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A TRANSFORMERLESS HYBRID SERIES ACTIVE FILTER FOR ENHANCING POWER QUALITY OF ELECTRIC TRANSPORTATION SYSTEMS

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ABSTRACT- In this paper to enhance the power quality in single-phase systems with critical loads a transformer less hybrid series active filter is proposed. This paper consists the power quality energy and management issues related to electric transportation and focuses on improving power to electric vehicle load connection to the grid. While protecting sensitive loads from voltage disturbances, sags, and swells initiated by the power system, ridded of the series transformer, this proposed method is advantageous for industrial implementation purpose. This proposed topology prevents or isolate the harmonics and compensates the voltage distortion could absorb or inject the auxiliary power to the grid function is advised. Here the control strategy is designed to mitigate the harmonics which is flowing to load. To protect the common coupling voltage from distortion voltage here DVR is used (dynamic voltage restorer). Here we are using the fuzzy controller compared to other controllers because of its high performance. The simulations results are shown using MATLAB/SIMULINK.

Index Terms—Current harmonics, electric vehicle, hybrid series active filter (HSeAF), power quality, real-time control, Fuzzy logic.

I. INTRODUCTION

Large power plants will continue to make sure the basic supply, however there'll also be renewable energy sources, inflicting fluctuations within the grid. in the not too distant future, flexible intermediate storage of temporary excess power within the grid are possible using electrical vehicles and stationary storage units. smart grid technologies emerged from earlier attempts at using electronic management, metering, and observation. The forecast of future sensible Grids related to electrical vehicle charging stations has created a serious concern on all aspects of power quality of the power system, while widespread electric vehicle battery charging units have damaging effects on power distribution system harmonic voltage levels. On the other hand, the expansion of harmonics fed from nonlinear loads like electrical vehicle propulsion battery chargers that so have prejudicial impacts on the power system and have an effect on plant instrumentation, should be thought of within the development of recent grids. Likewise, the accumulated rms and peak worth of the distorted current waveforms increase heating and losses and cause the failure of the electrical equipment. Such phenomenon effectively reduces system efficiency and will have properly been addressed.

Moreover, to protect the point of common coupling (PCC) from voltage distortions, using a dynamic voltage restorer (DVR) function is advised. A solution is to reduce the pollution of power electronics-based loads directly at their source. Although several attempts are made for a specific case study, a generic solution is to be explored. There exist two types of active power devices to overcome the described power quality issues. The first category are series active filters (SeAFs), including hybrid-type ones. They were developed to eliminate current harmonics produced by nonlinear load from the power system. SeAFs are less scattered than the shunt type of active filters. The advantage of the SeAF compared to the shunt type is the inferior rating of the compensator versus the load nominal rating. Numerous contributions to overall improvement of the efficiency of energy infrastructure are anticipated from the deployment of smart grid technology,

However, the quality of the configuration and necessity of an isolation series transformer had decelerated their industrial application within the distribution system. The second class was developed in concern of addressing voltage problems on sensitive loads. usually referred to as DVR, they need an identical configuration because the SeAF. These 2 categories are completely different from one another in their controlprinciple. This distinction depends on the purpose of their application within the system. The hybrid series active filter (HSeAF) was proposed to address the aforementioned issues with just one combination. Hypothetically, they're capable to compensate current harmonics, ensuring a power issue (PF) correction and eliminating voltage distortions at the PCC. These properties make it an appropriate candidate for power quality investments. The three-phase SeAFs area unit well documented, whereas restricted analysis works reported the single-phase applications of SeAFs within the literature. during this paper, a single-phase transformer less HSeAF is projected and capable of cleansing up the grid-side affiliation bus bar from current harmonics generated by a nonlinear load. With a smaller rating up to ten, it may easily replace the shunt active filter. furthermore, it could restore a sinusoidal voltage at the load PCC.

