A Comparative Study Of Various Configurations Of Hybrid Active Power Filter For Harmonic Mitigation

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Abstract -Solid state converter which uses thyristor and diodes is embraced for controlling of furnaces , welding process and heating . For the eradication of harmonics current in non- linear loads the shunt active power filters proves to be cost effective . This paper presents the active shunt and passive shunt topology of hybrid active power filter, passive series and active shunt topology of hybrid power filter and active series and passive shunt along with instantaneous reactive power theory as the control algorithm for the deprecation of harmonics and improvement of power quality. The topology also enhances the ratings of the active filter and also the compensating characteristics of passive filter in comparison to the pure active and passive filter . With the aid of simulation and results of experiment the constructiveness of the topology and control scheme is validated.

***Key Words*:**THD(Total Harmonic Distortion), harmonics, hybrid power filter, IRPT(Instantaneous Reactive Power Theory).

1.INTRODUCTION

The use of non linear loads have increased immensely with the use of non-linear loads which can be single phase or three phase loads such as adjustable speed drives, telecommunication networks, domestic equipment like television, ovens and so on. These non-linear loads generally causes the injection of harmonics, increment in the neutral currents and also promote unbalance in the loading of AC mains as they consist of electric power which is controlled by solid state control which further draw non-sinusoidal current and also results in reduction of efficiency. The use of passive filters for the eradication of harmonics and for the reactive power compensation finds its importance due its low cost, but it undergoes limitations such as:- by source impedance its design gets pretentious, distortion increases with the alteration in the operating conditions which causes the detuning of filter and so on hence the use of active filter is proposed which overcomes the disadvantages of the passive filter. However, the cost of the active filter is increased as its

ratings gets equivalent to 80% of the load. To overcome all

the drawbacks of the active filter and passive filter the hybrid power filters are evolved.

2. HYBRID POWER FILTERS :-

TheThe reduced efficiency and poor power factor are the causes of the disturbance precipitated due to injection of harmonics and burden of the reactive power. Harmonic mitigation can be achieved with the aid of passive filter and the reactive power compensation with the aid of capacitor. Fixed compensation and resonance along with the precision required in the selection of the values of L and C ramifies the performance of passive filter[1]. The increase in the harmonic pollution lead to the introduction of active filter which aids in the mitigation of harmonics and also in the improvement of demands of reactive power. For rating active filter greatly depends on the reactive power compensated and the harmonics which leads to the high current rating requirement and therefore is not a cost effective solution for mitigation of harmonics.

The hybrid active filter is the combination of active and passive filters which aids in overcoming the demerits of the active and passive filter when utilized individually for reactive power compensation and mitigation of harmonics. Harmonic filter as a combination of series active and shunt passive aids in reducing the precision required for tuning of passive filter and also improves the filter characteristics, thereby with the supply of reactive power maintains the regulation of voltage. The hybrid filter as a combination of shunt active and shunt passive reduces the filtering bandwidth requirement of the active filter[2-5].

Effective compensation of reactive power and harmonics is attained when the connection is in shunt with the load.

This paper presents the comparison of three topologies of hybrid filter namely hybrid filter as a combination of series active and shunt passive filter, hybrid filter as a combination of passive series and shunt active filterand hybrid filter as a combination of shunt active and shunt passive filter along with control algorithm of instantaneous reactive power theory.

2.1CONFIGURATIONS OF HYBRID ACTIVE POWER FILTERS:-

Hybrid 1: Combination of Series Active And Shunt Passive Filter

This combination of hybrid filter comprises of active filter connected in series with passive filter connected in shunt as shown in fig(1). The connection for active filter can be done in two ways : one is either by using transformer or one without transformer. Here, the connection with the aid of transformer is designed. The value of dc capacitor makes this configuration advantageous as it aids in reducing the rating of active filter. The fundamental voltage exclusively comes on the capacitor and hence no fundamental voltage appears across active filter.[6] Therefore, there will be a reduction in the rating of the switches.This configuration provides a practical harmoniccompensation solution by the provision of isolation of harmonics between the supply and load and thereby the problems of both passive filter and pure active filter ismitigated.[7-9]

