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ANN based Hybrid Active Power Filter for Harmonics Elimination with Distorted Mains

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ABSTRACT

The present paper describes dynamic neural network controlled Hybrid Active Power Filter (HAPF) designed for harmonic compensation under variable source/load conditions. A neural network based controller is employed to extract fundamental component of current from non-sinusoidal and unbalanced source currents of the considered supply system. Hybrid filter utilizing the merits of both shunt passive filter and shunt active filter for better compensation performance is applied in this work. Simulation and analysis of three phase hybrid active power filter under balanced and unbalanced load conditions, unbalanced & distorted source conditions have been incorporated using MATLAB/ SIMULINK. The detailed simulation level results have been presented to validate the proposed methodology.

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1. INTRODUCTION

In recent years, the increasing use of power electronics based non linear loads continuously deteriorated quality of power. Many of the important international standards define power quality as to maintain purely sinusoidal current waveform in phase with purely sinusoidal voltage waveform. Therefore, a power quality problem exists if any of the voltage, current or frequency deviation from sinusoidal nature occurs. Power quality problems are common in industrial, commercial and utility networks as power electronics appliances are widely used in these fields. These appliances generate harmonics and reactive power. Therefore it is very important to compensate the dominant harmonics and thus Total Harmonic Distortion (THD) below 5% as specified in IEEE 519 harmonic standard [1].

To lessen the effect of harmonic distortion two different filters are provided namely Active and Passive filters. The passive filtering is the simplest conventional solution to eliminate the harmonic distortion and power factor improvement in the power system utilities. Although with various advantages such as simplicity of construction, easy to implement and cheaper, the passive filter suffer from many disadvantages such as tuning problems due to tolerance, resonance, fixed compensation characteristics for fixed value of L & C and their bulky size. To overcome this problem Active Power Filter (APF) is brought in effect.

Active power filter is a dynamic and flexible solution for the mitigation of harmonic current due to their compact size, no requirement of tuning and stable operation. Active power filter acts as harmonic current source to provide emphatic result to compensate for harmonic currents as well as reactive power. It has the capability to inject harmonic current into the ac system with the same amplitude but in opposite phase of the load [2]. As the HAPF is complex with cost effective parameter control, the hybrid active power filter has been preferable in the subject of harmonic solution. Hybrid active power filter gives the efficacious combination of passive and active filter, which implies the advantages of both and eliminates the short-comes of each one shown in figure1.

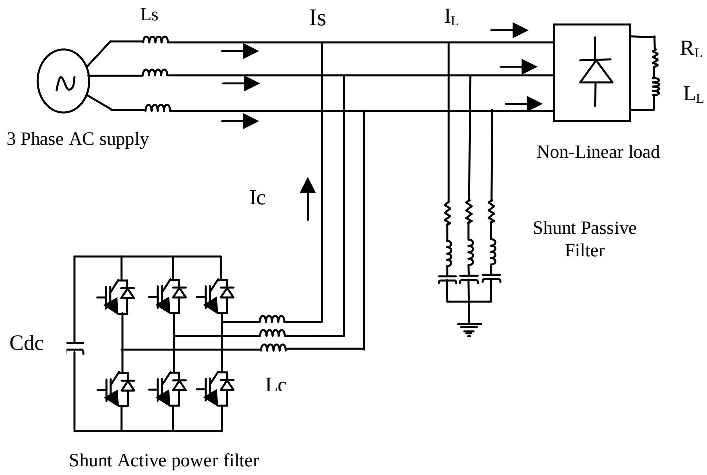

Figure 1. Hybrid Filter Configuration

Accuracy of this hybrid active power filter is depending upon the calculation of harmonic current and generation of reference current. In this paper, a three phase three wire neural network controlled shunt hybrid active power filter is proposed [3], [4], [5]. To make the shunt active power filter model more dynamic and robust in nature in this paper an ANN controller has been used to facilitate the calculation of reference currents. ANN controller is used to generate fundamental from non-ideal voltage source. The extracted fundamental currents are then subtracted from source current to evaluate the reference signal i.e. harmonic current. The proposed controller has self-learning with high accuracy and simple architecture and it can be successfully applied for harmonic filtering under various power system operating conditions. This paper, therefore, presents a hybrid power filter using neural network-controller to control the harmonics under different non-sinusoidal and unbalanced source/load conditions for its performance.