The advantage of the proposed configuration is that nonlinear harmonic voltage and current producing loads may be effectively compensated. The transformer less hybrid series active filter (THSeAF) is an alternative option to conventional power transferring converters in distributed generation systems with high penetration of renewable energy sources, wherever every phase are often controlled singly and will be operated severally of other phases. This paper shows that the separation of a three-phase converter into single-phase H-bridge converters has allowed the elimination of the pricey isolation transformer and promotes industrial application for filtering functions. The setup has shown great ability to perform requested compensating tasks for the correction of current and voltage distortions, PF correction, and voltage restoration on the load terminal.

II. SYSTEMARCHITECTURE

A. System Configuration

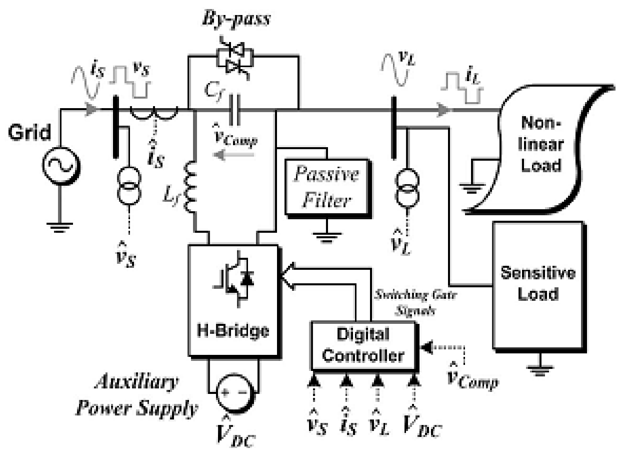

Fig. 1 Electrical diagram of the THSeAF in a single-phase utility.

The THSeAF shown in Fig. 1is composed of an H-bridge converter connected in series between the supply and also the load. A shunt passive capacitor ensures a low electrical resistance path for current harmonics. A dc auxiliary supply can be connected to inject power throughout voltage sags. The dc-link energy storage system is represented in [19]. The system is enforced for a rated power of 2200 VA. to ensure a quick transient response with sufficient stability margins over a good vary of operation, the controller is enforced on a dSPACE/dsp1103.

The system parameters ar identified in Table I. A variable supply of 120 Vrms is connected to a one.1-kVA nonlinear load and a 998-VA linear load with a 0.46 PF. The THSeAF is connected nonparallel so as to inject the compensating voltage. On the dc aspect of the compensator, an auxiliary dc-link energy storage system is installed. Similar parameters are applied for practical implementation.

TABLE I: CONFIGURATION PARAMETERS

Symbol	Definition	Value
v_s	Line phase-to-neutral voltage	120 Vrms
f	System frequency	60 Hz
$R_{non\text{-}linear\ load}$	Load resistance	11.5 Ω
$L_{non\text{-}linear\ load}$	Load inductance	20 mH
P_L	Linear load power	1 kVA
PF	Linear load power factor	46 %
Lf	Switching ripple filter inductance	5 mH
Cf	Switching ripple filter capacitance	2 µF
T_S	dSPACE Synchronous sampling time	40 µs
f_{PWM}	PWM frequency	5 kHz
G	Control gain for current harmonics	8 Ω
V_{DCref}^*	VSI DC bus voltage of the THSeAF	70 V

HSeAFs are often used to compensate distortions of the current type of nonlinear loads. For instance, the distorted current and voltage waveforms of the nonlinear system during normal operation and when the source voltage became distorted are depicted in Fig. 2. The THSeAF is bypassed, and current harmonics flowed directly into the grid. As one can perceive, even during normal operation, the current harmonics (with a total harmonic distortion (THD) of 12%) distort the PCC, resulting in a voltage THD of 3.2%. The behavior of the system when the grid is highly polluted with 19.2% of THD is also illustrated.

