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Fuzzy logic controlled multi level inverter based shunt hybrid active power filter with TCR for power quality improvement in HV systems

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ABSTRACT: The line current harmonics cause increase in losses, instability and also voltage distortion. With the proliferation of the power electronic converters and increased use of magnetic devices, power lines have become highly polluted. Both passive and active filters have been used near harmonic producing loads or at the point of common coupling to block current harmonics. Shunt filters till dominate the harmonic compensation at medium/high voltage level, whereas active filters have been proclaimed for low/medium, voltage ratings. Passive filtering has been preferred for harmonic compensation in low voltage distribution systems due to low cost, simplicity reliability and control less operation. The uncontrolled ac-dc converters suffer from operating problems of poor power factor, injection of harmonics into the ac mains, variations in dc link voltage of input ac supply, equipment overheating due to harmonic current absorption, voltage distortion due to the voltage drop caused by harmonic currents flowing through system impedances, interference on telephone and communication line etc. This paper proposes a combination of cascaded H-bridge seven level inverter (CHSLI) based shunt hybrid power filter (SHPF) with thyristor controlled reactor (TCR) for harmonic elimination in high voltage(HV) systems. Sinusoidal pulse width modulation is used for generating gate signals to CHSLI and d-q theory is used for reference current generation, sinusoidal PWM for controlling CHMLI and fuzzy logic controller is used for stabilizing DC bus voltage.. Tuned passive filters are used for suppressing fifth and seventh harmonics in the load current. The proposed circuit topology is stimulated using MATLAB/ SIMULINK and the results were presented. The results shown that fuzzy logic controlled SHPF with TCR is superior in compensating for harmonics when compared to shunt passive filter, shunt active filter and shunt hybrid active filter.

KEYWORDS: Harmonic compensation, Shunt hybrid power filter, Tuned passive filer, Thyristor controlled reactor, Shunt active filter.

I INTRODUCTION

A three-phase hybrid passive filter (HPF) can be used to compensate for reactive power and harmonics. The HPF consists of a shunt passive filter and a thyristor-controlled-reactor-based variable-impedance shunt passive filter (SPF).The special features of the HPF system are it is insensitivity to source-impedance variations, no series or parallel resonance problems, fast dynamic response; and significant size reduction in an SPF capacitor[1]. An active power filter and static var compensator with active power generation capability has been implemented using a 27-level inverter. Each phase of this inverter is composed of three H-bridges, all of them connected to the same dc link and their outputs connected through output transformers. The filter can compensate load currents with a high harmonic content and a low power factor, resulting in sinusoidal currents from the source. To take advantage of this compensator, the dc link, instead of a capacitor, uses a battery pack, which is charged from a photovoltaic array connected to the batteries through a maximum power point tracker. This combined topology make it possible to produce active power and even to feed the loads during prolonged voltage outages[2].

A multi resolution control strategy is proposed for a digital signal processor (DSP)-controlled 400 Hz active power filter (APF) to reduce the real-time computational requirements. By rearranging the computational elements into high- and low-frequency control groups, the proposed control strategy takes best advantages of the DSP computation resources to increase the control frequency for the high computational group, which mainly determines the APF performance. Based on bandwidth features of different control plants in APF, detailed analysis is given to determine the control and sampling frequencies for these plants. Anti-aliasing filters are designed to avoid aliasing when down sampling scheme is used to further reduce computation resource[3]. In this paper, a three phase shunt active power filter with series connected TCR and shunt connected tuned passive filters are used for eliminating harmonics caused by three phase diode rectifier load. It exhibits better reduction in total harmonic distortion of the ac line current when compared with traditional ac side shunt APF.

