A NOVEL APPROACH FOR HARMONICS ELIMINATION BY PWM TECHNIQUE USING SHUNT ACTIVE FILTER IN MATLAB

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*Abstract***— This paper deals with a parallel 3-phase active filter to eliminate harmonics and to compensate the reactive power of the non-linear loads. A 3-phase voltage source inverter bridge with a dc bus capacitor is used as an active filter (AF). A hysteresis current control and PWM current control is employed to derive the switching signals to the AF. Source reference currents are derived using load currents, dc bus voltage and source voltage. The command currents of the AF are derived using source reference and load currents. A 3- phase diode rectifier with capacitive loading is employed as the non-linear load.**

*Index Terms***—Harmonic Elimination, Reactive Power compensation, Active Power Filter**

I. INTRODUCTION

The application of power electronics devices such as arc furnaces, adjustable speed drives, computer power supplies etc. are some typical non-linear characteristic loads used in most of the industrial applications and are increasing rapidly due to technical improvements of semiconductor devices, digital controller and flexibility in controlling the power usage. The use of the above power electronic devices in power distribution system gives rise to harmonics and reactive power disturbances. The harmonics and reactive power cause a number of undesirable effects like heating, equipment damage and Electromagnetic Interference effects in the power system. The conventional method to mitigate the harmonics and reactive power compensation is by using passive LC filters but this method has drawbacks like large size, resonance problem and fixed compensation behavior etc., so this solution becomes ineffective [5]. Subsequently, the active filter (AF) comes in to the implementation, which gives promising solution to compensate for the above adverse effects of harmonics and reactive power simultaneously by using suitable control algorithms. Different AF topology has proposed by many authors, such as series, shunt and hybrid type and these may be based on current source or voltage source. Series AF is used to compensate the voltage harmonics and shunt type for current harmonics. As non-linear loads are injecting current harmonics to the power system, the suitable choice to eliminate current harmonics and reactive power is voltage source shunt AF.

Different control strategies are developed for active power line conditioners [2]. To extract the fundamental component of source current a new simpler control scheme [9-11] is used because of its easy mathematical calculation compared to p-q (Instantaneous theory) control algorithm. Further, switching signals to drive the VSI of the AF, popular control strategy namely PWM current control is used. Source reference currents are derived using load currents, dc bus voltage and source voltage. The command currents of the AF are derived using source reference and load currents.

II. SYSTEM CONFIGURATION AND CONTROL SCHEME

Figure 1 shows the basic AF scheme including a set of non linear load on a three phase three wire electric supply system. the load may be either single phase ,three phase and non linear in nature. In the present case, three phase non linear load is considered.

The AF is composed of a standard 3-phase voltage source inverter bridge with a dc bus capacitor to provide an effective current control. A hysteresis based carrier less PWM current control is employed to give fast response of the AF. The non-linear load is a dc resistive load supplied by 3-phase uncontrolled bridge rectifier with an input impedance and dc: capacitor on the output. Due to capacitive loading the uncontrolled bridge rectifier draws non sinusoidal pulsating currents from ac source. Depending upon the load magnitude and its parameters it also draws reactive power from the mains. The basic function of the proposed parallel AF is to eliminate harmonics and meet the reactive power requirements of the load locally so that the ac supply feeds only the sinusoidal balanced unity power factor currents. The desired AIF currents are estimated by sensing the load current, dc bus voltage, and source voltage. The hysteresis current controller generates the switching signals to AF devices to force the desired currents into the AF phases. With this control feature, the AF meets harmonic and reactive current requirements of tlhe load. The AF connected in shunt with the load, also enhances the system efficiency as the source does not process harmonic and reactive power.

