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PERFORMANCE OF SHUNT HYBRID COMPENSATOR FOR POWER QUALITY IMPROVEMENT USING SIMPLE CONTROL STRATEGY

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ABSTRACT

A simple and straight forward control scheme for reference current generation for improving power factor and reduction of harmonics in a distribution system employing hybrid filter is presented. The use of a shunt hybrid configuration retains the advantages of lower cost and simplicity of the passive filter along with reduced rating of the active filter. The suggested control strategy is based on the extraction of reference current from source voltage of one phase and source currents that minimize the number of sensors and complexity of control scheme. By focusing on the deviations of dc link voltage across the capacitor which is caused by harmonic components in the load currents the correction mechanism straight away utilizes the deviations by processing via a conventional PI controller generates the reference current. This proposed model has been demonstrated through the simulation using MATLAB Simulink software under various operating conditions. The results obtained are compared and presented.

Keywords: shunt hybrid power filter (SHPF), active filter, passive filter, reactive power compensation, harmonics, total harmonic distortion (THD).

1. INTRODUCTION

Nowadays, the power quality based issues are of at most concern due to the growth of power electronic based equipment. In industries in order to reduce the mechanical maintenance, reduction of the power consumption and production cost, processed power is used. The power electronics based power converters are employed for achieving the processed power to supply variable speed motor drives. The uncontrolled rectifiers present at the front end of the power converters in variable speed drives cause injection of harmonics into the distribution system due to their non-linear characteristic and make the input power factor poor[1][2]. The harmonics cause several problems like transformer overheating, increased losses, harmonic resonance in the utility, protection device malfunctioning, misfiring of variable speed drives, heating of electrical equipment and torque pulsation in motors.

The harmonics present in the supply system have been reduced by using various types of power filters. Passive filters are more economical but resonance and tuning of filters are the major problems of these filters [3] [4]. Alternatively series and shunt active filters have been used for reduction of harmonics but they require a current transformer and power semiconductor devices to withstand the high-current during compensation[5] [6] [7] [8]. To mitigate the drawbacks of above said filters various types of hybrid-power filter topologies and their control techniques have been reported in the literature [9] [10] [11]. In most of the control techniques, Proportional-integral controller has been implemented for active power filters and its dc-link voltage regulation [12] [13] [14]. In this work a hybrid filter topology consisting of active power filter connected in series with parallel combination of selective 5th and 7th harmonic elimination passive filters have been implemented with simple control strategy. In this control strategy indirect control of current method has been adopted to extract the harmonic content from the load current. PI controller is implemented for 3-phase SHPF to generate reference current from the dc link voltage. It is shown that of there is no power loss in the compensator and there is no real power drawn from it then the dc capacitor voltage is maintained constant. During transient states, the active power is supplied by the capacitor when load increases. The supply current alone is involved directly for the control of harmonics in this simple control strategy and hence, there is no delay in compensation of harmonics and it needs only few sensors[15]. The efficacy of this control strategy has been proven by the results obtained from the simulation.

2. THREE PHASE SHPF CONFIGURATION AND MODELING

Figure-1 presents the shunt hybrid power compensator topology for the reduction of harmonics in power distribution system. The non-linear loads preferred in this work are 3phase full bridge diode rectifier fed RL load and RC loads. Voltage source inverter employing IGBT's as semiconductor switches has been used as active power filter. The passive filter contains parallel combination of selective 5th and 7th harmonic elimination filters. The gate signal for the semiconductor switches of the active filter has been generated by pulse width modulation technique with the carrier frequency of 10 kHz. A purely sinusoidal supply current is obtained by eliminating the harmonics present in the system due to non-linear loads by injecting current harmonics in opposite phase with respect to reference waveform by the hybrid compensator.

