DIFFERENT CONTROL STRATEGIES ADOPTED IN ACTIVE HARMONIC CONDITIONER

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***Abstract*— "Power Quality" broadly refers to maintaining a near sinusoidal voltage and current at rated magnitude and frequency. Nowadays, the proliferation of non-linear loads (especially power electronics equipment) leads to deterioration of the quality of voltage waveforms at the point of common coupling (PCC) of various consumers. With rapid development of power semiconductor devices in power and control circuits, a new generation of equipment that help maintaining a good level of power quality, namely active power filters, has been developed. This paper presents the simulation of Shunt Active Harmonic Conditioner using of Synchronous Detection Method and Synchronous Reference Frame Method. These control strategies are applied to calculate compensating currents, while the three phase source is feeding a highly non-linear load.**

***Keywords*— Harmonic Conditioner, Synchronous Reference Frame Method, Synchronous Detection Method, PLL, THD**

I. INTRODUCTION

Power supply quality and electric utility waveform distortion problems are major issues facing utilities, consumers and users of both polluting and sensitive electronic type equipment. Nonlinear type loads have a complex nonlinear volt-ampere relationship that result in waveform distortion, harmonics and dynamic notching, dips and transient excursions. Nonlinear loads are classified broadly into three types, namely arc-type, converter- type, and magnetic saturation- type nonlinearities. Dynamic and quasi-static waveform distortion cause low utilization power factor, overloading, extra losses, equipment damage andmalfunctioning, data loss and spurious operation of sensitive devices and electronic type computers and data processing equipment.

II. HARMONIC COMPENSATION METHODS

There are three methods available, each with particular advantages and disadvantages for compensating the harmonics and reactive power. They are:

A. PASSIVE FILTERS

In passive filter a capacitor is used in series with a reactor in order to obtain tuning on a harmonic of a given frequency. This assembly placed in parallel on the installation has a very low impedance for its tuning frequency, and acts as a short-circuit for the harmonics. A number of assemblies tuned on different frequencies can be used simultaneously in order to remove several harmonic orders. The shunt passive filter has the following problems.

- The source impedance, which is not accurately known and varies with the system configuration, strongly influences filtering characteristics of the shunt passive filter.
- The shunt passive filter acts as a sink to the harmonic current flowing from the source. In the worst case, the shunt passive filter falls in series resonance with the source impedance.
- At a specific frequency, an anti resonance or parallel resonance occurs between the source impedance and the shunt passive filter, which is the so-called harmonic amplification.

B. TRANSFORMER SOLUTIONS - ISOLATION, ZIG-ZAG, VECTOR GROUPING

The aim of harmonic isolation is to limit circulation of harmonic currents to a small part of the installation using suitable coupling transformers. Use of Y-connected primary transformers with zig-zag secondary is an interesting solution as it ensures minimum distortion at the secondary.

C. ACTIVE HARMONIC CONDITIONER

The idea of Active filter or Active Harmonic Conditioners is relatively old, however the lack of an effective technique at a competitive price slowed its development for a number of years. Today, the widespread availability of insulated gate bipolartransistors (IGBT) and digital signal processors (DSP) have made the AHC a practical solution.

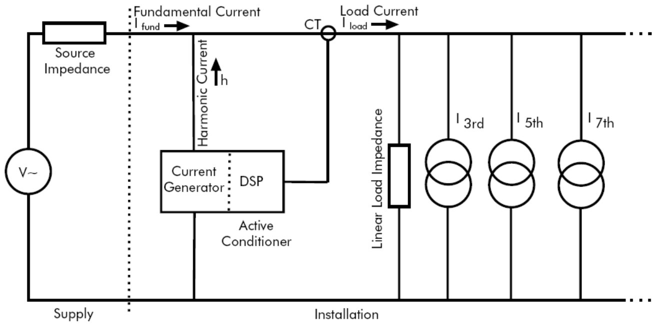

Fig 1. Active Harmonic Conditioner

In AHC power electronics is used to generate the harmonic currents required by the non-linear loads so that the normal supply is required to provide only the fundamental current. Figure 1 shows the principle of a shunt device. The load current is measured by a current transformer, the output of which is analyzed by a DSP to determine the harmonic profile. This information is used by the current generator to produce exactly the harmonic current required by the load on the next cycle of the fundamental waveform.