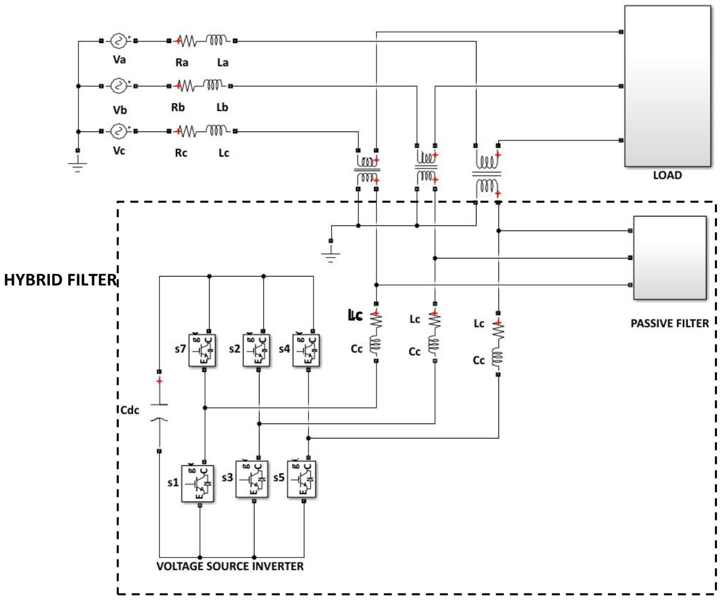

Fig -1: Hybrid Filter With a Combination Of Series Active And Shunt Passive Filter

Hybrid 2: Combination of Shunt Active And Shunt Passive Filter

The main advantage of this configuration is that impedance is relative between active and passive filter which therefore makes the passive filter to provide compensation even when the active filter is not in service[10]. This configuration reduces the rating of the active filter and hence proves to be more economical as compared when active filter is used alone.

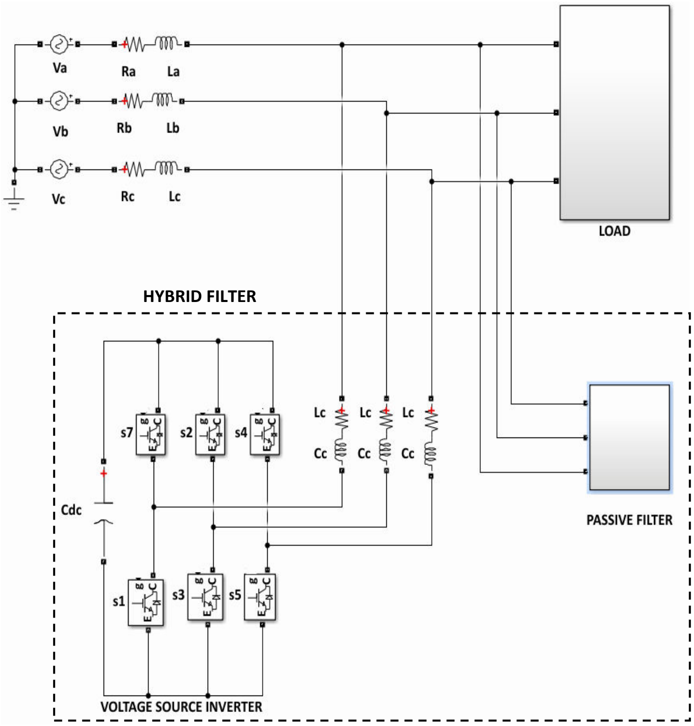

Fig -2: Hybrid Filter With a Combination Of Shunt Active And Shunt Passive Filter

Hybrid 3: Combination of Series PassiveAnd Shunt Active Filter

This configuration have passive filter connected in series with that of the active filter connected in shunt. The instantaneous reactive power theory is used as a control algorithm, thus have a similar control strategy as that of active shunt and passive shunt combination of hybrid filter. This hybrid filter combination is shown in fig(3).

