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Power Quality Improvement using Hybrid Power Filter-TCR with Fuzzy logic Control



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Abstract:

Power system harmonics are a menace to electric power systems with disastrous consequences. The line current harmonics cause increase in losses, instability, and also voltage distortion. With the proliferation of the power electronics converters and increased use of magnetic, 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 still dominate the harmonic compensation at medium/high voltage level, whereas active filters have been proclaimed for low/medium voltage ratings. In this paper combination of a thyristor-controlled reactor (TCR) and a shunt hybrid power filter (SHPF) for harmonic and reactive power compensation. The SHPF is the combination of a small-rating active power filter (APF) and a fifth-harmonic-tuned LC passive filter. The tuned passive filter and the TCR form a shunt passive filter (SPF) to compensate reactive power. A proportional–integral controller was used, and a triggering alpha was extracted using a lookup table to control the TCR. The proposed work study the compensation principle and different control strategies used here are based on PI/FUZZY controller of the shunt and TCR active filter in detail. The control strategies are modelled using MATLAB/SIMULINK

Index Terms:

Harmonic Suppression, Hybrid Power filter, Modeling, Hybrid Power filter And Thyristor-Controller Dreactor (SHPF-TCR Compensator), Fuzzy Logic Controller.

I. INTRODUCTION:

Nonlinear loads cause voltage and current waveforms distortion in the ac power network. It results in harmonic related problems including substantially higher transformer and line losses, reactive power and resonance problems, over-voltages, over-heating, Electro Magnetic Interference (EMI) problems, and other undesirable effects. The result is reducing system stability. Passive filters alone have been traditionally used to eliminate the harmonics in utilities due to their low cost and high efficiency. Shunt-connected passive filters, tuned to show low impedances at different dominant harmonic frequencies, are widely used. However, these filters have multiple drawbacks including that at fundamental frequency they generate fixed quantity of reactive power affecting sometimes the voltage regulation at the PCC. Active filters were developed to mitigate problems of passive filters. They are more effective in harmonic compensation and improved system performance [1]. But using only active filters is a very expensive solution because it requires comparatively high power converter ratings. Hybrid Active Filter (HAF) topologies which combine the advantages of both active and passive filters [4]-[6] is more appealing in terms of cost and performance.To overcome of such problem active power filters is introduced. It has no such drawbacks like passive filter. They inject harmonic voltage or current with appropriate magnitudes and phase angle into the system and cancel harmonics of nonlinear loads. But it has also some drawbacks like high initial cost and high power losses due to which it limits there wide application, especially with high power rating system. [3]-[5].They are more effective in harmonic compensation and have good performance[6]– [8].However, the costs of active filters are relatively high for large-scale system and require high power converter ratings[9],[10]. To minimize these limitations, hybrid power filter have been introduced and implemented in practical system applications. Shunt hybrid filter consists of an active filter which is connected in series with the passive filter and with a three phase PWM inverter. This filter effectively mitigates the problem of a passive and active filter. It provides cost effective harmonic compensation, particularly for high power nonlinear loads. Hybrid filters effectively soften the problems of the passive filter and an active filter solution and provide cost-effective harmonic compensation, particularly for high-power nonlinear loads [11]–[14]. Many control techniques such as instantaneous reactive power theory, synchronous rotating reference frame, neural network techniques, nonlinear control, feed forward control, Lyapunov-function-based control, etc., have been used to improve the performance of the active and hybrid filters. Several filter topologies for compensating harmonics and reactive power have been reported in the literature. In a combination of a thyristor controlled reactor (TCR) and a resonant impedance type hybrid APF for harmonic cancellation, load balancing, and reactive power compensation has been proposed.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. These works study the compensation principle and different control strategies used here are based on PI/FUZZY controller of the shunt and TCR active filter in detail. The control strategies are modelled using MATLAB/SIMULINK. The performance is also observed under influence of utility side disturbances such as harmonics, flicker and spikes with Non-Linear and Reactive Loads. The simulation results are listed in comparison of different control strategies and for the verification of results.

II. SYSTEM CONFIGURATION OF SHPF-TCR COMPENSATOR:

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 fifth-tuned LC passive filter. 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 filter in parallel with TCR forms a shunt passive filter (SPF).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.

