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A Survey on Hybrid Series Active Power Compensator to Improve Power Quality of Typical Households

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ABSTRACT- This paper proposes a configuration of Series hybrid active filters. The proposed configuration could be connected to the grid without requiring a costly series injection transformer. This topology is capable of compensating current harmonics at the source and voltage distortion at the point of common coupling. Furthermore, an appropriate controller could compel the Transformer-less hybrid series active filter (THSeAF). This configuration is more cost-effective than any other series compensators based mostly on a transformer to inject the compensating voltages.

Moreover, as a dynamic voltage regulator, the latter will compensate unwanted harmonics, unbalances, sags, and swells at terminals of a sensitive load. When performing as a series hybrid active filter, it cleans the power system from current distortions together with harmonics and unbalances. The detailed operation of the proposed topology is presented and analyzed. Modeling and controller design are given. Validation by simulations of the system dynamic for different load and supply conditions is presented.

Keywords: Non-linear load, hybrid series active filter, power quality, DVR, P-I Controller, real time control.

I. INTRODUCTION

Electric power system is considered to be composed of three functional blocks generation, transmission and distribution. For a reliable power system, the generation unit must produce adequate power to meet customer's demand, transmission systems must transport bulk power over long distances without overloading system stability and distribution systems must deliver electric power to each customer's premises from bulk power systems. Distribution system spot the end of power system and is connected to the customer, so the power quality mainly depends on distribution side [2]. The reason behind is that the electrical distribution system network failures about 90% of the average customer disruption. In the previous days, the major focus for power system reliability was on generation and transmission only the more capital cost is involved in this section. In addition their insufficiency can cause widespread serious consequences for both society and its environment. But now a day's distribution systems have begun to receive more attention for reliability assessment.

The growth of harmonics fed from nonlinear loads like electric vehicle propulsion battery chargers [6], which indeed have detrimental impacts on the power system and affect plant equipment. A solution is to reduce the pollution of power electronics based loads directly at their source.

There exist two types of active power devices to overcome described power quality issues. The first category are series active filters including hybrid type. They were developed to eliminate current harmonics produced by non-linear load from the power system. However, the complexity of the configuration and necessity of an isolation series transformer had decelerated their industrial application in distribution system [9]. The second category was developed in matter behind of voltage issues on sensitive loads. Commonly known as Dynamic voltage restorer (DVR) [13], they have a similar configuration as of Series active filter. These two categories are different from each other in their control principle. This difference relies on purpose of their application in the system.

Hybrid series active filter (HSeAF) [8] was proposed to address above issues with only one combination. They are capable to compensate current harmonics, ensuring a power factor correction, and eliminating voltage distortions at the PCC [4]. In this paper a single-phase THSeAF is proposed and capable of cleanup the grid side connection.

Advantage of the proposed configuration is that non-linear harmonic voltage and current producing loads could be effectively compensated. This paper proposes a linear current control scheme for single-phase APFs. The proposed control scheme gives high depletion to the harmonics coming from the load current side, the grid voltage, and the reference signal, resulting in a grid current (I) with lower harmonic distortion.

II. SYSTEM ARCHITECTURAL REVIEW

The constant 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, where nonlinear loads have deteriorate the power quality.

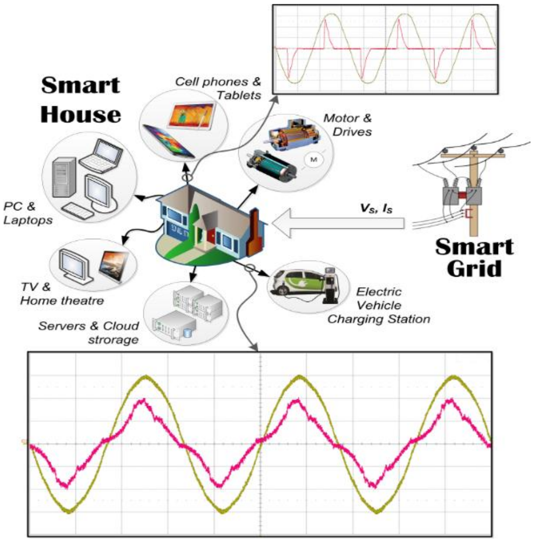

Fig-1Typical residential consumer with electronic loads, and measured electric car voltage and current patterns connected to an AC charging station, and a mobile charger.