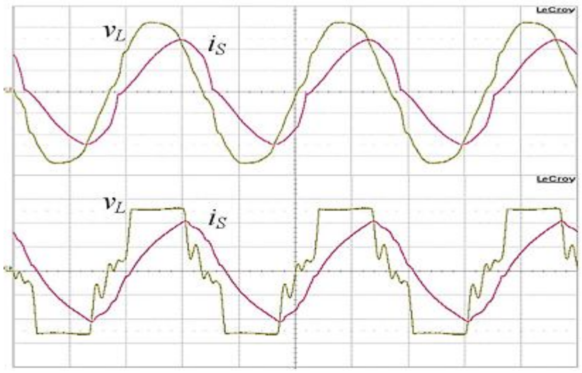

Fig. 2. Terminal voltage and current waveforms of the 2-kVA single phase system without compensator. (a) Regular operation. (b) Grid's voltage distortion (scales: 50 V/div for channel 1 and 10 A/div for channel 2).

TABLE II
SINGLE-PHASE COMPARISON OF THE THSeAF TO PRIOR HSeAFs

Definition	Proposed THSeAF	[21]	[22]	[12]
Injection Transformer	Non	2 per phase	1 per phase	1 per phase
# of semiconductor devices	4	8	4	4
# of DC link storage elements	1+Aux. Pow.	1	2	1+Aux. Pow.
AF rating to the load power	10-30%	10-30%	10-30%	10-30%
Size and weight, regarding the transformer, power switches, drive circuit, heat sinks, etc.	The Lowest	High	Good	Good
Industrial production costs	The Lowest	High	Low	Low
Power losses, including switching, conducting, and fixed losses	Low	Better	Low	Low
Reliability regarding independent operation capability	Good	Low	Good	Good
Harmonic correction of Current source load	Good	Good	Good	Low
Voltage Harmonic correction at load terminals	Good	Better	Good	Good
Power factor correction	Yes	Yes	Yes	No
Power injection to the grid	Yes	No	No	Yes

The proposed configuration could be solely connected to the grid with no need of a bulky and costly series injection transformer, making this topology capable of compensating source current harmonics 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 compensation voltage to the power grid. The optimized passive filter is composed of 5th, 7th, and high pass filters. The passive filter should be adjusted for the system upon load and government regulations. A comparison between different existing configurations is given in Table II. It is aimed to point out the advantages and disadvantages of the proposed configuration over the conventional topologies.

To emphasize the comparison table fairly, the equivalent single phase of each configuration is considered in the evaluation. Financial production evaluation demonstrated a 45% reduction in component costs and considerable reduction in assembly terms as well.

B. Operation Principle

In order to prevent current harmonics iLh to drift into the source, this series source should present low impedance for the fundamental component and high impedance for all harmonics as shown in Fig. 3. The principle of such modeling is well documented in [20]. The use of a well-tuned passive filter is then mandatory to perform the compensation of current issues and maintaining a constant voltage free of distortions at the load terminals. The behavior of the SeAF for a current control approach is evaluated from the phasor's equivalent circuit shown in Fig. 3.The nonlinear load could be modeled by a resistance representing the active power consumed and a current source generating current harmonics. Accordingly, the impedance ZL represents the nonlinear load and the inductive load.

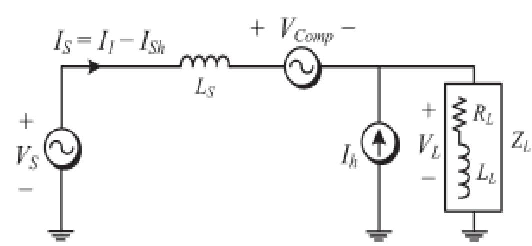

Fig. 3. THSeAF equivalent circuit for current harmonics

The SeAF operates as an ideal controlled voltage source (Vcomp)having a gain(G)proportional to the current harmonics(Ish)flowing to the grid(Vs)

$$V_{comp} = G.I_{sh} - V_{Lh} \quad (1)$$

This allows having individual equivalent circuit for the fundamental and harmonics

$$V_{source} = V_{s1} + V_{sh},$$
$$V_L = V_{L1} + V_{Lh} \quad (2)$$

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The source harmonic current could be evaluated

