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SIMULATION OF HYBRID SERIES ACTIVE FILTER FOR HARMONIC ELIMINATION IN THREE PHASE SYSTEM

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ABSTRACT:* Over the past few years, the enormous increase in the use of non-linear loads, arises many power quality issues like high current harmonics, voltage distortion and low power factor etc. on electrical grid [1]. Hence the proliferation of non-linear load in system generates harmonic currents injecting into the AC power lines. This distorted supply voltage and current causes malfunction of some protection devices, burning of transformers and motors, overheating of cables. Hence it is most important to install compensating devices for the compensation of harmonic currents and voltages produced due to nonlinear load. The degradation in power quality causes adverse economic impact on the utilities and customers. Harmonics in current and voltage are one of the most commonly known power quality issues and are solved by the use of hybrid series active power filter (HSAPF). In this paper, a new controller design using sliding mode controller-2 is proposed to make the HSAPF more robust and stable. An accurate averaged model of three-phase HSAPF is also derived in this paper. The design concept of the robust HSAPF has been verified through simulation and experimental studies and the results obtained are discussed.

I. INTRODUCTION

Now-a-days, harmonic interference become an important issue in power system because of increasing demand of non-linear loads. Harmonic interference causes harmonic contamination. This harmonic contamination affects power utility in many aspects such as increase losses in power system, decrease power factor and causes malfunction in customer's equipment. Traditionally passive power filters (PPFs) are widely used to mitigate harmonic contamination...
However, PPFs has huge drawbacks such as large in size, mistuning, resonance phenomenon etc. In the middle of 1940s the shunt active power filter is developed to overcome the drawbacks of PPFs. But the cost of active filter is very high because of its high rating. Due to the high cost the active filter is not preferable in large scale industries. Henceforth, to avoid these drawbacks of active filter, a combined system of passive filter and active filter. Among all the topology of HAPF, HSAPF is suitable for compensation of both voltage as well as current harmonics and also for compensation of reactive power. HSAPF is also gives better performance for both type of non-linear load such as voltage-type harmonic load and current-type harmonic load. Voltage-type of harmonic load is defined as a 3-phase full bridge diode rectifier, consists of a dc capacitor of larger value is in parallel with the resistor in DC side. Current-type harmonic load is built up by 3-phase diode bridge rectifier, with inductor in series with the resistor in output side. The performance of HSAPF system is developed by choosing a proper reference compensating voltage. This research article employed pq-theory for reference generation process. This theory is applied for the generation of compensating voltage. Performance of proposed HSAPF with p-q control approach is found feasible for both current-type harmonic load and voltage type harmonic load. This reference voltage is directly depends on load voltages and source currents. Hysteresis voltage controller is used for switching pattern generation because it is easy in computational intensive and fast in implementation. The control strategy is important to enhance the performance of HSAPF. In reality, many articles for hybrid power filter have already proposed advanced techniques to reduce current harmonics created by these non-linear loads. In this project a linear feedback-feed-forward controller is designed for hybrid power filter.
But this controller is not easy for getting both steady-state and transient state performances with the linear control strategy because the dynamic model of HSAPF system contains multiplication terms of control inputs and state variables. Due to the non-linear characteristics of HSAPF, a sliding mode controller is presented in this project. The sliding mode control is known as an appropriate control technique for controlling non-linear systems with uncertain dynamics and disturbances due to its order reduction property and low sensitivity to disturbances and plant parameter variations, which reduces the burden of the requirement of exact modeling.

II. HYBRID SERIES ACTIVE POWER FILTER

The principle of sliding mode control is defined as to enforce the sliding mode motion in a predefined switching surfaces of the system state space using discontinuous control. The switching surfaces should be selected in such a way that sliding motion would maintain desired dynamics of motion according to certain performance criterion. The conventional control methods, such as Linear-quadratic regulator (LQR) or Linear quadratic Gaussian (LQG) servo controller for linear systems, are required to choose proper switching surfaces. Then, the discontinuous control needs to be chosen such that any states outside of the discontinuity surface are enforced to reach the surface at finite time. Accordingly, sliding mode occurs along the surface, and the system follows the desired system dynamics. The main difficulty of hardware implementation of classical sliding mode control method is chattering. Chattering is nothing but an undesirable phenomenon of oscillation with finite frequency and amplitude. The chattering is dangerous because the system lags control accuracy, high wear of moving mechanical parts, and high heat losses occurs in electrical power circuits. Chattering occurs because of unmodeled dynamics. These unmodeled dynamics are created from servomechanisms, sensors and data processors with smaller time constants. In sliding mode control the switching frequency should be considerably high enough to make the controller more robust, stable and no chattering because chattering reduces if switching frequency of the system increases. The application of sliding mode controller in power converter systems for example in HSAPF, a natural way to reduce chattering is increasing switching frequency. However, it is not possible in case of power converters because of certain limitations in switching frequency for losses in power converters, for which it results in chattering. Therefore, this chattering problem cannot blame sliding mode implementation since it is mainly caused by switching limitations. In this paper it is shown that the chattering exponentially tends to zero if the relative degree of the system with actuators or sensors is two. Difference in current, voltage and frequency power quality issues will occur in power system network [2], due to nonlinear load the deviation will comes in currents. If the power quality problem is in power system network, results appliances in network is damaged or sometimes failure. And efficiency and performance of equipment's reduced [2].To eliminate the harmonics and improve power quality, Hybrid Active Power Filter (HAPF) particularly shunt HAPF are introduced. Hybrid Active Power filters are the merge with Active and passive filters [2]. HAPF is merge with passive filter and active power filter (APF). Passive filters are used to filter out the selected harmonics, and passive filters have some disadvantages, they are parallel resonance, size of passive filter is more, filtering feature is constant so it pretentious by the source impedance, so to overcome these negatives the active power filters and HAPF are introduced [2].

