Power Quality Enhancement in Electrified Transportation by using a Single-Phase Active Device

Mekala Santhosh Yadav[1], Mruthyunjaya Reddy[2]

[1]*M.Tech., PG Scholar,Akshaya Bharathi Institute of Technology, R.S. Nagar, Siddavatam, Kadapa*

[2]*Assistant Professor, Dept of EEE,Akshaya Bharathi Institute of Technology, R.S. Nagar, Siddavatam, Kadapa*

***Abstract*- A transformerless hybrid series active filter is proposed to enhance the power quality in single-phase systems with critical loads. This paper assists the energy management and power quality issues related to electric transportation and focuses on improving electric vehide load connection to the grid. The control strategy is designed to prevent current harmonic distortions of nonlinear loads to flow into the utility and corrects the power factor of this later. While protecting sensitive loads from voltage disturbances, sags, and swells initiated by the power system, ridded of the series transformer, the configuration is advantageous for an industrial implementation. This polyvalent hybrid topology allowing the harmonic isolation and compensation of voltage distortions could absorb or inject the auxiliary power to the grid. Aside from practical analysis, this paper also investigates on the influence of gains and delays in the real-time controller stability. The simulations and experimental results presented in this paper were carried out on a 2-kVA laboratory prototype demonstrating the effectiveness of the proposed topology.**

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

I. INTRODUCTION

Power quality improvement has become a major research topic in modern power distribution system. Nearly twenty years ago most of the loads used by the industries and consumers were passive and linear in nature, with a lesser number of non-linear loads thus having less impact on the power system. With the arrival of semiconductor and power electronic devices and their easier controllability have caused wide use of non-linear loads such as chopper, inverter switched mode power supply, rectifier, etc. The power handled by modern power electronics devices like silicon controlled rectifier (SCR), Insulated gate bipolar transistor (IGBT), power diode, Metal oxide semiconductor field effect transistor (MOSFET) are very large, which promotes their industrial as well as domestic applications. With addition to that various power electronic devices are used to increase the efficiencies and power factor of wind, solar, and other non-conventional sources of energy. While the advantages of using above devices are certainly good but there are some demerits of such excessive use of power electronic devices.

The use of above semiconductor devices is responsible for harmonic and reactive power disturbances. The harmonics and reactive power are the cause various problem which includes overheating of transformers, excessive neutral current, distortion of feeder voltage, low power factor, damages to power electronic devices and malfunction of sensitive equipment. To eliminate the harmonics in the power system, active power filters (APF) are installed at PCC. APF injects compensating current at PCC to cancel out the harmonics and to make source current sinusoidal. By installation of APF, harmonic pollution as well as low power factor in the power system can be improved.

Harmonic pollution in low voltage side is more prominent compare to high voltage side due wide use of nonlinear single phase loads (Computers, Battery charger, Printers etc.), which is unacceptable. It is a huge challenge to nullify the undesirable current harmonics and compensate the reactive power requirement in the power system. The performances of traditional practices (use of LC filter) are not acceptable due to its serious drawbacks as discussed. The series APF provides encouraging results compare to traditional one based up on appropriate control algorithms. The control strategy plays a key role for better dynamic performances of the APF.

Most of the existing control schemes used for active power filter involve three phase quantity. By little modification, those control strategies can be used for single phase system. The synchronous detection method is used for three phase active power filter; this project work proves that synchronous detection method can be used for single phase active power filter which involves lesser complexities compare to that of instantaneous reactive power algorithm.

Objectives of Project Work

The objectives of this project are

- To discuss effect of harmonics arising due to nonlinear load
- To study different control strategies already proposed for modeling of hybrid single phase series active power filter
- To model and simulate single phase active power filter in MATLAB/SIMULINK environment
- Design of hysteresis current controller
- Design of triangular carrier current controller
- Experimental validation of simulation work

