Implementation of Three phase Shunt Hybrid Filter Using ICOSϕAlgorithm

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Abstract– This paper presents a hybrid filter configuration to suppress harmonic current distortion in the source current. It is a combination of shunt active power filter and shunt passive filter. Major amount of harmonic currents generated by the nonlinear load are bypassed through the passive filter and the active power filter supplies the remaining harmonics and reactive power. Thus the power rating of the shunt active power filter can be reduced in the hybrid configuration compared with pure active filter configuration. The effectiveness of the adopted topology and control scheme has been verified by simulation and experimental results under various source/load conditions.

Keywords– Hybrid filter, Power quality, Harmonic compensation.

I. INTRODUCTION

A large number of solid state power converters such as diode bridge rectifiers and thyristor converters are used in industrial applications and transmission/distribution networks. All these breeds of power converters are nonlinear in nature and cause serious problems of current harmonics, poor power factor, non sinusoidal supply voltage, reactive power burden and low system efficiency. Hence, due to these serious issues there has been an increasing interest in the subject of power quality improvement techniques which can suppress supply harmonics, improve power factor and balance the input supply [1].

Many circuit configurations of filters have been suggested to limit harmonic current distortion. Passive filters which act as least impedance path to the tuned harmonic frequencies were used initially to reduce harmonics. This technique is simple and less expensive. But it has many drawbacks such as resonance, fixed compensation characteristics, bulky size, high no load losses etc. As a better option of complete compensation of distortions, active power filters [2, 3] have been researched and developed. Active filters overcome drawbacks of passive filter by using the switched mode power converter to perform complete harmonic current elimination. Shunt active power filters are developed to suppress the harmonic currents and reactive power compensation simultaneously by suitable control techniques to generate a compensating current in equal and opposite direction so that source current becomes harmonic free[2,4].

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However, the power rating and construction cost of active power filters in a practical industry is too high. To avoid this limitation, hybrid filter topologies have been developed. Using low cost passive filters with the active filter, the power rating of active converter is reduced compared with that of pure active filters. This hybrid filter retains the advantages of active filters and passive filters. Also hybrid filters are cost effective and become more practical in industry applications [5-9].

In this paper, the hybrid filter structure consisted of an active filter and a passive filter, connected in shunt is used for power quality improvement. The effectiveness of the hybrid filter configuration was verified with simulation and experimental results. The results prove that the proposed method can effectively eliminate harmonic currents, balance source currents, compensate reactive power i.e. in other words; power quality improvement of the power system is achieved by the proposed hybrid filter structure and control method.

II. STRUCTURE OF HYBRID FILTER CONFIGURATION

The hybrid filter structure consists of shunt passive filter and shunt active filter. Shunt passive filter is a series combination of a capacitor and a reactor tuned to a specific harmonic frequency. It provides low impedance trap to harmonic to which the filter is tuned, usually to lower order harmonics because the major contribution of harmonics is due to lower order harmonics. Remaining higher order harmonics only are to be filtered by shunt active filter; hence its power rating can be reduced. A three phase voltage source inverter (VSI) is used as the shunt active filter. The hybrid filter is connected in parallel with the nonlinear load. The diagram of hybrid filter structure is shown in the fig.1.

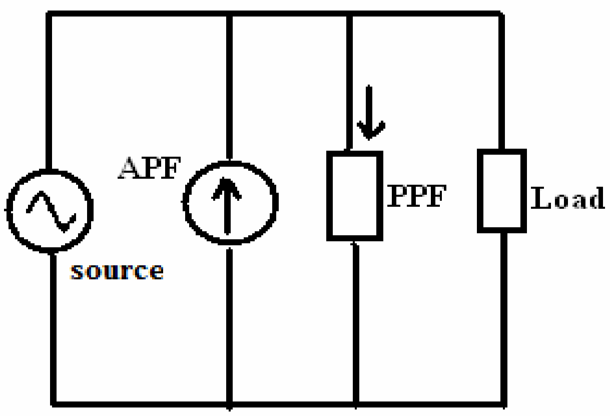


Fig.1. The shunt hybrid filter structure

The nonlinear loads considered in this study are three phase diode bridge rectifier and three phase thyristor converter. A proportional integral voltage controller is used to maintain the constant dc link voltage of the inverter. A hysterisis current comparator is used to track the output current to generate proper PWM pulses to the inverter.