$$V_{sh} = -Z_s I_{sh} + V_{comp} + V_{Lh} \quad (3)$$

$$V_{sh} = Z_s (I_h - I_{sh}) \quad (4)$$

Combining (3) and (4) leads to (5)

$$I_{sh} = \frac{V_{sh}}{(G-Z_s)} \quad (5)$$

If gain G is sufficiently large (G→∞), the source current will become clean of any harmonics (Ish→0). This will help improve the voltage distortion at the grid side. In this approach, the THSeAF behaves as high-impedance open circuit for current harmonics, while the shunt high-pass filter tuned at the system frequency creates a low-impedance path for all harmonics and open circuit for the fundamental; it also helps for PF correction.

III. MODELING AND CONTROL OF THE SINGLE-PHASE THSeAF

A. Average and Small-Signal Modeling

Based on the average equivalent circuit of an inverter [23], the small-signal model of the proposed configuration can be obtained as in Fig. 4. Here after, d is the duty cycle of the upper switch during a switching period, whereas ‾ v and ‾I denote 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 (6) and (7) as follows:

$$\bar{v}_o = (2d-1)V_{DC} \quad (6)$$

where the (2d−1) equals tom, then

$$\bar{\imath}_{DC} = m\bar{\imath}_f \quad (7)$$

Calculating the Thevenin equivalent circuit of the harmonic current source leads to the following assumption:

$$\bar{v}_h(j\omega) = \frac{-j\bar{\imath}_h}{C_{HPF}.\omega_h} \quad (8)$$

If the harmonic frequency is high enough, it is possible to assume that there will be no voltage harmonics across the load. The state-space small-signal ac model could be derived by a linearized perturbation of the averaged model as follows:

$$\dot{x} = A_x + B_u \quad (9)$$

Hence, we obtain

Moreover, the output vector is

$$y = C_x + D_u \quad (10)$$

The state-space representation of the model is obtained as shown in Fig. 4.

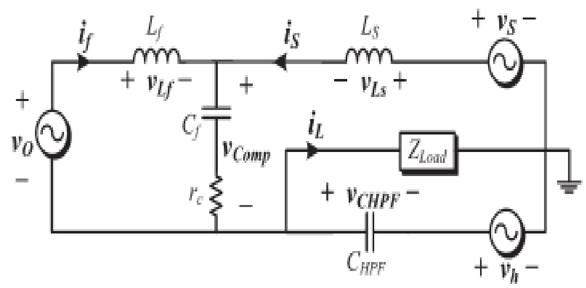

Fig. 4. Small-signal model of transformer less HSeAF in series between the grid and the load.

However, if the compensation of sags and swells is less imperative, a capacitor could be deployed. Consequently, the dc-link voltage across the capacitor should be regulated as demonstrated in Fig.5.

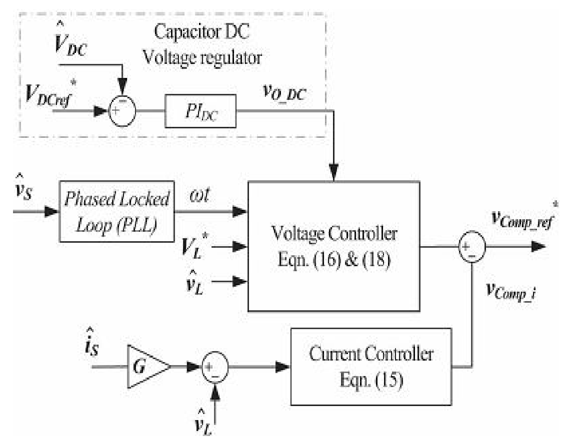

Fig. 5. Control system scheme of the active part.

B. Voltage and Current Harmonic Detection

The outer-loop controller is used where a capacitor replaces the dc auxiliary source. This control strategy is well explained in the previous section. The inner-loop control strategy is based on an indirect control principle. A fast Fourier transformation was used to extract the magnitude of the fundamental and its phase degree from current harmonics. The control gain G representing the impedance of the source for current harmonics has a sufficient level to clean the grid from current harmonics fed through the nonlinear load.

