Implementation of SHPF-TCR Suitable for Power Quality Issues at IT Parks

P. Nammalvar, L. Mahalakshmi

Abstract*—A widespread use of Computer technology in IT park leads to increased presence of distortion current and therefore to increased harmonics in the power system. The harmonics results into a poor power quality and have great adverse economic impact on the utilities and customers. This paper proposes a combined system of a thyristor-controlled reactor (TCR) and a shunt hybrid power filter (SHPF) for mitigating these problems. The main objective of this paper is to develop a novel SHPF-TCR for harmonic elimination and reactive power compensation. The SHPF is the combination of a small-rating active power filter (APF) and a LC passive filter. The tuned LC passive filter and the TCR form a shunt passive filter (SPF) to compensate reactive power. SVPWM technique is simulated to generate switching signal to Shunt Active Filter. Conventional PI controllers were used to control the compensation system. SVPWM technique is used in the present work for better utilization of dc bus voltage with efficient manner. The effectiveness of the compensator is verified through MATLAB Simulink. The simulation results are found to be quite satisfactory to mitigate harmonic distortions and reactive power compensation.

Keywords*—Harmonics, PI controller, Shunt Hybrid Power Filter, Thyristor Controlled Reactor, Space vector pwm, Point of common coupling.

I. INTRODUCTION

Global competition is ballooning, forcing companies to seek value and automate processes where ever possible. Computer technology is increasingly used to accomplish these goals, which means more compute power is required [1]. The growing use of non-linear and time varying loads has led to distortion of voltage and current wave forms and increased in reactive power demand in AC mains. Harmonic distortion is known to be source of several problems such as increased power losses, excessive heating of rotating machines, audible noise and incorrect operation of sensitive loads etc [2]. To design a more cost-effective power distribution system for modern computer systems, this paper defines mitigation technique using SHPF-TCR, discusses options that might be recommended to control Shunt Active Filter [1],[9].

Traditionally passive filters have been used to eliminate current harmonics of the supply network. However these devices are suffers from resonance. Recently the active filters were developed to mitigate the problems of passive filters and used to compensate the reactive power flow in the transmission line and The supply current is distorted by the non-linear loads such as UPS,DC drives, AC drives and arc furnaces etc.

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The THD obtained without using the shunt active filter is much more than described in the IEEE standard-519. According to this standard the THD value should be less than 5%. The THD equation for voltage harmonics is given by (1).

$$\%THD\ (V) = \frac{\sqrt{V_2^2+V_3^2+\cdots+V_n^2}}{V_1} \times 100 \tag{1}$$

and the THD equation for current harmonics is given by (2).

$$\%THD\ (I) = \frac{\sqrt{I_2^2+I_3^2+\cdots+I_n^2}}{I_1} \times 100 \tag{2}$$

In this paper, a new combination of a shunt hybrid power filter (SHPF) and a TCR (SHPF-TCR compensator) are proposed to suppress current harmonics generated from the load and compensate the reactive power.

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 filter in parallel with TCR forms a shunt passive filter (SPF) [3]. This latter is mainly for fifth 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 SPF aside from eliminating the risk of resonance between the grid and the SPF. 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 linear load [9].

A control technique is proposed to improve the dynamic response and decrease the steady state error of TCR. The shunt active filter needs to be controlled to obtain the best performance and thus PI controllers are used. The performance of shunt active filter here is studied under balanced and unbalanced source voltage condition for non-linear load. The simulation result shows that, this technology will throw light on the emerging solutions available for the power quality problem faced by IT parks, [8] especially with harmonics current and reactive power demand drawn by the non-linear loads.

Fig.1 shows the topology of the proposed combined SHPF and TCR. The SHPF consists of a small-rating APF connected in series with a tuned *LC* passive filter. In this paper, controlling of the shunt active filter using the PI controller with SVPWM technique is analyzed and studied.