2. PROPOSED TOPOLOGY

Three phase three wire hybrid power filter is used as prototype shown in figure 2. Shunt active power filter is used to generate compensation current in opposite phase. Power circuit for APF is proposed as an IGBT based three-phase voltage source inverter with DC storage capacitor for better compensation of non-linear unbalanced /balanced loads. Active power filter has two different control schemes; one is neutral network controller that accounts for reference current generation and second PI controller for DC voltage regulation.ANN comprises three adaptive linear neurons to extract the fundamental components of the three phase voltages from non-sinusoidal supply [6]. The capacitors are designed to limit the dc voltage ripple to a specified value, typically 1 to 2 %. In this case the capacitor should be designed for the worst case. Since the active filter will operate in several modes (balanced or unbalanced load), then the injection of compensation current is done in order to nullify or mitigate the harmonic currents. Injection of this compensation current gives improved power quality. The performance of the active power filters is dependent to a great extent upon the method used for the calculation of reference current.

Design of Hybrid filter

The requirement of reactive power is must for designing of hybrid power filter. The proposed control scheme generates the reference compensation current for the active power filtering with low order harmonics and VAR being taken care of, by the passive tuned filter [7], [8], [9]. As a result, no harmonic resonance occurs and no harmonic current flows in the supply. Following equations can be used for designing passive filter-

Let VAR requirement of load is $(\mathrm{VAR})_L$ so VAR supplied by passive filter is

$$(\mathrm{VAR})_S = \frac{(\mathrm{VAR})_L}{3} \quad (1)$$

Capacitance, inductance and resistance of the passive filter element can be calculated as