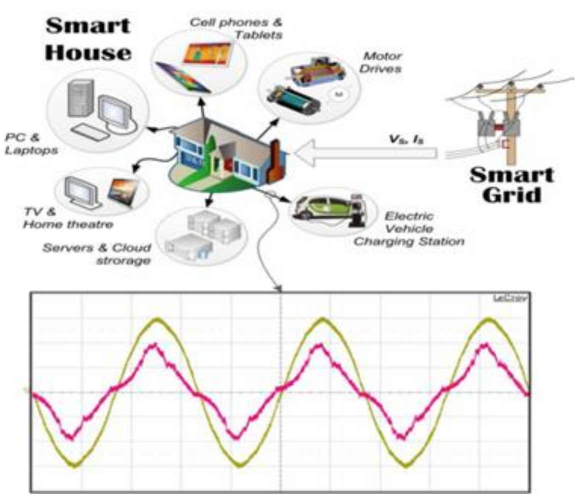

Fig. 1. Typical modern residential consumer with non-linear electronic loads

II LITERATURE SURVEY

Power electronics based devices/equipment are a major key component of today's modern power processing, at the transmission as well as the distribution level because of the numerous advantages offered by them. These devices, equipments, nonlinear load including saturated transformers, arc furnaces and semiconductor switches and so on, draw non-sinusoidal currents from the utility. Therefore a typical power distribution system has to deal with harmonics and reactive power support (Khadkikar et al 2009). When a Static Synchronous Compensator is employed at the distribution level or at the load end for power factor improvement, active harmonic filtering, dynamic load balancing, flicker mitigation and voltage regulation alone it is called as DSTATCOM (Distributed Static Compensator). DSTATCOM is a fast-compensating reactive power source that's applied on the transmission or distribution system to reduce voltage variations such as sags, surges and flicker, along with instability caused by rapidly varying reactive power demand. DSTATCOM can also help provide quick recovery for the transmission system after contingency events such as loss of part of the system or individual equipment. DSTATCOM is well suited to Integration of renewable energy sources, such as wind, concentrated solar and tidal power generation. It allows these renewable energy sources to meet utility interconnection requirements, as well as the power factor, voltage output and low voltage ride-through requirements of various worldwide grid codes. When it is used to do harmonic filtering and reactive power compensation, it is called as Active Power Filter (Bhuvaneshwari et al 2008). Passive filters are used to provide a low impedance path for current harmonics so that they flow in the filter and not the supply. Passive filters are suited only to particular harmonics, the isolating transformer being useful only for triple-N harmonics and passive filters only for their designed harmonic frequency. In some installations the harmonic content is less predictable. (Fujtha et al 1998). Power Factor Correction (PFC) techniques include both passive and active solutions for eliminating harmonic distortion and improving power factor. The passive approach uses inductors, transformers, capacitors and other passive components to reduce harmonics and phase shift. The passive approach is heavier and less compact than the active approach, which is finding greater favor due to new technical developments in circuitry, superior performance and reduced component costs. Specially corrected transformers are effective only for certain harmonic frequencies and most passive filters, once installed and tuned, are difficult to upgrade and may generate harmful system resonance. As for active PFC techniques, they must be applied to each individual power supply or load in the system, which complicates architecture and results in high system cost. (Singh et al 1999). APF supplies only the harmonic and reactive power required to cancel the reactive currents generated by nonlinear loads. In this case, only a small portion of the energy is processed, resulting in greater overall energy efficiency and increased power processing capability (Fujtha et al 1998). APF utilizes harmonic or current injection to achieve PFC. APF determines the harmonic distortion on the line and injects specific currents to cancel the reactive loads. This technique has been used for years in high power, three phase systems, but high costs and complicated high speed circuitry made it impractical for low level power systems. However, new techniques that utilize simpler circuitry are making active power filtering more attractive and advantageous for low power, single phase systems. APF is connected in parallel to the front end or AC input of the system and corrects all loads directly from the AC line. This type of APF provides excellent harmonic filtering that complies with international harmonic regulations.