III. MODELING AND CONTROL STRATEGY:

A. Modeling of SHPF:

The system equations are first elaborated in 123 reference frame. Using Kirchhoff's voltage law, one can write

$$\begin{aligned}
v_{s1} &= L_{\text{PF}}\frac{di_{c1}}{dt} + R_{\text{PF}}i_{c1} + v_{\text{CPF1}} + v_{1M} + v_{\text{MN}}\\
v_{s2} &= L_{\text{PF}}\frac{di_{c2}}{dt} + R_{\text{PF}}i_{c2} + v_{\text{CPF2}} + v_{2M} + v_{\text{MN}}\\
v_{s3} &= L_{\text{PF}}\frac{di_{c3}}{dt} + R_{\text{PF}}i_{c3} + v_{\text{CPF3}} + v_{3M} + v_{\text{MN}}\\
v_{\text{CPF1}} &= L_T\frac{di_{c1}}{dt} - C_{\text{PF}}L_T\frac{d^2v_{\text{CPF1}}}{dt^2}\\
v_{\text{CPF2}} &= L_T\frac{di_{c2}}{dt} - C_{\text{PF}}L_T\frac{d^2v_{\text{CPF2}}}{dt^2}\\
v_{\text{CPF3}} &= L_T\frac{di_{c3}}{dt} - C_{\text{PF}}L_T\frac{d^2v_{\text{CPF3}}}{dt^2}\\
\frac{dv_{\text{dc}}}{dt} &= \frac{1}{C_{\text{dc}}}i_{\text{dc}}.
\end{aligned} \tag{1}$$

The switching function ck of the kth leg of the converter (for k = 1, 2, 3) is defined as

$$c_k = \begin{cases} 1, & \text{if } S_k \text{ is On and } S'_k \text{ is Off} \\ 0, & \text{if } S_k \text{ is Off and } S'_k \text{ is On.} \end{cases} \tag{2}$$

A switching state function dnk is defined as

$$d_{\text{nk}} = \left(c_k - \frac{1}{3}\sum_{m=1}^{3} c_m\right)_n \tag{3}$$

Moreover, the absence of the zero sequence in the ac currents and voltages and in the [dnk] functions leads to the following transformed model in the three-phase coordinates [14]:

$$L_{\mathrm{PF}}\frac{di_{c1}}{dt} = -R_{\mathrm{PF}}i_{c1} - d_{n1}v_{\mathrm{dc}} - v_{\mathrm{CPF1}} + v_{s1}$$

$$L_{\mathrm{PF}}\frac{di_{c2}}{dt} = -R_{\mathrm{PF}}i_{c2} - d_{n2}v_{\mathrm{dc}} - v_{\mathrm{CPF2}} + v_{s2}$$

$$L_{\mathrm{PF}}\frac{di_{c3}}{dt} = -R_{\mathrm{PF}}i_{c3} - d_{n3}v_{\mathrm{dc}} - v_{\mathrm{CPF3}} + v_{s3}$$

$$C_{\mathrm{dc}}\frac{dv_{\mathrm{dc}}}{dt} + \frac{v_{\mathrm{dc}}}{R_{\mathrm{dc}}} = d_{n1}i_{c1} + d_{n2}i_{c2} + d_{n3}i_{c3}. \tag{4}$$

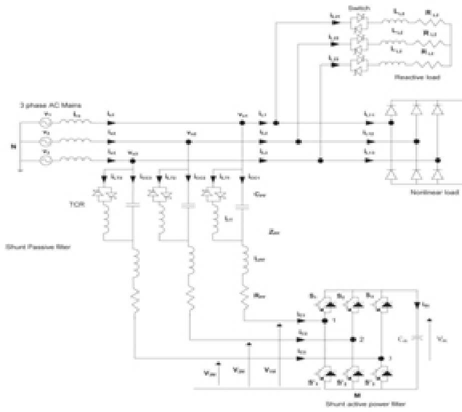

Fig.1. Basic circuit of the proposed SHPF-TCR compensator.

The system of (4) is transformed into the synchronous orthogonal frame using the following general transformation matrix:

$$C_{dq}^{123} = \sqrt{\frac{2}{3}}\begin{bmatrix} \cos\theta & \cos(\theta - 2\pi/3) & \cos(\theta - 4\pi/3) \\ -\sin\theta & -\sin(\theta - 2\pi/3) & -\sin(\theta - 4\pi/3) \end{bmatrix} \tag{5}$$

Where $\theta = \omega t$ and the following equalities hold:

$$C_{123}^{dq} = (C_{dq}^{123})^{-1} = (C_{dq}^{123})^{T}$$

Then, by applying dq transformation, the state space model of the system in the synchronous reference frame This model is nonlinear because of the existence of multiplication terms between the state variables {id, iq, Vdc} and the switching state function {dnd, dnq}. However, the model is time invariant during a given switching state. Furthermore, the principle of operation of the SHPF requires that the three state variables have to be controlled independently.

