

## Adaptive PI control based three phase three level shunt active power filter for PQ conditioning

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**Abstract**— This paper presents compensation algorithm schemes used for shunt active power filters applied to three-phase systems, allowing harmonic current suppression and reactive power compensation, which results in an effective power factor correction. The strategies used to extract the three phase reference currents are based on the synchronous reference frame method. Although this method is based on balanced three-phase loads, it can also be used for single-phase loads, allowing independent control of all three phases. Accordingly, a fictitious quadrature current needs to be generated through software implementation, and be orthogonal to the measured load current. This creates the fictitious balanced currents in the two-phase stationary reference frame system, allowing the choice of an adequate compensation strategy which will result in either balanced or unbalanced sinusoidal source currents. The proposed algorithms applied to the APF topologies are evaluated and discussed. Mathematical analyses of the SRF-based algorithms are presented and simulation results are performed to validate the theoretical development and confirm the performance of the shunt APFs.

**Keywords-** Multilevel Inverter, Synchronous Reference Frame Theory, dc link voltage control, Shunt Active Filter, PI control.

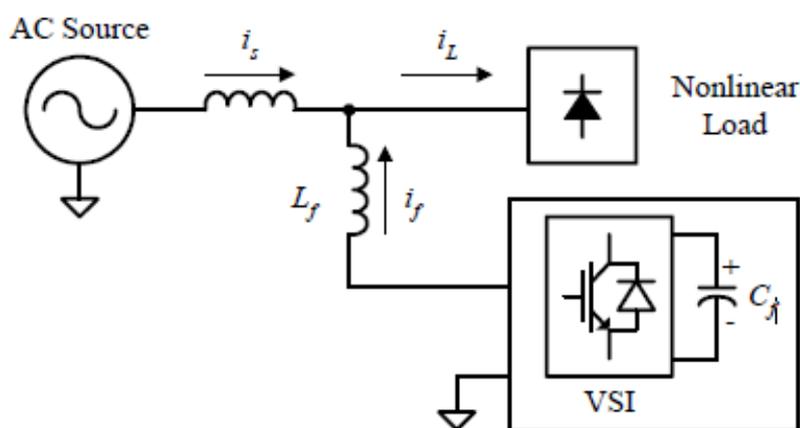
### I. INTRODUCTION

There has been a continuous rise of nonlinear loads over the years due to intensive use of power electronic control in industry as well as by domestic consumers of electrical energy. The utility supplying these nonlinear loads has to supply large vars. Moreover, the harmonics generated by the nonlinear loads pollute the utility. The basic requirements for compensation process involve precise and continuous var control with fast dynamic response and on-line elimination of harmonics. To satisfy these criterion, the traditional methods of var compensation using switched capacitor and thyristor controlled inductor coupled with passive filters are increasingly replaced by active power filters (APFs) and hybrid APFs. The hybrid APFs improve the characteristics of passive filters with smaller rated APFs. The majority of the reported APFs and hybrid APFs use a var calculator to calculate the reactive current drawn by the load and accordingly a reference current is generated. The compensator current is made to follow the reference current for the required compensation. This method exhibits good current profile and fast dynamic response; however the generation of reference current is a complicated process. In the proposed indirect current controlled APF, the reference current is generated from the DC link capacitor voltage directly, without calculating the reactive current drawn by the load. As the reference current in the proposed APF is generated from the DC link capacitor voltage, without calculating the reactive current drawn by the load, the compensation process is straight forward and simple as compared to the control techniques of conventional APFs. For higher rated nonlinear loads; multilevel inverters (MLIs) can be used. To control the output voltage and reduce undesired harmonics of MLIs, sinusoidal PWM, selective harmonic elimination or programmed PWM and space vector modulation techniques have been conventionally used in MLIs. The major complexity associated with such methods is to solve the nonlinear transcendental equations characterizing the harmonics using iterative techniques such as Newton–Raphson method. However, this is not suitable in cases involving a large number of switching angles if good initial