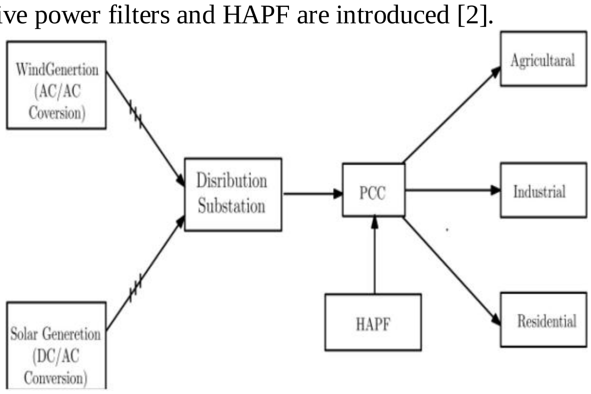

Fig. 3.1 Location of HAPF in Power system Network

This paper details about the modelling and analysis and comparative study of HAPF which is a combination of Shunt Passive Filter in series with active power filter, which the compensation currents are calculated using instantaneous reactive power theory and Fryze current compensation theories are implemented to reduce harmonics. Total Harmonic Distortion (THD) values under different loading conditions are listed and the MATLAB/SIMULINK results are presented. The overall system incorporates an three phase AC source, with connected with Nonlinear load connected with RL load, PF, APF, three phase universal bridge, unbalanced resistive Load, Hysteresis Current controller, PI Controller.

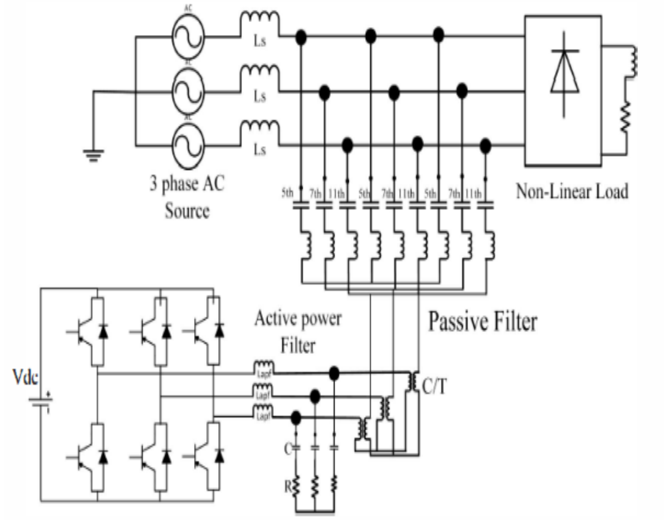

Fig 3.2- Block Diagram of Hybrid Active Power Filter

Using Instantaneous reactive power theory calculates real (p) and reactive power (q) using alpha beta transformation. For compensating currents calculation using Inverse Clark's transformation. These compensating currents are given input to the HCC. HCC generates the pulses to give filter inverter. Fig 3.1 shows location of HAPF. The overall structure of proposed system is shown in Fig 3.2.

III. CONTROLLING OF HYBRID SERIES ACTIVE POWER FILTER

The relative degree of HSAPF system is two. Because of this relative degree of HSAPF system and also for these obstacles in classical sliding mode controller, this research paper proposed a new controller i.e. sliding mode controller-2. This proposed controller suppressed chattering and enhance the performance of HSAPF. This controller is completely new for this topology of HSAPF system.

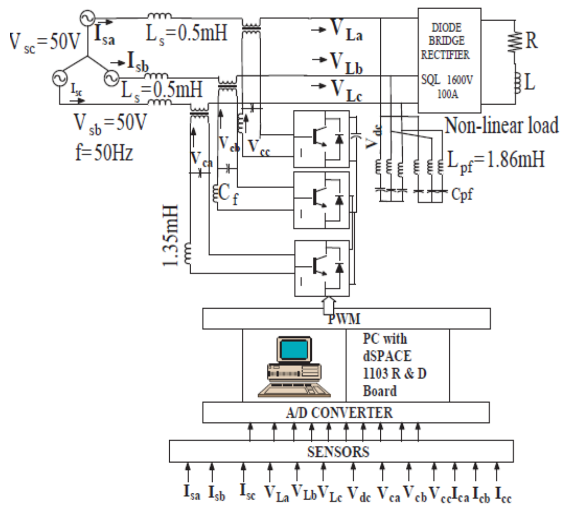

Fig. 3.3: Schematic diagram of the control and power circuit of HSAPF

In case of CBPWM, power system perturbations have not been taken into consideration and also the presence of a time delay at the reference tracking point gives rise to a slow response of the overall system. Thus, tracking error is not reduced effectively and stability of the system is minimally improved. To overcome this, a SMC- 2 controller is proposed for voltage source converter (VSC). The idea behind this controller is to achieve gain stability, perfect tracking and distortion free current and load voltage. In view of above mentioned issues, we give more emphasis on the development of robust controller with a faster reference tracking approach in HSAPF, which permits all perturbations such as load voltage distortion, parametric variation of load, source current distortion and supply voltage unbalance so that compensation capability of the HSAPF system can be enhanced.