To mitigate power quality issues, there exist three categories of compensators [16] the conventional and widespread used passive filters [14], the well-developed shunt active power filters [3]. Finally as last option comes the Series active filters (including Hybrid type ones) [5]. These compensators have been developed to eliminate current harmonics produced by non-linear type of loads such as vehicle charging stations as shows the waveform of load current in Fig. 1 with a THD of 25%

The hybrid series active filter shown in Fig.2 [8] consists of associate H-bridge convertor connected asynchronous between the supply and therefore the load. A shunt passive condenser ensures an occasional resistance path for current harmonics. A DC auxiliary supply can be connected to inject power throughout voltage sags [10]. The DC link energy storage system is delineated in. The system is enforced for a rated power of 2200 VA. To make sure a quick transient response with adequate stability margins over a large vary of operation.

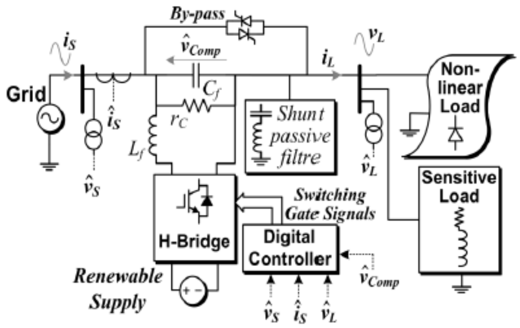

Fig-2 Electrical diagram of the HSeAF in a single-phase utility.

Even if the quantity of switches has augmented, the transformer less configuration is less expensive than the other series compensators that usually use an electrical device to inject the compensation voltage to the ability grid. The optimized passive filter consists of a fifth, 7th, and High-pass filters. The passive filter ought to be adjusted for the system upon load.

The series active filter represents a controlled voltage supply (VSI). So as to stop current harmonics iLh to drift into the supply, this series supply ought to gift low resistivity for the basic part and high resistivity for all harmonics as shown in Fig 3.

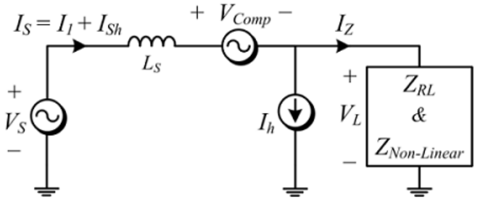

Fig-3 HSeAF equivalent circuit for current harmonics.

Voltage Source proportional to the current harmonic which flowing the fid which given by-

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

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

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

$$V_{comp} = +GI_{sh} - V_{Lh} + V_{sh} \tag{4}$$

Where *IZ* represents the load current in *ZL* shown in Fig. 3. Using the Kirchhoff's law the following equation is depicted for both the fundamental and harmonics.

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

$$V_{L1} = Z_L I_{s1} \quad , \quad V_{Lh} = Z_L(I_{sh} - I_h) \tag{6}$$

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

$$I_{s1} = \frac{V_{s1}}{(Z_s + Z_L)} \qquad (7)$$

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

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

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

$$V_{Lh} = -Z_L I_h \qquad (9)$$

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

III. HYBRID SERIES ACTIVE FILTER

The objective of the series active filter is to maintain a pure sinusoidal voltage waveform across the load. This is achieved by producing a PWM voltage waveform which is added or subtracted against the supply voltage waveform. The choice of power circuit used in most cases is the voltage-fed PWM [13] inverter without a current minor loop. The active filter acts as a voltage source and thus it is often a preferred solution of harmonic producing loads such as large capacity diode rectifiers with capacitive loads. In general way, series active filters are less commonly used compare to the shunt design. Unlike the shunt filter which carries mainly compensation current, the series circuit has to handle high load currents. For this reason an increased rating of the filter suitable to bear the increased current. Series filters offer the main advantage over the shunt configuration of achieving ac voltage regulation by eliminating voltage-waveform harmonics. This means the load contains a pure sinusoidal waveform.

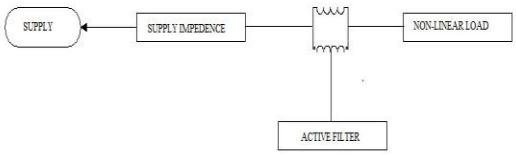

Fig- 4 Series active filter network configuration

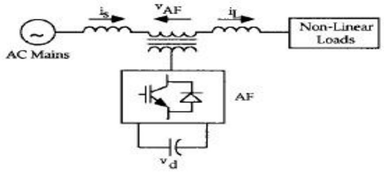

Fig- 7 Schematic diagram of series type Active Filter

The hybrid series power filter is developed to overcome the drawbacks of the passive power filter and the active power filter when used alone. Fig. 7 [12] illustrates the schematic circuitry of the proposed hybrid series power filter. The series active power filter is connected in series between the ac source, the passive filter and the non-linear load. The passive power filter consists of a bandstop filter composed of an inductor and AC capacitor connected in parallel.

