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Synchronous Rotating Reference Frame Based Control Technique for Three-phase Hybrid Active Power Filter: A Simulink Approach

[1]R. Balasubramanian, [1]Parkavi Kathirvelu, [1]Shashwat and [2]S. Palani
[1]School of Electrical and Electronics Engineering, SASTRA University, India
[2]Sudharsan Engineering College, Tamil Nadu, 622501, India

Abstract: A nonlinear control technique with Hybrid Active Power Filter topology (HAPF) is projected in this study for eliminating current harmonics produced via onlinear load when connected along a power system. An active power filter linked to a shunt inactive LC Filter constitutes the proposed hybrid filter. Hybrid filter performance is been evaluated from the results obtained from the simulations done by Simulink software. Influence of Q factor and passive filter ratings on the hybrid scheme's compensation performance are also evaluated. It is shown that the proposed configuration can effectively suppress current harmonics.

Key words: Hybrid active power filter, shunt active power filter, current harmonics, total harmonic distortion, passive tuned filter, Q factor

INTRODUCTION

Proliferation of nonlinear loads like three phase Power converters, arcing devices, Fluorescent lighting and adjustable speed drives causes the Power system having Power quality problems. Occurrence of Power quality problems like harmonics along a power system is damaging; as it use to have further power losses and reduces the system efficiency (Akagi, 1994; Dugan *et al*., 2004; Rivas *et al*., 2003). The performance of the equipments causing the harmonic disturbances in the power system is quite sensitive to harmonic disturbances (Dugan *et al*., 2004).

The power system specialists have a major distress on the harmonic contamination which results from the above mentioned facts, due to its detrimental effects on sensitive loads and on power distribution system. Harmonic distortion reduction has conventionally allocated via usage of inactive LC filters (Rivas *et al*., 2003; Das, 2004). Nevertheless the harmonic reduction using inactive filters can result in parallel resonance having network impedance, overcompensation of volatile power on ultimate frequency plus deprived tractability for vibrant reimbursement of dissimilar harmonic components frequency. Thus passive filters are not effective in dynamically changing load conditions. These difficulties have been overcome by employing Active filters.

Main advantages of animated power filters are as follows: Reimbursement of voltage harmonics plus current harmonics, regulation of terminal voltage, reactive power and suppression of flicker, can able to advance the voltage equilibrium in three phase (3Φ) systems and it mechanically conforms to changes in the load oscillations network. Though it can be compensated for numerous harmonic orders, they are not exaggerated by foremost variations in the network characteristics. This eliminates risk of resonance among network impedance and the filter. Hence, extensive research work has been carried out in the field of Active power filters (Akagi, 1994, 2005; Dugan *et al*., 2004; Rivas *et al*., 2003; Mendalek *et al*., 2003; Das, 2004; Luo *et al*., 2009).

Animated powers filters are mainly categorized into three categories namely shunt animated power filter, series animated power filter and their hybridize. Of these series plus shunt animated power filters can be used only for low and medium power range systems (Mendalek *et al*., 2003; Akagi, 2005). Hybridize animated power filter topology provides appropriate means for reimbursement of high power range structures.

The present work pertains to the study of nonlinear load characteristics on the power system's distortion of current and enactment of three phase hybridize animated power filter topology with selective harmonic elimination using Simulink software. The reimbursement act of the hybridize scheme is studied for various values of passive filter Q factor and its rating.