The fuzzy controller used in the outer loop was to enhance the effectiveness of the controller when regulating the dc bus. Thus, a more accurate and faster transient 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 harFmonics from flowing into the grid [22], [24]. As previously discussed, for a more precise compensation of current harmonics, the voltage harmonics should also be considered. The compensating voltage for current harmonic compensation is obtained from

$$v_{comp\_i}(t) = (-G\hat{i}s \quad + \hat{v}_L) - [|-Gi_{s1} + v_{L1}|.\sin(\omega_s t - \theta)] \qquad (11)$$

Hereby, as voltage distortion at the load terminals is not desired, the voltage sag and swell should also be investigated in the inner loop. The closed-loop equation (16) allows to indirectly maintaining the voltage magnitude at the load side equal to V∗L as a predefined value, within acceptable margins

$$v_{comp\_v} = \hat{v}_L - V_L^* \sin(\omega_s t) \qquad (12)$$

The entire control scheme for the THSeAF presented in Fig. 5was used and implemented in MATLAB/Simulink for real-time simulations and the calculation of the compensating voltage. The real-time toolbox of d-SPACE was used for compilation and execution on the dsp-1103 control board. The source and load voltages, together with the source current, are considered as system input signals. According to Srianthumrong et al. [25], an indirect control increases the stability of the system.

The source current harmonics are obtained by extracting the fundamental component from the source current

$$v^*_{com\_ref} = v_{comp\_v} - v_{com\_i} + v_{DC\_ref} \qquad (13)$$

According to the presented detection algorithm, the compensated reference voltage v∗Comp_ref 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.

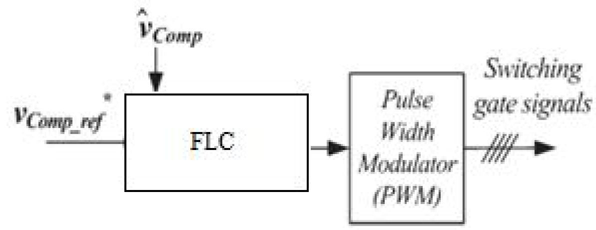

Fig. 6. Block diagram of THSeAF and PI controller.

C. Stability Analysis for Voltage and Current Harmonics

The stability of the configuration is mainly affected by the introduced delay of a digital controller. This section studies the impact of the delay first on the inclusive compensated system according to works cited in the literature. Thereafter, its effects on the active compensator is separated from the grid. The delay time of the digital controller, large gain G, and the high stiffness of the system seriously affect the stability of the closed-loop controlled system

$$I_{sh}(s) = \frac{V_{sh} - V_{comp} - V_{Lh}}{L_S s} \qquad (14)$$

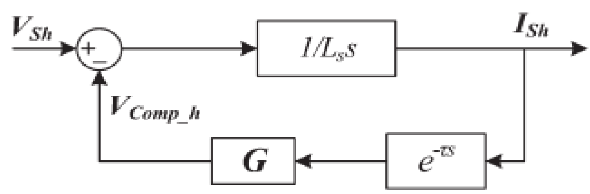

Fig. 7. Control diagram of the system with delay.

For the sake of simplicity, the overall delay of the system is assumed to be a constant value τ.

A system with a typical source inductance Ls of 250μH and a delay of 40μs is considered stable. when the gain G is smaller than 10Ω. simulation results confirm the stability of the system presented in this paper. Moreover, the influence of the delay on the control algorithm should also be investigated.. Thus, assuming an ideal switching characteristic for the IGBTs, the closed-loop system for the active part controller is shown in Fig. 8.

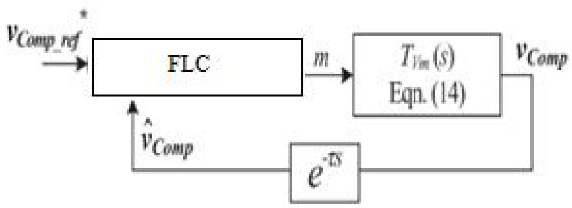

Fig. 8. Closed-loop control diagram of the active filter with a constant delay time τ.

