# Comparison of Main Hybrid Power Filter Topologies and Practical Implementations Using Matlab® and dSpace® DSP

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***Abstract*—This paper presents a comparison of behavior of two hybrid filtering topologies used in conditioners. This is applied in a system with a nonlinear load . Simulations of filtering structures, control algorithms and non-linear loads were implemented using Matlab® and Simulink and Power System Blocksets. It is used a dSpace DSP for control of filters. This DSP allows high level programming, using the same blocks generated by Simulink. The simulations results are compared with practical results.**

***Index Terms*—Active Filter, Hybrid Filter, Power Conditioner Power Quality.**

## I. Introduction

In recent years, the growing of use the equipment with power electronics converters due to low cost and new technologies has been increased the interest for research and new developing in this area. These devices demand an energy with high quality to work in perfect conditions and performance. The input current of these equipment is non linear and as consequence, the current is rich in harmonics. Also considering the expansion of non linear loads connected in power systems, power quality problems have been increasing in importance. Power quality is affected when the occurrence of disturbances in network and its reflect in the wave form of voltage and current. The main characteristic of this phenomenon is a harmonic superposition which can generate misoperation, fails and permanent damage in equipment and power system. The present challenge is find out new manners to mitigate power quality problems, with multifunctional, low cost and efficiency attributes. The hybrid power filters have been used to minimize this problem. These filters consisting of active and passive filters connected in series or parallel with each other combine the advantages of both filters, thus leading to the best effectiveness in cost, performance and benefit. By improving the compensation characteristics of the passive filters, hybrid active filters get a reduction in the rating of the active filter [1,2,3,4,5,6].

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In this paper two main hybrid filter topologies and his filtering algorithm are presented with Matlab® simulations[7] on the basis of the Synchronous Reference Frame developed in [3]. Two variations for power hybrid filter systems are presented, tested and compared with simulation and practical experimentation.

To improve the design process, development and analyse of controls scheme of hybrid power system this paper tackle the use of *The Matworks´s Development Software* (MATLAB)[8,9] and dSpace® DSP[10] as developed in [11,12,13].

## II. Simulations of Power Hybrid active Filters Using MATLAB®.

In this paper is applied two possible implementations of power hybrid active filters. A hybrid filter is an association of active and passive filters, where the active filter acts as an impedance inserted in the system, changing its harmonic behavior. The aim is to combine passive filter robustness with active filter performance, improving system reliability [6]. Two possible implementations are presented in the Fig. 1.a, ***Hybrid Series Active Filter (HSAF)*** and Fig. 1.b, ***Hybrid Parallel Active Filter (HPAF)***.

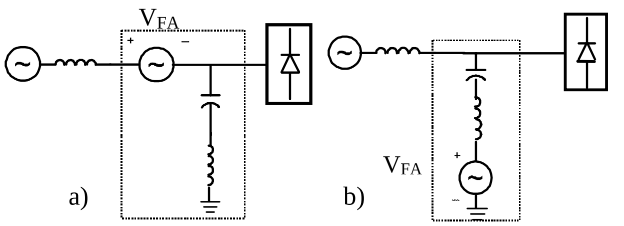


Fig. 1. a)Hybrid series active filter (**HSAF**) and b)Hybrid parallel active filter (**HPAF**).

### A. *Hybrid Series Active Filter (HSAF)*

This association is shown in Fig. 2. The goal of this series active and shunt passive filters combination is to operate the active filter as a short-circuit for line frequency and as an open-circuit for low-order harmonic currents. With this scheme, harmonics are forced to flow through the passive filters achieving harmonic isolation between source and load.

