ELIMINATION OF HARMONICS BY USING MULTILEVEL SHUNT ACTIVE POWER FILTER AND COMPARISON BETWEEN SRF, I_D-I_Q AND MODIFIED I_D-I_Q THEORY

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1. Abstract—The "multilevel converter "has drawn tremendous Interest in the power industry. The general structure of the multilevel converter is to synthesize a sinusoidal voltage from several levels of voltages, multilevel voltage source converter are emerging as a new bride of power converter options for high power applications, these converted topologies can generate high quality voltage wave forms with power semi conductor switches operating at a frequency near the fundamental among the available multi level converter topologies ,the cascaded multi level converter constitutes a alternative, providing a modular design that can be extended to allow a transformer less connection. This paper present different types of SRF methods for real time generation of compensating current for harmonic mitigation. The three techniques analyzed are the synchronous reference frame theory (SRF), SRF theory without synchronizing circuit like phase lock loop (PLl) also called I_d-I_q theory and finally modified SRF theory. This proposed cascaded five level active power filter system is validated through MATLAB/SIMU LINK platform.

Key words: Synchronous reference frame theory (SRF), I_d-I_q, modified SRF, active filter, harmonics, PI controller

2. INTRODUCTION:

With the developments of power electronic equipments and nonlinear loads, the power quality has been deteriorating in distribution system. Current harmonics can cause serious harmonic problems in distribution feeders for sensitive consumers. Some technology options have been reported in order to solve power quality issues. Initially, lossless passive filters have been used to mitigate harmonics and compensate reactive power in nonlinear loads. However, passive filters have the demerits of fixed compensation, large size and resonance with the supply system.

Active filers have been explored in shunt and series configurations to compensate different types of nonlinear loads; nevertheless, they have some drawbacks. As a case in point, their rating is sometimes very close to load, and thus it becomes a costly option for power quality improvement. Many researchers have classified different types of nonlinear loads and have suggested various filter options for their compensation.

In response to these factors, a series of hybrid filters has been evolved and extensively used in practice as a cost effective solution for the compensation of nonlinear loads. State-of-the-art power electronic technology has enabled engineers to put active filters into practical use. Many shunt active filters consisting of voltage-fed pulse width modulated (PWM) inverters using IGBT or GTO thyristors are operating successfully in all over the world. These filters have provided the required harmonic filtering, reactive power compensation [1].

An important technology on active filters is the detecting method of harmonics to reduce the capacity of the energy storage components. Various control strategies have been proposed in recent publications for this type of active filters. The control strategy presented in is based on the calculation of the real part of the fundamental load current while this is useful in some configurations such as hybrid series active filter, since it cannot compensate reactive power completely and needs many complicate calculations [2]. The active power filter proposed in uses a dc capacitor voltage closed loop control; the author uses an adaptive method with Kalman filter to predict reference current; in and the authors use a modified phase-locked loop for extraction of the reference current.

In the cited references, the computation involves various control parameters or needs complex calculations. Also, the dynamic performance of the compensator is not desire in the case of fast-changing load

3. SHUNT ACTIVE POWER FILTER PROPOSED SYSTEM

The active power filter is connected in the distribution network at the PCC through filter inductances and operates in a closed loop. Three phase active power filter comprises of IGBT's with freewheeling diodes. The shunt APLC system contains a voltage source inverter with capacitor, RL-filter a compensation controllers (synchronous reference frame, I_d-I_q and modified I_d-I_q) and switching signal generator as shown in the fig.1

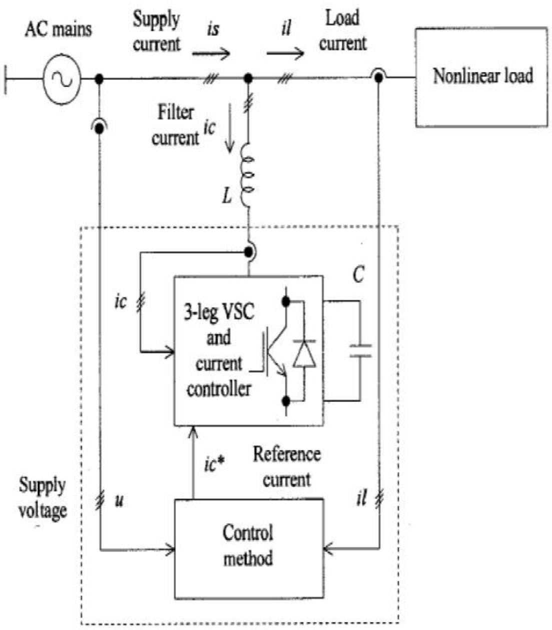

Fig.1-Basic circuit diagram of shunt Active power filter

A single phase supply source is connected with the non-linear load. The non-linear load currents should contain fundamental component and harmonic current components. For harmonic compensation, the active filter must provide compensation current. At the time, source current will be in phase with the utility voltage and become sinusoidal [3].

