International Journal For Technological Research In Engineering
Volume 8, Issue 4, December-2020 *ISSN (Online): 2347 - 4718*

SIMULATION AND COMPARISON OF HYBRID SERIES ACTIVE FILTER AND TRANSFORMERLESS HYBRID SERIES ACTIVE FILTER FOR POWER QUALITY ENHANCEMENT USING PR CONTROLLER

[1]Mr. Poojara Mit G, [2]Mr.Jaydeepsinh Chauhan
[1]PG Scholar, [2] Assistant Professor
Electrical Department
SVBIT, Unava
Gandhinagar, Gujarat, India

Abstract— In this paper a Transformer less Hybrid Series Active Filter (Multilevel-THSeAF) is proposed to enhance the power quality of a single-phase residential household. The proposed topology reflects new trends of consumers towards electronic polluting loads and integration of renewable sources which in fact may lead to the scope of a reliable and sustainable supply. This paper contributes to improvement of power quality for a modern single-phase system and emphasis integration of a compensator with energy storage capacity to ensure a sustainable supply. A proportional resonant (P+R) regulator is implemented in the controller to prevent current harmonic distortions of various non-linear loads to flow into the utility. The main significant features of the proposed topology include the great capability to correct the power factor as well as cleaning the grid simultaneously, while protecting consumers from voltage disturbances, sags, and swells during a grid perturbation. It investigates aspects of harmonic compensation and assesses the influence of the controller's choice and time delay during a real-time implementation. Combinations of analysis and experimental results performed on a laboratory setup are presented for validation.

Keywords—SAPF, HSAPF, PR, THD, etc.

1. INTRODUCTION

Electrical energy is the most efficient and popular form of energy and the modern society is heavily dependent on the electric supply. The life cannot be imagined without the supply of electricity. At the same time the quality of the electric power supplied is also very important for the efficient functioning of the end user equipment. The term power quality became most prominent in the power sector and both the electric power supply company and the end users are concerned about it. Now-a-days with the advancement of technology, the demand for electric power is increasing at an exponential rate. Many consumer appliances demand quality power continuously for their operation. The quality of power delivered to the consumers depends on the voltage and frequency ranges of the power. If there is any deviation in the voltage and frequency of the electric power delivered from that of the standard values then the quality of power delivered is affected.

The performance of the end user equipment is heavily dependent on the quality of power supplied to it. But the quality of power delivered to the end user is affected by various external and internal factors. They are like voltage and frequency variations, faults, outages etc. These power quality problems reduce the life time and efficiency of the equipment. Thus, to enhance the performance of the consumer equipment and also the overall performance of the system these problems should be mitigated. Now-a-days with the advancement in technology there is a drastic improvement in the semi-conductor devices. With this development and advantages, the semi-conductor devices got a permanent place in the power sector helping to ease the control of overall system.

Moreover, most of the loads are also semi-conductor based equipment. But the semi-conductor devices are non-linear in nature and draws non-linear current from the source. And also the semi-conductor devices are involved in power conversion, which is either AC to DC or from DC to AC. This power conversion contains lot of switching operations which may introduce discontinuity in the current. Due to this discontinuity and non-linearity, harmonics are present which affect the quality of power delivered to the end user. In order to maintain the quality of power delivered, the harmonics should be filtered out. Thus, a device named *Filter* is used which serves this purpose. There are many filter topologies in the literature like- active, passive and hybrid. In this paper the use of hybrid power filters for the improvement of electric power quality is studied and analyzed.

The rising interest in the use of electronic devices levies nonlinear loads to the source that draw active current, reactive current and harmonic current. Due to the reactive current and harmonic current electromagnetic interference with nearby equipment and heating of transformers occur. Power system can sop up harmonic currents with no problem. Resonant condition mainly affects the power problem.

2. PROBLEM IDENTIFICATION AND OBJECTIVES OF HSAPF

The forecast of a smart grid associated with the continuous increase of switch-mode power converters, drives, as well as domestic and industrial nonlinear loads has created a serious concern on the power quality of the future distribution power systems as shown in Fig.1. Along with integration of renewables into the smart micro-grids, and expansion of electronic polluting devices as well as electric vehicle charging stations would have harmful impacts on the power quality.

Electric vehicles market shows a considerable growth, therefore it became crucial to monitor and evaluates their behaviour and associated current waveforms when charging. Moreover, in some existing North American EV charging stations, the cars are connected between two phases of the 3P4W system, creating heavy unbalances. On the other hand, pushed by social efforts, governments start to investigate more on implementation of renewable energy sources, creating research and developments in this field.

