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DESIGN AND IMPLEMENTATION OF THREE PHASE SHUNT APF CURRENT CONTROLLER WITH ANN TECHNIQUE

S. Dhayanandh[1] and S. Manoharan[2]
[1]Department of Electronics and Communication Engineering, Kathir college of Engineering, Coimbatore, India
[2]Department of E and I, Karpagam College of Engineering, Coimbatore, India
E-Mail: dhayacbe79@gmail.com

ABSTRACT

The increasing use of nonlinear loads such as adjustable speed drives, electric arc welders and switching power supplies cause's large amounts of harmonic currents injects in to distribution system. LC passive filters are traditionally utilized to compensate the harmonic currents since they are simple and low cost solution. However, they are often large and heavy. In contrast, shunt active power filter purpose is to generate harmonic currents having the same magnitude and opposite phase with the harmonics produced by the nonlinear load and to ensure the supply currents contains only fundamental component. Adopting the advantage of indirect current control schemes i.e., absence of harmonic detector, this paper proposes an advanced control strategy to enhance the APF performance. In the proposed control scheme the supply currents are directly measured and regulated to be sinusoidal by an effective harmonic compensator, which is developed based on a PI and VPI controllers and implemented in the fundamental reference frame. In place of PI and VPI controller a new controller implemented with ANN technique applied as current controller for three phase Shunt Active Power Filter then THD will be further reduced and dynamic response of the system also reduced.

Keywords: active power filter, harmonic detector, current controller, ANN technique.

INTRODUCTION

Power Quality problem is an occurrence manifested as a nonstandard voltage, current or frequency that results in a failure of end user equipment. To compensate harmonics conventional Passive Filters are used for specific number of harmonics. To compress total harmonic content active power filters are used. For all types of power quality solutions at the distribution system voltage level DFACTS also called as Custom Power Devices are introduced to improve Power Quality. Harmonics are periodic sinusoidal distortions of the supply voltage or load current caused by non-linear loads. Harmonics are measured in integer multiples of the fundamental supply frequency. Using Fourier series analysis the individual frequency components of the distorted waveform can be described in terms of the harmonic order, magnitude and phase of each component. The study of power quality, and ways to control it, is a concern for electric utilities, large industrial companies, businesses, and even home users. The study has intensified as equipment has become increasingly sensitive to even minute changes in the power supply voltage, current, and frequency.Due to these problems[6], harmonic restriction standards such as IEEE-519 or IEC 61000-3-2 have been published to demand those harmonic currents injected into utility networks to be below the specified values [9]. In order to improve the power quality of distribution networks as well as to meet these restriction standards, two main solutions have been introduced: LC passive filters and active power filter (APF) [7].

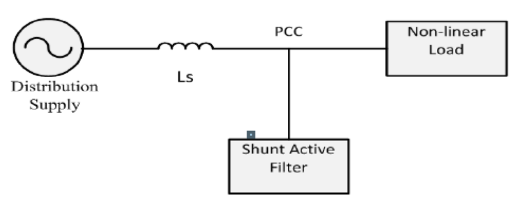

Figure-1. Shunt active filter network configuration.

It is the most widely used and dominant form of APFs to compensate the load current harmonics and reactive power as well. It is connected in parallel to the distribution supply at PCC and it injects harmonic current that is equal in magnitude to the load harmonic current but having 180 degree phase shift to cancel out the load current harmonics and the source current becomes sinusoidal. This configuration consists of four distinct categories of circuit, namely inverter configurations, switched-capacitor circuits, lattice structured filter and voltage-regulator-type filters.

PROPOSED CONTROL STRATEGY FOR APF

In order to simplify the control scheme and to enhance the accuracy of the APF, an advanced control strategy is proposed, as shown in Figure-2. The proposed control scheme is implemented by using only the supply current ($i_{Sa}$and i_{Sb}) without detecting the load current ($i_{S,abc}$) and filter current($i_{F,abc}$). The proposed control scheme can be implemented with only two loops, the outer voltage control and the inner current control. The outer loop aims to keep dc-link voltage of the APF constant through a PI controller, which helps the APF deal with load variations. The output of this control loop is the reference active current in the fundamental reference frame (i^*_{sq}).

