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Design and Simulation of Three Phase Shunt Active Power Filter Using SRF Theory

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Abstract

Active power filters are widely used for the reduction of harmonics in the power system caused by nonlinear loads. The Shunt Active Power Filter (SAPF) injects a suitable compensating current at a point of the line known as the point of common coupling (PCC) so that the harmonics present in the line are cancelled out and the sinusoidal nature of voltage and current waveforms are restored. A three phase current controlled voltage source inverter (VSI) with a DC link capacitor across it is used as an active filter. Synchronous Reference Frame (SRF) algorithm is used to extract the harmonic components. Hysteresis band current control (HBCC) technique is used for the generation of firing pulses to the inverter. This system is simulated using MATLAB/Simulink and the results are presented.

Keywords: Shunt active power filter, synchronous reference frame algorithm, hysteresis current control, compensation current..

1. Introduction

The large scale use of power electronics equipment has led to increase in harmonics in the power system. The nonlinear loads generate harmonic current which distorts the voltage waveform at PCC. These current harmonics will result in a power factor reduction, decrease in efficiency, power system voltage fluctuations and communications interference [3]. So harmonics can be considered as a pollutant which pollutes the entire power system. Traditionally a bank of tuned LC filters was used as a solution for the problems caused by the system harmonics, since they are easy to design, have simple structure, low cost and high efficiency. [7] Phase advancers, synchronous capacitors etc. were also employed for the power system quality enhancement. However traditional controllers have many drawbacks. It provides only fixed compensation, generates resonance problems and are bulky in size [6]. To overcome these disadvantages, active power filters are introduced which compensate for the current harmonics and reduces the total harmonic distortion.

The SAPF is connected in parallel with the line through a coupling inductor. Its main power circuit consists of a three phase three-leg current controlled voltage source inverter with a DC link capacitor. An active power filter operates by generating a compensating current with 180 degree phase opposition and injects it back to the line so as to cancel out the current harmonics introduced by the nonlinear load. This will thus suppress the harmonic content present in the line and make the current waveform sinusoidal. So the process comprises of detecting the harmonic component present in the line current, generating the reference current, producing the switching pulses for the power circuit, generating a compensating current and injecting it back to the line.

In this paper a nonlinear load supplied by a three phase voltage source is projected. An active power filter is introduced in parallel to this system for the compensation of current harmonics caused by the nonlinear loads. Here SRF algorithm is used for the reference current extraction from the distorted source current, which is being explained in section II. The switching pulses for the power circuit is generated using the Hysteresis Current Control technique as explained in section III and is found to be very effective. The simulation results are projected in section IV. Figure 1 shows a three phase shunt active power filter.

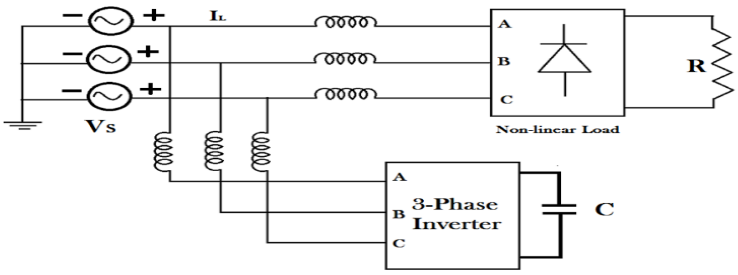

Figure 1: Three phase shunt active power filter.

2. Synchronous Reference Frame Algorithm

There are different control strategies being used for the calculation of reference currents in active power filter namely Instantaneous Reactive Power Theory (p-q theory), Unity Power Factor method, One Cycle Control, Fast Fourier Technique etc.Here, SRF theory is used to extract the three-phase reference currents (i_{ca}*, i_{cb}*, i_{cc}*) used by the active power filters [8]. Figure 2 shows the block diagram which explains three-phase SRF-theory, used for harmonic component extraction.

