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Improving Power Quality by Shunt Active Filter with PID control Strategy

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Abstract:
In this paper Shunt Active Filters (SAF) is used to supply the required compensating source current which is one of the power quality issue. DC bus of Voltage Source Inverter (VSI) is controlled by PI and PID control techniques. Synchronous Reference Frame Theory (SRFT)is the control algorithm implementation of SAF. SAF is realized using 3-phase, 3leg Voltage Source Inverter (VSI). The results obtained from PI model and PID model are compared with respect to Total Harmonic Distortion (THD). THD is compared without and with compensation. All the simulation are carried out in Matlab simulink environment and result discussion is providing based on the optimum method for controlling DC bus of VSI.

Keywords*: PI controller, PID controller, Synchronous Reference Frame Theory, Total Harmonic Distortion, source harmonics*

1. Nomenclature

- AF- Active Filter
- CC-VSI - Current Controlled Voltage Source Inverter
- FFT- Fast Fourier Transform
- IGBT- Insulated Gate Bipolar Transistor
- IRP- Instantaneous Reactive Power theory
- PWM- Pulse Width Modulation
- VSI- Voltage Source Inverter
- SAF - Synchronous Reference Frame Theory
- THD- Total Harmonics Distortion, %

2. Introduction

Early equipment was designed to withstand disturbances such as lightning, short circuits, and sudden overloads without extra expenditure. Current power electronics (PE) prices would be much higher if the equipment was designed with the same robustness. Pollution has been introduced into power systems by nonlinear loads such as transformers and saturated coils; however, perturbation rate has never reached the present levels. Due to its nonlinear characteristics and fast switching, PE create most of the pollution issues. Most of the pollution issues are created due to the nonlinear characteristics and fast switching of PE.

Increase in such non-linearity causes different undesirable features like low system efficiency and poor power factor. It also causes disturbance to other consumers and interference in nearby communication networks. The effect of such non-linearity may become sizeable over the next few years. Hence it is very important to overcome these undesirable features.

Classically, shunt passive filters, consist of tuned LC filters and/or high passive filters are used to suppress the harmonics and power capacitors are employed to improve the power factor. But they have the limitations of fixed compensation, large size and can also exile resonance conditions.

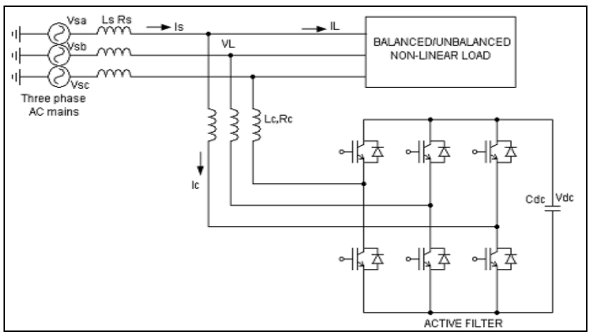
Active power filters are now seen as a viable alternative over the classical passive filters, to compensate supply current harmonics of the non-linear loads. The objective of the active filtering is to solve this problems by combining with a much-reduced rating of the necessary passive components[1].

Various topologies of active power filters have been developed so far. The shunt active power filter based on current controlled voltage source type PWM converter has been proved to be effective even when the load is highly non-linear. Most of the active filters developed are based on sensing harmonics and reactive volt-ampere requirements of the non-linear load and require complex control. A new scheme has been proposed in, in which the required compensating current is determined by sensing load current which is further modified by sensing line currents only. An instantaneous reactive volt-ampere compensator and harmonic suppressor system is proposed without the use of voltage sensors but require complex hardware for current reference generator.

In this paper, a three-phase, three-wire shunt active filter is presented to eliminate supply current harmonics, to balance the nonlinear/linear unbalanced loads based on SRF theory as shown in Fig.1. The reference currents are derived from the control algorithm. Sensed currents are fed to a hysteresis Pulse Width Modulation (PWM) current controller, to generate switching signals to Active Filter (AF). VSI is realized by using a controlling DC bus voltage through PI controller and PID controller.