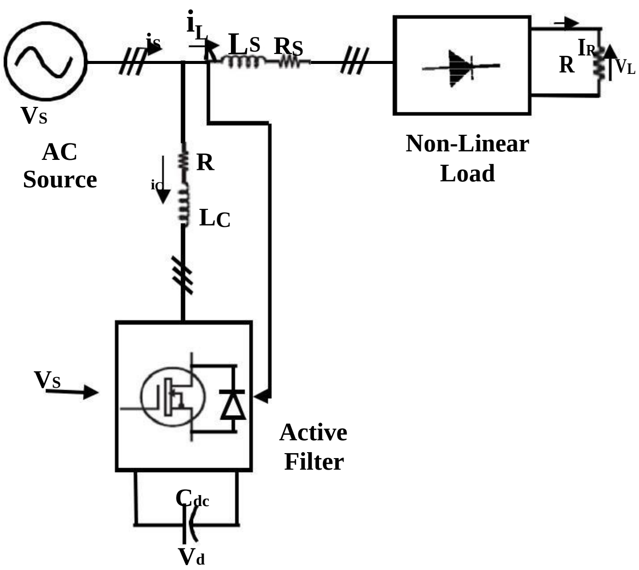


Fig. 1Basic Building Block of Active Filter

Fig. 2 shows the proposed control scheme of the shunt AF [14]. The ac source feeds fundamental active power component of load currents and another fundamental component of current to maintain the average capacitor voltage to a desired value. This later component of source current is to feed the losses in the converter such as switching loss, ohmic loss, capacitor leakage loss, etc. in the steady state and to maintain the stored energy on the dc bus during transient conditions such as sudden fluctuations of load etc.

This component of source current (I^*_{smd}) is computed using dc bus capacitor value (C_{dc},), average voltage on dc bus (V_{dc}) and a chosen reference voltage of the dc bus (V^*_{dc}). The fundamental active power component of the load currents (I^*_{smp}) is computed using sensed load currents and voltages. The total reference source peak current (I^*_{sm}) is computed using components (I^*_{smp}) and (I^*_{smd}). The reference instantaneous source currents (i^*_{sa}, i^*_{sb} and i^*_{sc}) are computed using their peak value (I^*_{sm}) and unit current templates (u_{sa},u_{sb} and u_{sc}) derived from sensed source voltages. The command currents of the AF (i^*_{ca}, i^*_{cb} and i^*_{cc}) are computed by taking the difference between instantaneous source reference currents (i^*_{sa}, i^*_{sb} and i^*_{sc}) and sensed load currents (i_{La}, i_{Lb} and i_{Lc}). The carrier-less PWM current controller is employed over the reference AF currents (i^*_{ca}, i^*_{cb} and i^*_{cc}) to obtain the gating signals to the devices of the AF. The devices of the AF are considered ideal. The value of AF inductance (L_c) is selected on the basis of proper shaping of compensating currents. With higher value of L_c compensating currents do not track reference currents and if a lower value of L_c is chosen, there are large ripple in compensating currents. The AF meets the requirements of harmonic and reactive components of load currents locally, resulting in sinusoidal unity power factor source currents under varying operating conditions of the system.