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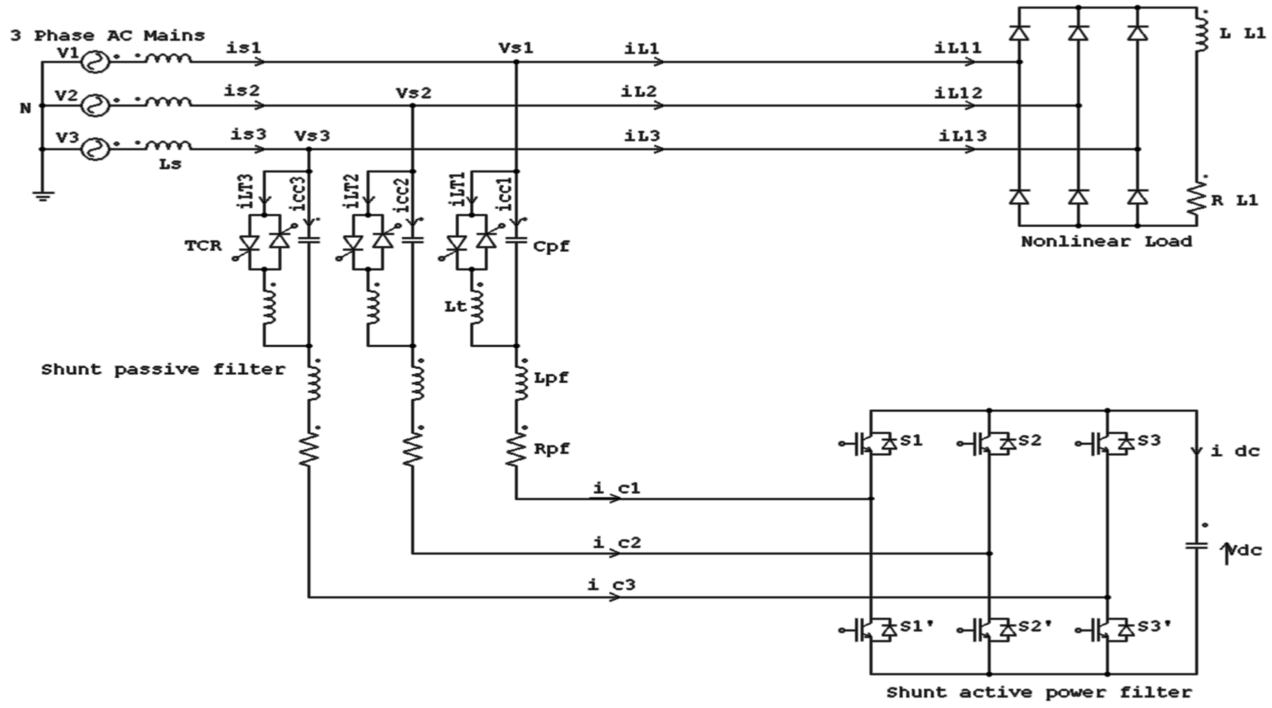

Fig. 1 SHPF-TCR Topology

In Section II, the type of the power filters and the compensation principle of the SHPF-TCR are explained. Section III focuses on the importance of the DC link voltage in the shunt active filter as well as its influence in the system and why to maintain it equal to the reference value. Section IV includes the simulation part and followed by Section V which deals with the results and its analysis. Section VI gives the final conclusion of this paper followed by references.

II. SYSTEM CONFIGURATION OF SHPF-TCR COMPENSATOR

A. Thyristor-Controlled Reactor

A linear air - cored reactor is connected in series with the anti-parallel connected thyristor is known as TCR. Fig .2 shows the schematic representation of the TCR [3]. The TCR goal is to obtain the regulation of reactive power. The anti-parallel connected thyristor pair acts like a bidirectional switch, with the thyristor valveT1 conducting in positive half cycles and the thyristor valve T2 conducting during the negative half cycle. The firing angle of the thyristors is measured from the zero crossing of the voltage appearing across its terminals.

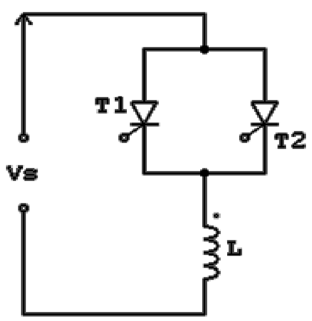

Fig. 2 Thyristor-controlled reactor

B. Shunt Hybrid Power Filter

The schematic diagram of the shunt hybrid power filter (SHPF) is presented in Fig.3. The scheme contains the supply voltage, diode rectifier and the filtering system consists of a small-rating active power filter connected in series with the LC passive filter. This configuration of hybrid filter ensures the compensation of the source current harmonics by enhancing the compensation characteristics of the passive filter besides eliminating the risk of resonance [4]. It provides effective compensation of current harmonics and limited supply voltage distortion. The hybrid filter is controlled such that the harmonic currents of the nonlinear loads flow through the passive filter and that only the fundamental frequency component of the load current is to be supplied by the ac mains.