3. System Configuration

LC tuned filters, has the advantage of high reliability and low cost. The main disadvantages are its, fixed compensation, overloading, inability to function in saturated condition. The increased severity of harmonic pollution in power networks has attracted the attention of power electronic and power systems engineers to develop dynamic and adjustable solutions to the power quality problems, such equipment, generally known as Active filters[2]. Control and performance of AF is performed using, an Insulated Gate Bipolar Transistor (IGBT) based Current Controlled Voltage Source Inverter (CC-VSI) with a dc bus capacitor is used as the SAF.



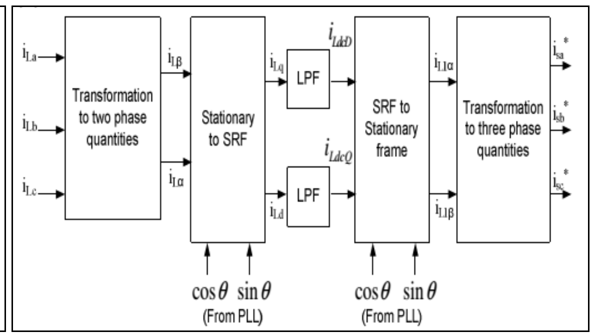
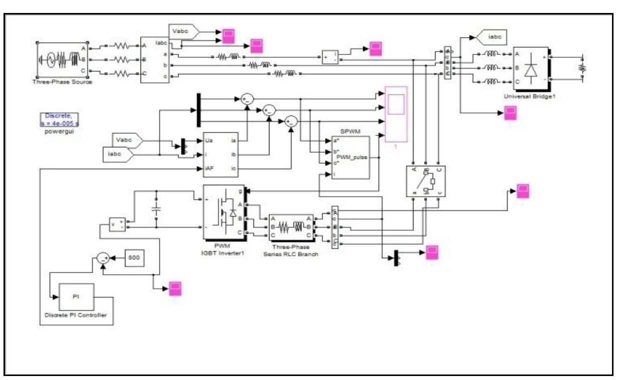


Fig.1 Block Diagram of Test System *Fig.2 Control scheme of AF with SRF Theory*

Using Instantaneous Reactive Power theory (IRP), the AF currents are directly controlled by calculating the reference AF currents. In synchronous reference algorithm (SRF) and unit template techniques, the gating pulses to the AF are generated by employing hysteresis control over reference and sensed source currents resulting indirect current control as shown in Fig.2. Using the shunt AF, the supply current harmonics, reactive power and unbalance compensation are achieved in all the control algorithms. In addition, zero voltage regulation at PCC is also achieved by modifying the unit template algorithm suitably[3].

In this work both PI and PID logic controlled shunt active power filter for the supply current harmonic of a nonlinear load are implemented. The control scheme is based on sensing line currents only; an approach different from convention ones, which are based on sensing harmonics and reactive volt-ampere requirements different from convention ones, which are based on sensing harmonics and reactive volt-ampere requirements of the nonlinear load[4]. A comparison is carried out for these control logics based on their Total Harmonics Distortion (THD).



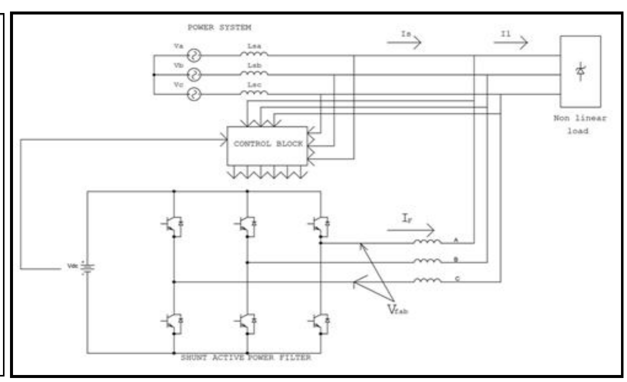


Fig.3 Matlab model to eliminate source harmonics with PI controller
Fig.4 Matlab model for Active Filters

