A Single-Phase Active Device for Power Quality Improvement of Electrified Transportation

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Abstract

A transformer-less 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 vehicle 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 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 have detrimental effects on power distribution system harmonic voltage levels. On the other hand, the growth of harmonics fed from nonlinear loads like electric vehicle propulsion battery chargers, 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. Moreover, to protect the point of common coupling (PCC) from voltage distortions, using a dynamic voltage restorer (DVR) function is advised.

A solution is to reduce the pollution of power electronics-based loads directly at their source. Although several attempts are made for a specific case study, a generic solution is to be explored. There exist two types of active power devices to overcome the described power quality issues. The first category are series active filters (SeAFs), including hybrid-type ones. They were developed to eliminate current harmonics produced by nonlinear load from the power system. SeAFs are less scattered than the shunt type of active filters. The advantage of the SeAF compared to the shunt type is the inferior rating of the compensator versus the load nominal rating.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.

INTRODUCTION

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 volt age 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 trans-formerless 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.

The advantage of the proposed configuration is that nonlinear harmonic voltage and current producing loads could be effectively compensated. The transformerless hybrid series active filter (THSeAF) is an alternative option to conventional power transferring converters in distributed generation systems with high penetration of renewable energy sources, where each phase can be controlled separately and could be operated independently of other phases [17]. This paper shows that the separation of a three-

phase converter into single-phase H-bridge converters has allowed the elimination of the costlyisolation transformer and promotes industrial application for filtering purposes. The setup has shown great ability to perform requested compensating tasks for the correction of current and voltage distortions, PF correction, and voltage restoration on the load terminal [18].

This paper is organized as follows. The system architecture is introduced in the following section. Then, the operation principle of the proposed configuration is explained. The third section is dedicated to the modeling and analysis of the control algorithm implemented in this work. The dc voltage regulation and its considerations are briefly explained, and the voltage and current harmonic detection method is explicitly described. To evaluate the configuration and the control approach, some scenarios are simulated. Experimental results performed in the laboratory are demonstrated to validate simulations. This paper is summarized with a conclusion and appendix where further mathematical developments are demonstrated.

Existing method

The existing method describes a 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 have detrimental effects on power distribution system harmonic voltage levels. 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.

Proposed method

The proposed method describes a 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.These properties make it an appropriate candidate for power quality investments. The three-phase SeAFs are well documented 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.
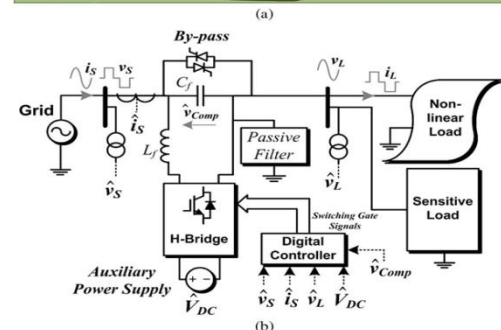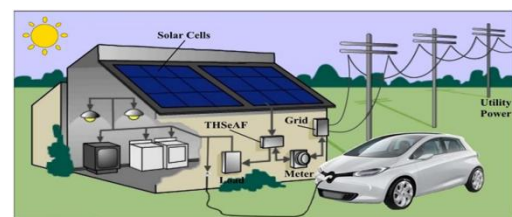
Advantages

1. Without using transformer so it is not cost effective.
2. By using filters we can eliminate the unwanted harmonics.
3. By installing filters we can improve the power quality.

Applications

1. The hybrid filters are applied to large machines to eliminate frequencies.
2. The hybrid filtering is applied to mostly grids.

SYSTEM ARCHITECTURE

(a) Schematic of a single-phase smart load with the compensator installation.
(b) Electrical diagram of the THSeAF in a single-phase utility.

During voltage sag and swell, the auxiliary source supplies the difference of power to maintain the magnitude of the load side voltage regulated. The harmonic content and THD factor of the source utility and load PCC presented show dramatic improvements in THD, while the load draws polluted current waveforms. Furthermore, although the grid's voltage is polluted, the compensator in a hybrid approach regulates and maintains a harmonic-free load voltage.