APF system can be divided into two sections as: The control unit and the power circuit. Control unit consists of reference signal generation, gate signal generation, and capacitor voltage balance control and voltage/current measurement. Power circuit of APF is generally comprised of energy storage unit, DC/AC converter, harmonic filter and system protection. Active power filters are generally designed to compensate current harmonic, reactive power, voltage harmonic and to balance the supply current and supply voltage. Control strategy is based on the overall system control, extraction of reference signal and capacitor voltage balance control. The converter types of APF can be either Current Source Inverter or Voltage Source Inverter (VSI) bridge structure. VSI structures with Insulated Gate Bipolar Transistor (IGBTs) or Gate Turn Off Thyristor (GTO) have become more dominant, since it is lighter, cheaper and expandable to multilevel and multistep versions, to enhance the performance with lower switching frequencies. IGBTs are generally used up to 1 MVA rating, GTO Thyristors are generally used higher than 1 MVA rating (Aredes et al 1998). The presence of harmonics and reactive power in the grid is harmful, because it will cause additional power losses and malfunctions of the grid components. Conventionally, passive filters composed of tuned L-C components have been widely used to suppress harmonics because of their low initial cost and high efficiency. However, passive filters have many disadvantages, such as large size, mistuning, instability and resonance with load and utility impedances (Aredes et al 1998). Active Power Filters have now become an alternative solution for controlling current harmonics in supply networks at the low to medium voltage distribution level or for reactive power and/or voltage control at high voltage distribution level (Afonso et al 2000). APF such as shunt APFs, series APFs, hybrid APFs, UPQC and other combinations have made it possible to mitigate some of the major power quality problems (Khadkikar et al 2009)

III. RELATED WORK

Control strategy in the frequency domain is based on the Fourier analysis of the distorted voltage or current signals to extract compensating current/voltage reference (Akagi et al 1984). Frequency domain approaches are suitable for both single and three-phase systems. The frequency domain algorithms are sine multiplication technique, conventional Fourier and Fast Fourier Transform (FFT) algorithms and modified Fourier series techniques (Das et al 2004). Control methods of APF's in the time domain are based on instantaneous derivation of compensating commands in the form of either voltage or current signals from distorted and harmonic polluted voltage or current signals (Chen et al 2004). Time domain approaches are mainly used for three-phase systems. The time domain algorithms are dq method, synchronous flux detection algorithm, fictitious power compensation algorithm ,constant active power algorithm, constant power factor algorithm, Instantaneous active and reactive Power theory (Agaki et al 1984) and neural network (George et al 2007). A component that has a frequency between the two frequencies is called an interharmonic. A method for real-time detection and extraction of interharmonic components in a power signal with potentially time-varying characteristics (Fujitha et al 1998).

Classification according to current/voltage reference estimation techniques can be made as time domain control and frequency domain control that are processed by the open loop or closed loop control techniques .Active Power Filters have now become an alternative solution for controlling current harmonics in supply networks at the low to medium voltage distribution level or for reactive power and voltage control at high voltage distribution level.

APFs are used in low power (<100 kVA), medium power (100 kVA-10 MVA) and high power (>10 MVA) applications. For low power applications, APFs can be applied for single- phase and three-phase systems.

For single-phase systems, APFs generally mitigate the current harmonics. For three phase systems, APFs generally provide acceptable solution for unbalanced load currents and mitigate the current harmonics. For medium and high power applications, the main aim is to eliminate or reduce the current harmonics. (Ghosh et al 2002).

Because of economic considerations, reactive power compensation using active filters at the high voltage distribution level is not generally regarded as viable. For high power applications, the harmonic pollution in high-power ranges is not such a major problem as in lower-power systems. One of the few applications of active filters in high power systems is the installation of parallel combination of several active filters because the control and co-ordination requirements of these filters are complicated (Karimi et al 2003).

Power circuit configuration of APFs can be parallel active filter, series active filter and combination of series and parallel filters. The purpose of parallel active filters is to cancel the load current harmonics fed to the supply. It can also perform the reactive power compensation and balancing of three-phase currents. The series active filter produces a PWM voltage waveform which is added or subtracted from the supply voltage to maintain a purely sinusoidal voltage waveform across the load. However, series active filters are less common industrially than their rivals, parallel active filters (Ghosh et al 2002).

Combinations of several types of filter can achieve greater benefits for some applications. The examined combinations are combination of both parallel and series active filters, combination of series active and parallel passive filters, combination of parallel active and passive filters and active filter in series with parallel passive filters. Seven-level APF configuration is also examined in (Jindal et al2005).

Multilevel three-leg center-split VSIs are more preferable in medium and large capacity applications due to lower initial cost and fewer switching devices that need to be controlled. The series stacked multilevel converter topology, which allows standard three phase inverters to be connected with their DC busses in series (Gunther et al 1995). This converter has both regenerated energy generation and active power filtering capabilities.

An inductance for output filtering of VSI is used to eliminate the harmonic at different frequencies. The different combinations of L and C filters to attenuate the switching ripple currents (Zhilli et al 2010).

