# Matlab Simulation of Sliding Mode Control of Shunt Active Filter for Power Quality Improvement

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*Abstract: - The* shunt active filter has proved to be a useful device to harmonic currents and to compensate reactive power for linear/nonlinear loads. This paper presents a simulation of Sliding mode control of three-phase shunt active power filter to improve the power quality using Matlab Power system blockset. After compensation, the source current is sinusoidal under ideal and non-ideal mains voltage conditions. A three-phase six-pulse converter with R-L load is considered as the non-linear load. The PWM pattern generation is based on carrier-less hysteresis based current control to obtain the switching signals. The MatLab/simulink simulation results are presented under transient and steady state conditions.

*Key words: - Sliding* mode control, Active power filter, Harmonic and Reactive power compensation

## 1 Introduction

Active compensation of harmonics, reactive power and unbalance is required for improving power quality, control and protection. An integral part of an active compensation device is the detection unit, which generates the reference signals. Various methods such as Instantaneous Active and Reactive power p-q method, Instantaneous Power Balance method, Instantaneous Active and Reactive current component id-iq method, and Fourier series method have been presented in the literature for this purpose.

Figure 1 shows the SAPF, which is controlled to supply a compensating current $i_c$ at the point of common coupling (PCC) and cancels current harmonics on the supply side. Now, the source current $i_s$ will be sinusoidal and in-phase with the supply voltage $V_s$. The performance of SAPF depends on the method of extraction of the reference compensating current. This reference current and the actual SAPF current is given to a hysteresis based, carrier-less PWM current controller to generate the switching signals of the inverter.

Akagi et al., [1] proposed an innovative approach based on the instantaneous reactive power theory to compute active filter reference compensating current. This approach inspired the development of many other p-q theory based methods for active filters.

In the conventional methods, the performance of the SAPF degrades when the supply voltage is distorted and unbalanced. In this paper, sliding mode controller is presented and the source current is maintained sinusoidal even when the supply voltage is distorted and unbalanced. The dc side capacitor voltage of the PWM inverter is regulated and peak value of the reference source current is obtained. The reference source current is obtained by multiplying this peak value with the unit sine vectors that are in-phase with the supply voltage.

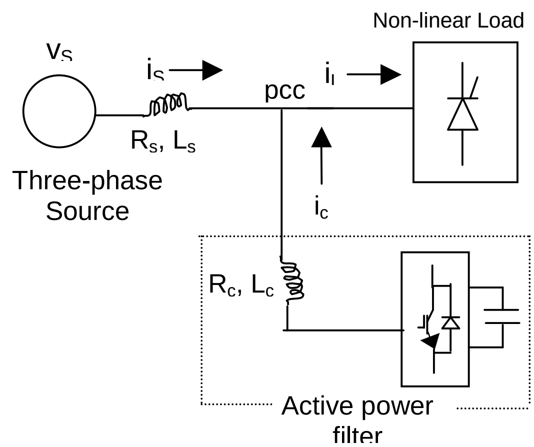


Fig. 1 Basic compensation principle of SAPF

## 2 DC link voltage regulation method

In this method, peak value of the reference source current is obtained by regulating the dc side capacitor voltage of the PWM inverter. This capacitor voltage is compared with a reference value and the error is processed in a PI controller.

The instantaneous currents can be written as

$$i_s(t) = i_L(t) - i_c(t) \quad (1)$$

Source voltage is given by $v_s(t) = V_m \sin(\omega t)$

If non-linear load is applied, then the load current will have fundamental, reactive and harmonic components, which can be represented as

$$i_L(t) = \sum_{n=1}^{\infty} I_{Ln} .\sin(n\omega t + \phi_n) \quad (2)$$

$$= I_{L1}.\sin(\omega t + \phi_1) + \sum_{n=2}^{\infty} I_{Ln} .\sin(n\omega t + \phi_n)$$