III. REFERENCE SIGNAL GENERATION IN ACTIVE HARMONIC CONDITIONER

Shunt active power filters inject ac currents on to the network. A three-phase voltage inverter with current regulation is used to inject the compensating current into the power line. There are different methods for implementing the detection of harmonic currents. These methods were studied in symmetrical conditions in the literature. Some of that control methods are explained here.

A. INSTANTANEOUS POWER THEORY (P-Q)

In instantaneous P-Q theory, the instantaneous imaginary power, which is a new electrical quantity, is introduced in three-phase circuits. Then, the instantaneous reactive power is defined as a unique value for arbitrary three-phase voltage and current waveforms including all distorted waveforms, by using the abovementioned instantaneous imaginary power. According to the theory developed in paper [1], a new instantaneous reactive power compensator is proposed, comprising switching devices without energy storage components. This compensator can eliminate not only the fundamental reactive power in transient states but also some harmonic currents. For example, the harmonic currents having the frequencies of f ± 6f0 in a three-phase-to three-phase naturally commutated cycloconverter can be eliminated, where f is the input frequency and f is the output frequency. This is the first proposed shunt active filtering algorithm by Akagi. This method can be effective only when the supply voltages are balanced.

B. UNIT VECTOR TEMPLATE GENERATION METHOD (UVTG)

The unit vector templates generation by using Phase Locked Loop (PLL) can be applied for shunt APF to compensate the harmonic currents generated by non-linear load. The shunt APF is used to compensate for current harmonics as well as to maintain the dc link voltage at constant level. To achieve the aforementioned task the dc link voltage is sensed and compared with the reference dc link voltage. The error is then processed by a PI controller. The output of the PI controller then will be the peak amplitude of fundamental input current, Im, which must be drawn from the supply in order to maintain dc link voltage at constant level and to supply losses associated with shunt active filter. This peak amplitude, Im, is then multiplied with unit vector templates giving reference current signals for shunt APF, as shown in Fig. 2

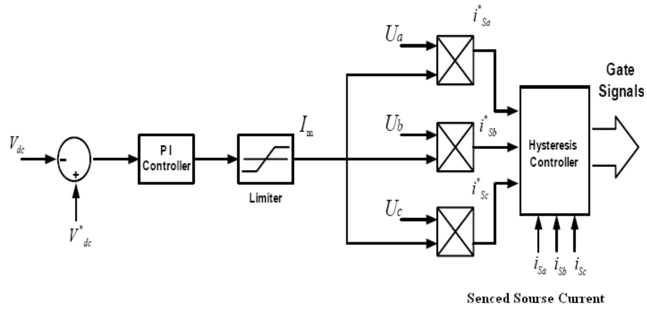

Fig 2 Control block diagram of Unit Vector Template Generation Method

Where Ua, Ub, Uc are the unit vectors generated by the PLL. After extracting the reference voltage and current signals for shunt APF, the next step is to force the inverters to follow these reference signals. This can be done by switching the inverter IGBTs in a proper manner. To have the required gating signals, the modulation technique is used; here the Hysteresis Band Control technique based on PWM strategy is considered for APFs. The generated reference current signals for shunt APF are compared with actual sensed source current. The Hysteresis controller gives the switching instant whenever the error exceeds the Hysteresis band. The detailed explanation of this method is given in reference [2]. It is very difficult to tune the PI controller to get the desired reference source current.

C. SYNCHRONOUS DETECTION METHOD

The equal current synchronous detection method (CSD) is applied to calculate the reactive and harmonic current compensation components for triggering an active power filter in an unbalanced three-phase power system. The simulation and experiment results of active filter operation using the synchronous detection method are effective to eliminate line current harmonics and compensate the reactive current component. The merits of the proposed method are its capability to operate under unbalanced three-phase system by perphase calculation. The detailed analysis of this method is given in reference papers [3] and [4].

D. SYNCHRONOUS REFERENCE FRAME METHOD(SRF)

Synchronous reference frame strategy is a popular method used in the generation of the current reference. The synchronous reference frame strategy uses co-ordinate transformations to generate the current reference. It employs the well-known Clarke's Transformation and Park's Transformation for this purpose.

