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SIMULATION AND FUZZY LOGIC CONTROL OF SHUNT HYBRID POWER FILTER AND THYRISTOR-CONTROLLED REACTOR FOR POWER QUALITY

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ABSTRACT

This paper deals with the implementation of fuzzy logic based Shunt Hybrid Active Filter (SHAF) with non-linear load to minimize the source current harmonics and provide reactive power compensation. Comparison with Proportional Integral (PI) based SHAF is also analyzed. Shunt Hybrid Active Filter is constituted by Active Filter connected in shunt and shunt connected three phase single tuned LC filter for 5th harmonic frequency with rectifier load. 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 modeled 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.

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

I. INTRODUCTION

Power quality is becoming important due to proliferation of nonlinear loads, such as rectifier equipment, adjustable speed drives, domestic appliances and arc furnaces. These nonlinear loads draw non-sinusoidal currents from ac mains and cause a type of current and voltage distortion called as ‘harmonics’. These harmonics causes various problems in power systems and in consumer products such as equipment overheating, capacitor blowing, motor vibration, transformer over heating excessive neutral currents and low power factor. Power quality problems are common in most of commercial, industrial and utility networks. Natural phenomena, such as lightning are the most frequent cause of power quality problems. Switching phenomena resulting in oscillatory transients in the electrical supply.

Shunt active power filters (SAPF) represent a feasible solution to the problems caused by the non- linear loads. These loads draw non-sinusoidal currents from the 3-phase sinusoidal, balanced voltages which are classified as identified and unidentified loads. The SAPF can compensate for the harmonics, correct the power factor and work as a reactive power compensator, thus providing enhancement of power quality in the system [1, 2]. The control scheme of a SAPF must calculate the current reference waveform for each phase of the inverter, maintain the dc voltage constant, and generate inverter gating signals.

The current reference circuit generates the reference currents required to compensate the load current harmonics and reactive power, and also try to maintain constant the dc voltage across the capacitor [3].

In this paper, a new combination of a shunt hybrid power filter (SHPF) and a TCR (SHPF-TCR compensator) is proposed to suppress current harmonics and compensate the reactive power generated from the load. The hybrid filter consists of a series connection of a small-rated active filter and a fifth-tuned LC passive filter. 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 significantly the volt-ampere rating of the APF part. The control method of the combined compensator is presented. 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. A nonlinear control of SHPF is developed for current tracking and voltage regulation purposes. It is based on a decoupled control strategy, which considers that the controlled system may be divided into an inner fast loop and an outer slow one.

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

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

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

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

A switching state function dnk is defined as

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

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 [15]:

$$\begin{aligned} L_{\mathrm{PF}}\frac{di_{c1}}{dt} &= -R_{\mathrm{PF}}i_{c1} - d_{n1}v_{\mathrm{dc}} - v_{\mathrm{CPF1}} + v_{s1} \\ L_{\mathrm{PF}}\frac{di_{c2}}{dt} &= -R_{\mathrm{PF}}i_{c2} - d_{n2}v_{\mathrm{dc}} - v_{\mathrm{CPF2}} + v_{s2} \\ L_{\mathrm{PF}}\frac{di_{c3}}{dt} &= -R_{\mathrm{PF}}i_{c3} - d_{n3}v_{\mathrm{dc}} - v_{\mathrm{CPF3}} + v_{s3} \\ C_{\mathrm{dc}}\frac{dv_{\mathrm{dc}}}{dt} + \frac{v_{\mathrm{dc}}}{R_{\mathrm{dc}}} &= d_{n1}i_{c1} + d_{n2}i_{c2} + d_{n3}i_{c3}. \end{aligned} \quad (4)$$