The instantaneous currents can be given as

$$\begin{aligned} p_L(t) &= v_s(t) . i_L(t) \\ &= V_m I_{L1} \cos(\phi_1).\sin^2(\omega t) + \\ &\quad V_m I_{L1}\sin(\phi_1).\sin(\omega t).\cos(\omega t) + \\ &\quad V_m \sin(\omega t). \sum_{n=2}^{\infty} I_{Ln} \sin(n\omega t + \phi_n) \\ &= p_f(t) + p_r(t) + p_h(t) \end{aligned} \quad (3)$$

From (4.3), real power drawn by the load

$$p_f(t) = V_m I_{L1} \cos(\phi_1) . \sin^2(\omega t) = v_s(t) . i_s(t) \quad (4)$$

From (4.4), source supplied by the source after compensation

$$i_s(t) = p_f(t)/ v_s(t) = I_{L1} \cos(\phi_1) . \sin(\omega t) = I_{sm} \sin(\omega t)$$

where, $I_{sm} = I_{L1} \cos(\phi_1)$ (5)

Also, there are some switching losses in the PWM inverter. Hence, the utility has to supply for the capacitor leakage and inverter switching losses in addition to the real power of the load. Hence, total peak current supplied by the source is expressed as

$$I_{sp} = I_{sm} + I_{sL} \quad (6)$$

If active filter provide the total reactive and harmonic power, then $i_s(t)$ will be in phase with the utility voltage and pure sinusoidal. The active filter provides the following compensation current

$$i_c(t) = i_L(t) - i_s(t) \quad (7)$$

The peak value of the reference current $I_{sp}$ can be estimated by controlling the dc side capacitor voltage. The desired source currents after compensation can be given as

$$\begin{aligned} i_{sa}^* &= I_{sp} \sin\omega t \\ i_{sa}^* &= I_{sp} \sin(\omega t - 120^\circ) \\ i_{sa}^* &= I_{sp} \sin(\omega t + 120^\circ) \end{aligned} \quad (8)$$

where $I_{sp}$ is the amplitude of the desired source current, while the phase angle can be obtained from the source voltages. Hence, the waveform and phases of the source currents are known, only the magnitude of the source currents need to be determined.

This peak value of the reference current has been estimated by regulating the dc side capacitor voltage of the PWM inverter. This capacitor voltage is compared with a reference value and the error is processed in a sliding mode controller. The output of the sliding mode controller is considered as the amplitude of the desired source current. The reference source current is obtained by multiplying this peak value with the unit sine vectors.

## 3 Role of dc side capacitor

DC side capacitor serves two main purposes (i) it maintains a dc voltage with small ripple in steady state, and (ii) serves as an energy storage element to supply real power difference between load and source during transient period. In steady state, the real power supplied by the source should be equal to the real power demand of the load plus a small power to compensate the losses in the active filter. Thus, the dc capacitor voltage can be maintained at a reference value.

However, when the load condition changes the real power balance between the mains and the load will be disturbed. This real power difference is to be compensated by the dc capacitor. This changes the dc capacitor voltage away from the reference voltage. In order to keep the satisfactory operation of the active filter, the peak value of the reference current must be adjusted to proportionally change the real power drawn from the source. This real power charged/discharged by the capacitor compensates the real power consumed by the load. If the dc capacitor voltage is recovered and attains the reference voltage, the real power supplied by the source is supposed to be equal to that consumed by the load again.

Thus, in this fashion the peak value of the reference source current can be obtained by regulating the average voltage of the dc capacitor. A smaller dc capacitor voltage than the reference voltage means that the real power supplied by the source is not enough to supply load demand. Therefore, the source current (i.e. the real power drawn from the source) needs to be increased. While a larger dc capacitor voltage than the reference voltage tries to decrease the reference source current. This change in capacitor voltage can be verified from the simulation results shown in Figure 4.

## 4 Design of sliding mode controller

The amplitude of reference source current is computed using sliding mode controller over the average dc bus voltage ($V_{dc}$) and its reference value ($V_{ref}$). The dc bus voltage error $v_e$ at nth instant is:

$$v_e(n) = V_{ref}(n) - V_{dc}(n) = x_1 \quad (9)$$

and its derivative is defined as:

$X_2 = X_1 = (v_e(n) - v_e(n-1))/T$ (10)

where T is the sampling interval and $x_1$ and $x_2$ are the state variables.

