Implementation of SRF based Multilevel Shunt Active Filter for Harmonic Control

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***Abstract**—In this paper a power line conditioner using a cascaded multilevel inverter based shunt active filter using synchronous reference frame (SRF) controller is developed to improve the power quality in the distribution system . The cascaded multilevel inverter consists of two H bridges in which each bridge has separate dc source. Gating signals to the cascaded multilevel voltage source inverter are generated from proposed triangular-periodical current controller. Here control strategy is different from conventional methods and provides superior performance. Using Reference Frame Transformation, the current is transformed from $a-b-c$ stationery frame to rotating $0-d-q$ frame. Using the PI controller, the current in the $0-d-q$ frame is controlled to get the desired reference signal. From simulation results observed that the cascaded multilevel inverter based shunt active filter effectively compensates the current harmonics.*

***Keywords**—Power line conditioner, Synchronous reference frame controller, triangular carrier current controller, power quality.*

I. INTRODUCTION

The increased use of nonlinear devices in industry has resulted in direct increase of harmonic distortion in the industrial power system in recent years. Conventionally, this problem can be solved by using passive filters whose main components are inductors and capacitors. Although this kind of filter has the advantage of low hardware cost, the performance of this configuration is often significantly affected by system impedance and load characteristics. With the emergence of power electronics, an active power filter that helps to suppress the harmonics and improves the power quality. This proposal was mainly based on the theory of harmonic current injection. In the circuit operation. The current-controlled power converter generates the harmonic current that is opposite to the load harmonic current injecting into the power feeders. Hence, the current harmonics can be effectively suppressed and only the fundamental component of load current is extracted. In other words, the active power filter can also be regarded as a harmonic current source that is allocated in parallel with the power system. Therefore the notorious resonance problems can be easily avoided. However, because the switching frequency of the power ratings, the design of active power filters power converter is inversely proportional to for high-power applications should be made carefully.

This paper presents a synchronous reference frame controller based cascaded shunt active power filter for the harmonics and reactive power mitigation of the non-linear loads. The cascaded H-bridge active filter has been applied for power quality applications due to increase in number of voltage levels, low switching losses and higher order of harmonic elimination. The cascade M-level inverter consists of (M-1)/2 H-bridges and each bridge has its own separate dc source . The cascaded voltage source inverter switching signals are generated using proposed triangular periodical current controller; it provides better dynamic performance under both transient and steady state conditions. The compensation process is based sensing load currents only, which require current harmonics and reactive power elimination due to the loads. The PI-controller is used to maintain the capacitance voltage of the cascaded inverter constant.

II. DESIGN OF SHUNT APLC SYSTEM

The shunt APLC system contains a cascaded multilevel inverter, RL-filters, a compensation controller (synchronous reference frame controller) and switching signal generator (triangular-periodical current controller) as shown in the Fig 1.
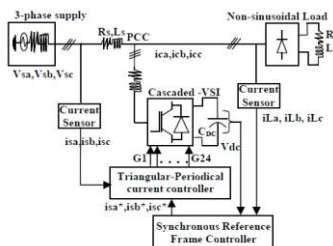

Fig1: **Shunt Active Power line Conditioners System**
.Three phase supply source connected with the non-linear load.

The parallel active filter approach is based on the principle of injection of load harmonic currents and hence is characterized by non sinusoidal current reference tracking and high current regulator bandwidth requirement. The parallel active filter is controlled as a harmonic current source and requires a suitable controller for extraction of load harmonic currents and an appropriate current regulator. The nonlinear load current should contain fundamental component and harmonic current components. For harmonic compensation, the active filter must provide the compensation Current $ti_c(t)=i_L(t)-i_S(t)$.
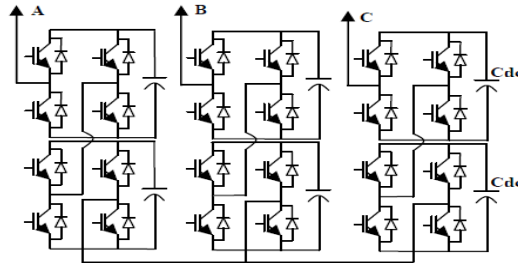
III. MULTI LEVEL INVERTER

