Control of Shunt Active Power Filter Using Instantaneous Symmetrical Component Technique

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Abstract:

The active power filter (APF) is one of power filters which have better dynamic performance. The APF needs an accurate control algorithm that provides robust performance under source and load unbalances. The control methods are responsible for generating the reference currents which used to trigger the Voltage Source Inverters (VSI). Thus, compensation of harmonics depends largely on the algorithm adopted. For any Shunt APF system there is various way of implementing the control block whose output goes to gate of the voltage source Inverter. Further, the harmonic and frequency has been modelled to propose a new control strategy for the shunt Active Power Filter. The Instantaneous Symmetrical Component Theory (ISCT) algorithm is the basic estimation algorithms which estimate the parameters based on only present data. In this thesis, main aim is to implement a basic control algorithm in MATLAB-SIMULINK first then the harmonic and unbalance estimation part is implemented in MATLAB.

Keywords : Voltage Source Converter (VSI), Total Harmonic Distortion (THD), Static Compensator (STATCOM), Power Quality Conditioner (PQC)

1. INTRODUCTION

Improving power quality has been the major research topic in last few decades due to flooding of semiconductor and other non-linear devices. The power quality of any sources judged by the some indexes defined by international bodies such harmonics factor, telephonic interference etc. Therefore, the author's motivation was development of the compensation device, fulfilling three basic functions: improving power quality, providing continuity of supply and balancing energy in the system.

The solution proposed in this thesis is a power conditioning system based on power electronic converters and energy storage system. The main objective of the proposed device is ensuring uninterrupted and high quality energy supply even during serious voltage variations and disturbances. The assumption is that proposed conditioner can operate as an independent, “plug and play” device. Using feedback from the grid voltage, such devices can operate in parallel, supporting grid voltage in many points of the distribution network. The shunt configuration is chosen due to ease of installation in the network, as well as due to popularity of shunt-connected converters in the network. In author’s opinion many solutions presented in this thesis may be adopted to RES or vehicle charging infrastructure and play important role in future smart grid.

2. OPERATING PRINCIPLE

The shunt compensators are well recognized in the compensation of reactive power and therefore the regulation of voltage bus bar where they are connected. The SAP can be considered as a static synchronous generator that is used to generate asynchronous three-phase alternative voltage with the mains voltage coming from direct voltage source. There was no exchange of energy with the active network, but only reactive power to be injected (or absorbed) by the SHAF as shown in fig. 1.