4. PROPOSED CONTROL TECHNIQUES:

By using control techniques we can generate the reference currents that must be provided by the power filter to compensate reactive power and harmonic currents demanded by the load. The proposed control system consists of reference current control strategy using SRF, I_d-I_q *and Modified* I_d-I_q (level shift controller) for switching signals of cascaded VSI

5. SRF BASED CONTROL STRATEGY:

The synchronous reference frame theory is developed in time-domain based reference current generation techniques. The SRF performing the operation in steady-state as well as for generic voltage and current; it's capable of controlling the active power filters in real-time system. Another important characteristic of this theory is the simplicity of the calculation. The block diagram of the synchronous reference frame controller is shown in fig.2.

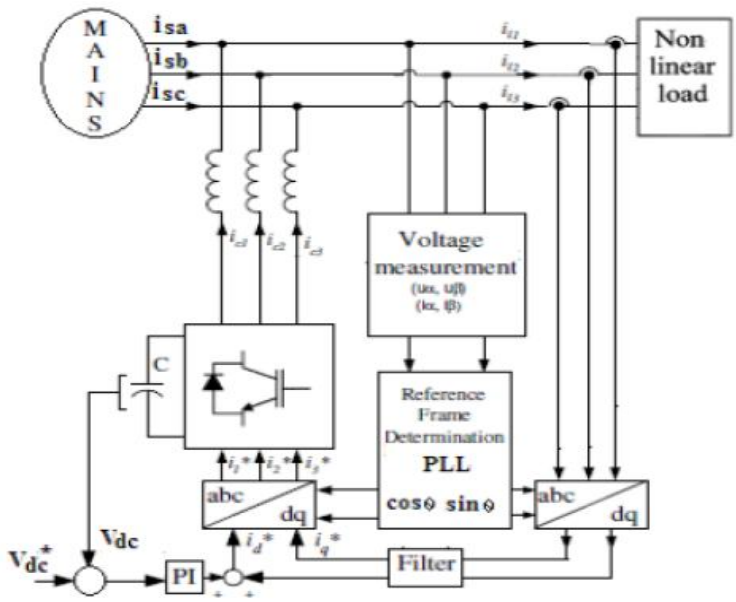

Fig.2-Basic Synchronous Reference Frame Configuration

The basic structure of SRF methods consists of direct (d-q) and inverse $(d\text{-}q)^{-1}$ park transformation, which allow the evaluation of a specific harmonic of the input signals. The reference frame transformation is formulated from a three phase a-b-c stationary system to the two phase direct axis (d)-quadratic axis (q) rotating coordinates system [4]. In a-b-c stationary axes are fixed on the same plane and separated from each other by 120^0.These three phase space vectors stationary coordinates are easily transformed into two axis d-q rotating reference frame. This proposed algorithm derivative from a three-phase stationary coordinates load current i_{la}, i_{lb} & i_{lc} are convert to i_d-i_q rotating coordinate current, as follows

$$i_d = \frac{2}{3}\left[i_{la}\sin(\omega t) + i_{lb}\sin(\omega t - \frac{2\pi}{3}) + i_{lc}\sin(\omega t + \frac{2\pi}{3})\right] - (1)$$

$$i_q = \frac{2}{3}\left[i_{lc}\cos(\omega t) + i_{lb}\cos(\omega t - \frac{2\pi}{3}) + i_{lc}\cos(\omega t + \frac{2\pi}{3})\right] - (2)$$

The d-q transformation output signals depend on the load current (fundamental and harmonic frequency components) and the performance of the phase locked loop [5] & [6]. The PLL circuit of rotation speed (rad/sec) of the rotating reference frame t set as fundamental frequency component. The PLL circuit is providing Sinθ and cosθ for synchronization. The i_d-i_q current passed through low pass for filtered. The harmonic component and allows only the fundamental components. The design is based on Butterworth method and the filter order is 2.The band edge frequency is selected the fundamental of 50 Hz for eliminate the higher order harmonic components. The algorithm is further developed to the desired reference current signals in d-q rotating frame is converted back into a-b-c stationery frame [7]. The inverse transformation from d-q rotating frame to a-b-c stationery frame is achieved by the following equations

$$i_{sa}* = i_d \sin(\omega t) + i_q \cos(\omega t) - (3)$$

$$i_{sb}* = i_d \sin(\omega t - \frac{2\pi}{3}) + i_q \cos(\omega t - \frac{2\pi}{3}) - (4)$$

$$i_{sc}* = i_d \sin(\omega t + \frac{2\pi}{3}) + i_q \cos(\omega t - \frac{2\pi}{3}) - (5)$$

The reference frame is rotates synchronous with fundamental currents. Therefore, time variant currents with fundamental frequencies would be constant after transformation. Thus, currents would be separated to AC and DC components [8].

6. I_D-I_Q THEORY

In this method reference currents are generated through the instantaneous active and reactive current component of the nonlinear load. In the same way three phase current component a-b-c will be transformed into α-β-0 components in stationary frames then it will be rotated by angle θ in synchronous reference frame based on the Park transformation [9]. Further, control scheme is described how to regulate DC voltage across the DC bus capacitor and the construction of PI controller which is very important for the generation of the error signal for switching purpose. During distorted voltage condition it is found that this method is superior to instantaneous active and reactive power method. .The block diagram of the I_d-I_q controller is shown in fig.3.