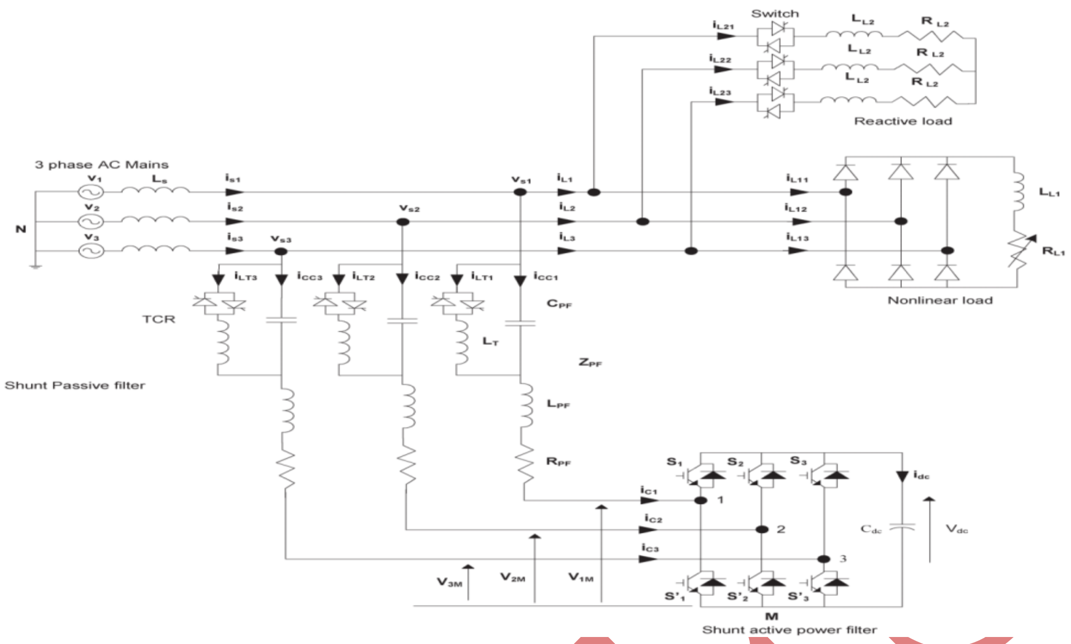

Fig. 1. Basic circuit of the proposed SHPF-TCR compensator

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.

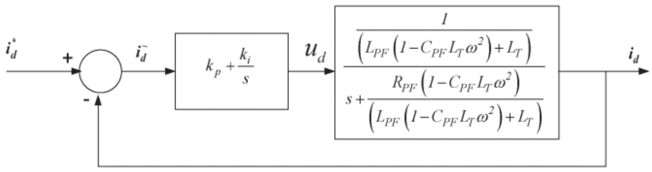

Fig. 2. Inner control loop of the current id.

Consequently, they can practically be ignored. Define the equivalent inputs by (28) as given in the Appendix. 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.

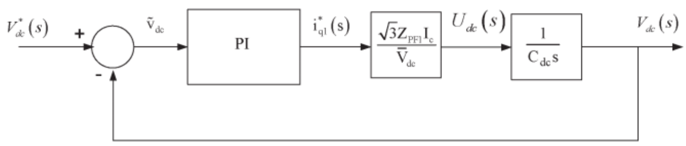

Fig. 3. Compensated voltage regulated model.

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

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.

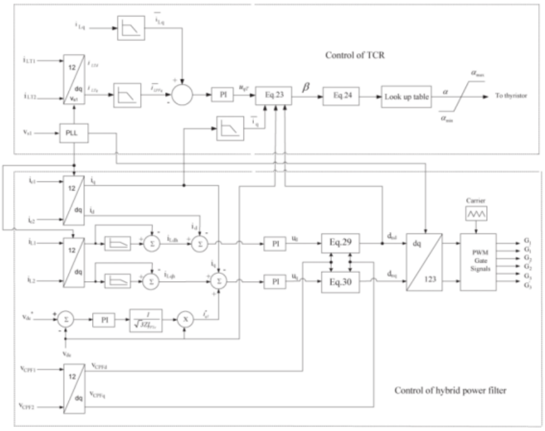

Fig. 4. Control scheme of the proposed SHPF-TCR compensator.