A rectifier employing phase control with extra low inductance characteristic or load which high frequency input current, may affect APF and causing it to malfunction or shutdown. While APF is being applied to this type of load, a reactor (3% to 5%) is recommended to install at the input side of the load to reduce the rising rate of load input current. LC passive filter is used for harmonic elimination and reactive power compensation. LCL filter is used in (Rong et al2009) that gives advantages in costs and dynamic performance since smaller inductors can be used compared to L-filter in order to achieve the necessary damping of the switching harmonics.

APFs are basically categorized into four types, namely, single phase two-wire, three- phase three wire, three-phase three-wire with Zig-Zag transformer and three-phase four wire configurations to meet the requirements of the three types of nonlinear loads on supply systems. (Fujita et al 1998).

IV. PROPOSED WORK

The forecast of future Smart Grids associated with electric 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 [1], [2] have detrimental effects on power distribution system harmonic voltage levels [3]. On the other hand, the growth of harmonics fed from nonlinear loads 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. Likewise, the increased rms and peak value of the distorted current waveforms increase heating and losses and cause the failure of the electrical equipment. Such phenomenon effectively reduces system efficiency and should have properly been addressed [6], [7]. 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 [8], [9]. The advantage of the SeAF compared to the shunt type is the inferior rating of the compensator versus the load nominal rating [10]. However, the complexity of the configuration and necessity of an isolation series transformer had decelerated their industrial application in the distribution system. The second category was developed in concern of addressing voltage issues on sensitive loads. Commonly known as DVR, they have a similar configuration as the SeAF. These two categories are different from each other in their control principle. This difference relies on the purpose of their application in the system. The hybrid series active filter (HSeAF) was proposed to address the aforementioned issues with only one combination. Hypothetically, they are capable to compensate current harmonics, ensuring a power factor (PF) correction and eliminating voltage distortions at the PCC [11], [12]. These properties make it an appropriate candidate for power quality investments. The three-phase SeAFs are well documented [13], [14], whereas limited research works reported the single-phase applications of SeAFs 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 [15]. With a smaller rating up to 10%, it could easily replace the shunt active filter [16]. Furthermore, it could restore a sinusoidal voltage at the load PCC.

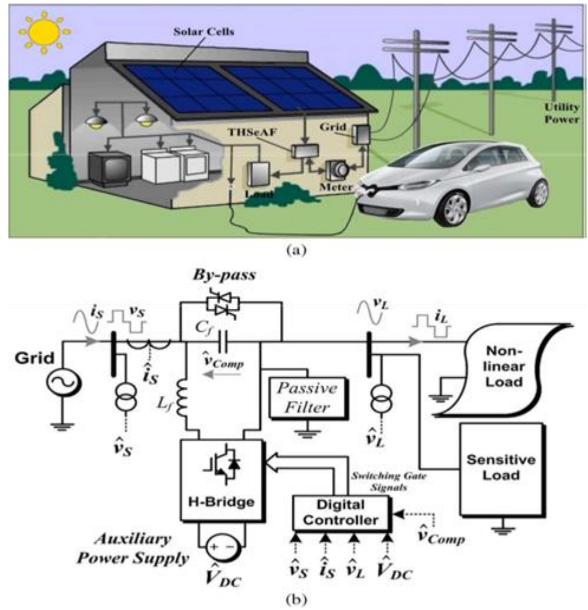

Fig. 4.1. (a) Schematic of a single-phase smart load with the compensator installation.

(b) Electrical diagram of the THSeAF in a single-phase utility. The THSeAF shown in Fig.4.1 is composed of an H-bridge converter connected in series between the source and the load. A shunt passive capacitor ensures a low impedance path for current harmonics. A dc auxiliary source could be connected to inject power during voltage sags. The dc-link energy storage.

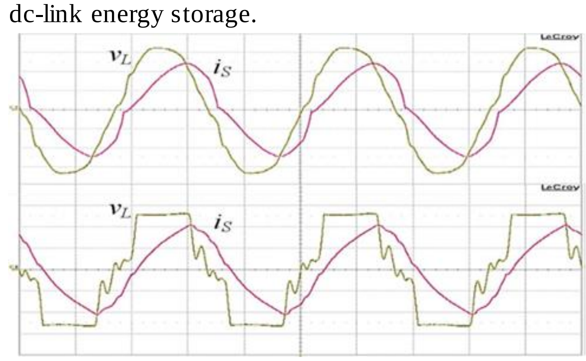

Fig. 4.2. Terminal voltage and current waveforms of the 2-kVA single-phase system without compensator. (a) Regular operation. (b) Grid's voltage distortion (scales: 50 V/div for channel 1 and 10 A/div for channel 2).

