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Shunt Active Power Filter for Enhancement of Power Quality

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Abstract

This project deals with the shunt active power filter to enhance the power quality. The performance of shunt active filter is studied through simulation result. MATLAB is the simulation tool used to study the performance of shunt active power filter. The simulation is carried out for non-linear load. The shunt active filter allows compensating harmonic current, reactive power, unbalanced load and zero sequence currents. Compensating any of the above problems always tends to enhancement of power quality

***Keywords:** Shunt Active Power Filter (SAPF), p-q problems, non linear load.*

INTRODUCTION

In today's power system power quality improvement is the most focused topic. Nearly two decades ago, passive loads having linear nature were being used by consumers and various industries, with a lesser number of non-linear loads thus having less impact on the quality of power system. With the arrival of semiconductor and power electronic devices and their easier controllability have caused wide use of non-linear loads such as chopper, rectifier, etc.

The use of semiconductor devices is responsible for harmonic and reactive power disturbances. These disturbances causes various problems such as overheating of transformer, excessive neutral current, distortion of feeder voltage, damage to power electronic devices, malfunction of sensitive equipment. Harmonics play major role in disturbing power quality, called harmonic distortion. This problem of Harmonic distortion is increasing day by day in electric distribution system as the use of nonlinear loads is increasing. These harmonics are required to be reduced in the current. Nonlinear loads create harmonic current and increase the deterioration of the power system voltage and current waveforms.

These loads are responsible for the deformation of sine wave of the current. Harmonics in the power system can be measured through the measurement of THD. Limits for harmonics are defined by IEEE. Some solutions have been reported to solve power quality problems.

Initially, passive power filters (PPF) which are the combinations of capacitors and inductors were normally used to mitigate the power quality problems. These techniques were high in use in high voltage DC transmission (HVDC) for removing the harmonics on the AC and DC sides. However, this approach is not suitable at the distribution level as PPF can only correct specific load conditions or a particular state of the power system. These filters are unable to response rapidly to the dynamic behavior of system conditions. Thus, the active power filter (APF) was introduced to remove and mitigate harmonics and reactive power. The purpose of APF power line conditioner used to compensate the utility line current waveform so that it approximates a sine wave in phase with the line voltage when a nonlinear load is connected to the system. Classically, shunt power line conditioner (shunt PPF) consists of tuned LC filters and high pass filters are used to suppress harmonics and power capacitors are employed to improve the power factor of the utility or mains. This method of PPF has some limitations as of fixed compensation; there large size and can also lead to resonance conditions. Hence active power filter is introduced as a viable alternative to compensate harmonics and improve PF.

This project is focusing on the application of shunt active power filter in treating the harmonics distortion. It is connected in parallel with the nonlinear load to detect its harmonic and reactive current and to injects a compensating current into the system. Most of the active filters developed are based on sensing harmonics and reactive volt-ampere requirements of the nonlinear load and require complex control. In this work PI controlled shunt active power filter for the mitigation of harmonics of a nonlinear load is implemented.

The control strategy senses line currents only. SAPF can be used with different current control strategy such as d-q method, p-q method, fuzzy logic controller, neural networks etc. which is useful in removing effective harmonic from power system. This project mainly concentrates on the instantaneous active and reactive power method. A detailed simulation program is developed to observe the performance of the system.

Basic Configuration of SAPF

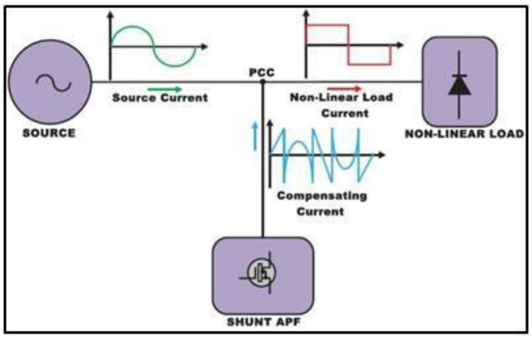

Figure 1: Basic Configuration of SAPF

Shunt active filter The shunt active filter has a Voltage Source Inverter (VSI), Interfacing Inductor, and ripple filter. The design of VSI includes the DC bus voltage level, the DC capacitance and the rating of IGBTs used. The design of Interfacing Inductors and the Ripple Filter is presented here. The design is carried out considering a right shunt APF.

