A COMPARATIVE ANALYSIS OF POWER FILTERING STRUCTURES BASED ON MATLAB / SIMULINK SIMULATIONS

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***Abstract* – The objective of this paper is to present a comparative study between six different filtering topologies based on Matlab / Simulink simulations, in order to provide a better understanding about how these systems can be dealt with. The relevant waveforms will be shown in order to prove the efficiency of active / hybrid filtering so as to improve power quality. In addition, the total power rating is provided in each simulation for a 10 kVA nonlinear load, illustrating the fact that in hybrid filtering the power rating is lower than in active filtering.**

KEYWORDS

Power quality, active filtering, filter topologies, computational simulations.

I. INTRODUCTION

The applications of power semi-conductors have been increasing according to the development of technology. Proliferation of nonlinear loads, such as a diode bridge rectifier, has caused degradation of the power quality utility through the generation of harmonic current or voltage. In recent years, many publications have come out on the harmonics, reactive power, imbalance and other disturbances related to power quality. There are also hundreds of publications on filtering solutions to mitigate problems associated with the quality of electrical power; these tend to have detrimental effects on the equipment fed with a poor electrical energy. Common symptoms of severe degradation of power quality include nuisance tripping of computer-controlled industrial processes, medical equipment, excessive heating in transformers and equipment failure and/or malfunction. Since sensitive equipment is frequently affected by neighboring nonlinear loads, the disruption of industrial assembly line processes often leads to expensive downtime and ruined products, causing production losses and high costs.

Thus, there are lots of aspects that have to be considered before implementing a strategy to compensate line disturbances. Some of them can be classified following the criteria described in [4], such as power rating, power-circuit configuration, parameters to be compensated and control techniques employed. Active and hybrid filters have proved advantageous in solving power quality problems. Several publications have described the development of these filtering techniques; however a comparative study showing the differences between the filtering topologies based on the criteria above mentioned has not been made yet.

This paper presents a comparative study between six different filtering topologies based on Matlab / Simulink simulations, so that better understanding in dealing with these systems can be accomplished. It also shows the characteristics of each type, as well as alternative tests and analysis of the suitable control strategy for the active filter in each case.

II. POWER FILTER TOPOLOGIES

Fig. 1 shows the power filter configurations simulated in this paper. These structures were chosen based on the fact that they can compensate most disturbances related with the utility. These filters aim to provide the best possible power quality. The term power quality is defined as the combination of voltage quality and current quality. The first is concerned with deviations of the voltage from the ideal waveform (single-frequency sine wave of constant frequency and constant magnitude) and the second is concerned with deviations of the current from the ideal waveform (single-frequency sine wave of constant frequency and magnitude and in phase with the supply voltage).

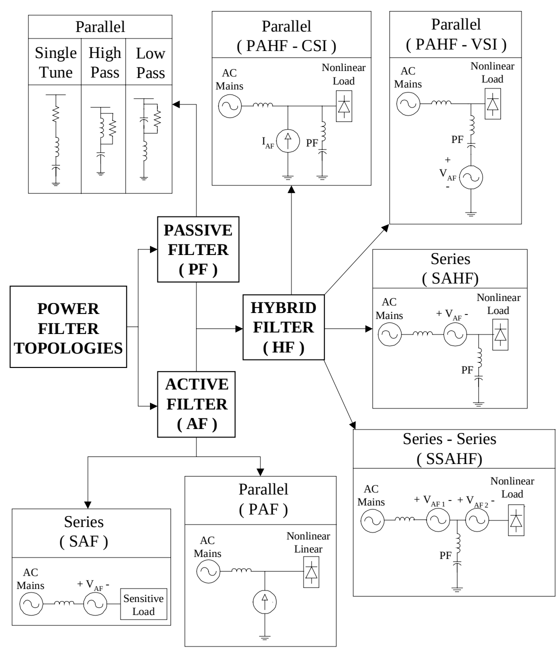

Fig. 1 – Power filtering structures simulated by Matlab / Simulink.