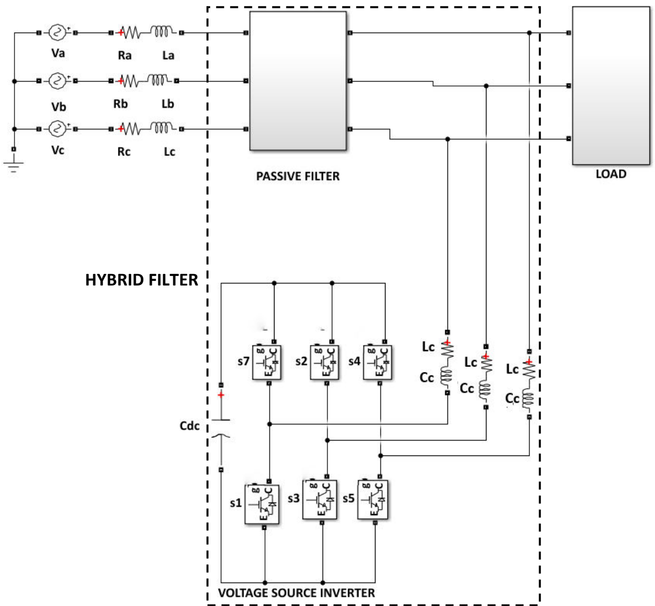

Fig -3: Hybrid Filter With a Combination Of Series Passive And Shunt Active Filter

The combination is utilized when there is harmonics content in the voltage source as well. The poor power factor is obtained throughout the range of operation when only passive filter is connected thus it gets improved with combination of active filter.

3CONTROL STRATEGY

There are different control strategies which aids in the generation of gating pulses for inverter action. The control strategy aims that the compensated current should be sinusoidal and balanced. Thus the control strategy objective includes the generation of sinusoidal and balanced reference current for the generation of switching pulses of the inverter[8]. Two control strategies are proposed in this paper which are instantaneous reactive power theory and indirect current control technique.

3.1 INSTANTANEOUS REACTIVE POWER THEORY

The block diagram of instantaneous reactive power theory is shown in fig 4.

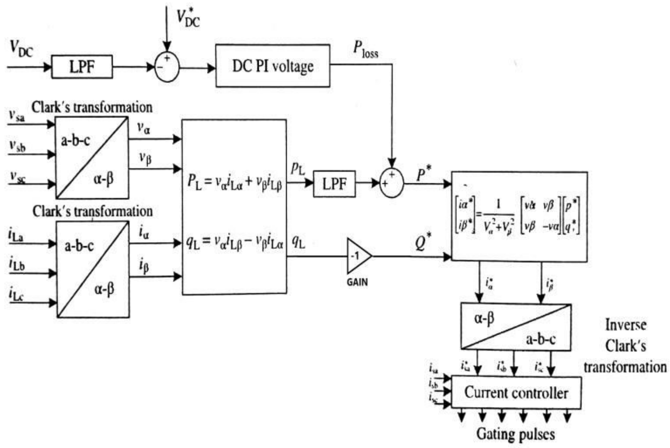

Fig -4: Instantaneous Reactive Power Theory

In instantaneous reactive power theory by sensing the load currents and voltages at point of common coupling the active and reactive power are calculated then the calculated active power for the eradication of ripple current is passed through the butter-worth low pass filter.[11]

Clark's transformation is used for the transformation of filtered three phase load voltages into two phase α-β orthogonal coordinates given as (v_0, v_α, v_β).

$$\begin{pmatrix} v_\alpha \\ v_\beta \end{pmatrix} = \sqrt{\frac{2}{3}} \begin{pmatrix} 1 & -\frac{1}{2} & -\frac{1}{2} \\ 0 & \frac{\sqrt{3}}{2} & -\frac{\sqrt{3}}{2} \end{pmatrix} \begin{pmatrix} v_{sa} \\ v_{sb} \\ v_{sc} \end{pmatrix} \qquad (1)$$