This work proposes an efficient three-phase Transformer less Hybrid Series Active Filter (THSeAF) capable to rectify current related issues in the smart micro-grids which also provides sustainable and reliable voltage supply at the PCC where residential and commercial buildings are connected with nonlinear time varying load side demand. The use of this device will facilitate the integration of energy storage systems and renewables for modern systems. The compensator is connected at distribution level of the power system to prevent harmonic currents of a load to flow into the grid while protecting the downstream loads from voltage perturbations coming from the utility and protecting the later from sags and swells.

This proposed low cost configuration ride of the common bulky series transformer is an economic key toward power quality improvement of Smart grid's power quality development. This compensator cleans the current harmonics from the utility and similarly to a DVR, the Point of Common Coupling (PCC) and utility's smart meters will be protected from voltage distortions and wrong computation of power and energy balance. This compensator could inject or absorb active power during grid voltage variations to ensure high quality and reliable supply along with complete decoupling the grid from polluted loads.

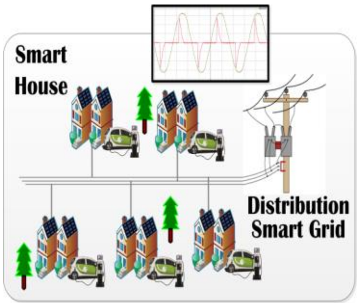

Fig. 1. Smart residential consumer with non-linear electronic loads

3. PROPOSED WORK

The series APF used for the power quality improvement is realized as a Voltage Source Inverter (VSI). It can be a three-phase VSI or three single-phase VSI‟s can also be used. The VSI is connected in series with the source impedance through a matching transformer. The circuit diagram is shown in Fig.2. A capacitor is used at the input if the VSI to provide constant input voltage to VSI.

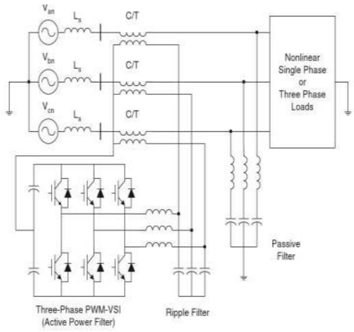

Figure-2 Overall Circuit Diagram of the System with Hybrid Filter

A passive filter is also connected at the PCC. This filter is tuned to eliminate higher order harmonics. In certain cases there may be two or more LC branches tuned to eliminate specific order harmonics (especially 5th and 7th). A ripple filter is used in series with VSI. The filter parameters are selected such that they do not exceed the transformer burden. The design criteria is-

- XCrf<<XLrf, such that at switching frequency the inverter output voltage drops across Lrf
- XCrf<< ZS + ZF, to make the voltage divide between Lrf and Crf

Thus, with an efficient control strategy, the APF compensates the voltage unbalances and distortion. The control strategy is designed such that the series APF together with the passive filter act as a balanced resistive load on the overall system. In a four-wire system, the harmonic currents circulated in the neutral wire are also reduced due to series APF.

CONTROL STRATEGY

The series APF should be controlled such that the voltage injected by it should compensate the harmonics present in the system and should help in improving the quality of power. To achieve the above purpose, the output voltage of the APF should be controlled. For this to happen, at first a reference voltage is generated which when injected by APF will serve the desired purpose. Then the actual output voltage of the series connected APF is controlled using a PI controller such that the actual output voltage generated is equal to the reference value. The overall control strategy is shown by the flow chart given in Fig.3.

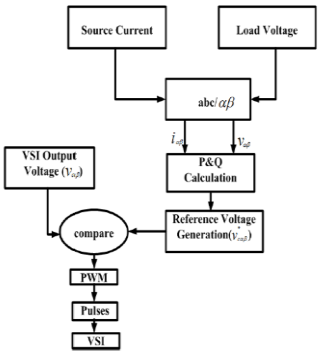

Figure-3 Flow Chart of Control Strategy

COMPENSATION STRATEGY

The compensation strategy to compensate the harmonics is designed based on “Dual Instantaneous Reactive Power Theory”. In general, the power company tries to generate electric power at sinusoidal and balanced voltage. To achieve this condition, the load current at the Point of Common Coupling (PCC) should be co-linear with the supply voltage. This condition is satisfied if the load is a linear, balanced and resistive. This condition is expressed in equation form as-

$$v = R_e i \quad \text{……………………..} (1)$$

Where Re is the equivalent resistance.
Thus, the average power supplied by the source is given as-

$$P_s = I^2 R_e \quad \text{……………………..} (2)$$

In case of unbalanced loads, where harmonics exist, only the fundamental component of the current helps in supplying the active power to the load. So the current in the equation (2) is only the fundamental component and is represented as *I1*. The load power is the summation of the source power and the compensator power. But the power exchange by the compensator should be null. So the load power is equal to the source power.
Therefore, the equivalent resistance is obtained as-

$$R_e = \frac{p_L}{I_1^2} \quad \text{……………………..} (3)$$

Thus, the voltage at the PCC in α-β co-ordinates is obtained as-

$$v_{PCC\alpha\beta} = R_e i_{\alpha\beta}$$
……………………... (4)