The proposed nonlinear controller of the proposed SHPFTCR compensator is shown in Fig. 4.

IV. DC LINK WITH PI CONTROLLER

PI control With a view to have a self-regulated dc bus, the voltage across the capacitor is sensed at regular intervals and controlled by employing a suitable closed loop control. The dc link voltage, vdc is sensed at a regular interval and is compared with its reference counterpart v_{dc}*. The error signal is processed in a PI controller. The output of the PI controller is denoted as $i_{sp(n)}$. 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-TCR 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-TCR is maintained to have a proper current control.

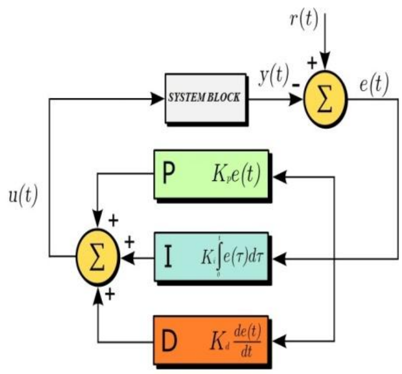

Fig.5. PID controller block with system

- 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. The reset action can be achieved by introducing an integral controller to act on the reference setting to change the speed set point. The integral controller increases the order of the system by one.
- Uncontrolled system is subject to steady state errors and so control strategy is required. The control specifications are
- Control loop must be characterized by a sufficient degree of stability
- Following a step load change, the harmonics error should return to zero. This is referred to as is synchronous control. Magnitude of transient harmonics must be minimized.
- Integral of the voltage sag , swell and harmonics error should be minimized.
- The individual transmission of the upqc controller should divide the total non-linear load for improve the power quality.
- Let ΔP_c be the negative feed-back signal drawn from frequency deviation. Suppose, if it was not an integral feedback, i.e. if $\Delta P_c=-K_1\Delta F(s)$ where $k_1\rightarrow$gain for proportion control
- $U(t)=K_P\, e(t) + K_i\, d/dt(E(t))$ the PD controller increases the damping of the system which results in reducing the peack overshoot
- $U(t)=K_P e(t) + K_i \int_0 E(t)$ PI controller reduces the steady state error. The PI controller increases the order and type number of the system by one.

V. FUZZY LOGIC CONTROLLERS

The word Fuzzy means vagueness. Fuzziness occurs when the boundary of piece of information is not clear-cut. In 1965 Lotfi A.Zahed propounded the fuzzy set theory. Fuzzy set theory exhibits immense potential for effective solving of the uncertainty in the problem. Fuzzy set theory is an excellent mathematical tool to handle the uncertainty arising due to vagueness. Understanding human speech and recognizing handwritten characters are some common instances where fuzziness manifests. Fuzzy set theory is an extension of classical set theory where elements have varying degrees of membership. Fuzzy logic uses the whole interval between 0 and 1 to describe human reasoning. In FLC the input variables are mapped by sets of membership functions and these are called as “FUZZY SETS”.

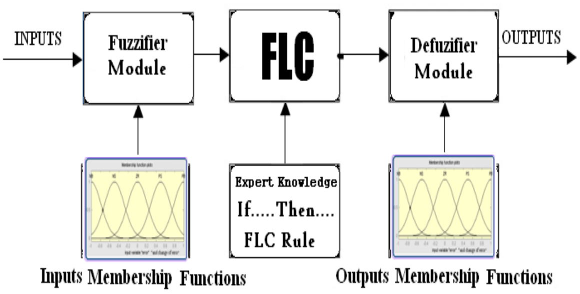

Fig. 6. FUZZY BASIC MODULE

Fuzzy set comprises from a membership function which could be defines by parameters. The value between 0 and 1 reveals a degree of membership to the fuzzy set. The process of converting the crisp input to a fuzzy value is called as "fuzzificaton." The output of the Fuzzier module is interfaced with the rules. The basic operation of FLC is constructed from fuzzy control rules utilizing the values of fuzzy sets in general for the error and the change of error and control action. The results are combined to give a crisp output controlling the output variable and this process is called as "DEFUZZIFICATION."