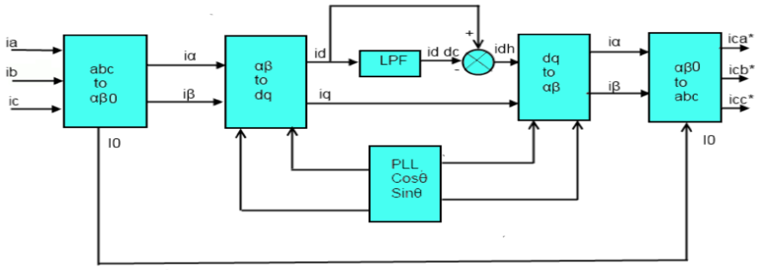

Figure 2: Block diagram of SRF based algorithm.

In this method, the source currents (ia,ib, ic) are first detected and transformed into two-phase stationary frame (αβ-*0*) from the three-phase stationary frame (a-b-c), as per equation (1).

$$\begin{bmatrix} i_\alpha \\ i_\beta \\ i_o \end{bmatrix} = \sqrt{\frac{2}{3}} \begin{bmatrix} 1 & -1/_2 & -1/_2 \\ 0 & \sqrt{3}/_2 & -\sqrt{3}/_2 \\ 1/_{\sqrt{2}} & 1/_{\sqrt{2}} & 1/_{\sqrt{2}} \end{bmatrix} \begin{bmatrix} i_a \\ i_b \\ i_c \end{bmatrix} \tag{1}$$

Now, the two phase current quantities i_α and i_β of stationary αβ-axes are transformed into two-phase synchronous (or rotating) frame (d-q-axes) using equation (2), where cosθand sinθrepresents the synchronous unit vectors which can be generated using phase-locked loop system (PLL).

$$\begin{bmatrix} i_d \\ i_q \end{bmatrix} = \begin{bmatrix} cos\theta & sin\theta \\ -sin\theta & cos\theta \end{bmatrix} \begin{bmatrix} i_\alpha \\ i_\beta \end{bmatrix} \tag{2}$$

The d-q currents thus obtained comprises of AC and DC parts. The fundamental component of current is represented by the fixed DC part and the AC part represents the harmonic component. This harmonic component can be easily extracted using a high pass filter (HPF), as implemented in Figure 2. The d-axis current is a combination of active fundamental current ($i_{d\ dc}$) and the load harmonic current (i_h). The fundamental component of current rotates in synchronism with the rotating frame and thus can be considered as dc. By filtering i_d, the current is obtained, which represents the fundamental component of the load current in the synchronous frame. Thus, the AC component i_{dh}can be obtained by subtracting $i_{d\ dc}$ part from the total d-axis current (id), which leaves behind the harmonic component present in the load current. In the rotating frame the q-axis current (i_q) represents the sum of the fundamental reactive load currents and part of the load harmonic currents. So the q-axis current can be totally used to calculate the reference compensation currents.

Now inverse transformation is performed to transform the currents from two – phase synchronous frame d-qinto two-phase stationary frame α-β as per equation (3).

$$\begin{bmatrix} i_\alpha \\ i_\beta \end{bmatrix} = \begin{bmatrix} cos\theta & -sin\theta \\ sin\theta & cos\theta \end{bmatrix} \begin{bmatrix} i_{dh} \\ i_q \end{bmatrix} \quad (3)$$

Finally the current from two phase stationary frame αβ0 is transformed back into three-phase stationary frameabc as per equation (4) and the compensation reference currents i_{ca}*, i_{cb}* and i_{cc}* are obtained.

$$\begin{bmatrix} i_{ca}^* \\ i_{cb}^* \\ i_{cc}^* \end{bmatrix} = [T_{abc}] \begin{bmatrix} i_\alpha \\ i_\beta \\ i_0 \end{bmatrix} \quad (4)$$

Where,

$$[T_{abc}] = \sqrt{\frac{2}{3}} \begin{bmatrix} 1 & 0 & 1/\sqrt{2} \\ -1/2 & \sqrt{3}/2 & 1/\sqrt{2} \\ -1/2 & -\sqrt{3}/2 & 1/\sqrt{2} \end{bmatrix} \quad (5)$$

3. Hysterisis Band Current Control

The hysteresis band current control (HBCC) technique is used for pulse generation in current controlled VSIs. The control method offers good stability, gives a very fast response, provides good accuracy and has got a simple operation [5].