III. MATLAB / SIMULINK IMPLEMENTATION

In order to show how each structure works, it is important to bear in mind that the implementation of the active filter plays the main role in the simulations. It is difficult to model a configuration using real components such as a PWM inverter because the software has computational limitations. What is more, depending on the adopted structure, the calculus involving the filtering processes may lead the convergence of the simulation to be very slow.

On the basis of this, ideal controlled voltage and current sources are used to implement, respectively, a voltage source inverter and a current source inverter, considering that the aim is to test different structures, control strategies and to show different compensation characteristics. Fig. 2 shows how these active filters are implemented. The control strategies are calculated and provided for the controlled sources, which inject the necessary compensation to mitigate the line disturbances. In order to avoid algebraic loops, a very small transport delay is connected before these controlled sources. Another detail to obtain a successful simulation is to connect a shunt resistor in the output terminal of the controlled current source.

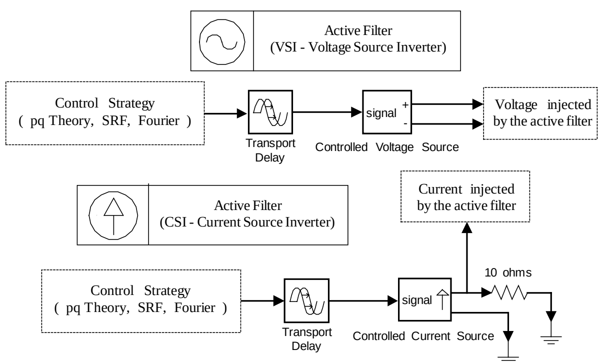

Fig. 2 – Implementation of the active filters using block diagrams from Matlab / Simulink.

Fig. 3 shows an example of the implementation of a parallel active filter (PAF) using Matlab / Simulink. A voltage source of 127 V rms was used in all simulations and a 10 kVA nonlinear load as well. The passive filters were implemented based on the reactive power calculated by the pq Theory [5]. Two single-frequency tune filters were used for the 5th and 7th harmonics and a high pass filter tuned with the 11th harmonic.

A desirable characteristic of the Matlab / Simulink software is that it can integrate control and power system block diagrams in the same structure. Furthermore, distinct filtering topologies can be implemented and both their chacteristics and control strategies analyzed.

Fig. 1 shows the filtering topologies used in the Matlab / Simulink simulations. A brief description of each structure is accomplished in the following paragraphs. The next section provides the simulation results.

- Parallel Active Filter (PAF): this active filter (current source inverter) is placed in parallel between the ac source and the load in order to inject a reference current that is calculated to mitigate harmonic currents, reactive power and current imbalances;

- Series Active Filter (SAF): this active filter (voltage source inverter) is placed in series between the ac source and the load. It works as a controlled voltage source that provides the compensation for voltage disturbances like sag, swell, flicker and harmonic distortion;

- Hybrid Filter with the Active Filter in Parallel (PAHF – CSI): the shunt active filter (current source inverter) is controlled to draw a compensating current to mitigate current disturbances. The high frequency harmonics are compensated by the shunt passive filter for the shunt active filter to require a low power rating. The shunt active filter also has the capability of damping harmonic resonance between an existing passive filter and the supply impedance;

- Hybrid Filter with the Active Filter in Parallel (PAHF – VSI): the active filter (voltage source inverter) is placed in series with the shunt passive filters in order to provide a harmonic voltage that is proportional to harmonic currents so that the passive filtering can be improved;

- Hybrid Filter with the Active Filter in Series (SAHF): the active filter is connected in series with the utility in order to provide a variable impedance that blocks harmonic currents and it therefore isolates harmonic currents from the ac source. So, they tend to flow though the shunt passive filters;

- Hybrid Filter with the Active Filters in Series (SSAHF): both active filters are connected in series between the ac source and the load. They operate as voltage source inverters and despite the fact that they have the same configuration, their control algorithms are distinct and, consequently, each active filter has a peculiar funcionality. The first active filter (AF1) has the function of active impedance, blocking the harmonic currents from the nonlinear load. Then, it reduces the harmonic spectrum of the ac source current. Because of the operation of the first active filter, the total harmonic distortion of the terminal voltages increases due to the harmonic currents through the passive filters. So, the second active filter is used in order to compensate disturbances in the terminal voltages.