The DC capacitor connected at the DC bus acts as energy buffer and provides dc voltage for the normal operation of the shunt APF. The DC bus voltage VDC, DC a bus capacitance CDC, interfacing inductors (Lf), and voltage and current rating of switches are calculated as below.

Selection of the DC bus voltage

The minimum DC bus voltage of VSC of shunt APF should be greater than twice the peak of phase voltage of the distribution system. The DC bus voltage is calculated as

$$V_{DC=}\,2*\,2\sqrt{2}*V_{LL}/\sqrt{3}\,m \qquad 1$$

Where m is modulation index and considered 1 and VLL is the AC line output voltage of the shunt APF, during transient the energy conservation is applied as

$$1/2*C_{DC}*\left(V_{DC}{}^{2}-V{}^{2}{}_{DC1}\right)=K\,{}_{1}3VaIt \qquad 2$$

Where Vdc is the nominal DC voltage equal to the reference DC voltage and Vdc1 is the minimum voltage level of the DC bus , α is the overloading factor, V-phase voltage, I-phase current, and t-time by which the DC bus voltage is to be recovered.

DC Link Voltage

The minimum DC bus voltage of the VSI of the UPQC should be greaterthan twice of the peak of the phase voltage of the distribution system. The DC bus voltage as

VDC = 2 √ 2VLL/ √ 3m 3

Where m is the modulation index and is considered is 1 and VLL is the Ac output voltage of the shunt APF. Thus VDC is selected as 700 V as for VLL is 415V.

Selection of Components

Rating of SAPF

The VA rating of the APF to provide harmonic compensation:

1) Current rating= Current flowing through the filter
2) Voltage rating= Voltage across the filter
3) The VA rating of filter= 3*Vf*If
4) Selection of AC inductor

The value of the interfacing inductor is as

AC inductance(Lf)
=(√ m*Vdc)/(12*a*fs*Icrpp)

Selection of DC link capacitor

The value of the DC bus capacitor is computed as;

0.5*Cdc [( ) − ( )] **= 3*Vph (I)*t**

Where, Vdc - the reference voltage,

Vdc1 - the minimum voltage level of DC bus

- the overloading factor,

I - the phase current of VSI and t is the time for which DC bus voltage is to be recovered.

CONTROL ALGORITHM

The shunt active power filter control algorithm is shown in Figure 2. the shunt active power filter can be controlled by Instantaneous reactive power (p-q) theory in real time.

Controller Techniques

The important part of the active power filter system is its controller. Proper control method allows active power filter to carry out harmonic reduction as well as reactive power compensation. The controller of shunt active power filter is divided into two parts i.e.

1. PI controller
2. Hysteresis current controller

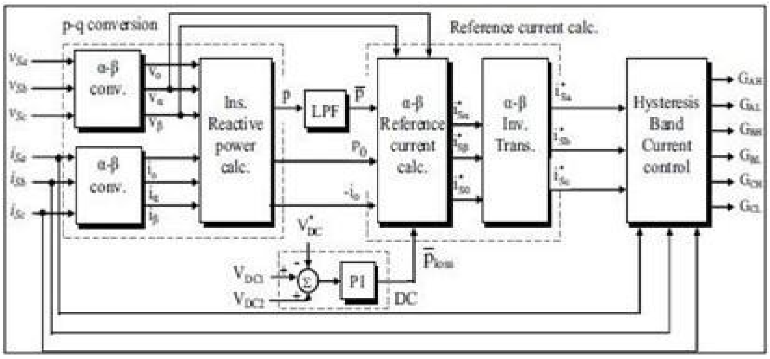

Figure 2: Shunt active power filter control diagram

PI CONTROLLER

To control DC bus voltage, it is required to maintain little amount of power flowing into DC capacitor, thus compensating for switching and conduction losses, the dc link voltage control loop does not required to be as fast as it responds to steady state operating condition. The actual DC link voltage and a reference DC link voltage are compared and passed through a PI controller To maintain dc-link voltage at a fixed reference value, the dc-link capacitor requires a certain amount of real power, which is directly proportional to the difference between the reference and actual voltages. The control signal coming from PI controller to regulate DC link voltage can be expressed as