Similarly, the transformation of three phase load currents(i_{La},i_{Lb},i_{Lc}) is done into two phase α-β orthogonal coordinates which can be given as $(i_{L\alpha}, i_{L\beta})$.

$$\begin{pmatrix} i_{L\alpha} \\ i_{L\beta} \end{pmatrix} = \sqrt{\frac{2}{3}} \begin{pmatrix} 1 & -\frac{1}{2} & -\frac{1}{2} \\ 0 & \frac{\sqrt{3}}{2} & -\frac{\sqrt{3}}{2} \end{pmatrix} \begin{pmatrix} i_{La} \\ i_{Lb} \\ i_{Lc} \end{pmatrix} (2)$$

Load side instantaneous active power can be given as:-

$$p_L = v_\alpha i_{L\alpha} + v_\beta i_{L\beta} (3)$$

and the load side instantaneous reactive power can be given as:-

$$q_L = v_\alpha i_{L\alpha} - v_\beta i_{L\beta} \qquad (4)$$

The estimation of the reference three phase current (supply current) $(i_{sa}^*, i_{sb}^*, i_{sc}^*)$ is given as below:-

$$\begin{pmatrix} i_{sa}^* \\ i_{sb}^* \\ i_{sc}^* \end{pmatrix} = \sqrt{\frac{2}{3}} \begin{pmatrix} 1 & 0 \\ -\frac{1}{2} & -\frac{\sqrt{3}}{2} \\ -\frac{1}{2} & \frac{\sqrt{3}}{2} \end{pmatrix} \begin{pmatrix} v_\alpha & v_\beta \\ -v_\beta & v_\alpha \end{pmatrix}^{-1} \begin{pmatrix} p^* \\ q^* \end{pmatrix} \qquad (5)$$

In this configuration of instantaneous reactive power theory the reference current $(i_{sa}^*, i_{sb}^*, i_{sc}^*)$ are compared with the source current(i_{sa}, i_{sb}, i_{sc}) for the generation of gating pulses of voltage source inverter.

3.2MODIFIED INSTANTANEOUS REACTIVE POWER THEORY:-

Instantaneous reactive power theory can be modified to obtain improved result. In this algorithm the source currents are sensed instead of the load currents for the calculation of the active and reactive power, then for the eradication of ripple currents the calculated active power is passed through high pass filter. The control algorithm can be shown as follows:-

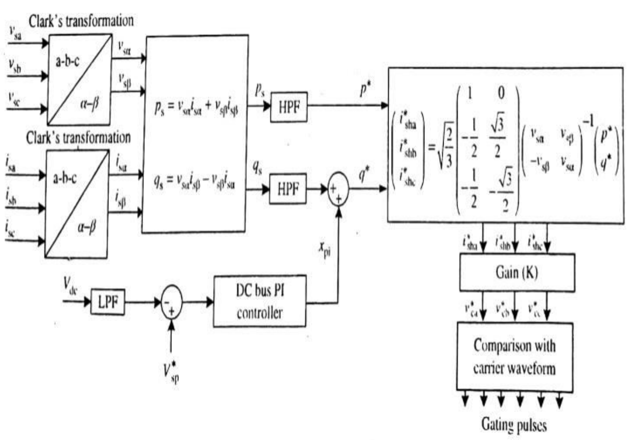

Fig -5: Modified Instantaneous Reactive Power Theory

The transformation of supply voltages(three phase) to orthogonal two phase α-β coordinates is given as:-

$$\begin{pmatrix} v_\alpha \\ v_\beta \end{pmatrix} = \sqrt{\frac{2}{3}} \begin{pmatrix} 1 & -\frac{1}{2} & -\frac{1}{2} \\ 0 & \frac{\sqrt{3}}{2} & -\frac{\sqrt{3}}{2} \end{pmatrix} \begin{pmatrix} v_{sa} \\ v_{sb} \\ v_{sc} \end{pmatrix} \qquad (6)$$