II POWER QUALITY IMPROVEMENT USING SHUNT HYBRID POWER FILTER WITH TCR

A new combination of a shunt hybrid power filter (SHPF) and a TCR (SHPF-TCR) is proposed to suppress current harmonics and compensate the reactive power generated from the load. In the proposed topology, the major part of the compensation is supported by the passive filter and the TCR while the APF is meant to improve the filtering characteristics and damps the resonance, which can occur between the passive filter, the TCR, and the source impedance. The shunt APF when used alone suffers from the high kilo volt-ampere rating of the inverter, which requires a lot of energy stored at high dc-link voltage. On the other hand, as published by some authors, the standard hybrid power filter is unable to compensate the reactive power because of the behavior of the passive filter. Hence, the proposed combination of SHPF and TCR compensates for unwanted reactive power and harmonic currents. In addition, it reduces the volt-ampere rating of the APF part. A control technique is proposed to improve the dynamic response and decrease the steady-state error of the TCR. It consists of a PI controller and a lookup table to extract the required firing angle to compensate a reactive power consumed by the load. The currents injected by the SHAPF are controlled in the synchronous orthogonal d-q frame using a decoupled feedback linearization control method. The dc bus voltage is regulated using fuzzy logic controller. The SHPF can maintain the low level of dc bus voltage at a stable value. The proposed nonlinear control scheme has been simulated and validated to compute the performance of the proposed SHPF-TCR compensator with harmonic compensation and analysis through the total harmonic distortion (THD) of the source and the load current.

A)CIRCUIT DIAGRAM OF PROPOSED SYSTEM WITH SHPF AND TCR

Fig. 1 shows the topology of the proposed combined SHPF and TCR. The SHPF consists of a small-rating APF connected in series with TCR. The APF consists of a three-phase full-bridge voltage-source pulse width modulation (PWM) inverter with an input boost inductor (Lpf,Rpf)and a dc bus capacitor (Cdc). The APF sustains very low fundamental voltages and currents of the power grid, and thus, its rated capacity is greatly reduced. Because of these merits, the presented combined topology is very appropriate in compensating reactive power and eliminating harmonic currents in power system.

The tuned passive filters in parallel with shunt active power filter (SAPF) are mainly used for fifth and seventh harmonic compensation and PF correction. The small-rating APF is used to filter harmonics generated by the load and the TCR by enhancing the compensation characteristics of the SAPF aside from eliminating the risk of resonance between the grid and the SAPF. The TCR goal is to obtain a regulation of reactive power. The set of the load is a combination of a three phase diode rectifier and a three-phase star-connected resistive inductive nonlinear load.

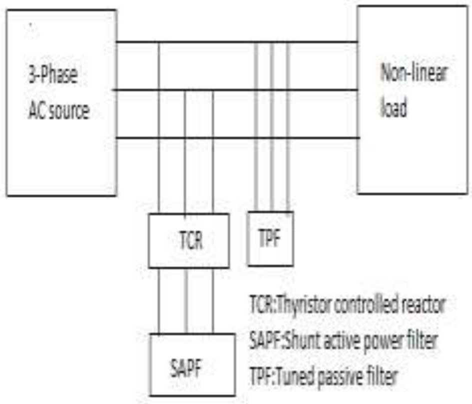


Fig. 1 Block diagram of proposed system with SHPF and TCR compensation.

B) CIRCUIT DIAGRAM OF TCR

A thyristor controlled reactor is a three-phase assembly, normally connected in a delta arrangement to provide partial cancellation of Harmonics. Often the main TCR reactor is split into two halves, with the thyristor valve connected between the two halves. This protects the vulnerable thyristor valve from damage due to flashovers, lightning strikes etc. The circuit diagram of TCR is shown in Fig.2.

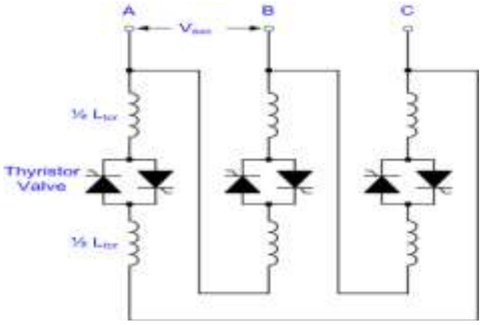


Fig. 2 Circuit diagram for thyristor controlled reactor.

III MATLAB/SIMULINK MODEL OF HV TEST SYSTEM WITH PROPOSED 7-LEVEL SHAPF WITH TCR COMPENSATION

E power source in the simulation model of HV test system is a three phase 4500 V(peak), 50 Hz sinusoidal AC voltage source. An inductance (L_s) which represents source and line combined inductance is connected in series with each phase to limit the inrush current. The selected value of L_s is 15 mH in each phase. It consists of a three-phase full-bridge diode rectifier with R-L load on DC side. The passive components in the load are R=20 ohm and L=0.1 mH .