The interaction between the inner current loop and the outer dc bus voltage loop can be avoided by adequately separating their respective dynamics.

B.Harmonic Current Control:

A fast inner current loop, and a slow outer dc voltage loop, is adopted. The first two equations in the model can be written as shown in the Appendix by (27). Note that the first and the second time derivative TCR capacitor voltages have no significant negative impact on the performance of the proposed control technique because their coefficients are too low. Consequently, they can practically be ignored. Define the equivalent inputs by (28) as given in the Appendix.

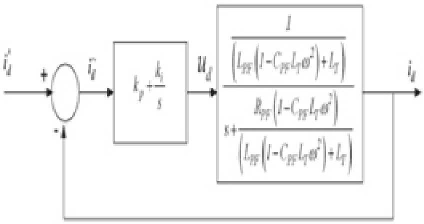

Fig.2.Inner Control loop of The Current id.

Thus, with this transformation, the decoupled dynamics of the current tracking is obtained. The currents id and iq can be controlled independently. Furthermore, by using proportional integral compensation, a fast dynamic response and zero steady-state errors can be achieved. The expressions of the tracking controllers are

$$u_d = \left(L_{\mathrm{PF}}(1 - C_{\mathrm{PF}}L_T\omega^2) + L_T\right)\frac{di_d}{dt} + R_{\mathrm{PF}}(1 - C_{\mathrm{PF}}L_T\omega^2)i_d$$

$$= k_p\tilde{i}_d + k_i\int \tilde{i}_d dt$$

$$u_q = \left(L_{\mathrm{PF}}(1 - C_{\mathrm{PF}}L_T\omega^2) + L_T\right)\frac{di_q}{dt} + R_{\mathrm{PF}}(1 - C_{\mathrm{PF}}L_T\omega^2)i_q$$

$$= k_p\tilde{i}_q + k_i\int \tilde{i}_q dt$$

The transfer function of the proportional–integral controllers is given as

$$G_{i1}(s) = \frac{U_d(s)}{\tilde{i}_d(s)} = k_{p1} + \frac{k_{i1}}{s}$$

$$G_{i2}(s) = \frac{U_q(s)}{\tilde{i}_q(s)} = k_{p2} + \frac{k_{i2}}{s} \tag{7}$$

The inner control loop of the current *id* is shown in Fig.2. The closed-loop transfer functions of the current loops are

$$\frac{I_d(s)}{I_d^*(s)} = \frac{k_{p1}}{A}\frac{\left(s+\frac{k_{i1}}{k_{p1}}\right)}{s^2+\left(\frac{B+k_{p1}}{A}\right)s+k_{i1}}$$

$$\frac{I_q(s)}{I_q^*(s)} = \frac{k_{p2}}{A}\frac{\left(s+\frac{k_{i2}}{k_{p2}}\right)}{s^2+\left(\frac{B+k_{p2}}{A}\right)s+k_{i2}} \tag{8}$$

The closed-loop transfer functions of the current loops have the following form:

$$\frac{I_d(s)}{I_d^*(s)} = 2\zeta\omega_{\text{ni}}\frac{s+\frac{\omega_{\text{ni}}}{2\zeta}}{s^2+2\zeta\omega_{\text{ni}}s+\omega_{\text{ni}}^2}$$

Where ω ni is the outer loop natural angular frequency and ζ is the damping factor. For the optimal value of the damping factor ζ = √2/2, the theoretical overshoot is 20.79%. The following design relations can be derived:

$$k_{\text{p1}} = k_{\text{p2}} = 2\zeta\omega_{\text{ni}}\left(L_{\text{PF}}\left(1-C_{\text{PF}}L_T\omega^2\right)+L_T\right)-R_{\text{PF}}\left(1-C_{\text{PF}}L_T\omega^2\right)$$

$$k_{i1} = k_{i2} = \left(L_{\text{PF}}\left(1-C_{\text{PF}}L_T\omega^2\right)+L_T\right)\omega_{\text{ni}}^2$$

The control law is given in the Appendix by (29) and (30). Note that the inputs qnd and qnq consist of a nonlinearity cancellation part and a linear decoupling compensation part.

