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Power Quality Enhancement using Hybrid Filter in Interconnected Grid System

Kavitha .D[1], K. Rajangam[2]

[1]P.G Scholar, Electrical and Electronics Engineering Department, Madanapalle Institute of Technology and Science, AP, India

[2]Associate Professor, Electrical and Electronics Engineering Department, Madanapalle Institute of Technology and Science, AP, India

Abstract: ***The power quality problems have been paid a great attention because of their economical impacts on both utilities and customers.The most common problem for power quality is current harmonics,voltagesag and swell.The main objective of this paper is the mitigation of current harmonics to the grid side from non linearload,ensuring power factor correction and the protection of point of common coupling from voltage distortions. A transformerless hybrid series active filter is considered as a combination of H-Bridge and passive filter. Hysteresis current controller is proposed which will reduce the current harmonics and is used due to simple, fast dynamic response and insensitive to load parameters.***

Keywords: Current harmonics, voltage sag and swell,Transformerless hybrid series active filter, Hysteresis current controller

1. Introduction

The estimation of future Smart Grids associated with electric vehicle charging stations has created a severe concern on all aspects of power quality of the power system,while widespread electric vehicle battery charging units [1],[2] have detrimental effects on harmonic voltage levels [3]. On the other hand, the development of harmonics fed from nonlinearloads like electric vehicle propulsion battery chargers [4],[5],which indeed have detrimental impacts on the power system and affect plant equipment, should be considered in the development of modern grids. The increased level of distortions in current which will increase the heating losses and cause the failure of electric equipment so the system efficiency will be reduced [6].

Now a days the usage of power electronic devices increases the current and voltage harmonics generated causing harmonic distortion which will decrease the power quality. Due to harmonic distortion so many problems are occur which are increased heat losses, life span reduction transformer,operation problems on protecting relays,circuit breakers and fuses.The solution of reducing the total harmonic distortion is by using filters are the best. There are two types of active power devices which are shunt and series active filters including hybrid ones.Inthese the first category includes the series active filters including hybrid type. In these series active filters are used due to more advantages compared to shunt active filters. Series active filters (SeAFs) are less scattered than shunt type filters [7].There are so many advantage compared to series type filters than shunt type. The second category of these filters is developed for the voltage issues on sensitive loads.

The hybrid series active filter are capable to mitigate current harmonics, thus ensures the power factor correction and eliminates the distortions of voltage at PCC [8] . The three-phase SeAFs are well research works are reported but single phase applications of SeAFs has limited research work in the literature. In this paper, a single-phase transformerless HSeAF is proposed and capable of cleaning up the grid-side connection bus bar from current harmonics generated by a nonlinear load [9-12].

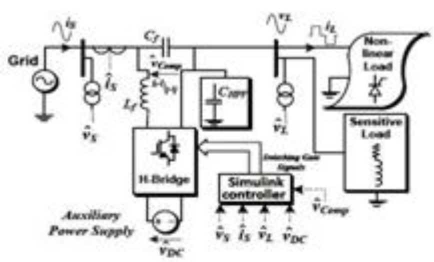

Figure 1:Schematic electric diagram of the single phase THSeAF

2. System Architecture

a) System configuration

The transformerless hybrid series active filter is shown in fig.1 which is composed of an H-bridge and passive filter. H-bridge is the electronic circuit which enables a voltage to be applied across the load in any direction. H-bridge is connected in between the source and the load. A passive capacitor which ensures low impedance path for harmonics in current. A dc auxillary source could be connected to inject power during voltage drop.The system is implemented for a rated power of 2.2kVA.The system configuration parameters are shown in Table 1.A source voltage of 230Vrms is connected to a 1000 VA nonlinear load and a 998 VA linear load with a power factor of 0.46.The THSeAF is connected in series to inject the compensation of voltage.On the dc side of the compensator the auxiliary dc-link energy storage system is installed.HSeAF are used to compensate distortions of the current type of nonlinear loads.

The THSeAF is avoided, the current harmonics flowed directly into the grid.As one can perceive, even during normal operation,the THD for currentharmonics 4.4% distort the PCC, resulting in a voltage THD of 0.44%.The behavior of the system when the grid is highly polluted with 4.4% of THD is instanced.

