Modeling Of Frequency Domain Control of Shunt Active Power Filter Using MATLAB/Simulink and Power System Blockset

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ABSTRACT
This paper presents modeling and simulation of a shunt active power filter in frequency domain, using MATLAB and its tools Simulink and Power System Blocket. The proposed method offers many additional features over other methods. It attributes the responsibility of utility and customer at PCC. It provides an additional feature of compensation of either harmonics only, or the compensation of both harmonics and reactive power simultaneously, based on the desired capacity of the APF.

Keywords - Power Quality, Active Power Filter, Frequency Domain Control, Harmonics and Reactive Power Control.

I. INTRODUCTION

Now a day the power electronic equipments are widely used in distribution networks which act as nonlinear loads [3]. Many power quality disturbances such as harmonics pollution, unbalanced load current, and reactive power problems are caused by the nonlinear loads. As a result poor power factor, weakening efficiency, over heating of motors and transformers, malfunction of sensitive devices etc. are encountered [2].

Various control algorithms are proposed for the control of shunt active power filter. The control strategies of the active filters [7] are implemented mainly in three steps- Signal conditioning, estimation of compensating signals and generation of firing signals for switching devices as shown in Fig.1.

Estimation of compensating signal is the most important part of the active filter control [1]. It has a great impact on compensation objectives, rating of active filters and its transient as well as steady state performance. The control strategies use either frequency domain or time domain approaches to extract compensating signals from the corresponding distorted currents and/or voltages.
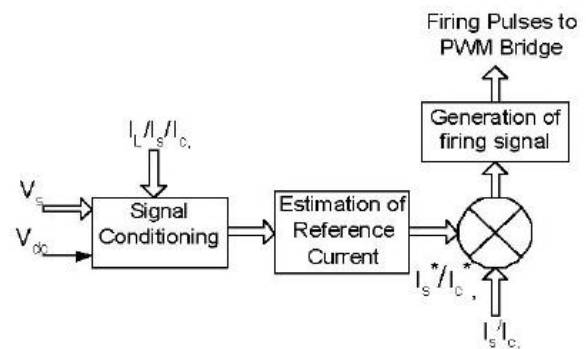

Fig. 1 Control strategy of active power filter

Instantaneous reactive power theory is widely used for the calculation of the desired compensation current, which is mainly based of sensing harmonics and reactive power components of current, which is very complex and difficult to implement [11]. Another approach has been proposed which does not require sensing the harmonic or VAR requirement of the load, in which reference current has been estimated by regulating the dc side capacitor voltage. This method is simple and easy to implement but compensate both harmonics and reactive power simultaneously, which is not preferred sometimes due to increased rating of APF [2]. The size and cost of APF depends on how much harmonics are to be compensated. These techniques are based on instantaneous extraction of compensating commands from the distorted currents or voltage signals in time domain.

Although, time-domain compensation has fast response, easy implementation and less computation burden, these techniques take measurements at only one point, they are limited to single node applications and are not well suited for overall network correction [3].

On the contrary, control strategy in the frequency domain is based on the extraction of the Corresponding compensating signals from the distorted current or voltage signals based on Fourier analysis. Various harmonic components are extracted from polluted signal and are combined to generate the reference commands using Fourier transformation, Frequency domain compensation can handle single node problems and can also be extended to minimize harmonic distortion throughout the network [6]. The greatest drawback of this

technique is the requirement of cumbersome computation time. With the increase in highest harmonic to be eliminated, number of calculations also increase, which results in a large response time. Therefore, compensation in on-line applications has been limited in references to harmonics at or below the 20th multiple. However, recent development in fast processor and expert systems may help in improving their response time [4].

This paper presents modeling and simulation of a control algorithm of active power filter in frequency domain using MATLAB and its tools Simulink and Power System Blocket. Frequency domain control offers an advantage to compensate only those harmonics, which are generated by the customer using harmonic generated loads [5]. If utility voltage is distorted, APF allows similar level of distortion in the compensated current. Therefore, the resultant source current will have the same waveform as that of the supply voltage, thereby attributing the responsibility of utility and customer at the point of common coupling (PCC). The proposed scheme provides an additional feature of compensation of either harmonics only, or the compensation of both harmonics and reactive power simultaneously, based on the desired capacity of the APF [15].