$$C = \frac{(\mathrm{VAR})_S}{\omega . V^2} \quad (2)$$

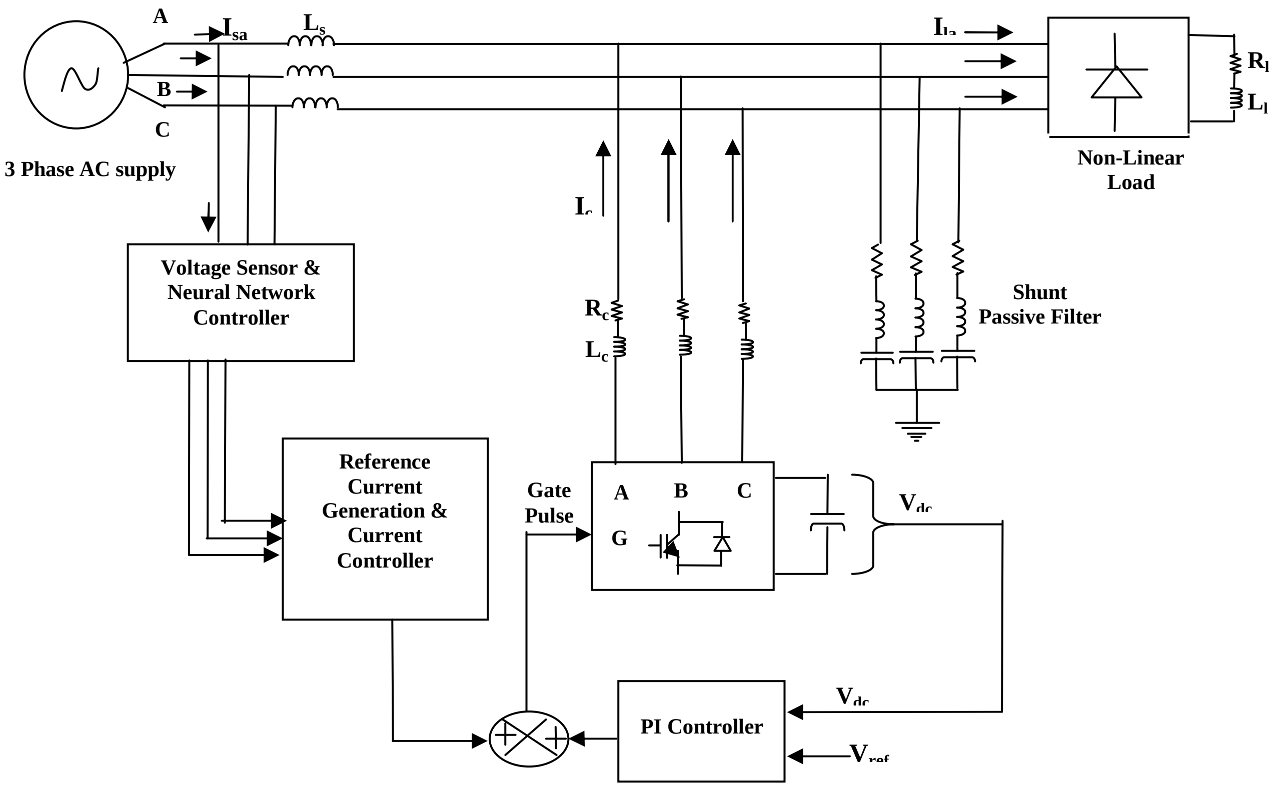

Figure 2. Proposed topology of shunt active power filter

$$L = \frac{1}{\omega^2 C} \tag{3}$$

$$R = \frac{\omega L}{Q} \tag{4}$$

Where, Q is the Quality factor. Value of R, L & C varies with different values of VAR and Q. After further analysis following equation is obtained

$$B_P = \frac{1}{Q} \tag{5}$$

Where, B_P is the bandwidth of the passive filter. With high value of Q the bandwidth is narrow therefore it is difficult to obtain the tuning.
The total impedance of system is given by the equation

$$Z = \frac{Z_5\, Z_7\, Z_S}{Z_5\, Z_7 + Z_5\, Z_S + Z_7\, Z_S} \tag{6}$$

Where, Z_S is the source impedance and Z_5 & Z_7 are the 5^{th} and 7^{th} tuned passive filter impedances.

3. CONTROL STRATEGY

The main function of control scheme is shown in figure 3 to maintain supply current waveform sinusoidal, identification of harmonic content, regulation of DC voltage and controlling scheme of HSAPF is compulsory which provides compensating current to the power system as well as supplies harmonic currents to the three phase non-linear load at the same instant. For the proper response of APF the extraction of fundamental component of current from non-sinusoidal input, reference current generation, DC voltage regulation and injection of compensation currents are essential tasks [10]. These tasks can be achieved only by using various controlling schemes. The indirect method of current/voltage sensors is used. The three phase unit voltage vectors (v_{sa}, v_{sb}, v_{sc}) are obtained from the supply voltages. These unit vectors, when multiplied with reference supply current (I^*_{sm}), result in three phase reference supply currents (I^*_{sa}, I^*_{sb}, I^*_{sc}). The reference supply currents and sensed supply currents (I_{sa}, I_{sb}, I_{sc}) are the inputs for the pulse generator, which generates the firing pulses for the gating signals to the IGBT's of the active power filter[11], [12]. Hysteresis current control is a method of controlling a voltage source inverter so that the output current is generated which follows a reference current waveform.