The system parameters described in Table I demonstrates a smooth operation in the stable region. By means of MATLAB, the behavior of the system's transfer function F(s)is traced in Fig. 9. The root locus and the Bode diagram of the compensated open-loop system demonstrate a gain margin of 8.06 dB and a phase margin of 91◦.

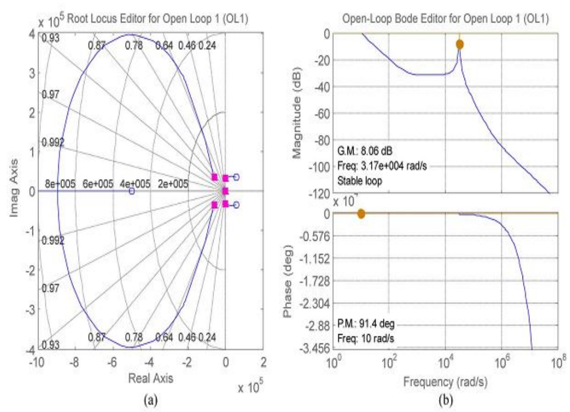

Fig. 9. Compensated open-loop system with delay time of 40μs. (a) Root locus diagram. (b) Bode diagram.

IV. FUZZY LOGIC CONTROLLER

In FLC, basic control action is determined by a set of linguistic rules. These rules are determined by the system. Since the numerical variables are converted into linguistic variables, mathematical modeling of the system is not required in FC.

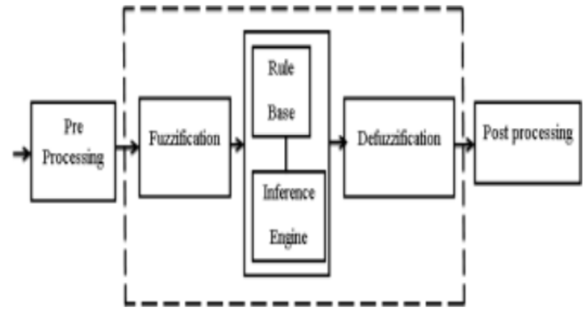

Fig.10.Fuzzy logic controller

The FLC comprises of three parts: fuzzification, interference engine and defuzzification. The FC is characterized as i. seven fuzzy sets for each input and output. ii. Triangular membership functions for simplicity. iii. Fuzzification using continuous universe of discourse. iv. Implication using Mamdani's, 'min' operator. v. Defuzzification using the height method.

TABLE I: Fuzzy Rules

Change in error	Error						
	NB	NM	NS	Z	PS	PM	PB
NB	PB	PB	PB	PM	PM	PS	Z
NM	PB	PB	PM	PM	PS	Z	Z
NS	PB	PM	PS	PS	Z	NM	NB
Z	PB	PM	PS	Z	NS	NM	NB
PS	PM	PS	Z	NS	NM	NB	NB
PM	PS	Z	NS	NM	NM	NB	NB
PB	Z	NS	NM	NM	NB	NB	NB

Fuzzification: Membership function values are assigned to the linguistic variables, using seven fuzzy subsets: NB (Negative Big), NM (Negative Medium), NS (Negative Small), ZE (Zero), PS (Positive Small), PM (Positive Medium), and PB (Positive Big). The Partition of fuzzy subsets and the shape of membership CE(k) E(k) function adapt the shape up to appropriate system. The value of input error and change in error are normalized by an input scaling factor.