$$- \quad = (\quad - \quad) + \quad \int$$

$$(\quad - \quad)$$

Where, Kp and Ki are proportional and integral gains of the PI controller. By increasing proportional gain (Kp) reduces rise time and steady-state error but it causes increase in the overshoot and settling time. Similarly increase of integral gain (Ki) reduces steady state error but it increases overshoot and settling time

1) Hysteresis Current Controller

The hysteresis band current controller is used to generate gate pulses for the triggering pattern of the inverter. There are number of current control methods, but hysteresis current control method much more superior than other current control methods because of fast current controlling and easy implementation. Some of the better properties possessed by hysteresis band current controllers are robustness, excellent dynamics and fastest control with minimum hardware. This method switches the transistor when the error current fed to it is over the fixed band. Smaller the band width better is the accuracy. If current becomes more than the upper limit of the hysteresis band (+h) , the switch in the upper part of the inverter arm becomes by using turned off and the switch in the lower arm becomes on. Hence, the current starts decreasing. While decreasing if the current falls below the lower limit of the hysteresis band (-h), the lower switch of the inverter arm becomes turned off and the upper switch becomes turned on. Consequently, the current gets back into the hysteresis band. So, the actual current follows the reference current within the hysteresis band. Switching frequency is ariable and this is the disadvantages of this method. The turn-on off conditions for the inverter switches is

For Upper switch off: (iact – iref) >HB.

For Lower switch off: (iact – iref) <-HB

2) *Instantaneous p-q Technique for SAPF*

Instantaneous p-q technique is used for the control of shunt inverter of SAPF in order achieve mitigation of source current harmonics.

The control requires to measure source current ISabc and source voltage VSabc from the system in order estimate a reference current using instantaneous p-q technique. Source voltage and current are transformed to αβ0 reference using (4) and (5)

$$\begin{bmatrix} V_0 \\ V_\alpha \\ V_\beta \end{bmatrix} = \sqrt{2/3} \begin{bmatrix} \sqrt{1/3} & \sqrt{1/3} & \sqrt{1/3} \\ 1 & -1/2 & -1/2 \\ 0 & \sqrt{3}/2 & -\sqrt{3}/2 \end{bmatrix} \begin{bmatrix} V_{sa} \\ V_{sb} \\ V_{sc} \end{bmatrix} \quad 4$$

$$\begin{bmatrix} i_0 \\ i_\alpha \\ i_\beta \end{bmatrix} = \sqrt{2/3} \begin{bmatrix} 1/\sqrt{2} & 1/\sqrt{2} & 1/\sqrt{2} \\ 1 & -1/2 & -1/2 \\ 0 & \sqrt{3/2} & -\sqrt{3/2} \end{bmatrix} \begin{bmatrix} i_{sa} \\ i_{sb} \\ i_{sc} \end{bmatrix} \quad 5$$

The instantaneous real and imaginary power components are calculated by using equation (6). The instantaneous real and imaginary powers include both oscillating and average components as shown in equation (7).

The average components of p and q consist of positive sequence components (p and q) of source current and the oscillating components of p and q consist of harmonic and negative sequence components of source currents. The reference currents isa*, isb* and isc* can obtained by using (9)

$$\begin{pmatrix} p \\ q \end{pmatrix} = \begin{pmatrix} V_\alpha & V_\beta \\ -V_\beta & V_\alpha \end{pmatrix} \begin{pmatrix} i_\alpha \\ i_\beta \end{pmatrix} \quad 6$$

$$P_0 = V_0 * i_0 * \qquad p = \overline{p} + \overline{p} \quad 7$$

$$\begin{pmatrix} i^*_{s\alpha} \\ i^*_{s\beta} \end{pmatrix} = 1/V^2\alpha + V^2\beta \begin{pmatrix} V_\alpha & V_\beta \\ V_\beta & V_\alpha \end{pmatrix} \left(p + \overline{po}\right) \quad 8$$