A. FUZZY RULES:

Control e \ Δe	NL	NM	NS	ZR	PS	PM	PL
NL	NL	NL	NL	NL	NL	NL	NL
NM	NL	NL	NM	NM	NS	NS	NS
NS	NL	NM	NM	NS	NS	NS	ZR
ZR	ZR	ZR	ZR	ZR	ZR	ZR	ZR
PS	ZR	PS	PS	PS	PM	PM	PL
PM	PS	PS	PS	PM	PM	PL	PL
PL	PL	PL	PL	PL	PL	PL	PL

Fig. 7. Control strategy based on 49 Fuzzy controls Rule with combination of seven error states multiplying with seven changes of error states.

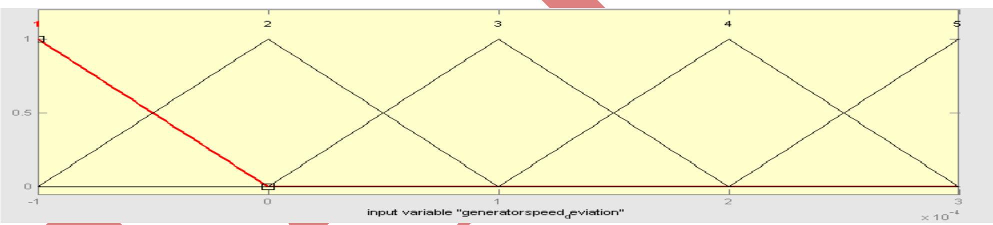

Fig. 8. SHPF-TCR grid Voltage deviation (Δe)

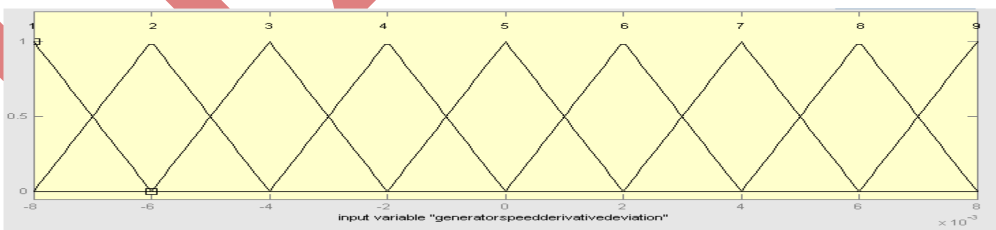

Fig. 9. SHPF-TCR Grid voltage derivative deviation (Δe).

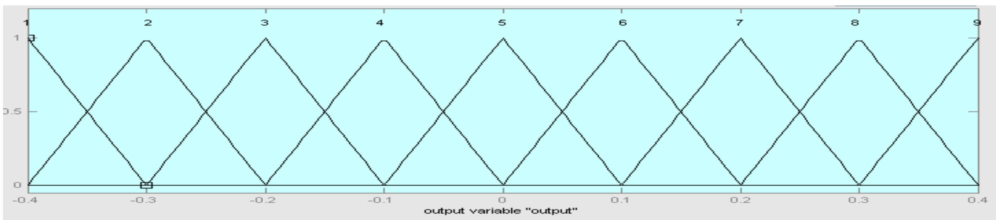

Fig. 10. SHPF-TCR of Fuzzy output.

VI. SIMULATION RESULTS

Simulations were performed numerically using the “Power System Blockset” simulator operating under Matlab/Simulink environment, in order to verify the operation of the proposed SHPF-TCR compensator using the nonlinear control.