Similarly, the transformation of three phase supply currents(i_{sa},i_{sb},i_{sc}) is done into two phase α-β orthogonal coordinates which can be given as ($i_{s\alpha}, i_{s\beta}$).

$$\begin{pmatrix} i_{s\alpha} \\ i_{s\beta} \end{pmatrix} = \sqrt{\frac{2}{3}} \begin{pmatrix} 1 & -\frac{1}{2} & -\frac{1}{2} \\ 0 & \frac{\sqrt{3}}{2} & -\frac{\sqrt{3}}{2} \end{pmatrix} \begin{pmatrix} i_{sa} \\ i_{sb} \\ i_{sc} \end{pmatrix} \qquad (7)$$

The instantaneous active power(p_s) and reactive power(q_s) obtained from the above equations can be given as:-

$$\begin{pmatrix} p_s \\ q_s \end{pmatrix} = \begin{pmatrix} v_{s\alpha} & v_{s\beta} \\ v_{s\beta} & -v_{s\alpha} \end{pmatrix} \begin{pmatrix} i_{s\alpha} \\ i_{s\beta} \end{pmatrix} \qquad (8)$$

The estimation of reference three phase harmonic currents ($i^*_{sha}, i^*_{shb}, i^*_{shc}$) is given as:-

$$\begin{pmatrix} i^*_{sha} \\ i^*_{shb} \\ i^*_{shc} \end{pmatrix} = \sqrt{\frac{2}{3}} \begin{pmatrix} 1 & 0 \\ -\frac{1}{2} & -\frac{\sqrt{3}}{2} \\ -\frac{1}{2} & \frac{\sqrt{3}}{2} \end{pmatrix} \begin{pmatrix} v_{s\alpha} & v_{s\beta} \\ -v_{s\beta} & v_{s\alpha} \end{pmatrix}^{-1} \begin{pmatrix} p^* \\ q^* \end{pmatrix} \qquad (9)$$

Gain k is multiplied in each harmonic current and amplifies it which is given as input to the pulse width modulation controller as reference voltage $V^*_c = KI_{sh}$. The comparison of V^*_c with triangular wave gives the gating pulses for voltage source inverter.

4. SIMULATION RESULTS

Three topologies of hybrid filter are simulated using MATLAB simulation and the results are compared. The various design parameters for the system are as follows:-

Source voltage(peak)=239 volts.
Line impedance: Rs=1 ohm, Ls= 15.112 mH.
Load Resistance=20 ohm
Load Inductance=55mH
The passive filter parameters for hybrid configuration of active series and passive shunt filter and hybrid configuration of passive series and active shunt is as follows:-

Table -1: Passive Filter Parameters

	Passive Filter Parameters		
	Resistance (ohms)	**Inductance (mH)**	**Capacitance (μF)**
5th order harmonics	0.01(or negligible)	16.14	25
7th order harmonics	0.01(or negligible)	8.14	25
11th order harmonics	85.87	4.14	25

The passive filter parameters for shunt active and shunt passive hybrid filter is:-

Table -2: Passive Filter Parameters

	Passive Filter Parameters		
	Resistance (ohms)	**Inductance (mH)**	**Capacitance (μF)**
5th order harmonics	--	2.8112	70
7th order harmonics	--	3.4199	60
11th order harmonics	60	10	40

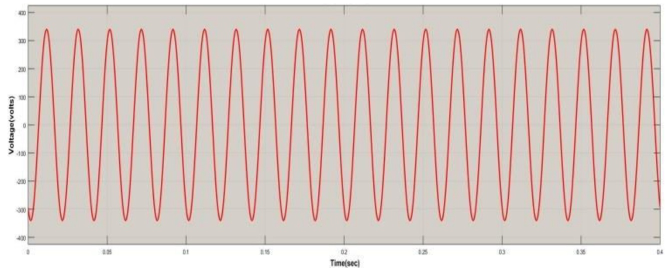

Fig -6: Source voltage waveform

Configuration 1:Series active shunt passive basedhybrid filter
The source current and source voltage of series active shunt passive filter without compensation is shown in fig(6) and fig (7). The THD of the filter without compensation is 12.34%. The control strategy used is instantaneous reactive power theory.