In this paper performance of Shunt Active Harmonic Conditioner is analysed by adopting different control strategies. Design and simulation of a 5KVA AHF is done by adopting Synchronous Detection method and Synchronous

Reference Frame method. Compare the performance under balanced source and load condition, unbalanced magnitude supply voltage condition and sudden load change condition

IV. MAJOR ELEMENTS IN AHF

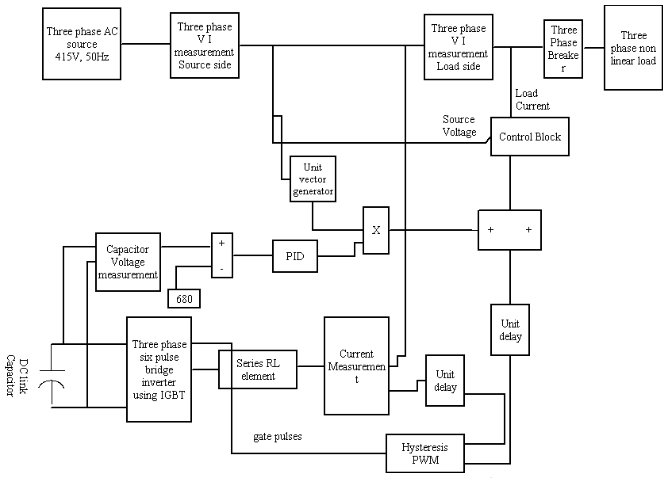

Figure 3 Block diagram representation of AHF

A. INVERTER

Three phase six pulse bridge inverter consists of three arms,each having two IGBTs are used.

B. HYSTERESIS PWM GENERATOR

Shunt active filter performance depends on the dynamics of the modulation technique used to control the IGBT switches and the method used to determine reference current value. In hysteresis PWM a hysteresis band is selected in such a way that it is 2-4% of the reference signal. The actual compensating current is compared with the upper limit of the reference band, if it violates the upper limit then next IGBT is turned on and compensating current goes down. When it reaches below hysteresis band that IGBT turned off and the other IGBT in that arm turned on.

C. PID CONTROLLER

When the operation of the control system fails to satisfy the specified transient or steady state performance requirements we need to modify the characteristics of the system by introducing a controller into the system, although it may introduce additional changes in the system. There are mainly three basic type of controllers that we can select

- Proportional controller
- Derivative controller
- Integral controller

Here we use PI controller for tuning the system.

D. DC LINK CAPACITOR

In a practical converter the semi conducting switches are not lossless, and therefore the energy stored in the dc capacitor would be used up by the internal losses. The dc capacitor also has a vital function, it is used for maintain the necessary energy balance between the input and output during the dynamic changes of the VAR output. The dc link capacitor can control real and reactive power exchange with the ac system and it can function as a static synchronous generator.

E. UNIT VECTOR GENERATOR

Unit vector can be generated by using PLL. A PLL is an electronic circuit that consists of a phase detector, a low pass filter and a voltage controlled oscillator.

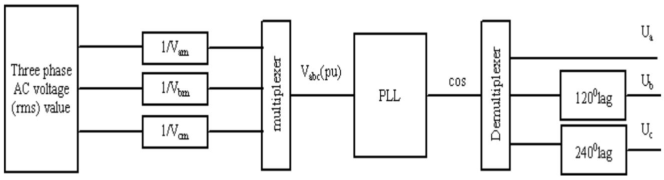

Figure 4 Unit vector template generation using PLL

F. THREE PHASE V-I MEASUREMENT

This block is used to measure three phase voltages and currents in a circuit. When connected in series with a three phase element it returns the three phase to ground voltages and line currents.

Three phase six pulse bridge in

V. DESIGN OF POWER CIRCUIT FOR SHUNT ACTIVE POWER FILTER

Design of a power circuit includes three main parameters:

- Selection of filter inductor, Lc
- Selection of dc link capacitor, Cdc, and
- Selection of reference value of dc side capacitor voltage, Vdc.

VI. ANALYSIS OF CONTROL METHODS

Here in this project mainly two control methods are used.