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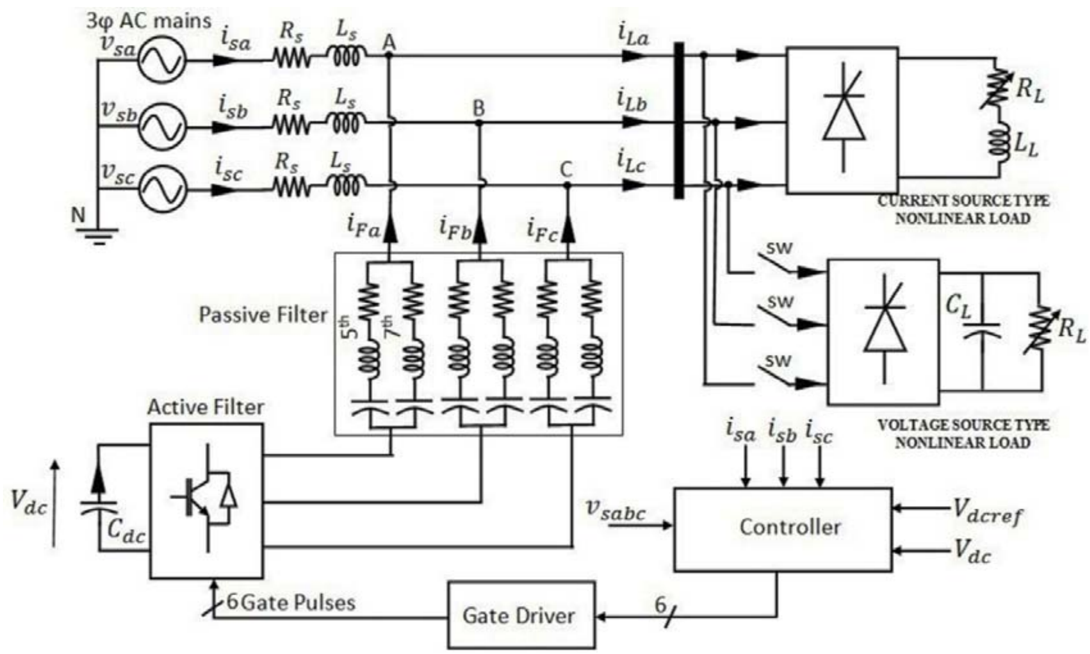

Figure-1. Block diagram for 3 phase SHPF.

The mathematical modeling of the proposed hybrid compensator system has been obtained to implement the control strategy [8] [16]. The instantaneous supply current for one phase is expressed by applying Kirchhoff's current law at node A in the Figure-1 which yields

$$i_{sa}(t) = i_{La}(t) - i_{Fa}(t) \tag{1}$$

where, $i_{Fa}(t)$ is reckoned as an injected current from the shunt hybrid filter. The supply voltage is given by

$$v_{sa}(t) = V_m \sin \omega t \tag{2}$$

The source current contains harmonics and fundamental currents due to the presence of non-linear load in the distribution system and generally it can be expressed as,

$$I_L(t) = \sum_{n=1}^{\infty} I_n \sin(n\omega t + \phi_n) \tag{3}$$

$$I_L(t) = I_1 \sin(\omega t + \phi_1) + \sum_{n=2}^{\infty} I_n \sin(n\omega t + \phi_n) \tag{4}$$

The instantaneous value of the load power is calculated from load current and supply voltage as,

$$p_L(t) = i_s(t) \times V_s(t)$$

$$= V_m I_1 \sin^2 \omega t \ \cos\phi_1 + V_m I_1 \sin \omega t \ \cos \omega t \ \sin\phi_1 + V_m \sin \omega t \times \left(\sum_{n=2}^{\infty} I_n \sin(n\omega t + \phi_n) \right) \tag{5}$$

The above power can be further expressed in general form as,

$$p_L(t) = p_{Fundamendal}(t) + p_{\mathrm{Re}active}(t) + p_{Harmonic}(t) \tag{6}$$

From the above equation it is clear that the load power consists of real, reactive and harmonic power components. The real power is expressed as

$$p_{Fundamental}(t) = V_m I_1 \sin^2 \omega t \cos\phi_1 \tag{7}$$

Depending on the requirement of non-linear load if the harmonic power and reactive power are supplied by the designed filter then the supply current can be in phase with the supply voltage[6]. After compensation the three phase source currents can be expressed as,

$$i_{sa}^{*}(t) = \frac{p_{Fundamental}(t)}{v_s(t)} = I_1 \cos\phi_1 \sin \omega t = I_{\max} \sin \omega t \tag{8}$$

where, $i^{*}_{sa}(t)$ can be interpreted as the desired or reference current

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Similarly,

$$i_{sb}^{*}(t) = I_{\max}\sin(\omega t - 120°) \quad (9)$$

$$i_{sc}^{*}(t) = I_{\max}\sin(\omega t + 120°) \quad (10)$$

The reference current peak magnitude I_{max} is calculated from the PI controller which regulates the dc link capacitor voltage.

3. CONTROL STRATEGY

The control block diagram of simple current control technique using PI controller is shown in Figure-2. This block diagram contains two major parts. While extraction of reference current is done by PI controller with unit current vector a PWM generator with IGBT's based voltage source inverter acts as an active filter. It has been clearly shown in Figure-2 that the dc link voltage of the capacitor is sensed (V_{dc}) and compared with the reference value (V_{dcref}). The error signal obtained from the comparison has been processed through the PI controller[7]. The output of the PI controllers is given as

$$I_{\max}^{*} = K_P(V_{dcref} - V_{dc}) + \frac{K_I}{s}(V_{dcref} - V_{dc}) \quad (11)$$

where, $I_{\max}^{*}$ is the PI controller output which decides the reference current peak value. K_P and K_I are the parameters of PI controller.