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 transformerless 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.In Table 2 the comparison between the different existing systems of configurations are shown.

Table 1: Configuration Parameters

Definition	*Symbolic representation*	*Value*
Source voltage	Vs	230Vrms
Frequency	F	50Hz
Load resistance	$R_{non-linear\ load}$	11.5Ω
Load inductance	$L_{non-linear\ load}$	20mH
Load power	P_L	1kVA
Load power factor	PF	46%
Switching ripple filter inductance	L_f	5mH
Switching ripple filter capacitance	C_f	2μF
Sampling time	T_s	40μs
Hysteresis current controller loop frequency	F_{hys}	5kHz
Control gain for current harmonics	G	8Ω
Dc bus voltage of the THSeAF	$V_{dc\ ref}^{*}$	80v
Proportional gain	K_p	0.025
Integral gain	K_i	10

B.Operating principle

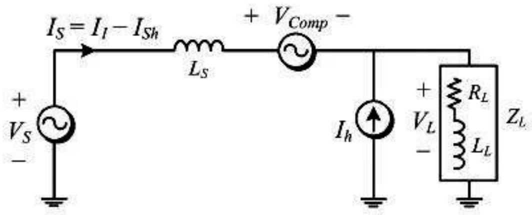

Figure 2: Equivalent circuit of THSeAF for current harmonics

The SeAF represents a controlled voltage source (VSI). In order to prevent current harmonics $i_{lh}$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.2. The use of passive filter is to perform the compensation of current harmonics and to maintain the constant voltage free of distortions. The behavior of the SeAF for a current control approach is evaluated from the phasor's equivalent circuit shown in fig 2.

Table 2: Comparison of THSeAF With HSEAF

Definition	Proposed THSeAF	[8]	[11]	[12]
Injection transformer	Non	1	2	1
Semiconductor devices	4	4	8	4
No of Dc link storage elements	1+aux.pow	1+	1	2
Rating of AF to load power	10-30%	10-30%	10-30%	10-30%
Size and weight of the Transformer	Lowest	Good	High	Good
Power loss	Low	Low	Better	Low
Reliability	Good	Good	Low	Good
Current harmonic correction	Good	Low	Good	Good
Voltage harmonic correction	Good	Good	Better	Good
Power factor correction	Yes	No	Yes	Yes
Power injection to the grid	Yes	Yes	No	No

The nonlinear load could be modeled by a resistance representing the active power consumed and a current source generatingCurrent harmonics. Accordingly, the impedance $Z_L$represents the nonlinear load and the inductive load.

The SeAF operates as an ideal controlled voltage source(V_{comp}) having a gain (G) proportional to the current harmonics (I_{sh}) flowing to the grid(V_s)

$$V_{comp} = GI_{sh} - V_{Lh} \quad (1)$$

This allows having individual equivalent circuit for the fundamental and harmonics

$$V_{source} = V_{s1} + V_{sh} \quad (2)$$

$$V_L = V_{L1} + V_{Lh} \quad (3)$$

The source current harmonics could be evaluated as

$$V_{sh} = -Z_s . I_{sh} + V_{comp} + V_{Lh} \quad (4)$$

$$V_{Lh} = Z_L(I_h - I_{sh}) \quad (5)$$

Combining (4) and (5) leads to (6)

$$I_{sh} = \frac{Vsh}{(G - Zs)} \quad (6)$$

The source current will become clean of any harmonics($I_{Sh}\rightarrow 0$) occurs if the gain G is sufficiently large($G\rightarrow\infty$).At grid side this will help to improve the voltage distortion.

In this THSeAF acts as a high impedance open circuit for current harmonics,while the shunt high pass filter tuned at the systemfrequency creates a low impedance path for all harmonics and open circuit for the fundamental.It also helps for PF correction.

3. Modelling and Control of the Single –Phase Thseaf

A. Average and small-signal modeling

Based on the average equivalent circuit of an inverter,the small-signal model of the proposed configuration can be obtained as in fig.4.