C. DC Bus Voltage Regulation:

In order to maintain the dc bus voltage level at a desired value, acting on iq can compensate the losses through the hybrid power filter components. The output of the controller is added to the q-component current reference iq as shown in Fig. 4. The third equation in the model (6) is rewritten

$$C_{\text{dc}}\frac{dv_{\text{dc}}}{dt}+\frac{v_{\text{dc}}}{R_{\text{dc}}} = d_{\text{nq}}i_q \tag{10}$$

The three-phase filter currents are given by

$$\begin{bmatrix} i_{c1} \\ i_{c2} \\ i_{c3} \end{bmatrix} = \sqrt{\frac{2}{3}}i_q\begin{bmatrix} -\sin\theta \\ -\sin\left(\theta-\frac{2\pi}{3}\right) \\ -\sin\left(\theta-\frac{2\pi}{3}\right) \end{bmatrix} \tag{11}$$

The fundamental filter rms current *Ic* is

$$I_c = \frac{i_q}{\sqrt{3}}. \tag{12}$$

The *q*-axis active filter voltage *v*Mq is expressed as

$$v_{\text{Mq}} = q_{\text{nq}}v_{\text{dc}} = -Z_{\text{PF1}}i_{q1}^* \tag{13}$$

Where *ZPF*1 is the impedance of the passive filter at 60 Hz and *i** *q*1 is a dc component.
An equivalent input *u*dc is defined as

$$u_{\text{dc}} = q_{\text{nq}}i_q \tag{14}$$

The control effort of the dc voltage loop is deduced

$$i_{q1}^* = \frac{v_{\text{dc}}}{-Z_{\text{PF1}}i_q}u_{\text{dc}}. \tag{15}$$

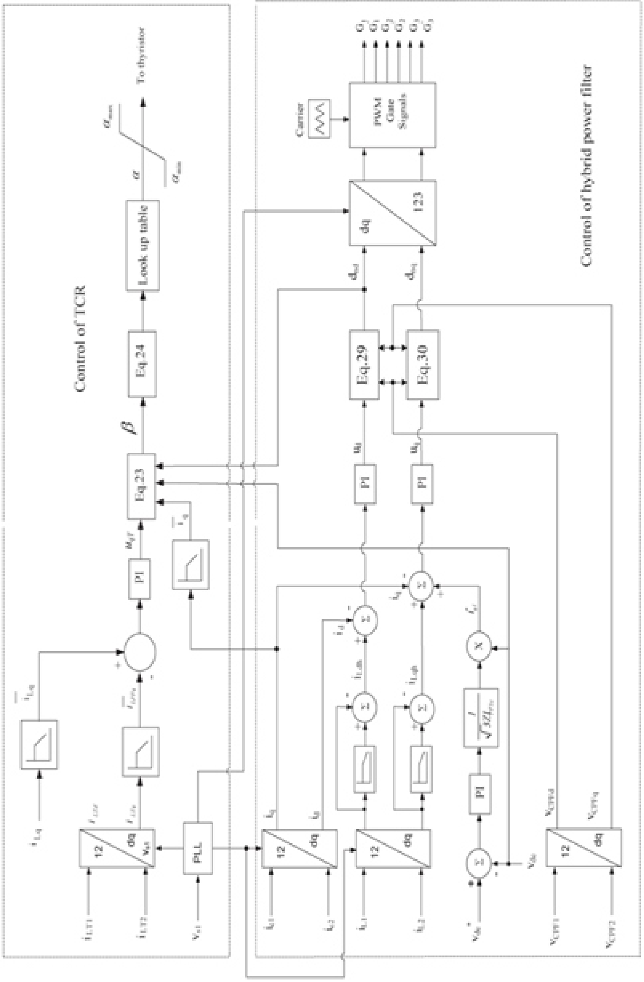

Fig.3.Control Scheme of the Proposed SHPF-TCR Compensator.