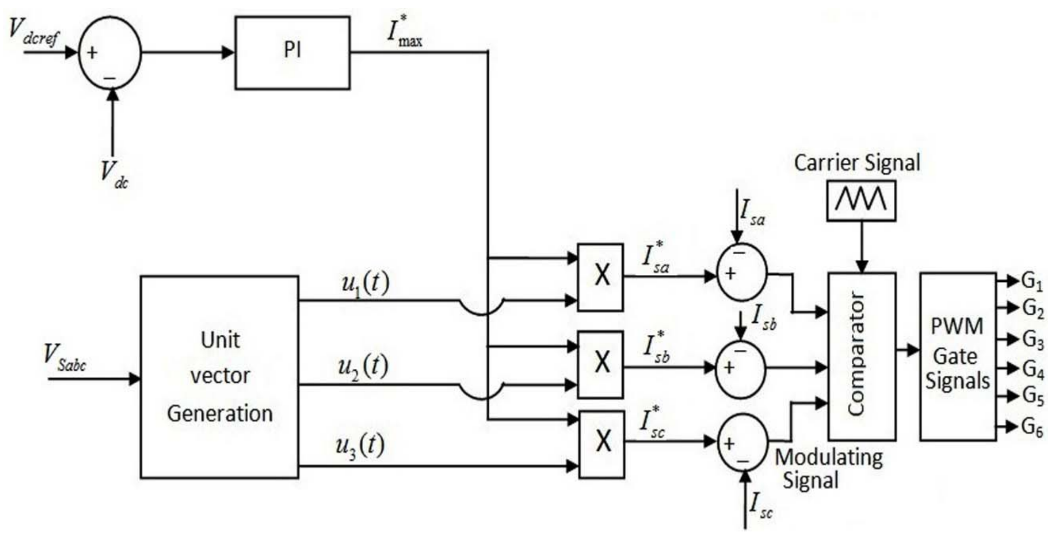

Figure-2. Block diagram of current control scheme with PI controller.

PI controller parameter values are adjusted to maintain the dc link voltage against deviation from its reference value [6] [14]. In this work K_P value is obtained using the derivation $K_P = 2\xi\omega_n C$ and K_I value is calculated using $K_I = C\omega_n^2$. where, ξ is damping factor, ω_n is natural frequency chosen as the supply frequency. Regulating the dc link voltage is an important function of the PI controller against the disturbances due to load variation, sag and swell. The perturbations in the dc link voltage are the function of variation in the average power of nonlinear load. This property has been utilized to generate reference current [15]. The output of the PI controller has been multiplied by a three phase sinusoidal unit current vector deduced from the source voltage. This makes the supply current in phase with supply voltage which leads to unity power factor operation of three phase system. Generation of unit vector for reference estimation is given below:

$$u_1(t) = \frac{v_{sa}(t)}{V_{\max}} = \sin\omega t \quad (12)$$

$$u_2(t) = \sin(\omega t - 120) \quad (13)$$

$$u_3(t) = \sin(\omega t + 120) \quad (14)$$

where, $u_{123}(t)$ are the unit sine wave and $v_{sa}(t)$ is the supply voltage with maximum value of $V_{\max}$

The PI controller output peak current is multiplied with unit vector in order to generate the reference current for the control strategy. The reference currents are obtained as given below:

$$i_{sa}^{*}(t) = u_1(t)\times I_{\max}^{*} = I_{\max}^{*}\sin\omega t \quad (15)$$

$$i_{sb}^{*}(t) = u_2(t)\times I_{\max}^{*} = I_{\max}^{*}\sin(\omega t - 120°) \quad (16)$$

$$i_{sc}^{*}(t) = u_3(t)\times I_{\max}^{*} = I_{\max}^{*}\sin(\omega t + 120°) \quad (17)$$

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where, $i^*_{sabc}(t)$ are the reference currents in sinusoidal form with the frequency of ω.

The reference current obtained in the above step has been compared with actual source current and then the difference is sent to PWM generator to generate gate pulses for the active filter in hybrid scheme. In many active filter control applications PWM type of gating signal generation has been preferred to fire the semiconductor switches. The three phase active filter contains three legs with each leg having two switches which are operated alternatively in order to avoid short circuit. Hence three reference current waveforms obtained above are compared with one triangular carrier to produce gating signals for the upper arm switches while the inverted gating signals are given to the lower arm switches. The gating pulses drive the active filter to inject the reference current into the point of common coupling in order to mitigate the harmonics present in the source current and also to force it to have same phase relationship with source voltage. In this control strategy the supply current and reference currents generated by PI controller are compared directly and hence only few sensors are needed for the sensing of supply current, which makes the control strategy very simple.