II. ESTIMATION OF REFERENCE CURRENT

A new control algorithm is proposed by S.Jain, characterized as the "compensation of customer generated harmonics", for the control of shunt active power filter. It compensates harmonics and reactive power requirement of nonlinear loads, and maintains similar distortion in the compensated current as present in the mains voltage. Therefore, load behaves as a linear/resistive load, and the resultant source current will have the same waveform as that of the supply voltage.

The non-sinusoidal utility voltage and current signal can be expressed as a sum of sinusoidal signal of various frequencies as –

$$V_s(t) = \sum_{n=1}^{k} V_n \sin(n\omega t + \theta_n), \text{ and} \qquad (1)$$
$$i_L(t) = \sum_{n=1}^{k} I_n \sin(n\omega t + \phi_n) \qquad (2)$$

When θ_n and ϕ_n are the phase difference of nth order voltage and current waveform. The reference current drawn from the source is the portion of the current, which retains the same level of distortion as of the voltage, while at the same time accounts for the entire fundamental frequency component. The reference current has the same graphical pattern of variation as the voltage. It might have a time leg or lead or may be in phase with the voltage, depending on the harmonic and reactive power compensation capability. Thus the fundamental frequency component of load current I_1 (plus loss component) for harmonic compensation, and $I_1 \cos\phi_1$ (plus loss component) for both harmonic and reactive power

compensation respectively. All other frequency components will be in the same proportion as their counterparts in the voltage, which can be mathematically expressed as-

For Harmonic Compensation

$$i_{s,ref}(t) = \sum_{n=1}^{k} \left(\frac{I_1}{V_1}\right) V_n \sin(n\omega t + \theta_n + n(\phi_1 - \theta_1)) \qquad (3)$$
$$(I_1 = I_1 + I_{Loss}, \text{ for n=1})$$

For both Harmonic and Reactive Power Compensation

$$i_{s,ref}(t) = \sum_{n=1}^{k} \left(\frac{I_1}{V_1}\right) V_n \sin(n\omega t + \theta_n) \qquad (4)$$
$$(I_1 = I_1 \cos\phi_1 + I_{Loss}, \text{ for n=1})$$

Based on this principle it is possible to estimate the reference current, which customer should draw from the utility. *The reference current component can be estimated by measuring the supply voltage harmonics, fundamental load current and their respective angles, as in eq. (3) and (4).*

III. CONTROL SCHEME

The complete schematic diagram of the proposed 3-phase shunt active power filter is shown in Fig.2. A 3-phase thyristor converter is used as a nonlinear load. A voltage source PWM converter with a dc bus capacitor is used as an APF. A series passive filter has been connected at the PCC to reduce the bandwidth of the APF.

In order to estimate the reference current command, the source voltages and load currents of two phases are measured and their harmonic components are computed. Using fundamental load current (I_1), fundamental voltage (V_1), harmonic components of voltage $(V_3, V_5.....)$, and their respective angles $(\phi_1, \theta_1, \theta_3, \theta_5.......)$, reference currents are obtained (for two phases) as per eq. (3) or (4). Third reference current can be obtained by a using a negative adding circuit. DC bus capacitor voltage is regulated to obtain the loss component and added with the fundamental component of load current. Estimated reference currents and the actual mains currents are then processed in Hysteresis controller, to obtain the switching signals.