A. SYNCHRONOUS DETECTION METHOD

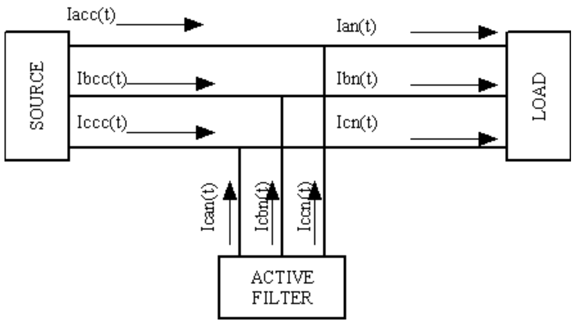

Fig 5. Shunt Active Power Filter

Assume the peak value of source current is balanced after compensation.

$$I_{am} = I_{bm} = I_{cm} \qquad (1)$$

It can be expressed in terms of active power and peak supply voltage.

$$I_{am} = \frac{2.P_a}{V_{am}}, I_{bm} = \frac{2.P_b}{V_{bm}}, I_{cm} = \frac{2.P_c}{V_{cm}} \quad (2)$$

Where Pa, Pb, Pc are real powers from each of the phases and Vam, Vbm, Vcm are the phase values of peak voltages in three phases.

From equation (1) and (2)

$$\frac{2.P_a}{V_{am}} = \frac{2.P_b}{V_{bm}} = \frac{2.P_c}{V_{cm}} \quad (3)$$

From (3)

$$P_b = P_a . \frac{V_{bm}}{V_{am}} \quad (4)$$

$$P_c = P_a \frac{V_{cm}}{V_{am}} \quad (5)$$

Total average power, $P_{ave} = P_a + P_b + P_c$ (6)

Combine eqns (4), (5), (6) then

$$P_a = \frac{V_{am}}{V_T}.P_{ave} \quad (7)$$

$$P_b = \frac{V_{bm}}{V_T}.P_{ave} \quad (8)$$

$$P_c = \frac{V_{cm}}{V_T}.P_{ave} \quad (9)$$

Where $V_T = V_{am} + V_{bm} + V_{cm}$ (10)

The reference active source currents are calculated using the average power Pave as

$$i_{acc} = \frac{2.P_{av}}{V_{am}.V_t} V_{an}(t) \quad (11)$$

$$i_{bcc} = \frac{2.P_{av}}{V_{bm}.V_t} V_{bn}(t) \quad (12)$$

$$i_{Ccc} = \frac{2.P_{av}}{V_{cm}.V_t} V_{cn}(t) \quad (13)$$

Compensating current at the output of the control block is given below:-

$$i_{can}(t) = i_{an}(t) - i_{acc}(t) \quad (14)$$

$$i_{cbn}(t) = i_{bn}(t) - i_{bcc}(t) \quad (15)$$

$$i_{cbn}(t) = i_{cn}(t) - i_{ccc}(t) \quad (16)$$

B. SYNCHRONOUS REFERENCE FRAME METHOD

In the SRF, the load current signals are transformed into the conventional dq rotating frame by using the equations given below.

$$\begin{bmatrix} i_d^s \\ i_q^s \end{bmatrix} = \sqrt{2/3} \begin{bmatrix} 1 & -1/2 & -1/2 \\ 0 & \sqrt{3}/2 & -\sqrt{3}/2 \end{bmatrix} \begin{bmatrix} i_{an} \\ i_{bn} \\ i_{cn} \end{bmatrix} \quad (1)$$

Where i_d^s represents two phase stationary direct axis current which consists of fundamental and harmonic active currents and i_q^s represents two phase stationary quadrature axis current which consists of reactive fundamental and harmonic components. In order to separate fundamental active current from this we need to convert it into rotating reference frame by using some kind of synchronizing system. Here we use a PLL for generating unit sine and cosine vectors from the supply voltage and finally we get rotating two phase system as given below.

$$\begin{bmatrix} i_q^e \\ i_d^e \end{bmatrix} = \begin{bmatrix} \cos w & -\sin w \\ \sin w & \cos w \end{bmatrix} \begin{bmatrix} i_q^s \\ i_d^s \end{bmatrix} \quad (2)$$

Where i_d^e consists of a DC component corresponding to fundamental active current and non dc quantity corresponding to active current harmonics. i_q^e consists of reactive fundamental and harmonic current. By using a low pass filter we can separate the active fundamental current and the remaining quantities are converted back to three phase system. These can be represented by the equations given below.

$$\begin{bmatrix} i_q^s \\ i_d^s \end{bmatrix} = \begin{bmatrix} \cos w & \sin w \\ -\sin w & \cos w \end{bmatrix} \begin{bmatrix} i_q^e \\ i_d^e \end{bmatrix} \quad (3)$$

Two phase to three phase conversion can be done by the equation given below.

$$\begin{bmatrix} i_{an} \\ i_{bn} \\ i_{cn} \end{bmatrix} = \begin{bmatrix} 1 & 0 \\ -1/2 & \sqrt{3}/2 \\ -1/2 & -\sqrt{3}/2 \end{bmatrix} \begin{bmatrix} i_d^s \\ i_q^s \end{bmatrix} \quad (4)$$

The block diagram representation of this method is shown in the figure given below.

