Power Quality Enhancement for Future Household System Associated with Electric Vehicle Charging Station by using HSeAF

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ABSTRACT-*Power quality Enhancement in Households electrical devices is an important concern under consideration. An electrical device such as: -motors & drives, vehicle charging stations, cloud storage, PC Laptop, TV, Home Theater etc., has created a serious concern on the power quality of the future distribution power systems, where nonlinear loads have deteriorate the power quality. Hybrid series active filter is used to enhance the power quality in single-phase systems with crucial loads.*

In this paper we are mostly going through energy management as well as power quality problems in the electric transportation. We also think about improving electric load connection to the grid. To overcome the drawbacks of the current harmonic distortions we implemented control strategy. This implementation is very crucial to avoid damages in sensitive loads from voltage disturbances, sags andswells due to the power system which is considerations in industrial implementation. This implementation on polyvalent hybrid topology will give permission to harmonic isolations as well as the compensation can absorb auxiliary power to grid. We are getting gains and delays for real time controller stability.

Keywords: *Non-linear load, Hybrid series active filter, DVR, Fuzzy Controller, Real time control.*

I. INTRODUCTION

The increase in electronic polluting devices, such as PCs, laptops, and smart TV's etc., power supplies, has raised concerns on power quality issues of modern households. The increase of such devices as shown in Fig. 1, associated with recent electric vehicle charging stations request early investigation on power quality and current harmonics compensation [1]. These harmonics not only reduces system's efficiency, they also have detrimental impacts on voltage quality [2, 3]. There exist references in the literature addressing common power quality issues either related to voltage distortions or current harmonics [4-6]. The first category of papers which investigate on voltage distortions, use Dynamic voltage restorers (DVR) to address the voltage perturbation, sag or swell on the loads terminals[7,8]. The second subject is current related issues and those papers are proposing solutions to overcome current related issues [9, 10]. The third group is considering both issues together, and tries to overcome them in one place.

Regarding the increase of charging stations in residential and commercial buildings, it became crucial to monitor and evaluates their power quality characteristics [11, 12]. Fig. 1 shows the current pattern of a Hybrid electric car plugged to the 220- 240V charging station. In addition, pushed by social efforts, distributed generation and renewable energy sources are been popularized requiring more research and investigation on their wide application on the power quality of the system [13, 14]. This work proposes an efficient Transformer less Hybrid Series Active Filter (THSeAF) capable to rectify current related issues and provides sustainable and reliable voltage supply at the PCC where important residential consumers are connected. The use of this device will facilitate the integration of such energy storage systems and renewables for future smart systems [15, 17]. The compensator could be connected at the entrance of a townhouse right after the power meters as shown inn Fig 1. It will thus clean the current flowing into the grid from harmonic components while correcting the power factor as well. The proposed compensator is capable of ensuring a regulated and harmonic-free voltage to the consumer despite perturbation in the utility's supply.

This proposed low cost configuration ride of the any series transformer helps power quality improvement of future Smart households. This compensator cleans the current drawn from the utility and similarly to a DVR [22-24], the point of common coupling (PCC) and utility smart meters will be protected from voltage distortions. It will then prevent wrong computation of power and energy balance, assisting a more reliable smart metering. This compensator could inject or absorb active power during grid voltage sags or swells to ensure a sustainable supply to the consumer. It is eminent that a fast electric vehicle charging station [16].

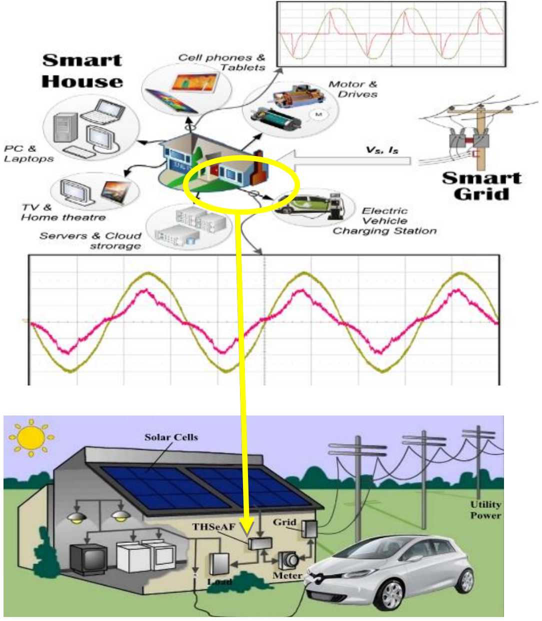

Fig. 1. Typical residential consumer with non-linear electronic loads, and measured current waveforms plugged to a charging station.