IV. SIMULATION RESULTS

This section provides simulation results of the filtering structures shown in Fig. 1. Figs. 3 to 10 illustrate the relevant waveforms in each filtering topology. Fig. 3 shows a diagram block of the Matlab / Simulink implementation of a PAF. Fig. 4 shows the waveforms of this implemented structure, before and after the active filtering. It also shows the total power rating of the PAF for a 10 kVA nonlinear load.

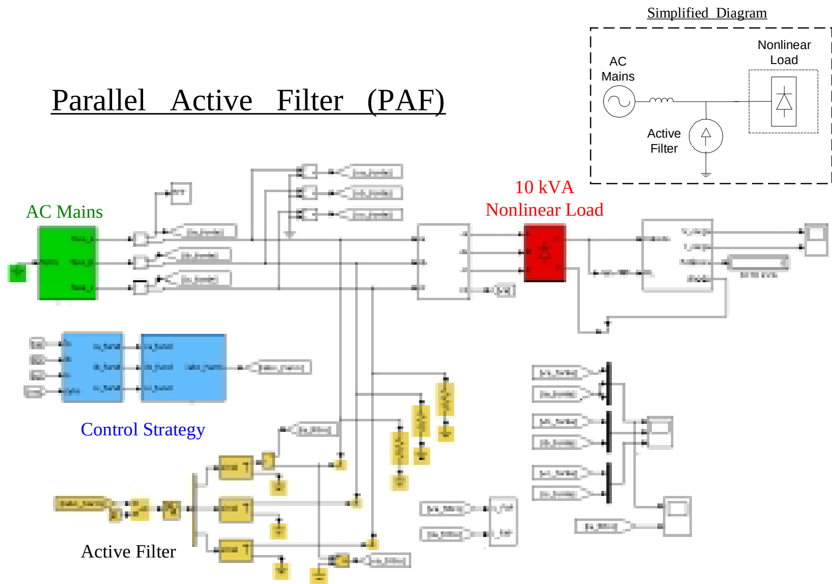

Fig. 3 – Example of a parallel active filter implementation using Matlab / Simulink.

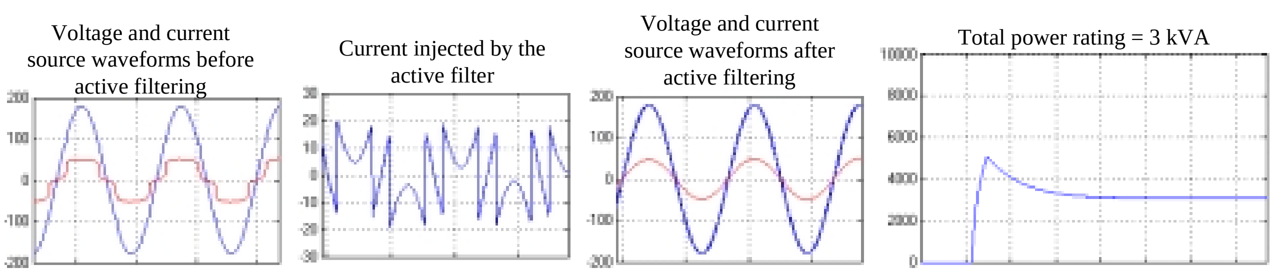

Fig. 4 – Simulation waveforms for the Parallel Active Filter (PAF).

Fig. 5 shows how the SAF can be implemented in the Matlab / Simulink via block diagrams. In Fig. 6, a voltage waveform containing harmonics, an injected voltage by the SAF, a conditioned voltage in the sensitive load and the total power rating of the SAF are presented.

Figs. 7 and 8 present, respectively, two parallel hybrid filters (CSI and VSI) with their relevant waveforms. In Fig. 8, it can be noted that the power rating of the active filter in hybrid structure is lower than the one in pure active filtering. These filtering topologies, as well as all structures, are implemented in the same way as Figs.4 and 5.