Fig2: **Cascaded Multilevel Active Power Filter**

The three-phase active filter comprises of 24-power transistors and each phase consists of two-H-bridges in cascaded method for 5-level output voltage shown in Fig 2. Each H-bridge is connected a separate dc capacitor and it serves as an energy storage element. A cascade M-level inverter consists of (M-1)/ H bridges in ts to supply a real power difference between load and source during the transient period. The capacitor voltage is maintained constant using PI-controller and the output voltage is *Vdc* . The 24-power transistors switching operations are performed using proposed triangular-periodical current controller and harmonics is achieved by injecting equal but opposite current harmonic components at point of common coupling (PCC).

IV. PROPOSED CONTROLLERS

SRF method is used to generate reference signals and triangular-periodical current controller is used for generating switching signals to cascaded VSI.

A). SRF Control Method

The synchronous reference frame theory is developed in time-domain based reference current generation techniques. The conventional SRF method can be used to extract the harmonics contained in the supply voltages or currents. For current harmonic compensation, the distorted currents are first transferred into two-phase stationary coordinates using $\alpha-\beta$ transformation (same as in $p-q$ theory).After that, the stationary frame quantities are transferred into synchronous rotating frames using cosine and sinus functions from the phase-locked loop (PLL). The sine and cosine functions help to maintain the synchronization with supply voltage and current.. The conventional SRF algorithm is also known as $d-q$ method, and it is based on $a-b-c$ to $d-q-0$ transformation (park transformation), which is proposed for active filter compensation. This proposed algorithm derivate from a three-phase stationary coordinate load current iLa, iLb, iLc are convert to id-iq rotating coordinate current, as follows

$$i_{d=\frac{2}{3}[i\,La}\sin(\omega t)_{+iLb}\sin(\omega t-\frac{2\pi}{3})_{+\,iLc}\sin(\omega t+\frac{2\pi}{3})_]} \quad (1)$$
$$i_{q=\frac{2}{3}[iLa}\sin(\omega t)_{+iLb}\sin(\omega t-\frac{2\pi}{3})_{+\,iLc}\sin(\omega t+\frac{2\pi}{3})_]} \quad (2)$$

Here the Proportional Integral (PI) controller is used to eliminate the steady state error of the DC-component of the cascaded multilevel inverter and maintains the dc-side capacitor voltage constant
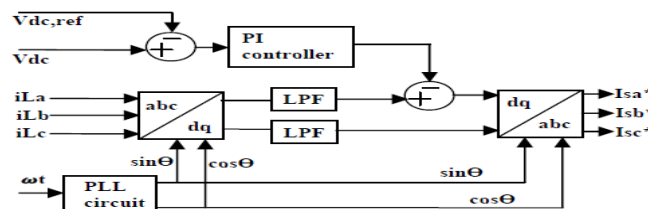

Fig3: **Synchronous Reference Frame Controller**

The dc capacitor voltage is sensed and compared with reference voltage to calculate the error voltage. These error voltage involved the P-I gain (KP=0.1 and KI=1) for regulate the capacitance voltage in the dynamic conditions. In accordance to the PI controller output is subtracted from the direct axis (d axis) of harmonic component for eliminate the steady state error. Similar to the $p-q$ theory, using filters, the harmonics and fundamental components are separated easily and transferred back to the $a-b-c$ frame as reference signals for the filter.

$$I_{sa}^* = i_d\sin(\omega t)_{+\;iq}\cos(wt) \quad \text{(3)}$$
$$I_{sb}^* = i_d\sin(\omega t - \frac{2\pi}{3})_{+\;iq}\cos(wt - \frac{2\pi}{3}) \quad \text{(4)}$$
$$I_{sb}^* = i_d\sin(\omega t + \frac{2\pi}{3})_{+\;iq}\cos(wt + \frac{2\pi}{3}) \quad \text{(5)}$$

b) PI Controller

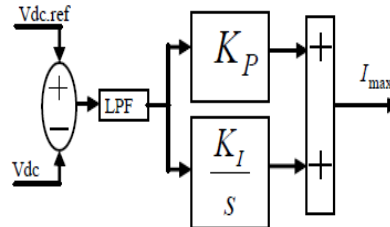The DC side capacitor voltage is sensed and compared with a desired reference voltage.

