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CONTROL SCHEMES FOR SHUNT ACTIVE FILTERS TO MITIGATE HARMONICS USING TRIANGULAR CARRIER CURRENT CONTROLLER

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ABSTRACT

This paper presents a method for obtaining the desired reference current for Voltage Source Converter (VSC) of the Shunt Active Power Filter (SAPF) using Synchronous Reference Frame Theory. The method relies on the performance of the Proportional-Integral (PI) controller for obtaining the best control performance of the SAPF using Particle Swarm Optimization (PSO). SAPF compensates the harmonics by injecting a compensating current which is equal in magnitude but opposite in phase to the disturbance in the system. The current controller based on Triangular Carrier Current Controller is used to generate the gate pulses. Compensation current is generated to track command current so as to eliminate the harmonic current of non-linear load and reduced total harmonic distortion (THD), improved accuracy and strong robustness in the presence of parameters variation and nonlinear load. The results of simulation study of APF control technique presented in this paper are found quite satisfactory to eliminate harmonics and reactive power components from source current.

KEYWORDS: Harmonic Distortion, PI Controller, Current Harmonics, Active Power filters.

INTRODUCTION

The deterioration in power quality due to the increase in nonlinear loads has sparked a new interest in the filtering techniques used in transmission and distribution systems. Recent wide spread of power electronic equipment has caused an increase of the harmonic disturbances in the power systems [1]. The existence of current and voltage harmonics in power systems increases losses in the lines, decreases the power factor and can cause timing errors in sensitive electronic equipment. Traditionally, the passive filters have been used to eliminate current harmonics and to increase the power factor, which are simple and low cost. However, the use of passive filter has many disadvantages, such as large size, tuning and risk of resonance problems [2]. With the proliferation of non-linear loads in industries application and distribution systems, the compensation of harmonics is becoming a significant concern. Non-linear loads behave as a current source, injecting harmonic current into the supply network. This constitutes the problems of power system harmonics. One of the problems is the supply voltage distortion at the Point of Common Coupling (PCC). When non-linear loads inject a distorted current into supply network, a harmonic voltage is developed across the source impedance. The voltage at the PCC, being the difference of the source voltage and the voltage across the source impedance will distort [3]. The modern solution to cope with harmonics pollution is to implement active power filters (APF) [4]. The Shunt Active Power Filter is connected in a common point connection between the source of power system and the load system which presents the source of the polluting currents circulating in the power system lines [5]. Indeed, compared to conventional passive filters, APFs feature a higher flexibility, a better filtering capability and a smaller physical size. There are various APF configurations but the most widely implemented in industrial scale products are the shunt configurations [4].

The presented work was oriented mostly on the active filters instead of passive filters. The basic difference between the passive and active filters is that the active filters have the capability to compensate random varying currents. Fig.1 shows the basic compensation principle of SAPF [2]. Active filter can implement simultaneous tracking and compensation of varying harmonic and reactive power [6]. At present two Conventional methods are mostly used in the current control for APF, hysteresis current control [7] and triangle wave current control [8]. This paper presents a compensating system for harmonics and reactive power in a three phase distribution network by voltage source inverter (VSI) based SAPF using Triangular carrier current controller PWM.

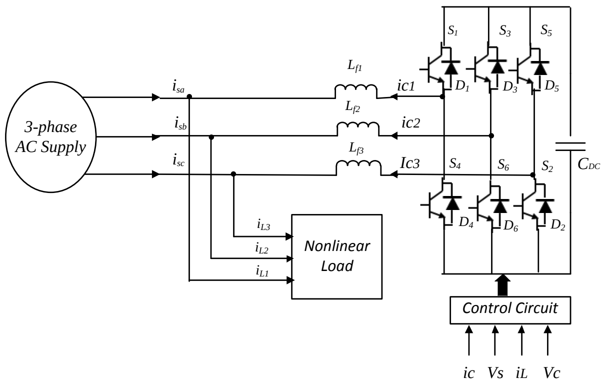

Figure 1: Basic Compensating Principle of SAPF.

