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COMPARATIVE STUDIES OF DIFFERENT CONTROL STRATEGIES FOR SHUNT ACTIVE FILTER

M. Chakravarthy, P. M. Sarma and S. N. Saxena
Department of Electrical and Electronics Engineering, GRIET, Hyderabad, India
E-Mail: chakri4330@gmail.com

ABSTRACT

Shunt Active power filter reduces the harmonics by injecting a current into the system proportional to the reference signal. Various strategies for affecting it are studied and compared. It is shown that PID control scheme yields better results.

Keywords: shunt active power filter, hysteresis control, PID control, total harmonic distortion, α-β frame, Clarkes transformation.

1. INTRODUCTION

When the power systems consists of loads having power electronics switching devices such as diodes, thyristors, GTO's etc. feeding loads consisting of capacitors, dc motors etc., the current drawn from the system is no longer sinusoidal. The voltage also gets distorted. This causes current drawn from the system to be full of harmonics and also results in low power factor. These harmonics cause unnecessary wastage of power in hysteresis losses in the transformer and copper losses in the transmission lines. This is compounded with the bad effects of low power factor. These effects can be mitigated by connecting tuned static filters at the load end. However, these devices cause resonance effects which is undesirable. So research is going on to develop power electronics based device which can eliminate the harmonics, improve the power factor and in general, improve the grid performance.

2. ACTIVE POWER FILTER

An active power filter can be considered as a modified voltage source inverter. Figure-1 shows the detailed circuit diagram of an active power filter.

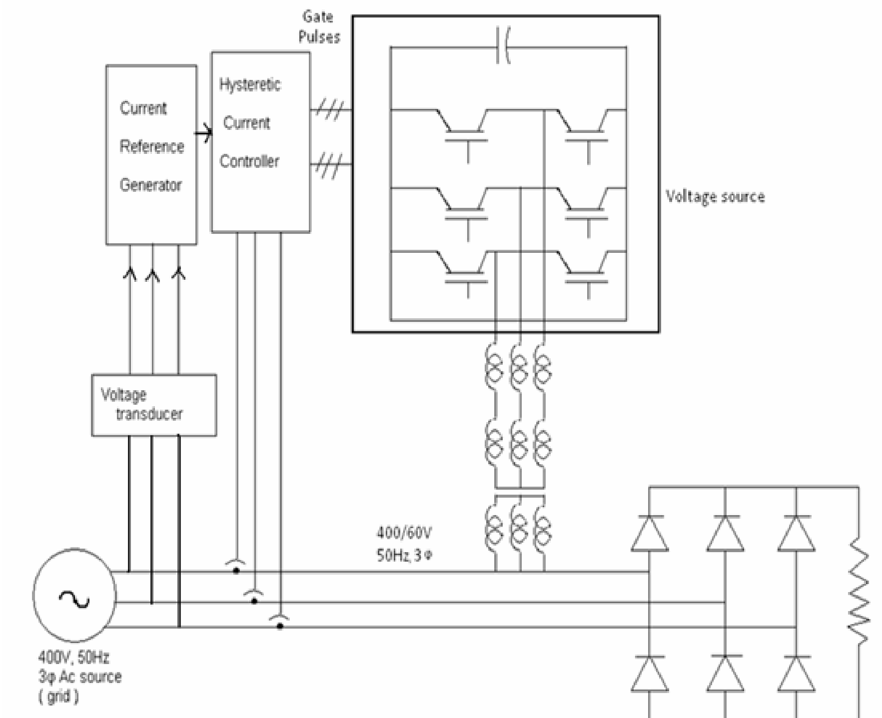

Fig 1: Schematic diagram showing connections to the Active Filter wit the system having Non Linear Load

Power electronic devices, normally used as converters causes various harmonics to be produced and also cause low power factor in the system. Earlier, passive filters were used to reduce harmonics and improve power factor but their disadvantages are that they are not responsive to changes in load and contribute to unwanted resonance in the circuit. In this paper, control algorithm for active power filter is discussed and a comparison is made between current control strategies.

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Figure-2 shows the diagrammatic representation of the shunt active filter. The modified inverter injects currents into the system to compensate for harmonics and for reactive power requirements.