4. MATLAB MODEL OF SHUNT HYBRID COMPENSATOR

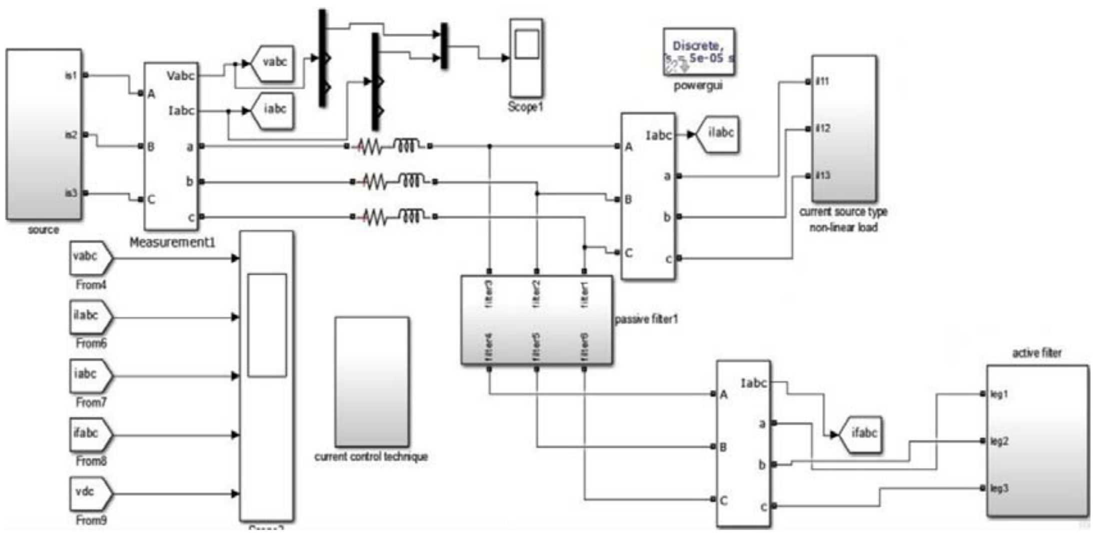

Figure-3. Shunt hybrid compensator model in Matlab.

Figure-3 shows the model of shunt hybrid compensator system in MATLAB. The nonlinear load used in the simulation has been modeled using three phase diode bridge rectifier supplied from three phase ac mains. The output side of the rectifier connected to RL type load and RC type load resembles current source type and voltage source type nonlinear loads respectively. The active filter is modeled by using IGBT switches based three phase inverter terminated by a dclink capacitor. In this model active filter is connected in series with the parallel combination of selective 5^{th} and 7^{th} harmonic elimination passive filters. A measurement block is connected with the hybrid filter as well as dc link capacitor for filter current and voltage measurement. The control block consists of reference current generation system and PWM gating signal generation blocks. Series inductor and resistor have been connected between the load terminals and source terminals in order to realize system impedance. The entire system simulation has been carried out in a discrete mode at variable step size with ode 45 (Dormand-Prince) solver.

5. SIMULATION RESULTS

The simple control strategy proposed in this work for shunt hybrid compensator is simulated using power system block set of Matlab/Simulink software. The performance improvement of the hybrid compensator using the proposed control strategy has been analysed for different types of nonlinear loads and its dynamic variations. Table-1 shows the parameter characterising the 3-phase non-linear system.

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Table-1. Parameter specifications.

Supply side phase voltage	230V, 50 Hz
Dc link capacitor value	6600μF
V_{dc} reference voltage	50V
Line impedance	R_s =0.1Ω, L_s =4mH
PI controller parameters	Kp=0.5, Ki=16.5
Current source type nonlinear load	R_L = 26 Ω, L_L = 10mH
Voltage source type nonlinear load	R_L = 32Ω, C_L =1000μF

5.1 Harmonic reduction in current source type nonlinear load

A three phase diode bridge rectifier feeding a RL load at its dc side represents a nonlinearity causing flow of harmonic currents in the distribution system. The simulation results at steady state of the hybrid compensator controlled by using the proposed strategy are shown in Figures 5(a)-(e), which depict the waveforms of supply voltages (V_{S123}), currents in the Load (I_{L123}), supply currents (I_{S123}), compensator currents (I_{F123}) and dc link voltage respectively. It is clearly shown in the figure that the source current waveform after compensation is nearly sinusoidal. Figures 4(a) and (b) depict the harmonics spectrum of the source current without and with filter respectively, indicating the THD being reduced from 23.25% before filtering to 3.93% after filtering.