$$\begin{pmatrix} i^*_{sa} \\ i^*_{sb} \\ i^*_{sc} \end{pmatrix} = \sqrt{2/3} \begin{pmatrix} 1/\sqrt{2} & 1 & 0 \\ 1/\sqrt{2} & -1/\sqrt{2} & \sqrt{3/2} \\ 1/\sqrt{2} & -1/\sqrt{2} & -\sqrt{3/2} \end{pmatrix} \begin{pmatrix} i^*_{s0} \\ i^*_{s\alpha} \\ i^*_{s\beta} \end{pmatrix} \quad 9$$

Table.1.System and design parameters used for simulation

	Parameter	Value
Source	AC mains line voltage	415 V
	Supply frequency	50Hz
Source impedance	Resistance	0.01 ohm
	Inductance	1 mH
Load	Non-linear load	10 ohm
DC link Capacitor	DC link Capacitor	40 µF
Inductor	Inductor	1.2mH

RESULTS AND DISCUSSION

In figure 3, we are going to mitigate harmonics which is caused due to nonlinear load. Thus, we are switching the shunt Active Power Filter through circuit breaker and feeding the equal but in opposite magnitude compensating current in the line. Thus, we are getting the clean source current which before distorted due to presence of harmonics. Figure 4 shows the sinusoidal waveform of the source current from the distorted waveform after the application of the shunt active power filter.

THD Analysis:

Figure 5 shows the Total Harmonic Distortion (THD) of source current waveform due to nonlinear load present in systemFigure 6 shows the Total Harmonic Distortion (THD) of source current when filter injecting current into system.