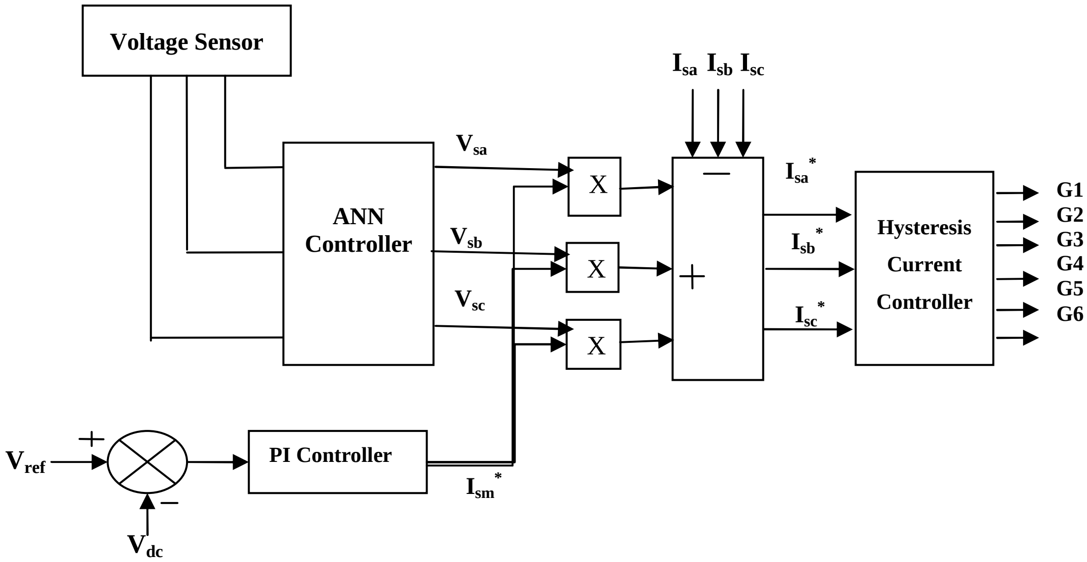

Figure 3. Block diagram of control strategy for shunt active power filter

3.1. Neural Network Controller

One important issue that assesses and evaluates the quality of the delivered power is the estimation or extraction of fundamental components from distorted current or voltage waveforms. In order to provide high-quality power supply electricity, it is essential to accurately estimate or extract time varying fundamental components, both the magnitude and the phase angle, to mitigate harmonic component using active power filters. There is harmonic estimation technique reported based on Artificial Neural Networks (ANN) controller. ANN is found to be most advantageous so therefore ANN used in this work. Usually, a low pass filter is utilised for separating fundamental component from voltage which is inefficient in actual conditions proposed earlier. Moreover, it has problems related to accurate phase and gain tuning and three additional current sensors are required for sensing load currents. We know that the decision of particular order and cut-off frequency plays a major role in designing a filter. Hence, in the proposed method, a neural network is employed for extracting fundamental components from each phase of source currents instead of load currents for non-ideal mains supply and resulting real power due to fundamental components of currents is calculated. The architecture of proposed ADALINE neural network has two layer (input and output) network having n-inputs and a single output shown in figure 4.

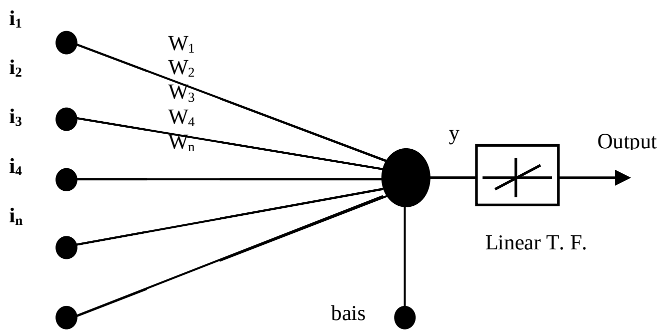

Figure 4. Internal blocks of proposed Neural Network

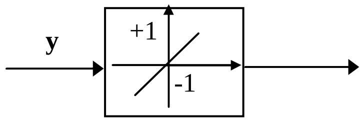

Figure 5. Input/Output relationship of purlin transfer function

The basic blocks of this network are input signal delay vector, a purelin transfer function, weight matrix and bias is shown in figure 5. The input output relationship is expressed as:

$$y = \sum_{n=1}^{61} \mathrm{w_n} * \mathrm{i_n} + \mathrm{b} \quad (7)$$

Where 'b' is bias, 'w' is weight, and 'i' is the input to the NN. The input to the network is a time-delayed series of the signal whose fundamental component is to be extracted. The length of this delay series is 61, which has been decided considering expected maximum distortion and unbalance in 3-phase input signal. The input of the ANN system is supply voltage and current and the output of the system is APF reference current. The weight adjustment is performed during the training process of the ADALINE using Widrow-Hoff delta rule [6]. The mean square error between desired output and the actual output was reduced to $3.2e^{-5}$ by repetitive training with the learning rate of 0.0006.

3.2. Proportional Integral Controller

PI controller algorithm involves two separate parameters; the Proportional and the Integral. The Proportional value determines the reaction to the current error; the Integral determines the reaction based on the sum of recent errors. A comparison of the average and the reference values of the dc bus voltage for the shunt AF results in a voltage error, which is fed to a proportional integral (PI) controller and the output of the PI controller is multiplied by the mains voltage waveform V_{sa}, V_{sb}, V_{sc} in order to obtain the supply reference currents i_{sa}*, i_{sb}*, i_{sc}*.

A PI controller used to control the DC-bus voltage is shown in Figure 6 whose transfer function can be represented as

$$H(s) = k_p + \frac{k_i}{s} \quad (8)$$

Where, k_p is the proportional constant that determines the dynamic response of the DC-bus voltage control, and k_i is the integration constant that determines it's settling time.