The hybrid series active filter is suitable for the nonlinear load with a large capacity for filtering harmonics. The loads include voltage fed type of harmonic producing load and current fed [12] type of harmonic producing load**.**

IV. CONTROL STRATEGY

The outer-loop controller is employed wherever a condenser replaces the DC auxiliary supply. This management strategy is well explained within the previous section. The inner-loop management strategy is predicated on Associate in nursing indirect management principle.

The second PI controller employed in the outer loop, was to reinforce the effectiveness of the controller once control the DC bus. Therefore an additional correct and quicker transient response was achieved while not compromising compensation behavior of the system. In keeping with the speculation, the gain G ought to be unbroken in an exceedingly appropriate level, preventing the harmonics flows into the grid. Compensating voltage for current harmonic compensation is given by the following equation as shown:

$$\begin{aligned} V_{comp_i}(t) = (-G\widehat{i_s} + \widehat{v_L}) \\ - [l - G i_{s1} \\ + V_{L1} l . \sin(w_s t - \theta)] \end{aligned} \qquad (10)$$

Maintain voltage magnitude is as shown below:

$$V_{comp\_v} = \widehat{v_L} - v_L^* \sin(w_s t) \qquad (11)$$

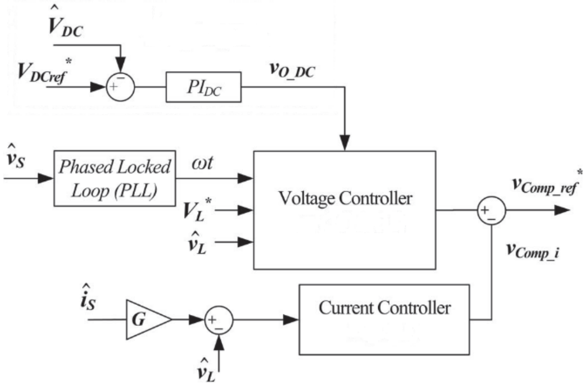

Fig. 8 Control system scheme of the active part.

$$V^*_{comp\_ref} = V_{comp\_v} - V_{comp_i} + V_{DC_{ref}} \qquad (12)$$

Voltage required for DC bus is as

$$V_{DC\_ref}\,(t) = V_{o\_DC}.\sin(w_s t) \qquad (13)$$

According to the given detection formula, the compensated reference voltage V*Comp_ref is calculated. Thereafter, the reference signal is compared to the measured output voltage and applied to a Proportional Integral controller to get the comparable gate signals as in Fig. 8.

V. RELATED WORK

P. T. Staats, et.al. proposes [6] a statistical method for predicting the effect that widespread electric vehicle (EV) battery charging will have on power distribution system harmonic voltage levels. This method uses for a statistical model for nonlinear load currents to generate the prospective value of specific harmonic voltage levels. The statistical model for the harmonic currents produced by a concentration of EVs accounts for partial harmonics cancellation introduced by uncertainty and variation in charger start-time and initial battery state-of-charge.

W. R. N. Santos, et.al. presents [11] a universal active filter for harmonic and reactive power compensation for single-phase systems applications. The proposed system is a combination of parallel and series active filters without transformer. It is suitable for applications where size and weight are critical factors. The model of the system is derived and it is shown that the circulating current observed in the proposed active filter is an important quantity that must be controlled. A complete control system, including pulse-width modulation (PWM) techniques, is developed.

A. Javadi, et.al. proposes [8] a novel configuration of Series hybrid active filters. The proposed configuration could be connected to the grid without requiring a costly series injection transformer. This topology is capable of compensating current harmonics at the source and voltage distortion at the point of common coupling. Furthermore, an appropriate controller could compel the Transformer less hybrid series active filter (THSeAF) to perform as (UPQC) with quit-similar behavior. The transformer less configuration is more cost-effective than any other series compensators based mostly on a transformer to inject the compensating voltages. It cleans the power system from current distortions together with harmonics and unbalances, similar to a shunt active filter.