III. CONTROL STRATEGY OF SHUNT ACTIVE FILTER

Various control algorithms were developed in literature such as instantaneous reactive power theory, synchronous detection, dc bus voltage algorithm etc [2]. The instantaneous reactive power theory and synchronous detection algorithm operates satisfactorily under balanced conditions only. In this work, ICOSΦ algorithm is used which is tested satisfactorily under distorted and transient conditions[4,10,11].The shunt active filter uses $ICOS\phi$ algorithm, In $ICOS\phi$ algorithm, mains required to supply only the real component of the load current, remaining parts of load current – reactive component and harmonics – is to be supplied by the active filter [4]. The extraction of real component of load current can be done as follows:

The load current contains fundamental component and harmonic components. The lower order tuned frequency components are filtered by the passive filters. Remaining harmonic components are filtered with active filter. These harmonics are sensed with the help of low pass (biquad) filter. Its output is fundamental component delayed by 90° (i.e. $i_m \sin(\omega t - \phi - 90°)$). At the time of negative zero crossing of the input voltage, i.e.,$\omega t = 180°$, instantaneous value of fundamental component of load current is $i_m \cos\phi$.The magnitude of the desired source current $\left|I_{s(ref)}\right|$ can be expressed as the magnitude of real component of the fundamental load current in the respective phases. i.e. for phase a it can be written as $\left|I_{s(ref)}\right| = \left|\mathrm{Re}(I_{La})\right|$.

The desired (reference) source currents in the three phases are given as,

$$i_{sa(ref)} = \left|I_{s(ref)}\right| \times U_a = \left|I_{s(ref)}\right|.\sin\omega t$$

$$i_{sb(ref)} = \left|I_{s(ref)}\right| \times U_b = \left|I_{s(ref)}\right|.\sin(\omega t - 120^0)$$

$$i_{sc(ref)} = \left|I_{s(ref)}\right| \times U_c = \left|I_{s(ref)}\right|.\sin(\omega t + 120^0) \qquad (1)$$

The compensation currents to be injected by the shunt active filter are the difference between the actual load currents and the desired source currents.

$$i_{a(comp)} = i_{La} - i_{sa(ref)}\ ; \quad i_{b(comp)} = i_{Lb} - i_{sb(ref)}\ ;$$

$$i_{c(comp)} = i_{Lc} - i_{sc(ref)}\ ; \qquad (2)$$

IV. SIMULATION RESULTS

As case studies, three phase diode bridge rectifier and three phase thyristor converter are considered as harmonic loads.

Case I: Diode bridge Rectifier Load

A three-phase 400 V, 50 Hz balanced supply is given to a 15kW AC-DC Diode bridge rectifier feeding a variable inductive load. The MATLAB model of the system is shown in Fig.2.

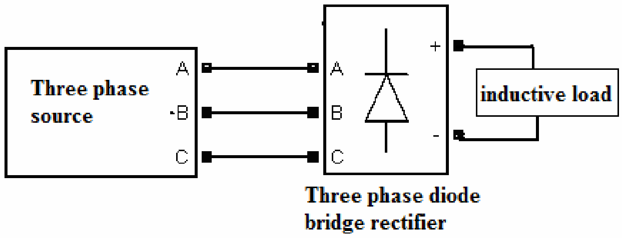


Fig.2: The three-phase system with diode bridge rectifier

A. Without filter:

The performance of diode bridge rectifier feeding an inductive load was studied without any filter in the system. The system was simulated under balanced source and balanced load conditions. The source current is highly distorted.

B. With passive filter:

The 5th and 7th order of shunt passive filters are designed to sink in respective harmonic currents. The capacitors for the passive filter are selected to supply the specified percentage of the reactive power requirement of the load. The MATLAB model of the system with passive filters is shown in Fig.3.

Table 1: Parameter values of passive filter

Harmonic	Resistor	Inductor	Capacitor
5^{th}	0.0314Ω	10mH	40µF
7^{th}	0.0160Ω	5.1mH	40µF

Table 1 gives the parameter values of passive filter components for compensation.

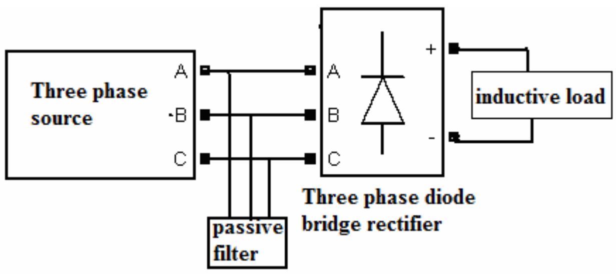


Fig.3: Simulation model of the three-phase system with Passive filter

The passive filter helps to reduce the major amount of distortions in source current. i.e., the passive filter sinks the 5th and 7th harmonic currents by providing a low impedance path.