The complete simulink model of the HV test system with proposed SHPF with TCR compensation is modelled using the MATLAB/Simulink and is depicted in Fig. 3. The proposed SHPF compensation consists of a seven level inverter (SLI) and its control system including d-q-0 theory based reference compensation current estimator, Constant switching frequency subharmonic PWM technique for switching signal generation , Fuzzy logic controller for DC bus voltage regulation, parallel connected tuned passive filters and TCR.

The DC bus voltages at all LV cells are measured and their average is taken and it is compared with reference voltage of 1.5 kV to generate error signal. The error and their derivatives are applied to FLC to obtain control signal which in turn applied to d-q theory based reference compensating current estimator to control the gating signals of VSI to maintain constant DC bus capacitor voltage at LV cell. The two inputs and the output use seven triangular membership functions namely Negative Big (NB), Negative Medium(NM), Negative Small(NS), Zero(ZE), Positive Small (PS),

Positive Medium(PM), Positive Big(PB). The triangular MFs are chosen in this work. The membership values of input and output variables are shown in the Fig. 4. A rule table relating each one of 49 input label pairs to respective output label is given in Table 1. The type of fuzzy inference engine used is Mamdani and the Centroid method is used for Defuzzification.

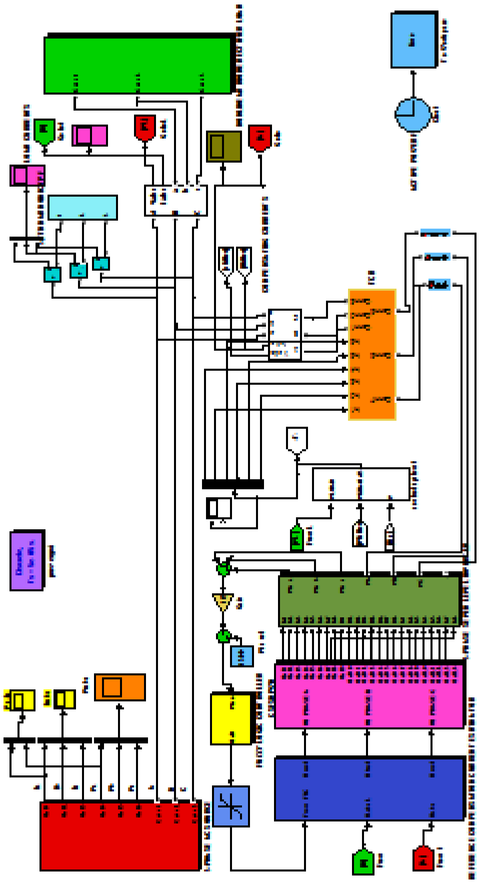
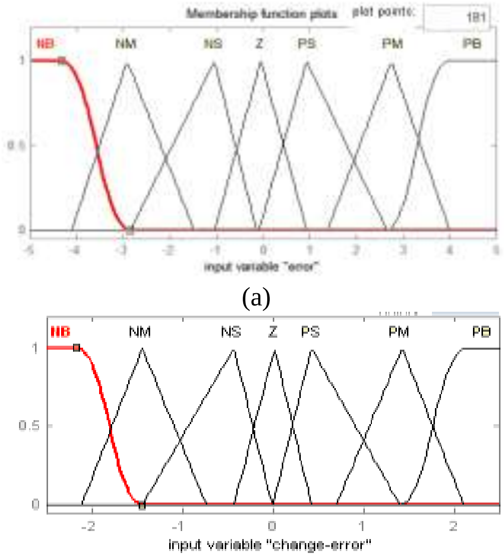
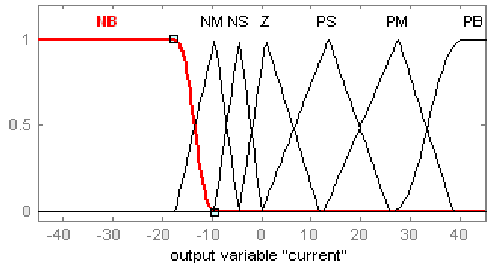


Fig. 3 Simulation model of HV test system with proposed 7-level SHAPF with TCR compensation



(a)

(b)



(c)

Fig. 4. The degree of membership functions for (a) The error (b) The derivative of error and (c) The output.

e / de	NB	NM	NS	ZE	PS	PM	PB
NB	NB	NB	NB	NB	NM	NS	ZE
NM	NB	NM	NM	NM	NS	ZE	PS
NS	NB	NM	NS	NS	ZE	PS	PM
ZE	NB	NM	NS	ZE	PS	PM	PB
PS	NM	NS	ZE	PS	PS	PM	PB
PM	NS	ZE	PS	PM	PM	PM	PB
PB	ZE	PS	PM	PB	PB	PB	PB

Table.5.1 Fuzzy rule representation

A)TCR CONTROLLER:

The simulink model of TCR controller is shown in Fig.5. The subsystem of TCR is shown in fig.6.