II. SYSTEM ARCHITECTURE

A. System configuration

The THSeAF shown in Fig. 2 is connected in series between the utility and the load. A bank of tuned passive filters ensures a low impedance path for current harmonics and a dc source could be connected to inject power during voltage sags and absorbs it during overvoltage. The dc source is consisted of a combination of PV and energy storage devices [19]. To ensure a fast transient response with sufficient stability margins over a wide range of operation. A variable source to simulate utility sag and swell is connected to combination of a voltage fed non-linear load with a 0.8 lagging power factor and linear inductive load with a 0.7 power factor. Similar parameters are applied for simulation and practical implementation.

The proposed topology could be solely connected to the grid without a bulky series injection transformer to compensate current harmonics at the source and voltage distortion at the PCC. Even if the number of switches has increased, the transformer-less configuration is more cost-effective than any other series compensators, which generally uses a transformer to inject the compensating voltages to the grid.

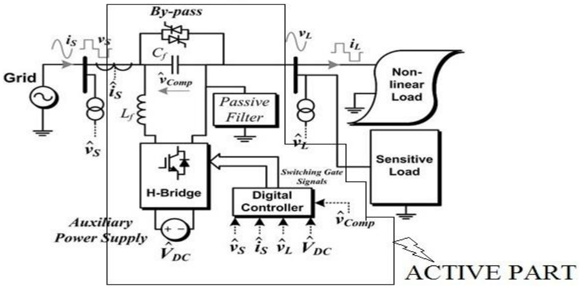

Fig-2 Electrical diagram of the THSeAF in a single-phase utility.

Using the circuit of Fig. 2 showing the block diagram and model of equivalent house circuit connection with utility meters and Multilevel-THSeAF connected in series, several critical scenarios such as grid distortion, sag or swell are simulatedas shown in Fig-3. The THSeAF connected in series injects a compensating voltage which results in a drastic improvement of source current distortions and a cleaned load voltage. While the utility is highly polluted with a THD$V_S$of 25.0%, the load voltage is regulated and contains a THD V_L of only 5.98%.

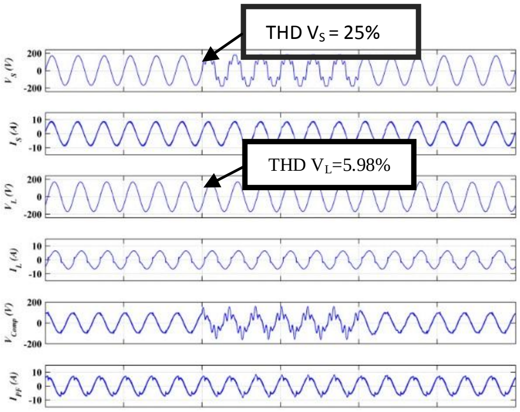

Fig. 3. Compensating voltage regulation, during grid initiated distortions. (a) source voltage Vs, (b) source current Is, (c) load voltage V_L, (d) load current I_L, (e) active-filter voltage (V_{comp}).(e) Harmonics current of the passive filter (I_{pf}).

B. Principle of proposed current compensation approach

A voltage type of non-linear load could be modeled as a harmonic voltage source in series with an impedance $Z_{\text{non-Linear}}$or by its Norton equivalent modeled with a harmonic current source in parallel to the impedance. The Thevenin's model and the Norton equivalent circuit are depicted in Fig. 4. In this paper the common Norton equivalent is chosen to follow major related papers. In this paper the approach to achieve optimal behavior during the time the grid is perturbed is implemented on the controller [20]. The use of a passive filter is mandatory to compensate current issues and maintaining a constant voltage free of distortions at the load terminals. The non-linear load is modeled by a resistance representing the active power consumed and a current source generating harmonics current.