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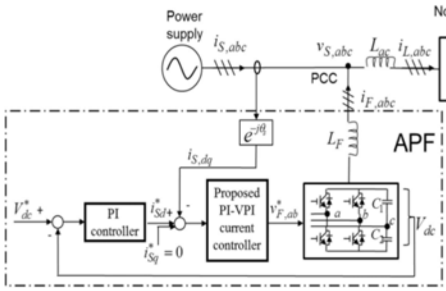

Figure-2. Typical control scheme of a shunt APF.

Meanwhile, the reference reactive current (i^*_{sq}) is simply set to be zero, which ensures the reactive power provided by the power supply to be zero. And, the reactive power caused by loads is supplied by the shunt APF [1]. The inner loop is then used to regulate the supply current in the fundamental reference frame (i_{Sdq}) by using the proposed PI-VPI current controller. The output of this loop becomes the control signal (v^*_{Fab}) applied to the four-switch APF which is implemented by the FSTPI. Since the current control is executed without the harmonic detector, the control performance of the APF only relies on the current controller.

PLL FOR SUPPLY VOLTAGE

Supply voltage is regularly not pure sinusoidal but contains harmonic components, which may affect to the accuracy of the PLL [4]. To overcome this problem, a band pass filter (BPF) tuned at the fundamental frequency of the supply voltage is implemented to reject all of the harmonic components contained in supply voltage, and its output contains only the fundamental component which is used as the input of the PLL block. Even though the BPF used in the PLL can cause a small time delay in tracking the phase angle of the supply voltage, it is negligible because the PLL usually operates at steady-state condition before the APF is active.

SUPPLY CURRENT CONTROL LOOP

This loop regulates the supply current by means of the proposed current control scheme shown in Fig-3. The reference active current i^*_{Sd} is the output of the dc-link voltage control loop, while the reference reactive current i^*_{Sq} is simply set to be zero. Consequently, the reactive power caused by loads can be fully compensated by the APF, and also unity power factor condition is achieved at the supply side.

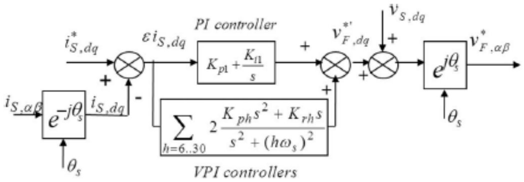

Figure-3. Block diagram of the proposed current control scheme.

CONTROL SIGNAL COMPUTATION FOR FOUR SWITCH 3φ- INVERTER

The circuit diagram of the four-switch three-phase dc/ac converter when fed by a single-phase or a three-phase diode rectifier. The three-phase solution is shown in Figure-4. The B4 inverter employs four switches and four diodes to generate two line-to-line voltages and, where as is generated according to Kirchhoff's voltage law from a split.

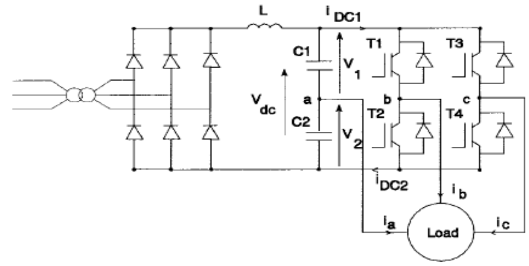

Figure-4. Three-phase rectifier capacitor bank.

Due to the circuit configuration, the maximum obtainable peak value of the line-to-line voltage equals In order to get a higher dc-link voltage, an input transformer can be considered as shown in Figure-4. For the analysis, the inverter is considered to be built by ideal switches. The output voltages are defined by the gating signals of the two leg switches and by the two dc link voltages and this way, it is further possible to take into account the influence of the variations of the voltage across the two dc-link capacitors. The expressions of the output voltages and the dc-link currents yield by writing the Kirchhoff equations for the load, and taking into consideration two switching functions for the two inverter legs.