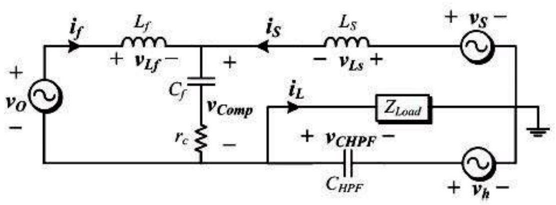

Figure 3: THSeAF small-signal model in series between grid and load

The mean converter output voltage and current are expressed as follows

$$\bar{V}_o = (2d-1)V_{DC} \tag{7}$$

Where d= duty cycle of the upper switch during a switching period.

$\bar{v}$ = average values in a switching period of voltage.

$\bar{\imath}$= average values in a switching period of current

(2d-1)=m then eq.(7) becomes

$\bar{V}_o = mV_{DC}$

$$\bar{\imath}_{DC} = m\bar{\imath}_f \tag{8}$$

For fig 2.equivalent circuit calculating Thevenins voltage

$$\bar{V}_h(j\omega) = \frac{-j\,\bar{\imath}H}{CHPF\ .\omega h} \tag{9}$$

The harmonics across the load will be zero when the harmonic frequency is high.The state space model for small signal model is

$$\dot{x} = Ax + Bu \tag{10}$$

Hence we obtain

$$\frac{d}{dt}\begin{bmatrix}\bar{v}cf\\ \bar{v}cHPF\\ \bar{\imath}s\\ \bar{\imath}f\\ \bar{\imath}L\end{bmatrix}=\begin{bmatrix}0&0&\frac{1}{Cf}&\frac{1}{Cf}&0\\ 0&0&\frac{1}{CHPF}&0&\frac{-1}{CHPF}\\ \frac{-1}{Ls}&\frac{-1}{Ls}&\frac{-rc}{Ls}&\frac{-rc}{Ls}&0\\ \frac{-1}{Lf}&0&\frac{-rc}{Lf}&\frac{-rc}{Lf}&0\\ 0&\frac{1}{Lf}&0&0&\frac{-RL}{LL}\end{bmatrix}\times\begin{bmatrix}\bar{v}cf\\ \bar{v}cHPF\\ \bar{\imath}s\\ \bar{\imath}f\\ \bar{\imath}L\end{bmatrix}+\begin{bmatrix}0&0&0\\ 0&0&0\\ \frac{1}{Ls}&0&\frac{1}{Ls}\\ 0&0&\frac{-1}{Ll}\end{bmatrix}\times\begin{bmatrix}\bar{v}s\\ VDC\\ \bar{v}h\end{bmatrix} \tag{11}$$

The output vector is

$$Y = C\,x + D\,u \tag{12}$$

Or

$$\begin{bmatrix}\bar{v}comp\\ \bar{v}l\end{bmatrix}=\begin{bmatrix}1&0&rc&rc&0\\ 0&1&0&0&0\end{bmatrix}\times\begin{bmatrix}\bar{v}cf\\ \bar{v}cHPF\\ \bar{\imath}s\\ \bar{\imath}f\\ \bar{\imath}L\end{bmatrix}+\begin{bmatrix}0&0&0\\ 0&0&-1\end{bmatrix}\times\begin{bmatrix}\bar{v}s\\ VDC\\ \bar{v}h\end{bmatrix} \tag{13}$$

By means of eq.(11) and (13),the state space representation of the model is obtained as shown in fig.3.To control the active part independently,the transfer function should be from the grid configuration.TheTv_m transfer function explains the relation between the output voltage of the converter versus the duty cycle of the first leg converter's upper switch.