Accordingly, the impedance $Z_L$is the equivalent of the nonlinear ($Z_{\text{Non-linear}}$) and the linear load (Z_{RL}). The Series active filter, whose output voltage Vcomp is considered as an ideal controlled voltage source is generating a voltage based on the detecting source current, load voltage, and also the source voltage to achieve optimal results as of (4). This established hybrid approach gives good result and is quite less sensitive to the value of the gain G to achieve low level of current harmonics. The gain G is proportional to the current harmonics (I_{sh}) flowing to the grid. Assuming the grid contains voltage distortions, the equivalent circuit for the fundamental and harmonics are:

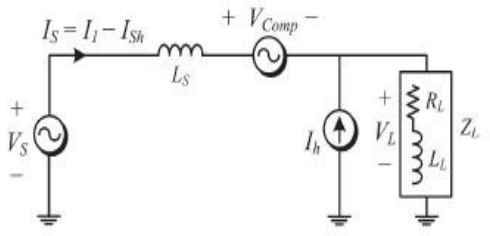

Fig. 4. Single-phase equivalent model for VSC type of loads.

$$V_{source} = V_{s1} + V_{sh} \tag{1}$$

$$V_L = V_{L1} + V_{Lh} = Z_L I_L = Z_L (I_S - I_h) \tag{2}$$

$$I_h = I_{s1} + I_{sh} = I_z + I_h \tag{3}$$

$$V_{comp} = \mathrm{Gi}_{\mathrm{sh}} - \mathrm{v}_{\mathrm{Lh}} \tag{4}$$

Where $I_Z$represents the load current in Z_LUsing the Kirchhoff's law the following equation is depicted for both the fundamental and harmonics.

$$V_{Sh} = -Z_s I_s + V_{comp} + V_L \tag{5}$$

$$V_{Lh} = Z_L (I_{Sh} - I_h) \tag{6}$$

By substituting the equation (6) in (5), the source current at fundamental frequency is obtained.

$$I_{sh} = \frac{V_{sh}}{(G - Z_s)} \tag{7}$$

By substituting (4) in (5) for the harmonic components, the harmonic source current is reached as follow.

$$V_{Sh} = Z_S I_{Sh} + G I_{Sh} - V_{Lh} + V_{Sh} + V_{Lh} Z_L \rightarrow I_{Sh} = 0 \tag{8}$$

If gain is sufficiently large (G→∞), the source current will become clean of any harmonics (I_{sh}→0). This will help improve the voltage distortion the grid side.

By introducing (8) into the harmonic component of the load PCC voltage (6), following equation is achieved.

$$V_{Lh} = -Z_L I_h \tag{9}$$

Consequently under this approach even in presence of source voltage distortions the source current will remain clean of any harmonic components. To some extent in this approach the filter behaves as high impedance likewise an open circuit for current harmonics, while the shunt high pass filter [11] tuned at the system frequency, could create a low-impedance path for all harmonics and open circuit for the fundamental component. This argument explains the need of a Hybrid configuration to create an alternative path for current harmonics fed from a current source type of nonlinear loads.

III. MODELING AND CONTROL STRATEGY

A Transformer-less Hybrid series Active filter configuration is considered in this paper in order to avoid current harmonic pollution along the power line caused by a single-phase households and vehicle charging station. The THSeAF which structure is illustrated in Fig. 6 acts as a controlled voltage source connected in series with the loads between the grids [15] and the PCC.

A. Modeling of Transformer less Series Active Filter

According to Fig. 2, and the average equivalent circuit of an inverter developed, the small-signal model of the proposed configuration can be obtained as shown in Fig. 5. Kirchhoff's rules for voltages and currents, as applied to this system, provide us with the differential equations including the LC filter.

Thereafter, *d* is the duty cycle of the upper switch of the converter leg in a switching period, whereas $\bar{\mathbf{v}}$ and $\bar{\mathbf{i}}$ denotes the average values in a switching period of the voltage and current of the same leg. The mean converter output voltage and current are expressed by (10) and (11) as follow.