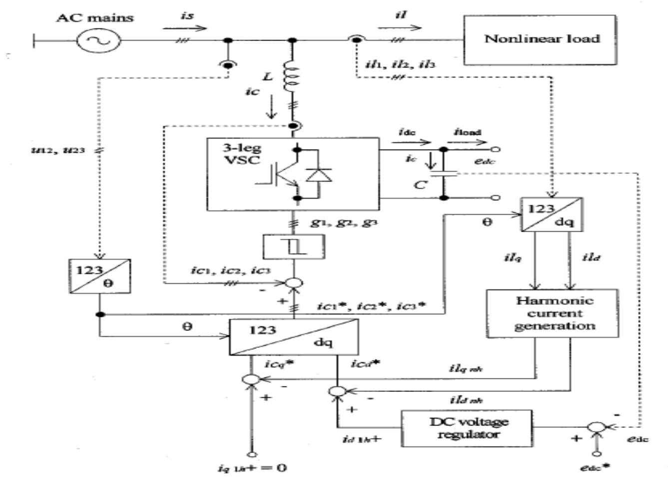

Fig.3-Basic i_d-i_q Configuration

In this method the active filter currents i_{ci} can be obtained from the instantaneous active and reactive current components i_{ld} and i_{lq} of the nonlinear load. By using Park transformation on two phase α-β (by Clarke transformation) we will get (*d-q*) components [10]. .In Park transformation two phase α-β are fed to vector rotation block where it will be rotated over an angle θ to follow the frame *d-q* .The calculation to obtain these components (i_{ld} ,i_{lq}) follows the same method to the SRF theory and α-β components will be calculated as same way calculated in (1) and (2) . However, the *d-q* load currents components are derived from a synchronous frame based on the Park transformation [6].

$$\begin{pmatrix} i_{ld} \\ i_{lq} \end{pmatrix} = \begin{pmatrix} \cos\theta & \sin\theta \\ -\sin\theta & \cos\theta \end{pmatrix} = \begin{pmatrix} i_{l\alpha} \\ i_{l\beta} \end{pmatrix} - (6)$$

Where

$$\theta = \tan-1(\mu_\beta / \mu_\alpha) - (7)$$

Where θ is a transformation angle

Under balanced and sinusoidal mains voltage condition θ is a uniformly increasing function of a time. With transformation the direct voltage component is

$$\mu_d = |\mu_{\alpha\beta}| = |\mu_{dq}| = \sqrt{\mu_\alpha^2 + \mu_\beta^2} - (8)$$

And the quadrature voltage component will be always null, u_q=0.So from the geometric relation equation (6) can be written [11]

As

$$\begin{pmatrix} i_{ld} \\ i_{lq} \end{pmatrix} = \frac{1}{\sqrt{\mu_\alpha^2 + \mu_\beta^2}} \begin{pmatrix} \mu_\alpha & \mu_\beta \\ -\mu_\beta & \mu_\alpha \end{pmatrix} \begin{pmatrix} i_{l\alpha} \\ i_{l\beta} \end{pmatrix} - (9)$$

The voltage regulation on the VSC dc side will be performed by a proportional-integral (PI) controller. The input to the PI controller is the capacitor voltage error. On regulation of first harmonic active current of positive sequence it is possible to control the active power flow in the VSI and thus the capacitor voltage C_{dc}. The reactive power flow may be controlled by the regulation of first harmonic quadrature current of positive sequence. On the contrary the primary end of the active power filters is just the exclusion of the harmonics caused by non-linear loads hence

The control scheme comprises of PI controller, limiter, and three phase sine wave generator for reference current generation and generation of switching signals. The peak value of reference currents is studied by regulating the DC link voltage. The definite capacitor voltage will be common error signal is then fed through a PI controller, which gives to zero steady error in tracking the reference current signal [12]. The output of the PI controller is presumed as peak value of the supply current (*Imax*), which is composed of two components: (a) fundamental active power component of load current, and (b) loss component of APF; to preserve the average capacitor voltage to a constant value. Peak value of the current (*Imax*) so found, will be multiplied by the unit sine vectors in phase with the individual source voltages to obtain the reference compensating currents. These expected reference currents (I_{sa}*, I_{sb}*, I_{sc}*) and detected actual currents (Isa, Isb, Isc) are equated at a hysteresis band, which delivers the error signal for the modulation technique [13]. This error signal chooses the operation of the converter switches.

In this current control circuit configuration the source/supply currents I_{sabc} are made to follow the sinusoidal reference current I_{abc}, within a fixed hysteretic band. The width of hysteresis window regulates the source current pattern, its harmonic spectrum and the switching frequency of the devices. The DC link capacitor voltage is always preserved constant during the operation of the converter. In this scheme, each phase of the converter is measured independently. To increase the current of a particular phase, the lower switch of the converter related with that particular phase is turned on while to decrease the current the upper switch of the corresponding converter phase is turned on. With this one can recognize, potential and viability of PI controller [14].

7. MODIFIED I_D-I_Q THEORY:

The principle of the Modified I_d-I_q is the same as the Id-Iq. However there are two differences in the determination of the instantaneous position of the rotating reference frame. The αβ voltages are used to calculate transformation angle, low pass filters (LPF) are used to reduce harmonics of the network signals, and consequently use on the control process.