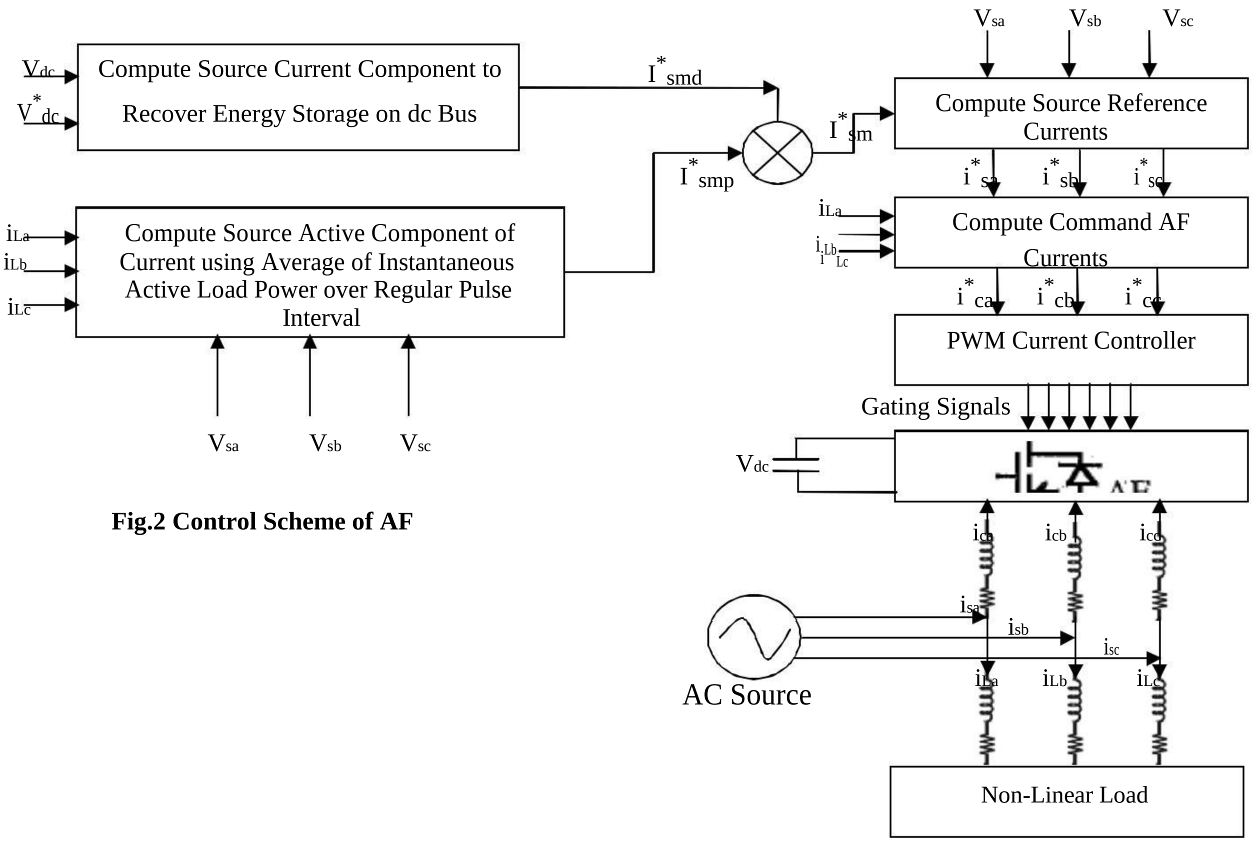


Fig.2 Control Scheme of AF

III. ANALYSIS AND MODELLING

The system comprises of ac source, non-linear load, the AF and the control scheme. The components of the system are analyzed separately and integrated to develop the complete model for the simulation.

A. Control Scheme

The operation of the control scheme has been explained in the previous section. The governing equations for the different blocks are deduced in sequence.

Peak Source Current Estimation

The peak source current (I^*_{sm}) has two components estimated as follows. The source active component corresponding to the load (I^*_{smp}) is computed from the average load power (P_S). The instantaneous power P_L is,

$$P_L = v_{sa} i_{La} + v_{sb} i_{Lb} \text{-------------------------} (1)$$

Here, i_{La}, i_{Lb} and i_{Lc} are three phase sensed load currents and v_{sa}, v_{sb} and v_{sc} are the sensed 3-phase source voltages and under ideal conditions these can be expressed as

$$v_{sa} = V_{sm} \sin \omega t$$

$$v_{sb} = V_{sm}(\sin \omega t - 2\pi/3) \text{----------------} (2)$$

$$v_{sc} = V_{sm}(\sin \omega t + 2\pi/3)$$

In Eq. (2),Vsm is the peak of source voltage and is the frequency of the ac mains in rad/sec