The response of the dc bus voltage loop is a second-order transfer function and has the following form:

$$\frac{V_{\mathrm{dc}}(s)}{V^*_{\mathrm{dc}}(s)} = 2\zeta\omega_{\mathrm{nv}}\frac{s+\frac{\omega_{\mathrm{nv}}}{2\zeta}}{s^2+2\zeta\omega_{\mathrm{nv}}s+\omega^2_{\mathrm{nv}}}$$

The closed-loop transfer function of dc bus voltage regulation is given as follows:

$$\frac{V_{\mathrm{dc}}(s)}{V^*_{\mathrm{dc}}(s)} = \frac{\frac{\sqrt{3}Z_{\mathrm{PF1}}k_pI_c}{V_{\mathrm{dc}}C_{\mathrm{dc}}}s+\frac{\sqrt{3}Z_{\mathrm{PF1}}k_iI_c}{V_{\mathrm{dc}}C_{\mathrm{dc}}}}{s^2+\frac{\sqrt{3}Z_{\mathrm{PF1}}k_pI_c}{V_{\mathrm{dc}}C_{\mathrm{dc}}}s+\frac{\sqrt{3}Z_{\mathrm{PF1}}k_iI_c}{V_{\mathrm{dc}}C_{\mathrm{dc}}}}$$

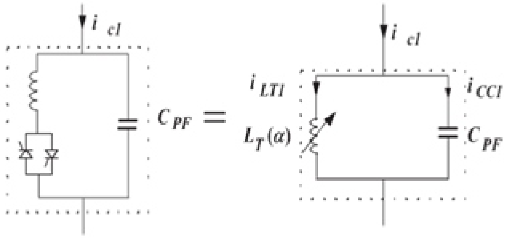

Fig.4.TCR Equivalent Circuit.

IV.FUZZY LOGIC CONTROL:

L. A. Zadeh presented the first paper on fuzzy set theory in 1965. Since then, a new language was developed to describe the fuzzy properties of reality, which are very difficult and sometimes even impossible to be described using conventional methods. Fuzzy set theory has been widely used in the control area with some application to power system [5]. A simple fuzzy logic control is built up by a group of rules based on the human knowledge of system behavior. Matlab/Simulink simulation model is built to study the dynamic behavior of converter. Furthermore, design of fuzzy logic controller can provide desirable both small signal and large signal dynamic performance at same time, which is not possible with linear control technique. Thus, fuzzy logic controller has been potential ability to improve the robustness of compensator. The basic scheme of a fuzzy logic controller is shown in Fig.5. and consists of four principal components such as: a fuzzy frication interface, which converts input data into suitable linguistic values; a knowledge base, which consists of a data base with the necessary linguistic definitions and the control rule set; a decision-making logic which, simulating a human decision process, infer the fuzzy control action from the knowledge of the control rules and linguistic variable definitions; a de-fuzzification interface which yields non fuzzy control action from an inferred fuzzy control action [10].

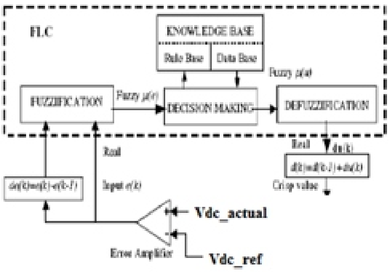

Fig.5. Block diagram of the Fuzzy Logic Controller (FLC) for proposed converter.

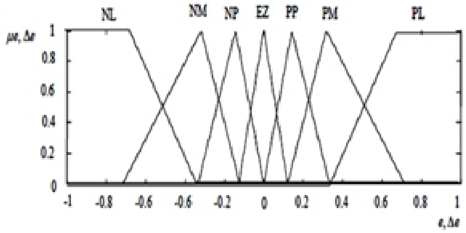

Fig.6. Membership functions for Input, Change in input, Output.

Rule Base: the elements of this rule base table are determined based on the theory that in the transient state, large errors need coarse control, which requires coarse in-put/output variables; in the steady state, small errors need fine control, which requires fine input/output variables. Based on this the elements of the rule table are obtained as shown in Table , with 'Vdc' and 'Vdc-ref' as inputs

e Δe	NL	NM	NS	EZ	PS	PM	PL
NL	NL	NL	NL	NL	NM	NS	EZ
NM	NL	NL	NL	NM	NS	EZ	PS
NS	NL	NL	NM	NS	EZ	PS	PM
EZ	NL	NM	NS	EZ	PS	PM	PL
PS	NM	NS	EZ	PS	PM	PL	PL
PM	NS	EZ	PS	PM	PL	PL	PL
PL	NL	NM	NS	EZ	PS	PM	PL

V.MATLAB/SIMULINK RESULTS:

Case 1: Performance of SHPF-TCR for harmonic generated load.

