SIMULATION & ANALYSIS OF SHUNT ACTIVE FILTER FOR POWER QUALITY IMPROVEMENT

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Abstract– Currently wide spread of power electronic equipment has caused an increase of the harmonic disturbances in the power systems. Current harmonics generated by nonlinear loads such as adjustable speed drives, static power supplies and UPS. The harmonics causes problems in power systems and in consumer products such as equipment overheating, capacitor blowing, motor vibration, low power factor. Conventionally, passive LC filters and capacitors have been used to eliminate line current harmonics and to compensate reactive power by increasing the power factor. But these filters have the disadvantages of large size, resonance and fixed compensation behavior. Without the drawbacks of passive harmonic filter, the shunt active power filter appears to be a viable solution for eliminating harmonic currents and current transient condition. Shunt active power filter compensates current harmonics injecting equal and opposite harmonic compensating current. In this paper a three-phase three wire shunt active filter under distorted load conditions, the power quality problems are compensate through a synchronous reference frame (SRF) and hysteresis controller based control method. The proposed SAF system can improve the power quality at the point of common coupling (PCC). The simulation results based on MATLAB Simulink are discussed in detail to support the SRF and hysteresis controller based control method presented in the paper.

Keywords: Shunt Active power Filter (SAPF), Hysteresis current controller, a synchronous reference frame (SRF).

I. INTRODUCTION

The electric power system is considered to be self-possessed of three functional blocks – transmission, generation, distribution. Generation of harmonics from non-linear loads, such as switch mode power converters and adjustable speed drives, as well as other unbalanced loads in distribution networks deteriorate power quality in power transmission and distribution systems. Nonlinear loads increase losses and produce harmonic distortion in the grid. As a consequence, poor power quality causes various problems in both the power grid and connected equipment. This harmonic distortion can be mitigated using passive filters. However, the use of traditional compensation with capacitor banks and passive filters produces harmonic propagation and harmonic voltage amplification, due to possible resonance between line inductance and shunt capacitors. Thus, passive filters cannot always offer a complete compensation solution. As an alternative, different active filter solutions have been continuously analyzed in recent years. A conventional (APF) is typically composed of three single phase inverters and pulse width modulation (PWM) and can be attached to the load either in parallel or in series [1].

The concept about active power filter to mitigate harmonic problems and to compensate reactive power was offered more than two years ago [2, 4]. Since then, the concepts and application of active power filters have become more widespread and have involved great attention [5].

Another solution is the use of selective harmonic control, where the APF bandwidth is tuned so that the harmonic currents are individually controlled. This allows the APF to mitigate the central harmonic currents, with the advantage of using a moderate switching frequency. Therefore, the APF can be tuned to selectively compensate only the characteristic harmonic currents, which are normally applied by a typical three-phase rectifier [1]. To solve these issues of design the APF (Active Power Filter) currents compensation is based on the requirement that the source currents after compensation must be sinusoidal and balanced or meet harmonic current distortion limits set by IEEE-519 standard and allowable levels of the source current imbalance [1].

II. SHUNT ACTIVE POWER FILTER

The shunt active power filter (APF) is a device that is connected in parallel to and cancels the reactive and harmonic currents from a nonlinear load. The resulting total current drawn from the ac main is sinusoidal. Ideally, the APF needs to generate just enough reactive and harmonic current to compensate the nonlinear loads in the line.

In an APF, a current controlled voltage source inverter is used to generate the compensating current (i_C) and is injected into the utility power source grid. This cancels the harmonic components drawn by the nonlinear load and keeps the utility line current (i_S) sinusoidal. A variety of methods are used for instantaneous current harmonics detection in active power filter such as synchronous reference frame (SRF), FFT (fast Fourier technique) technique, instantaneous p-q control theory or by using suitable analog or digital electronic filters separating successive harmonic components