In sliding mode controller, the values of switching functions $y_1$ and $y_2$ are defined as:

$y_1 = +1$ if $zx_1 > 0$

$= -1$ if $zx_1 < 0$

$y_2 \ +1$ if $zx_2 > 0$

$= -1$ if $zx_2 < 0$ (11)

where z is switching hyper plane function,

$z = c_1 x_1 + c_2 x_2$ (12)

The output of the SMC (u) is taken as the amplitude of supply current ($I_m^*$). Therefore in this investigation, the amplitude of reference supply current is given as below:

$u = c_3 x_1 y_1 + c_4 x_2 y_2$ (13)

where $c_1$, $c_2$, $c_3$ and $c_4$ are gain constants of the sliding mode controller. These gain constants have reasonable bearings on the dynamic response of the system. The control scheme is shown in Fig. 2.

# 5 Simulation results

Various simulations are carried out to study the performance of the active filter during both steady state and transient conditions. The parameters selected for simulation studies are: $V_s$ = 230 V, $R_s$ = 0.5 Ω, $L_s$ = 10 μH, $L_c$ = 3 mH, $C_{dc}$ = 2 mF, $c_1$ = 2.5, $c_2$ = 2.5, $c_3$ = 4 and $c_2$ = 4. A three-phase six-pulse converter with R-L load is considered as the non-linear load.

Simulation results are shown in Figures 3 – 7. Figure 4 shows the switch-in response of the active filter. Source voltage ($v_{sa}$), load current ($i_{La}$), source current ($i_{sa}$), active filer current ($i_{ca}$) and dc capacitor voltage are shown. Filter is switched on at 20 ms. The instant, filter is switched on, source current becomes sinusoidal from the stepped wave shape and capacitor voltage reaches to a steady state value within few cycles.

To show the performance during transient condition, the load current is changed at two time instants. Figure 7 shows the various waveforms during load change. When load current is reduced/increased, capacitor voltage increases/decreases to compensate the real power supplied by the source. This change in capacitor voltage is taken into account by the sliding mode controller to adjust the peak value of the reference current.