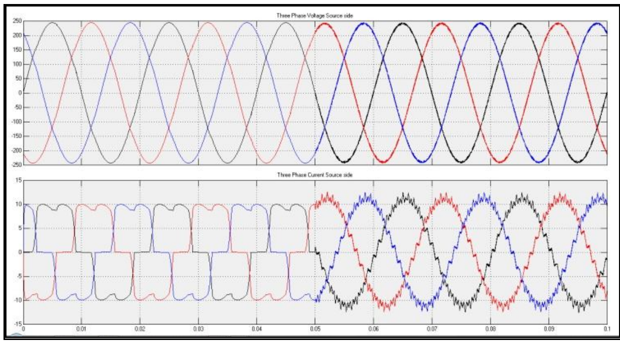
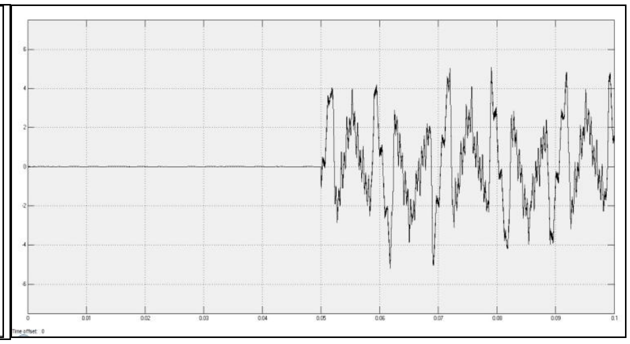



Fig.5 Source voltage and current waveforms.
Fig.6 Compensating current injected from SAF using PI technique

4. MATLAB Model For PI Controller

4.1. Shunt Active Filter

The voltage source of the test system is set to peak value of 230V and frequency of 50Hz. Three phase voltage and current model is used to measure and observe the sending end voltage and current. The non-linear load is modeled at the receiving end side. Rc & Lc are the input ripple filters designed with information on the carrier signal frequency and hysteresis bandwidth of the AF current.

Taking a Hysteresis bandwidth of 500mA and maximum switching frequency of 10KHz.

Lc=0.1*(240(sqrt 2))/10*500

Lc is designed at 6.77mH. Matlab model for PI based controller is shown in Fig.3. Fig.4 shows the Shunt active power filter topology. Fig.5 shows the different waveforms. Source voltage and current waveforms before and after compensation. Fig.6 shows the compensating current injected by the active filter containing all the harmonics, to make mains current sinusoidal.

4.2. Estimation of Reference Source Current

The instantaneous currents can be written as

is(t)=il(t)-ic(t) (1)

Source voltage is given by

Vs(0)=Vm Sinωt (2)

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

$$i_L(t)=\sum_{n=1}^{\infty} In \text{ Sin } (n\omega t+\varphi_n) \quad (3)$$
$$=I_1 \text{ Sin } (n\omega t+\varphi_n) + \sum_{n=2}^{\infty} \text{ Sin } (n\omega t+\varphi_n)$$

The instantaneous load power can be given as

$$PL(t)=Vs(t)*il(t) \quad (4)$$
$$=V_m I_1 \text{ Sin}^2 \text{ cot}*\cos\varphi_1+V_m I_1 \text{ Sin}\omega t*\cos\omega t*\text{Sin}\varphi_1+V_m \text{ Sin}\omega t * \sum_{n=2}^{\infty} I_n \text{ Sin}(n\omega t+\varphi_n) \quad (5)$$
$$= P_f(t)+P_r(t)+P_h(t) \quad (6)$$

from eq(5), the real (fundamental) power drawn by the load is

$P_f\ (i_f) = V_m I_1 \text{ Sin}^2 \text{ cot}*\cos\varphi_1 = v_s\ (t) * i_s\ (t)$ (6)

from eq(6), the source current supplied by the source, after compensation is

$i_s\ (t) = P_f\ (t) / v_s\ (t) = I_1 \cos \varphi_1 \sin\omega t = I_m \sin \text{cot}$ (7)