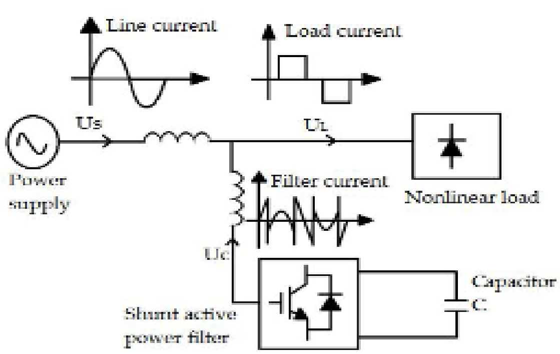


Figure-1: shunt active filter [1]

Figure 1. Shows a system configuration of a single-phase or three-phase shunt active filter is mainly used for compensate various types of current related problems. The shunt active filter is also consists of shunt converter with dc capacitor and shunt inductor. Shunt inductor (LSH) is mainly used to interface shunt converter into the network and also help in smoothing the current wave shape [1] [3].

III. DESCRIPTION OF SYNCHRONOUS REFERENCE FRAME (SRF)

The shunt active filter based on SRF method can be used to solve the current related power quality problems which are mainly generated by nonlinear load. The SRF method is used in shunt active filter for generating reference current signal [7]. The source currents (I_{Sabc}) are transform into d-q-0 which is given in below equation.

$$\begin{bmatrix} I_d \\ I_q \\ I_0 \end{bmatrix} = \sqrt{\frac{2}{3}} \begin{bmatrix} \sin(\omega t) & \sin\left(\omega t - \frac{2\pi}{3}\right) & \sin\left(\omega t + \frac{2\pi}{3}\right) \\ \cos(\omega t) & \cos\left(\omega t - \frac{2\pi}{3}\right) & \cos\left(\omega t + \frac{2\pi}{3}\right) \\ \frac{1}{\sqrt{2}} & \frac{1}{\sqrt{2}} & \frac{1}{\sqrt{2}} \end{bmatrix} \begin{bmatrix} I_{Sa} \\ I_{Sb} \\ I_{Sc} \end{bmatrix}$$

Figure 2. shows the control block diagram of shunt active filter based on d-q theory. For reference current calculation the SRF based method uses source voltages, source currents and dc link voltages as shown in figure 7. The phase locked loop (PLL) is used to generate the transformation angle (ωt) which presents the angular position of the reference frame. Figure 3. Shows the Simulink diagram of d-q theory for generating current reference signal in shunt active filter.[7]

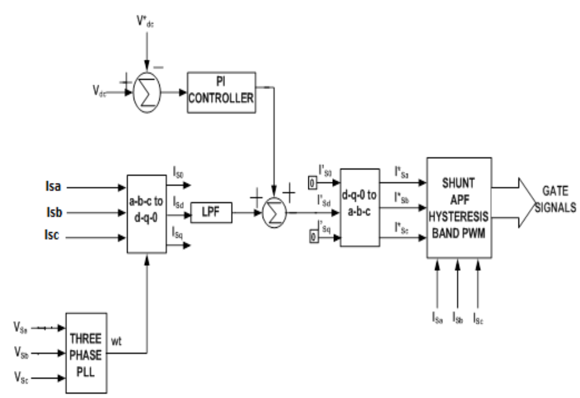


Figure 2. Control block diagram of d-q theory in shunt active filter

The inverse park transformation is used for generating reference current signal which is given in below equation is convert the reference source current (ISabc) are transform d-q-0 into a-b-c which is given in below equation.

$$\begin{bmatrix} I'_{La} \\ I'_{Lb} \\ I'_{Lc} \end{bmatrix} = \sqrt{\frac{2}{3}} \begin{bmatrix} \sin(\omega t) & \cos(\omega t) & \frac{1}{\sqrt{2}} \\ \sin\left(\omega t - \frac{2\pi}{3}\right) & \cos\left(\omega t - \frac{2\pi}{3}\right) & \frac{1}{\sqrt{2}} \\ \sin\left(\omega t + \frac{2\pi}{3}\right) & \cos\left(\omega t + \frac{2\pi}{3}\right) & \frac{1}{\sqrt{2}} \end{bmatrix} \begin{bmatrix} I_d \\ I_q \\ I_0 \end{bmatrix}$$

IV. CONTROL TECHNIQUE OF PROPOSED SYSTEM

Generally Control strategy of Active filter is the heart of the active filter and it is implemented in three different steps [1]:

Step 1: In the first step, the necessary voltage and current signals are sensed using PT's, current transformers (CT's), and hall-effect sensors.