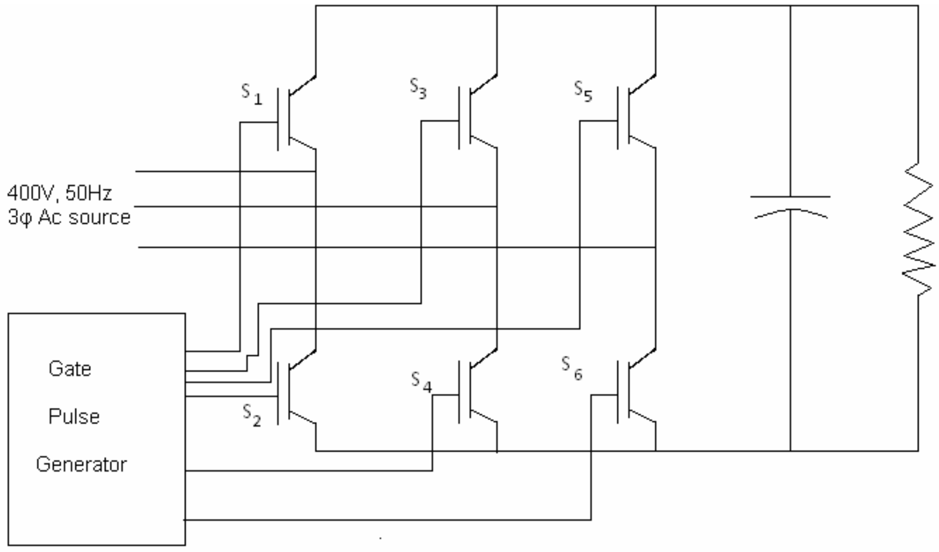

Fig 2: Diagram of voltage source inverter with gate pulse generation

3. CONTROL ALGORITHM

The three voltages V_a, V_b and V_c from the voltage transducers are given to the controller which converts them to V_o, V_α and V_β using the following equations.

$$V_o = \frac{1}{\sqrt{3}}(V_a + V_b + V_c) \quad (1)$$

$$V_\alpha = \sqrt{\frac{2}{3}}\left(V_a - \frac{V_b}{2} - \frac{V_c}{2} \right) \quad (2)$$

$$V_\beta = \sqrt{\frac{2}{3}}\left(\frac{\sqrt{3}}{2} V_b - \frac{\sqrt{3}}{2} V_b \right) \quad (3)$$

Similarly, the controller is fed with current signals from the current transducers which are converted to i_0, i_α and i_β using the following equations.

$$i_o = \sqrt{\frac{2}{3}}\left(\frac{i_a}{\sqrt{2}} + \frac{i_a}{\sqrt{2}} + \frac{i_a}{\sqrt{2}} \right) \quad (4)$$

$$i_\alpha = \sqrt{\frac{2}{3}}\left(i_a - \frac{i_b}{2} - \frac{i_c}{2} \right) \quad (5)$$

$$i_\beta = \sqrt{\frac{2}{3}}\left(\frac{\sqrt{3}}{2} i_b - \frac{\sqrt{3}}{2} i_b \right) \quad (6)$$

The real and reactive powers are obtained from the following equations.

$$P_o = V_o I_o \quad (7)$$

$$p = V_\alpha I_\alpha + V_\alpha I_\alpha \quad (8)$$

$$q = - V_\beta I_\beta + V_\beta I_\beta \quad (9)$$

This calculation is represented diagrammatically in Figure-3.

The active power signal p has a steady component and a fluctuating component. The steady component only should be drawn from the grid, whereas the fluctuating component should be drawn from the active power filter. If this can be done, the grid will not be affected by harmonic currents. If q can be supplied entirely from the active power filter, the power factor will also be improved. If reference currents can be calculated with this in view, the shunt active power filter will contribute in a great way to improve the power quality. The power signal p is passed through a high pass filter. A diagrammatic representation of this scheme is shown in Figure-4.

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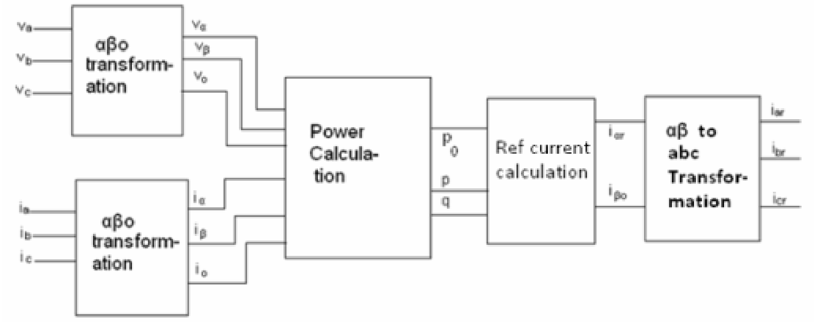

Fig 3: Block diagram representation of calculation of reference currents.