Eng. k. k. Sng, et.al. proposes [13] a transformer less self-charging dynamic voltage restorer series compensation device which is used to reduce voltage sags and swell. A detailed analysis on the control of the restorer for voltage sag mitigation and dc-link voltage regulation are presented. A nonlinear element is shown to exist in the regulator, the activation of which can adversely affect its stability. Proposed prototype to validate the analysis under both voltage restoration and self-charging operating conditions.

H Fujita, et.al. proposes [14] a combined system of a passive filter and a small-rated active filter, both connected in series with each other. The passive filter removes load produced harmonics just as a conventional one. On the other hand, the active filter plays a role to improve the filtering aspect of the passive filter. This results in a great reduction of the required rating of the active filter and in eliminating all the limitations faced by using only the passive filter, leading to a practical and economical system.

P. Salmerón, et.al. proposes [15] control algorithm for a three-phase hybrid power Filter, It is constituted by a series active filter and a passive filter connected in parallel with the load. The control strategy is based on the vectorial formulation for spontaneous reactive power, so that the voltage waveform injected by the active filter is able to compensate the reactive power and the load current harmonics and to balance asymmetrical loads. The proposed algorithm also improves the behavior of the passive filter.

VI. SIMULATION RESULTS OF HSeAPF

The performances of the hybrid series active power filter are simulated using MATLAB software. Simulink and SimPower Systems block sets are used for implementing the global system (PFC and HSeAPF). Fig. 9 shows the Simulink graph of nonlinear load (PFC) with SeAPF.

Simulation results are given here for non-linear load. Fig.9 shows the source voltage and current before hybrid series active filter connection and Fig. 10 shows the load voltage and current after HSeAF connection. FFT analysis of source voltage and FFT analysis of load voltage. It may be noted that, before filter connection, the source voltage waveform is non-sinusoidal because of which its THD is as 25.00% and its fundamental value is 169.7 V. However after filter connection the load voltage has a THD is 5.98% and its fundamental value is 169.4 V. The fundamental value remains approximately the same when the filter is connected which prove that the filter injects only the harmonic voltage and the grid injects the fundamental component of the load voltage.

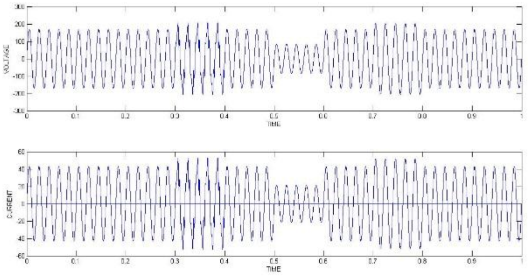

Fig.9 Source voltage and current before hybrid series active filter connection

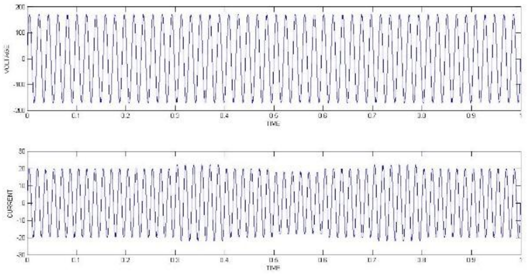

Fig. 10 Load voltage and current after HSeAF connection.

Table 1: Power quality improvement

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

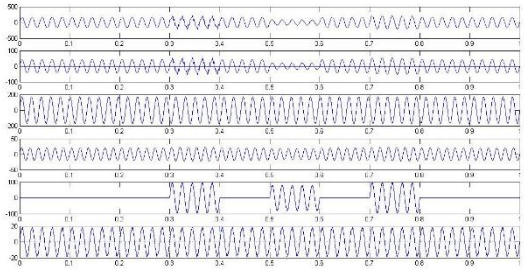

Fig. 11 shows the complete graph of source, load and filter voltage and current before and after HSeAPF connection

VII. CONCLUSION

In this paper, a 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 or household equipment. 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 HSeAF regulates and improves the PCC voltage. A novel THSeAF configuration with a PI controller was proposed to overcome power quality issues of a voltage fed type of non-linear load. The theoretical modeling has been realized and simulated for further developments. 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 modeling of the proposed configuration was investigated. The proposed configuration was simulated and experimentally validated. It was determine that, active compensator responds properly to the source voltage side variations by providing a constant or distortion-free supply at load terminals. Furthermore, it eliminates source harmonic currents and improves

Before Compensation				After Compensation			
Vs(V)	**Is(A)**	**Pf**	**THD**	**Vs(V)**	**Is(A)**	**Pf**	**THD**
169.7	43.02	0.8	25%	169.4	20.08	0.8	5.98%

the power quality of the grid without the usual bulky and costly series transformer.

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