$$\overline{v_0} = (2d-1)V_{DC} \tag{10}$$

where the $(2d-1)$ equals to *m*, then

$$\overline{i_{DC}} = m\overline{i_f} \tag{11}$$

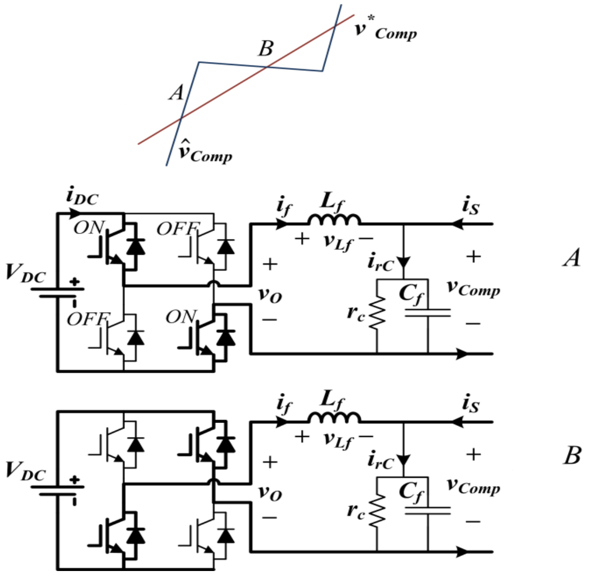

Fig. 5. Small-signal model of transformer less HSeAF in series between the Grid and the load.

According to the scheme on Fig. 5, the arbitrary direction of i_f is chosen to go out from the H-bridge converter. For dynamic studies the accurate model is considered.

$$mV_{DC} = L_f \frac{di_f}{df} + V_{Comp} \tag{12}$$

$$r_c C_f \frac{dV_{comp}}{dt} = -V_{comp} + r_c\left(i_f + i_s\right) \tag{13}$$

The state-space small-signal ac model could be derived by a linearized perturbation of averaged model as follow:

$$\dot{x} = Ax + Bu \tag{14}$$

Hence we obtain:

$$\frac{d}{dt}\begin{bmatrix} \hat{I}_f \\ \hat{V}_{Comp} \end{bmatrix} = \begin{bmatrix} 0 & -\frac{1}{L_f} \\ \frac{1}{C_f} & -\frac{1}{r_c C_f} \end{bmatrix} * \begin{bmatrix} \hat{I}_f \\ \hat{V}_{Comp} \end{bmatrix} + \begin{bmatrix} \frac{V_{DC}}{L_f} & 0 \\ 0 & \frac{1}{C_f} \end{bmatrix} * \begin{bmatrix} m \\ i_s \end{bmatrix} \tag{15}$$

The output vector is given by,

$$y = Cx + Du \tag{16}$$

$$y = [0 \quad 1] * \begin{bmatrix} \hat{I}_f \\ \hat{V}_{Comp} \end{bmatrix} \tag{17}$$

By means of (15) and (17), the state-space representation of the model could be obtained. The second order relation between the compensating voltage and the duty cycle could be reached as follow.

$$C_f \frac{d^2 v_{Comp}}{dt^2} + \frac{1}{r_c}\frac{dv_{Comp}}{dt} + \frac{1}{L_f} v_{Comp} = \frac{V_{DC}}{L_f} m + \frac{di_s}{dt} \tag{18}$$

This model is then used in the developing strategy for the converter's controller as in the following section.

B. Novel Fuzzy Controller forVoltageand Current Harmonic Detection

The controller's outer-loop is composed of two parallel section based on a harmonics extraction technique. The first part is dedicated to compensate for load's voltage regulation and added to a second part which compensates for source current harmonics. The controller demonstrated in the diagram of Fig. 6, restores a stable voltage at the load PCC terminals, while compensating for current harmonics and reactive power. In the source current regulation block, the filter extracts magnitude of the fundamental and its phase degree, leaving harmonics and the reactive component. The control gain ***G*** representing the impedance of the source for current harmonics, should be enough to clean the grid from current harmonics fed through the non-linear load. For a more precise compensation of current harmonics, the source and load voltage harmonics should also be considered in the algorithm.

The source and load voltages together with the source current are considered as system input signals. The Single-phase discrete phase-locked loop (PLL) was used to obtain the reference angular frequency synchronized with the source utility voltage (ω_s). Furthermore, the v_{compi} contains a fundamental component synchronized with the source voltage in order to compensate for the reactive power. The gain *G* representing the resistance for harmonics converts compensating current into a relative voltage. The generated reference voltage v_{comp_i} required to clean source current from harmonics.