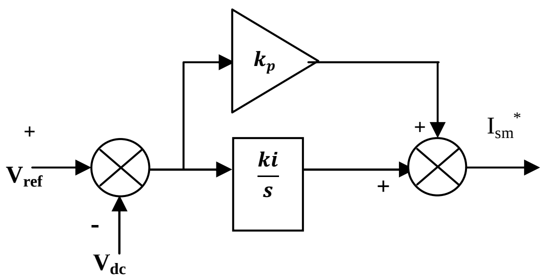

Figure 6. PI controller for DC-bus voltage control

It can be noted that if k_p and k_i are large, the DC-bus voltage regulation is dominant, and the steady-state DC-bus voltage error is low. On the hand, if k_p and k_i are small, the real power unbalance gives little effect to the transient performance. Therefore, the proper selection of k_p and k_i is essentially important to satisfy above mentioned two control performances.

The computed three-phase supply reference currents are compared with the sensed supply currents and are given to a hysteresis current controller to generate the switching signals to the switches of the shunt AF which makes the supply currents follow its reference values [13].

4. RESULT

The system parameters: Load resistance R_L = 100Ω, Load inductance L_L=37mH, Supply Phase voltage = 240 V(rms), Supply line parameters Rs =1Ω, Ls = 3mH, Filter coupling inductance Rc=0.5Ω, Lc=3mH, Inverter DC bus capacitor =2000µF, Reference Voltage = 480V, Hysteresis band limit =0.5A and Switching frequency =10kHz, PI controller parameters are K_i =10, K_p = 0.5.

The Active Power Filter with proposed neural network controller was modeled and simulated in MATLAB. The proposed controller simulated with balanced and unbalanced nonlinear loads with sinusoidal/distorted, balanced/unbalanced conditions of source voltages. Figure7 shows the three phase source current when a load is suddenly increased by 50% at the time t=0.12 sec. The waveforms are maintained sinusoidal in spite of such large variation in load. Figure 8 shows the filtering performance under unbalance load condition. In this simulation study, a 1- phase rectifier load is connected between phase 'r' and 'b' in addition to three phase rectifier. This creates an unbalance of 60% in line currents. The APF is starting at t = 0.06 sec. It can be seen that the proposed neural network controller keeps currents in each phase nearly sinusoidal and THD less than 4%. Figure 9 shows the performance of the shunt active filters when the source voltage is unbalance and distorted respectively. In Figure 8 the three phase unbalance source voltages are 240, 200 and 160Vrms. At t = 0.06 sec APF starts and THD of source current in each phase reduced to 4%. In Figure 8 the source voltage is contaminated with 3^{rd} and 5^{th} harmonics with THD of 12%. After filtering the THD of source current in each phase becomes 4%. Figure 10 shows the voltage across charging capacitor. The results shown in Figure 7-9 demonstrate the excellent steady state and dynamic performance of proposed neural network controller under AC source distortion and unbalance and nonlinear loading conditions.

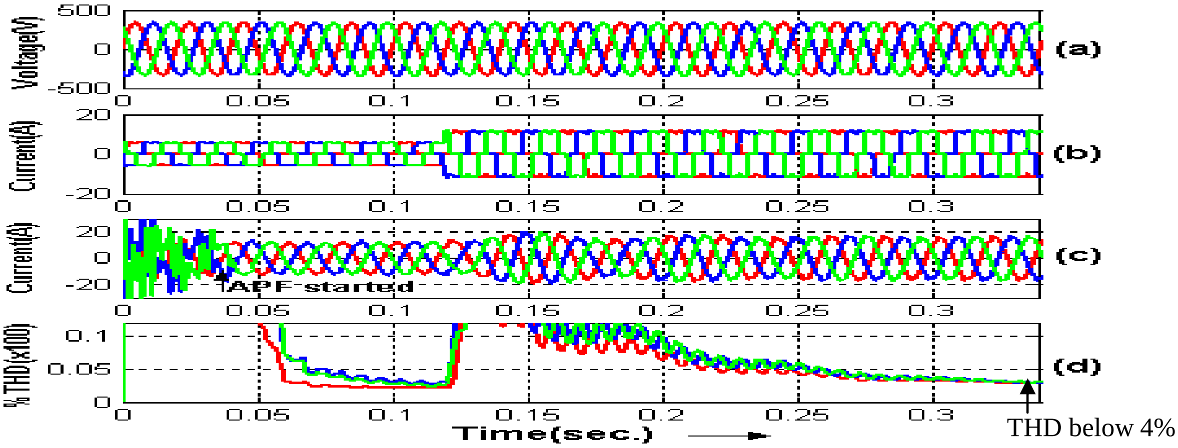

Figure 7. Dynamic performance: 50% Step change resistive load: (a) 3-ph source voltages (b) 3-ph load currents (c) 3-ph source currents (d) 3-ph THD