THE P-Q THEORY

The p-q Theory is based on the ab0 transformation, also known as the Clarke Transformation [Clarke (1943)], which consists in a real matrix to transform three-phase voltages and currents into the ab0 stationary reference frame, given by:

$$\begin{bmatrix} v \\ v_\alpha \\ v_\beta \end{bmatrix} = \sqrt{\frac{2}{3}} \begin{bmatrix} \frac{1}{\sqrt{2}} & \frac{1}{\sqrt{2}} & \frac{1}{\sqrt{2}} \\ 1 & -\frac{1}{2} & -\frac{1}{2} \\ 0 & \frac{\sqrt{3}}{2} & -\frac{\sqrt{3}}{2} \end{bmatrix} \begin{bmatrix} v_a \\ v_b \\ v_c \end{bmatrix}. \quad (1)$$

The inverse transformation is given by:

$$\begin{bmatrix} v \\ v_\alpha \\ v_\beta \end{bmatrix} = \sqrt{\frac{2}{3}} \begin{bmatrix} \frac{1}{\sqrt{2}} & 1 & 0 \\ \frac{1}{\sqrt{2}} & -\frac{1}{2} & \frac{\sqrt{3}}{2} \\ \frac{1}{\sqrt{2}} & -\frac{1}{2} & -\frac{\sqrt{3}}{2} \end{bmatrix} \begin{bmatrix} v_a \\ v_b \\ v_c \end{bmatrix}. \quad (2)$$

Similarly, generic instantaneous three-phase line currents (ia, ib, ic) can be transformed into ab axis.

One advantage of applying the ab transformation is the separation of zero-sequence components into the zero-sequence axis. Naturally, the a- and b-axis do not have any contribution from zero-sequence components. If the three-phase system has three wires (no neutral conductor), no zero-sequence current components are present and i0 can be eliminated in the above equations, simplifying them. The present analysis will be focused on three-wire systems. Therefore, zero-sequence voltage or current is not present. In this situation the real and imaginary powers are given by:

$$\begin{bmatrix} p \\ q \end{bmatrix} = \begin{bmatrix} v_\alpha & v_\beta \\ v_\beta & -v_\alpha \end{bmatrix} \begin{bmatrix} i_\alpha \\ i_\beta \end{bmatrix}. \quad (3)$$

where, p is the real power and represents the total energy flow per time unity in the three-wire three-phase system (p3f), in terms of abcomponents; q is the imaginary power and has a non-traditional physical meaning and gives the measure of the quantity of current or power that flows in each phase without transporting energy at any instant.

It is worth to note that in the above equation, q is equal to that defined in Akagi, Kanazawa and Nabae (1984) and Watanabe, Stephan and Aredes (1993), however, with a minus signal. With this change of signal, for a balanced positive sequence voltage source and balanced capacitive or inductive load, the new reactive (imaginary) power defined in (3) will have the same magnitude and signal of that calculated using conventional power theory (Q = 3VIsinf).

SIMULINK RESULTS
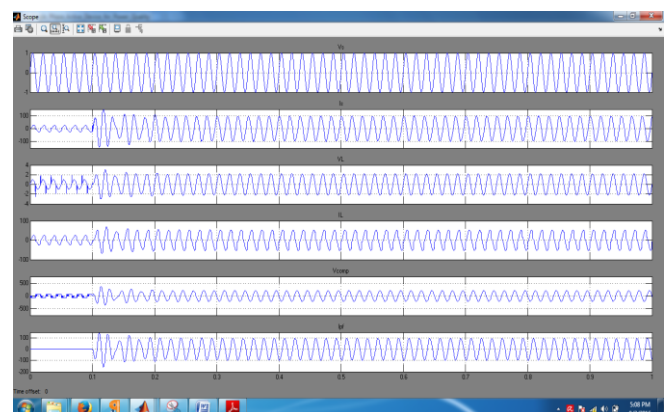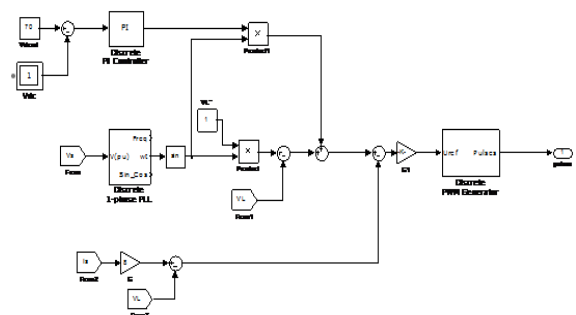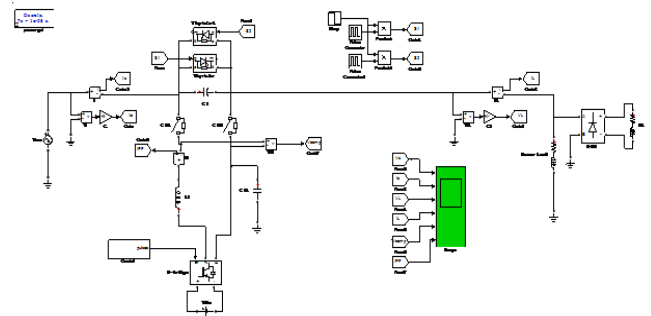
Conclusion:

In this paper, a transformer-less 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 modeling of the proposed configuration was investigated. The proposed transformer-less 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 bulkyand costly series transformer.

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