Shunt Active Power Filter Control by Instantaneous Reactive Power Compensation

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Abstract*— This paper presents a three-phase Shunt Active Power filter (SAPF) with PI control capacitor voltage regulation technique. In order to mitigate current harmonics in the source current Shunt Active Power filter is used. Quality power must be provided for safety, better operation of modern appliances and electric drives. In the modern world most of the automation works uses robots, drives which uses large number of switches. These loads in turn behave as nonlinear loads. These loads take non-sinusoidal currents introducing harmonics in the supply mains. Due to these nonlinear loads harmonics will be injected in the source current and it wont be pure sinusoidal anymore. Voltage source Inverter based Shunt Active Power filter is used for mitigation of harmonics and the DC link capacitor is used as energy source element connected across the Shunt Active Power Filter. Instantaneous Reactive Power theory(IRP) is used to control the operation of Shunt APF. By designing simulation block diagrams in the Matlab/Simulink the percentage of Total Harmonic Distortion(%THD) is calculated and found to be satisfactory.

Keywords— Harmonics, Shunt APF, IRP theory, VSI

I.INTRODUCTION

In recent years both power engineers and consumers have been giving focus on the "electrical power quality" i.e. degradation of voltage and current due to harmonics, low power factor etc. Nearly two decades ago majority loads used by the consumers are passive and linear in nature, with a few non-linear loads thus having less impact on the power system. However, due to technical advancement in semiconductor devices and easy controllability of electrical power, non-linear loads such as SMPS, rectifier, chopper etc. are more used. The power handling capacity of modern power electronics devices such as power diode, silicon controlled rectifier (SCR), Insulated gate bipolar transistor (IGBT), Metal oxide semiconductor field effect transistor (MOSFET) are very large, so the application of such semiconductor devices is very popular in industry as well as in domestic purpose. Whilst these advantages are certainly good but there lies of such excessive use of power electronic devices a great problem, i.e. generation of current harmonics and reactive power in the power system network. As a result, the voltage at different buses of power system network is getting distorted and the utilities connected to these buses are not operated as designed. The harmonic current pollute the power system causing problems such as transformer overheating, voltage quality degradation, rotary machine vibration, destruction of electric power components and malfunctioning of medical facilities etc. To provide clean power at the consumer-end active power filter (APF) is used. Fig.1 shows a shunt active power filter connected to the power system at the point of common coupling (PCC).

Harmonic extraction is the process in which, reference current is generated by using the distorted waveform. Many theories have been developed such as p-q theory (instantaneous reactive power theory), d-q theory, PLL with fuzzy logic controller, neural network etc... Out of these theories, more than 60% research works consider using p-q theory and d-q theory due to their accuracy, robustness and easy calculation. [1-3]

II.SHUNT ACTIVE POWER FILTER

To reduce the harmonics conventionally passive L–C filters were used and also capacitors were employed to improve the power factor of the ac loads. But the passive filters have several drawbacks like fixed compensation, large size and resonance problem. To mitigate the harmonics problem, many research work development are developed on the active power (APF) filters or active power line conditioners. Ideally Source current must be pure sinusoidal and harmonic less. In order to obtain this condition Shunt APF is used to compensate harmonics in the supply current. Shunt APF supplies compensating current in phase opposition to all harmonics present in supply current. In this Voltage source inverter based Shunt APF dc link capacitor is connected across APF which is used as energy source element.

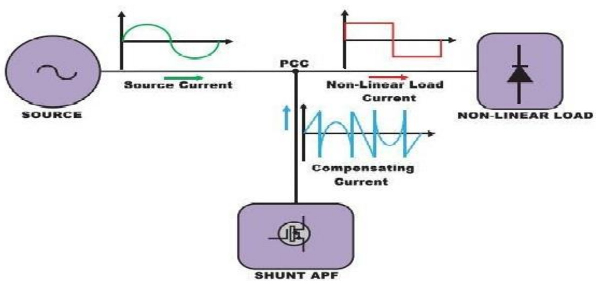

Fig 1: Shunt Active Power Filter

The Shunt APF connected in parallel to supply system protects utility from harmonics generated by non-linear load. It can be used to provide reactive power to the load as well. Shunt Active Power Filters are mainly operated as harmonic isolator between nonlinear load and utility system. The overall system

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can be described by equation (1). Shunt Active Power Filters are mainly operated as harmonic isolator between nonlinear load and utility system. [4-5]

$$I_S = I_L + I_C \tag{1}$$

I_S:- Source current, I_L:- Load current

I_C - Compensating current in phase opposition to harmonics in load current

The IRP theory is used for control of Shunt APF. The control algorithm has to do the work of pulse generation as well as capacitor voltage regulation at a time. So a controller is used for maintaining capacitor voltage equal to reference voltage. Hysteresis PWM is used for pulse generation for inverter operation.