Fig 4 : PI Controller

Figure 4 shows the block diagram of the proportional integral control scheme for the active Power filter. The DC side capacitor voltage is sensed and compared with a desired reference voltage. The voltage error $e=V_{dc\,,ref}$ -V_{dc} at the *n th* sampling instant is used as an input for PI controller. The error signal passes through Butterworth Low Pass Filter (LPF). The LPF filter has cutoff frequency at 50 Hz that can suppress the higher order components and pass only Fundamental components. The PI controller estimates the magnitude of peak reference current *I* max and controls the dc side capacitor voltage of cascaded multilevel inverter. It transferred by the function which is represented as,

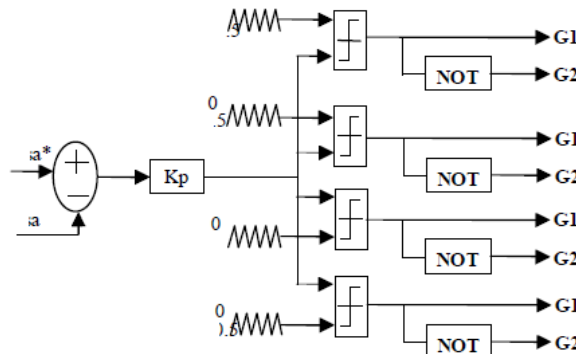$$H(s) = K_p + K_I/s$$

(c)Triangular carrier current controller

Fig5: Triangular carrier current controller

The triangular carrier current controller is one of the familiar methods for active power filter applications to generate gate control switching pulses of the voltage source inverter. To determine the switching transitions by means the error current [desired reference current (ia*) compared with the actual source current (ia)] is multiplied with proportional gain (Kp). The output signal of the proportional gain is compared with triangular carrier signal.

The four triangular signals are generated same frequency with different amplitude for cascaded multilevel inverter, because each phase in one converter does not overlap other phase shown in Figure 5 . Thus the switching frequency of the power transistor is equal to the frequency of the triangular carrier signal.