guess is not available. Another approach based on mathematical theory of resultant, wherein transcendental equations that describe the selective harmonic elimination problem are converted into an equivalent set of polynomial equations and then mathematical theory of resultant is utilized to find all possible sets of solutions for the equivalent problem has also been reported. However, as the number of harmonics to be eliminated increases (up to five harmonics), the degrees of the polynomials in the equations become so large that solving them becomes very difficult. The evolutionary algorithm can be applied for computing the optimal switching angles of the MLI with the objective of optimizing the individual harmonics to allowable limits. In this paper the compensation algorithms used to extract the three-phase reference currents are based on the synchronous reference frame (SRF) method. Although the SRF method is based on the balanced three phase loads, it can also be used for single-phase loads, allowing independent control of all three phases. The flexibility to choose the SRF-based controller strategy will determine if the negative, zero or both sequence current components will be compensated. The SRF-based algorithms will be evaluated under unbalanced load conditions and will be applied to APF topologies. Mathematical analyses of the SRF-based algorithms are presented and simulation results are performed to validate the theoretical development and confirm the performance of the shunt APFs.

## II. SHUNT ACTIVE POWER FILTER

Shunt active filters are by far the most widely accept and dominant filter of choice in most industrial processes. Figure 1 show the system configuration of the shunt design. The active filter is connected in parallel at the PCC and is fed from the main power circuit. The objective of the shunt active filter is to supply opposing harmonic current to the nonlinear load effectively resulting in a net harmonic current. This means that the supply signals remain purely fundamental. Shunt filters also have the additional benefit of contributing to reactive power compensation and balancing of three-phase currents. Since the active filter is connected in parallel to the PCC, only the compensation current plus a small amount of active fundamental current is carried in the unit. For an increased range of power ratings, several shunt active filters can be combined together to withstand higher currents. The APF consists of a DC-bus capacitor ( $C_f$ ), power electronic devices and a coupling inductors ( $L_f$ ). Shunt APF acts as a current source for compensating the harmonic currents due to nonlinear loads. This is achieved by “shaping” the compensation current waveform ( $i_f$ ), using the Current Controlled-VSI. The required compensating currents are obtained by measuring the load current ( $i_L$ ) and subtracting it from a sinusoidal reference.



*Fig. 1. Block diagram of the SAF system.*

The aim of shunt APF is to obtain a sinusoidal source current ( $i_s$ ) using the relationship:

$$i_s = i_L - i_f.$$

Current component ( $i_L, f$ ) and the current harmonics ( $i_{L,h}$ ) according to