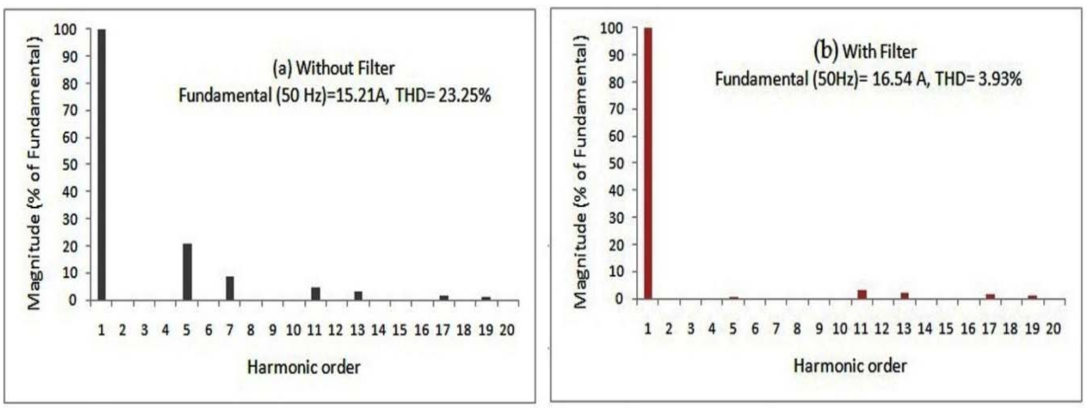

Figure-4. FFT spectrum of Source current for Rectifier fed RL load.

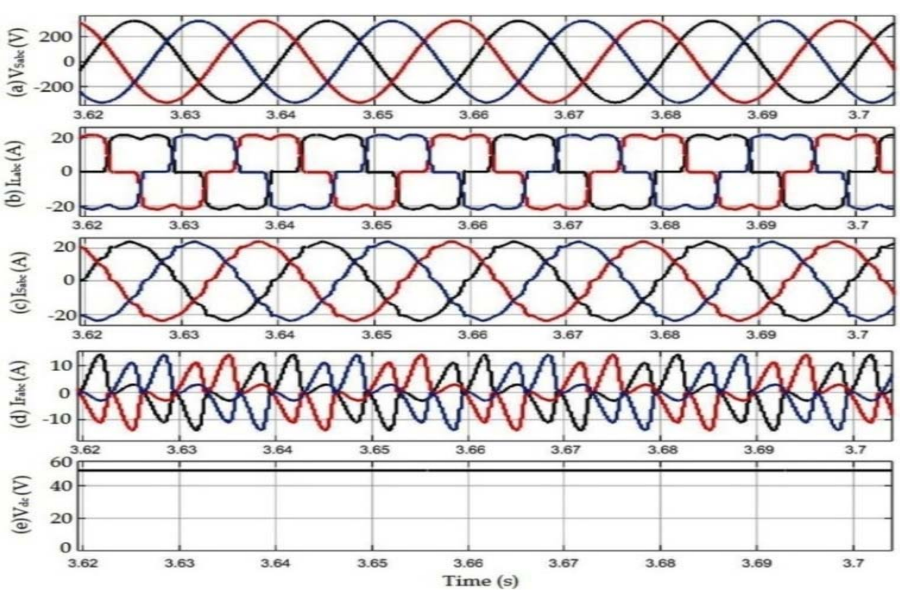

Figure-5. Performance of the filter for rectifier fed RL load.