POWER SYSTEM WITH NONLINEAR LOAD

Simulation model based on simulink is shown in Fig. 1 is used to study the effect of harmonics on three phase power system connected to a nonlinear load; the

Corresponding Author: R. Balasubramanian, School of Electrical and Electronics Engineering, SASTRA University, India

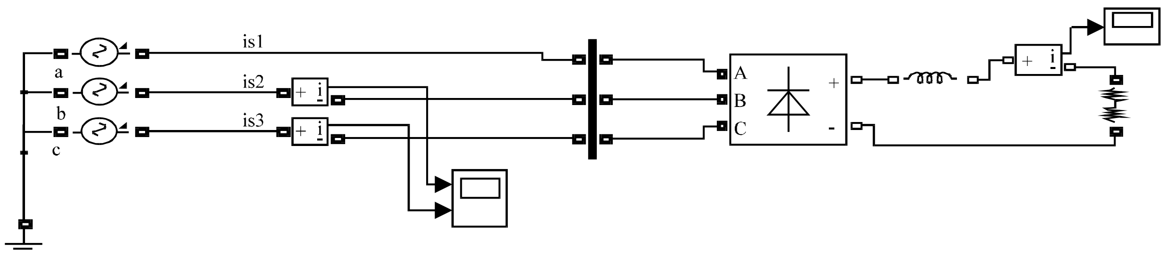

Fig. 1: Simulink model of three phase source with nonlinear load

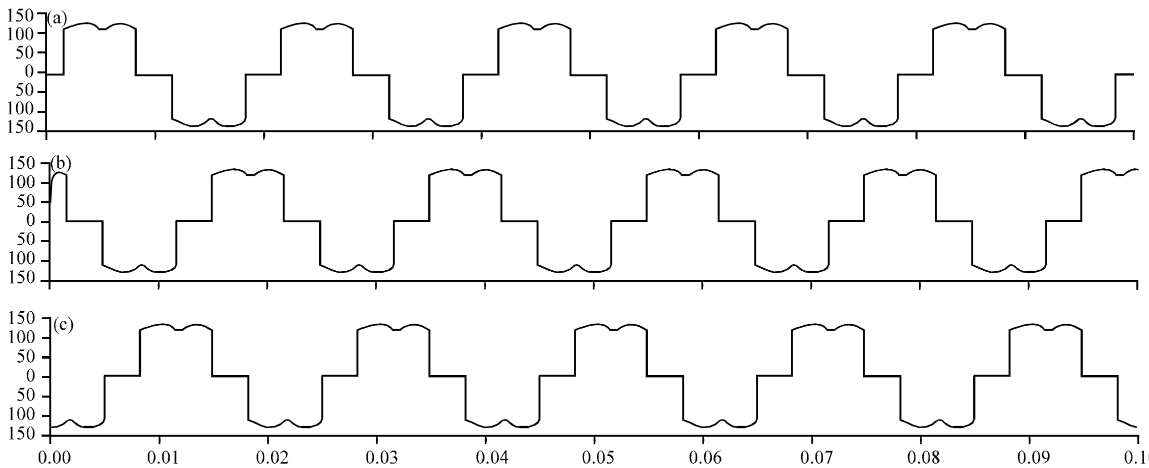

Fig. 2(a-c): Nonlinear load current wave form (Fund =138.3 peak, THD = 30.17%)

