRAPHIES OF AUTHORS

Jarupula Somlal, at present is working as an Associate Professor in the department of EEE, K L University, Guntur, Andhra Pradesh, India. He received B.Tech, degree in Electrical and Electronics Engineering from J.N.T.University, Hyderabad, A.P, India, M.Tech.,(Electrical Power Engineering) from J.N.T.University, Hyderabad, A.P, India and currently working towards the Doctoral degree in Electrical & Electronics Engineering at Acharya Nagarjuna University, Guntur, Andhra Pradesh, India. He published 7 papers in national and international journals and presented various papers in national and International conferences. His current research interests include active filtering for power conditioning, Fuzzy Logic and ANN applications to power quality.

Venu Gopala Rao Mannam, FIE, Member IEEE, at present is Professor & Head, department of Electrical & Electronics Engineering, K L University, Guntur, Andhra Pradesh, India. He received B.E. degree in Electrical and Electronics Engineering from Gulbarga University in 1996, M.E (Electrical Power Engineering) from M S University, Baroda, India in 1999, M.Tech (Computer Science) from JNT University, India in 2004 and Doctoral Degree in Electrical & Electronics Engineering from J.N.T.University, Hyderabad, India in 2009. He published more than 30 papers in various National, International Conferences and Journals. His research interests accumulate in the area of Power Quality, Distribution System, High Voltage Engineering and Electrical Machines.

Narsimha Rao.Vutlapalli, at present is pursuing M.Tech. in the department of EEE, K.L.University, Guntur, Andhra Pradesh, India. He received B.Tech, degree in Electrical and Electronics Engineering from J.N.T.University, Hyderabad, A.P, India.