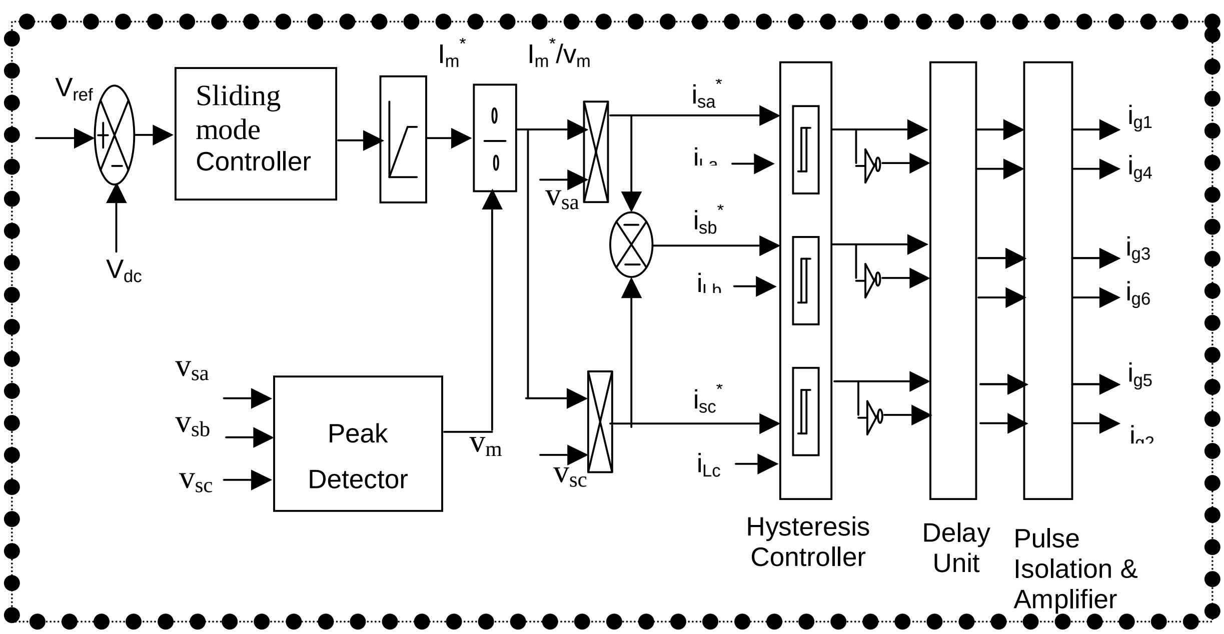


Fig. 2 Control scheme

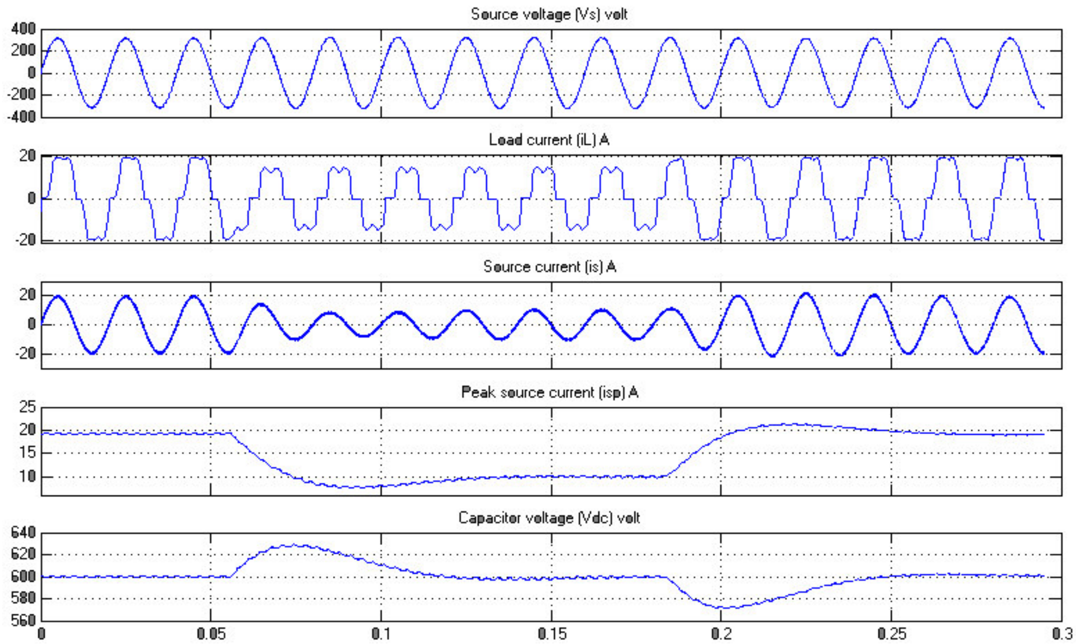


Fig 3 Variation of dc capacitor voltage and peak value of the reference current with the change in load current