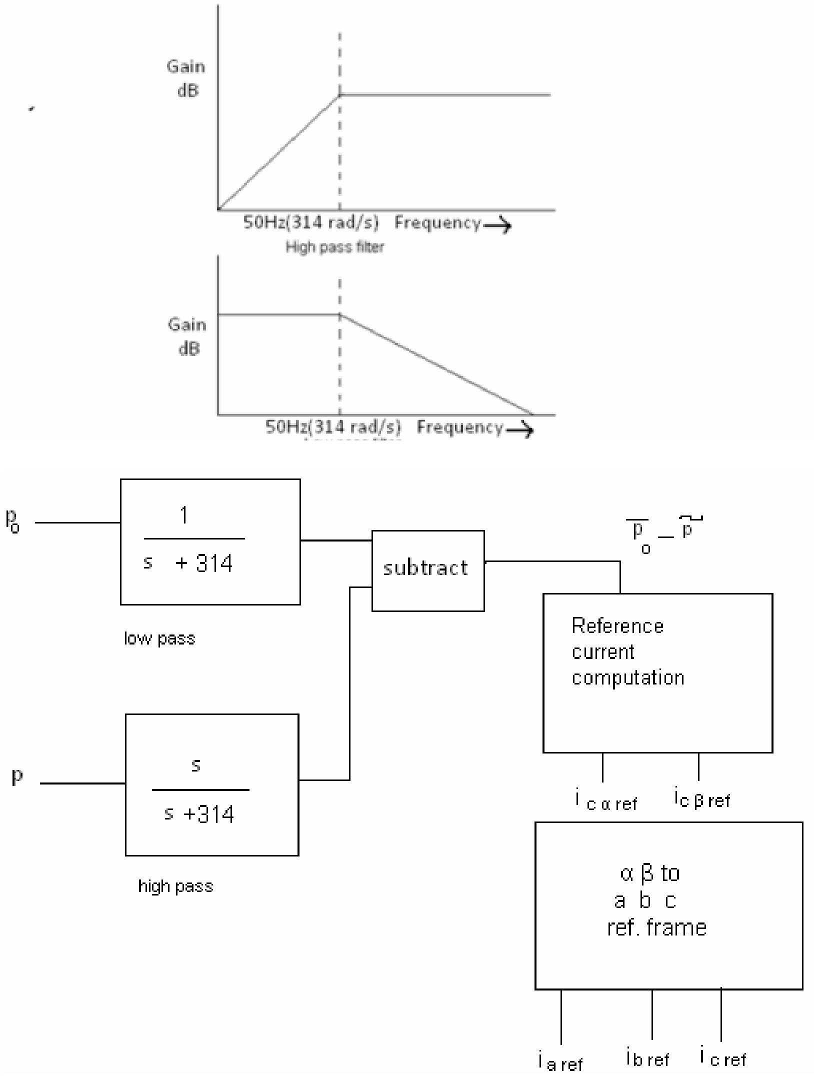

Figure-4. Calculation of reference currents.

p_o (zero sequence power signal) is passed through low pass filter and the active power signal is passed through high pass filter. The output of low pass filter is steady component of zero sequence power. In high pass filter, output is fluctuating component of power. So, this difference is $\overline{p_o}-\tilde{p}$ which is used to calculate the reference currents using the following expressions.

$$i_{c\alpha\,ref} = \frac{1}{V_\alpha^2+V_\beta^2}\left[V_\alpha(\overline{p_o}-\tilde{p}) + V_\beta q\right] \quad (10)$$

$$i_{c\beta\,ref} = \frac{1}{V_\alpha^2+V_\beta^2}\left[V_\beta(\overline{p_o}-\tilde{p}) + V_\alpha q\right] \quad (11)$$

These reference currents in the α-β frame are converted to a-b-c frame, using the reverse transformation given below.

$$i_{caref} = \sqrt{\frac{2}{3}}\left[\frac{(-io)}{\sqrt{2}} + i_{c\alpha ref}\right] \quad (12)$$

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$$i_{cbref} = \sqrt{\frac{2}{3}}\left[\frac{(-io)}{\sqrt{2}} - \frac{1}{2}(i_{c\alpha ref}) + \frac{\sqrt{3}}{2} i_{c\beta ref}\right]$$

(13)

$$i_{ccref} = \sqrt{\frac{2}{3}}\left[\frac{(-io)}{\sqrt{2}} - \frac{1}{2}(i_{c\alpha}) - \frac{\sqrt{3}}{2} i_{c\beta}\right]$$

(14)

4. HYSTERESIS CONTROL SCHEME

This scheme involves selection of two levels of current; one slightly above the reference current and other slightly below the reference current. Feedback signal from the actual current is taken. When the actual current is below lower value, the MOSFETs are switched on, and when the current crosses the upper value, the MOSFETs are switched off. As a result, the actual current remains within the upper and lower bands of the current reference. The scheme is explained diagrammatically in Figure-5.