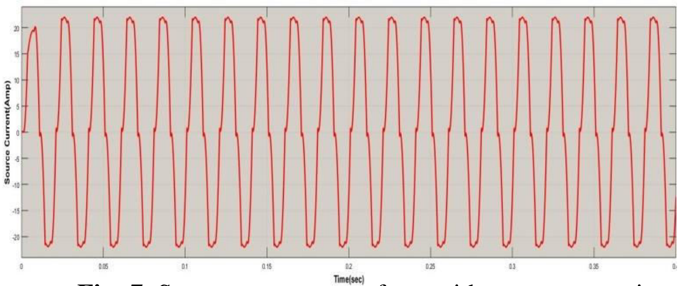

Fig -7: Source current waveform without compensation

To eliminate these harmonics filters are being used. When only passive filter is used alone with load the THD of source current becomes 9.05%. Then when hybrid filter that is the combination of both passive and active filter is used the THD becomes 2.45% with fundamental current of 28.74A. The source current waveform when hybrid filter is used is shown in fig(8).

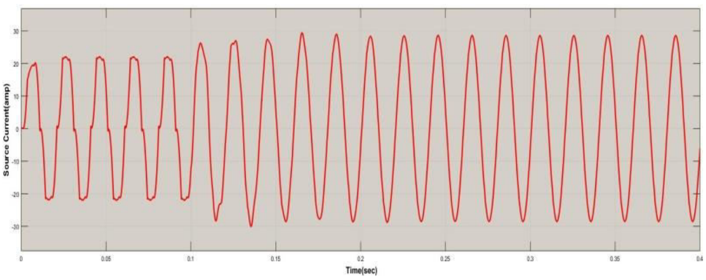

Fig -8: Source current waveform with Hybrid active power filter compensation

The dc link capacitor charging waveform when hybrid filter is used is shown in fig(9). The capacitor voltage is maintained approximately at 700V with the value of capacitance 3300 mF.

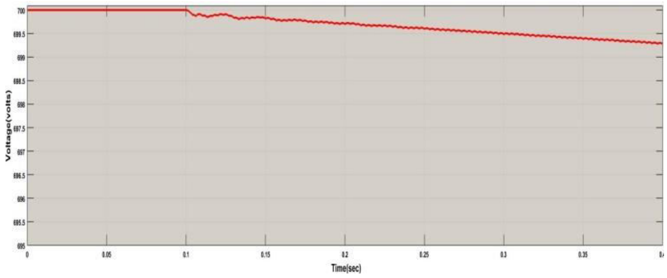

Fig -9: DC link capacitor voltage

Configuration 2:Series active shunt passive basedhybrid filter (with modified IRPT control algorithm)
The source current and voltage waveform without compensation is shown in fig(6) and fig(7) respectively. The THD of the source current without compensation is 12.34% which is similar to the previous strategy since the source and load configurations are similar. The THD of the source current after compensation when hybrid filter is working is 0.87% with fundamental current of 20.18A. the waveform of the source current with compensation is shown in fig(10).

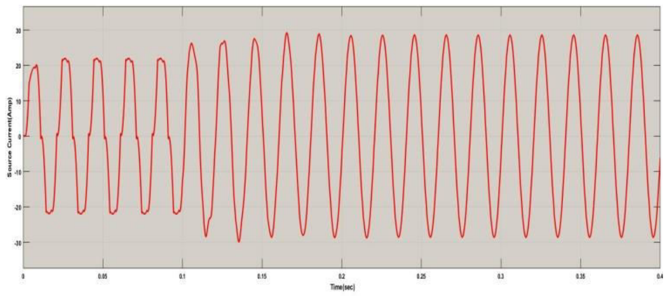

Fig -10: Source current waveform with hybrid filter compensation

The DC link capacitor voltage waveform is shown in figure fig(11). The capacitor charge is maintained at 700 V approximately with the capacitance value of 3300 mF.