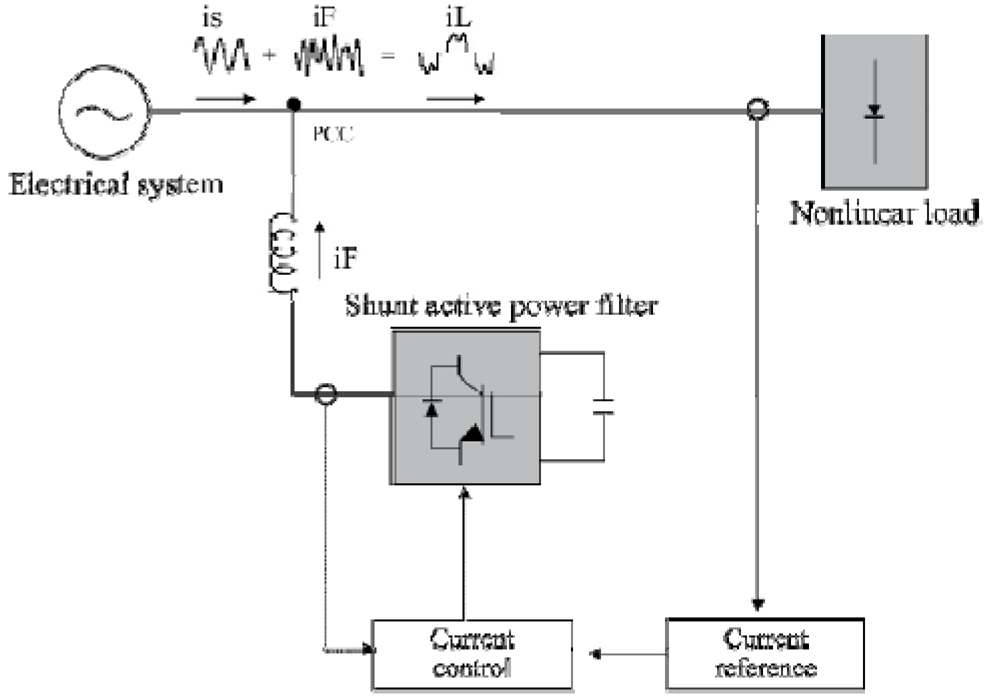


Fig. 1: Block diagram of Shunt Active Power Filter

3. MATHEMATICAL FORMULATION

System Configuration The configuration model of shunt active power filter using a voltage source converter (VSC) is shown in Fig. 3.1 [4]. In this model, the resistance$R$f in series with the voltage source inverter represents the sum of the coupling inductor resistance losses and the inverter conduction losses. The inductance Lf represents the leakage inductance of the coupling inductor. The sum of the switching losses of the inverter and the power losses in the capacitor is represented by Rdc which is in shunt with the DC-link capacitor Cdc. In Fig. 3.1,fa,Vfb, and Vfc are thethree-phase SAPF output voltages; vla, vlb, and vlc are the three phase bus voltagesat load-side;Ifa, Ifb and Ifc are the three-phase SAPF output currents.In order to analyse the balanced three-phase system more conveniently, the threephasevoltages and currents are converted to synchronous rotating frame byabc/dq0transformation.

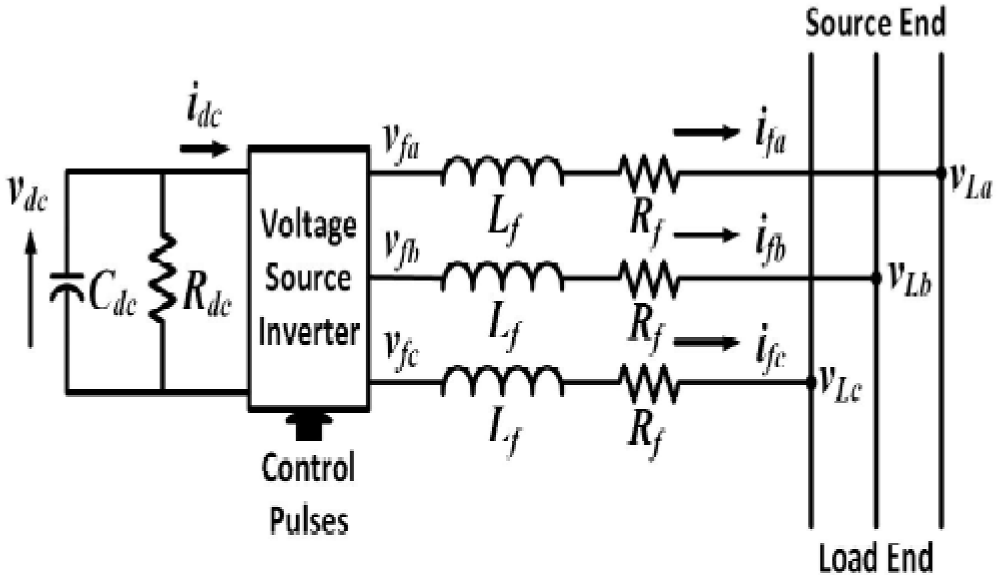


Fig. 2 Equivalent Circuit of SAPF

4. CONTROL SCHEME BASED ON INSTANTANEOUSSYMMETRICAL COMPONENT THEORY (ISCT)

Let the three phase instantaneous currents be defined as ia, ib and ic. The powerinvariant instantaneous symmetrical components are then defined by

$$\begin{bmatrix} i_{a0} \\ i_{a1} \\ i_{a2} \end{bmatrix} = \sqrt{\tfrac{1}{3}} \begin{bmatrix} 1 & 1 & 1 \\ 1 & a & a^2 \\ 1 & a^2 & a \end{bmatrix} \begin{bmatrix} i_a \\ i_b \\ i_c \end{bmatrix}$$

where a = ej$^{120^\circ}$, It is to be noted that, if the line currents are balanced,ia0 become zero because it is a real quantity. The ia1 and ia2 are the instantaneousvector and complex conjugate of each other. An assumption is taken in this schemethat the supply voltage is balanced. Here, the power factor angle is the angle betweenthe instantaneous vectors $i$sa1 and $v$sa1, that is the angle between the balancedsupply voltage and supply currents. In this control scheme the angle can be taken toany desired value. In addition, we specify that the supply or sink average power is notrequired by the compensator.