The system is implemented for a rated power of 2200 VA. To ensure a fast transient response with sufficient stability margins over a wide range of operation, the controller is implemented on a dSPACE/dsp1103. The system parameters are identified in Table I. A variable source of 120 Vrms is connected to a 1.1-kVA nonlinear load and a 998-VA linear load with a 0.46 PF. The THSeAF is connected in series in order to inject the compensating voltage. On the dc side of the compensator, an auxiliary dc-link energy storage system is installed. Similar parameters are also applied for practical implementation. 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.4.2.

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. 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 highpass 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.

V. RESULTS

To validate the study various scenarios similar to those effectuated in the simulation are performed on a laboratory prototype. Fig. 2 shows the setup components with parameters described in Table I. The Opal-RT real-time simulator, the NPC converter along with precise probes dedicated for RCP applications are noticeable in the picture. The compensation during steady state depicted in Fig.5.1, shows the polluted load harmonics isolated from the utility and a unity power factor (UPF) is reached. Moreover, the compensator maintains the load's voltage regulated with constant amplitude and free of all kinds of distortions independently of the grid condition.

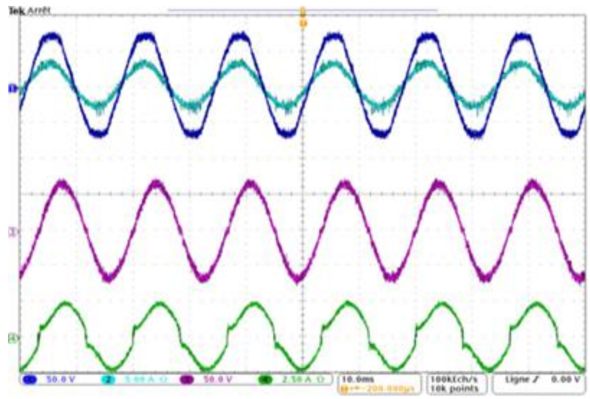

Fig.5.1. Steady state waveforms of the THSeAF compensating load current. (a) Source voltage vS [50V/div], (b) source current iS [5A/div], (c) load PCC voltage vL [50V/div], (d) load current iL [2.5A/div].

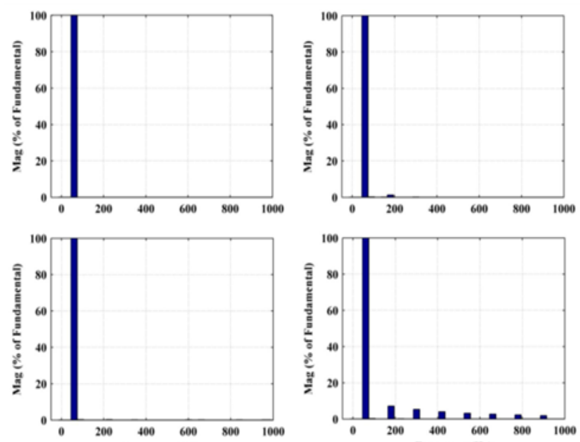

Fig. 5.2. Harmonic contents in percentage of fundamental when THSeAF in operation; (a,b) Source voltage and current, (c, d) Load voltage and current.

The load's voltage THD could be reduced to the desired value by performing a fine- tuning of the shunt passive filter which indirectly contributes to the voltages quality as explained in the previous section. This one-time tuning is independent of parameters of the system. The harmonic content and THD of sources and load voltage and current for the Fig. 16 are presented in Fig. 5.4

The line current shows dramatic improvements in its THD while the THSeAF is operating in a hybrid approach. A gain G of 3Ω equivalent to 0.4p.u. was used to control current harmonics. As mentioned earlier, the capability of operating with reduced DC voltage is considered as one of advantage of the proposed configuration, where for these tests it is maintained at 110VDC.