4.3. PI controller

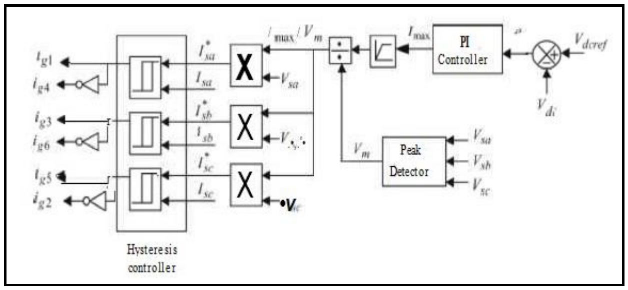


Fig.7 APF Control scheme with PI controller.

The error signal is fed to PI controller. The output of PI controller has been considered as peak value of the reference current. It is further multiplied by the unit sine vectors (usa, usb, and usc) in phase with the source voltages to obtain the reference currents (isa , isb , and isc). These reference currents and actual currents are given to a hysteresis based, carrier less PWM current controller to generate switching signals of the PWM converter[5]. The difference of reference current template and actual current decides the operation of switches. To increase current of particular phase, the lower switch of the PWM converter of that particular phase is switched on, while to decrease the current the upper switch of the particular phase is switched on as shown in Fig.7.

These switching signals after proper isolation and amplification are given to the switching devices. Due to these switching actions current flows through the filter inductor Lc, to compensate the harmonic current and reactive power of the load, so that only active power drawn from the source.

4.4. Result & Discussion

The importance of Three phase breaker is, the Shunt Active filters is not connected to the test system at the start of simulation time. Shunt Active filters is connected from 0.05 seconds to simulation time ends. The THD is tabulated before compensation and after compensation.

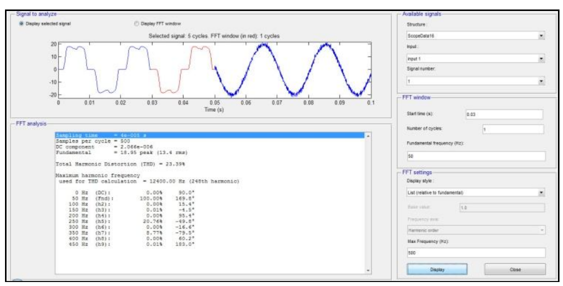


Fig.8 THD for phase A before compensation at time 0.03 seconds

Table 1 shows, THD with and without compensation for PI Controller

		THD Without Shunt Active Filters	THD With Shunt Active Filters
	Phase A	23.39%	7.16%
	Phase B	23.38%	7.11%
	Phase C	23.38%	7.28%

Table 1: THD without & with compensation

It can be observed from above Table that the Total Harmonics Distortion for phase A and other two phases are constant. At time 0.04 seconds, the Shunt Active Filters

(SAF) has not yet been connected. THe THD for Phase A is 23.39% for phase B, 23.38% and for phase C, 23.38%. Connecting the SAF after 0.05 seconds and remains connected till the end of simulation. The THD after applying Shunt Active filters for phase A,B and C are 7.16%,7311% and 7.28 respectively.

THD without compensation was tabulated in Table , keeping start time as 0.03 seconds. For tabulating THD after compensation, start time as 0.06 seconds. Fig.8 shows the waveform for phase A in Fast Fourier Transform tool box (FFT) at time 0.03 seconds. Fig.9 shows the FFT analysis for phase A after compensation at 0.06 seconds.