$$P_S = (3/2) V_{sm} I^*_{smp} \text{ ----------------------------------} (3)$$

The peak fundamental unity power-factor source current component can be estimated using P_S and V_{sm} from Eq. (3). The second component of source current (I^*_{smd})is to maintain the average voltage on the dc bus at a constant value, overcoming the switching, ohmic and capacitor losses in the AF.The computation of I^*_{smd} is based on the following logic. Areference dc bus average voltage (V^*_{dc} is assumed. By sampling the actual dc bus voltage the average (V_{dc},) is computed over the one sixth period of supply frequency (T_x). The energy difference corresponding to V^*_{dc} , andV_{dc} over the Tx, is :

$$\Delta e_{dc} = e^*_{dc} - e_{dc} = C_{dc}[(V^*_{dc})^2 - V^2_{dc}]/2$$

The AF attempts to draw this energy difference from ac mains through unity power-factor current with a peak value of I^*_{smd}, over the same interval T_x. This energy relationship can be expressed as

$$\Delta e_{dc} = \left(\frac{3}{2} V_{sm} I^*_{smd}\right) T_x \text{ ---------------------------------} (5)$$

From Eq. (5),I^*_{smd} is obtained. When V^*_{dc} Well chosen, under steady state operation V_{dc} will never become equal to V^*_{dc} but I^*_{smd} will established to a fixed value as demanded by the losses in the AF. Under transient condition, I^*_{smd} will take either positive or negative value as demanded bythe energy exchange between the AF and the load. The total peak source current from equations (3) and (4) is:

$$I^*_{sm} = I^*_{smp} + I^*_{smd} \text{ -------------------------------------} (6)$$

Source Reference Currents Generation

Harmonic free unity power-factor, 3-phase source currents may be estimated using unit current templates in phase with source voltages and the computed peak values. The unit current templates are derived from equation (2)as:

$$u_{sa} = v_{sa}/V_{sm} \;;\quad u_{sb} = v_{sb}/V_{sm} \;;\quad u_{sc} = v_{sc}/V_{sm} \text{ ---------------} (7)$$

The reference 3-phase source currents are estimated as:

$$i^*_{sa} = i^*_{sm} u_{sa} \;;\; i^*_{sb} = i^*_{sm} u_{sb} \;;\; i^*_{sc} = i^*_{sm} \text{----} (8)$$

Reference AF Currents Generation

The 3-phase AF reference currents are estimated using the reference source currents in Eq. (8) and the sensed load currents as:

$$i^*_{ca} = i^*_{sa} - i_{La} \;;\; i^*_{cb} = i^*_{sb} - i_{Lb} ;\; i^*_{cc} = i^*_{sc} - i$$

-------------------------- (9)

Hysteresis Current Controller

The current controller decides the switching pattern of the AF devices. The switching logic is formulated as follows:

If $i_{ca} < (i^*_{ca} - hb)$ upper switch is OFF and lower switch is ON for leg 'a' (SA= 1).

If $i_{ca} > (i^*_{ca} + hb)$ upper switch is ON and lower switch is OFF for leg 'a' (SA= 0).

The switching functions S Band SC for phases b and c are determined similarly, using the corresponding reference and measured currents and the hysteresis band hb. The AF currents i_{ca}, i_{cb} and i_{cc} are regulated to be in good agreement with the reference values i^*_{ca}, $i^*_{cb}$and i^*_{cc}.

PWM Current Controller

This current controller takes the three phase AF reference currents as input signals and generates gating signals for PWM-VSI of AF. The equation 4.9 gives these three phase AF reference currents.

B. **Modeling of Non-Linear Load**

The non-linear load is considered as a 3-phase bridge diode rectifier with R load.The diodes are arranged in three legs. Each leg has two series connected diodes. Upper diode D1, D3, D5 constitutes the positive group of diodes. The lower diodes D2, D4, D6 form the negative group of diodes. Positive group of diodes conduct when these have the most positive anode. Similarly, negative group of diodes would conduct if these have the most negative anode. Due to the presence of source inductance, six overlapping and six lion-overlapping conduction intervals occur in a cycle. The dynamic equations during non-overlap and overlap intervals are given below:

$$pi_d = \frac{(V_0 - (2R_S + R_L)i_d - 2v_d)}{2L_S + L} \qquad (10)$$

$$pi_d = \frac{(V_0 - (1.5R_S + R_L)i_d - 2v_d)}{1.5L_S + L} \qquad \text{---------------}\ (11)$$