$$Tv(s) = \frac{Vcomp}{Vo}$$

$$= \frac{rcCfs+1}{LfCfS2+rcCfs+1} \tag{14}$$

$$Tv_m(s) = \frac{Vcomp}{m}$$

$$= V_{DC}.T_V(s) \tag{15}$$

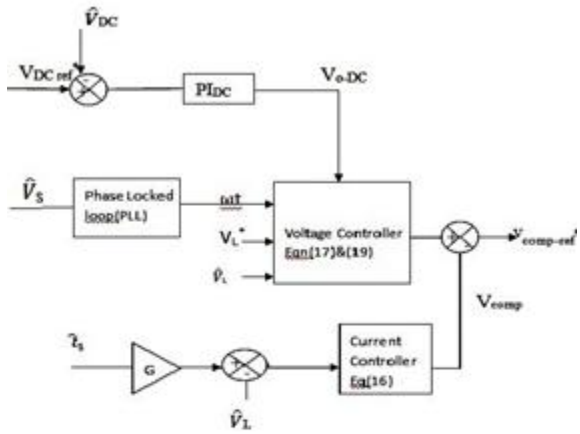

Figure 4: Active part control system scheme

To maintain an adequate supply on the load terminals a dc auxiliary source is used. It should absorb or inject power during voltage drop or swell to keep the voltage magnitude at the load terminals within a specified margin. A capacitor could be deployed, when the compensation of voltage sag and swells is less imperative.Consequently,the dc link voltage across the capacitor should be regulated as demonstrated in Fig.4.

B.Voltage and Current Harmonic Detection

The inner -loop control strategy is based on an indirect control principle.The controller for outer loop is used where a capacitor replaces the dc auxiliary source.A FFT was used to extract the phase degree and magnitude of the fundamental from current harmonics.To clean the grid from current harmonics fed from nonlinear load has the sufficient level of the control Gain G.

In this the second controller are used as proportional integrator (PI) controller.This controller used in outer loop was to raise the effectiveness of the controller when regulating the dc bus.Thus ,more accurate and faster transient response was reached without compromising the compensation behavior of the system.According to this the gain G should be held in a suitable level, preventing the harmonics which flowing to the grid.The compensating voltage for current harmonic compensation is obtained from this equation

$$V_{comp-i}(t)=(-G\hat{\imath}_S+\hat{v}_L)-[|-G\hat{\imath}s1Vl1|.\sin(\omega st-\theta)] \quad (16)$$

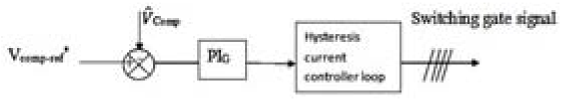

Figure 5: Block diagram of THSeAF and PI controller

Here by,as voltage distortion at the load terminals is not craved,the voltage swell and sag would also be investigated in the inner loop.The closed loop eq(17) allows to indirectly maintain the voltage magnitude at the load side equal to V_L^* as a predefined value,with in acceptable margins.

$$V_{comp} = \hat{v}_L - V^*_L\sin(\omega_s t) \quad (17)$$

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

$$V^*_{comp} = V_{comp-v} - V_{comp-i} + V_{DC-ref} \quad (18)$$

Where the V_{DC}_ref(t) is the required voltage to maintain the dc bus voltage.

$$V_{DC\_ref(t)} = Vo\_{DC}\ .\sin(\omega_S t) \quad (19)$$

A phase locked loop was used to get the reference angular frequency(ωs).The extracted harmonic current holds a fundamental component synchronized with the source voltage in order to correct the PF.This current represents the reactive power of the load.The gain G representing the resistance for harmonics converts current into a relative voltage.

C. Hysteresis current control loop

Hysteresiscurrent control(Hysteresis band PWM) is used for reducing the current harmonics which having four switches S_1,S_2,S_3 and S_4.In these operation are using relay and NOT gate.This controller has two signals they are modulation signal and carrier signal .The complete duty ratio is sensed to relay and not gate ,the signal is in between it the switch is on otherwise off.If the switches 1&4 are on and the remaining switches are off position.Hysterisis band PWM is basically an instant feedback current control method of PWM where the actual current continuously tracks the command current with in a hysteresis band.The main advantages of hysteresis band PWM are time taken will be less as compared to PWM,excellent dynamic performance and controllability of the peak to peak current ripple with in a specified hysteresis band.

4. Simulation Results

The proposed THSeAF configuration was simulated in MATLAB/simulink using the discrete time of T_s=10µs.The combination of a single-phase nonlinear load and linear load with a rated power of 2kVA with a 0.74 lagging 230 Vrms 50Hz variable source is used.THSeAF connected in series to the system compensates the current harmonics and voltage distortions.A gain G = 8Ω (=1.9 p.u) was used to control current harmonics.During the grid's voltage distortion,the compensator regulate the load voltage magnitude,compensates the current harmonics and corrects the PF.The load voltage V_L THD is 0.44% ,while the source voltage is highly distorted ($THDV_s$ = 1.45%).