5. SIMULATION RESULTS

5.1 Performance of SAPF as a Harmonic Compensator

Fig 3 presents the performance of SAPF as harmonic compensator. Under this modeSAPF performs the function of power factor correction and harmonic compensation insource currents by compensating the nonlinear load currents.

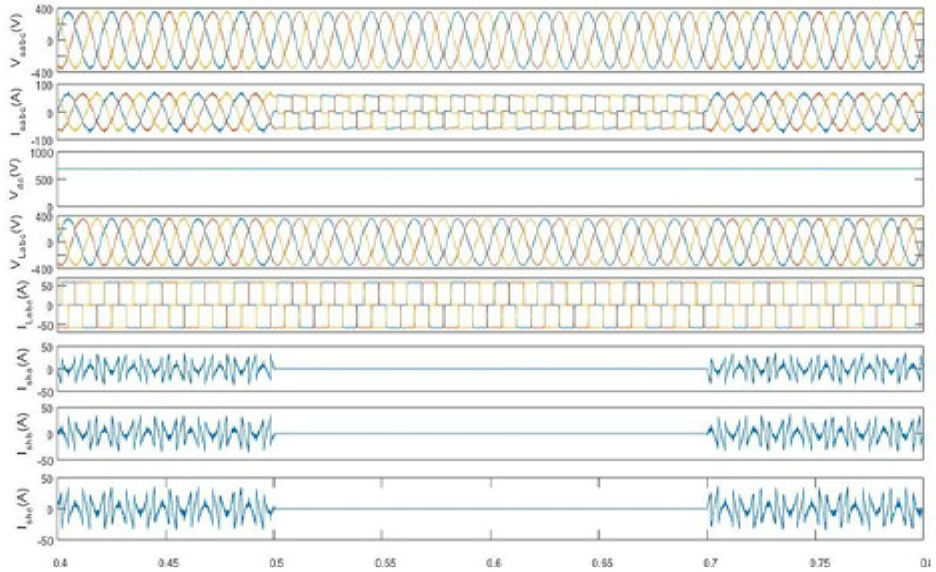


Fig. 3: Effect on the source current when the SAPF is switched off

SAPF compensates the nonlinearity presents in the load current waveform and makes the source current harmonic free. It is clearly seen that the DC link voltage is maintained constant. During 0.5-0.7 secs the SAPF is switched off therefore the source current becomes nonlinear during this instant.

5.2 Performance of SAPF during Unbalance Load Currents

Fig 4 and Fig 5 shows the performance SAPF during unbalance load conditions.

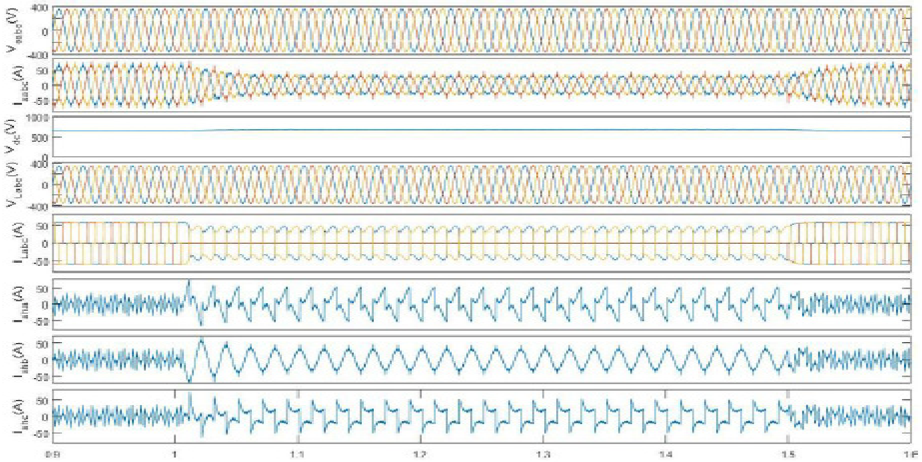


Fig 4: Compensation of source currents when the load currents are unbalanced

The unbalance condition is shown separately for linear and nonlinear loads. Fig 5shows the performance of SAPF compensating the unbalance nonlinear load current. During 1.0-1.5 secs the load currents are unbalanced. SAPF maintains the DC linkvoltage and balanced the unbalance source currents waveform.