C. With Active Filter

In the next stage, the simulation is repeated with the shunt active filter in the system. The circuit for ICOSφ [4] algorithm was simulated in MATLAB/SIMULINK and installed in the system. The MATLAB model of the system with active filters is shown in Fig.4.

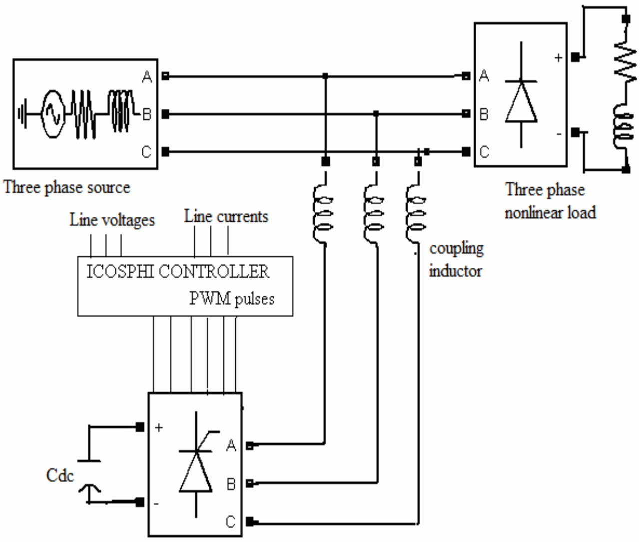


Fig.4: Simulation model of the three-phase system with I COSϕ controller based shunt active filter

Simulation results with addition of active filter are shown in Fig.5.The harmonics in source current is highly reduced and THD is within standard limits. The source voltage and source current are in phase and sinusoidal, and implies perfect reactive compensation. Certainly, it takes time delay more than 1 cycle for perfect compensation.

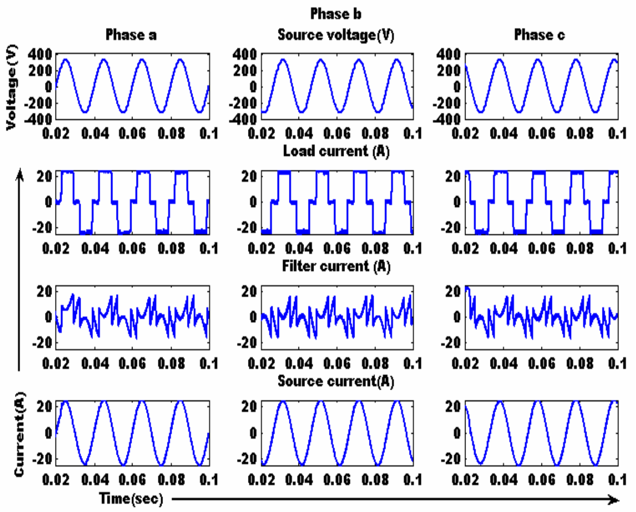


Fig.5: Source voltage and source current of three-phase system with shunt active power filter – for the diode bridge rectifier load.

C. With Hybrid Filter

Hybrid system uses a shunt passive filter to remove the lower order harmonics and a shunt active filter to remove the remaining harmonics and reactive power compensation. The shunt active filer uses the ICOSφ control algorithm. The fig.6 is the simulation model of the three phase system with hybrid filter.

The total harmonic distortion with hybrid filter is reduced to 0.47% and source current becomes in phase with source voltage. Fig.7 shows waveforms of source voltage, load current, source current waveforms of diode bridge rectifier load with hybrid filter.

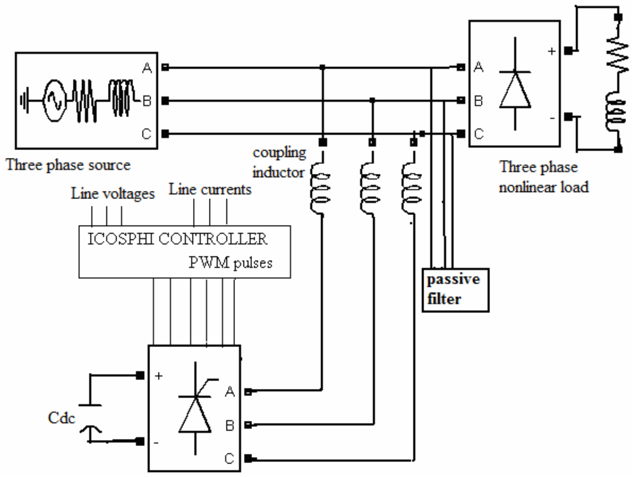


Fig.6: Simulation model of the three-phase system with Hybrid filter.