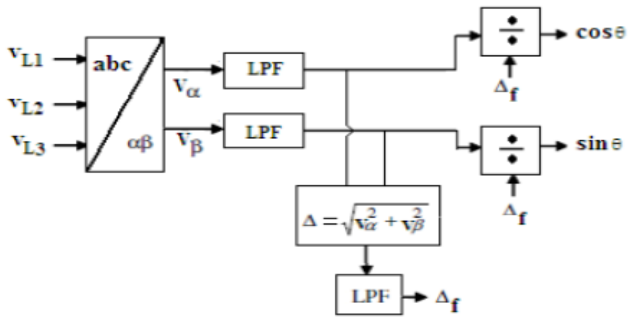

Fig. 4:- Principal of modified (i_d-i_q) method

The second modification consists in separating the Δ coefficient and to use a filtered Δ coefficient. This modification will gives better results to inverse sequence components [15]&[16]. These concepts are presented in fig.4 using block diagrams. The modified synchronous reference frame method has excellent results in balanced sinusoidal and unbalanced ac mains. The load is a three phase diode bridge with an inductive circuit on its dc side. The LPF_α, LPF_β and LPFΔ have different functions. Filters LPF_α, LPF_β are set to filter the ac mains and to avoid the influence of voltage harmonics presented on the network point of common coupling. The LPFΔ is set to avoid the oscillation of the Δ parameter that is due to the inverse sequence component. The low pass filter used for LPFα, LPFβ, and LPFΔ, the type of LPF are of 2^{nd} order Butterworth with cutoff frequencies. In this method the cutoff frequency of the Δ filter was set at 8 Hz and the cutoff frequency of the alpha and beta filters were also set to 60 Hz in Butterworth [17].

8. MULTILEVEL INVERTER:

Multilevel converters have been introduced as static high-power converters for medium-to high-voltage applicatios.The multilevel converters synthesize a desired stepped output voltage waveform by the proper arrangement of the power semiconductor devices from several lower dc voltage sources. The block diagram of the cascaded H-bridge multilevel inverters is shown in fig.5.The main advantages of multilevel converters are the use mature medium power semiconductor device, which operate at reduced voltages. As result, the switching losses and voltage stress on power electronic devices are reduced. There are three different basic multilevel converter diode clamped, flying capacitor and cascaded H-bridge [18].

The main drawback of the diode clamped topology is unequal voltage sharing between the series connected capacitors, which lead to dc-link capacitor unbalancing and requires a great number of clamping diodes for a high number of voltage level [19]. The cascaded H-bridge topologies are a good solution for high-voltage applications due to the modularity and the simplicity of control. But, in these topologies, a large number of separated voltage sources are required to supply each conversion cell. To reduce the number of separate dc voltage sources for high-voltage application, new configurations have also been presented; however, a capacitor-voltage balancing algorithm is required. A cascaded multilevel active power inverter is constructed by the conventional of H-bridges.the3-phase active filter comprises of 24-power IGBT's with diodes and each phase consists of two H-bridges in cascaded method for five level output voltage, shown in above fig. Each H-bridge is connected a separate dc-bus capacitor and it serves as an energy storage elements to supply a real power difference between load and source during the transient period. The 24 power IGBT's switching operations are performed using level-shift current controller and harmonics is achieved by injecting equal but opposite current harmonic components at point of common coupling (PCC) and fig.6 shows the 7-level ,multilevel inverter output wave form[20].