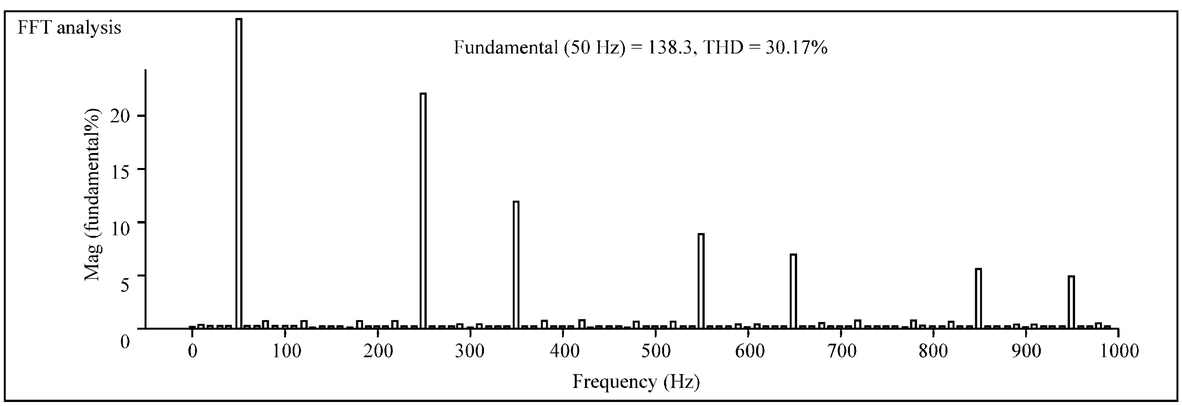

Fig. 3: Harmonic spectrum of load current

R-L load fed by a three phase diode rectifier being engaged as non-linear load. Table 1 contains the load details.

The results studied through simulation in power system with nonlinear load are given in Table 2. The harmonic spectrum of load current and its waveform are given in Fig. 2 and 3, respectively.

It can be observed from the simulation results presented that the Total Harmonic Distortion (THD), 5th, 7th, 11th, 13th and 17th order harmonics exceed the forbearances specified in the IEEE standard. Tripled harmonics are within the standard given in IEEE because of the load is balanced. Hence, there is a need for installation of filters in the power system with nonlinear load to mitigate the harmonics currents and THD belowthe standard given by IEEE.

Table 1: Load details

Variables	Values
Phase voltage and frequency	V = 230 V, 50 Hz
Three phase diode rectifier parameters	R_{load} = 4.285Ω, L = 1 mH

SHUNT ACTIVE POWER FILTER WITH POWER SYSTEM

Rahmani *et al*. (2010) have proposed a relative-primary law of control for the shunt active power filter with nonlinear control technique, in which the control loop of SAPF is decoupled into the inner current control loop with outer voltage control loop. This decoupling result to have SAPF dc bus voltage and filter currents are controlled independently.

Simulation model of shunt animated filter fabricated on simulink is shown in Fig. 4 used to study the effect of harmonics on power system connected to nonlinear load with shunt active power filter by the proposed control law (Rahmani *et al*., 2010). Power circuit of animated power filter has three phase (3Φ) VSI typically based on fast switching bi-directional IGBTs. The simulation parameters are shown in Table 3.

The simulation results of shunt animated power filter system are offered in Fig. 5, 6 and Table 4. The nonlinear load current and harmonic spectrums are depicted there. The fifth harmonic current and THD are above the limits given by IEEE standard, remaining harmonic currents are in the acceptable range.

Table 2: Harmonic current distribution and IEEE standard

Harmonic orders	Measured value (%)	IEEE standard 519-1992 (%)
3	0.14	4
5	22.13	4
7	11.85	4
9	0.14	2
11	8.77	2
13	6.99	2
17	5.50	2
THD	30.17	5

THREE PHASE HYBRIDIZE ANIMATED POWER FILTER TOPOLOGY

Figure 7 demonstrates the simulink model of three phase (3Φ) shunt hybridize power filter linked to power system supplying non-linear load. The system of filtering involves shunt passive filter tuned to the 5th harmonic frequency with shunt active power filter having nonlinear control loop (Luo *et al*., 2009; Rahmani *et al*., 2010). This configuration ensures that compensation of harmonics reduction of shunt animated power filter is improved by shunt inactive filter for the power system considered in

Table 3: System parameters for simulation of power system with SAPF

Variables	Values
Source voltage and frequency	230 (rms), 50 Hz
Three phase diode rectifier parameters	R_{load} = 4.285 Ω, L = 1 mH
Shunt active power filter parameters	L = 5 mH, C_{dc} = 1000 μF, V_{dc} = 35 V
Switching frequency	1080 Hz
Controller frequencies	W_{ni} = 8000 π rad sec^{-1}, W_{nv} = 80 π rad sec^{-1}
Low pass filter parameters	Cutoff frequency = 50 Hz, ζ = 0.707
PI controller parameters	K_p = 26.5573, K_i = 355305.7584, K_1 = 0.35543, K_2 = 63.165