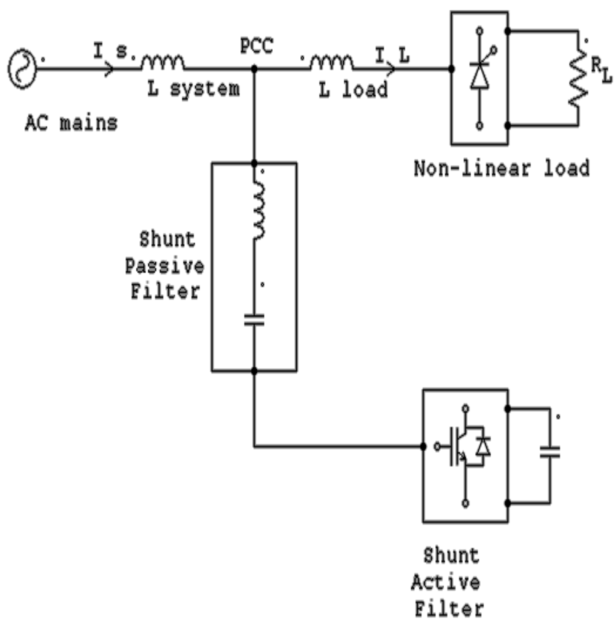

Fig. 3 Shunt Hybrid Power Filter circuit

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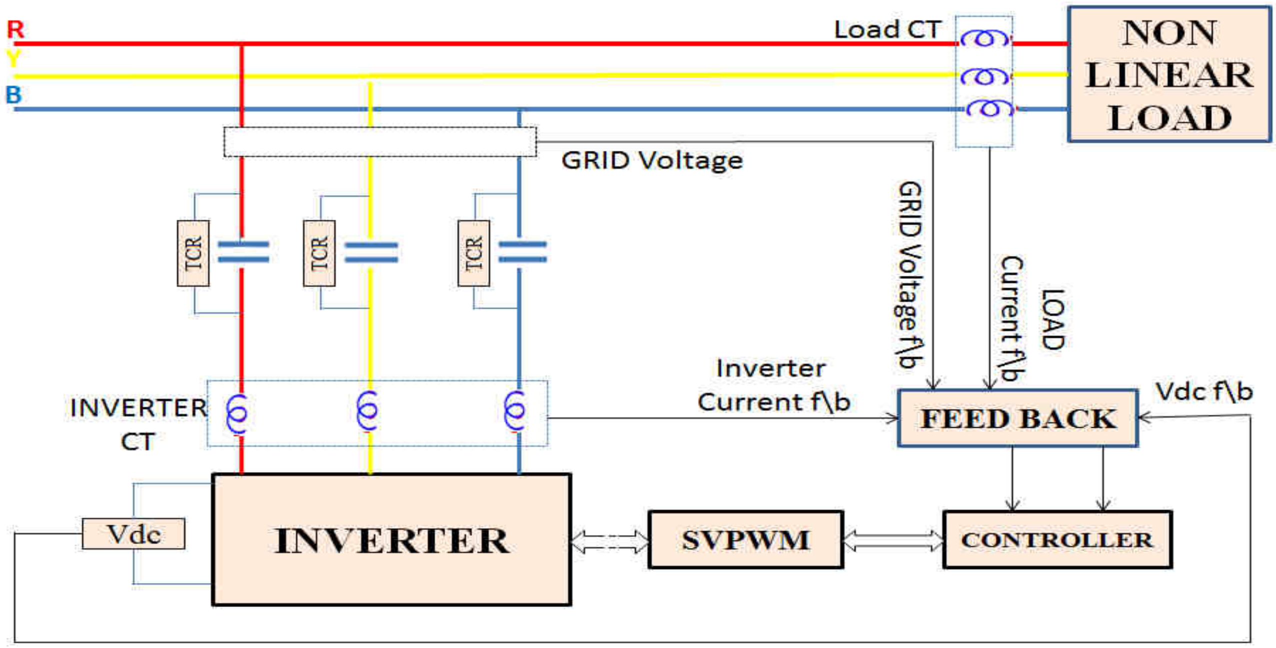

Fig. 4 Compensation Principle of a SHAF-TCR

The Active power filter is controlled by using PI controller to draw/supply the compensating current from/to the load to cancel out the current harmonics on AC side, to maintain the DC link voltage constant by maintaining the real power flow in the system and reactive power flow from/to the source, thereby making the source current in phase with source voltage [5], [6].