Step 2: In the second step, compensating commands signals in expressions of current or voltage levels are derived based on control methods and active filter configurations.

Step 3: In the last step, the gating signals for the solid-state devices of the active filter are created using hysteresis, pulse-width modulated control techniques.

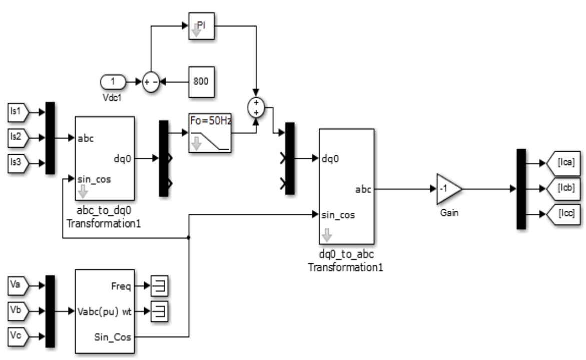


Figure 3. Simulink Model of SRF method

V. HYSTERESIS CONTROL TECHNIQUE FOR SHUNT ACTIVE FILTER

There are various types current controlled pulse width modulation (PWM) techniques available among all of them hysteresis controllers offer inherent simplicity in implementation and excellent dynamic performance. Hysteresis-band PWM is basically an instantaneous feedback current control technique of PWM where the actual current continually tracks the command current within a fixed hysteresis band. Figure 5. explains the operation principle of hysteresis band PWM for a half bridge inverter. The control circuit generates the sine reference current wave of desired magnitude and frequency, and it is compared with actual current wave.

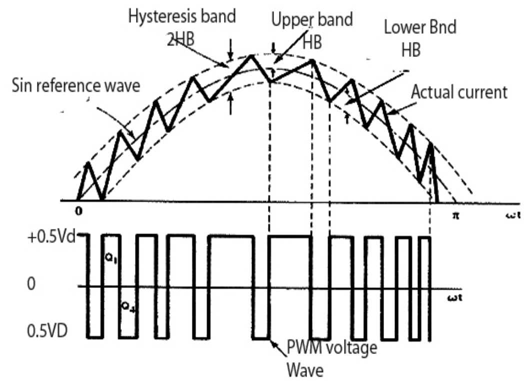


Figure 4. Hysteresis current control technique

As the current exceeds an upper hysteresis band, the upper switch in half bridge is turned off and lower switch is turned on. As a result, the output voltage transition from +0.5 Vd, and -0.5Vd, and the current starts to decay. In same way as current crosses the lower band limit, the lower switch is turned off and the upper switch is turned on. The main disadvantage of this method is variable switching frequency. To solve the problem of variable switching frequency so, adaptive hysteresis current control technique is applied [6]. The switching frequency is not fixed in hysteresis current control technique, so, it was introduced the concept of the average switching frequency. The hysteresis band current control for active power filter is used to generate the switching pattern of the inverter. There are various current control methods proposed for active power filter configurations; but the hysteresis current control method is proven to be the best among other current control methods, because of quick current controllability, easy implementation and unconditioned stability. The hysteresis band current control is robust, provides excellent dynamics and fastest control with minimum hardware [6] [8].

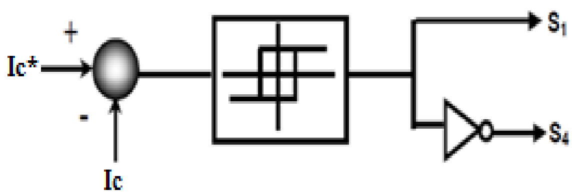


Figure 5. Hysteresis current control technique

Figure 5. Shows the comparison between the reference source current (I*S) and sensed source current (IS) and the generating error is given to hysteresis band which generates switching instants of shunt current source converter. Figure 6. Shows the Simulink diagram of hysteresis current controller.