By substituting equation (3) in (4) the voltage at PCC is obtained as-

$$v_{pcc\alpha\beta} = \frac{p_L}{I_1^2} i_{\alpha\beta}$$
……………………... (5)

From equation (6) the load voltage can be written as-

$$v_{\alpha\beta} = \frac{p}{i_{\alpha\beta}^2} i_{\alpha\beta} + \frac{q}{i_{\alpha\beta}^2} i_{\alpha\beta\perp}$$
……….(6)

$$v_{L\alpha\beta} = \frac{p_L}{i_{\alpha\beta}^2} i_{\alpha\beta} + \frac{q_L}{i_{\alpha\beta}^2} i_{\alpha\beta\perp}$$
……. (7)

Thus, the compensating voltage of the series APF is obtained as-

$$v_{C\alpha\beta}^* = v_{pcc\alpha\beta} - v_{L\alpha\beta}$$
……………. (8)

From equations (6) and (7) the equation (8) is modified as-

$$v_{C\alpha\beta}^* = \left(\frac{p_L}{I_1^2} - \frac{q_L}{i_{\alpha\beta}^2}\right) i_{\alpha\beta} - \frac{q_L}{i_{\alpha\beta}^2} i_{\alpha\beta\perp}$$
….. (9)

This is the reference value of the voltage that is to be supplied by the APF in order to make the set load and compensating equipment to act as resistive load.

a. Reference Vector Generation

To control the series connected APF the reference vector should be generated and compared with the actual voltage vector. The reference voltage vector given by equation (5.9) is generated by the following control block shown in Fig. 5.3. The fundamental current component calculation is shown in Fig.4. The fundamental component calculation needs the grid voltage angle to calculate the value. The grid voltage angle necessary for this calculation is extracted by using a Phased Lock Loop (PLL).

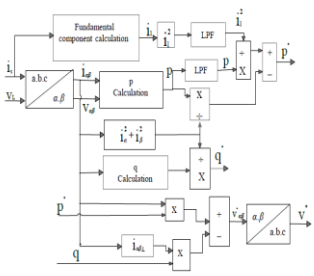

Figure-4 Control Block to Generate Reference Vector

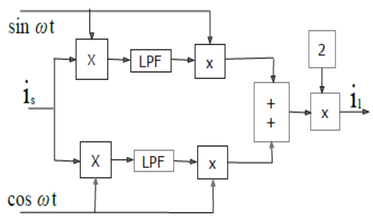

Figure-5 Fundamental Component Calculation

A Low pass filter (LPF) is used in the fundamental calculation block to filter out the harmonics and extract the fundamental component. A comparison is made between the actual and reference values of the output voltage of APF. The error is passed through a PI controller. The gain values of the controller are tuned in such a way that the error is zero and the actual value matches almost with the reference value. If this condition is achieved perfectly then the series APF improves the quality of power generated to the load by filtering out the harmonics and thus improving the performance of the system.

System configuration

Conventional series Hybrid active filters have a common configuration as shown in Fig. 6 with a three-phase converter and three isolating transformers, while the proposed configuration do not contain series transformers. The transformer less power hybrid filter shown in Fig. 7 is composed of a two-level H-bridge converter connected in series between the grid and the PCC, where the presented configuration allows an independent control on each individual phase regardless of the others. A bank of tuned passive filters ensures a low impedance path for current harmonics. A DC bidirectional source is connected to inject power during voltage sags and absorbs it during overvoltage.

The THSeAF is connected in series in order to inject the compensating voltage. On the DC side of the compensator, auxiliary dc-link energy storage components are installed. The shunt passive filter constituted of several tuned filters is composed of capacitor in series with an inductance with values tuned at desired frequency. Active filters are often keen to compensate current distortions, which is one of the priorities of the compensator.
The current harmonics of the load produces voltage distortions when passing through the line and system impedances. Thus, to address such power quality issues, the proposed topology will be connected to the grid without the use of the bulky series transformer. This configuration will compensates source current harmonics and voltage distortion at the PCC.