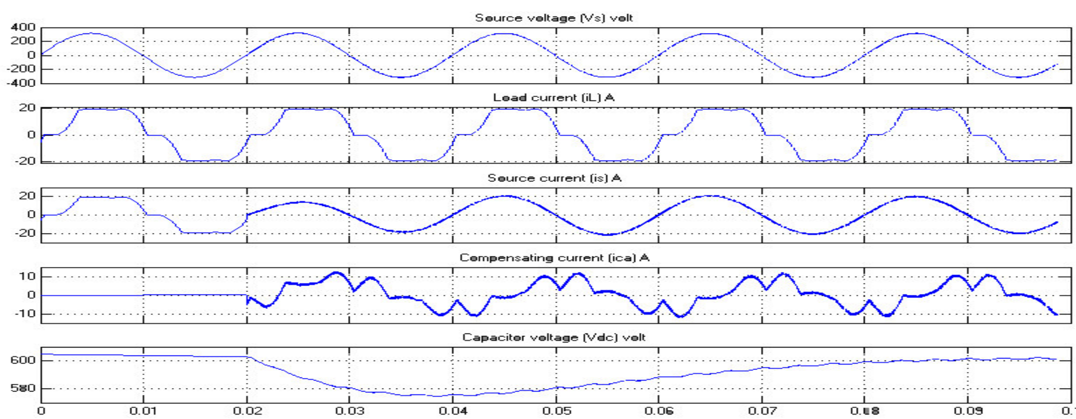


Fig 4 Switch-in response of the active power filter (Filter is switched on at 20 ms)