$$i_L = i_{L,f} + i_{L,h} \dots\dots(1)$$

Then the compensation current injected by the shunt APF should be

$$i_f = i_{L,h} \dots\dots\dots(2)$$

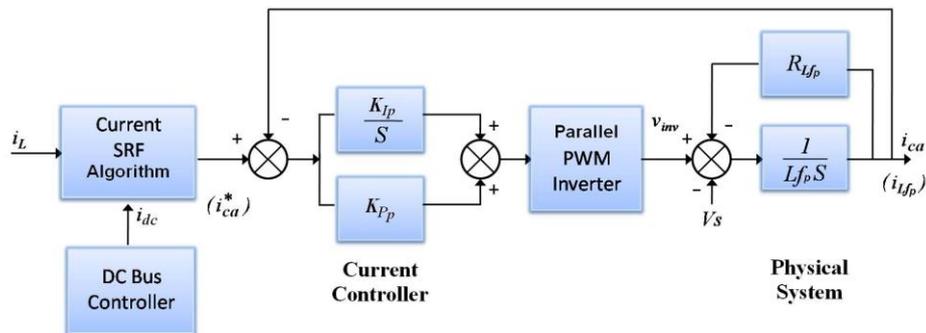
The resulting source current is

$$i_s = i_L - i_f = i_{L,f} \dots\dots\dots(3)$$

From the above equation (3) the source current contains only the fundamental component of the nonlinear load current and thus free from harmonics. When the shunt APF performs harmonic filtering, the ideal source current for a nonlinear load connected. In this way the shunt APF completely cancels the current harmonics from the nonlinear load, thus results in a harmonic free source current. The shunt APF can be considered as a varying shunt impedance from the nonlinear load current point of view. For the harmonic frequencies the impedance is zero, or at least small, and infinite in terms of the fundamental frequency. Due to this effect there is a considerable in voltage harmonics, because the harmonic currents flowing through the source impedance are reduced. The current carried by the Shunt APFs is the sum of the compensation current plus a small amount of active fundamental current supplied to compensate for system losses. Reactive power compensation is also possible through the Shunt APF. Moreover for higher power rating applications, it is also possible to connect several shunt APFs in parallel to meet the requirement for higher currents.

### III. SRF ALGORITHM

The SRF-based algorithms will generate the compensation reference currents ( $i_{ca}$ ,  $i_{cb}$ ,  $i_{cc}$ ) for all topologies and, specifically, the neutral reference current ( $i_{cn}$ ) when the F-L APF topology is used. The SRF-based algorithms can be used to perform load unbalance compensation or to independently compensate each of the three phases. When the load unbalance compensation is implemented the source currents become balanced and sinusoidal. However, when the phases are individually controlled the source currents will be sinusoidal but unbalanced. As the SRF-based algorithm is based on balanced three-phase loads, some modification must be done to apply it to a three-phase system, where each phase is treated as a single-phase system

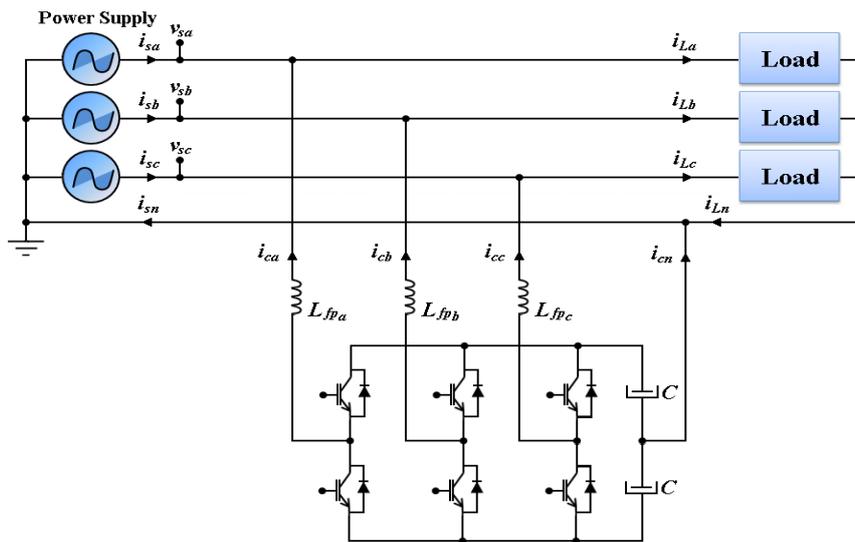


*Fig. 2. SRF current control block diagram.*

### IV. PROPOSED SHUNT ACTIVE FILTER

The proposed SRF controlled shunt APF is shown in Fig.3. It has a three phase three level cascaded type multilevel inverter and it has two control loops, the voltage control loop and the current control loop. The voltage control loop regulates the value of the DC link capacitor voltage ( $V_c$ ). The sensed DC link capacitor voltage is sent to a low pass filter (LPF) to remove the ripples present in it. The voltage thus obtained is compared with a reference DC voltage ( $V_{dc, ref}$ ) and the error is fed to a PI controller. The output of the PI controller is the amplitude ( $k$ ) of the current, which is used to derive the reference current. The derived reference current is compared with the source current in the current control loop for generating gate signals for the switches of the voltage source inverter (VSI) of the APF. SRF control has been used in the current control loop of the proposed APF. The VSI is controlled to produce a fundamental terminal voltage in-phase with the AC system voltage. When the fundamental inverter terminal voltage is more than the RMS value of