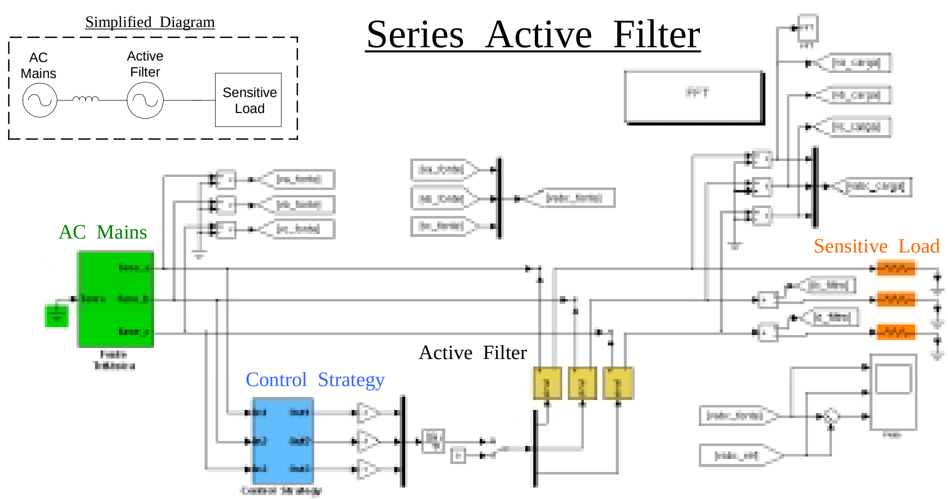

Fig. 5 – Example of a series active filter implementation using Matlab / Simulink.

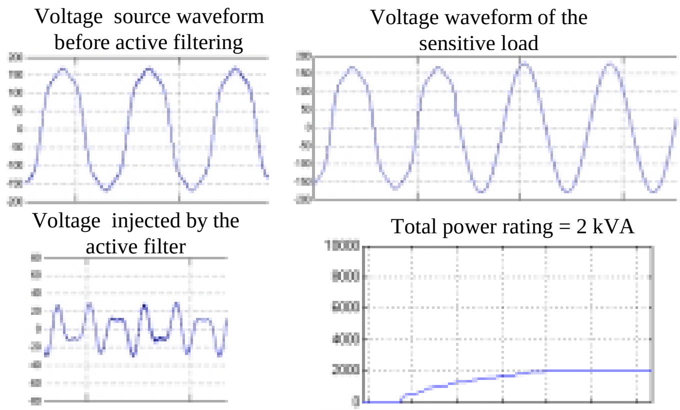

Fig. 6 - Simulation waveforms for the Series Active Filter (SAF).

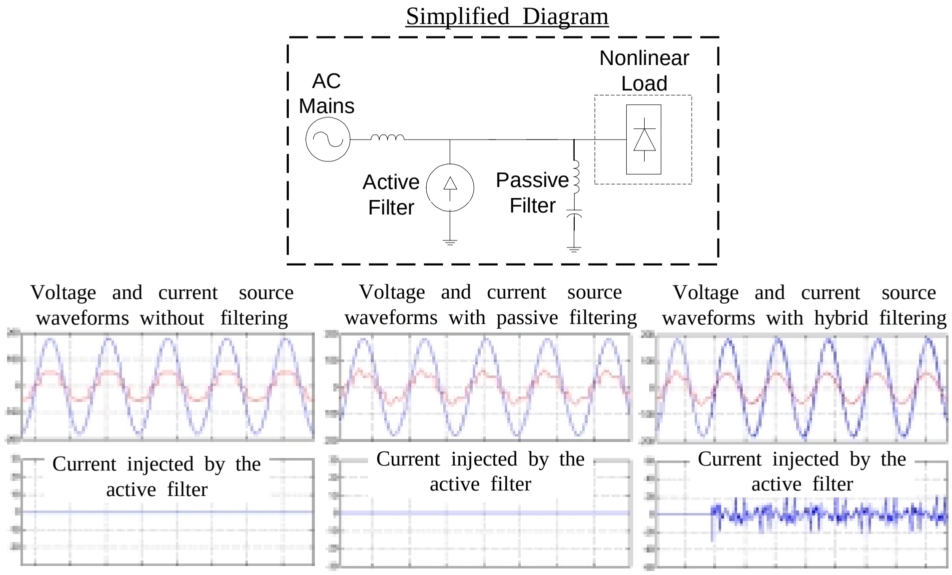

Fig. 7 - Simulation waveforms for the Hybrid Filter with the Active Filter in Parallel (PAHF – CSI).