In this system the input scaling factor has been designed such that input values are between -1 and +1. The triangular shape of the membership function of this arrangement presumes that for any particular E(k) input there is only one dominant fuzzy subset. The input error for the FLC is given as

$$E(k) = \frac{P_{ph(k)} - P_{ph(k-1)}}{V_{ph(k)} - V_{ph(k-1)}} \qquad (15)$$

$$CE(k) = E(k) - E(k-1) \quad (16)$$

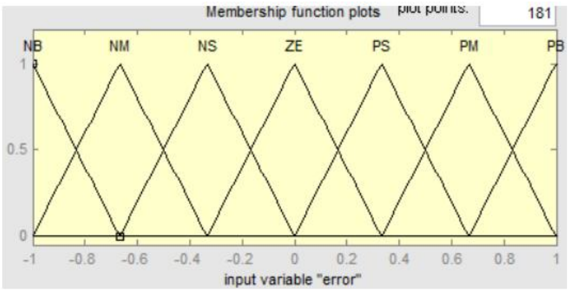

Fig.11.Membership functions

Inference Method: Several composition methods such as Max–Min and Max-Dot have been proposed in the literature. In this paper Min method is used. The output membership function of each rule is given by the minimum operator and maximum operator. Table 1 shows rule base of the FLC.

Defuzzification: As a plant usually requires a non-fuzzy value of control, a defuzzification stage is needed. To compute the output of the FLC, „height" method is used and the FLC output modifies the control output. Further, the output of FLC controls the switch in the inverter. In UPQC, the active power, reactive power, terminal voltage of the line and capacitor voltage are required to be maintained. In order to control these parameters, they are sensed and compared with the reference values. To achieve this, the membership functions of FC are: error, change in error and output

The set of FC rules are derived from

$$u=-[\alpha E + (1-\alpha)*C] \quad (17)$$

Where α is self-adjustable factor which can regulate the whole operation. E is the error of the system, C is the change in error and u is the control variable. A large value of error E indicates that given system is not in the balanced state. If the system is unbalanced, the controller should enlarge its control variables to balance the system as early as possible. One the other hand, small value of the error E indicates that the system is near to balanced state.

V. SIMULATION RESULTS

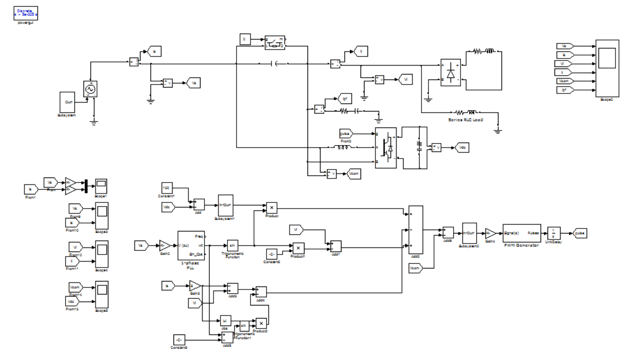

Fig. 12 simulation diagram of the proposed method

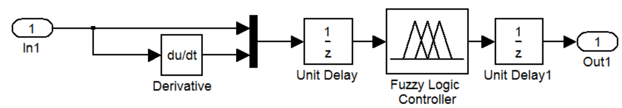

Fig. 13. Fuzzy controller of the proposed system

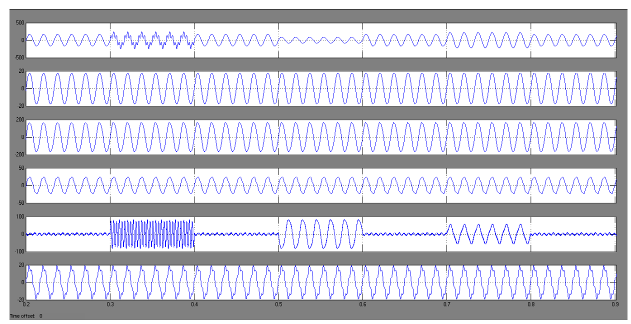

Fig. 14. Simulation of the system with the THSeAF compensating current harmonics and voltage regulation. (a) Source voltage vS, (b) source current iS, (c) load voltage vL, (d) load current iL, (e) active-filter voltage VComp, and (f) harmonics current of the passive filter iPF.