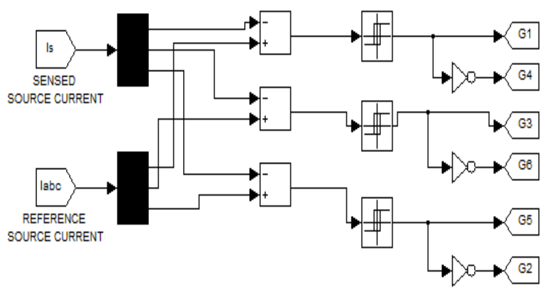


Figure 6. Simulink diagram of hysteresis current controller

The reference current to be injected by the shunt active filter is referred as I_S^* and the actual current of the shunt active filter is referred asI_S. The control scheme decides the switching pattern of shunt active filter in such a way to maintain the actual source current of the filter to remain within a fixed hysteresis band (HB) as indicated in figure 6.

The switching logic is formulated as follows:

$$I_S = I_S^* - HB \quad (1)$$

$$I_S = I_S^* + HB \quad (2)$$

Where, I_S = actual source current

I_S^* = reference source current

HB = Hysteresis band and S1, S2, S3, S4 are switches of voltage source inverter. During condition of equation (1) switches S1, S2 ON & S3, S4 OFF and during condition of equation (2) switches S1, S2 OFF & S3, S4 ON

From above discussion note that the switching frequency of the hysteresis current control technique described above depends on how fast the current changes from upper limit to lower limit of the hysteresis band. Therefore, the switching frequency does not remain constant throughout the switching operation, but varies along with the current waveform.

VI. ROLE OF DC SIDE CAPACITOR

The DC side capacitor serves two main purposes [10]: (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 the transient period. In the 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 satisfactory operation or 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 or 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 the 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 has been verified from the simulation results.

The real/reactive power injection may result in the ripple voltage of the DC capacitor. A low pass filter is generally used to filter these ripples, which introduce a finite delay. To avoid the use of this low pass filter the capacitor voltage is sampled at the zero crossing of the source voltage. A continuously changing reference current makes the compensation non-instantaneous during transient. Hence, this voltage is sampled at the zero crossing of one of the phase voltage, which makes the compensation instantaneous. Sampling only twice in cycle as compared to six times in a cycle leads to a slightly higher DC capacitor voltage rise/dip during transients, but settling time is less.

The design of the power circuit includes three main parameters:

• Selection of filter inductor, Lc.
• Selection of DC side capacitor, Cdc.
• Selection of reference value of DC side capacitor voltage, Vdcref.

VII. CONSTRUCTION OF PI CONTROLLER

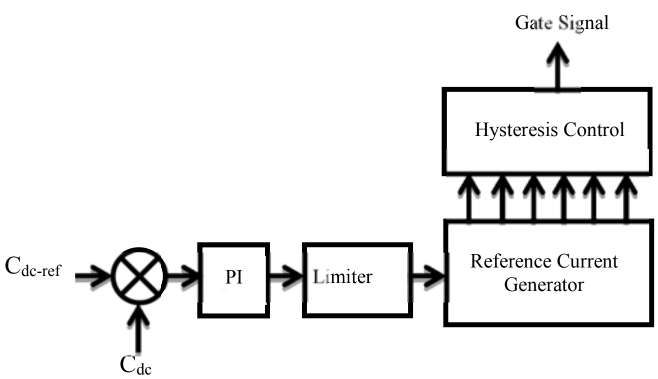


Figure 7. Block representation of PI controller

Figure 7. shows the schematic representation of the control circuit. 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. 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 Isabc are made to follow the sinusoidal reference current Iabc, 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 [9].

VIII. SIMULATION MODEL

In this section, the simulation result of series APF is shown.