DC-LINK VOLTAGE CONTROL LOOP

This control loop aims to keep dc-link voltage of the shunt APF constant through a simple PI regulator, whose output is the reference active current in the fundamental reference frame as follows:

$$i^*_{sd}=(K_{pdc}+K_{idc}/s)(V^*_{dc}-V_{dc}) \qquad (1)$$

Where $K_p$dc and $K_i$dc are the proportional and integrator gains of the PI controller, respectively, and V^*dc and Vdc are reference and measured dc-link voltages of the APF, respectively. In fact, since the four-switch APF has only two switching legs, the four-switch APF needs a higher dc-link voltage reference(V^*dc). In addition, since the dc-link voltage of the APF contains small ripples at harmonic frequencies due to harmonic currents, a low-pass filter (LPF) is designed to eliminate all ripples in the feedback measurement of the dc-link voltage, which helps in smoothing the reference current i^*_{Sd}. In the proposed control scheme, the role of the dc-link voltage controller is not only to ensure a proper operation of the APF but also to help the APF deal with load variations. Hence, by detecting and regulating the dc-link

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voltage, the shunt APF can recognize and respond against load variations without the load current measurement.

CONTROL SIGNAL COMPUTATION FOR FOUR SWITCH APF

The four-switch APF is introduced by replacing the traditional three-phase VSI with the FSTPI without degrading the performance of the proposed control strategy. The FSTPI, which is composed of four power switching devices and two split capacitors, has been applied for low-cost ac motor drives. Current controller is changed into control signals of the four-switch APF as the following equations:

$$v^*_{Fa}=\sqrt{(3/2)}\,v^*_{F\alpha}+\sqrt{(1/2)}\,v^*_{F\beta} \qquad (2)$$

$$v^*_{Fb}=\sqrt{2}\,v^*_{F\beta} \qquad (3)$$

where v^*_{Fa} and v^*_{Fb} are the control signals for leg a and b of the four-switch APF, respectively.

CURRENT CONTROLLER DESIGN

In order to designing of PI-VPI controller and investigate the effect of these gains on control performance, the closed-loop transfer function of the PI-VPI current controller defined. By selecting the resonant gains $K_{rh}= K_{ph}R_F/L_F$ and $K_{i1}= Kp1RF/LF$, In fact, $Kp1$ is the integrator gain of the PI controller that does not affect the harmonic compensation performance of the VPI controller. Thus, for the sake of simplification, $Kp1$ is kept constant, and $K_{ph}$is changed to determine the control performance of the VPI controller [5]. VPI controller is more selective and obtain better steady-state performance if $K_{ph}$is a smaller value. In harmonic compensation application, the steady-state performance is regarded as the most critical index

DESIGN OF THE ARTIFICIAL NEURAL NETWORK

The artificial neural network simulator processes the Ii's corresponding to each section and determines if the section should be recommended or not. It is organized in three layers of neurons, the input neurons that receive the information from the input processor, the hidden neurons that link the neurons in the other two layers, and the output neurons (only one in this case) that sends the results to the output processor.

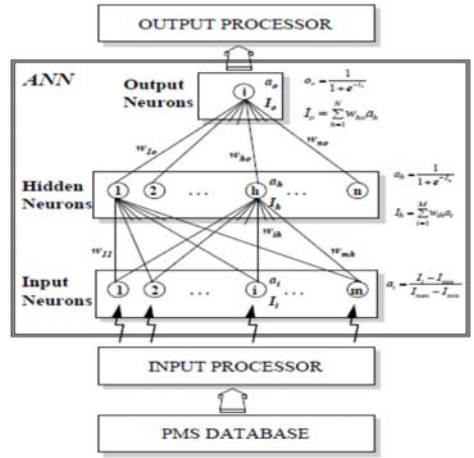

Figure-5. Scheme of the Artificial Neural Network.

The first step conducted by the neural network simulator is to process the input of each neuron *i* of the input layer, *Ii*, to a scale of 0 to 1; this is the activation level, *ai*, of the neuron *i*. The scaled values or activation levels are transmitted to all connected neurons in the hidden layer.

At the hidden layer, each neuron *h* computes its input, I_h, adding the level of activation (*ai*) of all connected input neurons weighted by the weights of the connections (*wih*). This input $I_h$is then processed to an activation level, *ah*, using an *activation functional*= $f(I_h)$. At the output layer, the input for the output neuron, *Io*, is computed adding the *ah* 's of the connected hidden neurons weighted by the connection weights (*who*). This input *Io* is processed to the output of the network, *oo*, using the activation formula. Finally, the output processor translates the numeric output received from the simulator.