The HBCC technique employed in an active power filter for the control of line current is shown in Figure 3. It consists of a hysteresis band surrounding the generated error current. The current error is obtained by subtracting the actual filter current from the reference current. The reference current used here is obtained by the SRF method as discussed earlier which is represented as I_{abc}*. The actual filter current is represented asIfabc. The error signal is then fed to the relay with the desired hysteresis band to obtain the switching pulses for the inverter.

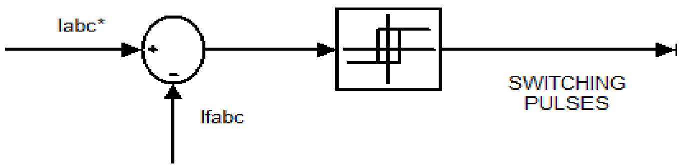

Figure 3: Hysteresis band current controller.

The operation of APF depends on the sequence of pulse generated by the controller. Figure 4 shows the simulation diagram of the hysteresis current controller.A band is set above and below the generated error signal. Whenever this signal crosses the upper band, the output voltage changes so as to decrease the input current and whenever the signal crosses the lower band, the output voltage changes to increase the input current. Accordingly switching signals are generated. [5]

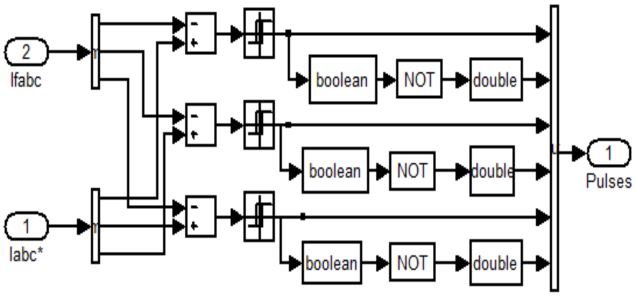

Figure 4: Simulation diagram of hysteresis current control.

The switching signals thus generated are fed to the power circuit which comprises of a three phase three leg VSI with a DC link capacitor across it. Based on these switching signals the inverter generates compensating current in phase opposition to the line current. The compensating current is injected back into the power line at the PCC and thus suppressing the current harmonics present in the line [1]. The overall simulation block diagram is shown in Figure 5.

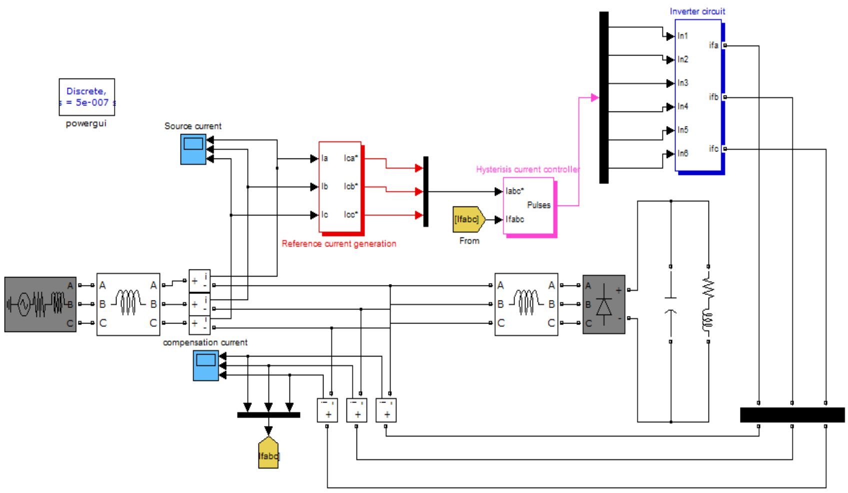

Figure 5: Overall simulation diagram.

4. Simulation Results and Discussion

The harmonic current compensation is implemented in a three-phase power system using a shunt active power filter. The rms value of source voltage of the system is set as 480V and a combination of three-phase universal bridge rectifier with an RLC load across it constitutes the nonlinear load which introduces the harmonics into the system. Table 1 shows the various circuit parameters and design specifications used in this simulation.