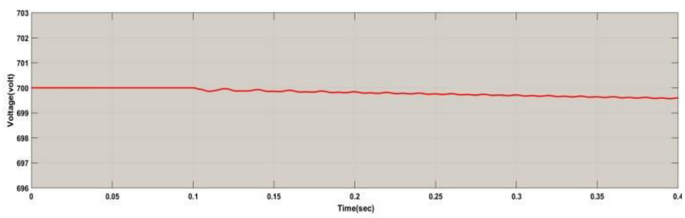

Fig -11: DC link capacitor voltage

Configuration 3:Shunt active and shunt passive based hybrid filter The source current waveform without compensation is shown in fig(7). The THD of the system without compensation is 12.34% with fundamental current of 23.29.

Thus to mitigate the harmonics the hybrid filter is used. The THD of the system with hybrid filter is 2.53% with fundamental current of 23.16. The source current waveform after compensation and dc link capacitor waveform is shown in fig(12) and fig(13) respectively. The capacitance value for the shunt topology of hybrid filter is 6600µF.

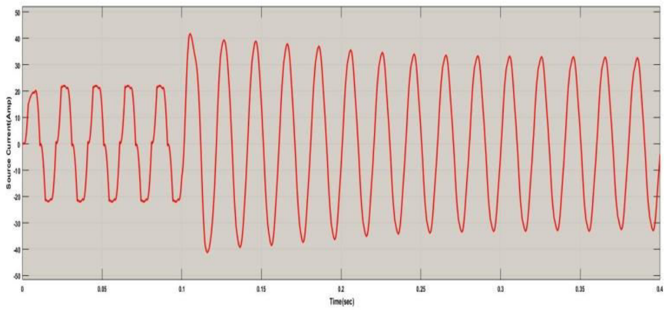

Fig -12: Source current waveform with Hybrid active power filter compensation

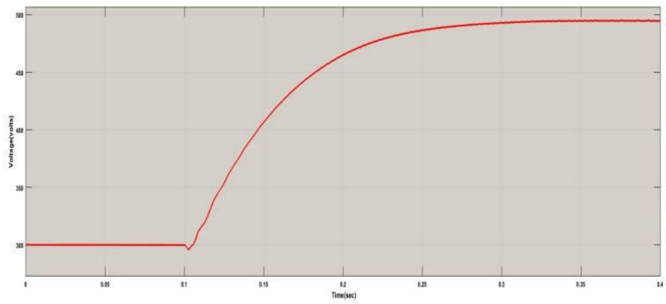

Fig -13: DC link capacitor voltage

Configuration 3:Passive series and shunt active based hybrid filter The source current waveform with passive filter working alone is shown in fig(14). The THD obtained is 3.11% with fundamental current of 21.9A. To mitigate this harmonics content active filter is connected in shunt and therefore the harmonics when both active and passive working reduces to 2.36% with fundamental current of 21.9A. The source current waveform with hybrid filter compensation is shown in fig(15). The DC link capacitor charging is shown in fig(16).