The developed model of series APF

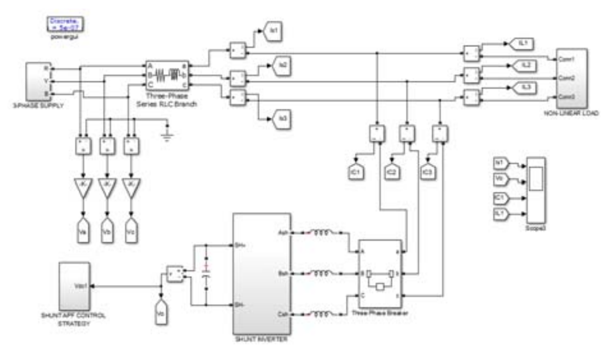
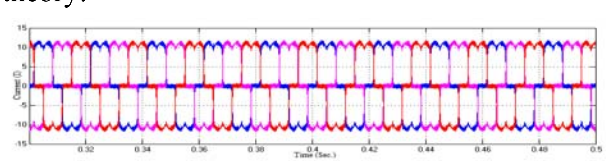


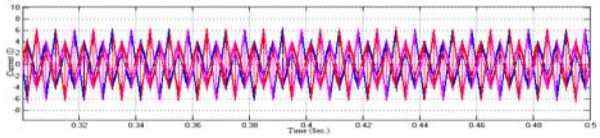
Figure 8. Simulation Model

IX. SIMULATION RESULTS

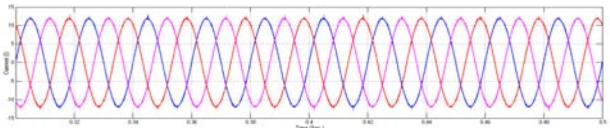
Simulation results and FFT analysis of shunt active filter using synchronous reference frame control theory:



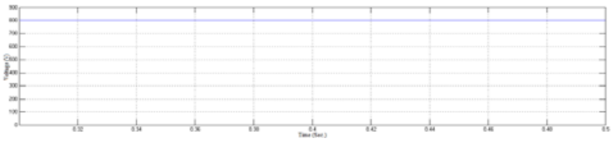
(a)



(b)

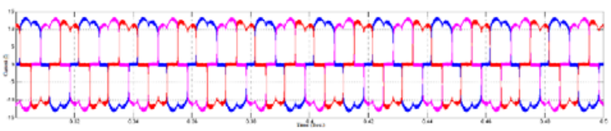


(c)

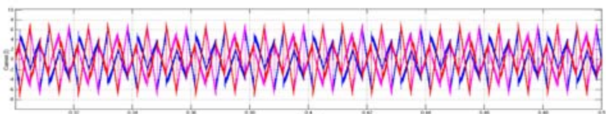


(d)

Figure-9: Balanced Voltage Condition (a) Load Current (b) SAPF Injected Current (c) Source Current (d) DC Source Voltage



(a)



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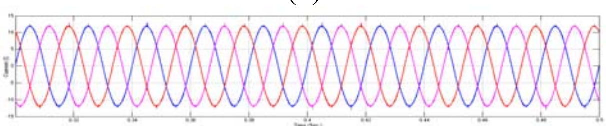

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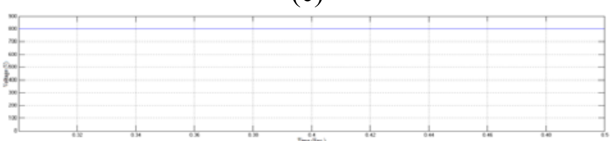
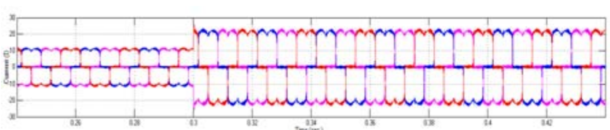
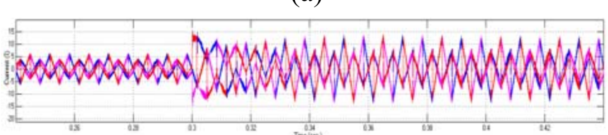


(d)

Figure-10: Unbalanced Voltage Condition (a) Load Current (b) SAPF Injected Current (c) Source Current (d) DC Source Voltage