IV. SIMULATION MODEL

The proposed algorithm has been simulated using MATLAB and its tools Power System Blockset and Simulink. Simulation model for obtaining different frequency components of voltage and currents for only harmonic compensation, and both harmonic and reactive power compensation are shown in Fig.3 (a) and (b) respectively. While Fig. 3(c) gives the simulation model for obtaining the reference current. Figure 3(d) shows the simulation model for hysteresis controller.
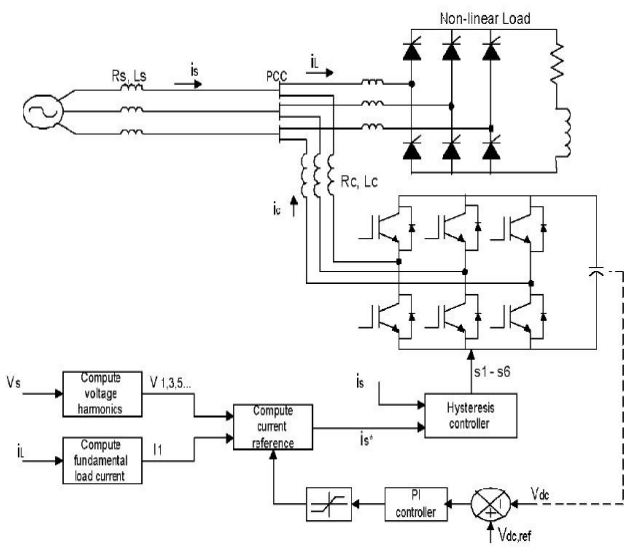
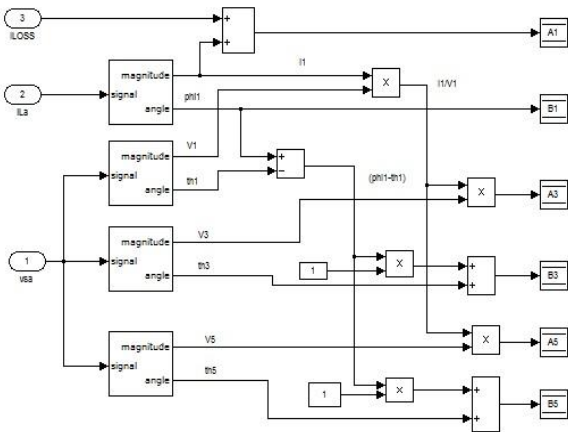**Fig. 2 Schematic diagram of control algorithm**

Fig.3 (c) Obtaining reference current
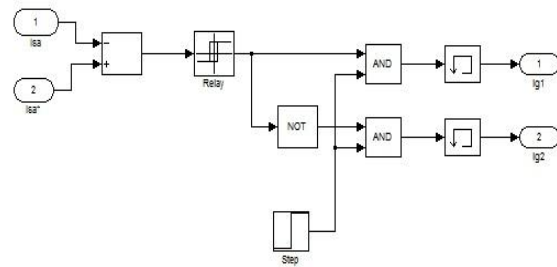
Fig.3 (d) Simulation model of Hysteresis controller

V. SIMULATION RESULTS

Various simulation results are obtained for both the cases (compensation of only harmonics, and compensation of both harmonics and reactive power simultaneously), under both ideal and distorted mains conditions. Essential parameters selected for the simulation study are shown below-

V_s = 230 volts, f = 50 Hz, R_B = 0.1 ohm, L_B = 0.5 mH, R_C = 0.4 ohm, L_C = 3.35 mH, R_p = 0.5 ohm, L_p = 5 mH, C_{dc} = 2000 μF, $V_{dc, ref}$ = 650/680 volts for only harmonic compensation, and both harmonics and reactive power compensation respectively.

Fig. 4 shows various waveforms for phase 'A', in steady state for only harmonic compensation case. After compensation, source currents become balances and sinusoidal, but they are not in phase with the respective voltages (i.e. only harmonics are compensated). THD of the source current is reduced from 25.3% (with series passive filter) to 1.02%, which is well below the 5% recommended limit.

Fig.3 (a) Obtaining different frequency components of voltage and current for harmonic compensation

Fig.3 (b) Obtaining different frequency components for both harmonic and reactive power compensation
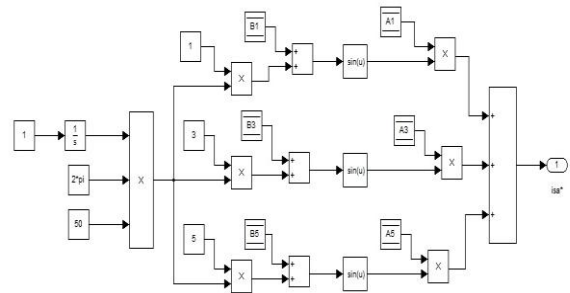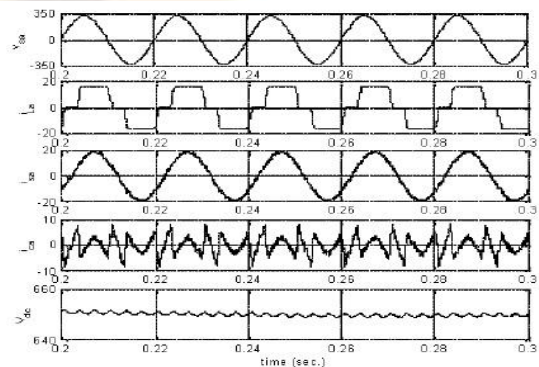