CONCLUSION

The paper highlighted the fact that, with the ever increase of nonlinear loads and higher exigency of the consumer for a reliable supply, concrete actions should be taken into consideration for future smart grids in order to smoothly integrate electric car battery chargers to the grid. In this proposed method the transformerless HseAF is developed and simulated. The key novelty of the proposed solution is that the proposed configuration could improve the power quality of the system in a more general way by compensating a wide range of harmonics current, even though it can be seen that the THSeAF regulates and improves the PCC voltage. Connected to a renewable auxiliary source, the topology is able to counteract actively to the power flow in the system. This essential capability is required to ensure a consistent supply for critical loads. Behaving as high-harmonic impedance, it cleans the power system and ensures a unity PF. The advantage of the proposed configuration is that nonlinear harmonic voltage and current producing loads may be effectively compensated. Here we are using the fuzzy controller compared to other controllers.ans the proposed method is simulated and results are shown. It was demonstrated that this active compensator responds properly to source voltage variations by providing a constant and distortion-free supply at load terminals. Furthermore, it eliminates source harmonic currents and improves the power quality of the grid without the usual bulky and costly series transformer. and hence the performance increased by using the fuzzy controller.

REFERENCES

[1] L. Jun-Young and C. Hyung-Jun, “6.6-kW onboard charger design using DCM PFC converter with harmonic modulation technique and two-stage dc/dc converter,”IEEE Trans. Ind. Electron., vol. 61, no. 3, pp. 1243–1252, Mar. 2014.

[2] R. Seung-Hee, K. Dong-Hee, K. Min-Jung, K. Jong-Soo, and L. ByoungKuk, “Adjustable frequency duty-cycle hybrid control strategy for fullbridge series resonant converters in electric vehicle chargers,” IEEE Trans. Ind. Electron., vol. 61, no. 10, pp. 5354–5362, Oct. 2014.

[3] P. T. Staats, W. M. Grady, A. Arapostathis, and R. S. Thallam, “A statistical analysis of the effect of electric vehicle battery charging on distribution system harmonic voltages,” IEEE Trans. Power Del., vol. 13, no. 2, pp. 640–646, Apr. 1998.

[4] A. Kuperman, U. Levy, J. Goren, A. Zafransky, and A. Savernin, “Battery charger for electric vehicle traction battery switch station,”IEEE Trans. Ind. Electron., vol. 60, no. 12, pp. 5391–5399, Dec. 2013.

[5] Z. Amjadi and S. S. Williamson, “Modeling, simulation, control of an advanced Luo converter for plug-in hybrid electric vehicle energy-storage system,”IEEE Trans. Veh. Technol., vol. 60, no. 1, pp. 64–75, Jan. 2011.

[6] H. Akagi and K. Isozaki, “A hybrid active filter for a three-phase 12-pulse diode rectifier used as the front end of a medium-voltage motor drive,” IEEE Trans. Power Del., vol. 27, no. 1, pp. 69–77, Jan. 2012.

[7] A. F. Zobaa, “Optimal multiobjective design of hybrid active power filters considering a distorted environment, ”IEEE Trans. Ind. Electron., vol. 61, no. 1, pp. 107–114, Jan. 2014.

[8] D. Sixing, L. Jinjun, and L. Jiliang, “Hybrid cascaded H-bridge converter for harmonic current compensation,”IEEE Trans. Power Electron., vol. 28, no. 5, pp. 2170–2179, May 2013.

[9] M. S. Hamad, M. I. Masoud, and B. W. Williams, “Medium-voltage 12-pulse converter: Output voltage harmonic compensation using a series APF,”IEEE Trans. Ind. Electron., vol. 61, no. 1, pp. 43–52, Jan. 2014.

[10] J. Liu, S. Dai, Q. Chen, and K. Tao, “Modelling and industrial application of series hybrid active power filter,”IET Power Electron., vol. 6, no. 8, pp. 1707–1714, Sep. 2013.

[11] A. Javadi, H. Fortin Blanchette, and K. Al-Haddad, “An advanced control algorithm for series hybrid active filter adopting UPQC behavior,” inProc. 38th Annu. IEEE IECON, Montreal, QC, Canada, 2012, pp. 5318–5323.