III. INSTANTANEOUS REACTIVE POWER THEORY

Akagi proposed a theory based on instantaneous values in three phase power system with or without neutral wire, and is valid for steady-state or transient operations, as well as for generic voltage and current waveforms called as Instantaneous Power Theory or Active- Reactive (p-q) theory which consists of an algebraic transformation (Clarke transformation) of the three-phase voltages in the a-b-c coordinates to the α-β-0 coordinates, followed by the calculation of the p-q theory instantaneous power components. The theory is based on a transformation from the phase reference system 1-2-3 to the 0-α-β system. [6]

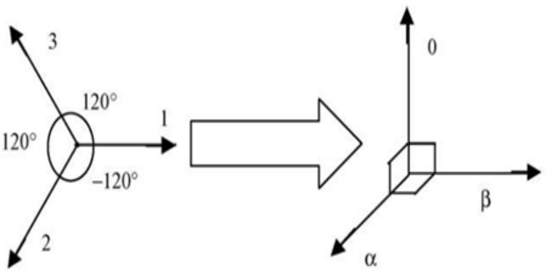

Fig 2: 0-α-β reference system

Instantaneous three-phase load currents and source voltages are transformed to 0-α-β coordinates shown in below equations :

$$\begin{bmatrix} V_0 \\ V_\alpha \\ V_\beta \end{bmatrix} = \sqrt{2}/\sqrt{3} \begin{bmatrix} 1/\sqrt{2} & 1/\sqrt{2} & 1/\sqrt{2} \\ 1 & -1/2 & -1/2 \\ 0 & \sqrt{3}/2 & -\sqrt{3}/2 \end{bmatrix} \begin{bmatrix} V_{S1} \\ V_{S2} \\ V_{S3} \end{bmatrix} \tag{2}$$

$$\begin{bmatrix} I_0 \\ I_\alpha \\ I_\beta \end{bmatrix} = \sqrt{2}/\sqrt{3} \begin{bmatrix} 1/\sqrt{2} & 1/\sqrt{2} & 1/\sqrt{2} \\ 1 & -1/2 & -1/2 \\ 0 & \sqrt{3}/2 & -\sqrt{3}/2 \end{bmatrix} \begin{bmatrix} I_1 \\ I_2 \\ I_3 \end{bmatrix} \tag{3}$$

Source side instantaneous real and imaginary powers are

$$\begin{bmatrix} P \\ Q \end{bmatrix} = \left[\begin{bmatrix} V_\alpha & V_\beta \\ -V_\beta & V_\alpha \end{bmatrix} \right] \begin{bmatrix} I_\alpha \\ I_\beta \end{bmatrix} \tag{4}$$

$$\mathrm{P} = V_\alpha * I_\alpha + V_\beta * I_\beta$$

$$\mathrm{P} = P_f + P_h \tag{5}$$

Power comprises of positive sequence P_f and negative sequence component with harmonic component P_h.

As dc link capacitor is used as energy source for shunt APF Power loss across capacitor is considered. We have to regulate voltage across capacitor.

$$P_{loss} = V_{dc} * I_{dc\_ref} \tag{6}$$

Where V_{dc} is voltage across capacitor and I_{dc} is current set by controller.
The reference currents in 0-α-β coordinates are

$$\begin{bmatrix} I'_\alpha \\ I'_\beta \end{bmatrix} = 1/(V_\alpha^2 + V_\beta^2) \begin{bmatrix} V_\alpha & -V_\beta \\ V_\beta & V_\alpha \end{bmatrix} \begin{bmatrix} P_F + P_{loss} \\ 0 \end{bmatrix} \tag{7}$$

These reference currents in 0-α-β coordinates are transformed into three phase by equation 8.

$$\begin{bmatrix} I_1^* \\ I_2^* \\ I_3^* \end{bmatrix} = \frac{\sqrt{2}}{\sqrt{3}} \begin{bmatrix} 1 & 0 \\ -\frac{1}{2} & \frac{\sqrt{3}}{2} \\ -\frac{1}{2} & -\frac{\sqrt{3}}{2} \end{bmatrix} \begin{bmatrix} I'_\alpha \\ I'_\beta \end{bmatrix} \tag{8}$$

These reference currents are compared against actual load currents.The difference is given to Hysterisis Band PWM, which generates appropriate pulses for operation of shunt APF.