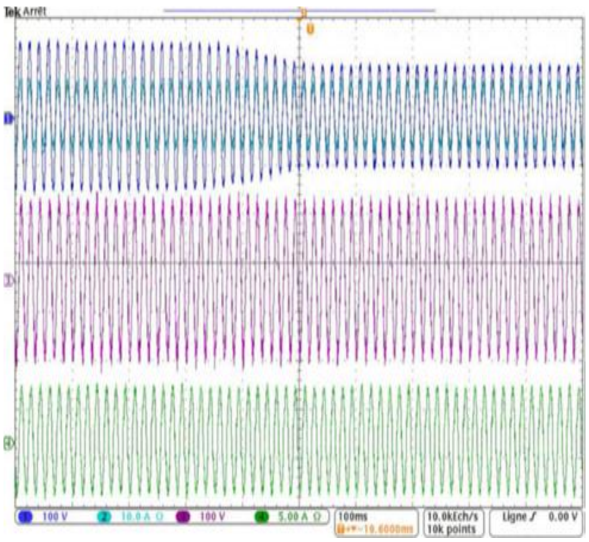

Fig. 5.3. Waveforms during a sags; (a) Source voltage vS, (b) source current iS, (c) load PCC voltage vL, (d) load current iL.

Experimented results illustrate high fidelity towards simulations. During a grid's voltage sags, the compensator regulates the load voltage magnitude, compensates current harmonics and corrects the power factor as shown in Fig. 5.5. These figures show possible cases in which the THSeAF could face during the worst scenario requiring compensation of the load voltage harmonics.

Clarified in section V, the auxiliary DC source, similar to a UPS, provides necessary amount of power to maintain the supply at the load terminals despite variation in the utility's voltage magnitude. The bidirectional DC source should exchange power with an auxiliary feeder or energy storage to maintain the DC voltage at a constant value. As expected from simulations, during a grid's extended voltage swell, the compensator regulates the load voltage magnitude by injecting active power while compensating current harmonics and correcting the PF as shown in Fig. 5.6.

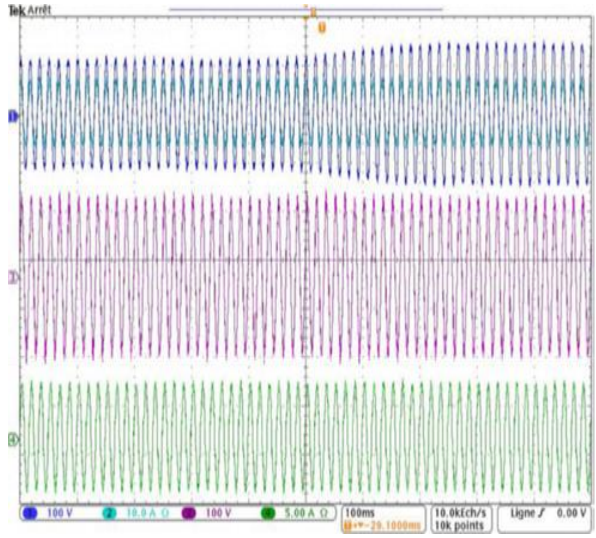

Fig. 5.4. Waveforms during a swells; (a) Source voltage vS, (b) source current iS, (c) load PCC voltage vL, (d) load current iL.

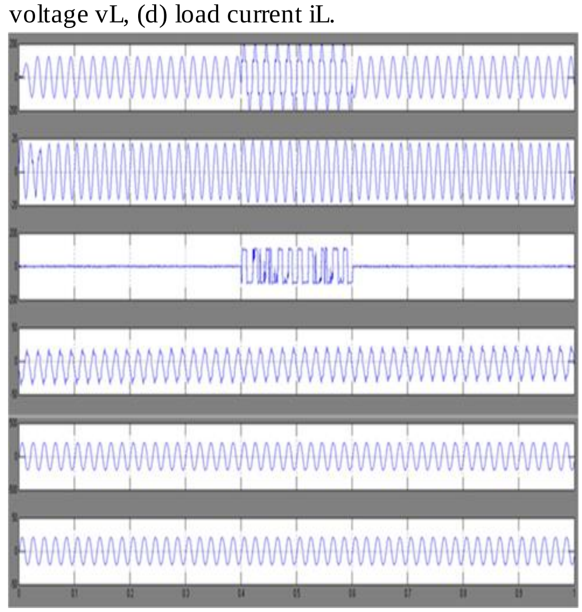

Fig 5.5. Simulink results for harmonic compensation

Harmonics can be defined as steady state distortion of voltage and current waveforms due to non-linear loads in the power system. Non-linear loads include adjustable-speed drives, arc furnaces and electronic power converters.