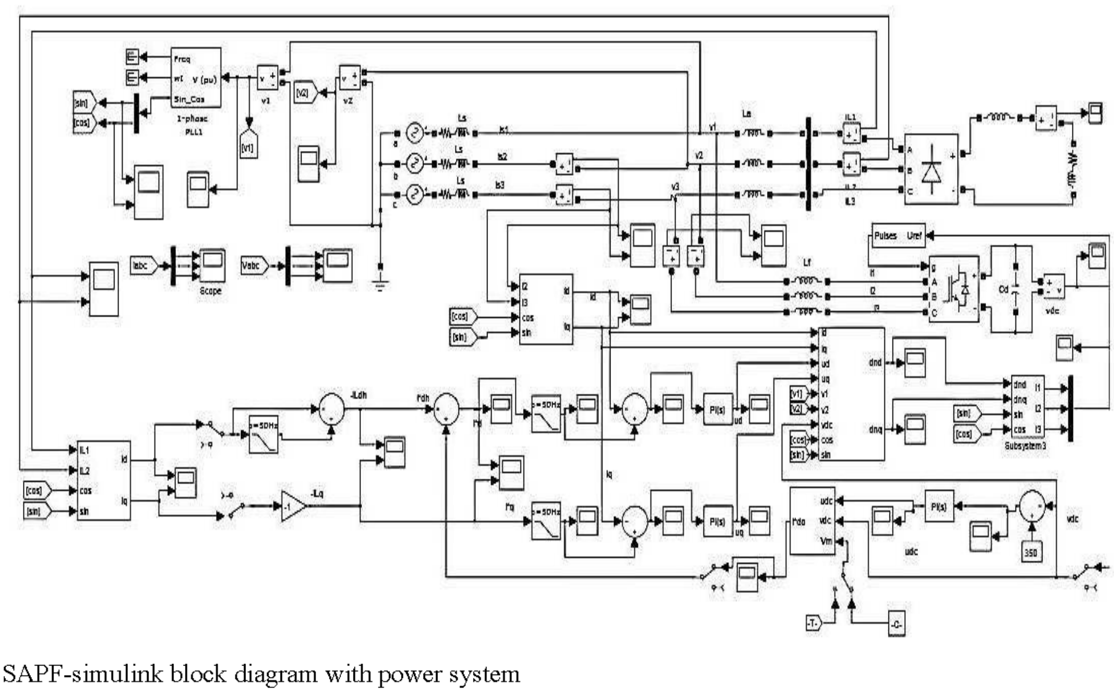

Fig. 4: SAPF-simulink block diagram with power system

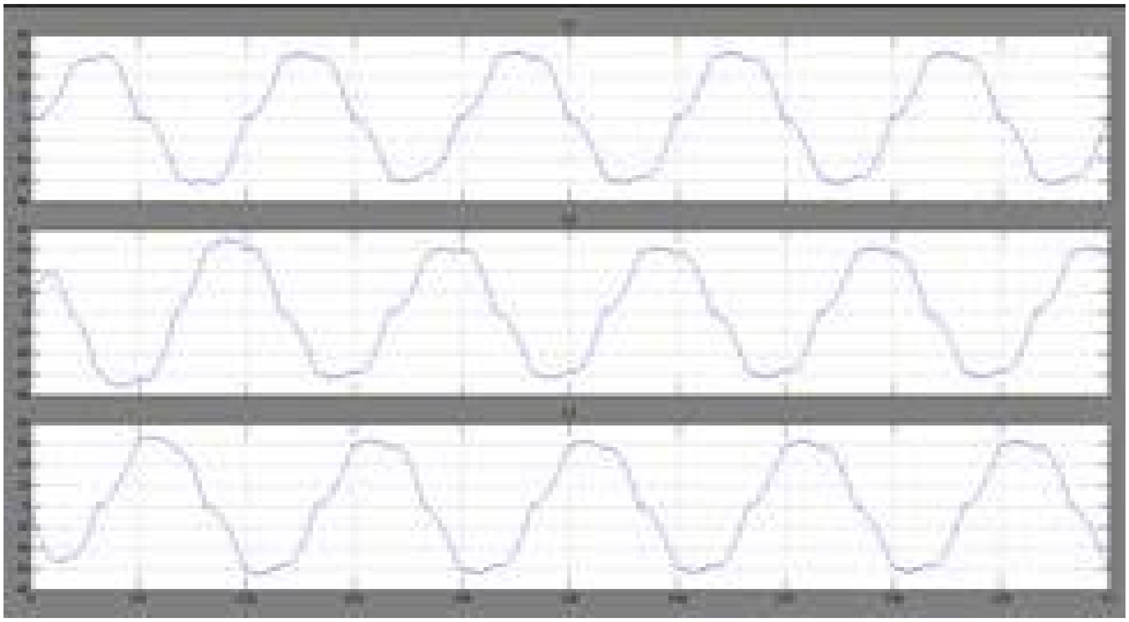

Fig. 5: Load current (THD = 9.82%, Fund = 62.84 peak)

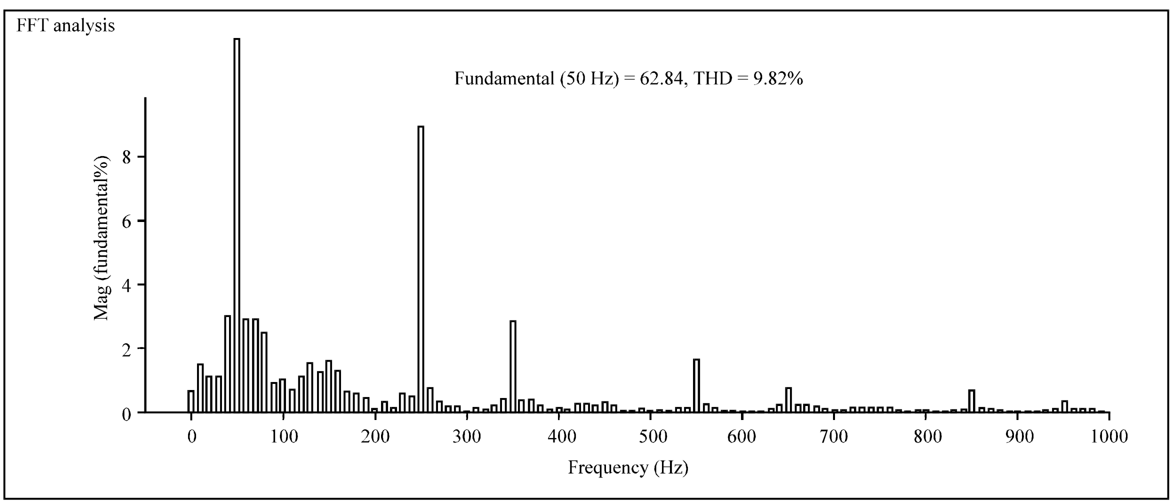

Fig. 6: Spectrum of load current with SAPF

this study. Here three phase single tuned harmonic filter subsystem available in the simulink library has been used as a passive tuned filter.

SIMULATION OUTCOMES

In mandate to reveal the enactment of hybrid topology projected in this study, complex power system

Table 4: Harmonic current distribution with SAPF

Harmonic orders	Measured value (%)	IEEE standard 519-1992 (%)
3	1.63	4
5	8.97	4
7	2.83	4
9	0.27	2
11	1.67	2
13	0.76	2
17	0.63	2
THD	9.82	5