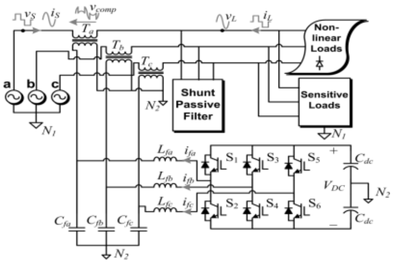

Fig. 6 Conventional Hybrid series active filter topology

B. Principle of the Hybrid Control Approach

The Series active filter represents a controlled voltage source Inverter (VSI). In order to prevent current harmonics to drift into the power system, this series source should have a high impedance characteristic for all harmonic components. The principle of such modelling is well documented in this paper.
The use of a passive filter becomes mandatory to compensate current issues while maintaining a constant voltage free of harmonic distortions at the load terminals. The behaviour of the series active filter (SeAF) for a current control approach is evaluated from the phasor's equivalent circuit shown in Fig. 6..

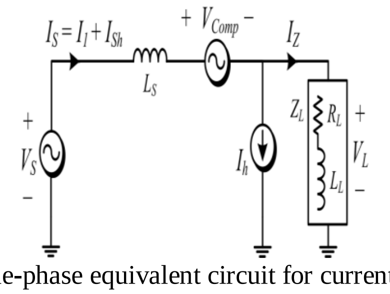

Fig. 7 Single-phase equivalent circuit for current harmonics

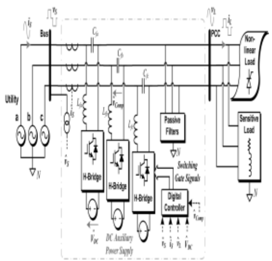

Fig. 8 The proposed three-phase THSeAF connected ahead of load PCC

Consequently in this approach even in presence of source voltage distortions the source current stays always clean of any harmonic component. An additional component is then added to regulate the load voltage terminals which will be described in the next section. This extra component assists the THSeAF to operate similar to a Dynamic voltage restorer (DVR) and maintain the load voltage regulated despite variation in the utility's voltage supply.

4. SIMULATION & RESULTS

MATLAB SIMULATION OF PROPOSED SYSTEM WITHOUT THSEAPF

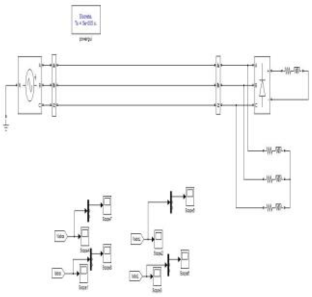

Fig 9 Matlab Model of Proposed System without Filter

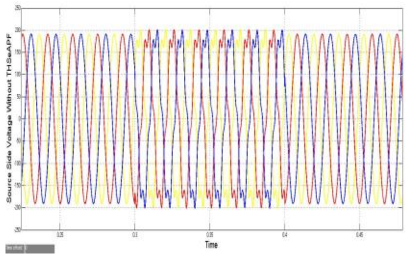

Fig 10- Source Side Voltage Waveform without Filter

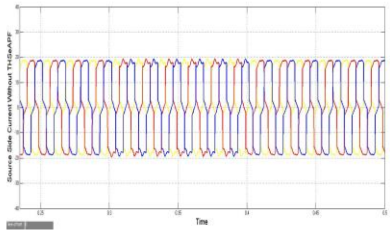

Fig 11- Source Side Current Waveform without Filter

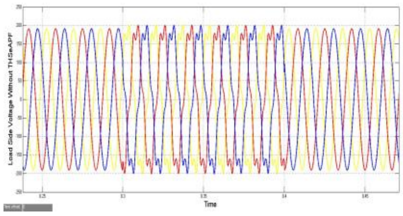

Fig 12- Load Side Voltage Waveform without Filter

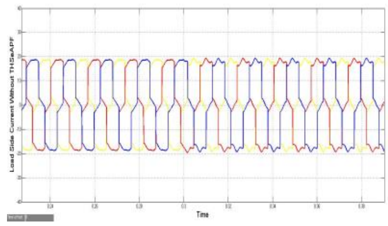

Fig 13- Load Side Current Waveform without Filter

MATLAB SIMULATION OF PROPOSED SYSTEM WITH THSEAPF

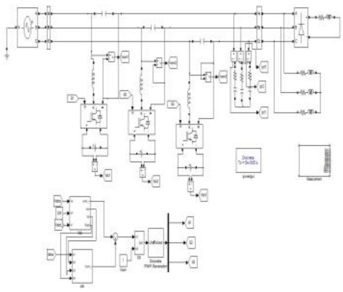

Fig 14- Matlab Model of The proposed three-phase THSeAF connected ahead of load PCC