V.   EXPERIMENTAL RESULTS

The performance of the proposed SRF controller based cascaded active filter is evaluated through Matlab/Similink power tools. The system parameters values are; Line to line source voltage is 440 V; System frequency (f) is 50 Hz; Source impedance of LS is 1 mH; Filter impedance of Rc, Lc is 0.1 Ω; 1 mH; diode rectifier RL, LL load: 20 Ω; 100 mH; DC side capacitance (CDC) is 2100 µF; Reference voltage (VDC, ref) is 700v.
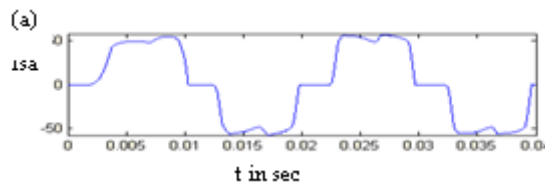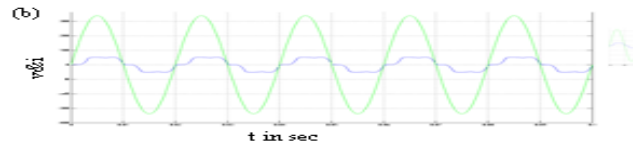
Fig:6 simulation results for SRF based APF before compensation (a) source current or load current before compensation. (b) p.f before compensation.
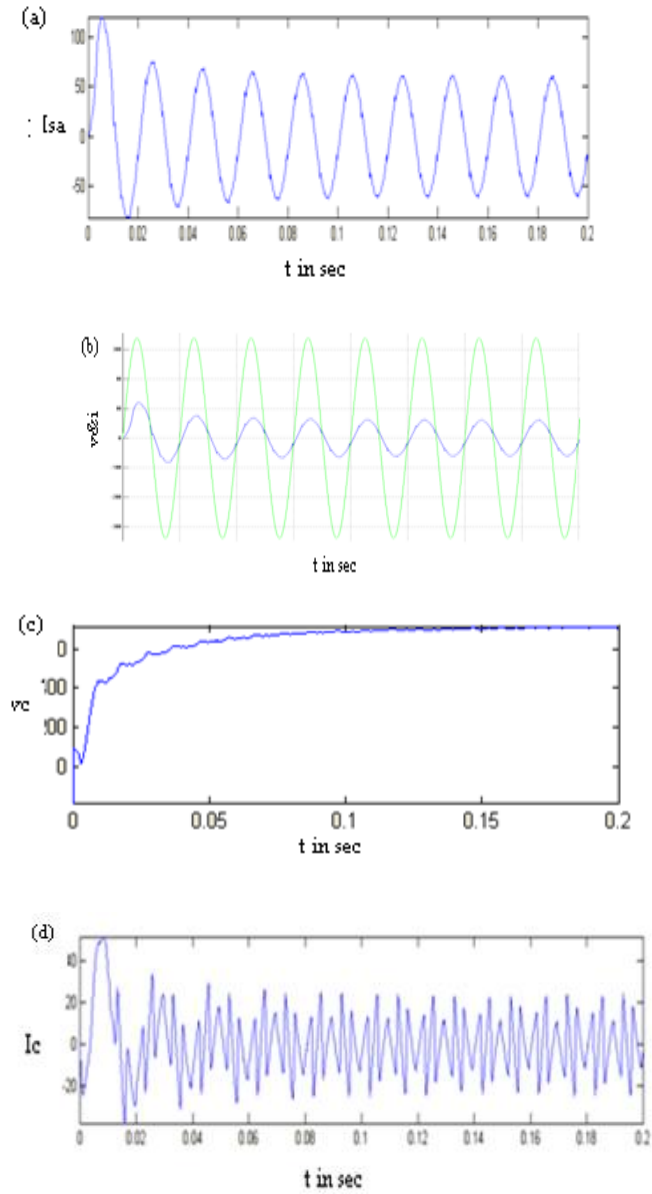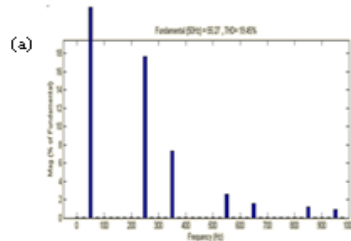

Fig:7 Simulation results for SRF based APF after shunt compensation (a)Source current after shunt compensation (b). P.F of the system after shunt compensation.(c). capacitor voltage (d) Compensation current.
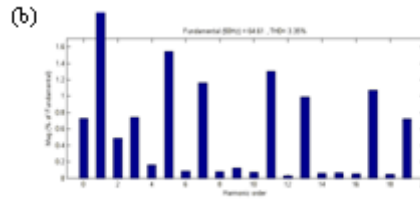
Fig 7 SRF based cascaded APF; Order of harmonics
(a) the source current without active filter (THD=19.45%), (b) with active filter(THD=3.35%).

The total harmonic distortion (THD) measured at the source(current) on the distribution system and the various parameters measured without APF and with APF are presented in Table 1

parameter	Source current(Isa) with out APF	Source current(Isa) with APF
Power factor	0.707	0.9659
Real power	9.8KW	16KW
Reactive volt Ampers	6.3KVAR	5.8KVAR
THD	19.45%	3.35%

Table1: Measurement of various parameters for SRF based APF with and without compensation

After providing the shunt compensation THD is reduced to 3.35% which is with in the permissible limits.

VI.   CONCLUSION

In this paper, the control strategy of the active power filter using multiple voltage-source converters was proposed on the basis of synchronous reference frame theory . SRF is employed to extract the fundamental component from the nonlinear load currents. This controller is developed by sensing load currents only. This approach is fairly simple to implement and gives better compensation characteristics. From the viewpoint of the initial and running cost, the active power filter is inferior to the passive power filter, i.e., the LC power filter at present. It is, however, most suitable to apply the active power filter to the suppression of the harmonic components present in the input current of large-capacity cycloconverters, because it is difficult for the passive power filter to eliminate their harmonic components having various frequencies.

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