Fig. 4 shows Compensation Principle of a SHAF-TCR and it serves as an energy storage element to supply the real power difference between load and source during the transient period. When the load condition changes, the real power in the system i.e. between the mains and the load also changes. Due to this unbalance of the real power in the system the improper functioning of the system happens and thus the real power disturbance is cleared by the DC link capacitor and in doing so the voltage across the DC link capacitor changes away from the reference voltage. To obtain the optimal performance of the system, the peak value of the reference source current must be adjusted to proportionally change the real power drawn from the source. 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. In this fashion, the peak value of the reference source current can be obtained by regulating the average voltage of the DC capacitor.

III. DESIGN STRATAGY

A. DC Link Voltage Regulation

Whenever there is a sudden change in the load condition, the real power flowing in the system is disturbed and this needs to be settled down. The DC link voltage is used to balance the real power flow in the system and thus the voltage across the DC link capacitor changes [5],[8]. If the active power flowing into the filter can be controlled in such a way that it is equal to the losses inside the filter, the DC link voltage can be maintained at the desired value. Thus the main purpose of the active power filter is to maintain the DC link voltage and to give the compensating current to mitigate the current harmonics present in the system [7]. This paper represents the control offered by two different controllers to control the shunt hybrid power filter (SHPF). PI controller which is a linear controller is used to control SHPF and the results are analyzed.

B. Mathematical analysis

The system equations are elaborated here. The supply voltage is sinusoidal form but the supply current is non-sinusoidal form due the connection of Non-linear loads in the supply line. The supply current will be distorted by non-linear load.

The supply voltage is given by (3)

$$V_S = V_m \sin(\omega_1 t)\, s \tag{3}$$

Due to the Non-linear loads, the supply current contains the fundamental components and harmonic component,

$$\mathrm{iL(t)} = \sum_{k=1}^{\infty} \mathrm{Iksin}\,(\mathrm{k}\omega_1 t + \varphi k) \tag{4}$$

$$\mathrm{iL(t)} = I_1\ \mathrm{sk}\omega_1\mathrm{t} + \phi 1) + \sum_{K=2}^{\infty} IKsin(K\omega t + \varphi K) \tag{5}$$

Where,
I_1 = fundamental current
I_k = kth harmonic current
V_m = maximum supply voltage
Φ_k = phase angle between the supply voltage and current of the kth harmonic component.

The load current is given by

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$$i_L(t) = i_f(t) + i_h(t) \quad (6)$$

For harmonic elimination and reactive power compensation, the supply current should have the fundamental component and it should be in phase with supply voltage.
The supply current is given by,

$$I_s(t) = I_1 \sin(k\omega_1 t) = i_f(t) \quad (7)$$

The harmonic current can be given as

$$i_h(t) = i_{af}(t) + i_{pf}(t) \quad (8)$$

The load current is given as

$$i_L(t) = i_{af}(t) + i_{pf}(t) + i_s(t) \quad (9)$$

Where $i_{af}(t)$ = active filter current.

The equation (5) can be expressed as

$$i_L(t) = I_1 \sin(\omega t) \times cos\varphi_1 + I_{r1} + I_d + I_{hr} \quad (10)$$

Where

$$I_{r1} = I_1 \cos(\omega_1 t)\, sin\varphi_1 \quad (11)$$

$$I_d = i_{pf} = I_{dm} \sin\,(d\omega_1 t + \varphi_d) \quad (12)$$

$$I_{hr} = \sum_{k=2}^{\infty} IKsin(k\omega_1 t + \varphi_k) \quad (13)$$

for k ≠ d

The filter current is given by

$$i_{af} = I_{r1} + I_{hr} \quad (14)$$

Where,
I_{r1} = fundamental reactive current component
I_d= dominant harmonic current
d = dominant harmonic order
I_{hr} = remaining harmonic component of the supply current
ϕ = phase angle between corresponding current and supply voltage.

The Zpf is the resonant filter tuned for the dominant frequency, so that it will inject the I_{pf} to the supply mains. The shunt active filter will inject the I_{hr} and the I_{r1} current so that the supply is free from the harmonics and the power factor[13] is near to unity.

C. The dq transformation theory

The time domain reference signal estimation technique is used for dq transformation. The dq components (i_{std},i_{stq}) are filtered by Bessels filter.