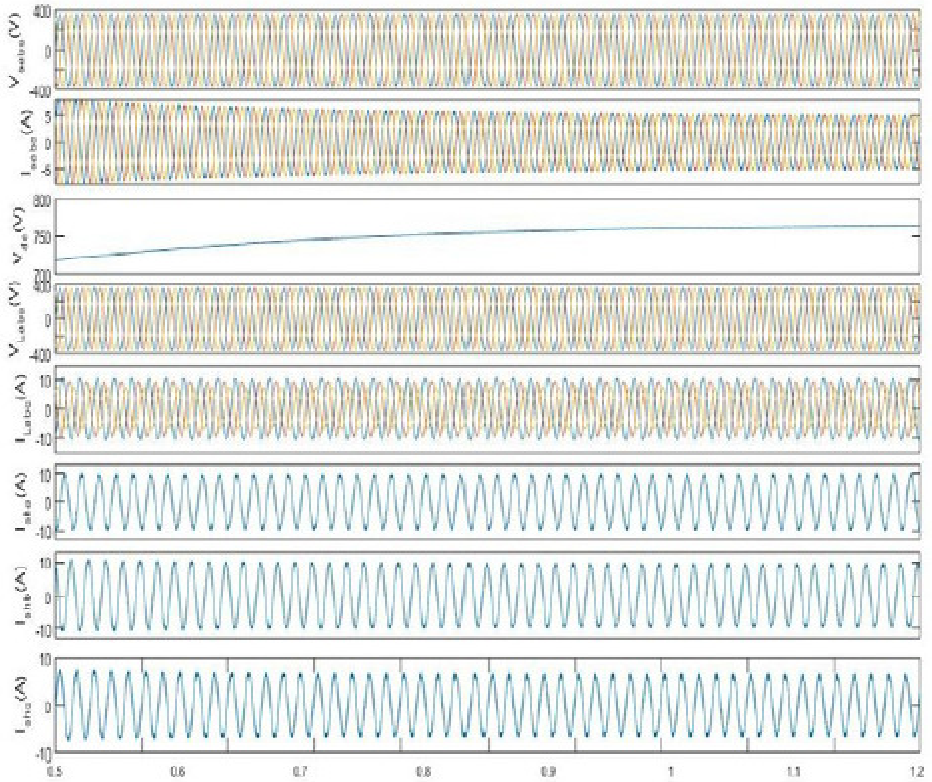
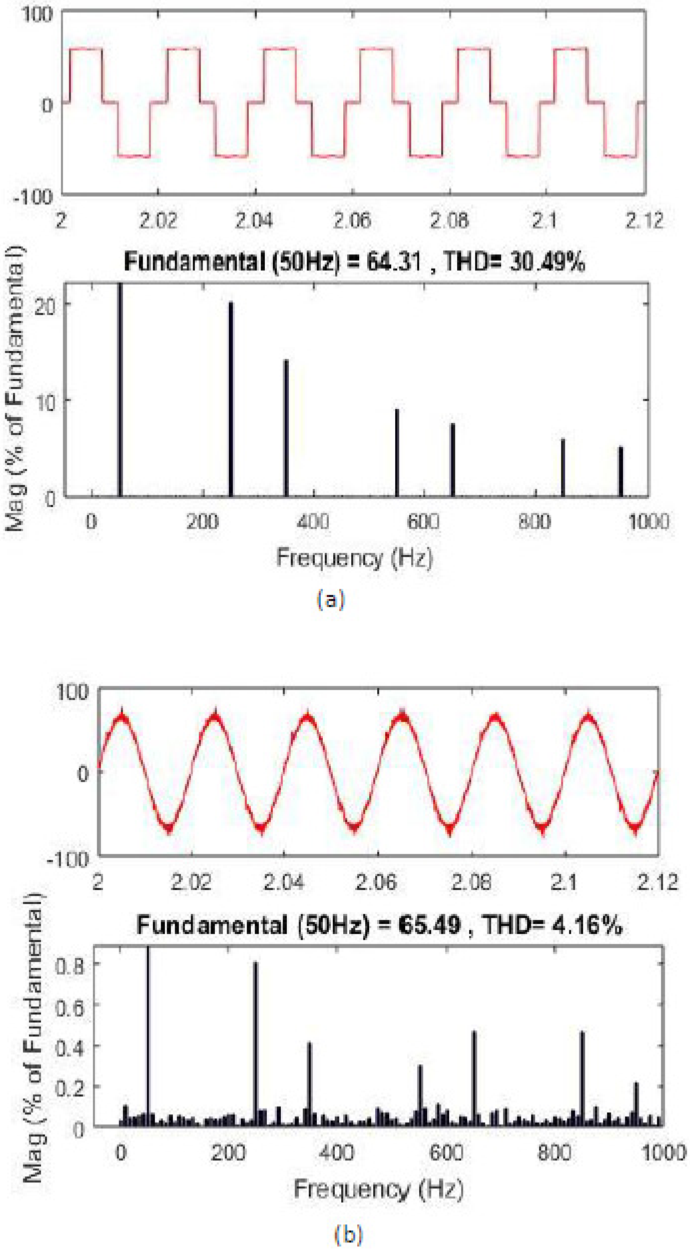