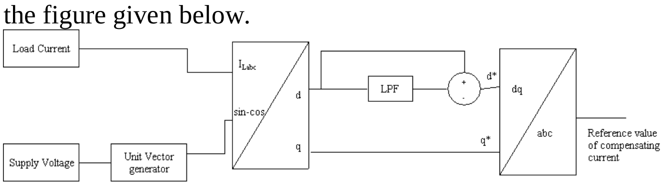

Fig 6. Shunt Active Power Filter

VII. MATLAB/ SIMULINK MODEL OF SHUNT AHC

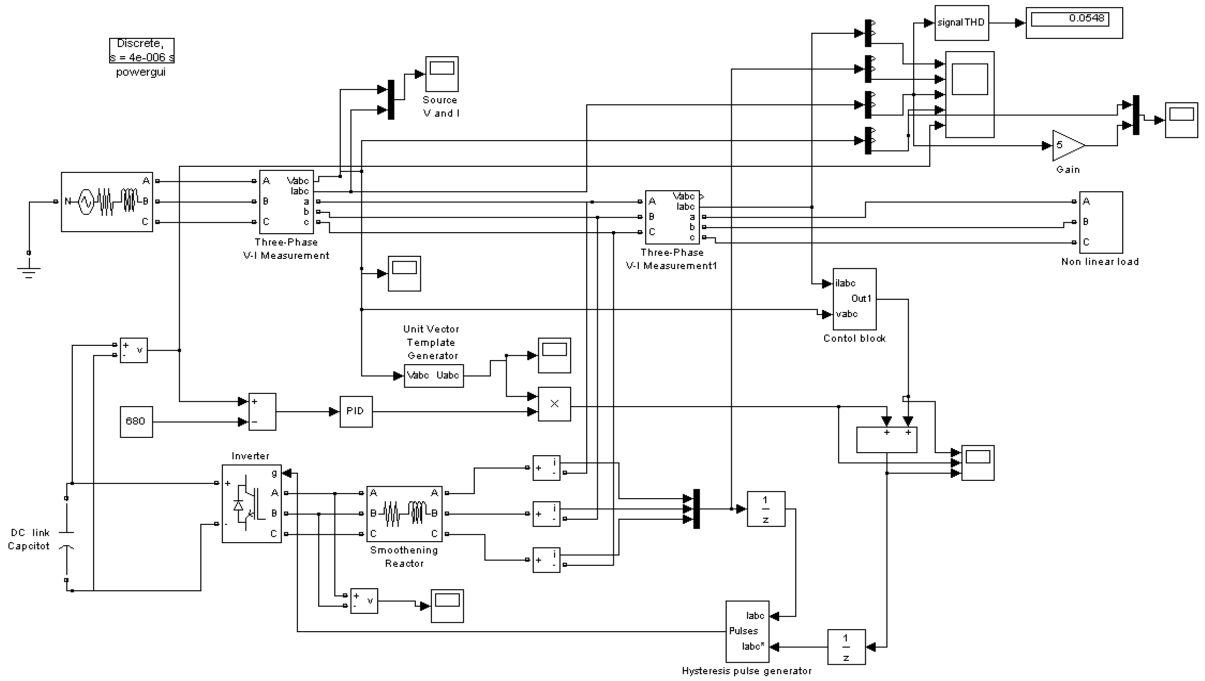

Fig 7.Simulink model of an AHF

A. *CONTROL BLOCK DIAGRAM REPRESENTATION OF SD METHOD*

Necessary equations used for reference compensating current generation by SD method are already discussed in session IV A. Corresponding SIMULINK block is shown in below figire.