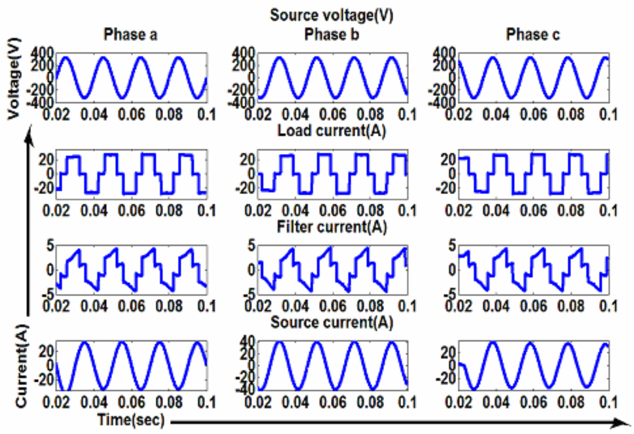


Fig.7: Source voltage, load current and source current of three-phase system with hybrid filter- for diode bridge rectifier load

The simulation results for diode bridge rectifier load are summarized in Table 2. The comparative study shows that hybrid filter much effectively reduces harmonic distortion in the source current with effective reactive power compensation. The performance of the shunt hybrid filter was verified experimentally with diode bridge rectifier.

Table 2: Performance of various filter configurations with diode bridge rectifier

Parameters	Without filter	With Passive filter	With Active filter	With Hybrid filter
Fundamental source current in rms (A)	16.87	21.47	17.04	18.55
THD in Source Current (%)	18.45	1.62	0.91	0.47

V. Analog Circuit Implementation of Hybrid Filter

A laboratory model of the shunt hybrid filter - ICOSϕ controller based shunt active filter and shunt passive filter - was set up for testing with the nonlinear load, three phase diode bridge rectifier. Fig.8 shows the hardware set up for the experiment. A voltage source inverter assembly, which consists of a three phase IGBT based inverter along with large DC link capacitor, is used as the shunt active filter. DC link capacitor of 1650mF / 800V is used to maintain steady voltage required by the inverter.

Fig.8. Hardware setup

The operations in the analog circuit can be explained as follows:

Step 1: The source voltages, load currents and active filter injection currents are sensed with hall effect voltage and current sensors.

Step 2: Detection of fundamental component of load current:

Low pass filtering by using biquad filter is done to extract fundamental component of load current. The advantages of using biquad filter, rather than other low pass filters, are it is easy to design, gives unity gain and exact 90° phase shift.

Step 3: Determination of real component of load current:

The circuit with the comparator and monostable multivibrator 74LS123 is used for getting sharp output pulses at the negative zero crossing of the phase voltage. These pulses and output of the biquad filter are fed to a sample and hold circuit to obtain instantaneous value of fundamental component of load current at negative zero crossing of source voltage, i.e., real part of load current .

Step 4: Obtaining desired source current waveforms:

The real component of load current is multiplied with unit sinusoidal waves to obtain desired source current waveforms, using AD 633 JN multiplier.

Step 5: Derive PWM pulses to inverter:

The reference compensation current is obtained by subtracting reference source current from load current. A comparator is used to compare reference compensation current and actual filter current. When reference filter current is more than actual filter current, output of the comparator is high and vice versa. The comparator is realized using op-amp 741 and IC 4049B. The isolation between power circuit and controller circuit is done using an optocoupler 6N136. The output pulses are amplified using transistor amplifier BC 547[4].

Based on reactive power requirement of the system under the rated load condition, passive LC filters are designed and inserted. The components of passive filters – inductor and capacitor – are designed for 6^{th} harmonic frequency, such that major amount of 5^{th} and 7^{th} harmonics can be eliminated with a single tuned passive filter.

VI. Experimental Study

The experimental results on a scaled down balanced three phase system connected to diode bridge rectifier feeding a resistive load (230V, 3kW) are presented in this section.

The passive filter is designed for 100% Var compensation and it is tuned to the sixth harmonic so as to avoid resonance condition and to sink both 5^{th} and 7^{th} harmonic currents to certain extent. This will reduce the size of the passive filter and hence the loading on the source also. In this case study, combination of passive filter elements used is 5mH-80µF.