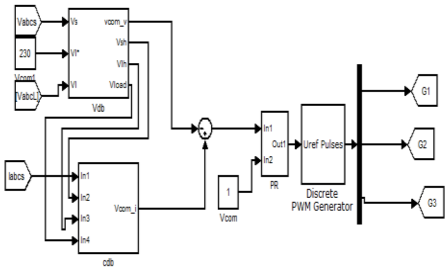

Fig 6.15- Matlab Model of Controller scheme

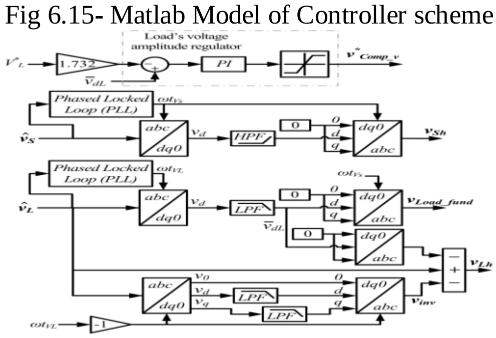

Fig 16- The voltage detection control pattern

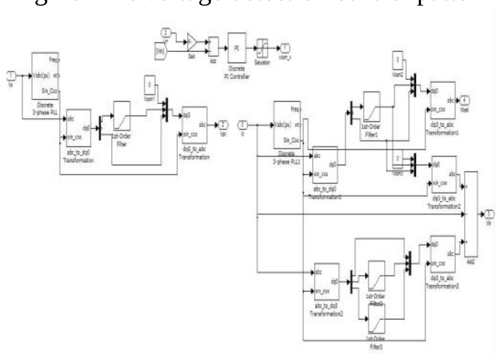

Fig 17- Matlab Model of Voltage control system

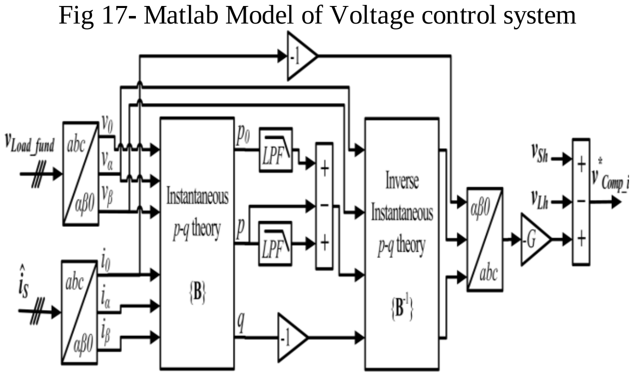

Fig 18- The current issues detection diagram

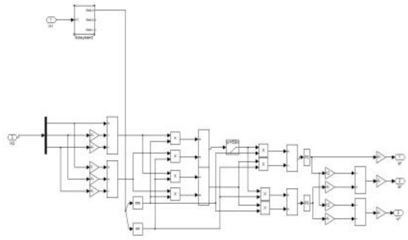

Fig 19- Current Control subsystem

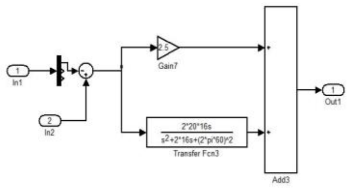

Fig 20- PR Controller Subsystem

5. SIMULATION RESULTS

CASE STUDY-I

In the simulation results shown in Fig. 21-25, the compensator starts operating at 0.05s. It can be clearly observed that the major part of the source current harmonics are instantly compensated reaching a current's total harmonic distortion (THD) of 0.7%, whereas the load's current is highly polluted with a THD of 21%. The P+R regulator is forcing within three cycles the converter to follow the reference to produce the exact compensating voltage. The voltage generated by the compensator will force the nonlinear loads to draw a sinusoidal current in phase with the corresponding source voltage to achieve a unity power factor. The shunt passive filter in the configuration is essential to prevent current harmonics to flow into the grid. The compensator do not interfere the active power flow, meanwhile it has the ability to control the power flow by lagging or leading the current.

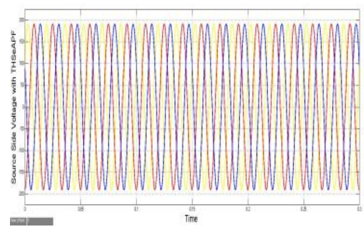

Fig.21 Transformerless-HSeAF compensating current harmonics. (a) Source voltage *Vs*

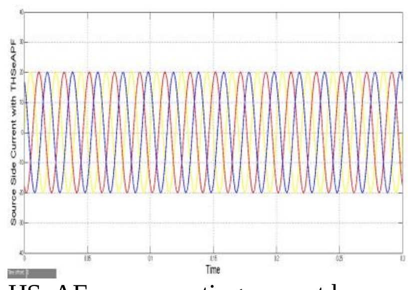

Fig. 22 Transformerless-HSeAF compensating current harmonics. (b) Source current *Is*