Fig. 4 Simulation results in steady state for only harmonic compensation (with ideal mains)

Table 1 gives the various frequency components present in the source, load and filter current (for phase 'A'). a thyristor converter with ideal mains draw almost balanced currents, therefore only phase 'A' parameters are shown. It is observed that the compensated source current contain only fundamental component, while all other components are absorbed by the filter. Difference in the magnitudes of the load and compensated source current is due to the loss component.

Table 1
Frequency components of load, source and filter current
(Only harmonic compensation with ideal mains)

Order of Harmonic s	Load current	Source current	Filter current
1	14.48-j10.71	15.26-j11.10	-0.79+j0.40
5	3.65-j0.19	-0.01+j0.03	3.64-j0.2
7	0.56-j2.03	0.05+j0.02	0.52-j2.04
11	0.94-j0.83	0.03+j0.05	0.92-j0.88
13	-0.38-j0.85	0.02-j0.06	-0.39-j0.8
17	0.08-j0.53	0.06+j0.04	0.03-j0.57
19	-0.37-j0.18	-0.05-j0.03	-0.32-j0.15
rms current	13.13A	13.34A	3.3A

Fig.5 shows the three compensated source currents with their respective source voltages for both harmonics and reactive power compensation. After compensation, all the three source currents becomes balanced and sinusoidal (having same shapes as of the mains voltage) and in phase with their respective source voltages. Hence reactive power is completely compensated. THD of the source current is reduced from 25.3% to 1.0%.
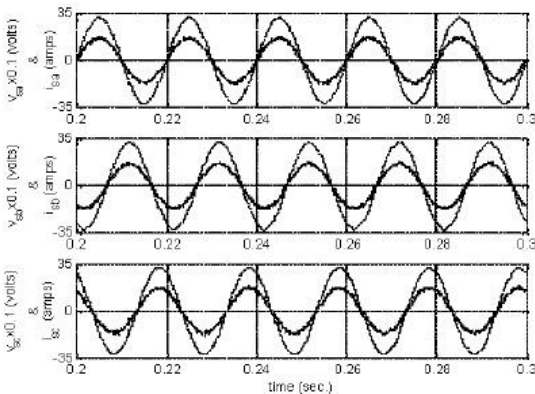

Fig. 5 Source voltages and source currents of all the three phases

Table 2
Frequency components of load, source and filter current
(Both harmonic and reactive power compensation, ideal mains)

Order of Harmonic s	Load current	Source current	Filter current
1	14.48-j10.71	16.85-j0.02	-2.37-j10.69
5	3.65-j0.19	-0.04+j0.05	3.68-j0.24
7	0.56-j2.03	0.05-j0.03	0.51-j2.00
11	0.94-j0.83	0.00+j0.07	0.94-j0.91
13	-0.38-j0.85	0.01-j0.07	-0.38-j0.77
17	0.08-j0.53	0.05+j0.05	0.03-j0.57
19	-0.37-j0.18	-0.03-j0.01	-0.34-j0.17
rms current	13.13A	11.92A	8.39A

Table 2 gives various frequency components present in the source, load and filter current. No fundamental reactive current component is present in the compensated source current, as well as all other frequency components are absorbed by the filter. APF has loss component and fundamental reactive power of load as fundamental component. It is observed that APF compensate all the harmonic and reactive power. However, APF current is increased from 3.3A to 8.39A to compensate both harmonic and reactive power simultaneously, as compared to only harmonic compensation, for similar loading.

Fig. 6 shows all the three source currents with their respective source voltages for only harmonic compensation case in steady state with distorted mains. It is observed from the simulation results that, APF allows similar level of distortion in the compensated source current as present in the source voltage. The shape of the source voltages and currents are same, but they are not in phase, hence no reactive power is compensated. Fundamental component present in the APF current is due to the loss component.