DYNAMICS OF ACTIVE POWER FILTER

The shunt active power filter (APF) is a device that is connected in parallel to cancels the reactive and harmonic currents from a nonlinear load[1]. The circuit system of APF can be divided into two parts, the first part is command current operating circuit used to detect the harmonic and reactive components of load current, which is defined as command current . This part is usually realized with the harmonic current detecting method based on synchronous reference frame theory. The second part is compensation current generating circuit made up of three parts: following control circuit, driving circuit and main circuit. This part is used to generate compensation current with the basis of command current from the first part, the process is that compensation current generating circuit enlarges the command current and gets the compensation current. Then the compensation current is injected into the line to compensate the harmonic and reactive components of the load current, and the line current is forced to become sine wave [9]. The three phases SAPF under study has the structure of Fig.1 . It consists of a three-phase full-bridge inverter and an energy storage capacitor C_{DC}, placed at the DC side. From the AC side, the SAPF is connected to the network through a filtering inductor (L_f); this reduces the circulation of the harmonics currents generated by the inverter. The SAPF function is to produce reactive and harmonic current components to compensate undesirable current harmonics produced by the nonlinear load. The DC–AC inverter operates in accordance to the well-known of Pulse Width Modulation principle (PWM) [4].

THREE-PHASE SAPF CONTROL DESIGN

The control strategy applied to SAPF to calculate the reference currents plays an important role in the characteristics and efficiency of harmonics compensation and its effectiveness [10]. The principle of operation is simple and requires only one sinusoidal reference signal that must be in phase with the respective phase to neutral voltage. The amplitude of this reference sinusoidal signal controls the amount of active power absorbed by each converter, depending on the converter dc voltage reference value. Doing so, the harmonics and reactive currents are constrained to circulate within a loop including only the load and the SAPF . In addition to this energy quality objective, there is an operational requirement that consists in regulating the DC voltage of the energy storage capacitor, placed next to the SAPF inverter. This DC voltage regulation loop control is necessary for the SAPF to work conveniently [4]. Using Reference Frame Transformation, reference signals are transformed from *a-b-c* stationery frame to *q-d*-0 rotating frame and by using the PI-PSO controller, the reference signals in the *q-d* rotating frame are controlled to get the desired reference signals for the Pulse Width Modulation. Fig. 2 shows simulation block diagram of the *id-iq* detecting approach. A sinusoidal function generator controlled by a phase locked loop circuit is applied. The mains voltages *vi* and the i_{Li} polluted currents in $\alpha\beta$ components must be calculated as in Eqn. (1) and Eqn. (2). The compensation currents may be calculated by Eqn. (3). However, the *dq* load current components are derived from a synchronous reference frame based on the Park transformation [11], where θ represents the instantaneous voltage vector angle Eqn. (4).

$$\begin{bmatrix} v_\propto \\ v_\beta \end{bmatrix} = \sqrt{\frac{2}{3}} \cdot \begin{bmatrix} 1 & -\frac{1}{2} & -\frac{1}{2} \\ 0 & \frac{\sqrt{3}}{2} & -\frac{\sqrt{3}}{2} \end{bmatrix} \cdot \begin{bmatrix} v_1 \\ v_2 \\ v_3 \end{bmatrix} \qquad (1)$$

$$\begin{bmatrix} iL_\propto \\ iL_\beta \end{bmatrix} = \sqrt{\frac{2}{3}} \cdot \begin{bmatrix} 1 & -\frac{1}{2} & -\frac{1}{2} \\ 0 & \frac{\sqrt{3}}{2} & -\frac{\sqrt{3}}{2} \end{bmatrix} \cdot \begin{bmatrix} iL_1 \\ iL_2 \\ iL_3 \end{bmatrix} \qquad (2)$$

$$\begin{bmatrix} ic_1 \\ ic_2 \\ ic_3 \end{bmatrix} = \sqrt{\frac{2}{3}} \cdot \begin{bmatrix} 1 & -\frac{1}{2} & -\frac{1}{2} \\ 0 & \frac{\sqrt{3}}{2} & -\frac{\sqrt{3}}{2} \end{bmatrix}^T \cdot \begin{bmatrix} ic_\alpha \\ ic_\beta \end{bmatrix} \qquad (3)$$