IV. CONCLUSIONS

In this paper, a transformerless HSeAF for power quality improvement was developed and tested. 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. 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 theoretical modelling of the proposed configuration was investigated. The proposed transformerless configuration was simulated and experimentally validated. 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.

REFERENCE

[1] Hasan Komurcugil ―Double-band hysteresis current-controlled single phase shunt active filter for switching frequency mitigation,‖ Electric Power and Energy System, vol. 69, pp. 131- 140, July 2015.

[2] C. S. Lam, M. C. Wong Y. D. Han, ―Hysteresis current control of hybrid active power filters,‖ IET Power Electronics, Vol. 5, pp. 1175 – 1187, Aug. 2012.

[3] Vinod Khadkikar, ―Enhancing Electric Power Quality Using UPQC:A Comprehensive Overview,‖ IEEE Transactions on Power Electronics, vol. 27, pp. 2284 – 2297, May 2012.

[4] S. Orts-Grau, F. J. Gimeno-Sales, A. Abellán-García, S. Seguí- Chilet, and J. C. Alfonso-Gil, Improved Shunt Active Power Compensator for IEEE Standard 1459 Compliance,‖ IEEE Transactions on Power Delivery, vol. 25, pp. 2692 – 2701, Oct. 2010.

[5] Reyes S. Herrera and Patricio Salmerón, Instantaneous Reactive Power Theory: A Comparative Evaluation of Different Formulations,‖ IEEE Transactions on Power Delivery, vol. 22, pp. 595 – 604, Jan. 2007.

[6] Anup Kumar Panda, Suresh Mikkili, ―FLC based shunt active filter (p–q and Id–Iq) control strategies for mitigation of harmonics with different fuzzy MFs using MATLAB and real-time digital simulator,‖ Electrical Power and Energy Systems, vol. 47, pp. 313– 336, May 2013.

[7] Rakhee Panigrahi, Prafulla Chandra Panda, Bidyadhar Subudhi, ―A Robust Extended Complex Kalman Filter and Slidingmode Control Based Shunt Active Power Filter,‖ Electric Power Components and Systems, vol. 42, pp. 520–532, Feb. 2014.

[8] Arunkumar, Bhim Singh, D.T. Shahani, ―Grid interfaced solar photovoltaic power generating system with power quality improvement at ac mains,‖ in Proc. Sustainable Energy Technologies (ICSET) 2012 IEEE Third International Conf., pp. 177 – 182.

[9] ambrish Chandra, bhim singh, b.n. singh and kamal al haddad ―an improved control algorithm of shunt active filter for voltage regulation, harmonic elimination, power factor correction, and balancing of nonlinear loads,‖ IEEE Transaction on Power Electronics, vol.15, May 2000.

[10] Karuppanan P Kamal Kant Mahapatra ―PI and fuzzy logic controllers for shunt active power filter- Areport,‖ ISA Transactions, vol. 51, pp. 163-169, Jan. 2012.

[11] Sara Eftekharnejad, Vijay Vittal, Gerald Thomas Heydt, Brian Keel, ―Impact of Increased Penetration of Photovoltaic Generationon Power Systems,‖ IEEE Transactions on Power Systems, vol. 28, pp. 893 – 901, May 2013.

[12] Chao-Shun Chen, Chia-Hung Lin, Cheng-Ting Hsu, ―Enhancement of PV Penetration With DSTATCOM in Tai power Distribution System,‖ IEEE Transactions on Power Systems, vol. 28, May 2013.

[13] Bhim Singh a, P. Jayaprakash B, D.P. Kothari, New control approach for capacitor supported DSTATCOM in three-phase four wire distribution system under non-ideal supply

voltage conditions based on synchronous reference frame theory,‖ Electrical Power and Energy Systems, vol. 33, pp. 1109–1117, Jun. 2011.

[14] Rade M. Ciric, Antonio Padilha Feltrin, and Luis F. Ochoa, ―Power Flow in Four-Wire Distribution Networks—General Approach,‖ IEEE Transactions on Power Systems, vol. 18, pp. 1283 – 1290, Nov. 2003.