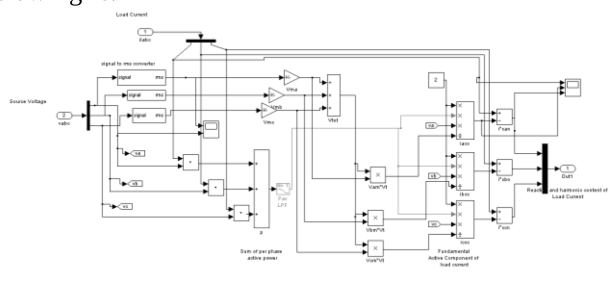

Fig 8.Control block of SD method

B. CONTROL BLOCK DIAGRAM REPRESENTATION OF SRF METHOD

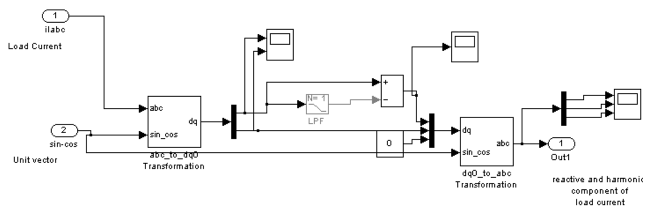

Fig 9.Control block of SRF method

VIII. SIMULATION RESULT & COMPARISON BETWEEN SD AND SRF METHOD

A. SIMULATION WITH BALANCED THREE PHASE AC SUPPLY WITHOUT ANY DISTURBANCES AT LOAD SIDE (SD METHOD)

415V, 3 phase ac supply is given to a 2.7KVA RL load through a full bridge rectifier circuit. Shunt active filter is connected in such a way that it supplies the harmonic and reactive part of the load current.

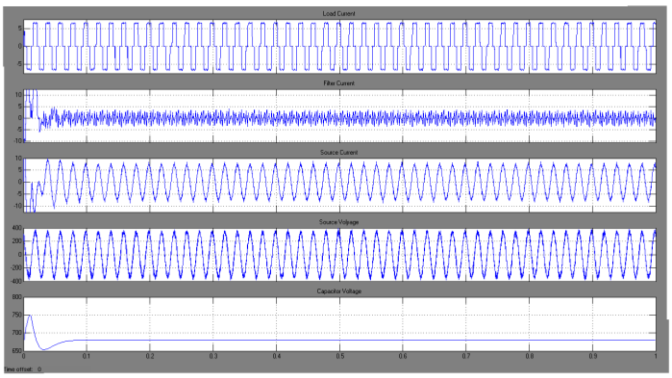

Fig 10.Simulation result for balanced three phase system

Figure below shows the FFT analysis of the system without connecting Shunt AHC. Then fifth, seventh, eleventh and thirteenth harmonics are predominant and Total Harmonic Distortion (THD) is around 27.17%.

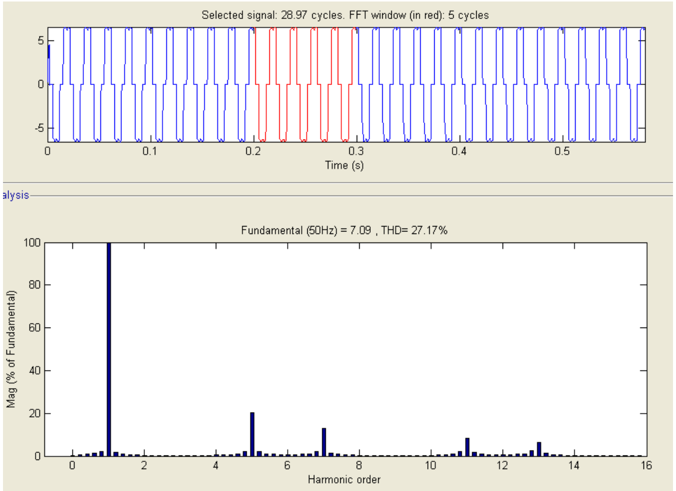

Fig 11 FFT analysis of the system without any compensation

Below given figure shows FFT analysis of the system with Shunt AHC. Then THD decreases to 3.01% from 27.27%.