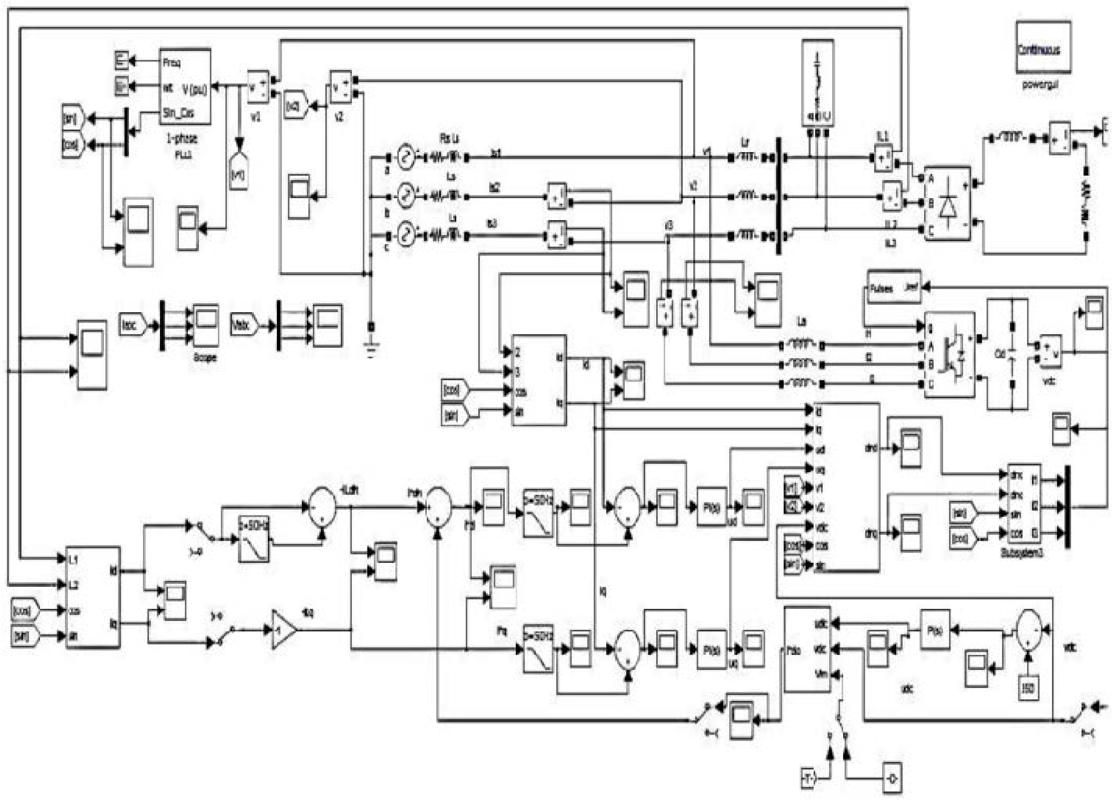

Fig. 7: Simulink model for three phase (3 Ω) hybridize animated power filter

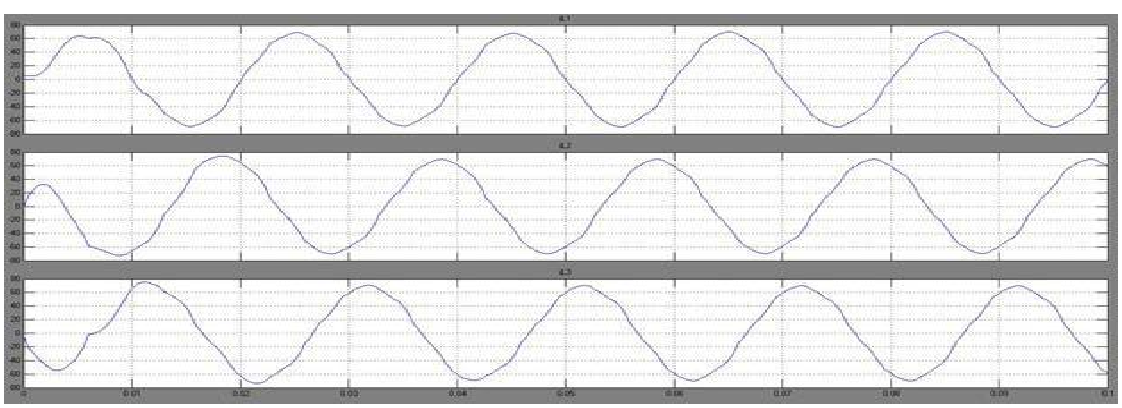

Fig. 8: Load current (THD = 4.25% Fund = 67.71(peak))