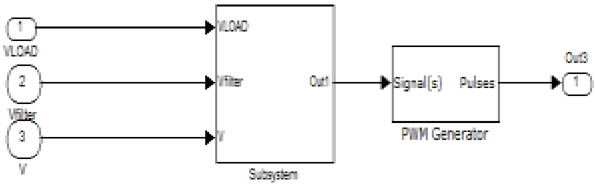


Fig. 5 TCR controller.

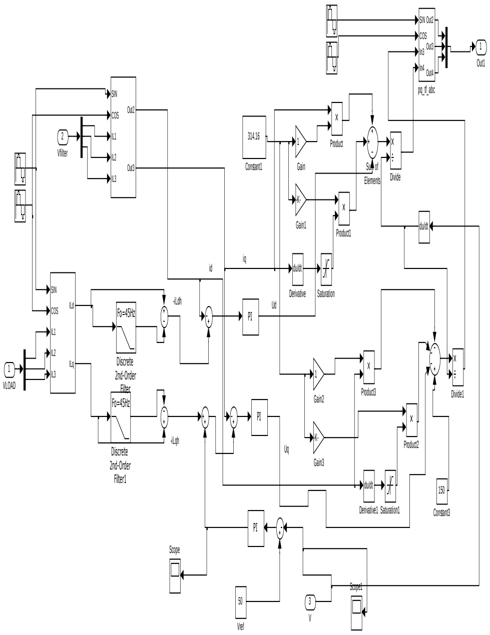
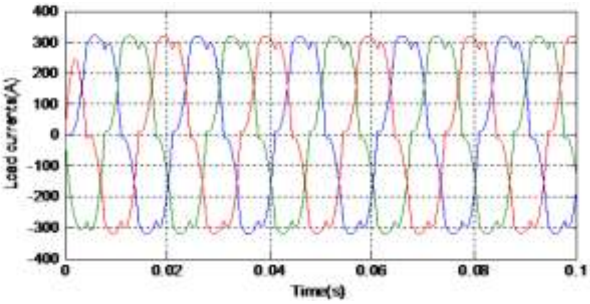


Fig. 6 Subsystem of TCR controller

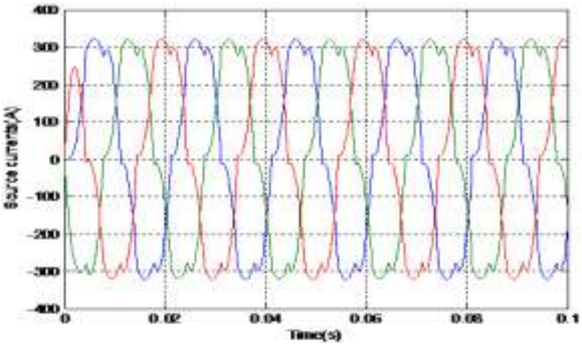
IV RESULTS

A)RESULTS OF HV TEST SYSTEM WITHOUT ANY COMPENSATION

Fig. 7 shows the simulation results of HV test system without any compensation. It shows three phase Load currents, source currents, source voltages, and phase angle comparison between source voltage and source current waveforms of phase-a. The resulting load current is highly distorted and leads to distortion in the source current and source voltage waveforms. The distortion in the source voltage waveform is due to the presence of source inductor (L_s) and distorted currents drawn by the load. The source voltage and source current for phase-a are shown in Fig. 7(d) in which it is seen that source current is out phase with source voltage leading to poor power factor.