Fig.3.3 shows the schematic diagram of the control and power circuit of 3-phase HSAPF. The SAPF consists of a voltage source inverter connected to the grid through an LC filter and a three phase linear transformer. The series resistance of the inductors are neglected. Where, Va, Vb and Vc are the duty cycle of the inverter legs in a switching period, whereas Vca, Vcb, Vcc are the output voltage of series active filter for three phases are shown in Fig. 3.3 and Ica, Icb, Icc are known as the three phase current output of active filter, VaN , VbN, VcN are the phase voltages for three phases, Isa, Isb, Isc are known as the three phase source current, VnN is the neutral voltage.

IV. MODELLING AND SIMULATION

The active filters can be classified into pure active filters and hybrid active filters in terms of their circuit configuration. Most pure active filters as their power circuit can use either a voltage-source pulse width-modulated (PWM) converter equipped with a dc capacitor or a current-source PWM converter equipped with a dc inductor. At present, the voltage source converter is more favorable than the current-source one in terms of cost, physical size, and efficiency. Hybrid active filters consist of single or multiple voltage-source PWM converters and passive components such as capacitors, inductors, and/or resistors. The hybrid filters are more attractive in harmonic filtering than the pure filters from both viability and economical points of view, particularly for high-power applications. However, single-phase active filters would attract much less attention than three-phase active filters because single phase versions are limited to low-power applications except for electric traction or rolling stock [1]. Fig. in series filter shows the configuration of the HSAF and nonlinear load proposed in this project. The HSAF consists of a series active filter and two parallel single tuned passive filters in series with the active filter. Two passive filters are tuned in dominants harmonic frequencies of 3rd and 5th. The effectiveness of the proposed method in harmonic elimination and reactive power compensation is shown using HSAF for a nonlinear load. In the following sections, the control method, the design process and simulation results are given. Harmonic elimination and reactive power compensation by HSAF is shown in this section through simulation. A HSAF with the process presented above is simulated in MATLAB. Fig. 4.1shows the simulation results when the active filter is in off-line mode. The power source current THD (iL) without compensation is calculated about 70 %. Also, in passive filter compensation mode, the THD of the power source current (is) decreases from 70% to about 41 %. Yet, this value has not been below the recommended value in standards such as IEEE 519-1992 [1] and IEC61000 [2]. To decrease the value of the THD, the active filter is employed with the dc capacitor voltage of 85 V. Fig. 4.10 shows the simulation results in this case. The THD of the power source current (is) decreases from 41% in off-line active filter mode to about 4.9 % in on-line active filter mode.