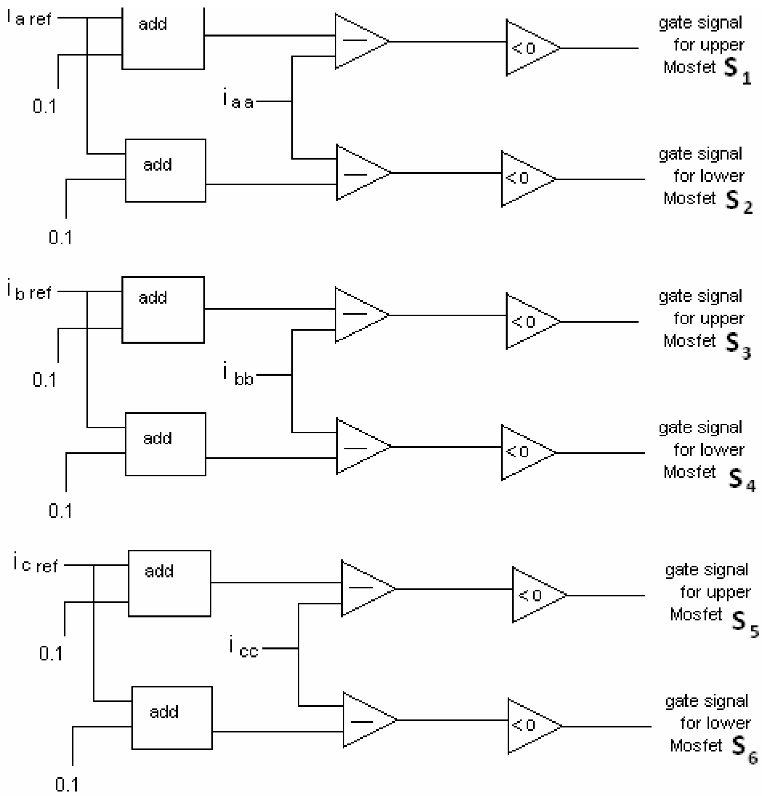

Figure-5. Control algorithm for hysteretic current controller.

5. PID CONTROL SCHEME

In this scheme, the reference current is compared with the actual current and the error is amplified by the PID block. The output of the PID block is compared with a triangular wave, resulting in a pulse width modulated output. These PWM pulses are fed to the MOSFETs to produce the desired reference current from the voltage source inverter. The PID control scheme is shown in Figure-6.

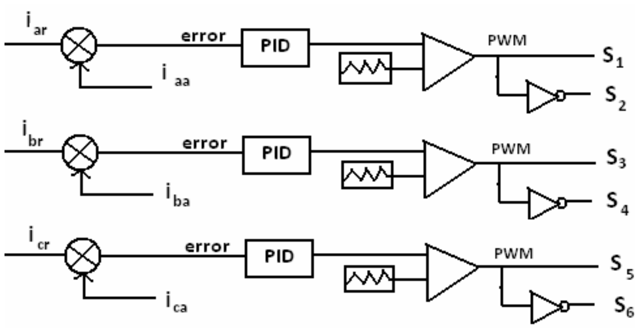

Figure-6. Generation of gate pulses using PID control scheme.

6. SIMULATION RESULTS

Figure-7 shows the reference currents generated by shunt active filter controller.