5. MATLAB Model For PID Controller

5.1. PID controller for VSI

The DC bus of VSI is controlled using PID controller. PID control is used at the lowest level; the multivariable controller gives the set points to the controllers at the lower level.

$u(t)=K(e(t)+ 1/ T_i \quad e(\tau)d \tau+T_d\, de(t)/ dt)$ ()

where y is the measured process variable, r the reference variable, u is the control signal and e is the control error (e = ysp − y). The reference variable is often called the set point. The control signal is thus a sum of three terms: the P-term (which is proportional to the error), the I-term (which is proportional to the integral of the error), and the D-term (which is proportional to the derivative of the error). The

controller parameters are proportional gain K, integral time Ti, and derivative time Td. The integral, proportional and derivative part can be interpreted as control actions based on the past, the present and the future. The control block is shown in Fig.10.

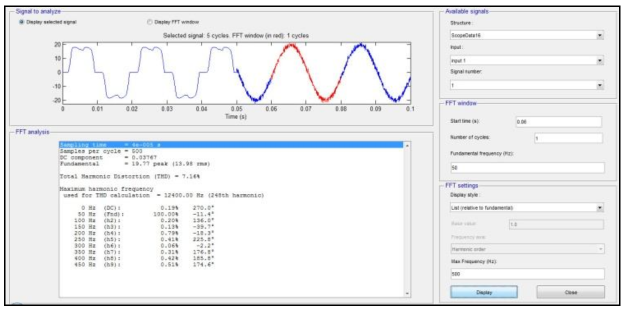
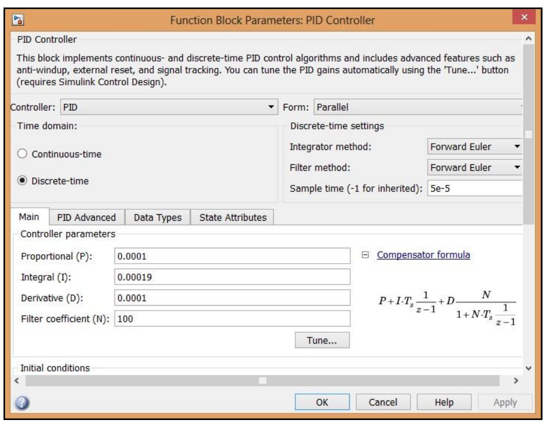


Fig.9 THD for phase A after compensation at time 0.06 seconds



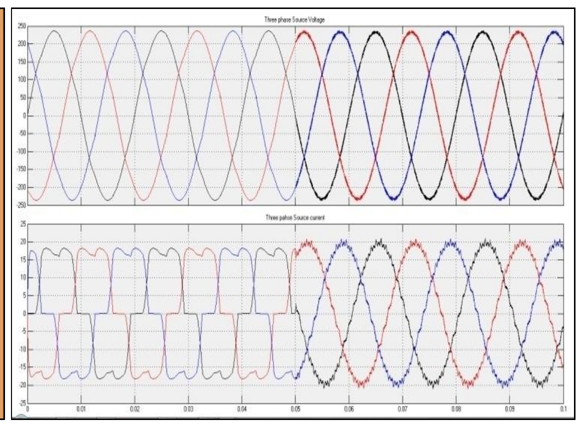


Fig.10 Control block for PID controller

Fig.11 Source voltage & current using PID technique

5.2. Result & Discussion

The THD for PID controlled VSI are tabulated in Table 2. SAF are connected after 0.05 seconds to the test system.