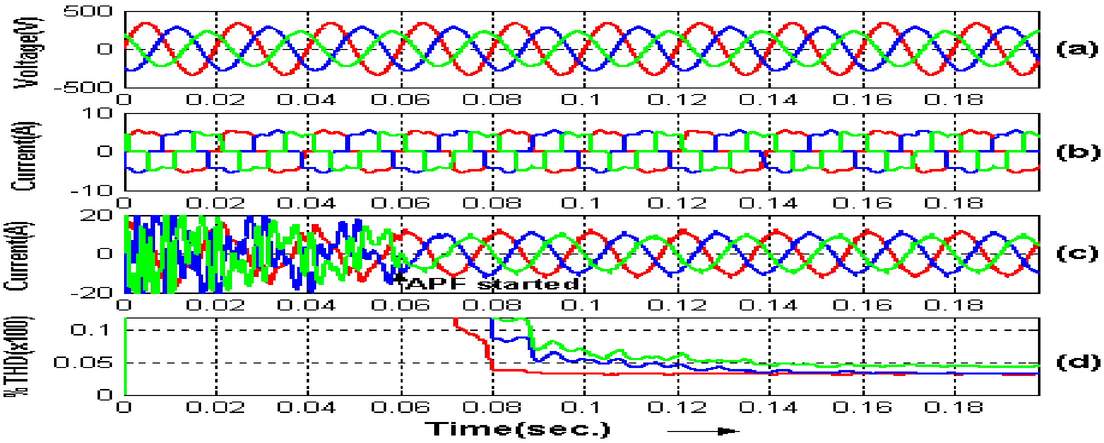

Figure 8. Filtering performance under unbalance source voltages: (a) 3-ph source voltages (b) 3-ph load currents (c) 3-ph source currents (d) 3-ph THD

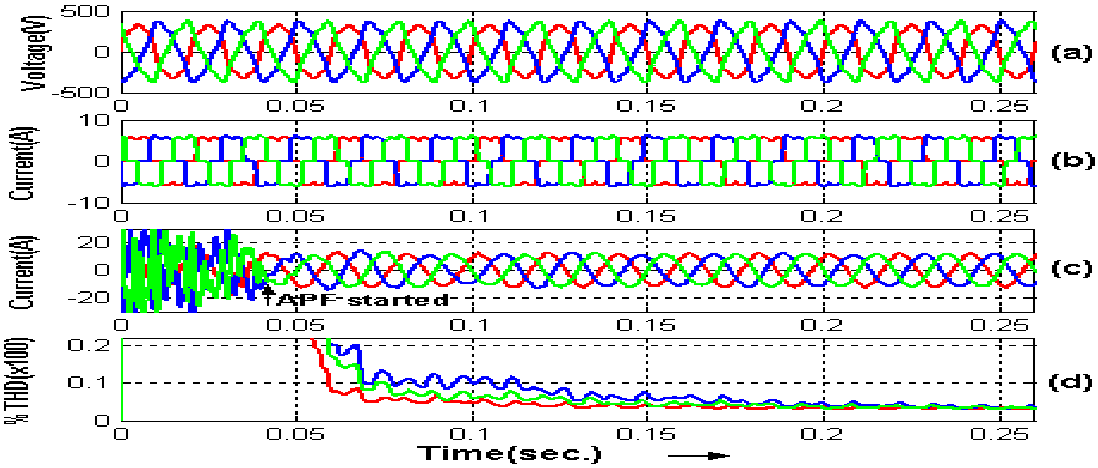

Figure 9. Filtering performance under distorted mains: (a) 3-ph source voltages (b) 3-ph load currents (c) 3-ph source currents (d) 3-ph THD