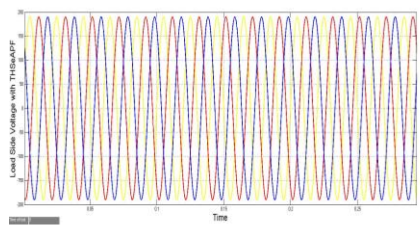

Fig 23- Transformerless-HSeAF compensating current harmonics. (c) Load voltage *Vl*

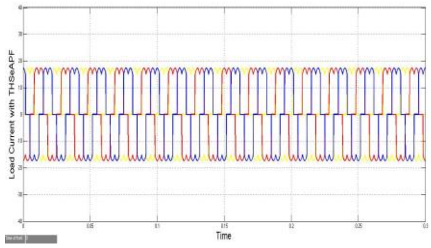

Fig 24- Transformerless-HSeAF compensating current harmonics. (d) Load current *Il*

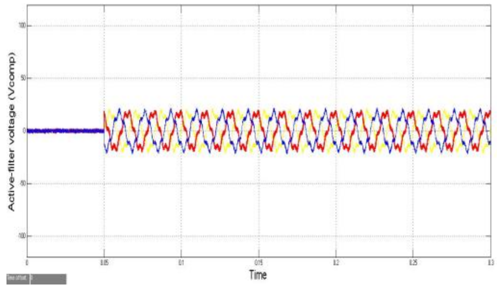

Fig 25- Transformerless-HSeAF compensating current harmonics. (e) Active-filter voltage *VComp*

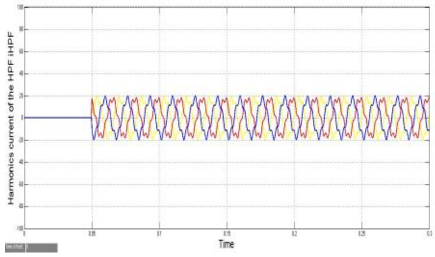

Fig 26- Transformerless-HSeAF compensating current harmonics. (f) Harmonics current of the HPF *iHPF*

CASE STUDY-II

During voltage perturbations, the compensator maintains a harmonic-free and regulated voltage at the load terminals. The simulation results fig 6.35 to 6.40 demonstrates the behaviour of the system during utility's voltage highly pollution with fifth and seventh order harmonics with 20 and 15 percent of the fundamental respectively resulting in a three-phase supply (***Vs***) containing a THD of 25%. The proposed compensator continues to clean the grid's current from harmonics and corrects the power factor while the load's voltage THD is kept under the 5% limitation imposed by standards and regulations.