DIRECT AXIS FRAME:

$$i_{std} = 0.67(i_{sta} \sin(\omega_1 t) - i_{stb} \sin(\omega_1 t - 2\pi/3) + istc\sin\omega 1t{+}2\pi 3 \quad (15)$$

QUATRATURE AXIS FRAME:

$$i_{stq} = 0.67(i_{sta} \cos(\omega_1 t) - i_{stb} \cos(\omega_1 t - 2\pi/3) + i_{stc} \cos(\omega_1 t + 2\pi/3)) \quad (16)$$

The ripple content present in the dq component is filtered using the bessels filter and it will be transformed into a-b-c coordinates to obtain the fundamental component of supply.

$$I_{ra} = i_d sin(\omega_1 t) + i_q cos(\omega_1 t) \quad (17)$$

$$I_{rb} = i_d sin(\omega_1 t - 2\pi/3) + i_q cos(\omega_1 t - 2\pi/3) \quad (18)$$

$$I_{rc} = i_d sin(\omega_1 t + 2\pi/3) + i_q cos(\omega_1 t + 2\pi/3) \quad (19)$$

Where I_{ra},I_{rb},I_{rc} are the reference currents and i_{sta},i_{stb},i_{stc} are the three phase supply current.

IV. CONTROL STRATAGY

A. Dc link with pi controller

PI control With a view to have a dc bus of self- regulated, the capacitor voltage is sensed at regular intervals and controlled by employing a suitable closed loop control. The dc link voltage is sensed at a regular interval and is compared with its reference counterpart v dc*. The error signal is processed in a PI controller [11]. A limit is put on the output of controller this ensures that the source supplies active power of the load and dc bus of the SHPF Later part of active power supplied by source is used to provide a self-supported dc link of the SHPF-TCR Thus, the dc bus voltage of the SHPF is maintained to have a proper current control. With the primary PLL loop, a change in the system load will result in a steady state time voltage and current flickering depending on the load In order to reduce the time deviation to zero, a reset action is to be provided.

B. Space vector PWM

The Space Vector Modulation was tried out in the present study as it optimally utilizes the DC bus voltage in the linear modulation range. However, the implementation of the space vector modulation technique by means of sector identification and dwelling time calculation is computationally complex [9].The principle of space vector PWM in three-phase mathematical system can be represented by a space vector. For example, known a set of three-phase voltages, a space vector can be distinct by (20)

$$v(t) = \frac{2}{3}\left[v_a(t)e^{i\theta} + v_b(t)e^{j\frac{2\pi}{3}} + v_c(t)e^{i\frac{4\pi}{3}}\right] \quad (20)$$

where Va(t), Vb(t), and Vc(t) are three sinusoidal voltages of the same amplitude and frequency but with ± 120ºphase shifts. The space vector at any given time maintains its magnitude. Therefore the space vector modulation was implemented by the conventional naturally sampled sinusoidal [12], with a special type of zero sequence component mixed to the sine references. This modified sinusoidal PWM references can be shown to be same as the space vector references.

Steps involved in the derivation of new space vector modulating signals from three phase sinusoidal references are [5], [9].

1. Find the three phase references for sinusoidal pulse

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width modulation (SPWM).

2. Compute the minimum of the absolute references at each instant.
3. Add half the value of the reference sinusoid of minimum absolute value at each instant to all three SPWM references, as offset.

Compare the modified SPWM references to triangular carrier wave to generate the space vector PWM (SVPWM) pulses. The SPWM reference, the offset and the modified SPWM reference for one phase generated are shown in Fig. 5. Though the phase voltage reference of modified space vector modulation is not sinusoidal (and contains a zero sequence component), the line to line voltage will be purely sinusoidal as the zero sequence component will get cancelled in the line to line voltage [10].

Equating real and imaginary part, we obtain (21) and (22):

$$v_\alpha = \frac{2}{3}\left[v_a + v_b \cos\left(\frac{2\pi}{3}\right) + v_c \cos\left(\frac{2\pi}{3}\right)\right] \tag{21}$$

$$v_\beta = \frac{2}{3}\left[v_b \sin\left(\frac{2\pi}{3}\right) + v_c \cos\left(\frac{2\pi}{3}\right)\right] \tag{22}$$