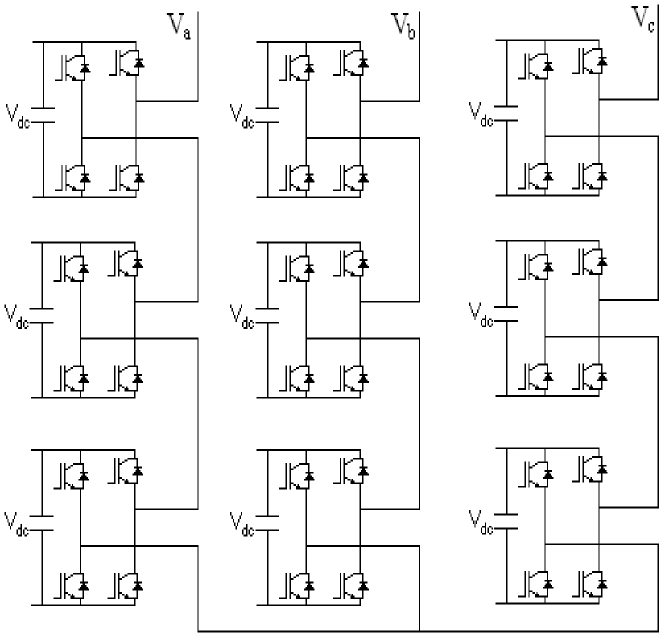

Fig.5- cascaded H-bridge multilevel inverters

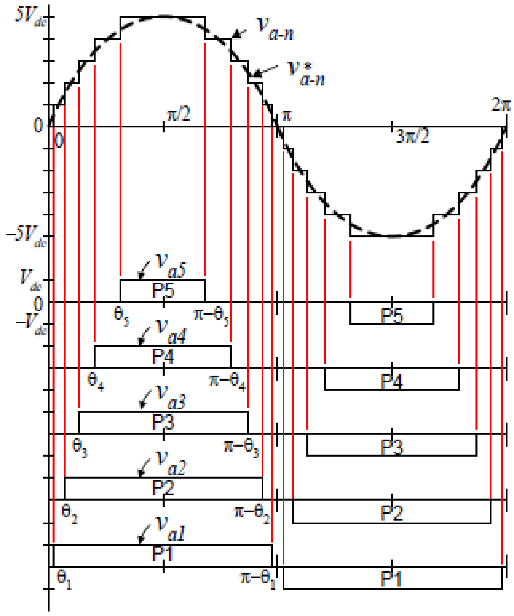

Fig.6-Output phase voltage waveform of an 11-level cascade inverter with 5 separate dc sources.

9. MATLAB/SIMULINK MODELING AND SIMULATION RESULTS

Here the simulation is carried out by seven cases 1.Non-liner load without Filter 2.Non-linear load with SRF based VSI active power filter 3. Non-linear load with I_d-I_q theory based VSI active power filter 4. Non-linear load with Modified I_d-I_q theory based VSI active power filter 5.Non-linear load with SRF based five level cascaded multilevel active power filter 6. Non-linear load with I_d-I_q theory based five level cascaded multilevel active power filter 7. Non-linear load with Modified Id-Iq theory based five level cascaded multilevel active power filter

10. CIRCUIT PARAMETERS:

S.NO	Parameters	Description
1	Source	1-phase supply 100v,50hz

2	Line impedance	R=1ohm,L=0.001henrys
3	Load	R-load 50ohm
4	Dcside capacitance Ref voltage	1e-6 100

CASE1: NON LINEAR LOAD WITHOUT ACTIVE POWER FILTER

The performance of the proposed system without active filter is evaluated through MATLAB/SIMULINK power tools. The system parameters values are, single phase source voltage is 230v; system frequency 50hz: source impedance of Ls is 1mh; diode rectifier R-load-50ohms.As diode rectifier is a non-linear load generates harmonics in load current .The simulation of system without active power filter is shown in fig.7.

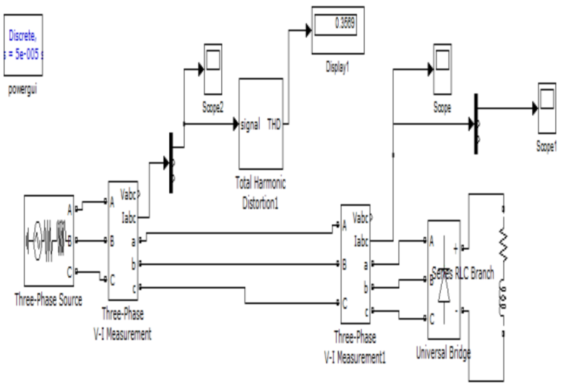

Fig.7-Simulation of System without SAPF

The simulation result of system without filter is shown in fig.8. In this fig (a) shows the supply current, (b) shows the load current. It is clear that without Active power filter load current and source current are same. The thd of source current is 0.356.

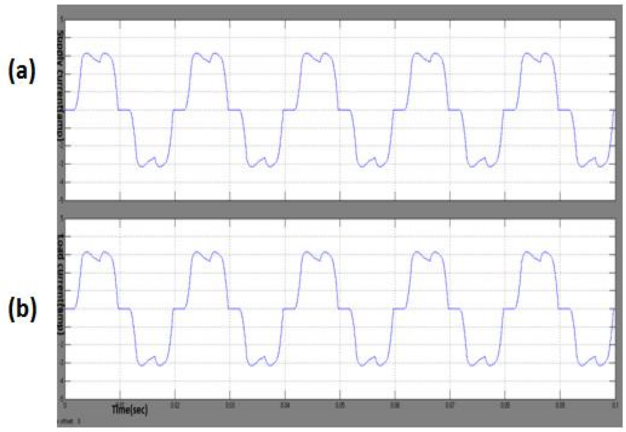

Fig.8-simulation results without shunt active power filter

CASE2:NON-LINEAR LOAD WITH SRF BASED VSI ACTIVE FILTER

The performance of the proposed SRF based VSI active power filter evaluated through Matlab/Simulink tools. The non-linear diode rectifier R-L load is connected with ac mains and VSI active filter is connected in parallel at the PCC for injecting the anti-harmonics and eliminating the harmonics and improving the reactive power. The simulation of system for sapf with srf theory is shown in below fig.9.