Fig 5: Balancing of source current for linear load during the unbalanced load current

As per phase SAPF compensating currents are also shown in the above figure which maintains the source currents profile.

Fig 5.3 shows the performance of SAPF compensating the unbalance linear load current. In this mode the SAPF compensates the linear unbalance load currents and makes the source current balanced and sinusoidal. The DC link voltage is also maintained nearly constant.

To study the harmonic compensation capability of SAPF using ISCT control algorithm analysis of waveform and harmonic spectrum of load and source current waveforms is done. The THD of load current is 30.49% whereas THD of source current obtained is only 4.16 %.Fig 5.4 shows the waveform and harmonic spectrum of load and source currents.



(a)

(b)

Fig 6:- Waveform, THD and Harmonic Spectrum of(a) Load Current (b) Source Current

A comparative analysis of both load current and source current is done to find out the compensation capability of SAPF.

Table 1: THD of IL and IS under different conditions for ISCT

	Load current	Source current	
		During Harmonic Compensation	During Unbalance
ISCT	30.49 %	4.16 %	7.36 %

6. CONCLUSION

The paper presents analysis of shunt APF in order to eliminate harmonic frequency present in the AC. A symmetrical component scheme and a filter based on the principle of id – iq compensation scheme has been projected in this work. Also symmetrical component scheme is put to application in SIMULINK. A mathematical study of id – iq compensation method has been done to assimilate the control schemes. As the id – iq compensation mechanism is dependent on a rotating frame resulting from mains voltages that does not incorporate phase locked loop and carries better-quality compensation results, simulation was done based on this control method. When we consider balanced conditions the id – iq control scheme is found to have satisfactory harmonic compensation performance. Here the harmonics were produced by three – leg VSC and by the application of the Hysteresis controller. The control scheme depicted vows for the operation of the Active Filter in changing frequency circumstances sans any adaptation. But the above method deals with balanced as well as unbalances system. Therefore symmetrical component method is also used to for unbalanced three phase systems. With regard to symmetrical component method, from the results and simulation findings, the projected synchronous detection scheme is aptly fit for harmonic compensation in a system that is unbalanced. It has been confirmed that, the performance of the ISCT method is superior to preceded methods. It is possible to obtain the acceptable THD values for source currents by using the latter method. The analysis has been assisted by the comparative tables presented in the chapter 5. Furthermore, the response of dc link voltage by PI controller is better. The constant dc-link voltage enhances the life of capacitor shunted across APF, so this method is more reliable .The algorithms has been simulated to demonstrate the feasibility and effectiveness of the study using MATLABSIMULINK. Further, the estimation part is presented in the Chapter 5, which motive is to understand the harmonic estimation.

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