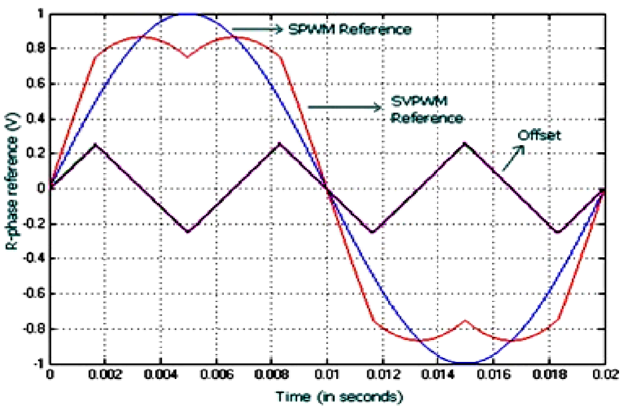

Fig. 5 Generation of SVPWM Reference Signal

The SVPWM reference is same as that of space vector modulation proving the equivalence. Naturally SVPWM compares a low frequency target reference waveform ref V (usually a sinusoid) against a high frequency carrier waveform. The phase leg is switched to the upper DC rail when the reference waveform is greater than the triangular carrier and to the lower DC rail when the carrier waveform is greater than the reference waveform.

C. Simulation circuit

The control algorithm discussed in pervious section has been validated by simulating in MATLAB software. The schematic representation of simulation circuit for the combination of shunt hybrid power filter and thyristor controlled reactor in reactive power compensation and harmonic elimination is shown in fig 6. The By considering grid voltage, drop across choke and losses, the DC bus voltage was fixed at 600V. Then the voltage controller of the shunt active filter was activated and the DC bus voltage was boosted to 600V. Once the DC bus voltage reached 600V, the current controller was activated to start harmonic compensation.

V. SIMULATION RESULTS

The simulation results of various model of the present work are presented.

A. Before compensation

The Non-linear load has been connected to AC supply. The source current I_S is shown in the figure 7 and the source voltage V_S is shown in the figure 8.

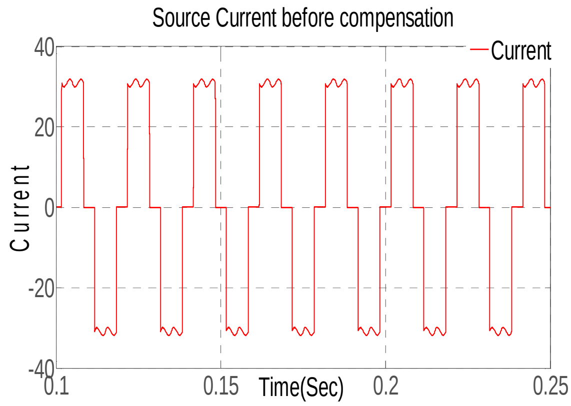

Fig. 7: Source current before compensation

The distortion in this current is due to the presence of Non – linear loads in the electrical networks.

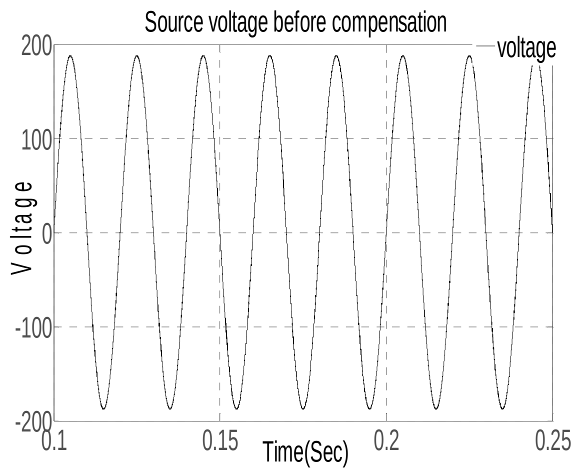

Fig. 8: source voltage after compensation

The voltage from the Ac supply is pure sinusoidal in nature.

B. Compensating current

The compensating current will be produced by the shunt active filter circuit by means of using the P_{loss} and the supply value. This resultant value will be given to the voltage source inverter such that the switches in the voltage source inverter will starts to perform its function properly.

As a result the compensating current will be produced which in equal and opposite phase to the supply component, Which eliminates the harmonic content present in the source voltage and source current. The compensating current is injected in parallel to the transmission line. The compensating current is shown in figure 9.