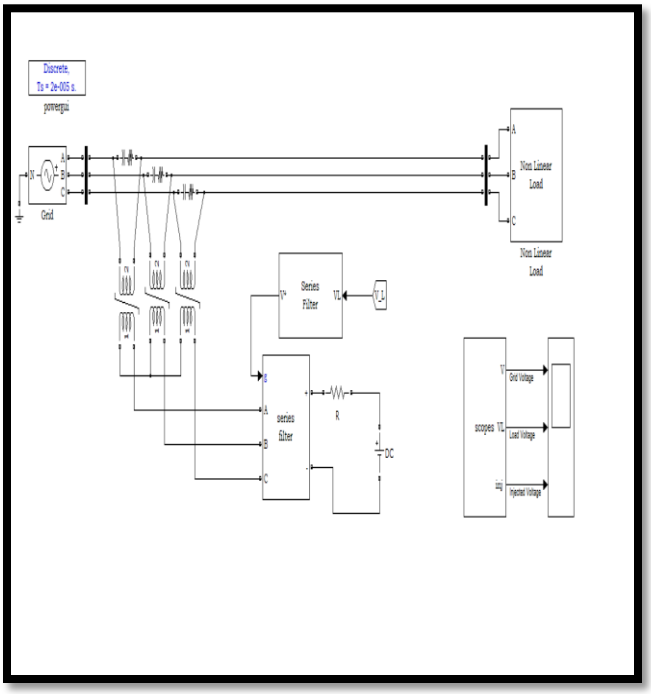

Fig 4.1- Series filter integrated proposed system

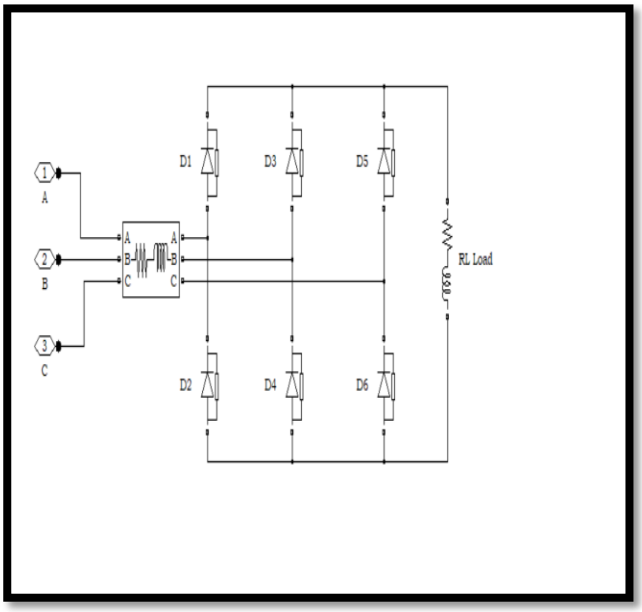

Fig 4.2- Nonlinear Load

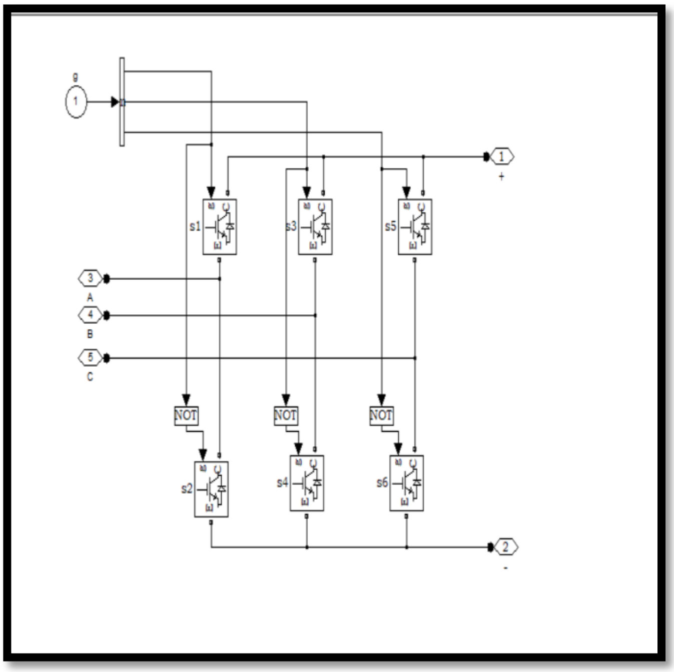

Fig 4.3- Series Filter subsystem

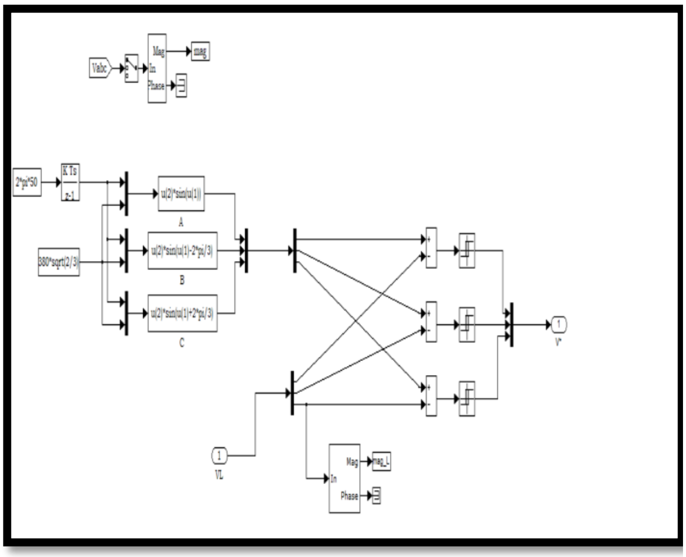

Fig 4.4- Series filter control subsystem

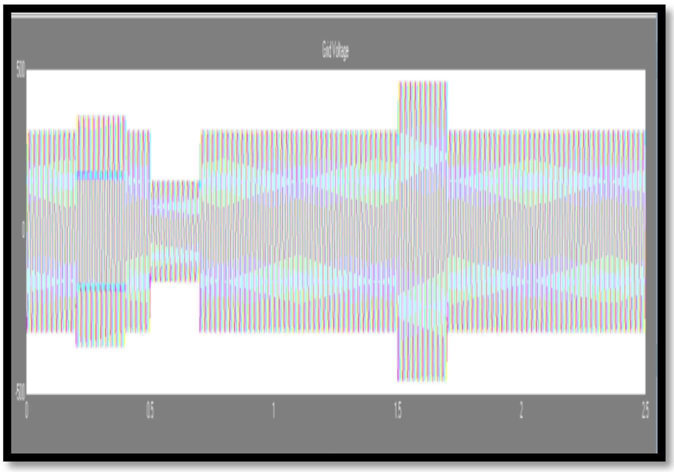

Fig 4.5- Grid side voltage waveform

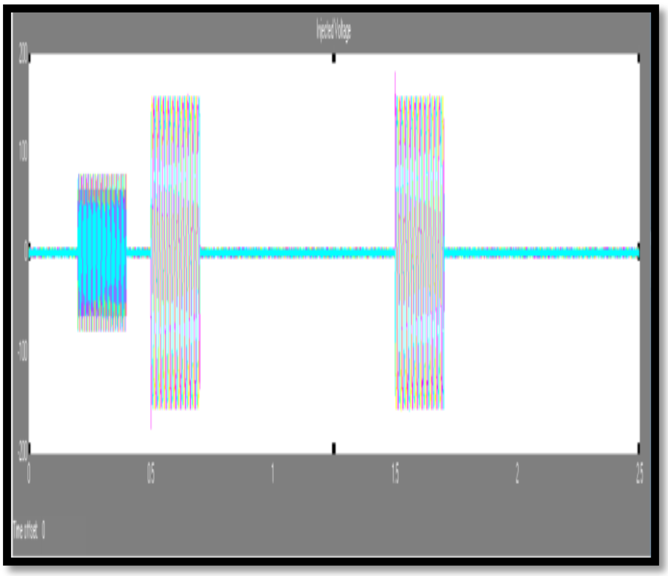

Fig 4.6- Series filter injected voltage waveform

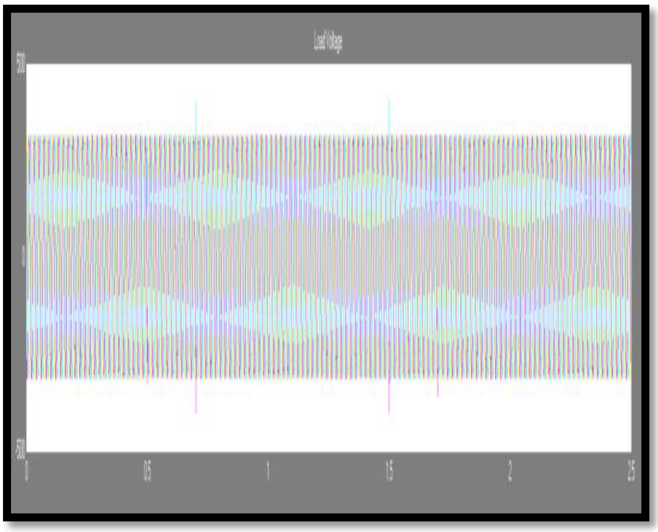

Fig 4.7 Load side voltage waveform

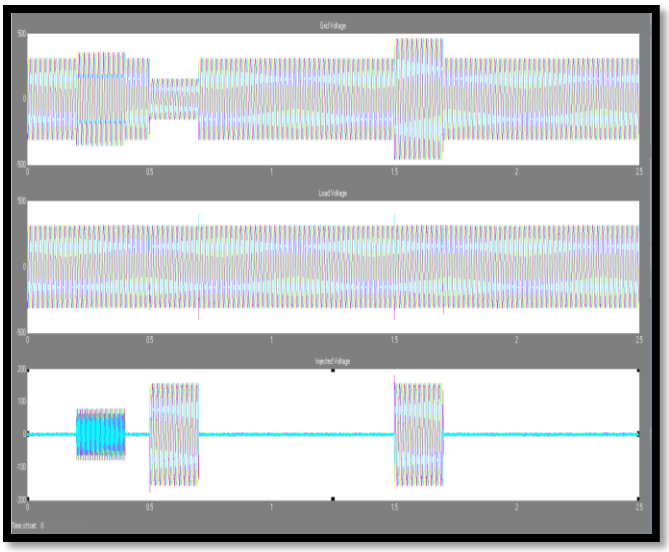

Fig 4.8- Output Parameters

V. SIMULATION AND RESULTS (WITH HYBRID SERIES ACTIVE FILTER)

The reference generation approach (the HSRF method) with the switching pattern generation scheme (i.e., SMC-2) of the HSAPF system given in Fig. 6.46 is tested using MATLAB/ Simulink software. A three-phase source voltage is applied to a harmonic voltage producing nonlinear load. This voltage producing nonlinear load comprises of a three-phase diode bridge rectifier feeding an *RL* load. Due to this type of nonlinear load, a harmonic distortion occurs in both source current and load voltage. This harmonic contamination is the reason of power quality disturbances. So, power quality disturbances can be eradicated by means of the HSAPF. The simulation parameters are encapsulated in Table-1. One reference generation technique and one modulation technique, i.e., hybrid control approach-based SRF method (HSRF) and sliding-mode-controller-based HSAPF, are verified and analyzed using the following MATLAB simulation results.

The goal of simulation is to reduce the total harmonic distortion (THD) response of the sliding-mode-controller-based HSAPF below 5%. And an HSRF combined with the sliding-mode controller technique utilizes dc-link voltage properly for equivalent control law generation. MATLAB simulation results for source voltage *Vs*, load current *IL*, source current *Is*, dc voltage *Vdc* for steady state, and the dynamic condition of load under the existing method have been presented in Fig.5.1. The nature of the source current without a filter is exactly like load current.