(a)



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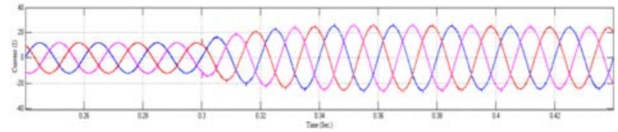

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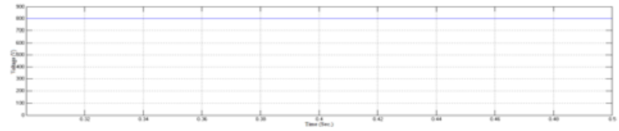

(d)

Figure-11: Transient Current Condition (a) Load Current (b) SAPF Injected Current (c) Source Current (d) DC Source Voltage

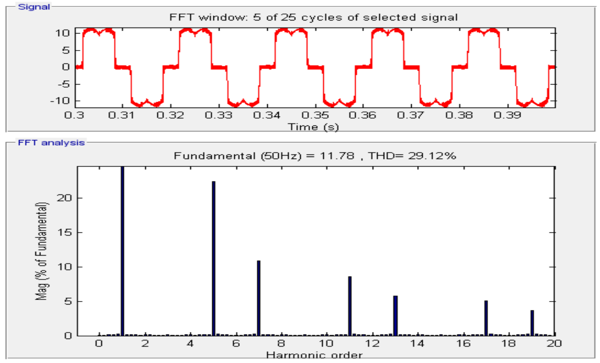

Figure 12.THD=29.12 % of Load Current

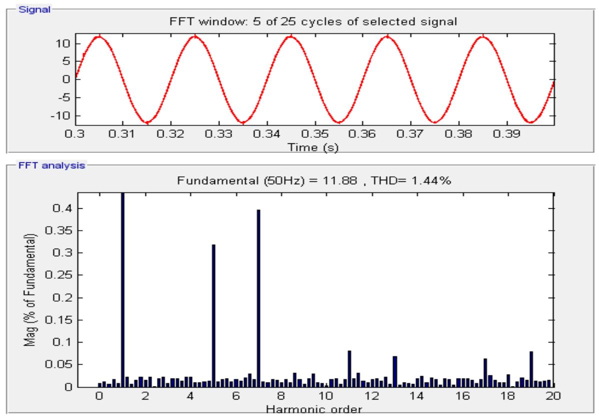

Figure 13.THD=1.44 % of Source Current

Table-1.Simulation results and THD level of Current waveforms at the PCC

X. CONCLUSION

From the above literature survey, we can conclude

System Condition	Phase		Before Shunt Compensation		After Shunt Compensation	
			Current THD (%)	RMS	Current THD (%)	RMS
Balanced Voltage (V)	A		29.12	8.67	1.44	8.40
	B		29.05	8.69	1.41	8.40
	C		28.98	8.68	1.40	8.40
Unbalanced Voltage (V)	A		25.73	8.57	1.60	7.92
	B		29.13	8.10	1.53	7.74
	C		33.80	7.41	1.51	7.82
Transient Current Condition	Low Load Condition	A	29.23	8.67	2.79	8.40
		B	29.06	8.69	3.36	8.40
		C	29.08	8.68	3.29	8.40
	High Load Condition	A	29.34	17.3	2.73	16.7
		B	29.47	17.3	2.73	16.7
		C	29.79	17.3	2.71	16.7

that the shunt active power filters represent an efficient solution for the mitigation of harmonics created by non-linear loads. Generally in three-phase three-wire system, a shunt active power filter can use as their power circuit a voltage source converter which is equipped with a dc capacitor, because the Voltage source converter is more favorable than Current source converter in terms of cost, small in size, and efficiency. The IGBT switch module are used in the shunt active power filter which does not need to provide capability of reverse blocking due to a anti parallel diode is connected in itself. Here the Unit Vector template Generation method is used as the control strategy of shunt active power filter, in which the synchronous reference frame from the distorted input supply. It is concluded that the current harmonics can be compensated very effectively using synchronous reference frame (SRF) technique.

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