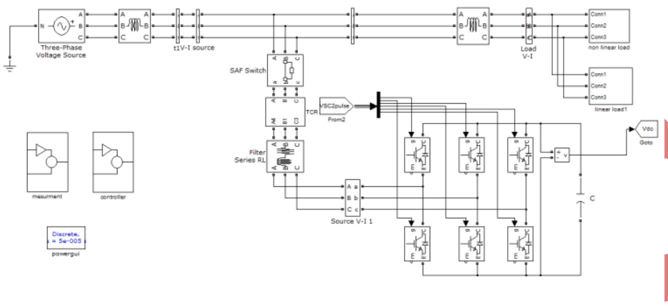

Fig. 11. Matlab/simulink model of Shunt Hybrid Power Filter and Thyristor-Controlled

Fugure11 shows the matlab/simulink model of Shunt Hybrid Power Filter and Thyristor-Controlled.

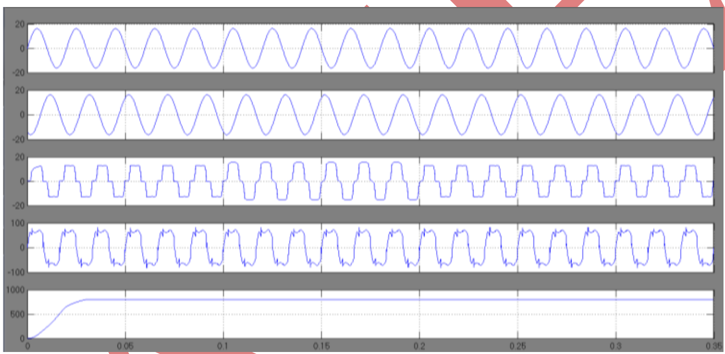

Fig. 12. Steady-state response of the SHPF-TCR compensator with harmonic generated load.

Figure12shows the steady-state waveform of the SHPF TCR compensator for harmonic elimination with a three-phase harmonic-produced load. The supply voltage(vs1), the supply current(is1), the load current (iL1), the SHPF-TCR current (ic1)in phase 1, and the dc bus voltage (vdc)are depicted in this figure.

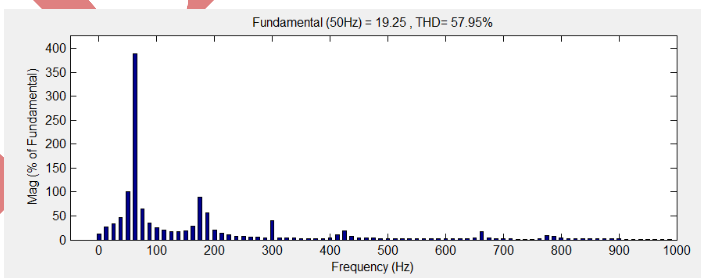

Fig. 13. Harmonic spectrum of source current in phase 1 Before compensation.

Figure13 shows the Harmonic spectrum of source current in phase 1 Before compensation.

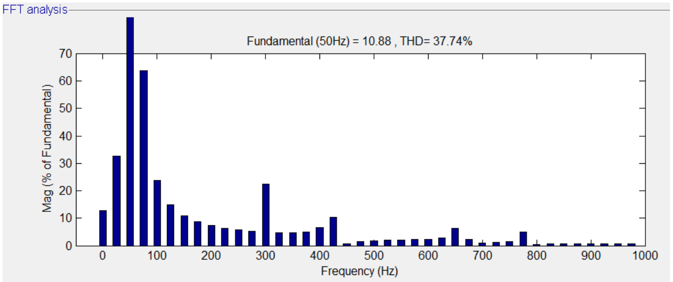

Fig. 14. Harmonic spectrum of source current in phase After compensation.

Figure14 shows the Harmonic spectrum of source current in phase After compensation.

Case1: Shunt Hybrid Power Filter and Thyristor-Controlled with fuzzy.