The grid is cleaned of current harmonics with a unity power factor (UPF) operation, and the THD is reduced to less than 1% in normal operation and less than 4% during grid perturbation. While the series controlled source cleans the current of harmonic components, the source current is forced to be in phase with the source voltage. The series compensator has the ability to slide the load voltage in order for the PF to reach unity. Furthermore, the series compensator could control the power flow between two PCCs.The compensator shows high efficiency in normal operation where the total compensator losses including switching, inductor resistances, and damping resistances are equal to 44 W which is less than 2.5% of the system rated power. While cleaning the source current from harmonics and correcting the PF, the compensator regulates the load terminal voltage.

Voltage sag waveform is shown in fig 6.The source voltage is highly effected due to this sag in the time period 0.4 to 0.6 sec.If the voltage change will occur the current waveform also changes which affect the system.In fig 7.the voltage swell are shown .Voltage swell means sudden increase in voltage.voltage swell occur in the time period of 0.6 to 0.8 sec. Fig 8 shows the simulation waveform for current harmonics in the system in time period of 0.3 to 0.4 the source current is highly affected due to this harmonics.

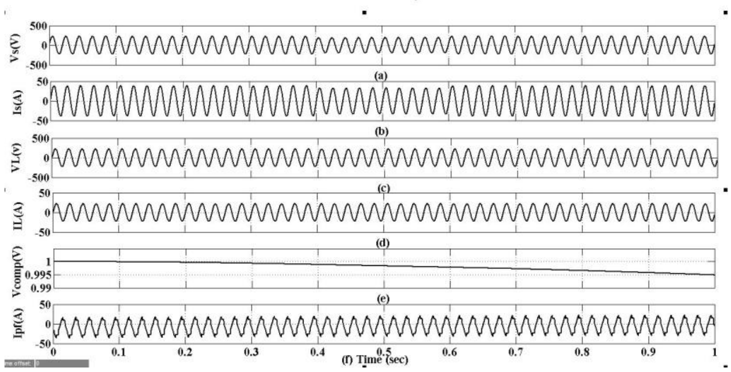

Figure 6: Simulation waveforms for voltage sag.(a).Source Voltage Vs,(b).Source current is, (c).load voltage V_L,(d) load current i_L,(e) Active-filter voltage Vcomp,and (f) Harmonic currentof the passive filter i_{PF}.

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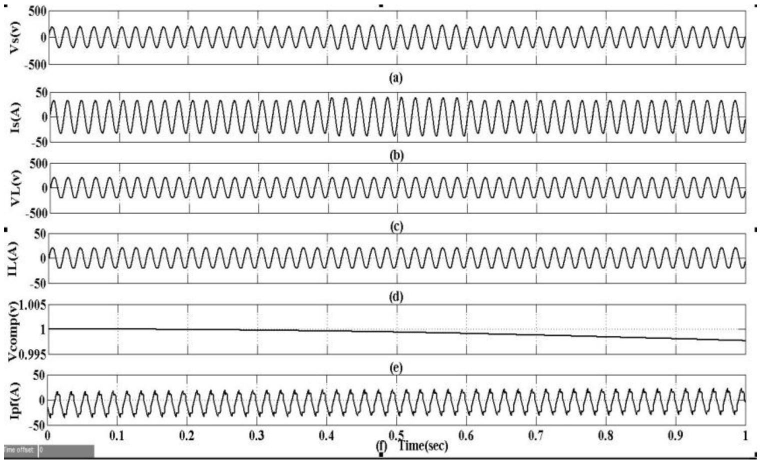

Figure 7: Simulation waveforms for voltage swell.(a).Source Voltage Vs,(b).Source current is, (c).load voltage $V_{L,}$(d) load current $i_{L,}$(e) Active-filter voltage Vcomp,and (f) Harmonic currentof the passive filter i_{PF}.