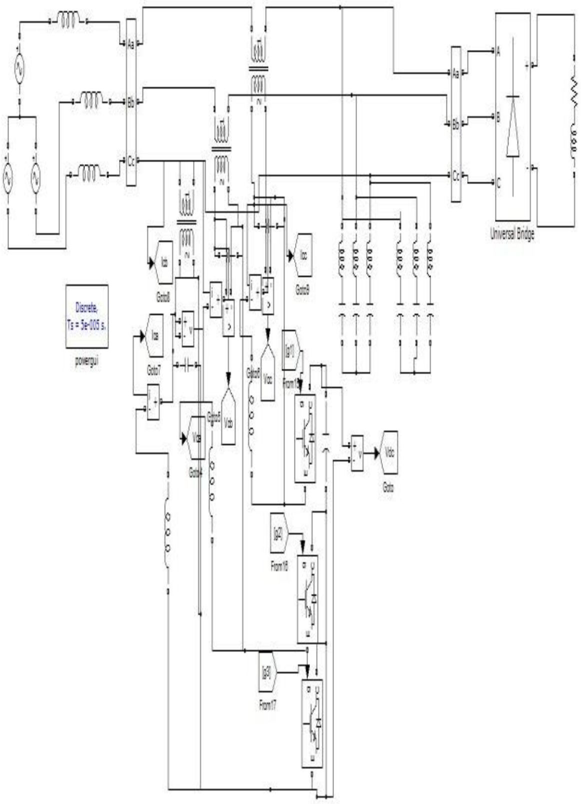

Fig 5.1- Main proposed system with HSAPF

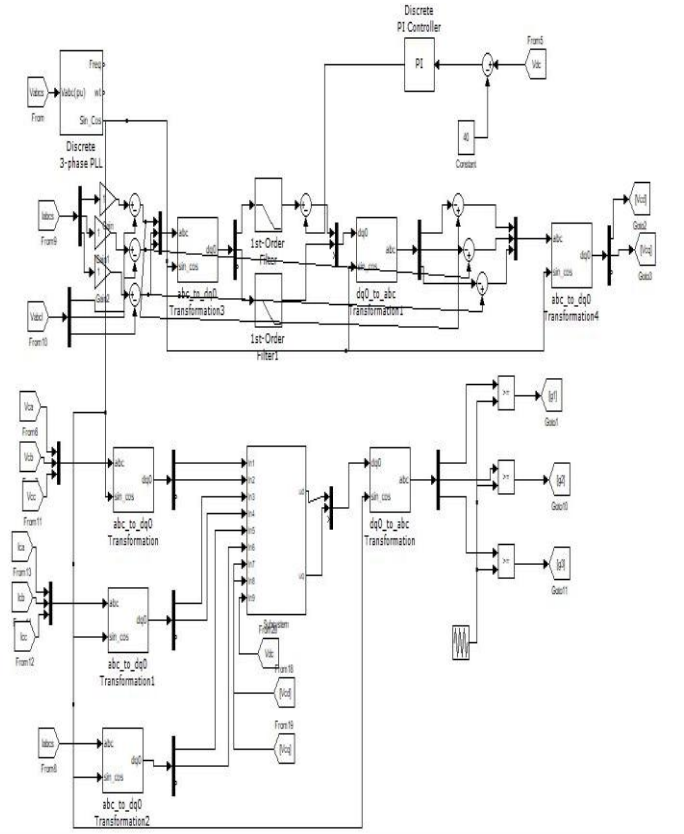

Fig 5.2- Matlab system of controlling for HSAPF

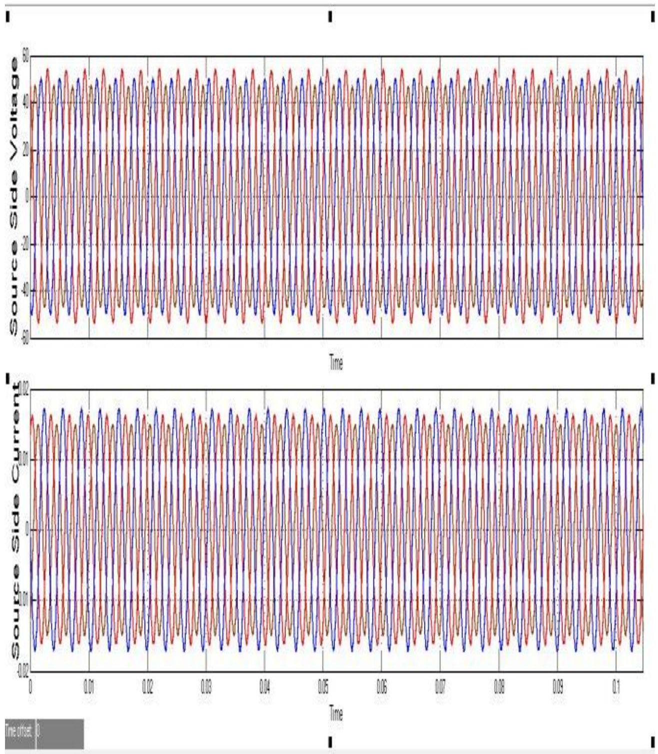

Fig 5.3- Source side three phase output voltage and current

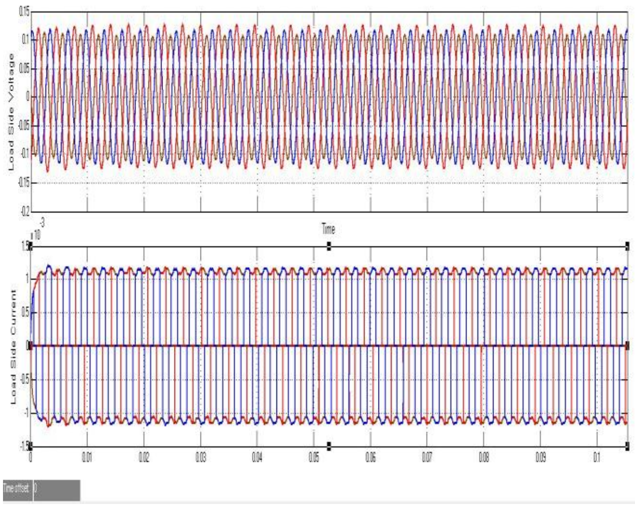