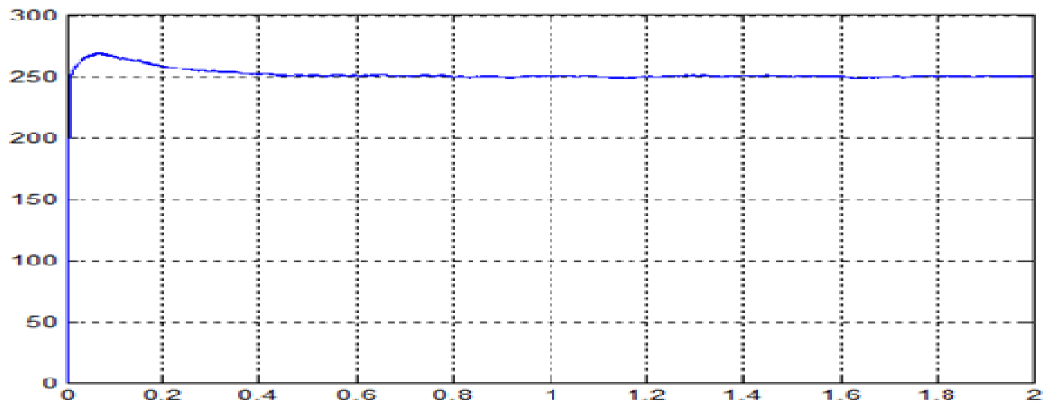

Figure 10. Voltage across Capacitor, V_{dc}

5. CONCLUSION

The In this paper, an analysis has been carried out for the estimation of the reduction in size and cost of the active filtering unit with the passive tuned filters inserted for partial compensation. The estimation has been done for varying VAR compensation of the passive filters. The novel approach which based on intelligent neural techniques has been proposed. The performance of the proposed ANN was verified through simulation studies with MATLAB. Proposed controller provides the fundamental component from distorted supply accurately. The estimation further strengthens the fact that the shunt active filtering system based on the ANN control scheme can be made quite cost-effective with the addition of a passive counterpart, as required in practical applications, for power quality improvement in retrofit systems.

REFERENCES

[1] Roger C.Dugan, Mark F. McGranaghan, Surya Santoso and H.Wayne Beaty, “Electrical power system quality”, Mcgraw-Hill.

[2] H. Akagi, “Trends in active power line conditioners,” IEEE Trans. Power Electronics, vol. 9, no. 3, pp. 263-268, May 1994.

[3] K. Sangsun, and P. N. Enjeti, "A new hybrid active power filter (APF) topology", IEEE Transactions on Power Electronics, vol.17, no. 1, pp. 48-54, 2002.

[4] S. Rahmani, K. Al-Haddad and F. Fnaiech, “A Series Hybrid Power Filter To Compensate Harmonic Currents and Voltages”, *IEEE Industrial Electronics Conference IECON 2002*, Seville, Spain November 5 to 8 2002, pp. 644-649.

[5] F. Z. Peng, "Application issues of active power filters", IEEE Industry Applications magazine, vol. 3, no. 4, pp. 21-30, 1998.

[6] J.R.Vazquez & P.Salmeron, “Active power filter control using neural network technologies,” IEE Proc.-Electr.Power Appli., vol.150, no.2, March 2003.

[7] G. Bhuvaneswari and Manjula G.Nair “Three-Phase Hybrid Shunt Filters for Power Quality Improvement” Journal of Power Electronics, Vol. 7, No. 3, July 2007

[8] S. Suresh et al. / (IJAEST) International Journal Of Advanced Engineering Sciences And Technologies Vol No. 3, Issue No. 1, 001 – 011.

[9] Victor Fabián Corasaniti, Maria Beatriz Barbieri, “Hybrid Power Filter to Enhance Power Quality in a Medium-Voltage Distribution Network” IEEE TRANSACTIONS ON INDUSTRIAL ELECTRONICS, VOL. 56, NO. 8, AUGUST 2009.

[10] H.Akagi, “New Trends in active power line conditioning,” IEEE Trans. Indu.Applica., vol.32, no.6, Nov./Dec. 1996.

[11] Singh B., Chandra A., Al-Haddad K., “Computer aided modeling and simulation of active power filters”, Electrical machines and power systems, vol27, pp1227-1241,1999.

[12] S. K. Jain, Pramod Agarwal, H. O. Gupta, "Control strategies for active power filter," Electrimax-05 Conference Proc.2005 Paper no. 117, pp. 1-6..

[13] Chen, D. –H. and Xie, S. –J. Review of Control Strategies Applied to Active Power Filters. Proceedings of the IEEE International Conference on Electric Utility Deregulation, Restructuring and Power Technologies (DRPT). April 5-8, 2004. Hong Kong: IEEE. 2004. 666-670.

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