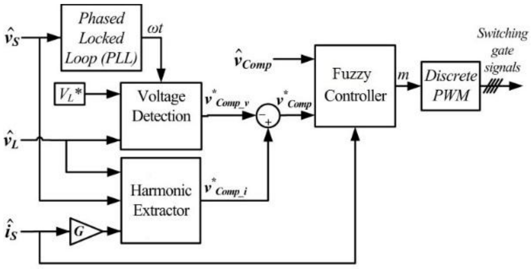

Fig. 6. Control system architecture scheme.

The second novel fuzzy controller [25] used in the outer loop was to enhance the effectiveness of the controller when regulating the dc bus. Thus, a more accurate and fastertransient response was achieved without compromising the Compensation behavior of the system. According to the theory, the gain G should be kept in a suitable level, preventing the harmonics from flowing into the grid [15], [17]. A more precise compensation of current harmonics, the voltage harmonics should also be considered. The compensating voltage for current harmonic compensation is obtained from

$$\mathrm{V}_{\mathrm{com\ p\_i}} = (\mathrm{Gi}_{\mathrm{sh}} - \mathrm{v}_{\mathrm{Lh}} + \mathrm{v}_{\mathrm{Sh}}) \qquad (19)$$

Maintain voltage magnitude is as shown below:

$$V_{com\ p\_v} = \widehat{v_L} - V_L^* \sin(w_s t) \qquad (20)$$

Where, $V_L$is the magnitude ofv_L. The final compensating voltage reference is reached by combination of the stated components related to current issues and voltage issues.

$$\mathrm{V}^*_{\mathrm{comp}} = \mathrm{V}_{\mathrm{com\ p\_v}} - \mathrm{V}_{\mathrm{com\ p\_i}} \qquad (21)$$

According to the presented detection algorithm, the compensated reference voltage v^*comp is calculated. Thereafter, the reference signal is compared with the measured output voltage and applied to a FUZZY controller to generate the corresponding gate signals as in Fig. 6.

IV. SIMULATION AND EXPERIMENTAL RESULTS

The compensator connected in series to the system compensates the current and voltage related issues instantaneously as demonstrated in the following simulation results of Fig.14.Table1 shows the parameter of the analyzed system.

Table- 1 system configuration parameter

System	Definition	Value
V_s	Phase to neutral voltage	120V_{rms}
f	System frequency	50H_z
R_{non}	Load resistance	11.5Ω
L_{non}	Load inductance	20mH
P_L	Linear Load Power	1KVA
L_f	Switching ripple filter inductance	5mH
C_f	Switching ripple filter capacitance	2μF
Ts	dSPACE Syn. Sampling time	40μs
f_{pwm}	PWM frequency	5kH_z
PI_G	Proportional(Kp) and integration gain(Ki)	0.5 and 0.35

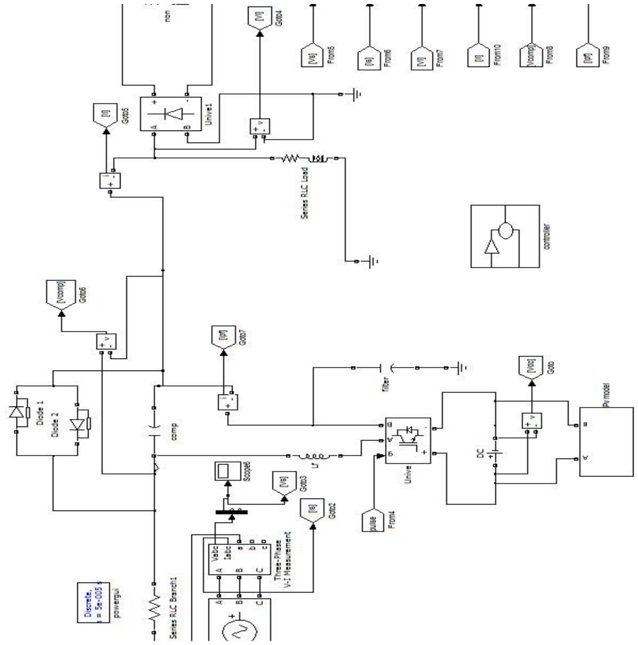

Fig.7 System Architecture using MATLAB simulation.

The THSeAF is preventing load currents distortions with a high THD to flow into the utility and correcting the power factor. As demonstrated in this simulation during a distortion or sag and swell in the grid's voltage, the compensator delivers a clean and regulated voltage supply at the residential entrance.