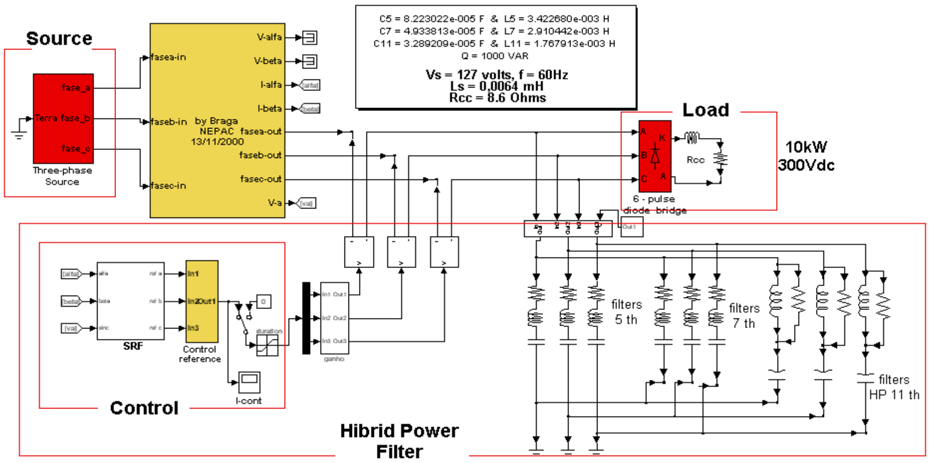


Fig. 2. Implementation of power system, filters and strategies of control using simulink and power system blockset for hybrid series active filter.

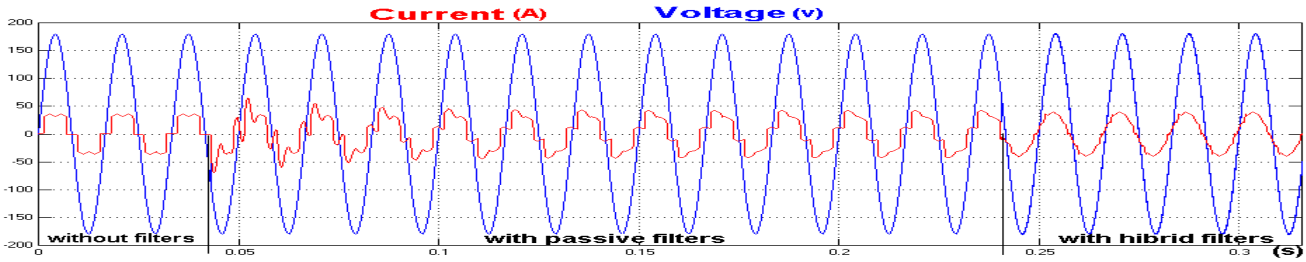


Fig. 3. Results of simulation in different stages for hybrid series active filter. a)Source voltage, b) Source current

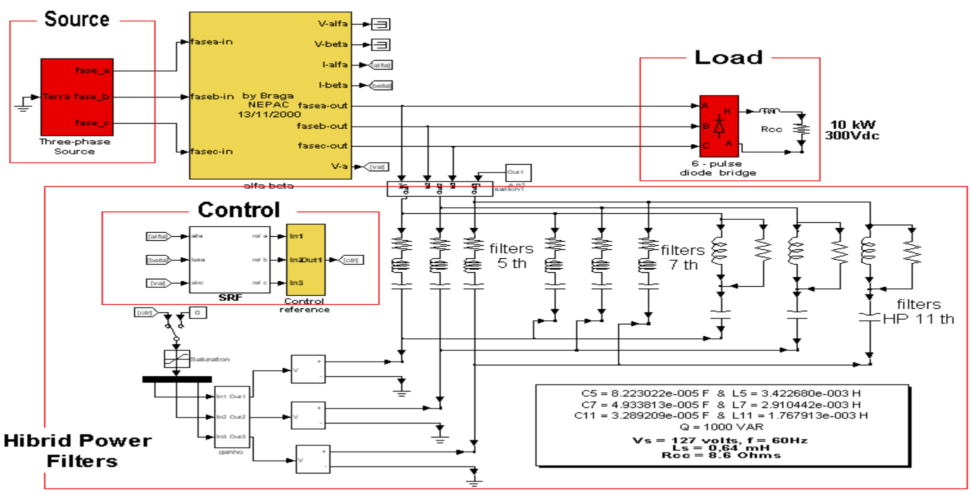


Fig. 4. . Implementation of power system, filters and strategies of control using simulink and power system blockset for hybrid parallel active filter.

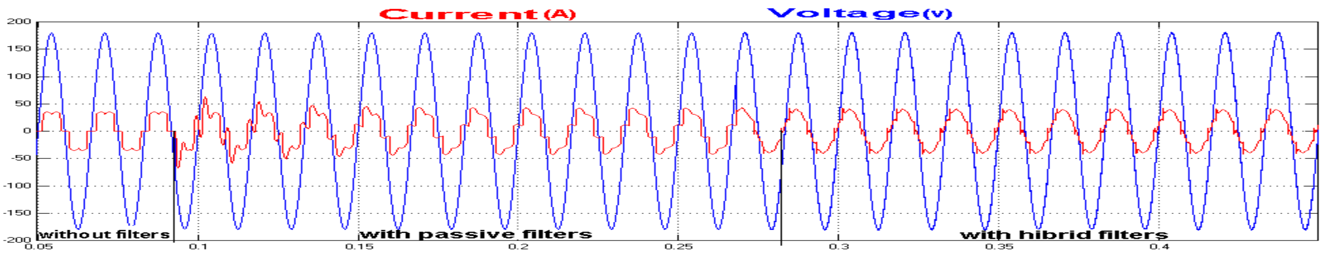


Fig. 5. Results of simulation in different stages for hybrid series active filter. a)Source voltage, b) Source current

Therefore, series active filter is sized only to a fraction of the total compensating power and the overall cost is limited.