(a)



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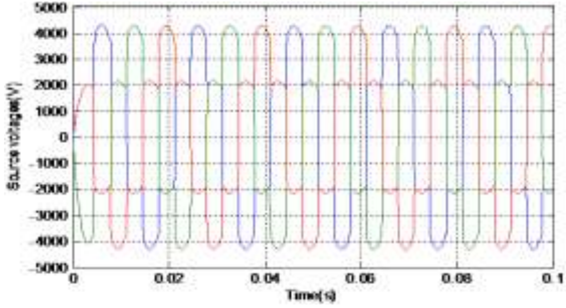

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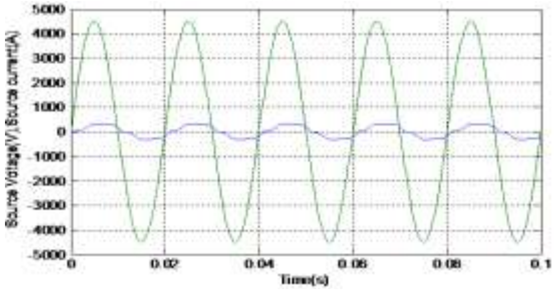


(d)

Fig. 7 Simulation results of HV test system without compensation a) Three phase nonlinear load currents b) Three phase source currents c) Three phase source voltages d) Phase angle comparison between source voltage and source current for phase-a.

B) RESULTS OF HV TEST SYSTEM WITH BASIC 7-LEVEL SAPF COMPENSATION

Fig. 8 shows the single phase seven level output voltage wave forms of asymmetric cascaded inverter based SAPF.

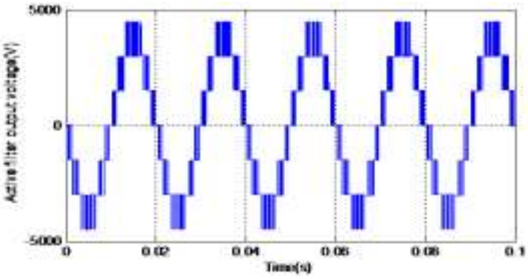
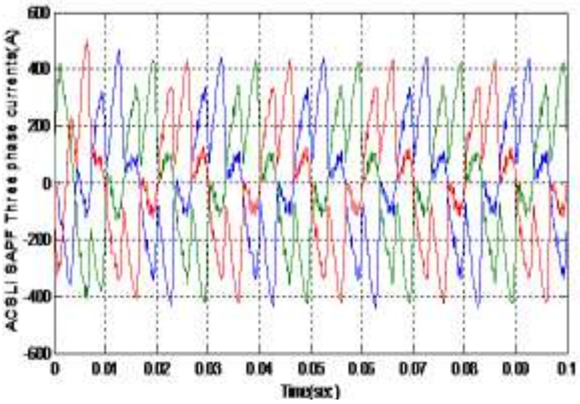
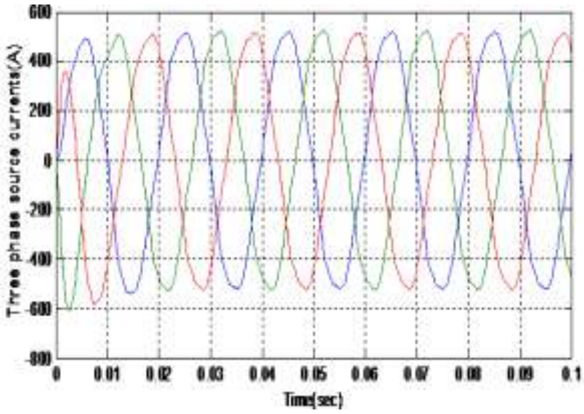


Fig. 8 Seven level voltages generated by the asymmetric cascaded inverter for (a) Phase-a.

From this Fig. 8, it is evident that the reference current estimator and CSFMCSH PWM method are worked satisfactorily and produced required gating signals for asymmetric cascaded seven level inverter to generate required seven level output voltage. The three phase compensating currents injected SLI SAPF for harmonic mitigation and three phase source currents after SAPF compensation are shown in Fig. 9.



(a)



(b)

Fig. 9. (a)Three phase SAPF currents and (b) Three phase source currents with SLI based SAPF compensation for HV test system.

From this Fig.9, it is seen that the harmonic content in the source current is very much reduced with SAPF compensation and the wave form attained near sinusoidal form compared to source current waveform without any compensation. It is observed that the load current is heavily distorted in phase–a and the ACSLI based SAPF has injected suitable harmonic current to compensate the load harmonics and hence the source current is almost pure sinusoidal. Also the filter current is injected at the PCC such that source current is sinusoidal and it is forced to be in phase with the voltage at the AC mains after compensation of SAPF, leading to near unity power factor asc shown in Fig 10.. The performance of SAPF mainly depends on the technique used for estimating reference signal for compensating currents and the method adopted to generate gating signals for voltage source inverter.