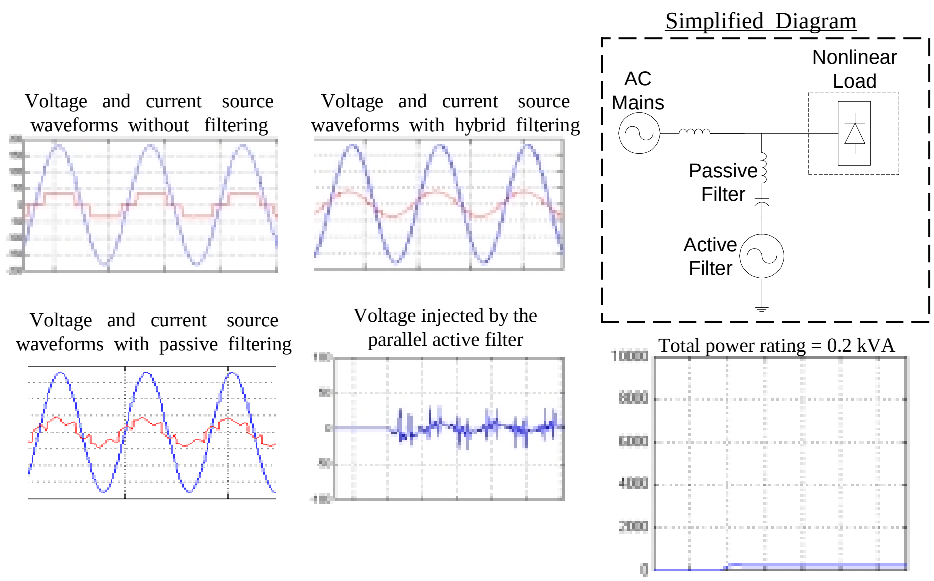

Fig. 8 – Simulation waveforms for the Hybrid Filter with the Active Filter in Parallel (PAHF – VSI).

Fig. 9 shows the simplified diagram and the simulation waveforms for the SAHF. It can be shown that the current waveform has a better performance with the use of hybrid filtering than of passive filtering. Fig. 10 shows a modified structure of the filter shown in Fig. 9. In this case, an active filter in placed between the shunt passive filter and the nonlinear load in order to improve the terminal voltage quality, which is poor when the first series active filter is operating. Furthermore, the progressive improvement of power quality using filtering methodologies (active and hybrid filters) is also shown in Figs. 9 and 10.

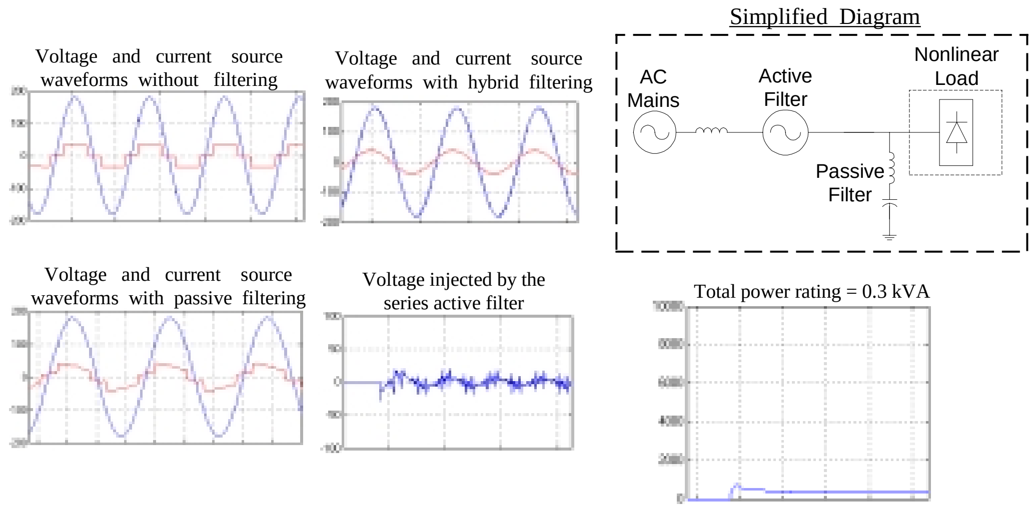

Fig. 9 – Simulation waveforms for the Hybrid Filter with the Active Filter in Series (SAHF).