SIMULATION MODEL OF SHUNT ACTIVE POWER FILTER WITH DISTRIBUTION SYSTEM

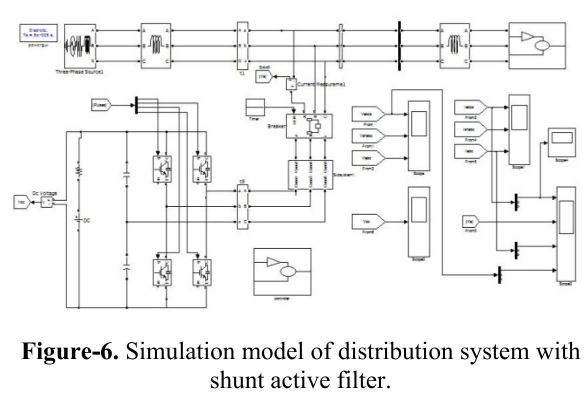

Figure-6. Simulation model of distribution system with shunt active filter.

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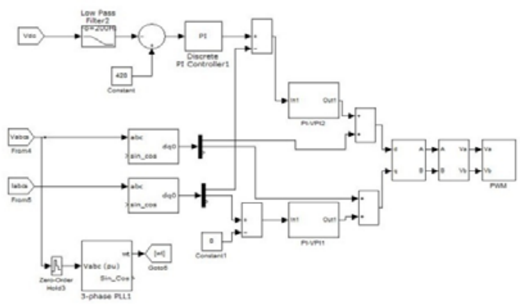

Figure-7. Simulation model of control circuit.

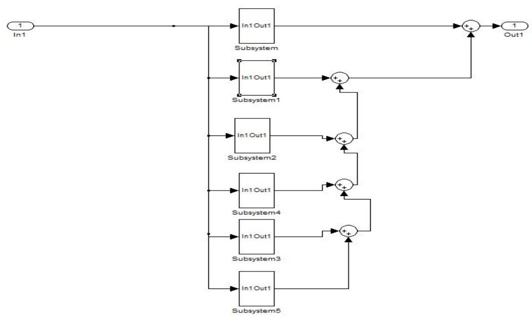

Figure-8. Simulation model of PI+VPI controller.

SIMULATION MODEL OF ANN CONTROLLER

In this ANN controller feed forward, two layer networks can be used as current controller and its simulation model as shown in Figure-9. In this two ANN blocks are connected in place of PI+VPI controllers. The error signal is given to the ANN controller which gives voltage signal and it is added to the supply voltage and it generates the reference for the generation gate pulses for 4-switch three phase inverter.

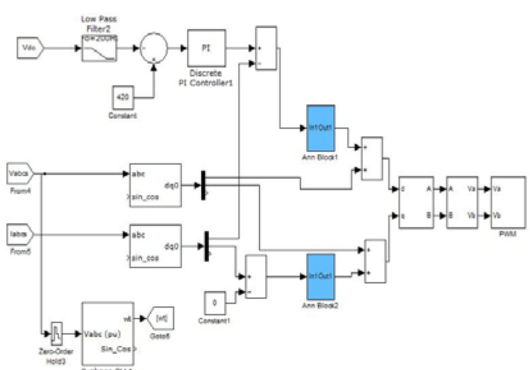

Figure-9. Simulation model of control circuit with ANN controller.

SIMULATION RESULTS WITH ANN CONTROLLER

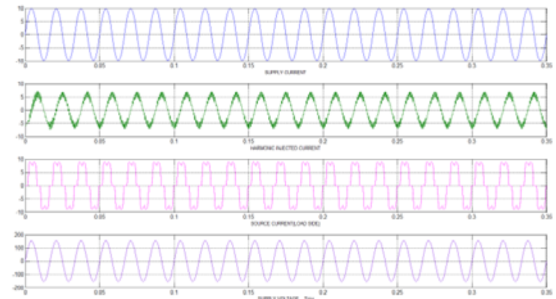

Figure-10. Steady state performs with ANN controller for RL load.