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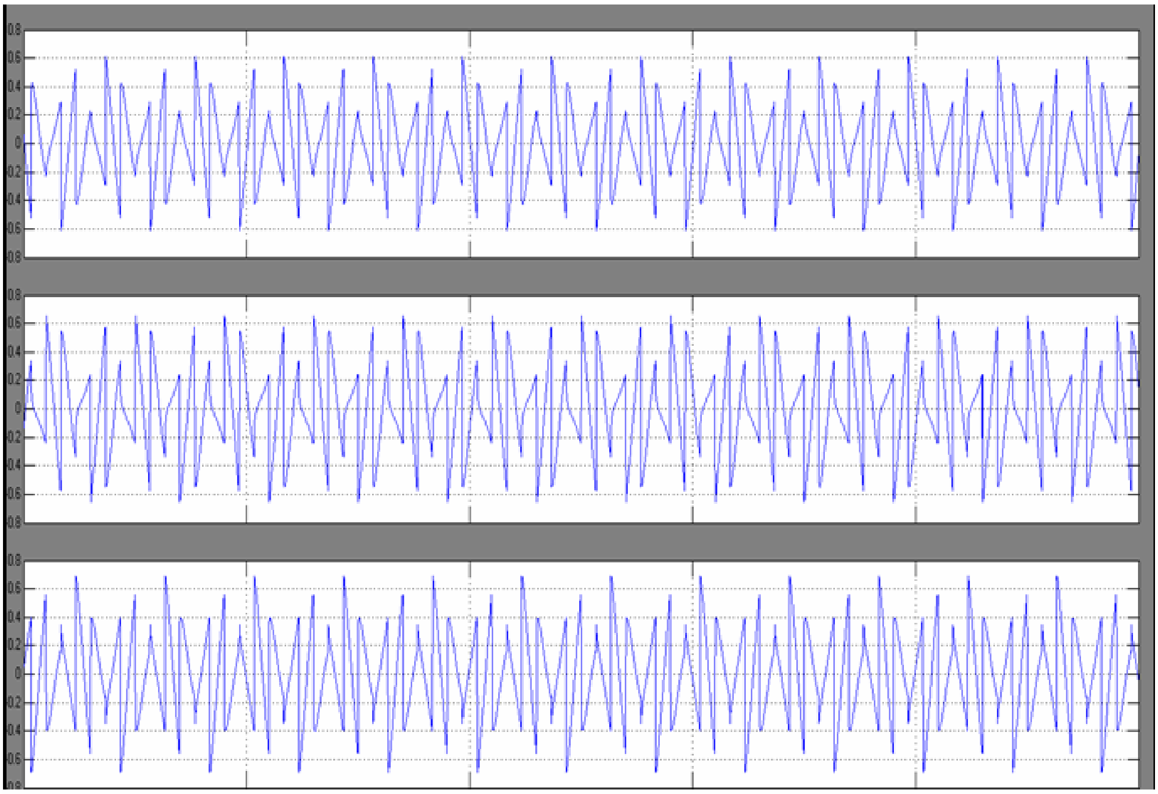

Figure-7. Reference currents generated by active filter controller.

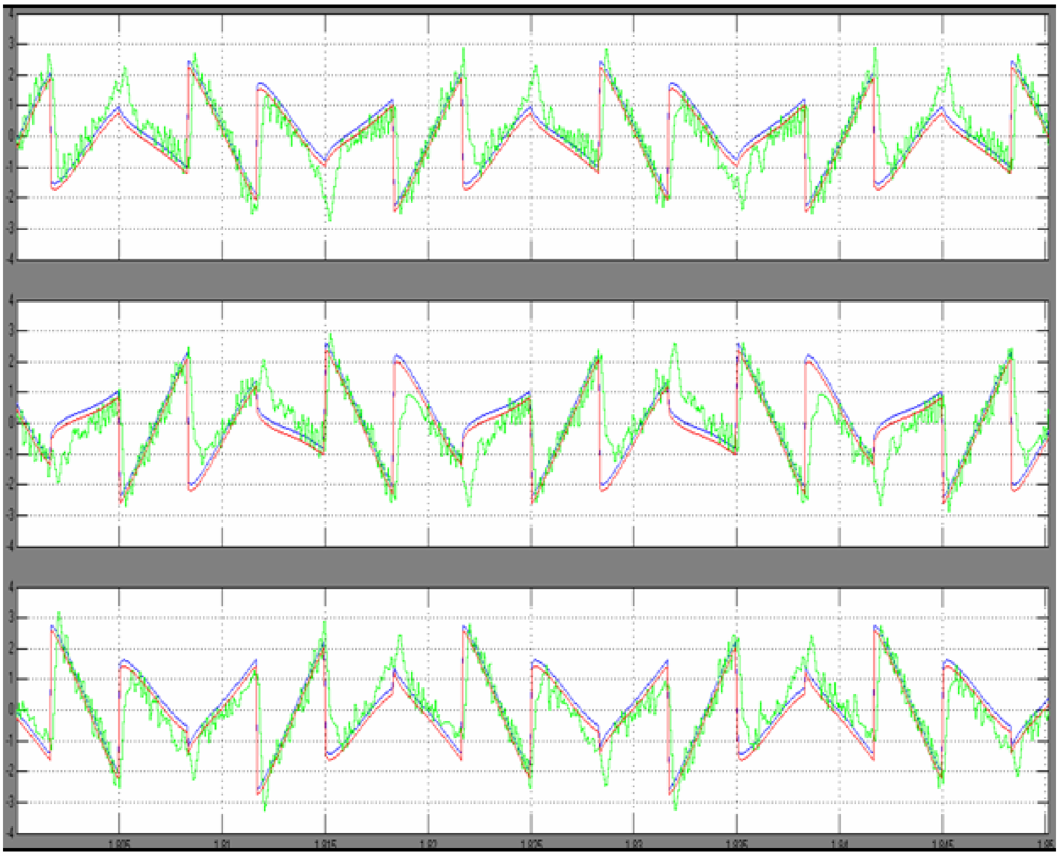

Figure-8. Hysteresis band of the reference currents.