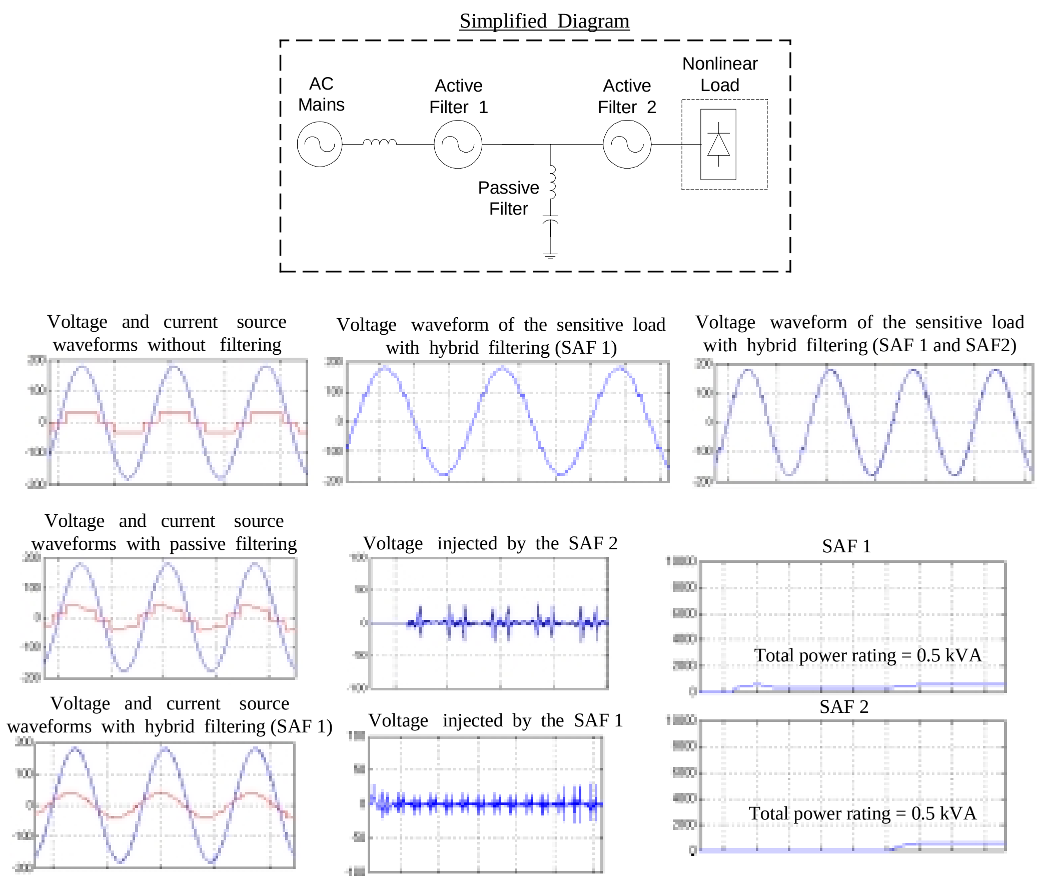

Fig. 10 – Simulation waveforms for the Hybrid Filter with the Active Filters in Series (SSAHF).

V. CONCLUSIONS

The aim of this paper is to present comparative simulations of active and hybrid filters in order to provide a practical way to analyze the characteristics of six filtering structures, which compensate for the more common utility disturbances. Implemented correctly, these simulations allow for tests involving control techniques, different power-circuit configurations and power rating. What is more, it can be observed that the disturbance to be compensated depends on these three criteria.

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