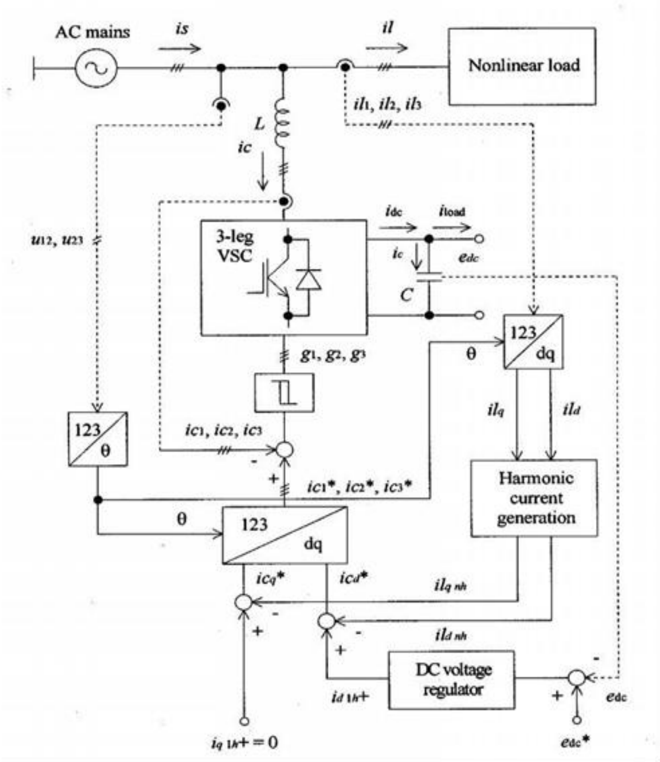

Fig 3: Shunt APF Reference current generation

IV. CAPACITOR VOLTAGE REGULATION METHOD

For better operation of Shunt APF, the voltage across DC link capacitor should be maintained constant at reference DC voltage. So, a regulator or controller to maintain voltage across capacitor is required. The controller is discussed in this paper a PI controller.

PI CONTROLLER

The control scheme comprises of PI controller, limiter, and three phase sine wave generator for reference current generation and generation of switching signals. The peak value of reference currents is studied by regulating the DC link voltage. Fig.4 shows the schematic representation of the control circuit.

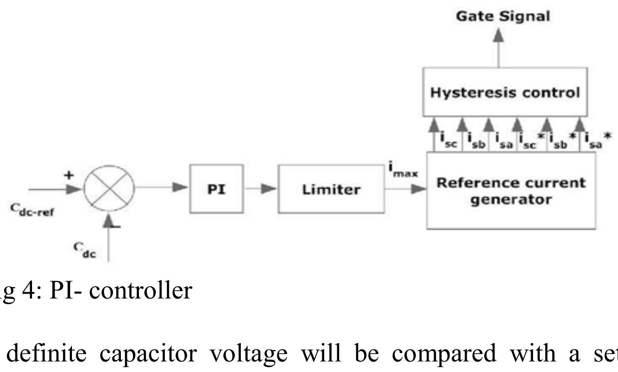

Fig 4: PI- controller

The definite capacitor voltage will be compared with a set reference value. The error signal is then fed through a PI controller, which gives to zero steady error in tracking the reference current signal. The output of the PI controller is presumed as peak value of the supply current (Imax), which is composed of two components: (a) fundamental active power component of load current, and (b) loss component of APF; to preserve the average capacitor voltage to a constant value. Peak value of the current (Imax) so found, will be multiplied by the unit sine vectors in phase with the individual source voltages to obtain the reference compensating currents. These expected reference currents (Isa*, Isb*, Isc*) and detected actual currents (Isa, Isb, Isc) are equated at a hysteresis band, which delivers the error signal for the modulation technique. This error signal chooses the operation of the converter switches. In this current control circuit configuration the source/supply currents Is_{abc} are made to follow the sinusoidal reference current I_{abc}, within a fixed hysteretic band. The width of hysteresis window regulates the source current pattern, its harmonic spectrum and the switching frequency of the devices. The DC link capacitor voltage is always preserved constant during the operation of the converter. In this scheme, each phase of the converter is measured independently. To increase the current of a particular phase, the lower switch of the converter related with that particular phase is turned on while to decrease the current the upper switch of the corresponding converter phase is turned on. With this one can recognize, potential and viability of PI controller.[7-9]

V. SIMULATION RESULTS

The Shunt APF block diagram is simulated in MATLAB/Simulink software and the performance of Shunt APF can be evaluated under the distorted load conditions. Shunt APF system parameters are shown in the table.1.The performance of Shunt APF are calculated by PI control voltage regulation method. The performance of this controller are shown for unbalance load diode bridge rectifier.