	THD Without Shunt Active Filters	THD With Shunt Active Filters
Phase A	23.40%	3.66%
Phase B	23.40%	3.62%
Phase C	23.40%	3.69%

Table 2: THD for VSI driven by PID controller

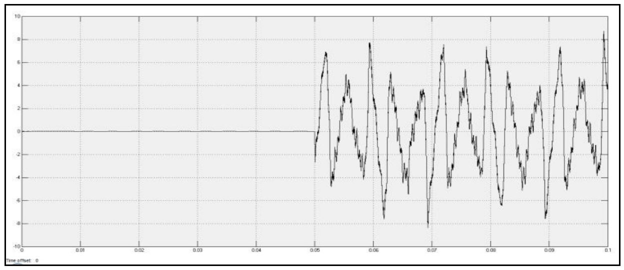


Fig.12 Compensating current injected from SAF using PID technique

From Table 2 it can be seen that, the THD before compensation for all phases is 23.40% at time 0.03 seconds. The three phase circuit breaker is closed after 0.05 seconds. THD after compensation is measured at time 0.06 seconds.

The THD for phase A is 3.66%; for phase B is 3.62% and for phase C is 3.69%. Thus the THD after compensation is less. Fig.11 shows the source voltage and current waveforms for PID control technique. Fig.12 shows the compensating current being injected through three phase circuit breaker.

6. Result & Discussion

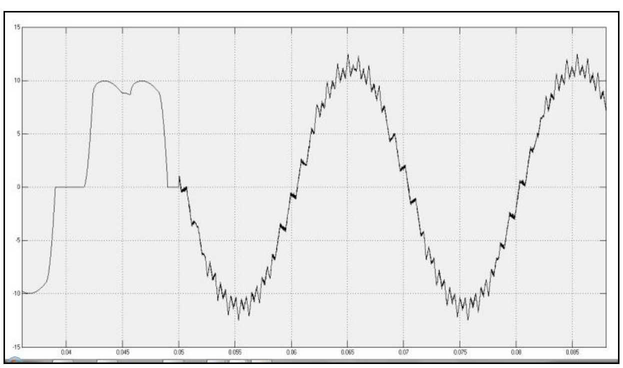
Results are obtained for THD before and after compensation with SAF. THD is compared for DC bus VSI, controlled by PI and PID technique. Values before and after compensation are tabulated respectively. For easy and read reference, the result of phase A for both techniques are given in Table 3.

	THD Without Shunt Active Filters	THD With Shunt Active Filters
Phase A	23.39%	7.16%
Phase B	23.40%	3.62%

Table 3: THD for Phase A with PI & PID technique

From Table 3 it can be see, THD before compensation is same for phase A at time 0.03 seconds. SAF is connected through three phase circuit breaker, at time 0.05 seconds. After compensation the THD for phase A, using PI controller is 7.16%. In case of PID controller it is 3.62%. Thus the THD using PID control technique is better that PI control. Fig.13 shows the source current waveform for phase A realizing PI technique. Fig.14 shows the source current waveform for A realizing PID technique.

It can be observed from Fig.13-14, the source current after compensation is closer to sinusoidal signal in case of PID controlled DC bus VSI compared to PI controlled VSI.



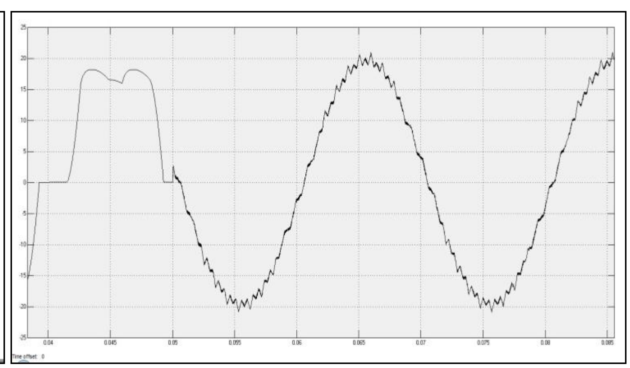


Fig.12 Source current waveform realizing PI technique

Fig.13 Source current waveform realizing PID technique

7. Conclusion

In this paper, the performance of AF with PI and PID control technique for three leg VSI is realized. The THD before compensation is same for all phases with PI and PID controller. The THD after compensation for PID controller is better than PI controller. Thus SAF with PID control technique is suitable to reduce the THD in source current.

8. References

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