Here, Rs and Ls are the elements of the source impedance, v_d is the drop across each device, R the element of load impedance, i_d is the load current flowing through the diode pairs and 'p' is the differential operator (d/dt). V_0 is the AC side line voltage segment

IV. PERFORMANCE OF AF SYSTEM

Performance characteristics of the AF system with proposed control scheme are given in Figs. 3-5 illustrating the steady skate and transient behavior at different loads. The parameters of the system studied are given in the Appendix.

Simulation Results Using Hysteresis Current Controller

Steady State Performance of AF with Hysteresis Current Controller

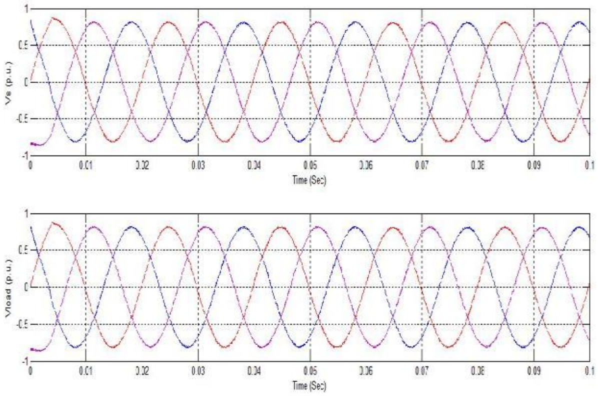


Fig.3 Source Voltage and Load Voltage

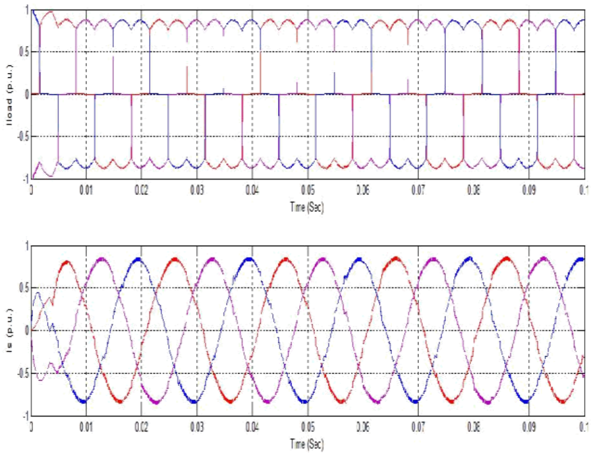


Fig. 4 Load Current and Source Current

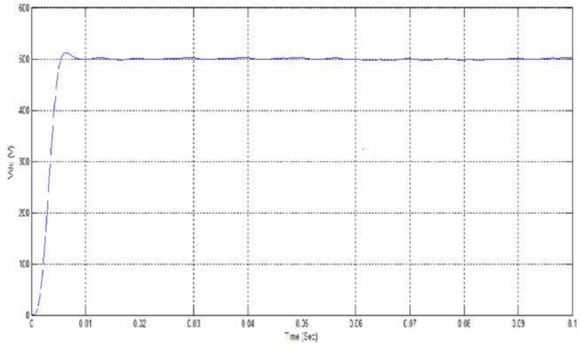


Fig. 5 *DC* Voltage across Capacitor

In steady state condition the simulation time is taken as t=0 to t=0.1 sec with constant load. The source voltage and load voltage is shown in Fig. 3.The load current and source current is shown in Fig. 4.The AF inject the compensating current to PCC, which results in compensation of source current. The compensating current containing only the harmonic current, which is introduced to the power system due to non-linear load but in opposite phase. The current after compensation is as shown in Fig. 4. It is clear from the Fig. that, the waveform is sinusoidal with some high frequency ripples. The DC voltage across capacitor is shown in Fig. 5.