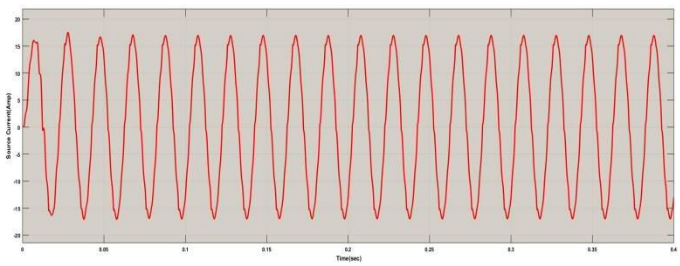

Fig -14: Source current waveform with passive filter only

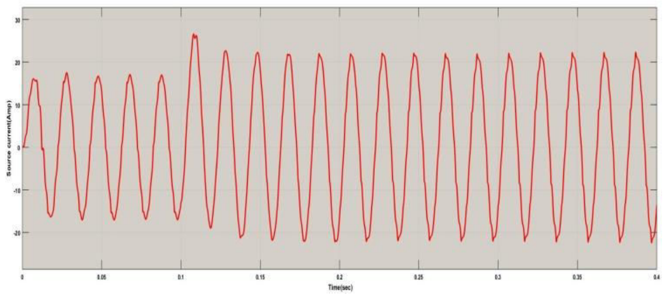

Fig -15: Source current waveform with hybrid filter compensation

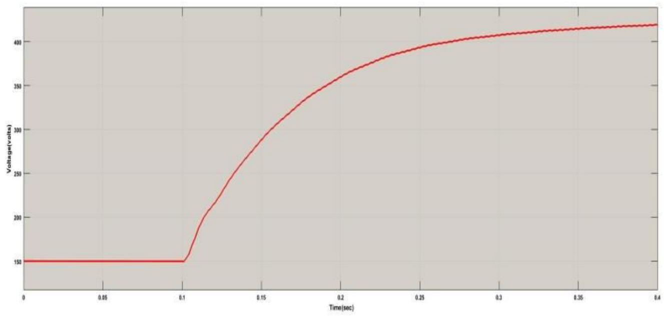

Fig -16: DC link capacitor voltage

Table -3: Comparison Of Three Different Hybrid Filter Topologies

Topologies		THD %	Fundamental Current	Power Factor
Hybrid Filter With Combination of Series Active and Passive Shunt filter	Without compensation	12.34	23.29	0.7649
	With Passive Filter Only	13.56	27.96	0.8504
	With Hybrid Filter	2.45	28.74	0.8704
Hybrid Filter With Combination of Passive Series and Active Shunt filter	With Passive Filter Only	3.11	16.82	0.5885
	With Hybrid Filter	2.36	21.9	0.7717
Hybrid Filter With Combination of Active Shunt and Passive Shunt filter	Without compensation	12.34	23.29	0.765
	With Passive Filter Only	6.07	36.03	0.8805
	With Active Filter Only	8.19	42.96	0.8775
	With Hybrid Filter	2.53	33.65	0.8905

A table of comparison is shown in table 2 in which the comparison is done on the basis of THD%, Fundamental current and power factor.

Table -4: Comparison Of Hybrid Filter As Combination Of Series Active And Shunt Passive Filterwith two different control strategies

Control Strategy	Hybrid Filter As a Combination Of Series Active And Shunt Passive Filter			
		THD %	Fundamental Current	Power Factor
Instantaneous Reactive Power Theory	Without Compen -sation	12.34	23.29	0.7649
	With Passive Filter Only	13.56	27.96	0.8504
	With Hybrid Filter	2.45	28.74	0.8704
Modified Instantaneous Reactive Power Theory	Without Compen -sation	12.34	23.29	0.7649
	With Passive Filter Only	6.47	28.94	0.8605
	With Hybrid Filter	0.87	28.57	0.8707

A table of comparison with hybrid active power filter as a combination of series active and passive shunt with two different control strategies is shown in table 3.

5. CONCLUSIONS

Various hybrid filter topologies and their control strategies is explained. From the comparative study of these topologies it is found that active series and passive shunt combination of hybrid filter is found efficient as it improves the system performance with mitigation of harmonics to a great extent. When compared with the ideal control strategy of instantaneous reactive power theory with the modified instantaneous reactive power theory, the active series and passive shunt hybrid filter topology performance improves with the control strategy. Therefore, with the proposed control algorithm the harmonic compensation feature of the passive filter is improved along with the power factor of the load.

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