Simulation results are given here for non-linear load. Fig.8 shows the source voltage and current before hybrid series active filter connection and Fig. 9 shows the load voltage and current after HSeAF connection. FFT analysis of source voltage and FFT analysis of load voltage. It may be noted that, before filter connection, the source voltage waveform is non-sinusoidal because of which its THD is as 25.00% and its fundamental value is 169.7 V. However after filter connection the load voltage has a THD is 5.98% and its fundamental value is 169.4 V. The fundamental value remains approximately the same when the filter is connected which prove that the filter injects only the harmonic voltage and the grid injects the fundamental component of the load voltage.

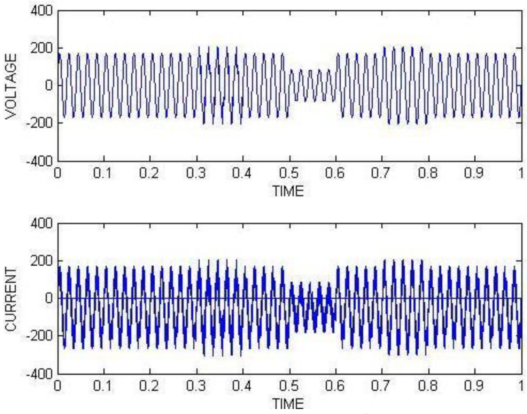

Fig.8 Source voltage and current before hybrid series active filter connection.

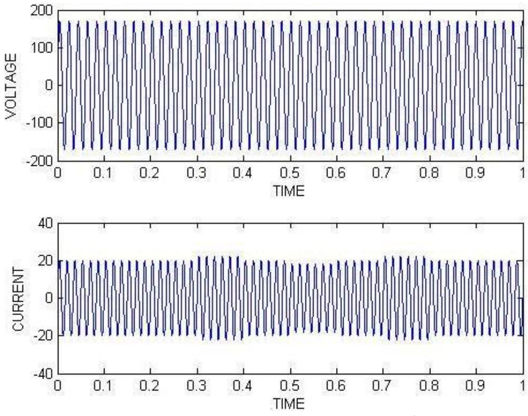

Fig. 9 Load voltage and current after HSeAF connection.

For successful performance of HSeAPF is reference voltage. The reference voltage using instantaneous reactive power factor is presented in this paper. HSeAPF helps in reducing total harmonic distortion and maintain it to acceptable level. HSeAPF helps in improving power quality. The simulation results using MATLAB/Simulink verifies that. **Novel Fuzzy Controller** can effectively and efficiently be used to control hybrid series active power filters.

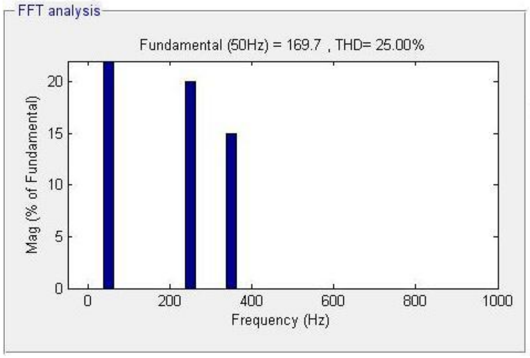

Fig. 10 FFT analysis of source voltage.

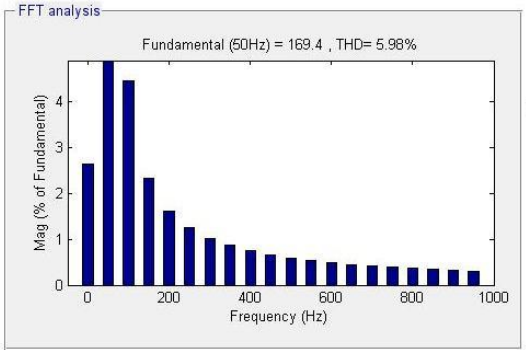

Fig. 11 FFT analysis of load voltage with compensation

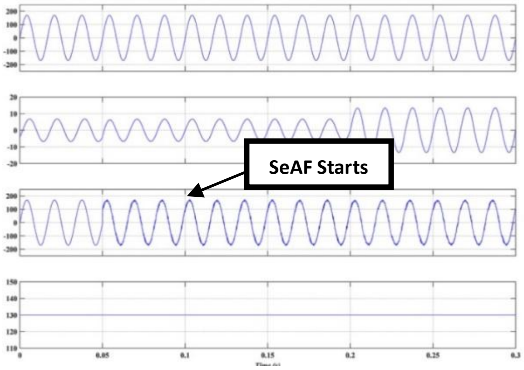

Fig. 12. Series compensator to correct the power factor; (a) Grid voltageVs, (b) source currentIs, (c) load voltage V_L (d) DC bus voltageV_{DC}.