The source current waveform without filter in a-phase is shown in Figure 6. The Total Harmonic Distortion (THD) spectrum in the system without filter is shown in Figure 7, which indicate a THD of 25.75%. The compensating current waveform in a-phase is illustrated in Figure 8. The source current after the injection of compensating current is shown in Figure 9. The THD with active power filter included is observed to be 4.87% which is within the allowable harmonic limit. Figure 10 shows the THD spectrum with active power filter in the circuit.

Table 1: Simulation Parameters.

Parameters	**Value**
DC bus voltage	480V
DC link capacitor voltage	400V
Line inductance	0.15mH
Filter inductance	6mH
DC link capacitor	1500μF
Load inductance	1mH
Load resistance	100Ω
Load capacitance	1500μF

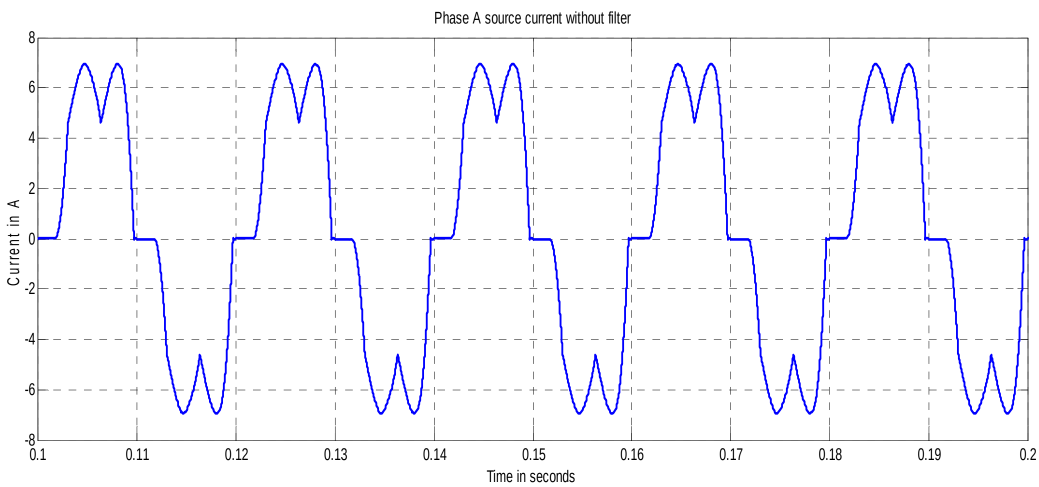