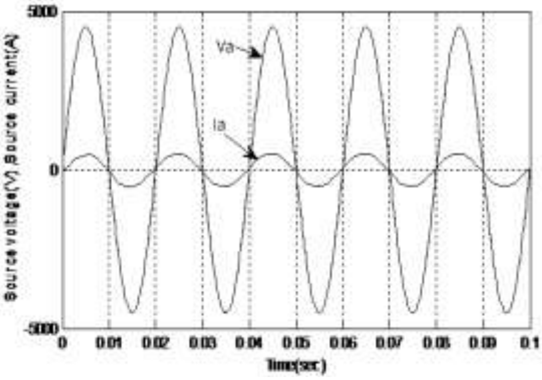


Fig. 10 Phase angle comparison between source voltage and source current for phase–a with SAPF compensation.

The Fig. 11 shows the DC bus capacitor voltage on LV cell. It is noted that the Fuzzy Logic Controller maintained 1.5 kV (LV cell) capacitor voltage constant.

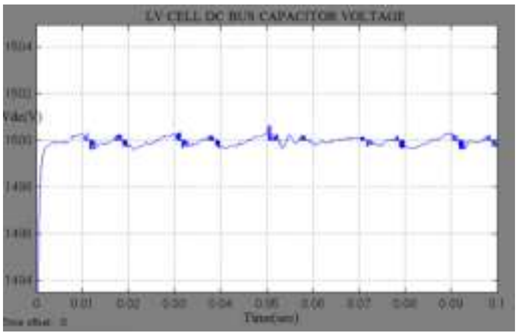


Fig. 11 DC bus capacitor voltage on LV cell.

C) Results of HV Test System with proposed Fuzz logic controlled SLI based SHPF with TCR Compensation

For the ease of comparison the load current, SAPF current, TPF current and source current for phase-a are given Fig. 12 when the HV system is compensated with SHPF and TCR.

It is seen that the combination of SAF current and tuned passive filter current effectively compensated for the harmonics in the load current.

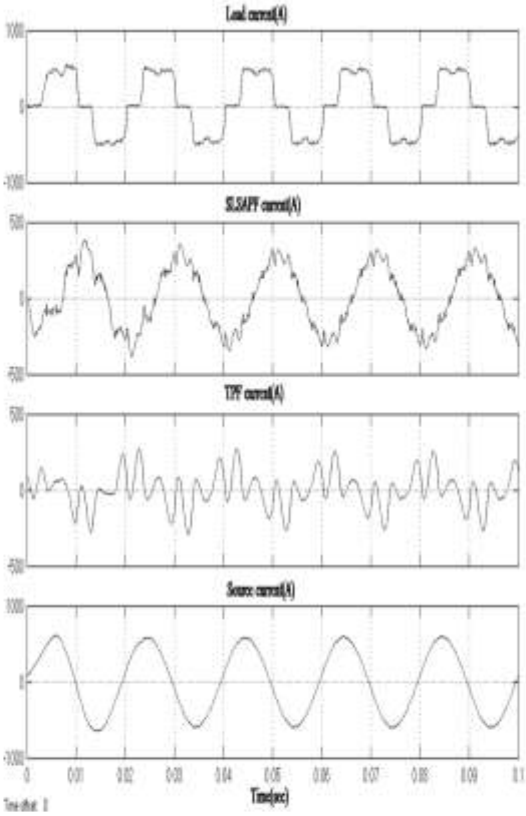
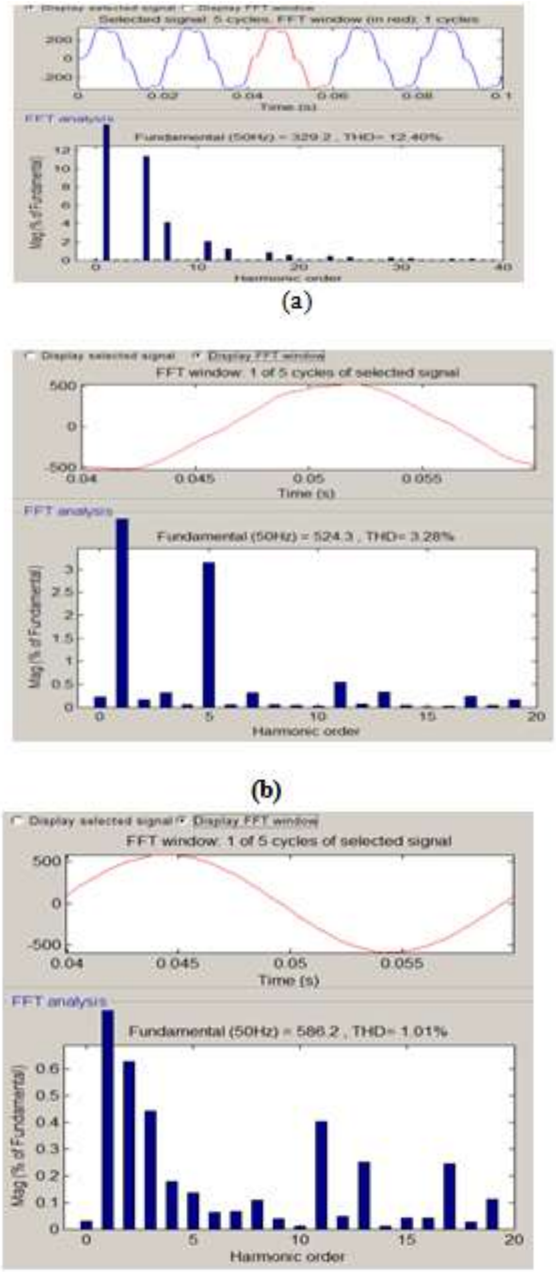