Fig. 3 depicts results of simulation with a gradual improvement of current waveform and decrease of total harmonic distortion while passive and active filters are associated in the system. It is verified that hybrid serie configuration presents good results.

*B. Hybrid Parallel Active Filter (HPAF)*

This association is shown in Fig. 4. In this approach, passive and active filters are connected in series. It allows the active filter to regulate the amount of harmonics flowing into the passive unit. The current flowing through the active filter is the same current of the passive filter, i.e. the harmonic current of the load plus fundamental reactive current flowing through the passive filter. If the hybrid filter is required to provide harmonic isolation plus active damping, the rating of the active filter increases substantially. Some advantages compared to the above association are the easy protection and that possible failures in active filter do not involve the load section itself.

The Fig. 5 shows a gradual increase in the quality of current waveform supplied for a source while passive and active filters are associated in the system. There is an improvement in the waveform, however, still have small current impulse in the waveform of current because of fast derivative in load current on positive and negative cycle.

## III. FILTERING ALGORITHM FOR HYBRID ACTIVE FILTERS

In this paper is applied a classical control method to handling with hybrid power filters the control based in the Synchronous Reference Frame(SRF) [3].

When the system has a voltage distortion, it is possible to avoid error in p-q theory calculation and its extensions by use of SRF control algorithm. The block diagram of the SRF is showed in Fig. 6. This algorithm creates a sinusoidal reference and co-sinusoidal synchronized with the network frequency. In this case is possible to get a current compensation of the sinusoidal source.

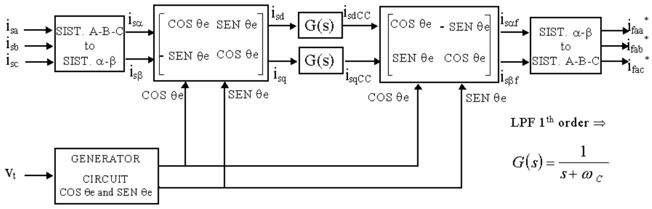


Fig. 6. Block diagram of the SRF control

This control schemes is implemented using Simulink for simulation and practical implementation as showed in Fig. 7.

The synchronism system of sinusoidal reference and co-sinusoidal synchronized with the network frequency is implemented together with control software generated with Simulink Blockset. In this case is not used other device to obtain synchronism, for example PLL (Phase Lock Loop)[3].

The Simulink has a function (hit crossing), which generate a pulse each passage of signal across zero. This pulse reset the integrator, which provide a time base for sine and cosine of reference frame.

A Fig. 7 shows the programming of hybrid filters control based in SRF Method using Simulink diagrams. In the bottom of Figure 7 is implemented the reference frame.

This control method is same for the two hybrid filters topologies as showed in simulated results yet, Fig. 3 and Fig. 5.