$$\begin{bmatrix} iL_d \\ iL_q \end{bmatrix} = \begin{bmatrix} cos\theta & sin\theta \\ -sin\theta & cos\theta \end{bmatrix} \cdot \begin{bmatrix} iL_\alpha \\ iL_\beta \end{bmatrix} \qquad (4)$$

$$,\theta = tan^{-1}\frac{v_\beta}{v_\alpha}$$

$$\left|\overline{v}_{dq}\right| = \left|\overline{v}_{\alpha\beta}\right| = \sqrt{v_\propto^2 + v_\beta^2} \qquad (5)$$

and the quadrature voltage component is always null, *vq*=0 ,so due to geometric relations Eqn. (4) becomes :

$$\begin{bmatrix} iL_d \\ iL_q \end{bmatrix} = \frac{1}{\sqrt{v_\propto + v_\beta}} \cdot \begin{bmatrix} v_\propto & v_\beta \\ -v_\beta & v_\propto \end{bmatrix} \cdot \begin{bmatrix} iL_\alpha \\ iL_\beta \end{bmatrix} \qquad (6)$$

$$\begin{bmatrix} ic_{\propto} \\ ic_{\beta} \end{bmatrix} = \frac{1}{\sqrt{v_{\propto}^2+v_{\beta}^2}} \cdot \begin{bmatrix} v_{\propto} & -v_{\beta} \\ v_{\beta} & v_{\propto} \end{bmatrix} \cdot \begin{bmatrix} ic_d \\ ic_q \end{bmatrix} \qquad (7)$$

Finally, Eqn. (3) and Eqn. (7) calculate the converter currents in the system coordinates.

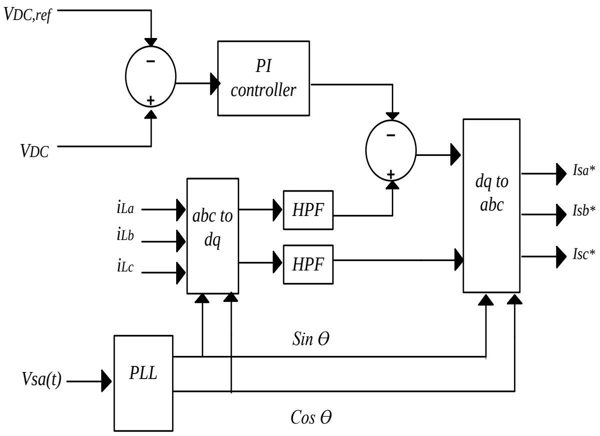

Figure 2: Simulation block diagram of the i_d ,i_q detecting approach.

TRIANGULAR CARRIER CURRENT CONTROLLER

According to above equations, we can easily get the output voltage of APF, and then through the triangle wave compare, the PWM signals of the switches are gained. Fig.3 shows the simulation block diagram of triangle wave [12]. 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. The modulation signal achieved by a current regulator from the current error signal is intersected with the triangle wave and the pulse signals obtained are the principles of the conventional triangle comparison PWM control. To determine the switching transitions by means the error current [desired reference current (i_a^*) compared with the actual source current (i_a)]. The output signal is compared with triangular carrier signal [13]. The technique has fast response and simple implementation [14].

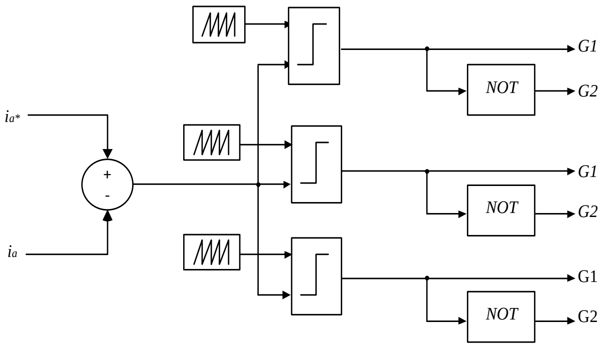

Figure 3: Triangular carrier current controller.

RESULTS AND DISCUSSION

In Fig.1, SAPF is connected in parallel with nonlinear load. Then, the three-phase uncontrolled rectifier with resistive load has to be compensated by the SAPF. The performance of the proposed control is investigated using Matlab/Simulink package with SimPower Toolbox. PI-PSO controller is used to control the DC side voltage, K_P=0.6284 k_I =29.7741.The parameters of the system for simulation are as in Table 1.