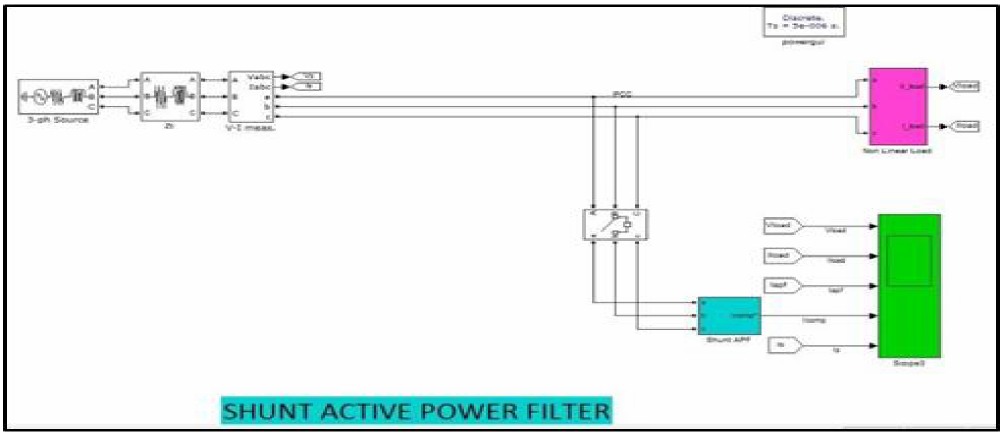

Figure.3. MATLAB Simulink model of SAPF

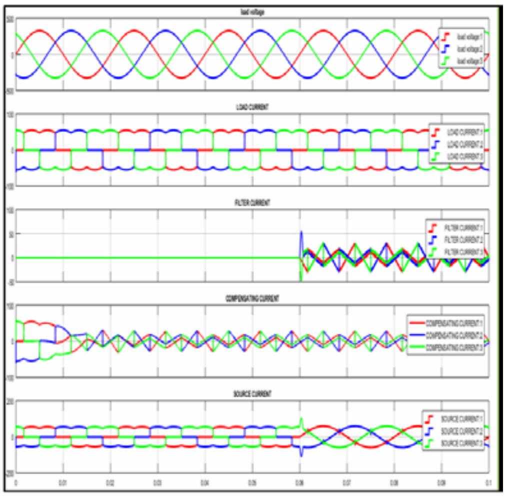

Figure 4: Waveforms showing effect of SAPF

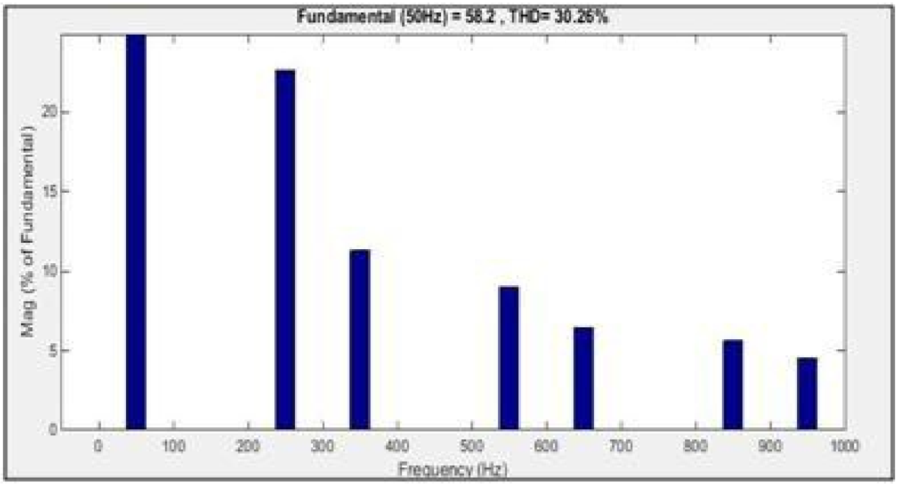

Figure 5: THD of distorted sine wave source current

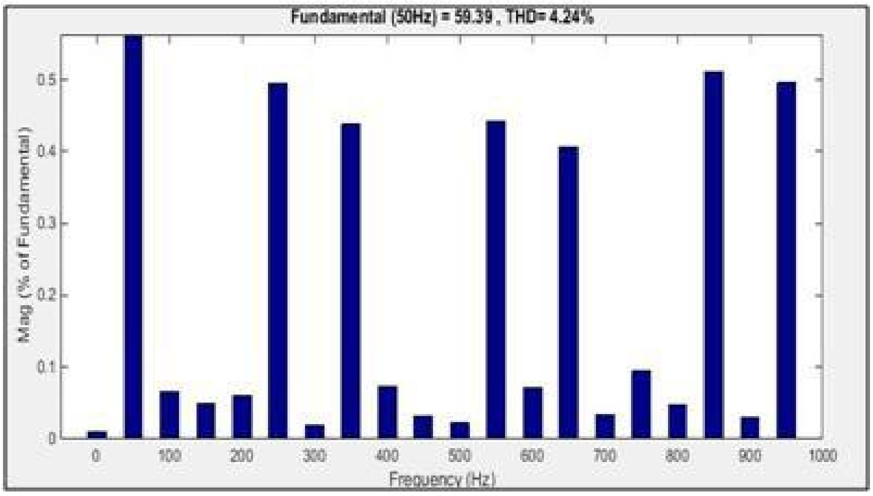

Figure 6: THD of pure sine wave source current

CONCLUSION

The modeling and simulation of a SAPF using MATLAB has been presented. The system is modeled in MATLAB Simulink which consists of a nonlinear load, with a shunt active power filter to compensate the harmonic current. The design of the active filter controller is based on time domain method that is the p-q theory along with PI controller. The main objective of the control scheme is to generate proper gate pulse and give to trigger gates of the voltage source inverter to draw opposite harmonics containing current. By applying instantaneous active and reactive power theory a reference current is generated and is fed to the current controller. Then the reference value with the original filter current is compared by hysteresis controller and the gate pulse is obtained and is given to the voltage source inverter. And the inverter output goes through the filter inductor to the line and draws an opposite harmonics from the line. In this way, the source current's harmonics are reduced.

The APF is able to reduce the THD in source current at a level well below the defined standards specified by PQ standard. The source current after the working of the APF becomes perfectly sinusoidal, free from harmonics. In figure 5 and 6 above, it is clearly visible from the FFT analysis of the MATLAB/SIMULINK model of the circuit with and without filter that the harmonic component present in the source is mitigated with use of filter.

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