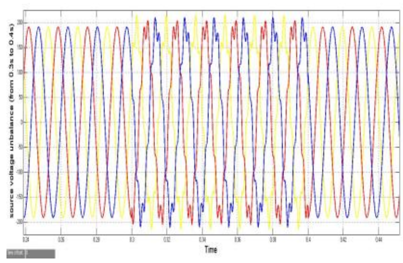

Fig. 27 Source Side Voltage waveforms during grid's perturbation

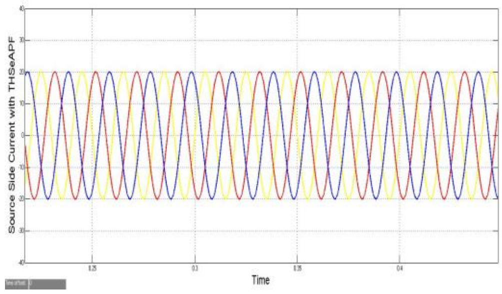

Fig. 28 Source Side Current waveforms during grid's perturbation

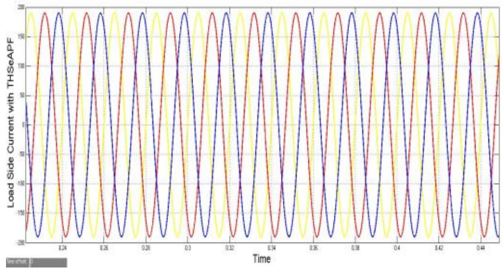

Fig. 29 Load Side Voltage waveforms during grid's perturbation

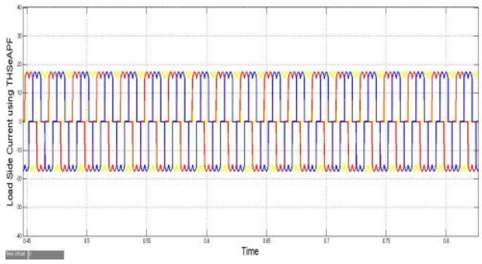

Fig.30 Load Side Current waveforms during grid's perturbation

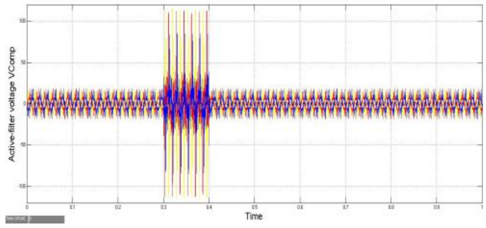

Fig. 31 Active Filter Voltage VComp waveforms during grid's perturbation

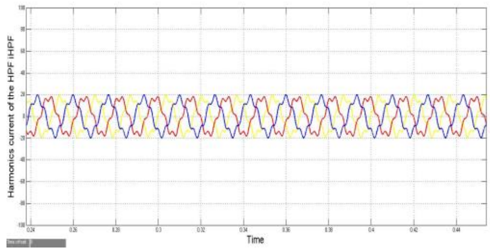

Fig.32 current of the HPF *iHPF* waveforms during grid's perturbation

CASE STUDY-III

The Simulation results below fig 33 to 37 illustrates the response of the system during source voltage unbalance (from 0.5s to 0.6s and 0.7s to 0.8s) while the filter regulates the load terminal voltage. This active power compensator is able to follow variation in the load consumption while preventing current harmonics to flow into the grid side. Furthermore, it maintains a sinusoidal and regulated voltage across the point of common coupling of loads.

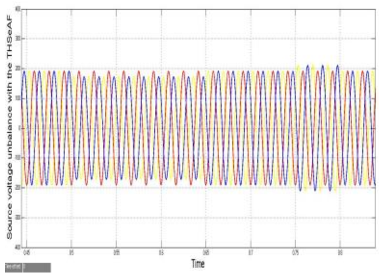

Fig.33 Source Voltage during voltage unbalance with the THSeAF delivering a regulated and balanced supply to the load PCC

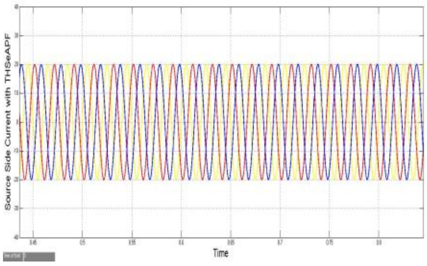

Fig. 34 Source Current during voltage unbalance with the THSeAF delivering a regulated and balanced supply to the load PCC

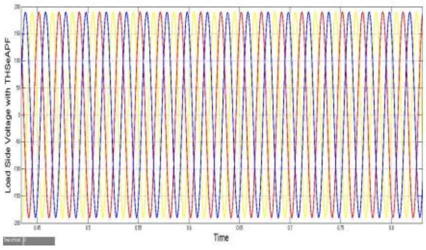

Fig. 35 Load Voltage during voltage unbalance with the THSeAF delivering a regulated and balanced supply to the load PCC

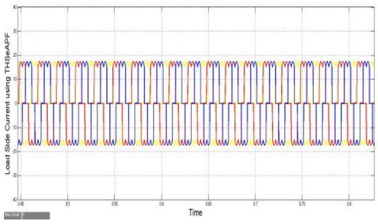

Fig. 36 Load Current during voltage unbalance with the THSeAF delivering a regulated and balanced supply to the load PCC

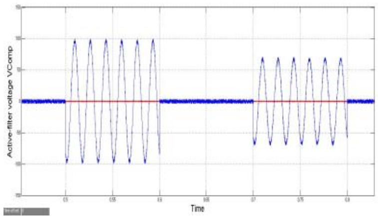

Fig. 37 Active Filter Voltage VComp during voltage unbalance with the THSeAF delivering a regulated and balanced supply to the load PCC

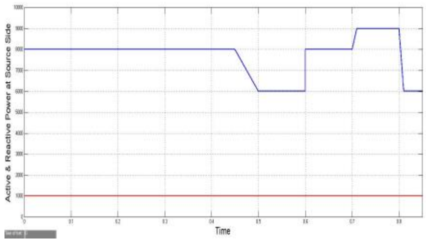

Fig. 38 Source Side Active and Reactive Power during voltage unbalance with the THSeAF delivering a regulated and balanced supply to the load PCC