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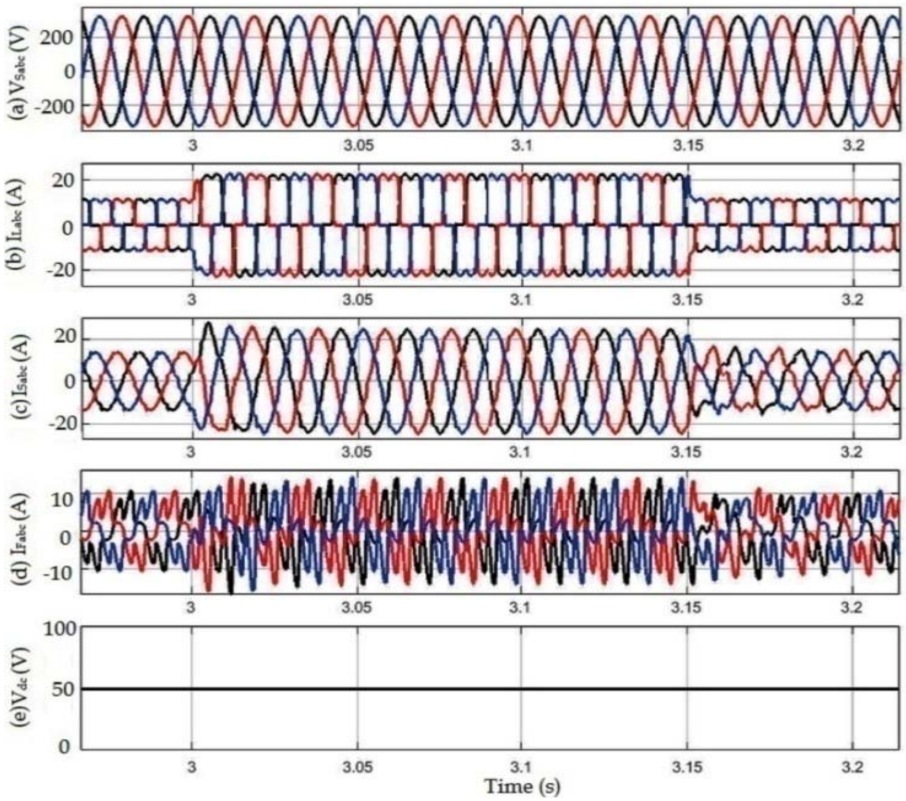

Figure-6. Performance of the filter for dynamically Varying RL load.

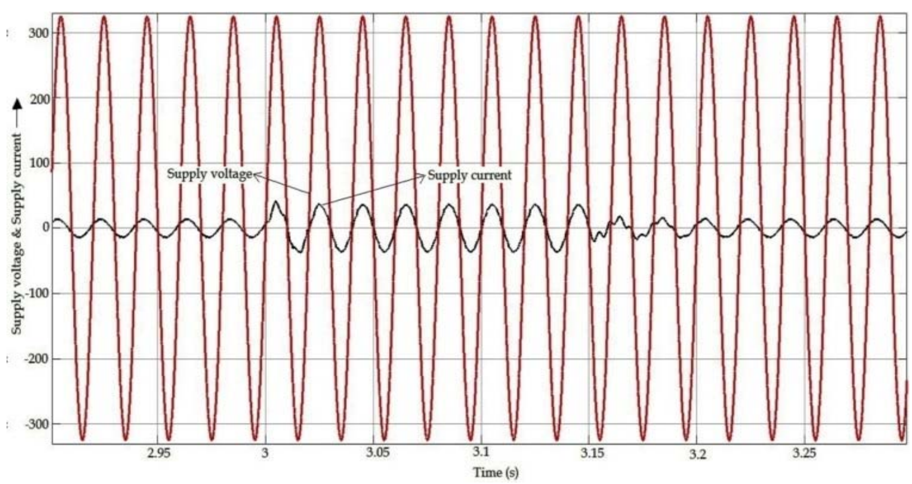

Figure-7. Supply voltage and current waveforms after compensation.

5.2 Dynamically varying rectifier fed RL type nonlinear load

In real time situations the loading conditions of the distribution system can change frequently. Hence it is necessary that the designed filter is able to handle the dynamic variation of load currents. Figure-6(a)-(e) exhibit the simulation response of the hybrid filter under dynamically varying load current conditions. The mains voltages (V_{Sabc}), load currents (I_{Labc}), mains currents (I_{Sabc}), filter currents (I_{Fabc}) and dc link voltage are shown in the figure for a step increase in the load current at t=3 sec and restoration of the same to the previous value at t= 3.15 sec respectively. It is found that the hybrid filter is capable of quickly compensating the harmonic currents following both the disturbances. Figure-7 shows the phase relationship between supply side phase voltage and phase current after compensation covering the entire interval of simulation run. The waveforms indicate the in-phase behavior of the source voltage and current, leading to power factor close to unity.

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5.3 Response to voltage Source type nonlinear load

The simulation has been carried out by replacing the nonlinear load as voltage source type and the performance of the hybrid filter has been presented in this section. Figures 9(a)-(e) show the simulation results at steady state of the simple control strategy for harmonic reduction by the shunt hybrid compensator. The waveforms of supply voltages (V_{Sabc}), currents in the load (I_{Labc}), supply currents (I_{Sabc}), filter currents (I_{Fabc}) and dc bus voltage are depicted. The source current waveform clearly shows that the distortion present in the current is meagre. Further, dc link voltage waveform across the capacitor is found to be maintained constant through the interval. The harmonic spectrum of the source current before and after filtering is shown in the Figures 10 (a) and (b) respectively. The corresponding Total Harmonic Distortion is reduced from 29.55% to 4.69%, which shows the performance improvement by the hybrid filter with proposed control strategy.