Transient State Performance of AF with Hysteresis Current Controller

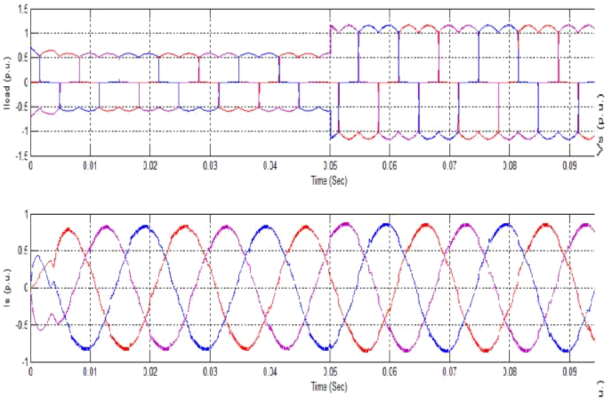


Fig. 6 Load Current and Source Current

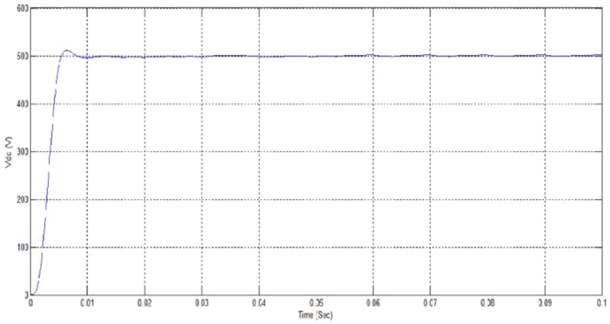
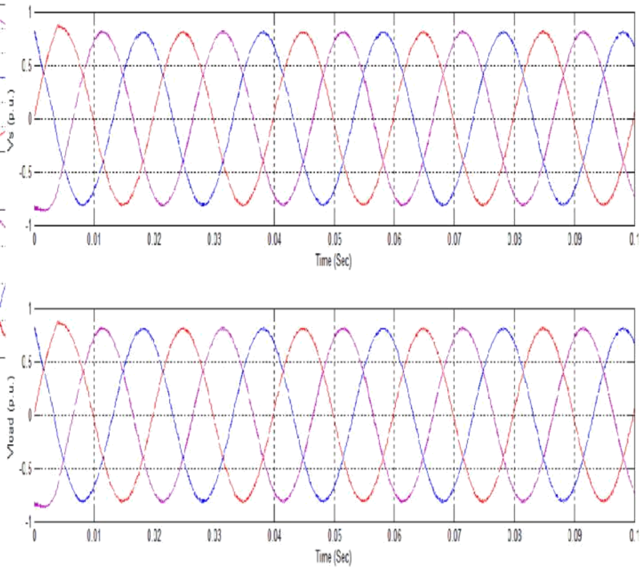


Fig. 7 Capacitor Voltage

During the period t=0 to t=0.05 sec R_S parameter of the nonlinear load is set as 15 Ω. From t=0.05 to 0.1 sec the load parameter is changed to 7.5 Ω. The corresponding waveforms obtained are shown in the Fig. 6. The load current and source current waveform is shown in Fig. 6. And Fig. 7 indicates that after 0.05 sec the load current magnitude is changing as the load is changing and settling very quickly. The AF supplies the compensating current for source current compensation. The source current after compensation is presented in Fig. 6 that indicates the current becomes sinusoidal. The capacitor voltage during transient period is nearly same as the steady period is shown in Fig. 7