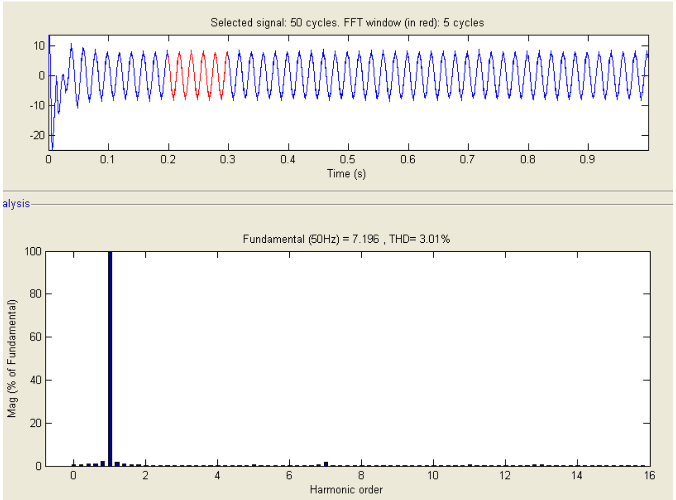

Fig 12 FFT analysis of Shunt AHC under balanced condition

B. WITH UNBALANCED THREE PHASE AC SUPPLY (MAGNITUDE).

In order to understand the system performance at different conditions first consider the system with supply voltage with magnitude unbalanced. The shunt active filter automatically adjusts in such a way that the current taken from the supply become balanced with almost equal magnitude. Corresponding response is shown in Fig 13.

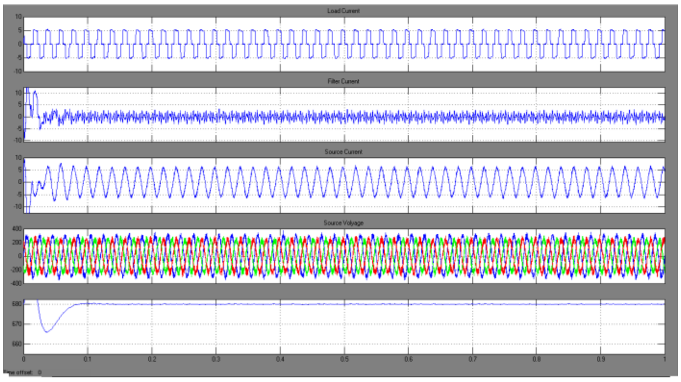

Fig 13 Simulation result for unbalanced (magnitude) three phase system

C. WAVEFORMS WITH SUDDEN CHANGE IN LOAD CONNECTED TO THE SYSTEM.

In this case an additional load of 1.8KVA is included in the system between 0.066sec to 0.5sec. The system respond to the variation without much disturbance to the source side. Correspondingwaveforms and FFT analysis are given in below figure.

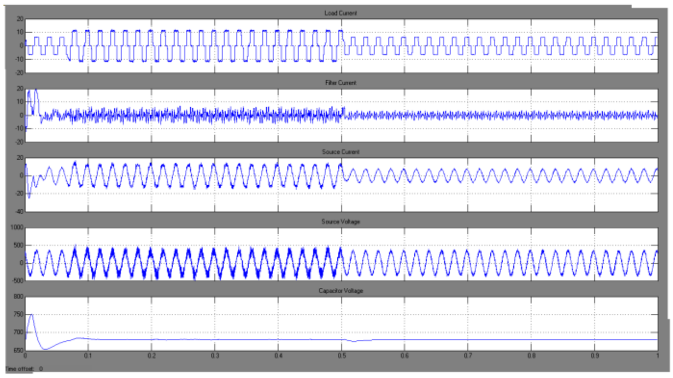

Fig 5.5 Simulation of the system when a variable load connected at the terminal

All these waveforms are obtained by synchronous reference frame method also.

D. COMPARISON BETWEEN SRF AND SD METHOD

Si No	Different Control Methods		
		SD	**SRF**
1	THD	3.01%	3.81%
2	Maximum Peak Over shoot	10.29%	0.22%
3	Settling time	0.04 sec	0.1 sec

IX. CONCLUSION

In this paper two control strategies used in Shunt Active Harmonic Conditioner are compared. The proposed models have been simulated in MATLAB. Newly introduced SD method is compared with commonly used SRF method. The

THD of the supply signal is improved by 90% in SD method and THD improvement in SRF method is about 86%. Time required to reach steady state condition is less in SRF method as compared with SD method. Test result shown by figures satisfies the designobjectives of harmonic and reactive current compensation. These methods can balance theunbalanced load current. These methods improve the defect of voltage unbalance problem.

X. FUTURE SCOPE

It is possible to use different newly derived soft control techniques such as neural network, fuzzy logic, wavelet transform based techniques etc for more effective harmoniccompensation.

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