model simulation has been carried out using Sim Power systems block in Simulink of MATLAB. Determination of the following performance aspects are the foremost purpose of this simulation (1) Harmonic reimbursement of shunt connected hybrid filter (2) Compensation performance improvements for various quality factors of passive tuned filter in a hybrid scheme and (3) Reimbursement performance of the hybridize filter for various values of inactive filter ratings. Passive filter parameters are chosen as V_m =325.27 V, f = 50 Hz, Q = 16, f_0 = 250 Hz and KVAR= 1.75 KVAR.

Compensation performance of hybrid filter: The results of simulation of hybrid active power filter system are presented in Fig 8-10 and Table 5. Shows the harmonic current magnitude of load current after and before

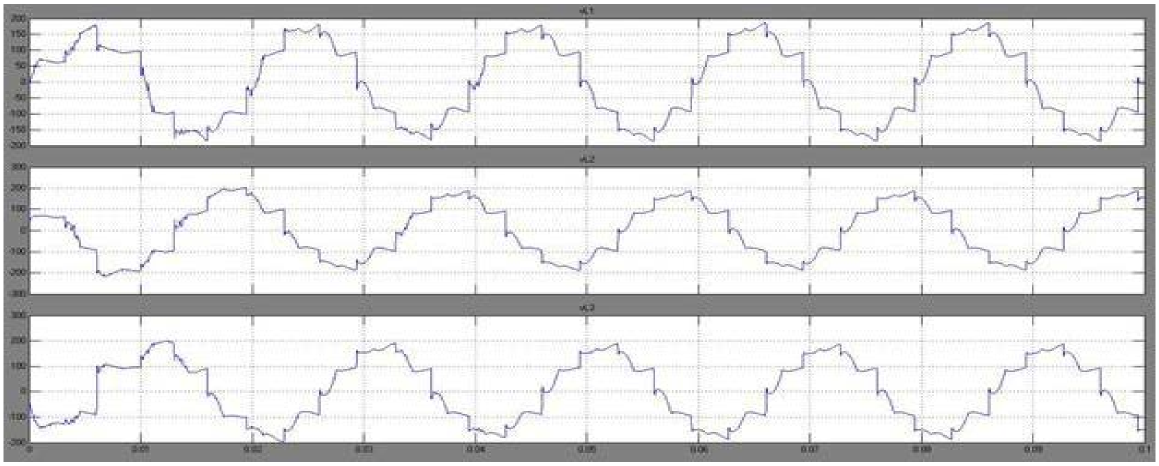

Fig. 9: Load voltage waveform

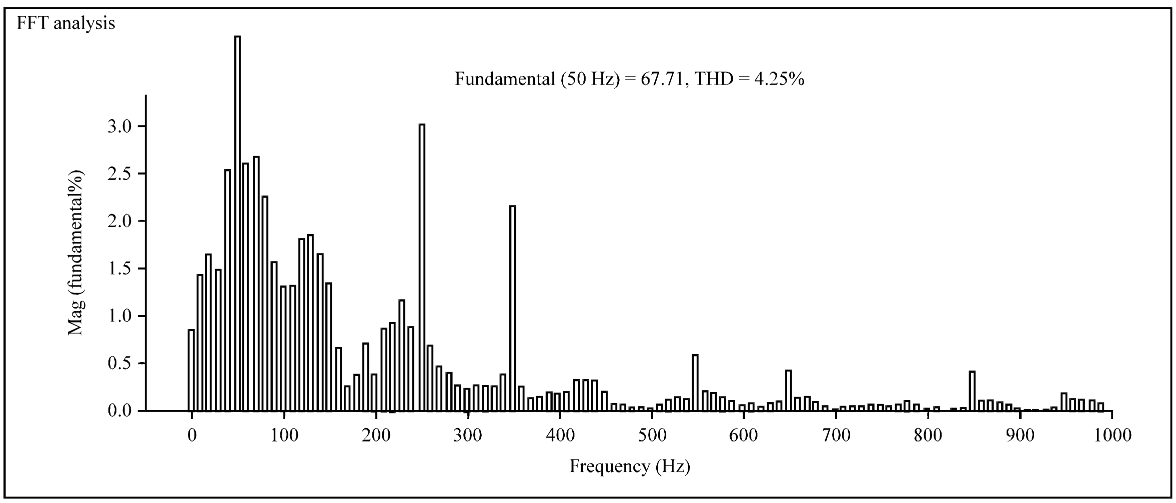

Fig. 10: Load current harmonic spectrum

Table 5: Harmonic load current magnitude before and after reimbursement

Harmonic order	Before compensation (%)	After compensation (%)	IEEE 519-1992 limit
3	0.14	1.33	4
5	22.13	2.99	4
7	11.85	2.14	4
9	0.14	0.20	2
11	8.77	0.59	2
13	6.99	0.42	2
17	5.50	0.40	2
THD	30.17	4.25	5

reimbursement where the current THD has been decreased as of 30.17% before reimbursement to 4.25% after compensation.

Compensation performance of hybrid scheme for various quality factor of tuned filter: The results of simulation for hybridize active filter system for various values of quality factor are presented in Table 6. The changes in the values of THD and individual harmonic contents are listed. It can be clearly seen from the results that the THD reduces significantly on increasing the value of quality factor for the given filter rating. Reimbursement enactment of the hybridize arrangement is significantly improved.