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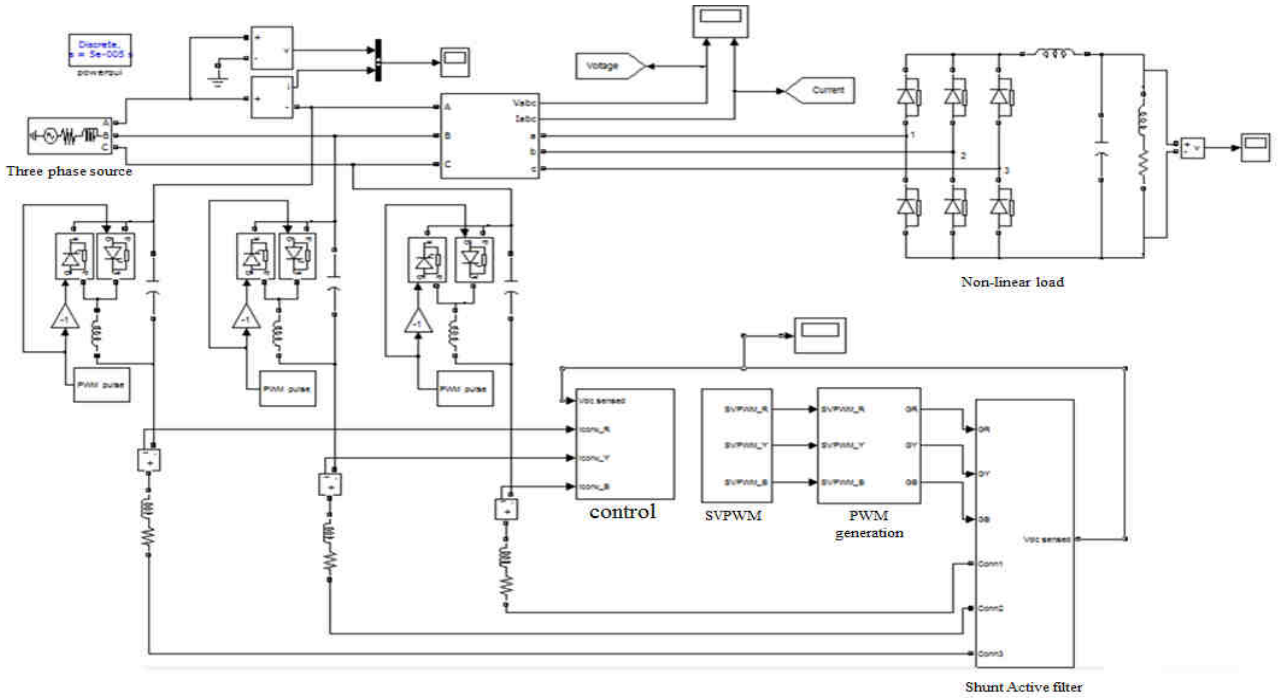

Fig. 8 Simulation Circuit Diagram of SHPF-TCR

The equivalent and opposite of the reactive current load current was supplied by the SHPF-TCR. Therefore the load draws only active current from the grid.

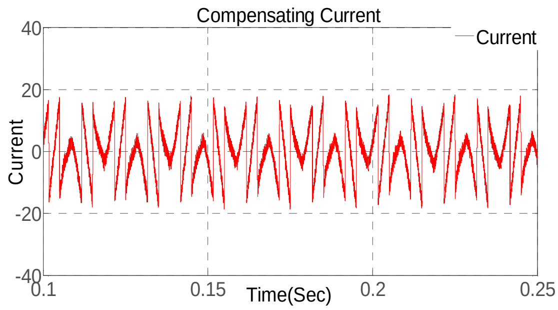

Fig. 9: Waveform of the compensating current by shunt active filter

C. After compensation

The distortion in the load current can be eliminated by the SHPF-TCR by means of using the compensating current. The source current with the SHPF-TCR is obtained as in fig 10,

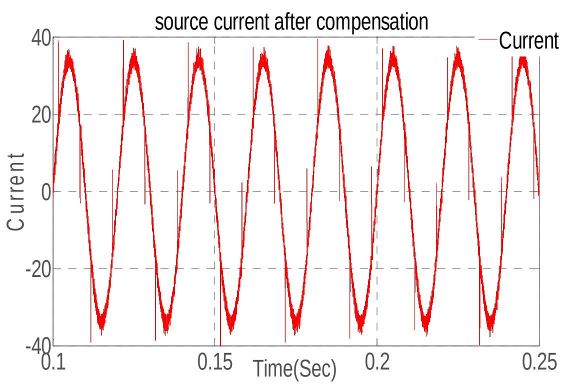

Fig. 10: Source current after compensation

The load voltage is obtained as in the figure 11 which is compensated by the inclusion of SHPF-TCR in the transmission line.