Table 1. Parameters of the System

Quantity	Symbol	Value
Supply phase voltage(peak)	V_S	311V
Supply frequency	f_S	50Hz
Switching frequency	f_{sw}	10KHz
Line inductor	L_L	0.01 H
Filter inductor	L_f	0.006 H
DC link capacitor	C_{DC}	2000 µF
DC link capacitor Voltage	V_{DC}	650V
Sample time	T_S	50 µs
DC Load resistance	R_{load}	50 Ω

The distorted source or load currents due to the presence of the nonlinear loads before compensation are shown in Fig. 4. The harmonic spectrum of the uncompensated source currents for the phase (a) is shown in Fig. 5. The THD is observed to be very high (22.93%). Fig. 6 shows the source voltages.

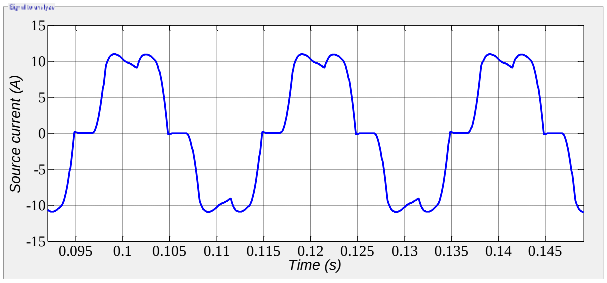

Figure 4: Source current, I_{sa} without APF.

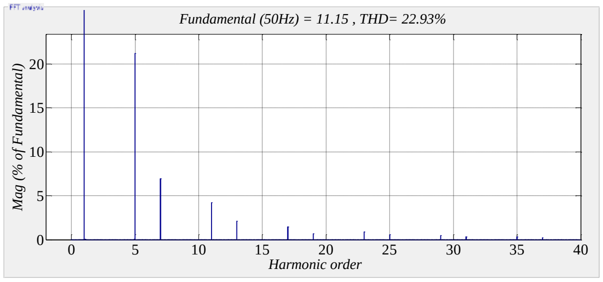

Figure 5: I_{sa} harmonic spectrum without APF.

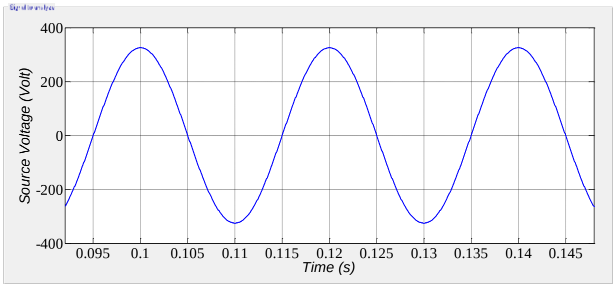

Figure 6: Supply voltage waveform.

Fig. 7 and Fig. 8 show source currents and inverter current of the phase (a) before and after compensation. The source currents without compensation are represented up to 0.1 s, and also after 0.2 s. The interval between 0.1 s to 0.2 s represents the compensated source currents. As seen from Fig. 7, the source currents before compensation up to 0.1 s and after 0.2 s are distorted. In the interval between 0.1 s to 0.2 s it can be seen that the source currents are sinusoidal and are in phase with the source voltages.

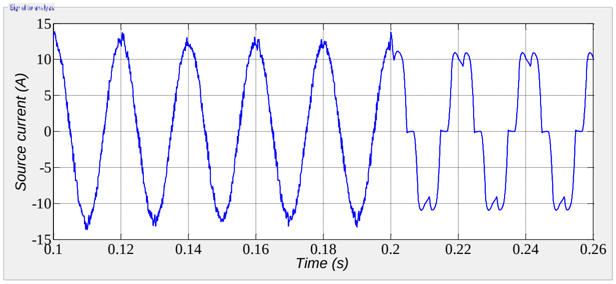

Figure 7: Source current, I_{sa} with and without APF.