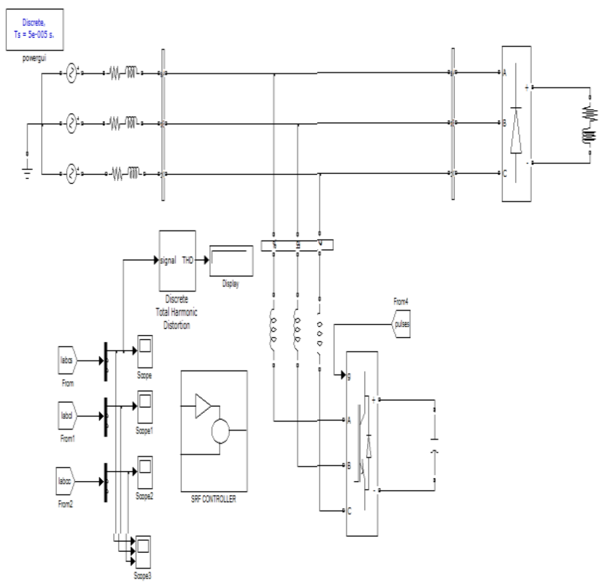

Fig.9-Simulation of System for SAPF with SRF theory

The simulation results of system with srf theory filter is shown in fig.10. In this fig (a) shows the supply current, (b) shows the load current and (c) shows the compensating current respectively. It is clear that with Active power filter load current are same and source currents are compensated. The thd of source current is 0.0108.

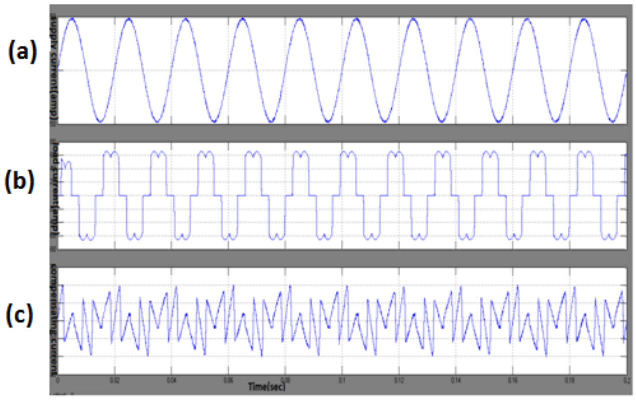

Fig.10-Simulation results of System for SAPF with SRF theory

CASE3:NON-LINEAR LOAD WITH I_D-I_Q THEORY BASED VSI ACTIVE FILTER

The performance of the proposed I_d-I_q theory based VSI active power filter evaluated through Matlab/Simulink tools The non-linear diode rectifier R-L load is connected with ac mains and VSI active filter is connected in parallel at the PCC for injecting the anti-harmonics and eliminating the harmonics and PI controller is used to regulate the dc voltage across the capacitor. The control circuit of sapf based on I_d-I_q theory is shown in fig.11.

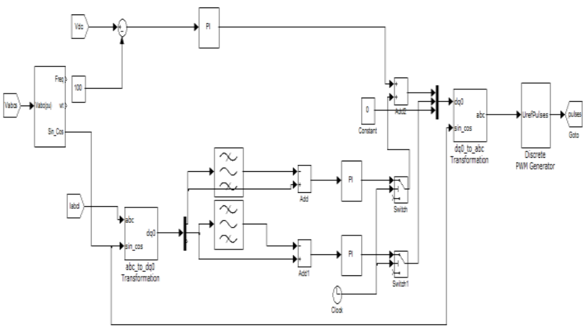

Fig.11-control circuit of SAPF based on I_d-I_q theory

The simulation results of sapf based on I_d-I_q theory is shown in fig.12. In this fig (a) shows the supply current, (b) shows the load current and (c) shows the compensating current respectively. It is clear that with Active power filter load current are same and source currents are compensated. The thd of source current is 0.02035.

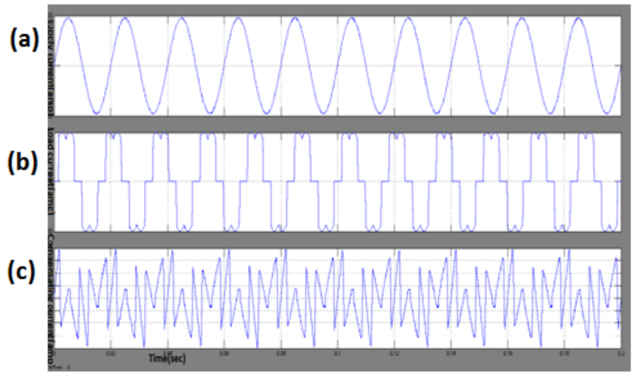

Fig.12-Simulation results of System for SAPF with Id-Iq theory

CASE4:NON-LINEAR LOAD WITH MODIFIED I_D-I_Q THEORY BASED VSI ACTIVE FILTER

The performance of the proposed modified Id-Iq theory Based VSI active power filter evaluated through Matlab/Simulink tools The non-linear diode rectifier R-L load is connected with ac mains and VSI active filter is connected in parallel at the PCC for injecting the anti-harmonics and eliminating the harmonics and PI controller is used to regulate the dc voltage across the capacitor. The control circuit of Sapf based on I_d-I_q theory is shown in fig.13.