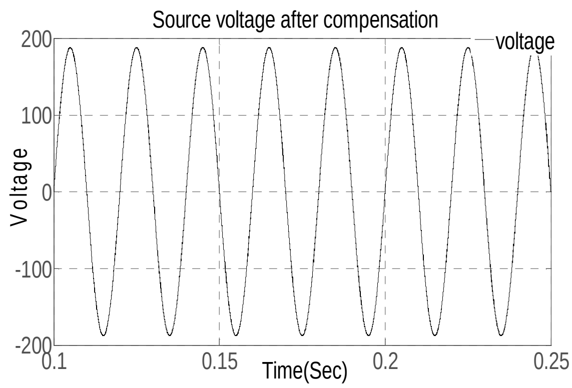

Fig. 11: Source voltage after compensation

D. THD analysis

To determine the reduction of harmonic current compensation of total harmonic distortion by using the FFT analysis in MATLAB Simulink models in Figs. 12 and 13.

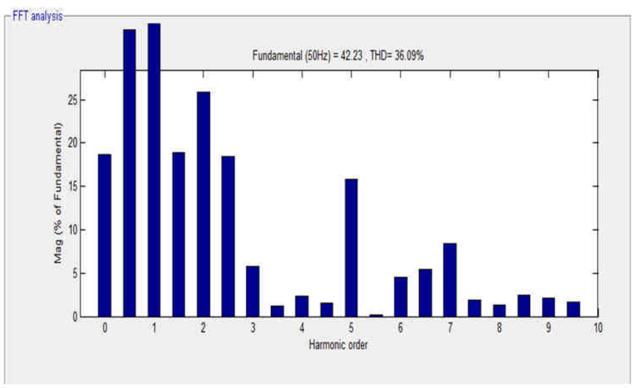

Fig. 12: THD Analysis of Before Compensation

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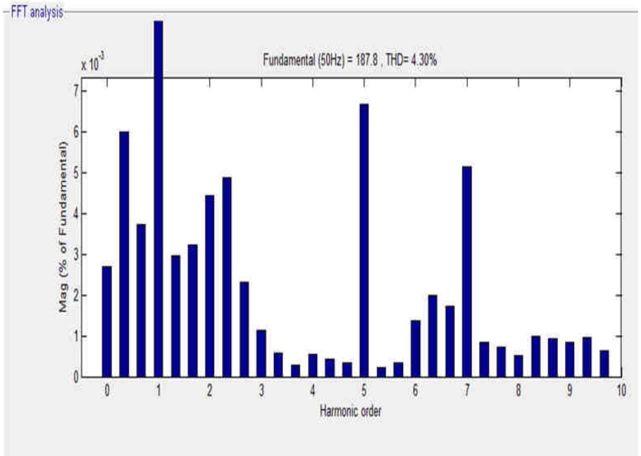

Fig. 13: THD Analysis of After Compensation

E. Real and reactive power compensation

The reactive power flow in the transmission line can be compensated by means of varying the firing angle of the thyristor-controlled reactor (TCR). The figure 14 gives the compensation of reactive power,

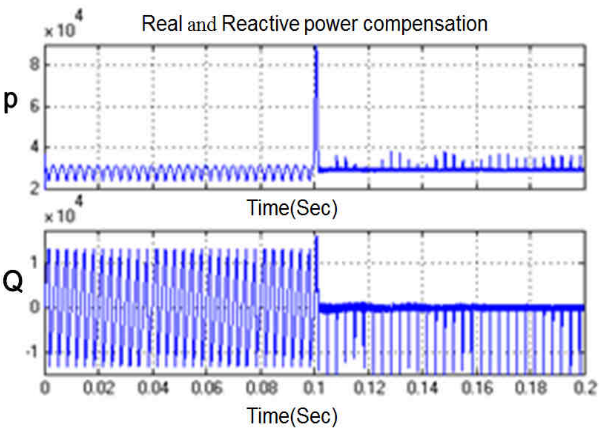

Fig. 14: Waveform of Real and Reactive power compensation

The reactive power flow in the transmission line is reduced by the thyristor- controlled reactor (TCR) and the flow control can be achieved by means of varying the susceptance of the inductor in the transmission line.

VI. CONCLUSION

In this work sources and effects of Harmonics and Reactive power, reactive power compensation principle and reactive and harmonics compensation devices are discussed in details. Combination of thyristor-controlled reactor and shunt hybrid power filter has been proposed in order to achieve the harmonic elimination and reactive power compensation. The waveforms and THD analysis are done using MATLAB simulink shows the reduction in supply current harmonics and compensation of reactive power flow in the transmission line. Thus, the combination of shunt hybrid power filter and thyristor controlled reactor is used to improve the performance in power quality.

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