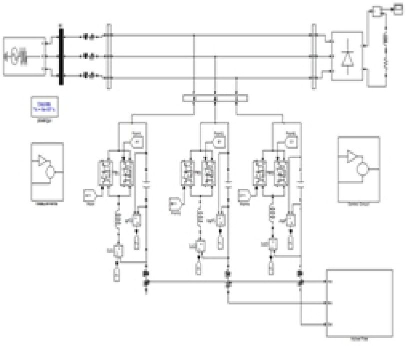

Fig.7.Simulink Circuit for SHPF-TCR under Harmonic Generated Load.

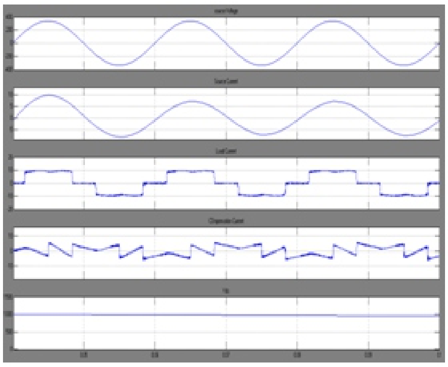

Fig.8.Simulation Results for Source Voltage, Source Current, Load Current, Compensation Currents and Dc Link Voltage.

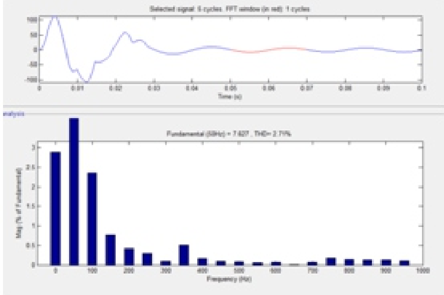

Fig.9.Harmonic Spectrum for Source Current with Compensation.

Case 2: Performance of SHPF-TCR for harmonic generated load with fuzzy controller

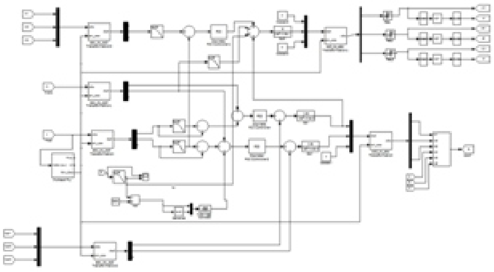

Fig.10.Control Strategy for Harmonic Generated Load with Fuzzy Logic Control.

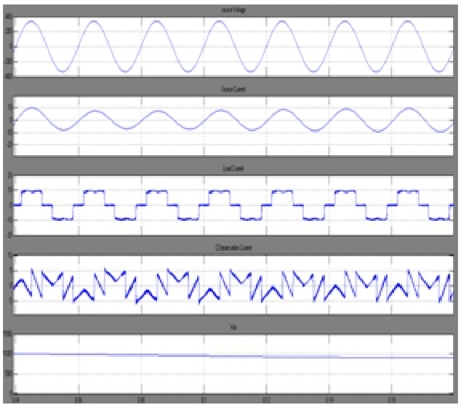

Fig.11.Simulation Results for Source Voltage, Source Current, Load Current, Compensation Currents and Dc Link Voltage.

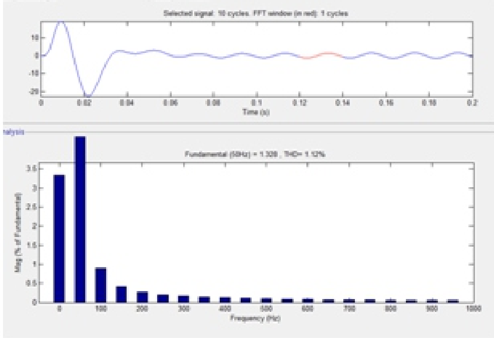

Fig.12.Harmonic Spectrum for Source Current with Compensation.

VI. CONCLUSION:

In this paper, a SHPF-TCR compensator of a TCR and a SHPF has been proposed to achieve harmonic elimination and reactive power compensation. A proposed nonlinear control scheme of a SHPF-TCR compensator has been established, simulated, and implemented by using the DS1104 digital real time controller board of d SPACE. The shunt active filter and SPF have a complementary function to improve the performance of filtering and to reduce the power rating requirements of an active filter.

A fuzzy logic controller has been designed for stabilization of power systems. The response of the power system with the fuzzy controller over a non-linear control system is observed.Overall, the fuzzy controller gives the best performance in comparison. It has been shown that the system has a fast dynamic response, has good performance in both steady-state and transient operations.

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