Fig 5.4- Load side three phase output voltage and current

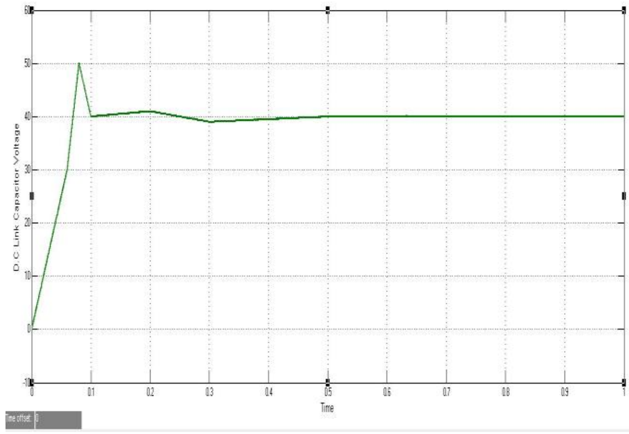

Fig 5.5- D.C link capacitor voltage

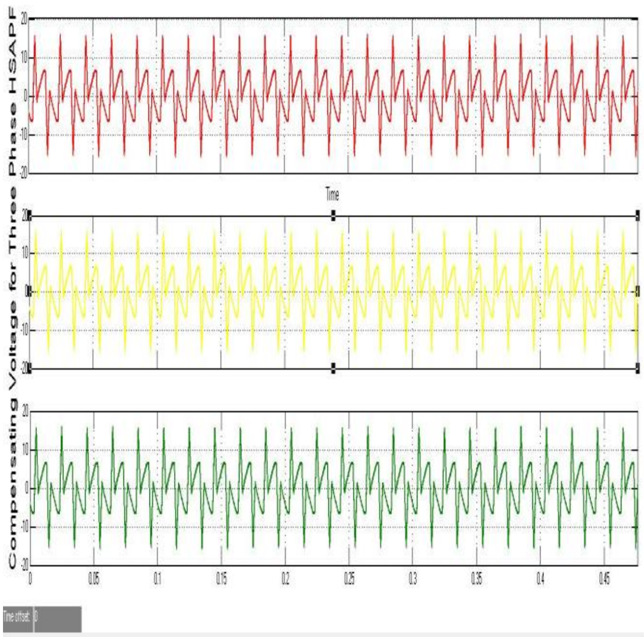

Fig 5.6- Three phase compensating voltage for proposed controller based HSAPF system

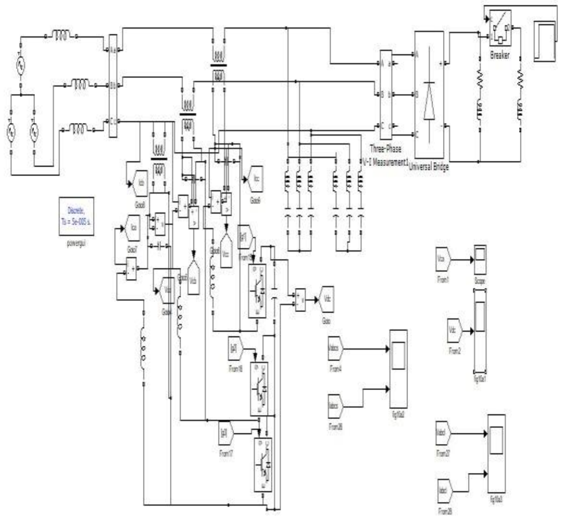
Fig 5.7- Controller-2 Main system with HSAPF