The ICOSφ controller senses load current, supply voltage and generate PWM pulses to IGBT inverter. The shunt active power filter is connected to three phase supply at point of common coupling through 10mH, coupling reactance. The system was operated under various source/load conditions and the results are shown in the following section. The test results are analyzed using FLUKE make *power quality analyzer*.

A: Balanced Source Balanced Load

The hybrid power filter, combination of shunt active and shunt passive filters, reduces total harmonic distortion in source current.

Passive filter reduces the lower order (5^{th} and 7^{th}) harmonics and the shunt active power filter injects the remaining harmonics in source current.Relevant results are shown in Fig.9 and Fig.10.

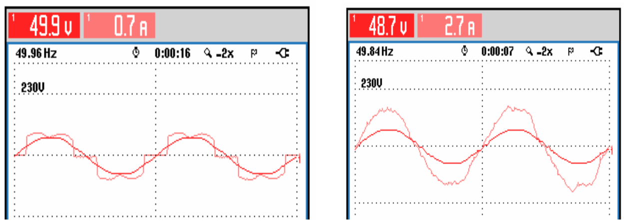
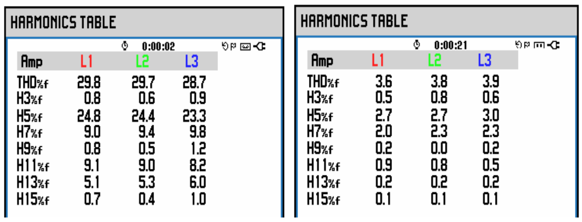


Fig.9: a-phase source voltage and source current
a) without hybrid filtering b) with hybrid filtering



HARMONICS TABLE (a) 0:00:02

Amp	L1	L2	L3
THD%f	29.8	29.7	28.7
H3%f	0.8	0.6	0.9
H5%f	24.8	24.4	23.3
H7%f	9.0	9.4	9.8
H9%f	0.8	0.5	1.2
H11%f	9.1	9.0	8.2
H13%f	5.1	5.3	6.0
H15%f	0.7	0.4	1.0

HARMONICS TABLE (b) 0:00:21

Amp	L1	L2	L3
THD%f	3.6	3.8	3.9
H3%f	0.5	0.8	0.6
H5%f	2.7	2.7	3.0
H7%f	2.0	2.3	2.3
H9%f	0.2	0.0	0.2
H11%f	0.9	0.8	0.5
H13%f	0.2	0.2	0.2
H15%f	0.1	0.1	0.1

Fig 10: a) Harmonic spectrum of source current
a) without hybrid filtering b) with hybrid filtering

B:Distorted source and Balanced Load

The distorted source voltages are applied across the diode bridge rectifier feeding resistive load. When there is distortion in the supply voltages, the fundamental components are first derived using suitably tuned second order low pass filters to make the voltages balanced and sinusoidal. The unit sine wave of these balanced voltages are used as templates as required by the ICOSφ algorithm to generate compensation currents. The experimental results are shown in Fig 11 and Fig 12.

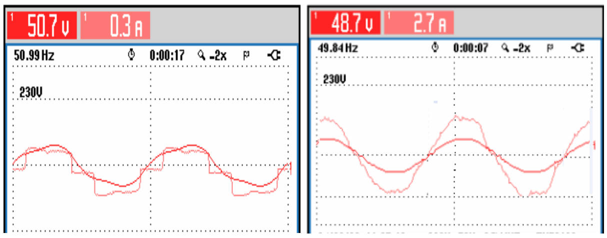
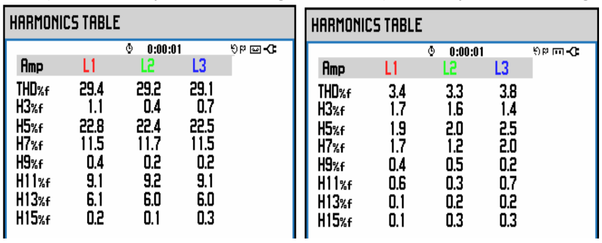


Fig.11: a-phase source voltage and source current
a) without hybrid filtering b) with hybrid filtering



HARMONICS TABLE 0:00:01

Amp	L1	L2	L3
THD%f	29.4	29.2	29.1
H3%f	1.1	0.4	0.7
H5%f	22.8	22.4	22.5
H7%f	11.5	11.7	11.5
H9%f	0.4	0.2	0.2
H11%f	9.1	9.2	9.1
H13%f	6.1	6.0	6.0
H15%f	0.2	0.1	0.3