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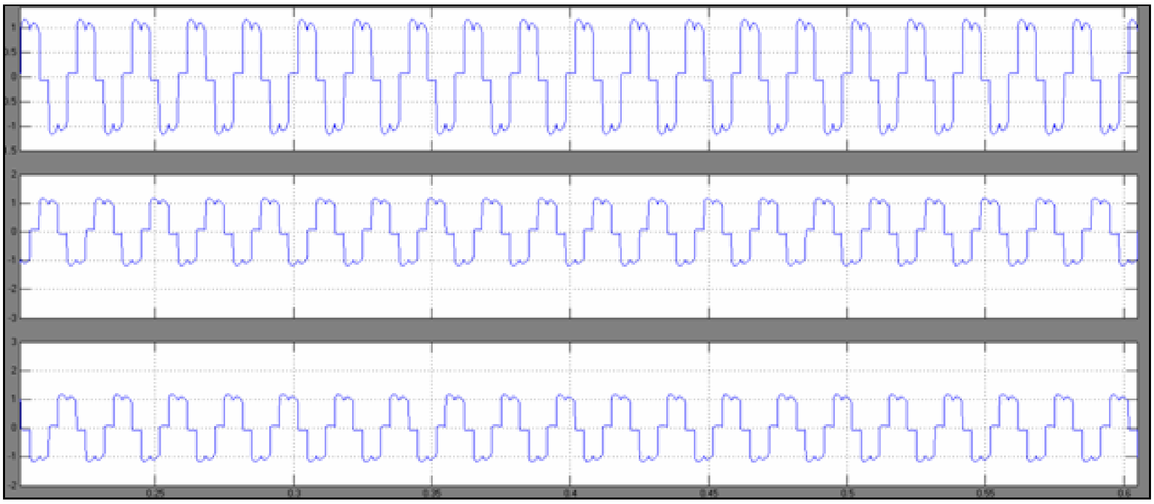

Figure-9. Source currents before compensation.

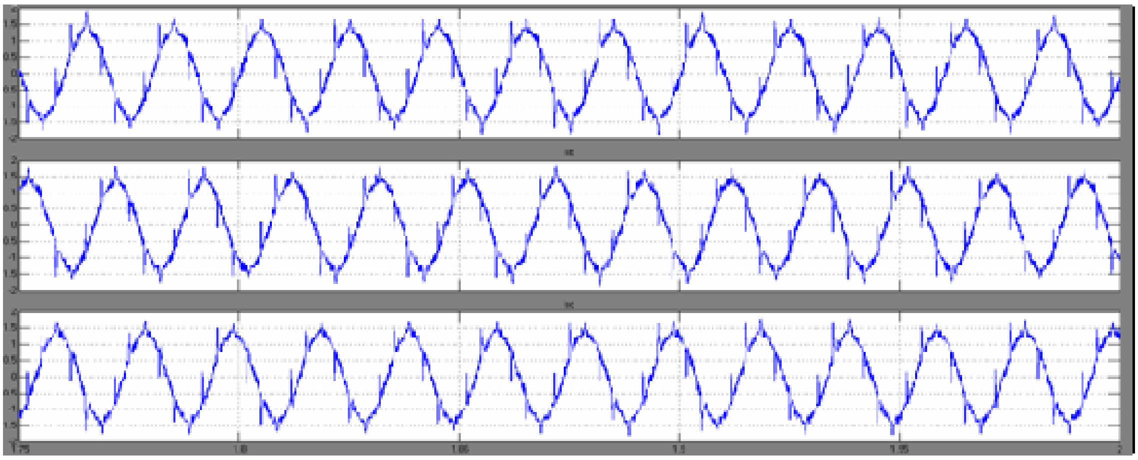

Figure-10. Source currents after compensation.

7. RESULTS OF PID SCHEME

Table-1. Results of PID scheme.

Line Inductance	Harmonic content		THD%
	5^{th}	7^{th}	
2.5 mH	4%	3.50%	5.72
5 mH	4%	4%	7
10 mH	6%	5%	9
1.25 mH	….	2.50%	4.80

From Table-1, the results 2.5 mH inductance connected between the active filter and the grid is finalized.