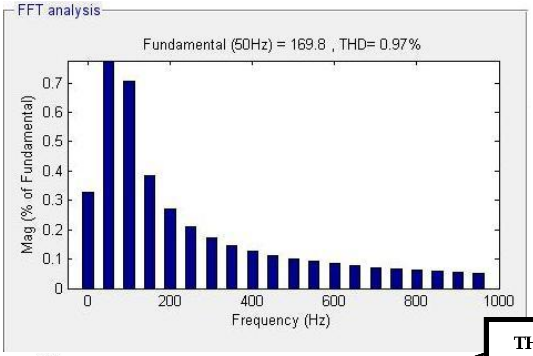

Fig. 13 FFT analysis of load voltage with fuzzy controller.

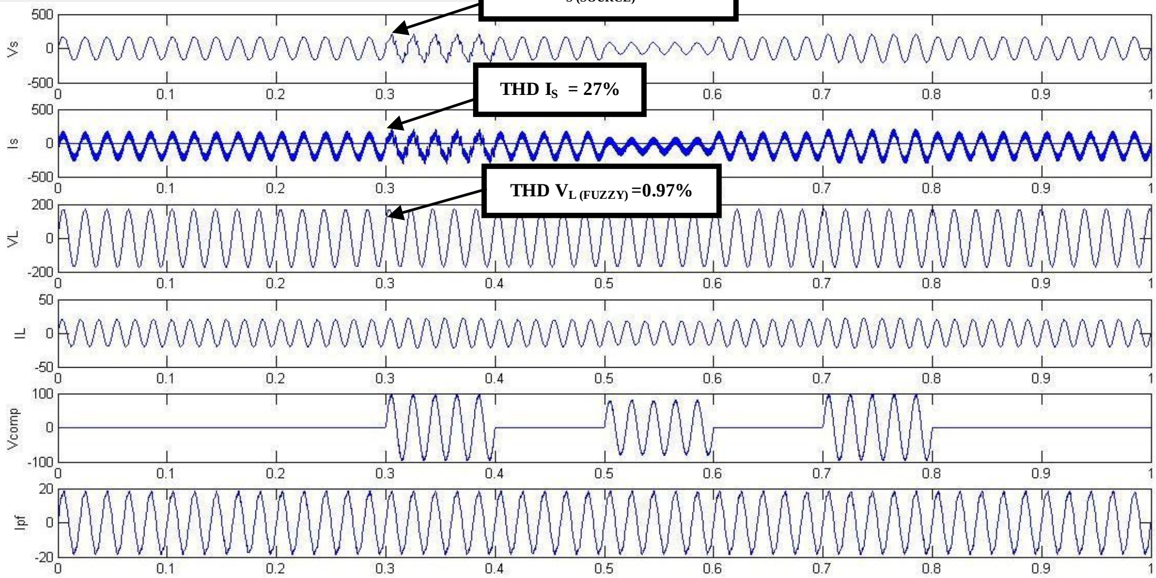

Fig. 14shows the complete graph of source, load and filter voltage and current before and after HSeAPF connection.

V. CONCLUSION

A comprehensive performance evaluation of hybrid power filter using fuzzy logic controller for power quality enhancement has been presented in this paper. The fuzzy logic based hybrid filter results in better controller performance with near sinusoidal source current and near unity input power factor. Thus proposed fuzzy control technique is found extremely satisfactory to stabilize dc link voltage. These hybrid filters damp resonances occurring between line impedances and passive filters and provide cost-effective, higher efficiency, enhanced reliability and better solutions for harmonic compensation with an extremely small-rated inverter in comparison to active power filter topologies and other options of power quality improvement. Thus it could be an economical solution to tackle current harmonics problem. Moreover, this configuration requires reduced size of series active power filter.

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