Figure 6: Source current in phase-a without filter

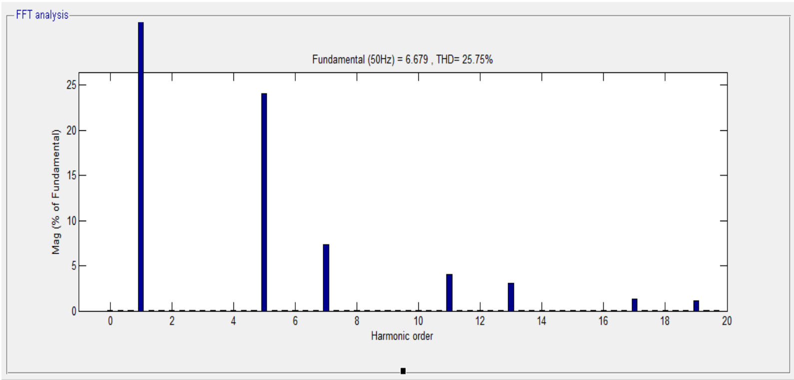

Figure 7: THD spectrum without filter

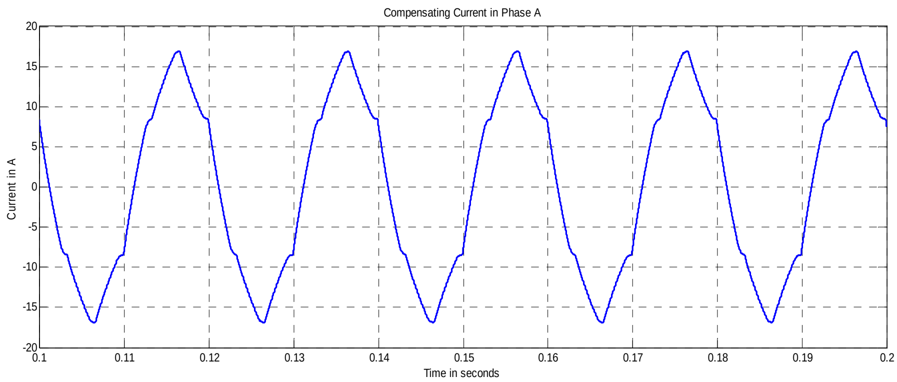

Figure 8: Compensating current in phase-a

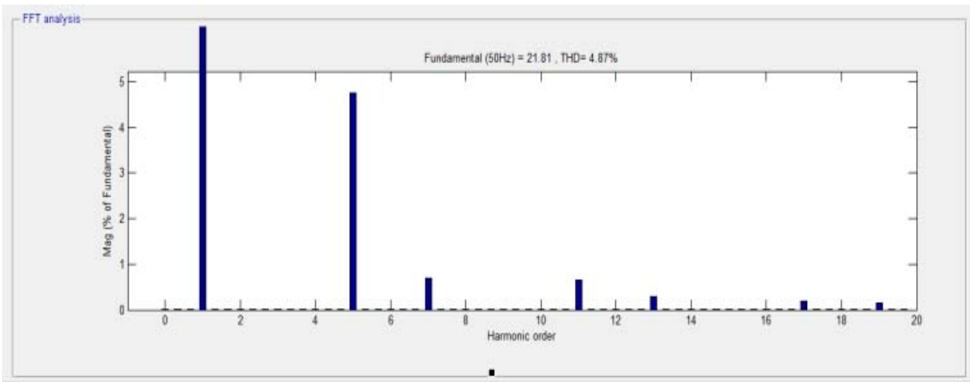

Figure 9: THD Spectrum with active power filter.

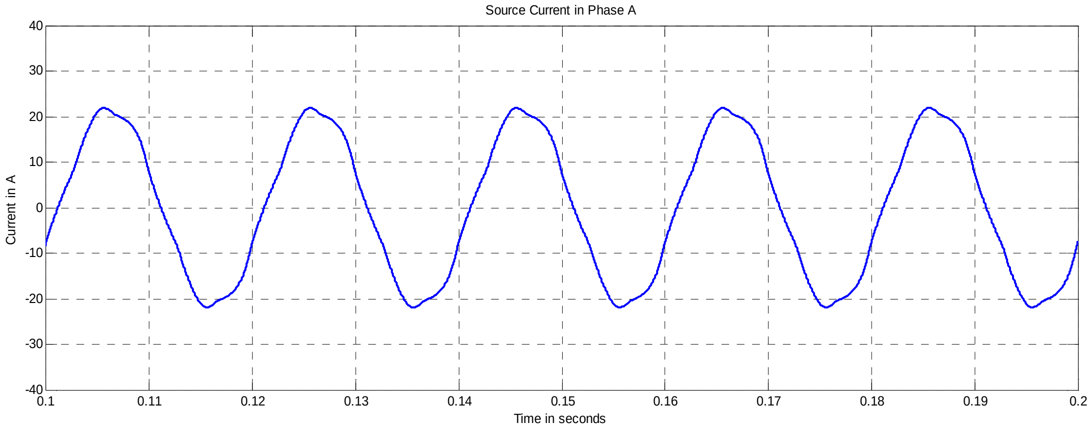

Figure 10: Source current in phase-a after compensation.

5. Conclusions

The SAPF explained in this paper compensate the line current harmonics generated due to the nonlinear loads in the system. HBCC technique used for the switching pulse generation was found to be effective and its validity is proved based on simulation results. Thus SAPF has been proved to be effective to keep the harmonic content in power lines within the permissible limit of IEEE standards.

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