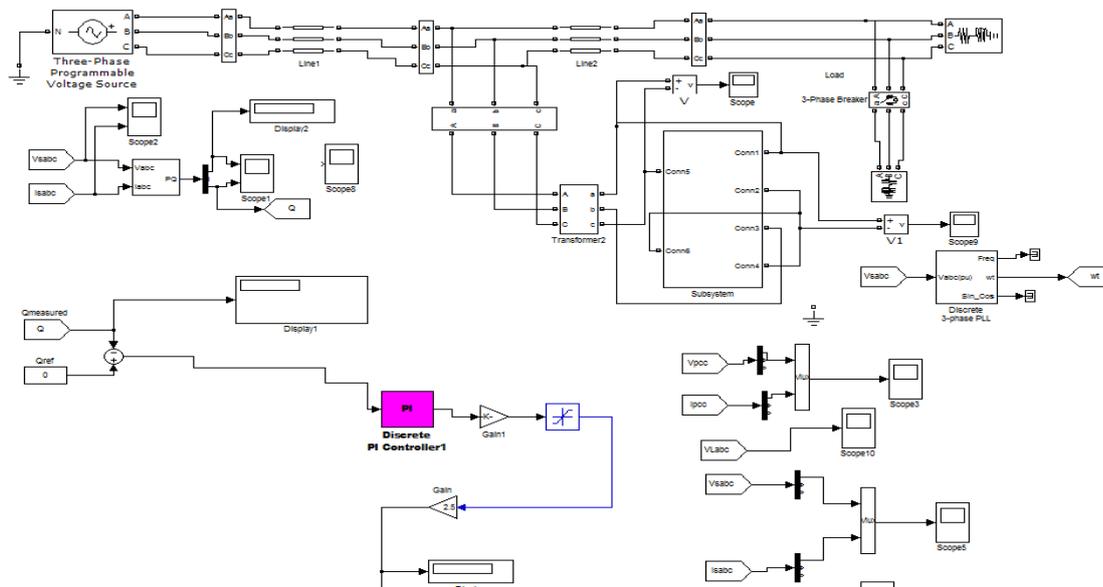
AC system voltage  $V_s$ , a leading current is drawn from the AC system and when the inverter terminal voltage is less than  $V_s$ , a lagging current is drawn from the AC system.



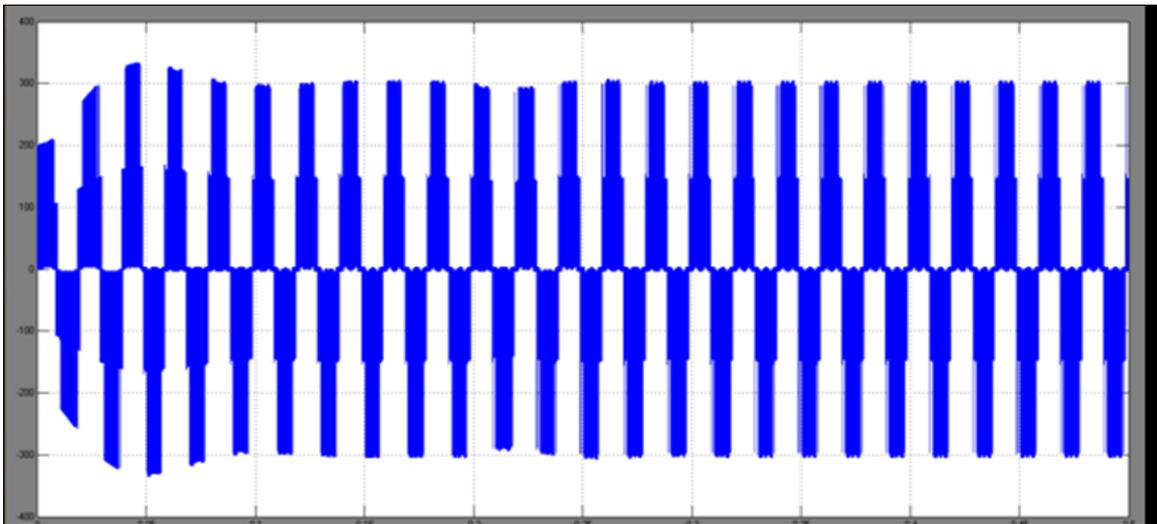
**Fig.3 Proposed system circuit diagram**