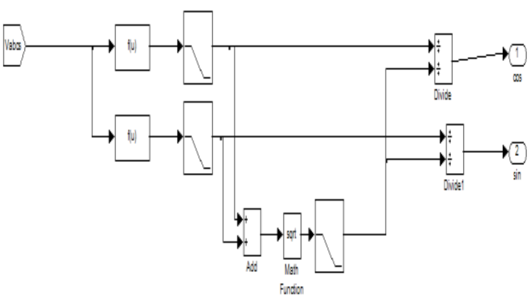

Fig.13- control circuit of SAPF based on I_d-I_q theory

The simulation results of five level multi level inverter based on modified I_d-I_q theory is shown in fig.14. In this fig (a) shows the supply current, (b) shows the load current and (c) shows the compensating. It is clear that with Active power filter load current are same and source currents are compensated. The thd of source current is 0.0103

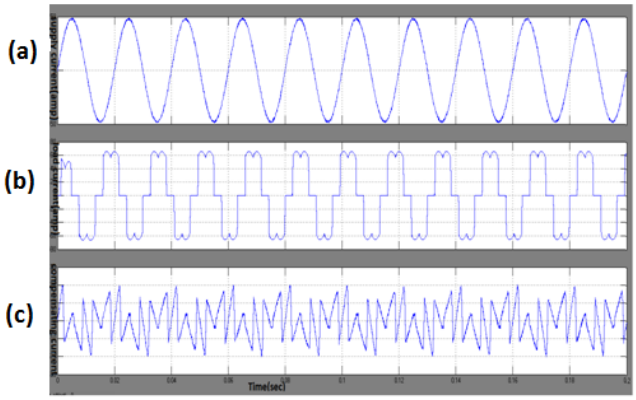

Fig.14-Simulation results of System for SAPF with Modified Id-Iq theory

CASE5:NON-LINEAR LOAD WITH SRF BASED FIVE LEVEL CASCADED MULTILEVEL ACTIVE POWER FILTERS

The performance of the proposed SRF based five level multilevel inverter evaluated through Matlab/Simulink tools The non-linear diode rectifier R-L load is connected with mains and five level shunt active power filter is connected in parallel at the PCC for injecting the anti-harmonics and eliminating the harmonics and improving the reactive power. The simulation of system for sapf with srf theory is shown in fig.15 and control circuit of five level cascaded multilevel Active power filters based SRF theory is shown in fig.16.

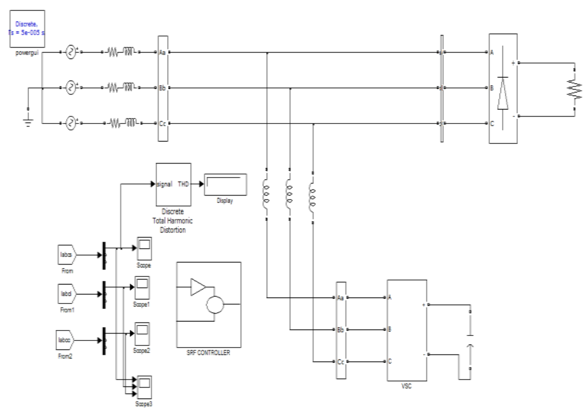

Fig.15-Simulation of System with SRF based five level cascaded multilevel Active power filters

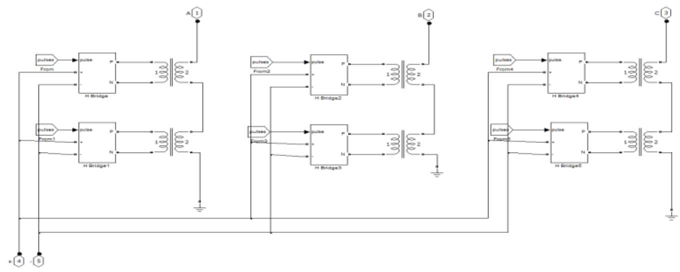

Fig.16-Contrl circuit of five level cascaded multilevel Active power filters based SRF theory

The simulation results of five level inverter with srf theory are shown in fig.17. In this fig (a) shows the supply current (b) shows the load current and (c) shows the compensating current respectively. It is clear that with Active power filter load current are same and source currents are compensated. The thd of source current is 0.0098.

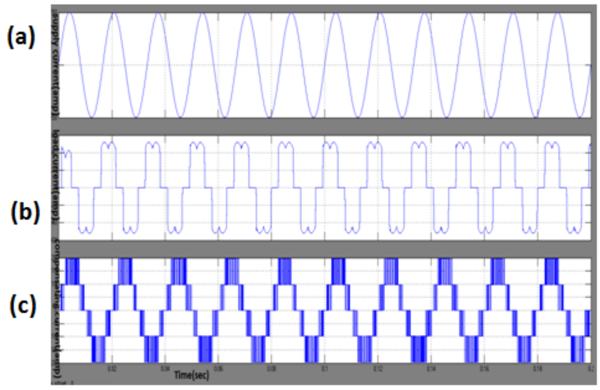

Fig.17-Simulation results of System with SRF based five level cascaded multilevel Active power filters

CASE6:NON-LINEAR LOAD WITH I_D-I_Q THEORY BASED FIVE LEVEL CASCADED MULTILEVEL ACTIVE POWER FILTERS

The performance of the proposed I_d-I_q based five level multilevel inverter evaluated through Matlab/Simulink tools The non-linear diode rectifier R-L load is connected with mains and five level shunt active power filter is connected in parallel at the PCC for injecting the anti-harmonics and eliminating the harmonics and improving the reactive power. The Control circuit of five level cascaded multilevel Active power filters based SRF theory is shown in fig.17.