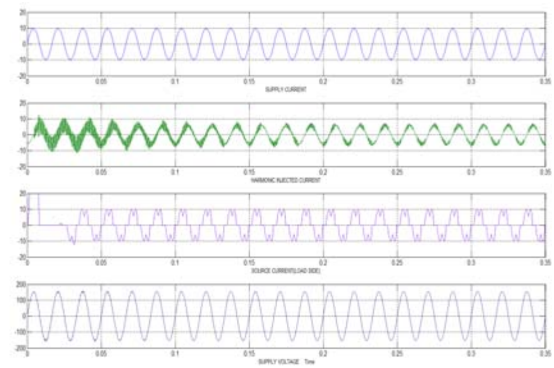

Figure-11. Steady state performs with ANN controller for RLC load.

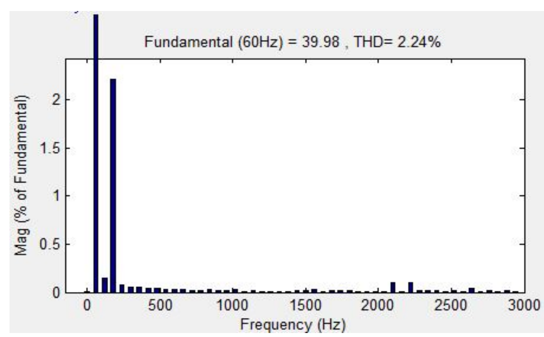

Figure-12. THD factors with ANN controller for RL load.

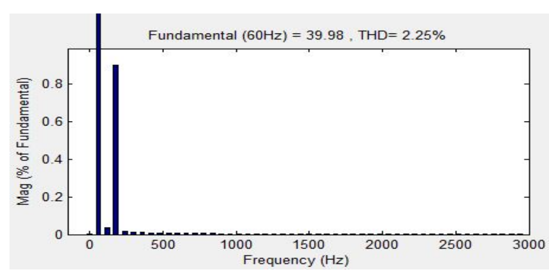

Figure-13. THD factors with ANN controller for RLC load.

EXPERIMENTAL RESULTS

The system consists of a 1.5-kVA shunt APF and a 3-kVA nonlinear load with the parameters listed in following Table.

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Table-1. System parameters.

Supply voltage RMS line-line	**127V**
Supply frequency	50Hz
5^{th} harmonic supply voltage	10% of the fundamental component
7^{th} harmonic supply voltage	10% of the fundamental component
DC link reference voltage for the six switch APF V_{dc}^*	260v
DC link reference voltage for the four switch APF V_{dc}^*	420v
DC-link capacitor for four switch APF C_1=C_2	1000µF
DC-link capacitor for four switch APFC= $C_{1+}C_2$	2000µF
Filter resistance R_F	0.05Ω
Filter inductance L_F	2mH
Nonlinear RLC load	$R_{L(min)}$=12.5 Ω $R_{L(max)}$=20 Ω L_L=1mH C_L=2200 µF

Figure-10 show that the harmonic currents are effectively compensated and the supply current is almost sinusoidal with a small THD factor of approximately 2.2% whereas the load current is highly distorted with the THD factor of 25.2%. From these results, the effectiveness of the proposed control scheme is verified and harmonic currents are effectively compensated without load. It is verified through experiments that the proposed control strategy has good steady-state performances as well as good dynamic responses with both nonlinear RL and RLC loads. In majority of previous studies, the supply voltage has usually been assumed to be an ideal sinusoidal, but this voltage condition is rare in practical networks. The non-sinusoidal supply voltage condition in practical networks may adversely affect the control performance of the APF. To verify the effectiveness of the proposed control algorithm under such conditions, experiments were carried out where the supply voltage was injected with fifth and seventh harmonic components of 10% and 5%magnitudes of the fundamental component, respectively. The results are illustrated in Figure-16.