The magnitude of the inverter terminal voltage depends on the DC link capacitor voltage  $V_c$ . By controlling the gate signals of the switches, the inverter terminal voltage can be made to lag or lead the AC system voltage, so that real power flows into or out of the inverter circuit. By suitable operation of the switches, a voltage  $v_{comp}$  having a fundamental component  $V_{comp1}$  is generated at the output of the inverter. When  $V_{comp1} > V_s$ , leading current (with respect to  $V_s$ ) will be drawn and the inverter supplies lagging vars to the system. The PI controller is used to reduce the load voltage error and makes the system load voltage remains constant.

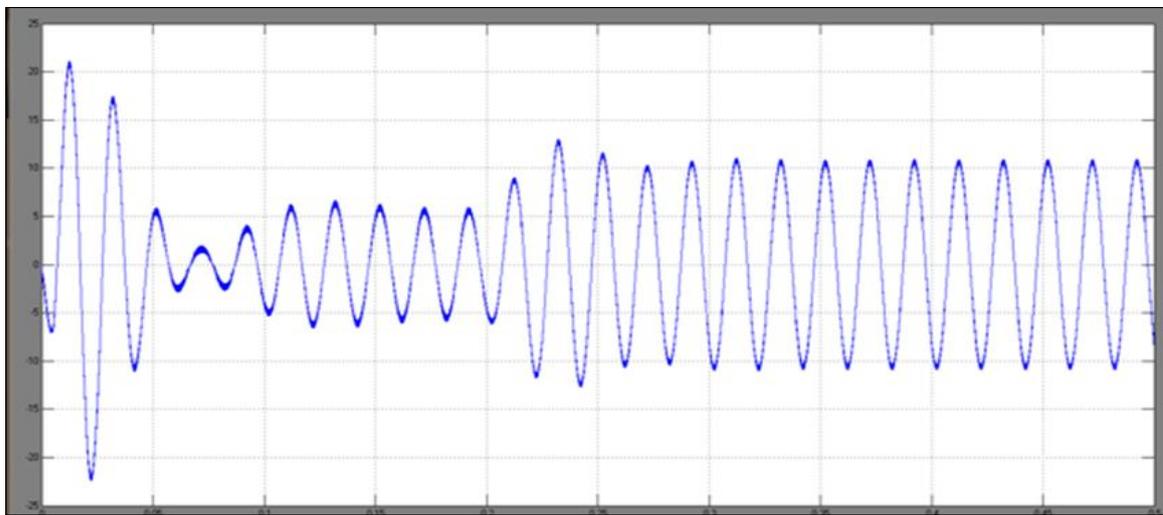
### V. SIMULATION RESULTS



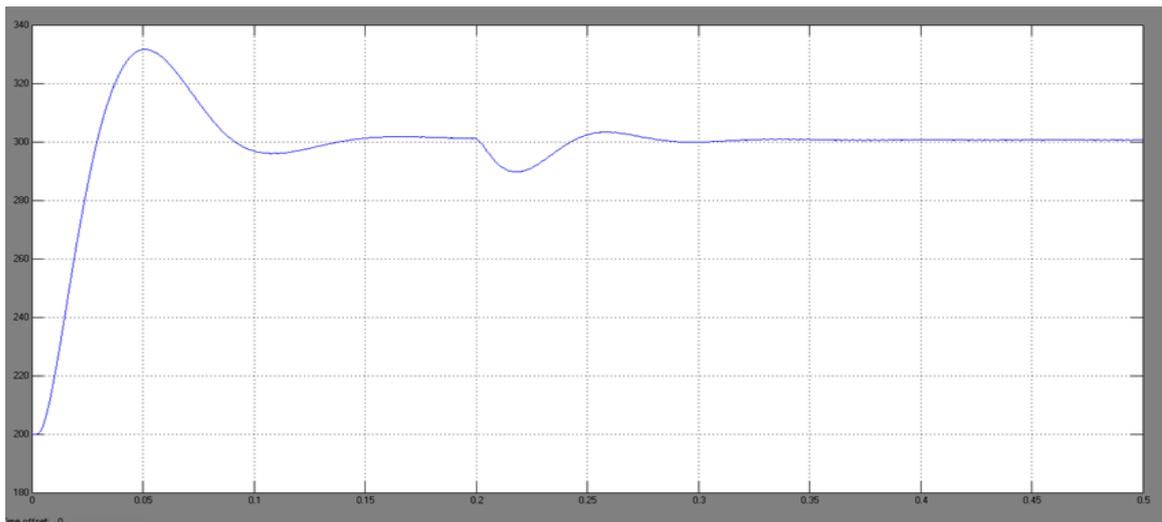
**Fig.4 Proposed system Matlab Simulink**



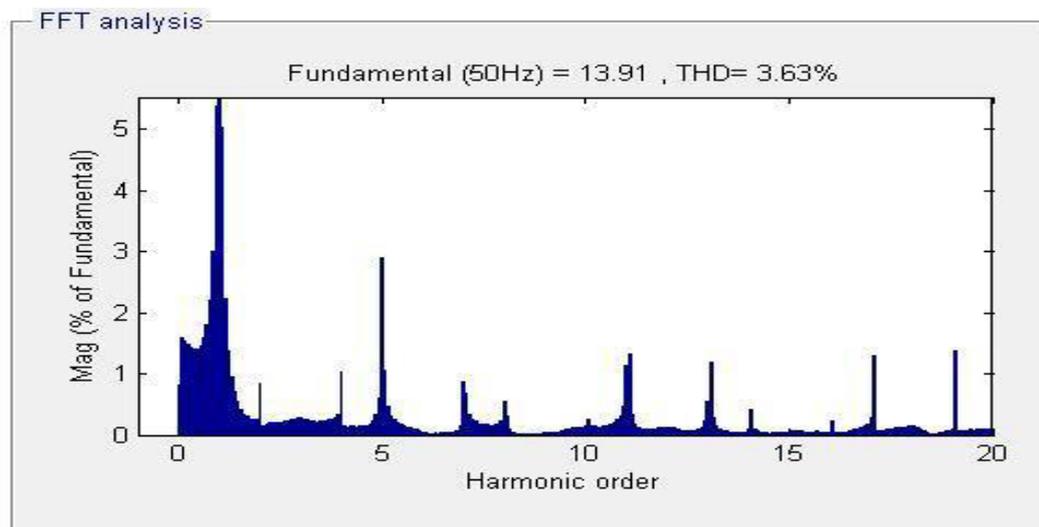
*Fig. 5 Proposed system multilevel inverter output voltage*



*Fig.6 Proposed system load current*



*Fig.7 Constant DC link voltage using PI control*



*Fig.8 THD Result*

## VI. CONCLUSIONS

This paper presented compensation strategies, based on SRF and PI controller, which can be used in shunt APF topologies, when applied to three-phase systems, which allow harmonic current suppression, reactive and neutral current compensations to be conducted. The SRF-based controllers were used in three phase shunt APF topologies, and performed effectively. The algorithms allow the compensation of both load unbalances to generate sinusoidal and balanced source currents, and control each of the three phases independently. In this case the source currents will be sinusoidal but unbalanced and the THD result is 3.63%.

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