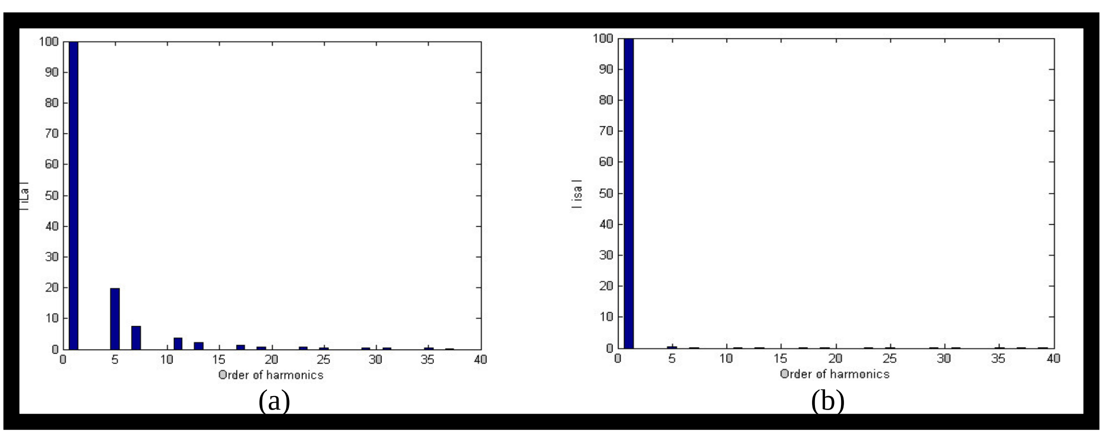


Fig.5 Frequency spectrum of (a) load current (b) source current

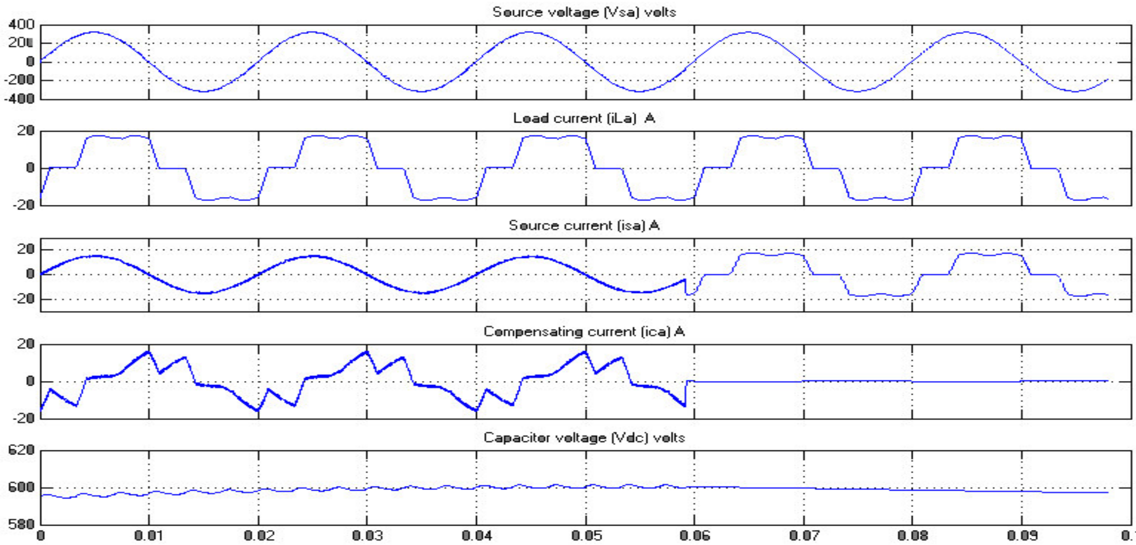


Fig. 6   Switch-off response of the active power filter

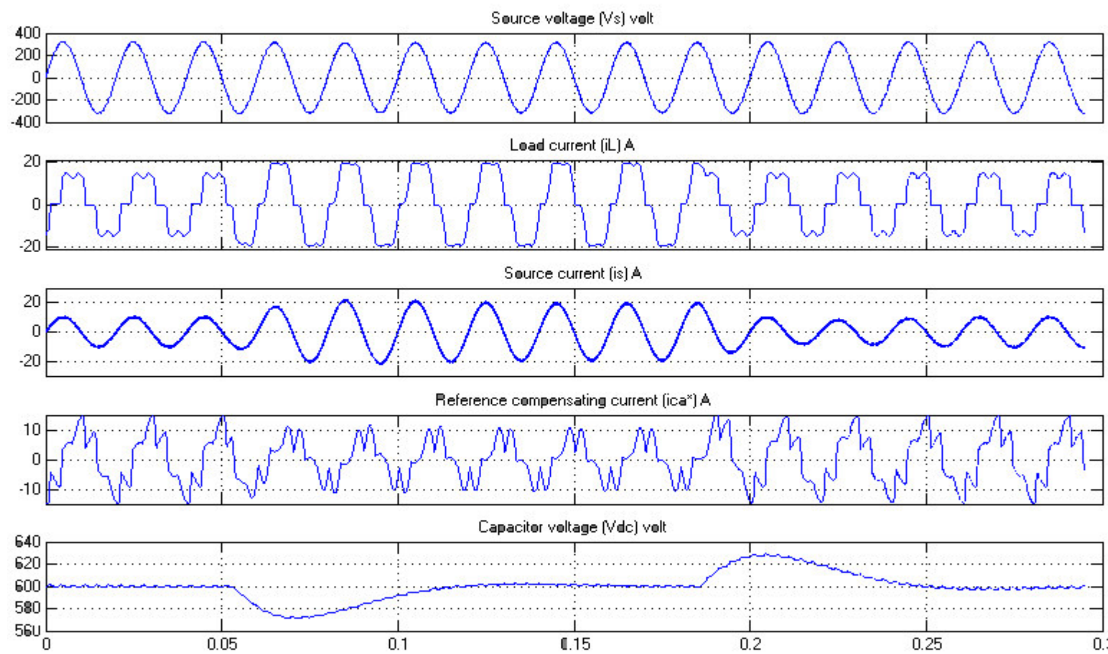


Fig 7   Load perturbation response of the shunt active filter

(Load current is changed at two time instants)

Figure 6 shows the switch-off response of the active filter. Source voltage ($v_{sa}$), load current ($i_{La}$), source current ($i_{sa}$), active filer current ($i_{ca}$) and dc capacitor voltage are shown in this figure. As soon as the active filter is switched-off, the supply current waveform becomes stepped wave shape from sinusoidal. Figure 5 shows the frequency spectrum of load and source current after compensation. After compensation, the THD (Total Harmonic Distortion) of the source current is reduced to well below 5% (21.51% to 1%).

# 6 Conclusion

The reference currents are estimated by regulating the dc capacitor voltage using sliding mode controller. After compensation, the source current is sinusoidal and in phase with the supply voltage. It compensates both harmonics and reactive power simultaneously. Unlike conventional methods, in this method, the source current is maintained sinusoidal even when the supply voltage is distorted and unbalanced. Also, the design is simpler as there is no any co-ordinates transformation. The transient response is good and the steady state is reached with in one cycle.

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