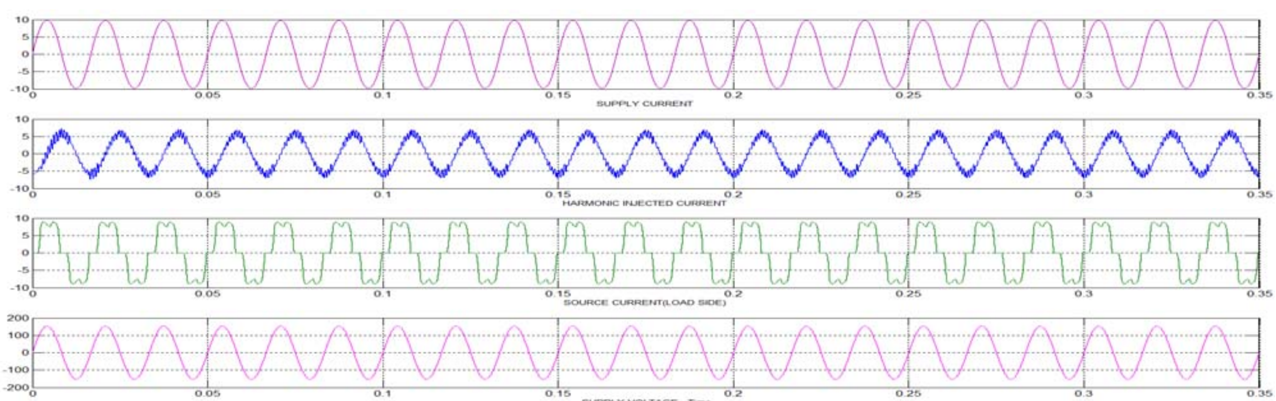

Figure-14. Steady-state performance with proposed control scheme under RL load.

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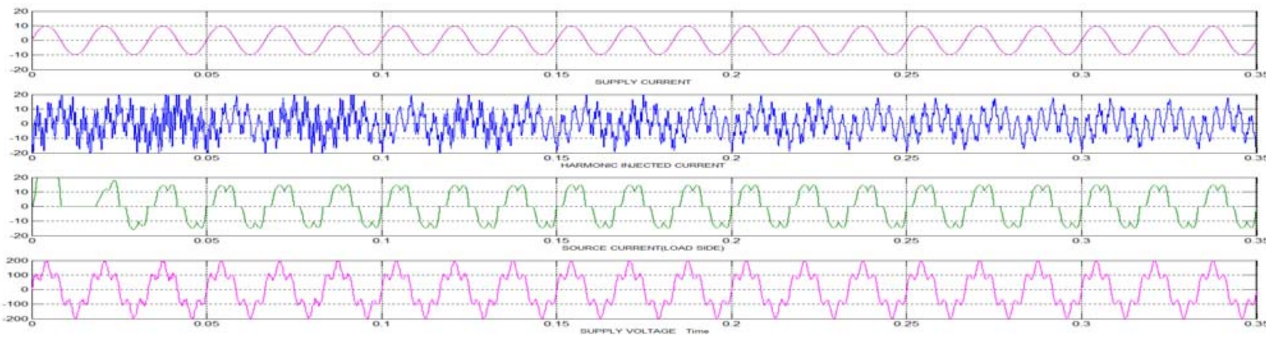

Figure-15. Steady-state performance with proposed control scheme under RLC load.

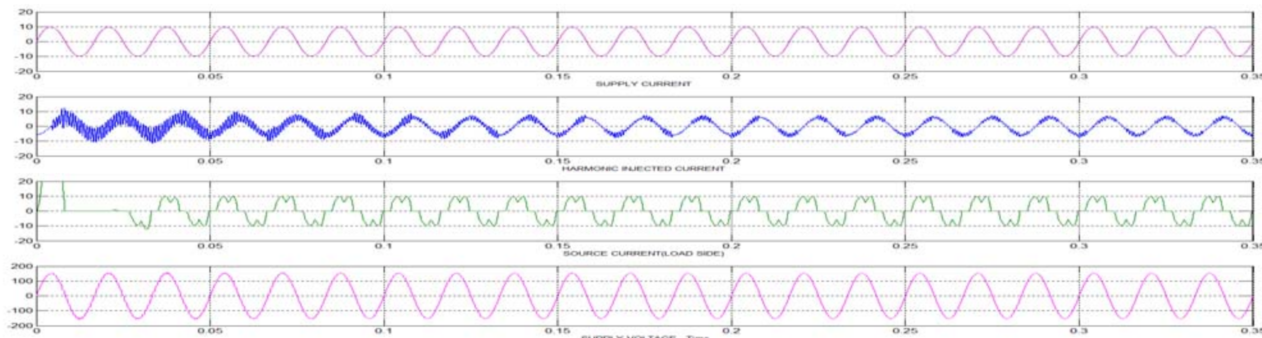

Figure-16. Steady-state performance of the proposed control scheme under distorted supply voltage condition with RL load.