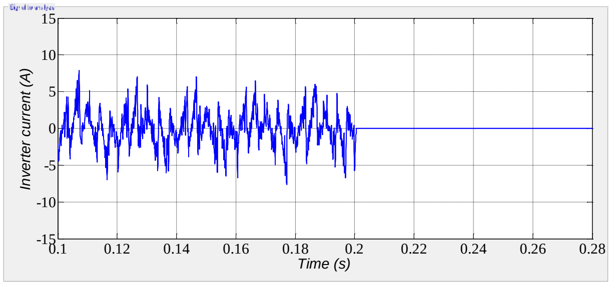

Figure 8: I_{sa} harmonic spectrum with and without APF.

Fig.9 show the harmonic spectrum of the source currents after compensation by the SAPF for the phase (a). The harmonic spectrum of the compensated source currents for the phase (a) is shown in Fig.10. It can be observed that the THD (2.34%) is minimized below the permissible limit of IEEE-519 standard i.e. less than 5%. Voltage DC link system shows in the Fig. 11.

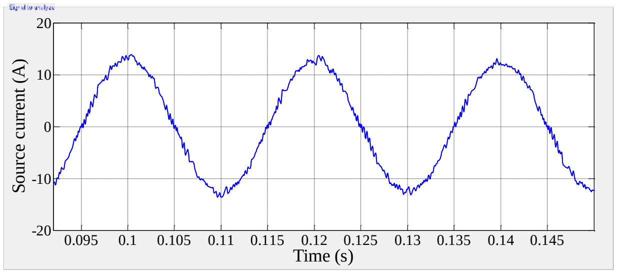

Figure 9: Source current, I_{sa} with APF.

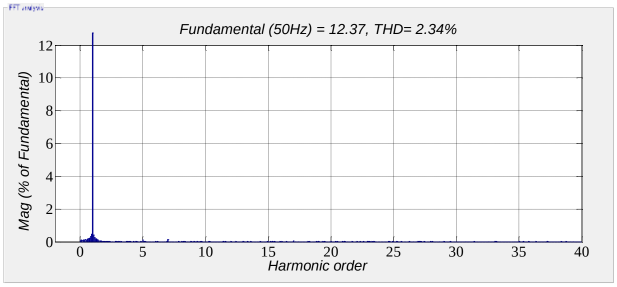

Figure 10: I_{sa} harmonic spectrum with APF.

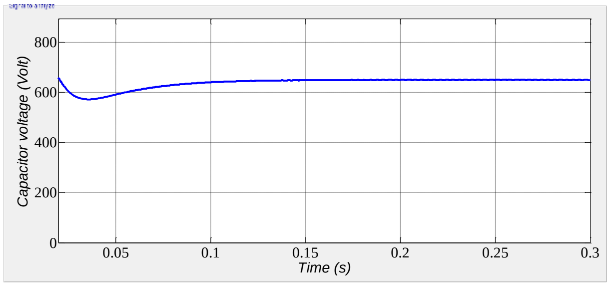

Figure 11: Capacitor voltage waveform (V_{DC}).

In order to demonstrate that the proposed control system has strong robustness in the presence of parameters variation, we investigate the APF with the parameters variation as shown from Table 2. We can see that THD is still in the acceptable range with the parameters variation. It can be concluded that the proposed control system has good robustness in the presence of parameter variations, we can see the best values of inductance and capacitance are L_f = 6 mH and C_{DC} = 2000 μF which give the lowest THD (2.34%) as shown in Table-2.

Table 2. Performance for Variation in Filter Inductance and DC Capacitor.

	THD%					
L_f / C_f	5mH	6mH	7mH	8mH	9mH	10mH
500µF	4.06	3.84	3.79	3.75	4.36	3.98
1000µF	3.69	3.30	3.77	3.40	3.34	4.06
2000µF	3.48	2.34	3.10	3.41	3.46	4.30

CONCLUSION

The proposed TCPWM control method based three-phase SAPF is effective to minimize the THD of the source current in a three-phase system. In addition the simulation results have demonstrated the capability of PI-PSO Based SAPF to effectively minimize the source current harmonics and the THD within the prescribed limits of IEEE519 Standards i.e. less than 5%. The simulation results show it has a good dynamic and static performance, can compensates harmonic and reactive current of system effectively. The control objective is to achieve current harmonics and reactive power compensation, as well as tight voltage regulation at the inverter output capacitor.

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