SIMULATION RESULTS USING PWM CURRENT CONTROLLER

Steady State Performance of AF with PWM Current Controller



. **Fig. 8 Source Voltage and Load Voltage**

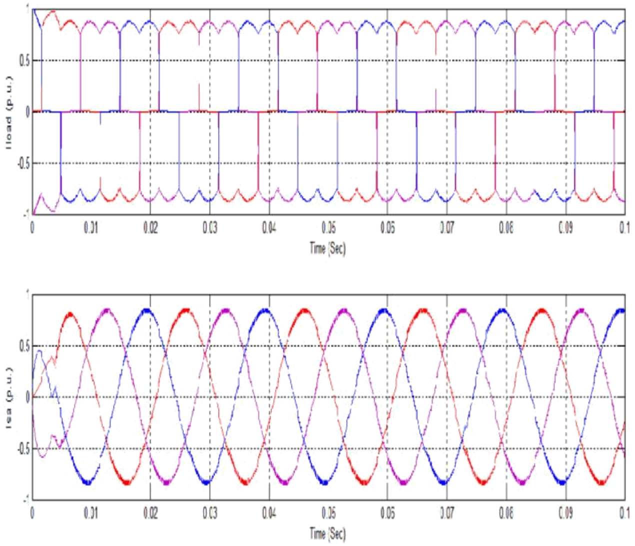


Fig. 9 Load Current and Source Current

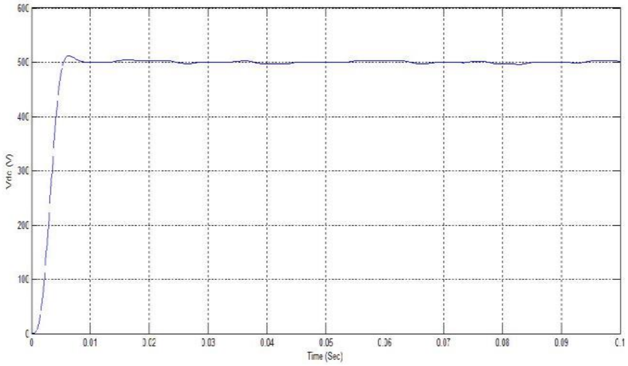


Fig. 10 DC Voltage across Capacitor

Transient State Performance of AF with PWM Current Controller

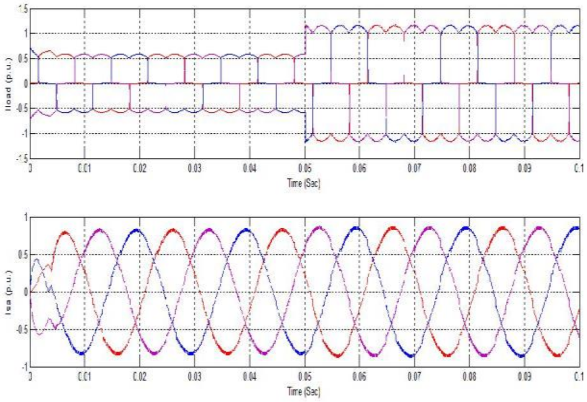


Fig. 11 Load Current and Source Current

V. APPENDIX

AF System Parameters

SYSTEM PARAMETERS	VALUE
Line Voltage	500 V
Supply Frequency	50 Hz
Source Impedance:(Resistance Rs, Inductance Ls)	0.1 Ω, 2.6 µH
Non-Linear load under steady state:(Resistance Rl, Capacitance Cl)	10 Ω ,50 µF
Filter Impedance:(Resistance Rc, inductanceLc)	0.4 Ω, 0.5mH
Dc side capacitance	3000 µF
Reference Dc Voltage	500 V
Power converter	6 MOSFET/DIODE

VI. CONCLUSION

The performance of the shunt active filter is analysed using a new simple technique for minimizing harmonics, compensating reactive power and improving the pf in the power system. The performances of the HCC and PWM Current Controller with shunt active power filter are verified with the simulation results. From the results; it clearly indicates that, the current ripple is less by using HCC and PWM Current Controller. The transient response and steady state performance of these current controllers have been calculated. The THD of the source current after compensation is 3.21% with HCC and 2.81% with PWM Current Controller which is less than 5 %, the harmonic limit imposed. So Active Filter is showing better THD performance with PWM Current Controller in comparison of HCC.

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