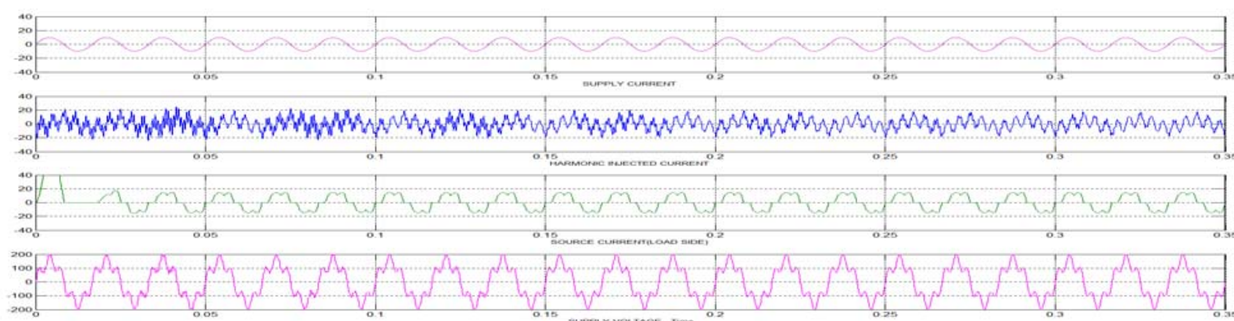

Figure-17. Steady-state performance of the proposed control scheme under distorted supply voltage condition with RLC load

As shown in Figure-16, the harmonic compensation performance of the APF is not deteriorated by the distorted supply condition where the supply current was also close to sinusoidal and similar with the results shown in Figures 15 and 14. Where an ideal sinusoidal supply voltage is given. There are only small increases in THD factors, approximately 2.32% and 2.38% for the cases of nonlinear RL and RLC loads, respectively.

THD factor for PI+VPI controller with RL and RLC load

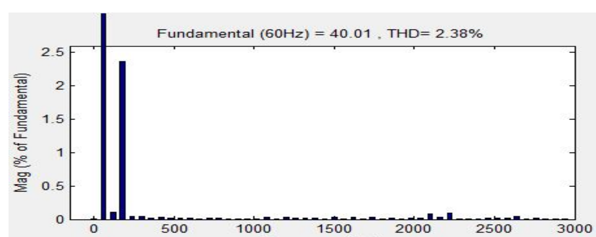

Figure-18. THD factor of RL load.

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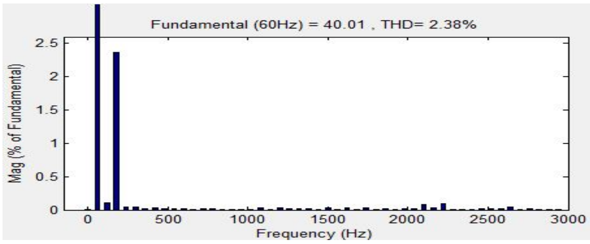

Figure-19. THD factor of RLC load.

FUTURE ENHANCEMENTS

The performance of shunt Active Power filter can be improved further in place of two level voltage source inverter multilevel inverter used as Shunt active power filter and harmonics in source voltages can be eliminated by implement as hybrid filter. This work is based on three phase three wire system and the active filter does not work well if there is a zero sequence in the supply voltage. In future, a detailed analysis can be carried out for a 3 phase four wire filter in order to compensate the zero sequence present in the system.

CONCLUSIONS

The shunt APFs are recognized as a flexible solution for harmonic current compensation. Since they are capable of compensating harmonic currents generated by nonlinear loads as well as providing a fast responses to load variations. Due to reactive power compensation by shunt active filter the power factor will be maintained unity. The PI controller is not suitable for higher order harmonic compensation. PI plus Resonant controller is used for compensating the harmonic currents but in the frequency response an undesirable peaks are appeared. Due to this the stability margin will be reduced. Here ANN technique is used to further reduce THD of supply current, dynamic response.

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