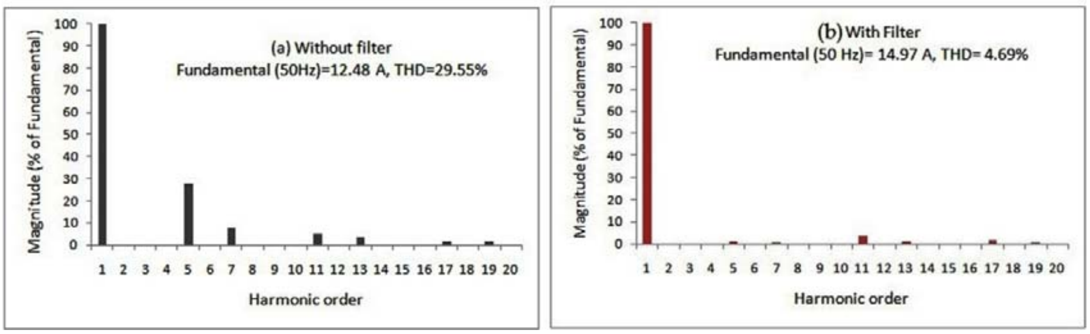

Figure-8. FFT analysis for rectifier fed RC load.

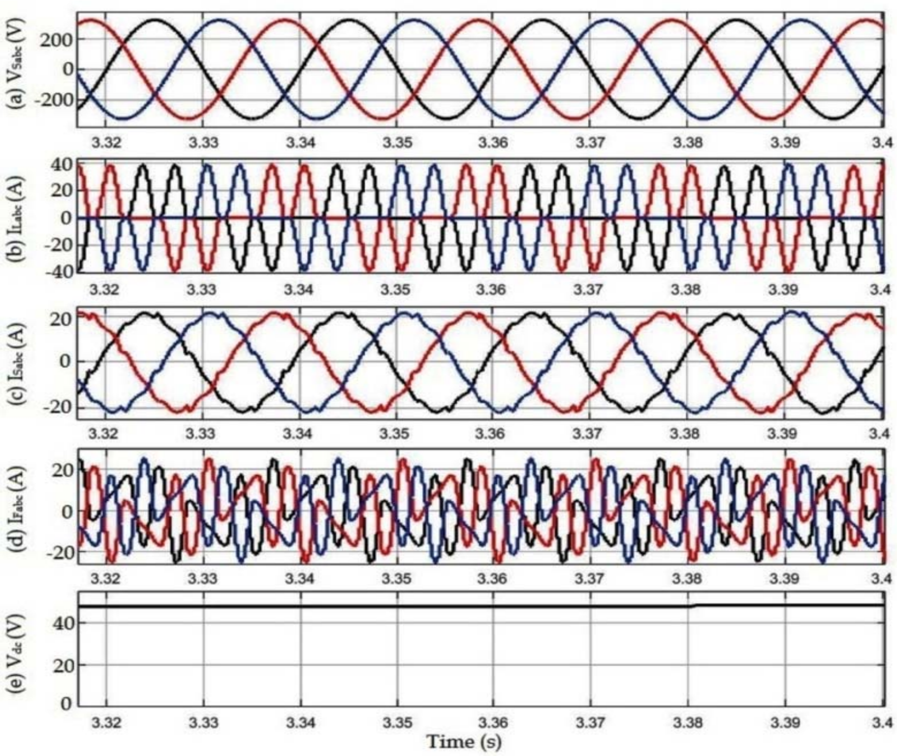

Figure-9. Response of the filter for Rectifier fed RC load.