Compensation performance of hybrid filter for various values of inactive filter ratings: Simulation results of hybrid filter system for various values of inactive filter

Table 6: THD and harmonic content for various values of Q at 1.75 KVAR

Q factor	THD (%)	Fund (peak)	h 3	h 5	h 7	h 9	h 11	h 13	h 15	h 17
16	4.25	67.71	1.33	2.99	2.14	0.20	0.59	0.42	0.07	0.19
16.5	4.22	67.81	1.30	2.94	2.14	0.19	0.60	0.43	0.07	0.19
17.5	4.17	67.78	1.24	2.87	2.09	0.20	0.63	0.44	0.08	0.20
18	4.10	67.85	1.29	2.79	2.11	0.20	0.63	0.45	0.08	0.19
21	3.92	67.82	1.29	2.54	2.05	0.20	0.69	0.49	0.08	0.19
22	3.88	67.92	1.31	2.48	2.04	0.21	0.71	0.49	0.08	0.19

Table 7: THD for various values of passive filter ratings

Inactive filter's KVAR rating	Inactive filter's Q factor	THD (%)
1.75	16	4.25
1.80	16	4.20
2.0	16	4.07

ratings are bare in Table 7. It is clearly realized from the results that the THD reduces significantly on increasing the value of filter rating for the particular quality factor. Reimbursement enactment of the hybridize arrangement is significantly improved when KVAR rating of inactive filter is increased.

CONCLUSION

The shunt active filter with non-linear control reduces total harmonic distortion of the power system studied. However, the reduction is not very significant which is mostly due to added nonlinearities with highest fifth order harmonic content. Hence, in this study Shunt connected tuned passive filter with SAPF is proposed. The results of simulation verify that the subsequent goals is been achieved successfully (1) Specific harmonic currents with the THD are reduced below standard given by IEEE 519-1992, (2) Reimbursement enactment improvement of hybridize arrangement by increase in the inactive filter's quality factor and (3) Reimbursement improvements by increase in inactive filter ratings.

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