Various frequency components of the load, source and APF current (phase 'A'), are given in Table 3, which shows that the APF allows a part of the 5th harmonics component in the compensated source current, as present in the mains voltage. Table 4 shows various power components after compensation, from which it is clear that no reactive power is compensated, therefore capacity of APF installed is reduced as compared to both harmonics and reactive power compensation case.
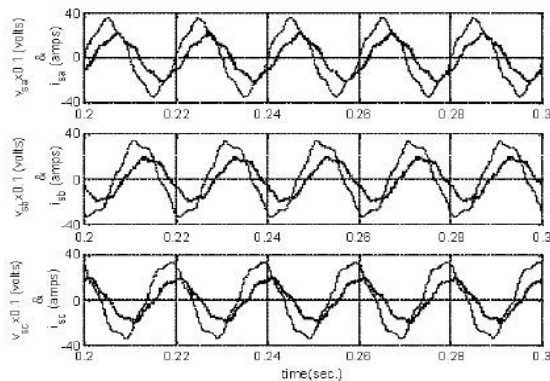
Fig. 6 Three- phase source currents with their respective source voltages (only harmonic compensation under distorted mains)

Table 3
Frequency components of load, source and filter current
(Phase 'A')
(Only harmonic compensation with distorted mains)

Order of Harmonics	Load current	Source current	Filter current
1	14.96-j11	15.80-j11.40	-0.89+j0.37
3	-0.58-j1.12	0.06-j0.02	-0.65-j1.10
5	2.93-j0.48	-1.83+j0.15	4.76-j0.62
7	0.55-j2.35	0.03-j0.05	0.53-j0.88
9	-0.76-j0.60	0.07-j0.06	-0.83-j0.55
rms current	**13.52A**	**13.84A**	**4.14A**

Table 4
Various power components after compensation
(Phase 'A')
(Only harmonic compensation with distorted mains)

Power component	Load	Source	APF
Active power, P	2477.9	2544.2	72.83
Reactive power, Q	1804.0	1847.5	50.97
VA rating	3109.6	3183.2	952.2
Fundamental power	2433.9	2571.6	144.2
Harmonic power	43.98	-27.37	-71.36

Table 5 gives various frequency components presents in the load, source and APF current (of phase A), for the compensation of both harmonics and reactive power simultaneously under distorted mains. This shows that the APF allows a part of the 5th harmonic component in the source current, as present in the mains voltage. At the same time, it is observes that the reactive components in all frequency components of the source current are negligible; hence the reactive power is fully compensated. Table 6 shows the various power components after compensation.

Table 5
Frequency components of load, source and filter current
(Phase 'A')
(Both harmonic and reactive power compensation with distorted mains)

Order of Harmonics	Load current	Source current	Filter current
1	14.96-j11	18.24-j0.02	-3.28-j11.06
3	-0.58-j1.12	0.00-j0.00	-0.58-j1.12
5	2.93-j0.48	1.75-j0.03	1.18-j0.45
7	0.55-j2.35	0.06+j0.00	0.49-j2.35
9	-0.76-j0.60	-0.01-j0.01	-0.75-j0.60
11	0.26-j0.50	-0.04+j0.02	0.29-j0.52
13	-0.53-j0.83	0.04-j0.03	-0.56-j0.80
rms current	**13.52A**	**12.96A**	**8.52A**

Table 6
Various power components
(Phase 'A')
(Both harmonic and reactive power compensation With distorted mains)

Power component	Load	Source	APF
Active power, P	2477.9	2990.6	512.7
Reactive power, Q	1804.0	-0.15	-1805.0
VA rating	3109.6	2980.8	1959.6
Fundamental power	2433.9	2964.3	530.4
Harmonic power	43.98	26.26	-17.72

VI. CONCLUSION

Paper presents the modeling and simulation of frequency domain control of shunt active power filter using MATLAB and its tools Simulink and

Power System Blocksets. Simulation results shows that, algorithm based on frequency domain require cumbersome calculation time, but offers many advantages over other methods. Therefore more attention and detailed investigations are required on this issue.

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