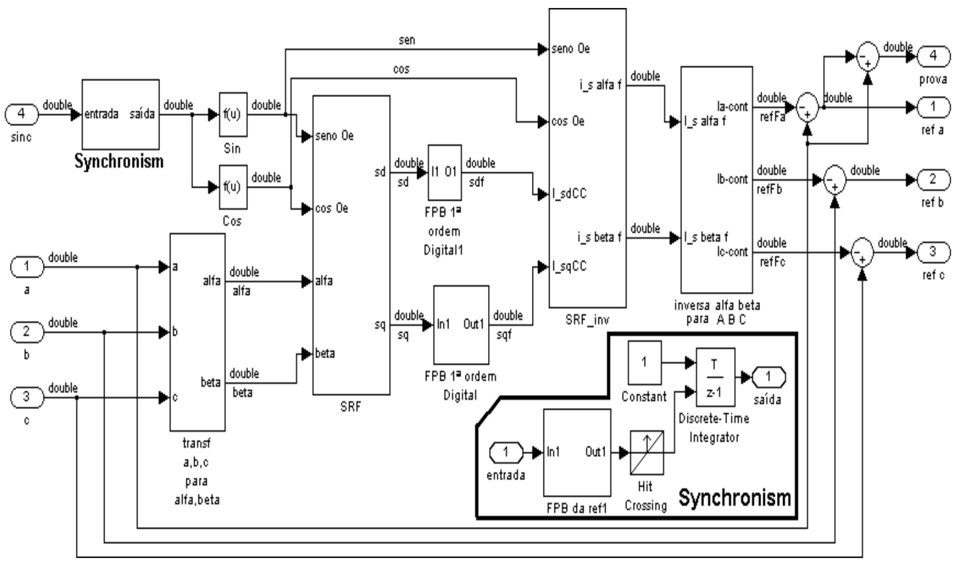


Fig. 7. Implementation of the control based in the Synchronous Reference Frame using Simulink.

Fig. 8 presents a programming detail about internal blocks where is control system equations.

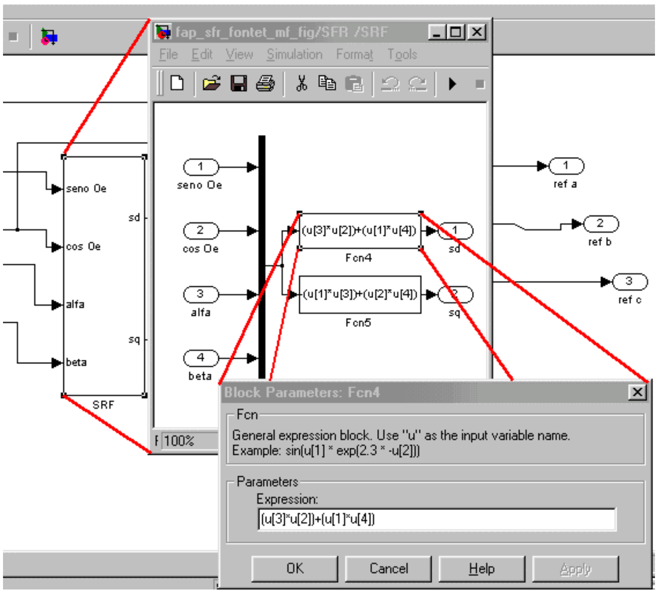


Fig. 8. . Detail of the programming of block diagram control.

## IV. Implementation for Real-Time Purpose Using Matlab and DSP

Due to the user-friendly characteristics of Simulink, it is used in this paper with two purposes: an implementation using visual programming and the real time mode.

The practical application of control scheme developing using Simulink is the use on DSP board[11]. To feasibility of this application, drivers to communicate with Matlab and data acquisition board should be provide. In this work is used Dspace board. An advantage of Simulink for this application is the use of visual programming to developing and implementation of control algorithm on DSP board. The other advantage is the speed of algorithm running on DSP board in relation other methods, for example when the software host in a PC[12]. The Fig. 9 shows the PC-to-Real-Time-Processor Communication using DSP with Matlab® drivers to improve the quality of results.

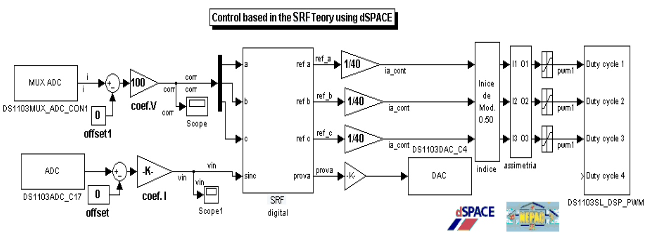


Fig. 9. Implementation of the control in DSP by Simulinkl®.

This method of implementation of active filter control can be used in the two hybrid filters topologies.

## V. Experimental Results

A simplified representation of parallel hybrid filter with characteristics values implemented in laboratory is illustrated in Fig. 10.

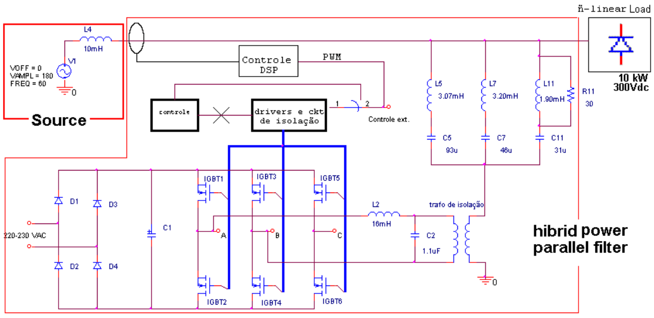


Fig. 10. Simplified power circuit of an experimental parallel hybrid filter.