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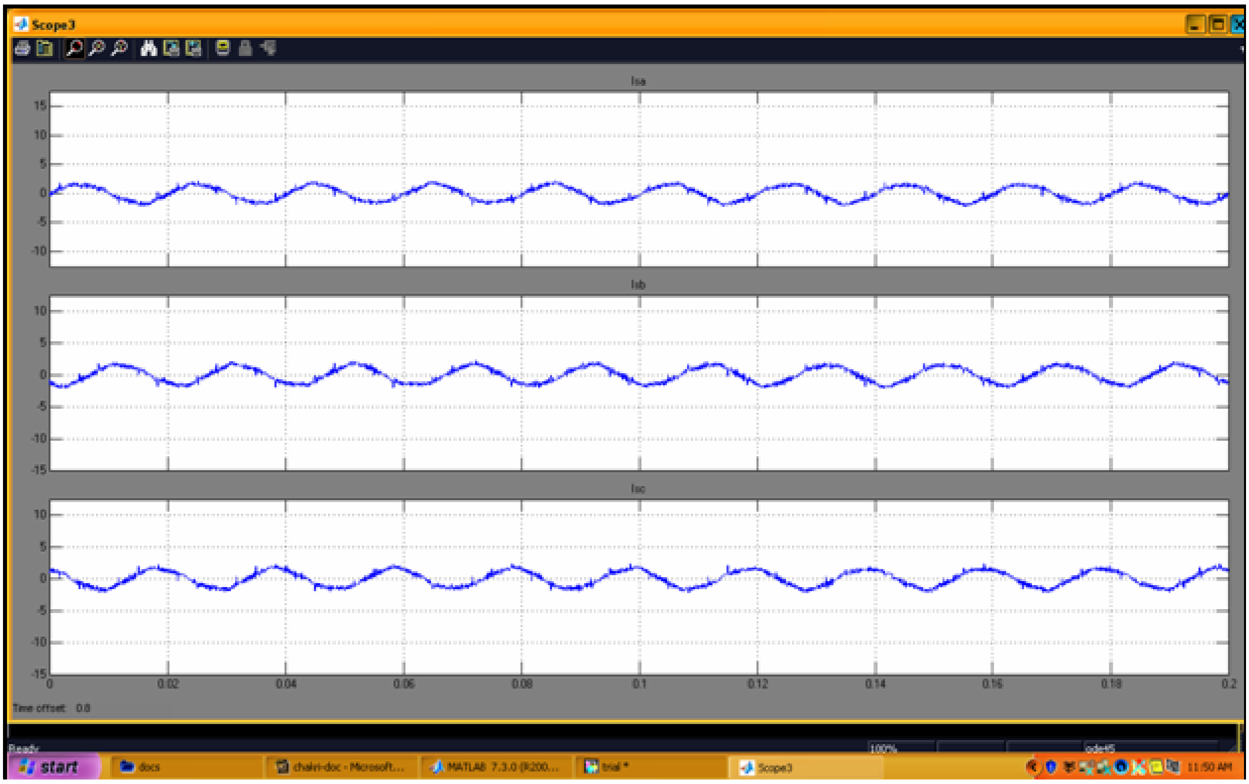

Figure-11. Source current waveform with a line inductance of 2.5 mH.

Standardization of K_p, K_i, K_d through simulation

Table-2 computed THD for different values of K_p, K_i, K_d for selecting K_p

Table-2.

K_p	K_i	K_d	5^{th}	7^{th}	THD %
1	0.1	0	5	7	5.72
2	0.1	0	3	3	5.4
3	0.1	0	3.2	3	5.81
4	0.1	0	3.6	3.5	5.67

From the results given in Table-2, K_p is standardized at 2.

Selection of K_i

Table-3 shows THD for different values of K_p, K_i, K_d for selecting K_i.

Table-3.

K_p	K_i	K_d	5^{th}	7^{th}	THD %
2	0.2	0	2.8	3	5.25
2	0.2	0	2.8	3	5.33

From the results in Table-3, K_i is standardized at 0.2.

Selection of k_d

Table-4 THD for different values of K_p, K_i, K_d for selecting K_d

Table-4.

K_p	K_i	K_d	THD %
2	0.2	0.1	2.42
2	0.2	0.2	2.57

From the results in Table-4, K_d is selected as 0.1. Thus from the above results, the values of K_p, K_i and K_d are standardized at 2, 0.2 and 0.1, respectively.