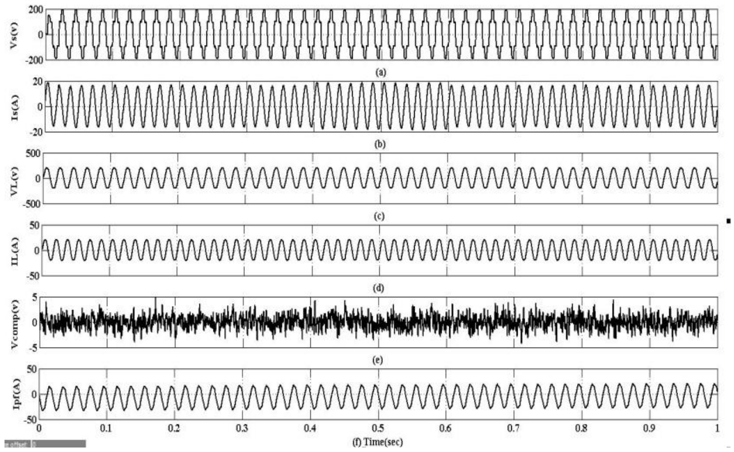

Figure 8: Simulation waveforms for current harmonics.(a).Source Voltage Vs,(b).Source current is, (c).load voltage $V_{L,}$(d) load current $i_{L,}$(e) Active-filter voltage Vcomp,and (f) Harmonic currentof the passive filter i_{PF}.

THD for current

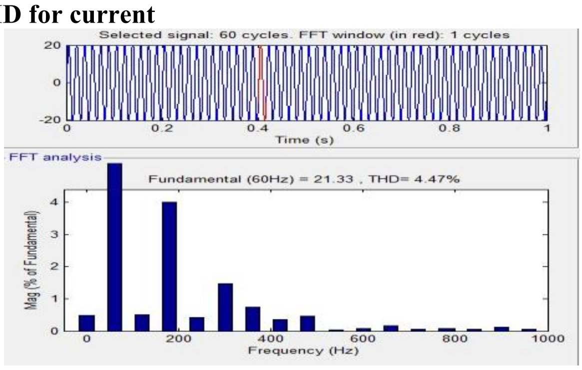

Figure 9: Total harmonic distortion for current

THD for voltage

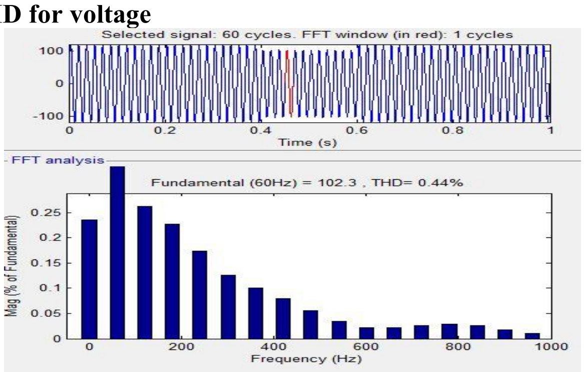

Figure 10: Total harmonic distortion for voltage

In Fig.9& 10 shows the total harmonic distortion levels in the current and voltage waveforms.The THD for current and voltage are 4.47% and 0.44%.The THSeAF reacts at once to this variation and does not interfere its operation functionality.To valuate the compensator during utilityperturbation,the power source become distorted.The source current become cleaned of the majority of harmonics are in the load current and has a unity power factor.The THSeAF defendsthe sensitive loads and maintain a sinusoidal and regulated voltage across the PCC of loads with a 0.44% of distortion.The compensator ought inject power to maintain the load PCC voltage regulated at the desired level.

The harmonic content and THD factor of the source utility and load PCC shows improvement in THD, the load draws polluted current waveforms.Although the grid's voltage is polluted,the compensator in a hybrid approach regulates and maintains harmonic-free load voltage.The various levels of THD for proposed system and existing system are shown in Table-3.

Table 3: THD of Current and Voltage for Load and Grid

	Load voltage V_L(v)	Load current I_L(A)	Grid voltage V_s(v)	Grid current I_L(A)
Proposed system	4.6%	6.9%	0.44%	4.47%
Existing system	6.6%	19.7%	25%	5.2%

5. Conclusion

A THSeAF for power quality improvement was arised in this paper and tested by simulation for a single phase system.The paper highlighted the concept 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. 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. It was demonstrated that this activecompensator 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.

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