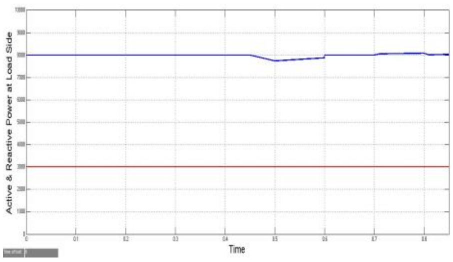

Fig. 39 Load Side Active and Reactive Power during voltage unbalance with the THSeAF delivering a regulated and balanced supply to the load PCC

CONCLUSION

In this paper a three-phase THSeAF based on VSC type of converters was introduced to improve power quality issues of Distribution level of the grid. The proposed control algorithm consisting of the *SRF* and the *p-q theory* was developed to extract voltage and current harmonics as well as unbalance, sags, and swells to be compensates. The key novelty of the proposed topology includes power quality improvement for small residential building and some low voltage distribution system that may result to the enhancement of the global power system. Furthermore, the proposed configuration can regulate and improve the load voltage PCC and when connected to a renewable auxiliary DC source, the topology is able to counteract actively to the power flow in the system similar to a UPS function. It was denoted that the active compensator responds seamlessly to voltage variations by ensuring a constant and distortion-free supply at load PCC. Furthermore, this compensator eliminates source current harmonics and improves grid power quality with no need to use the typical bulky series transformer. The Matlab Simulation of Proposed THSeAF system has been successfully carried out and THD analysis also done in this paper.

REFERENCES

1. Bhim Singh, Kamal Al-Haddad, Senior Member, IEEE, and Ambrish Chandra, Member, IEEE “A Review of Active Filters for Power Quality Improvement”.

2. Joao L. Afonso, Member IEEE, H. J. Ribeiro da Silva and Julio. S. Martins, Member IEEE “Active Filters for Power Quality Improvement”.

3. Juan W. Dixon, Senior Member, IEEE, Gustavo Venegas, and Luis A. Moran, Senior Member, IEEE“A Series Active Power Filter Based on a Sinusoidal Current-Controlled Voltage-Source Inverter”.

4. M.A. Mulla, Member, IEEE, R. Chudamani, A. Chowdhury, Member, IEEE “Series Active Power Filter Using Generalised Instantaneous Power Theory

5. Enio R. Ribeiro, Member, IEEE, and Ivo Barbi, Senior Member, IEEE “Harmonic Voltage Reduction Using a Series Active Filter under Different Load Conditions”.

6. Darwin Rivas, Luis Moran, Senior Member, IEEE, Juan W. Dixon, Senior Member, IEEE, and Jose R. Espinoza, Member, IEEE “Improving Passive Filter Compensation Performance With Active Techniques”.

7. T. Quoc-Nam and L. Hong-Hee, "Improvement of unified power quality conditioner performance with enhanced resonant control strategy," Generation, Transmission & Distribution, IET, vol. 8, pp. 2114-2123, 2014.
8. A. Q. Ansari, B. Singh, and M. Hasan, "Algorithm for power angle control to improve power quality in distribution system using unified power quality conditioner," IET Generation, Transmission & Distribution, vol. 9, pp. 1439-1447, 2015.
9. W. Yanzhi, L. Xue, and M. Pedram, "Adaptive Control for Energy Storage Systems in Households with Photovoltaic Modules," IEEE Trans. on Smart Grid, vol. 5, pp. 992-1001, 2014.
10. E. Cipriano Dos Santos, J. H. Gonzaga Muniz, E. R. Cabral da Silva, and C. B. Jacobina, "Nested Multilevel Topologies," IEEE Transactions on Power Electronics, vol. 30, pp. 4058-4068, 2015.
11. S. Kouro, J. I. Leon, D. Vinnikov, and L. G. Franquelo, "Grid-Connected Photovoltaic Systems: An Overview of Recent Research and Emerging PV Converter Technology," IEEE Ind. Electron. Magazine, vol. 9, pp. 47-61, 2015.
12. 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, pp. 43-52, 2014.
13. J. Liu, S. Dai, Q. Chen, and K. Tao, "Modelling and industrial application of series hybrid active power filter," IET Power Electron., vol. 6, pp. 1707-1714, 2013.
14. A. Javadi, A. Hamadi, L. Woodward, and K. Al-Haddad, "Experimental Investigation on a Hybrid Series Active Power Compensator to Improve Power Quality of Typical Households," IEEE Transactions on Industrial Electronics, vol. 63, pp. 4849-4859, 2016.
15. Y. Lu, G. Xiao, X. Wang, F. Blaabjerg, and D. Lu, "Control Strategy for Single-Phase Transformer less Three-Leg Unified Power Quality Conditioner Based on Space Vector Modulation," IEEE Trans. on Power Electron., vol. 31, pp. 2840-2849, 2016.