TABLE 1: Shunt APF System Parameters

Parameters	Rating
Source	400
Dc Link capacitor	700V,1100µF
DC side load Resistance	30Ω
DC side load Inductance	10mH
Shunt APF side coupling Inductance	3mH

Matlab/Simulink results of PI control for the Shunt APF were shown below:

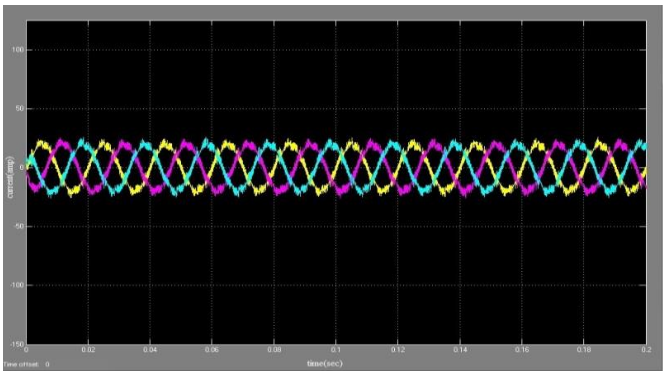

Figure 5: PI control Source current

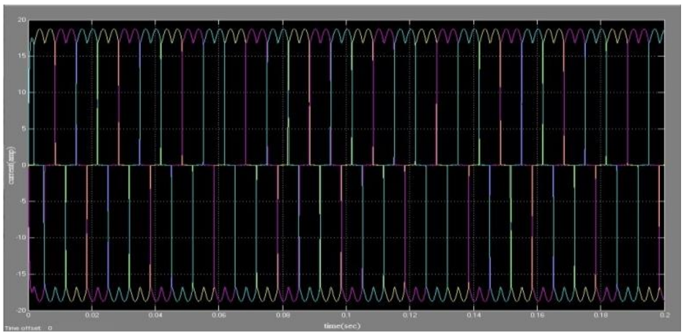

Figure 6: PI control Load current

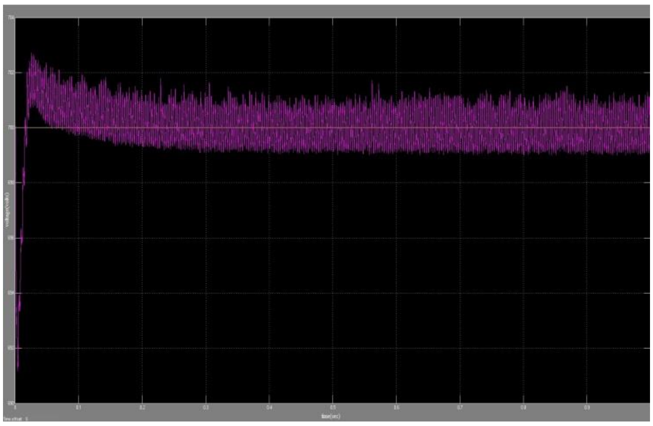

Figure 7: PI control voltage regulation

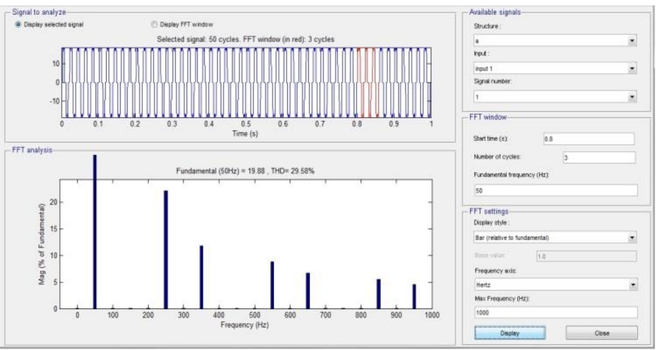

Fig. 8: %THD of Source current without Shunt APF

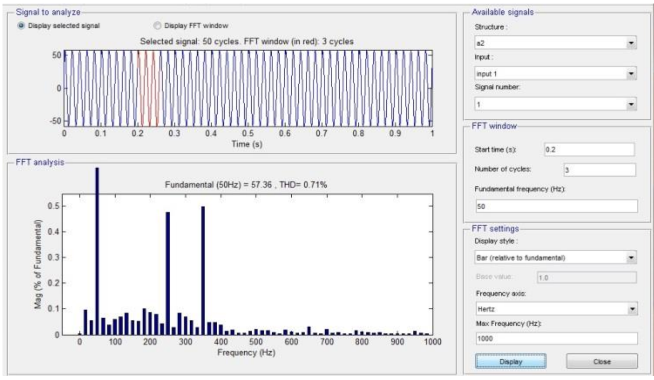

Fig. 9: %THD of Source current by PI control

VI. Conclusion

In this paper simulation was carried out through PI controller, by regulating the voltage across capacitor for Shunt APF. Maintaining constant voltage across the Dc link capacitor and mitigating the harmonics in the source current by the the controller is done. The %Thd of source current before compensation without Shunt APF is 29.58. By connecting Shunt APF it is reduced to 0.71 by PI control. Thus the Source current is compensated or harmonics are mitigated to the maximum extent by connecting Shunt APF.

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VIII. REFERENCES

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