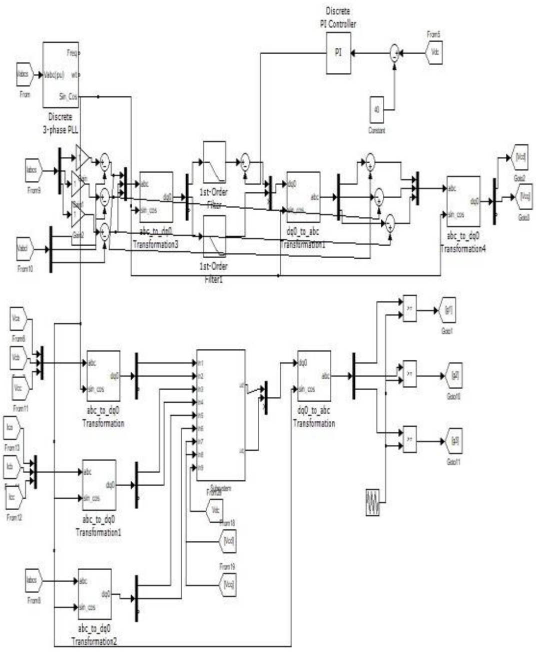

Fig 5.8- Controller-2 Matlab subsystem

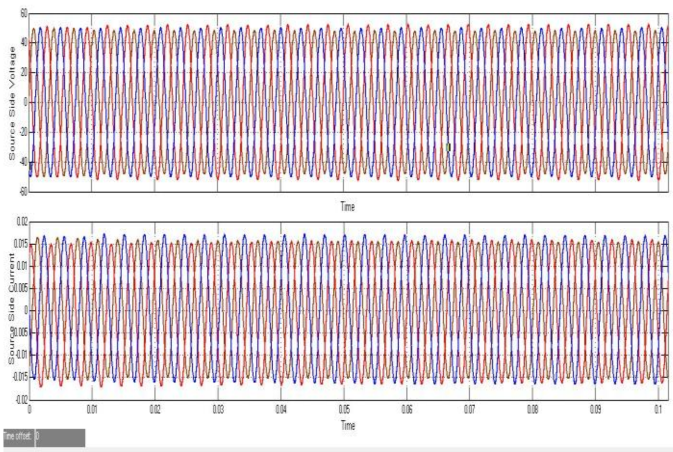

Fig 5.9- Three phase source voltage and current after compensation for existing controller based HSAPF

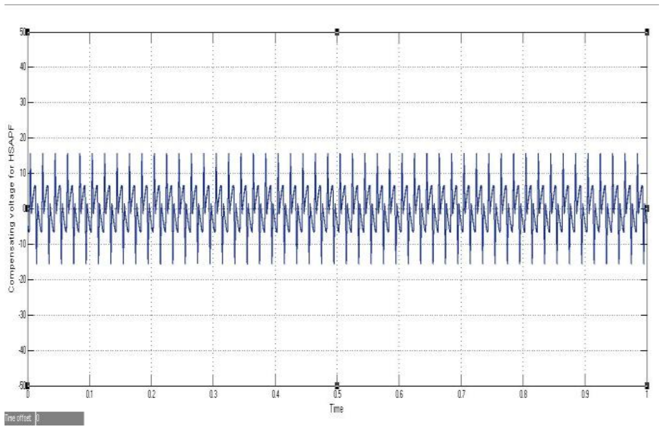

Fig 5.10- Compensating voltage for phase-a in parametric variation case of HSAPF system

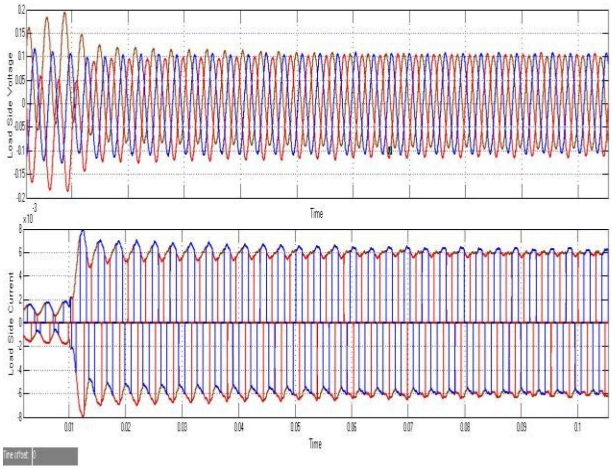

Fig 5.11- Three phase load voltage and Current after compensation for existing controller based HSAPF

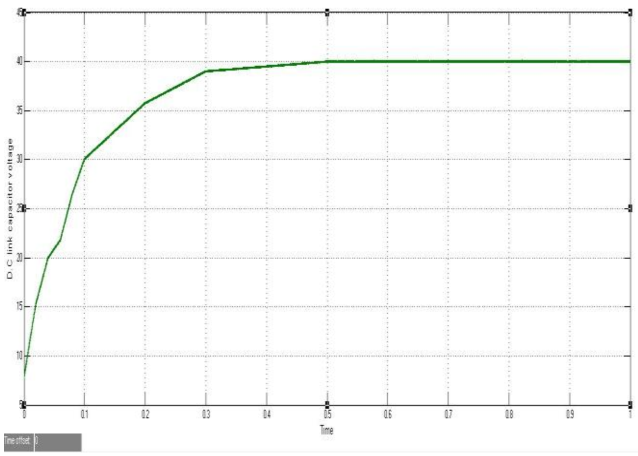

Fig 5.12- D.C link capacitor voltage

VI. CONCLUSION

In this paper a new robust controller design for HSAPF has been presented. The control design is established by sliding mode controller-2 that derives the equivalent control law. This control law is very much helpful for switching pattern generation. The robust- ness of the proposed controller has been verified by analyzing the performance under steady state as well as transient condition of the power system. With the application of this technique, the functionalities of the HSAPF are enhanced. From the obtained simulations as well as experimental results, the proposed HSAPF has been observed to provide efficient current as well as voltage harmonic mitigation, reference voltage tracking behaviour, and reactive power compensation with dynamically varying load conditions.

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