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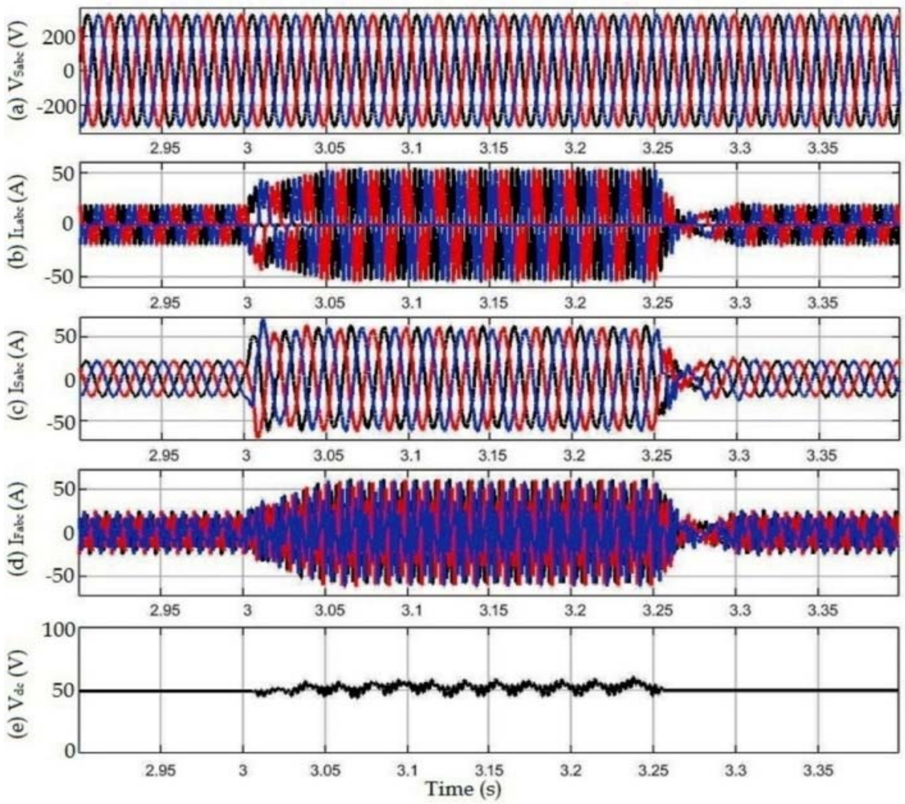

Figure-10. Response to dynamically varying RC load.

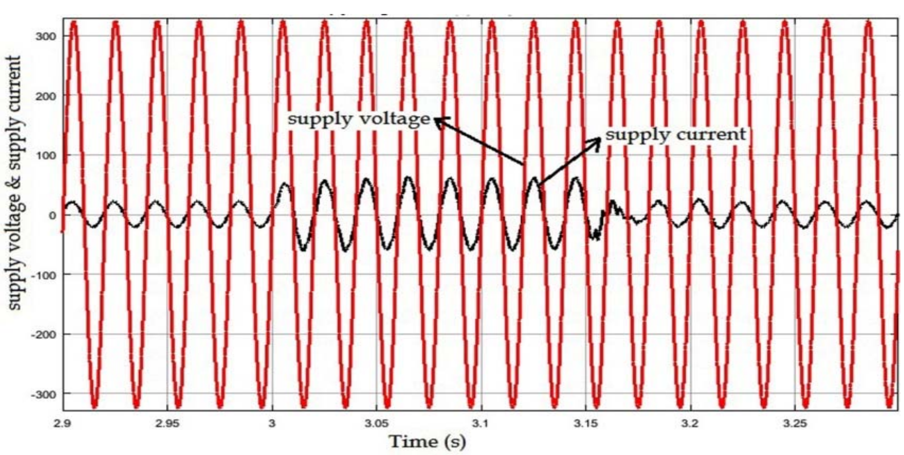

Figure-11. Source voltage and current waveform under varying load condition.

5.4 Response to dynamic variation in rectifier fed RC type nonlinear load

The response of the proposed compensator in transient operation has been evaluated by incorporating a step increase and decrease in the load current of about 100% at t=3sec and t=3.15 sec respectively. Figure-10 shows the simulation performance of the compensator under dynamically varying load condition. The waveforms clearly depict the dynamic response of the hybrid filter for the sudden variation in load current. The source voltage and current waveforms after compensation for phase 'a' has been shown in Figure-11 which shows that the power factor of the system is maintained nearly unity.

CONCLUSIONS

The proposed simple current control technique with conventional PI controller has been implemented for three phase SHPF to enhance the system response under steady and dynamic state conditions. This control technique is very simple and cost effective one when compared with various control techniques reported in the literature. This technique has an advantage of obtaining

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current reference without measuring the load or filter current; hence the number of sensors required for to implement this control strategy is very less compared to other methods. The THD of source current has been reduced from 23.25% befor filtering to 3.93% after filtering for rectifier fed RL type nonlinear load. In case of voltage source type nonlinear load the THD has been reduced from 29.55% to 4.69%. The THD of source current has been reduced by less than 5% as specified by IEEE 519-1992 standard even if the load current varies dynamically. The results clearly shows that the proposed control strategy with the hybrid filter is able to compensate current harmonics with improved power factor for both voltage and current source type of nonlinear load and its variation. Hence the performance of the control scheme is found to be better for various types of nonlinear loads.

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