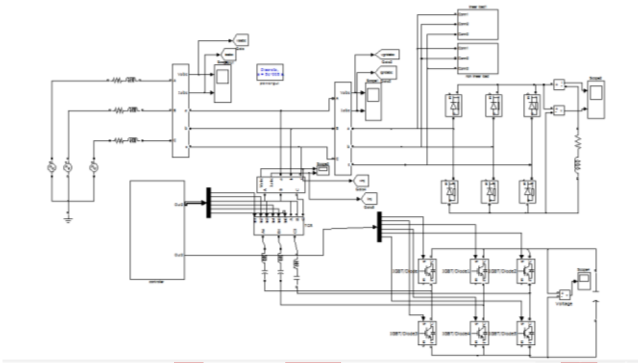

Fig. 15. matlab/simulink model of Shunt Hybrid Power Filter and Thyristor-Controlled with fuzzy.

Figure15 shows the matlab/simulink model of Shunt Hybrid Power Filter and Thyristor-Controlled with fuzzy.

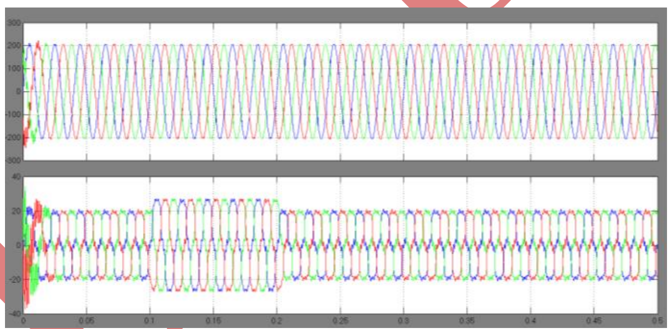

Fig. 16. Source voltage and source current Shunt Hybrid Power Filter and Thyristor-Controlled with fuzzy.

Figure16 shows the source voltage and source current Shunt Hybrid Power Filter and Thyristor-Controlled with fuzzy.

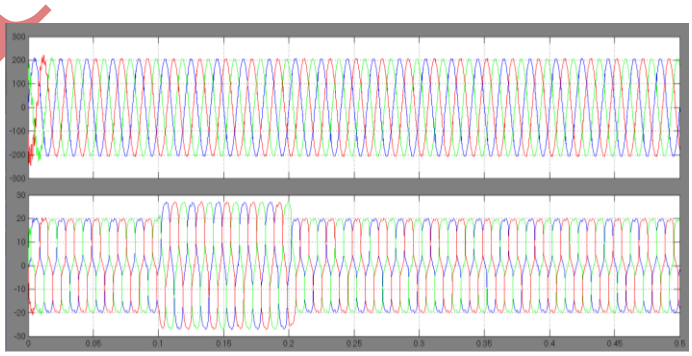

Fig. 17. Grid voltage and grid current of Shunt Hybrid Power Filter and Thyristor-Controlled with fuzzy.

Figure17 shows the Grid voltage and grid current of Shunt Hybrid Power Filter and Thyristor-Controlled with fuzzy.

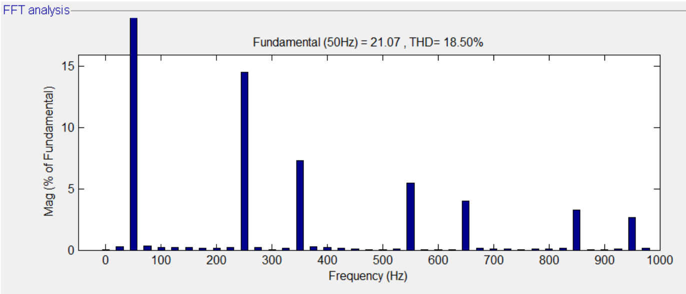

Fig. 18. Harmonic spectrum of source current in Shunt Hybrid Power Filter and Thyristor-Controlled with fuzzy.

Figure18 shows the Harmonic spectrum of source current in Shunt Hybrid Power Filter and Thyristor-Controlled with fuzzy.

VII. 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. The scheme has the advantage of simplicity and is able to provide self-supported dc bus of the active filter through power transfer from ac line at fundamental frequency. The performance of conventional PI controller and fuzzy controller has been studied and compared. Overall, the fuzzy controller gives the best SAPF performance in comparison with the PI controller in regards voltage regulation, % THD, settling time, current overshoot etc.

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