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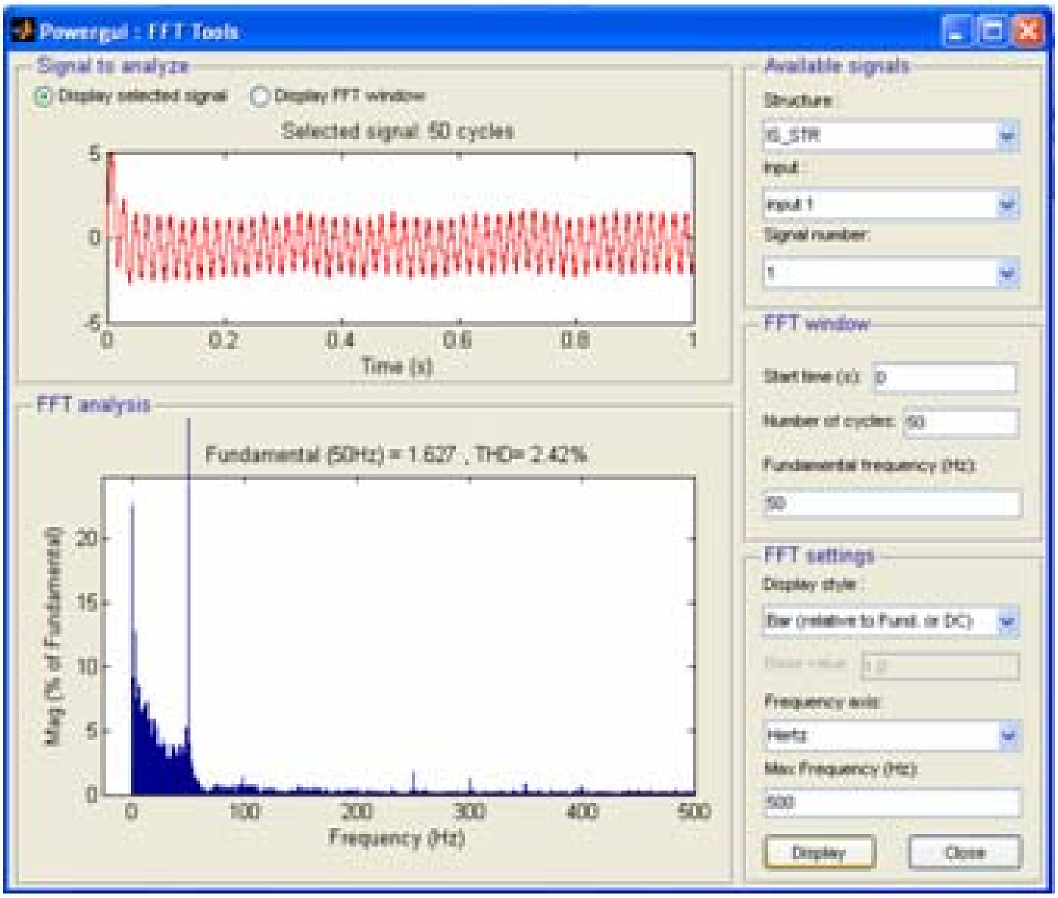

Figure-13. FFT analysis with the selected PID values.

Figure-14. Source current waveform with tuned PID values for shunt active filter.

Selection of switching frequency

Table-5 shows THD for different values of switching frequency.

Table-5.

K_p	K_i	K_d	f_s	THD %
2	0.2	0.1	1000	2.42
2	0.2	0.1	600	2.45
2	0.2	0.1	900	2.62

From the results in Table-5, the switching frequency is standardized as 1000Hz.

Figure-12 shows the three phase source currents with PID control scheme in shunt Active filter.

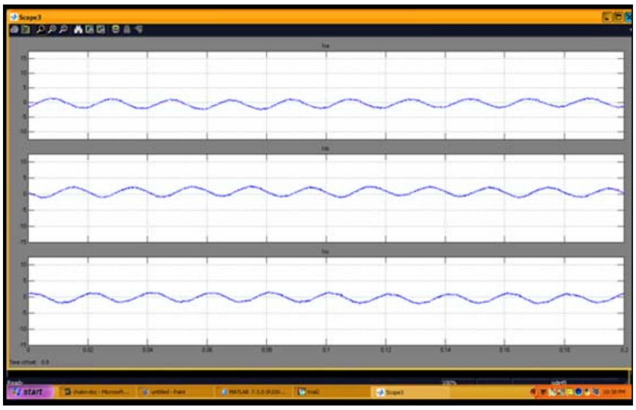

Figure-12. Source currents with PID control scheme in shunt active filter.

For a line inductance of 5 mH and varying the hysteretic band, the results were obtained. Table-6 shows THD for different values of hysteresis band.

Table-6.

Hysteretic band	THD %
±0.1	10.31
±0.05	10.38
±0.2	9.92
±0.4	9.44

From the results in Table-6 the hysteretic band of ±0.4 is standardized.

Now varying the inductance Table-7 shows the THD for different values of line inductance.

Table-7.

Line Inductance	THD %
2.5 mH	6.4
1.25 mH	4

From results in Table-7, a line inductance of 1.25mH is standardized.

8. CONCLUSIONS

It is found that the shunt active filter produced better results when PID control scheme was used than when hysteretic control scheme was used. Various parameters affecting the performance of both the controllers were investigated and the results were presented.

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