HARMONICS TABLE 0:00:01

Amp	L1	L2	L3
THD%f	3.4	3.3	3.8
H3%f	1.7	1.6	1.4
H5%f	1.9	2.0	2.5
H7%f	1.7	1.2	2.0
H9%f	0.4	0.5	0.2
H11%f	0.6	0.3	0.7
H13%f	0.1	0.2	0.2
H15%f	0.1	0.3	0.3

Fig 12: Harmonic spectrum of source current
(a) without hybrid filtering (b) with hybrid filter

C. Balanced source Unbalanced Load

The unbalance in three phase currents are introduced by a star connected unbalanced resistive load in shunt with diode bridge rectifier. The shunt active filter using the ICOSφ algorithm makes sure that the source currents in all the same phases remain balanced even in case of load unbalance. The active filter along with the passive filter reduces the THD in source currents and the experimental results are shown in Fig 13 and Fig 14.

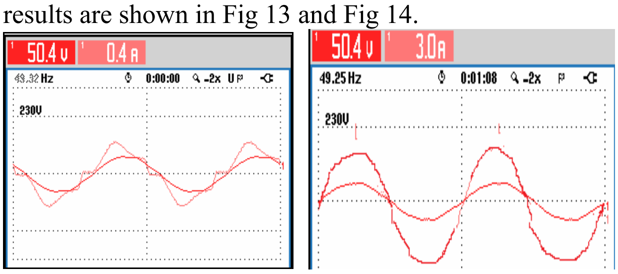
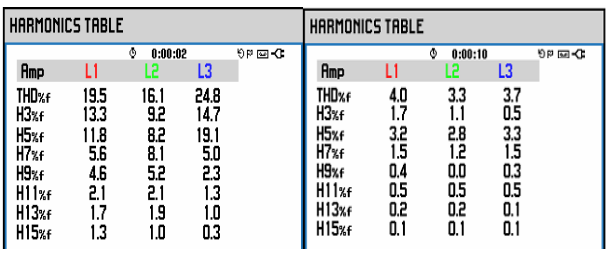


Fig.13: a-phase source voltage and source current
(a) without filtering b) with hybrid filtering



HARMONICS TABLE 0:00:02

Amp	L1	L2	L3
THD%f	19.5	16.1	24.8
H3%f	13.3	9.2	14.7
H5%f	11.8	8.2	19.1
H7%f	5.6	8.1	5.0
H9%f	4.6	5.2	2.3
H11%f	2.1	2.1	1.3
H13%f	1.7	1.9	1.0
H15%f	1.3	1.0	0.3

HARMONICS TABLE 0:00:10

Amp	L1	L2	L3
THD%f	4.0	3.3	3.7
H3%f	1.7	1.1	0.5
H5%f	3.2	2.8	3.3
H7%f	1.5	1.2	1.5
H9%f	0.4	0.0	0.3
H11%f	0.5	0.5	0.5
H13%f	0.2	0.2	0.1
H15%f	0.1	0.1	0.1

Fig 14: Harmonic spectrum of source current
(a) without hybrid filtering (b) with hybrid filtering

The experimental results are summarized in Table 3. Table 3 compares the performance of the test system with and without hybrid filtering. It can be seen that harmonics in the source current is highly reduced with the addition of the hybrid filter. Also it is calculated that size of the active filter can be reduced up to 30% in this hybrid configuration.

Table 3: Performance of various filter configurations with diode bridge rectifier

	THD in source current (%)					
	Without hybrid filter			With hybrid filter		
	R	Y	B	R	Y	B
Balanced Source And Load	29.8	29.7	28.7	3.6	3.8	3.9
Distorted Source And Balanced Load	29.4	29.2	29.1	3.4	3.3	3.8
Balanced Source Unbalanced Load	19.5	16.1	24.8	4.0	3.3	3.7

VII. CONCLUSION

With the development of more sophisticated power electronic nonlinear devices, more and more power quality issues were initiated. As remedies to these problems, many filtering techniques such as passive filter, active filter, hybrid filter etc. are developed. The simulation results show the shunt hybrid filter is much superior in performance compared to other configurations. The three-phase hybrid filter is implemented in hardware as combination of shunt passive filter and shunt active filter. The three-phase hybrid filtering system works quite efficiently under various source/load conditions such as balanced supply and balanced load, distorted source and balanced load ,balanced supply and unbalanced load etc.

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