Fig. 12 Load current, SAF current, tuned passive filter current and source current for phase- a with SHAF and TCR compensation.

D) HARMONIC DISTORTION ANALYSIS FOR HV TEST SYSTEM

The spectrum of the source current without compensation is shown in Fig. 13(a) for phase-a. From the spectra plot, it can be seen that the source current contains large amount of harmonic current components of frequencies below 1 kHz and the THD in source current is 12.4%. It is seen that the most dominant are 5th and 7th order harmonics in the spectra plot.



(a)

(b)

(c)

Fig.13 Harmonic spectrum of phase–a source current of HV test system a) without any compensation. b) with SAPF c) with SHPF and TCR.

The spectrum of three phase source currents of HV test system with SAPF compensation is shown in Fig. 13(b). The ACSLISAPF successfully filtered the harmonic current components caused by the nonlinear load. Although the high frequency harmonic components (i.e.

greater than 1 kHz) are filtered significantly, appreciable amount of lower order harmonics still remain in the source current spectrum. The most dominant are 5th and 7th order harmonics. To eliminate these harmonics shunt tuned passive filters are connected in addition to SAPF in the proposed hybrid filter. The source current harmonic spectrum of HV test system with the proposed SAPF with TCR compensation is shown in Fig.13(c).

From the Fig. 13, it is seen that the proposed SAPF with TCR reduces the THD in nonlinear load current well below the limit specified by IEEE. This implies that the proposed hybrid APF effectively compensates the load current harmonics. The source current THD is reduced from 12.4 % to 3.51 % with SAPF and with the proposed SHPF with TCR, the source current THD is further reduced to 1.01 %. Thus, the harmonic filtering performance of the proposed SHPF with TCR topology is superior compared to SAPF which is well below the harmonic limit imposed by IEEE Standard 519. The source current THD comparison is carried out for SAPF and SHPF with TCR compensations in Table 2.

Table 2 THD Comparison of source current of HV system for different compensations.

Type of compensation	**THD (%)**		
	I_{sa}	**I_{sb}**	**I_{sc}**
Without compensation	12.4	12.4	12.4
With ACSLISAPF	3.51	3.28	3.44
With proposed ACSLISHAPF and TCR compensation	1.01	1.29	1.25

CONCLUSION

In this paper, a SHAPF-TCR compensator has been proposed to achieve harmonic elimination. A proposed nonlinear control scheme of a SHAPF-TCR compensator has been established and simulated. The shunt active filter and PF have a complementary function to improve the performance of filtering and to reduce the power rating requirements of an active filter. It has been found that the SHAPF-TCR compensator can effectively eliminate current harmonics and reactive power compensation during steady and transient operating conditions for a variety of loads. The system has a fast dynamic response, good performance in both steady-state and transient operations, and is able to reduce the THD of supply currents well below the limit of 5% of IEEE-519 standard.

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