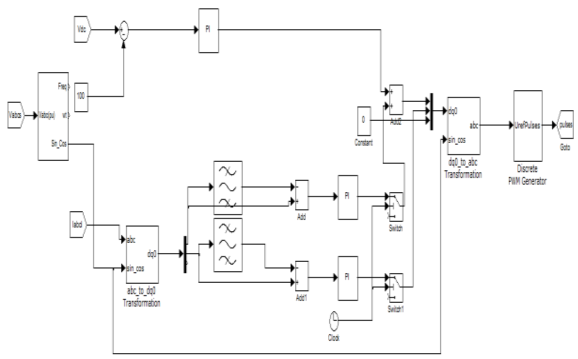

Fig.18-control circuit of five level cascaded multilevel inverter based on I_d-I_q theory

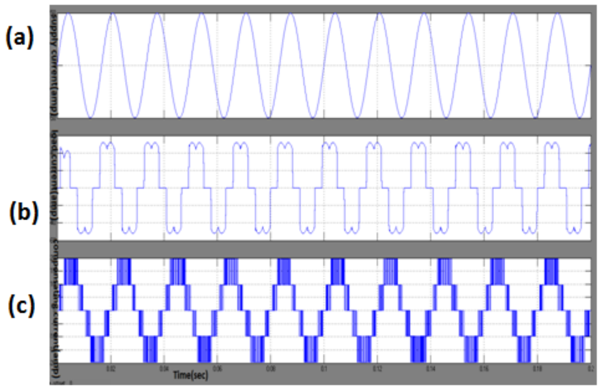

Fig.19-Simulation of System with Modified I_d-I_q theory based five level cascaded multilevel Active power filters

Fig.19- shows the simulation results of five level inverter with modified I_d-I_q theory. In this fig (a) shows the supply current, (b) shows the load current and (c) shows the compensating current respectively It is clear that with five level active power filter load current are same and source currents are compensated. The thd of source current is 0.00198

CASE7:NON-LINEAR LOAD WITH MODIFIED I_D-I_Q THEORY BASED FIVE LEVEL CASCADED MULTILEVEL ACTIVE POWER FILTERS

The performance of the proposed modified I_d-I_q theory based five level active power filter evaluated through Matlab/Simulink tools The non-linear diode rectifier R-L load is connected with ac mains and VSI active filter is connected in parallel at the PCC for injecting the anti-harmonics and eliminating the harmonics and PI controller is used to regulate the dc voltage across the capacitor. The control circuit with Modified I_d-I_q theory based five level cascaded multilevel Active power filters is shown in fig.20

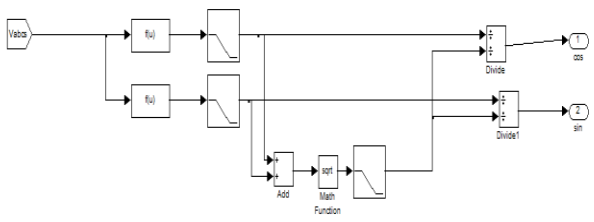

Fig.20-Simulation of System with Modified I_d-I_q theory based five level cascaded multilevel Active power filters

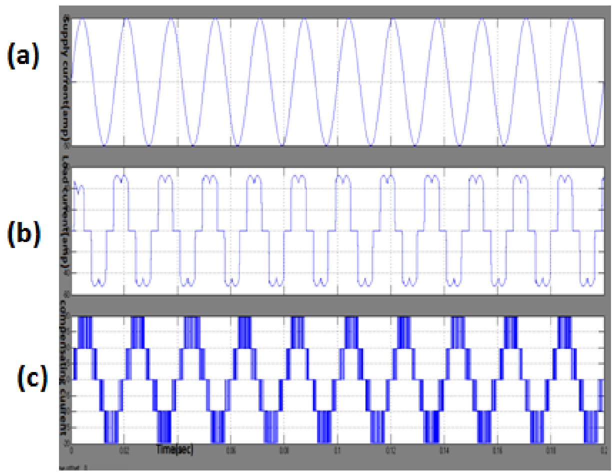

Fig.21-Simulation of System with Modified Id-Iq theory based five level cascaded

Fig.21- shows the simulation results of five level inverter with modified Id-I_q theory. In this fig (a) shows the supply current, (b) shows the load current and (c) shows the compensating current respectively It is clear that with Active power filter load current are same and source currents are compensated. The thd five level of source current is.009.

11. T.H.D TABLE FOR SAPF AND FIVE LEVEL SAPF

12. CONCLUSION:

The performance of the proposed control method is simulated for a With three different SDRF method namely normal SRF, I_d,I_q method, Modified SRF method, thus we conclude that modified SRF is the Best method in elimination of harmonics and reduction of THD and the extension is done using cascaded multilevel inverter method. As per IEEE standards the THD value is less than 5% (i.e.) is harmonic free response.

Filter	Proposed system without Filter	With filter based on SRF Theory	With filter based I_d-I_q theory	With filter base Modified I_d-I_q theory
2-level VSI	0.356	0.0108	0.02035	0.0103
Five level inverter	0.356	0.0098	0.00198	0.009

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