Fig. 11 depicts waveform of voltage and current of source before filtering. It can be observed that current has a characteristic waveform of a controlled six pulse three-phase rectifier with inductive filtering in DC side.

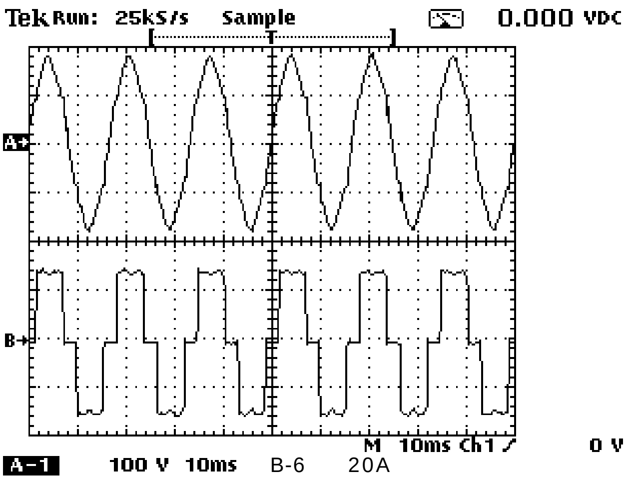


Fig. 11. Waveform of voltage and source current without filters.

Fig. 12 shows waveform of voltage and current of source after passive filtering connection. It can be verified that current waveform presents resonance which is generate for passive filters even though waveform is approximately a sinusoidal waveform.

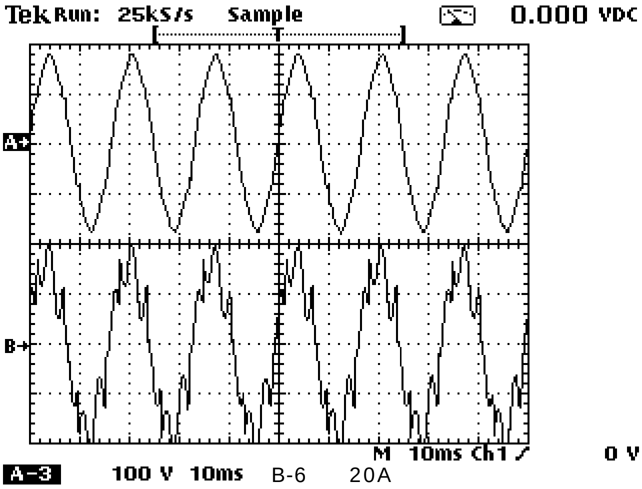


Fig. 12. Waveform of voltage and source current with passive filter.

Fig. 13 depicts waveform of voltage and current after start up of active part of hybrid filter. It can be observed a reduction of resonance produced for parallel passive filters, which result in the waveform close a sinusoidal waveform. Even thought have small current peaks produced for the fast derivate in the load current, it can be verified an improvement in the aspect of waveform of source current when compared with waveform without filtering (Fig.11).

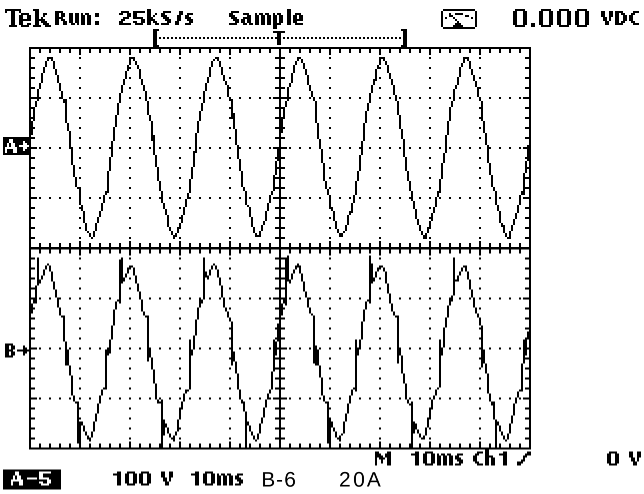


Fig. 13. Waveform of voltage and source current with parallel hybrid filter.

Fig. 14 shows waveform of current in three phases, obtained with auxiliary software called of ControlDesk. This can be using for monitoring all variables of control and power systems.

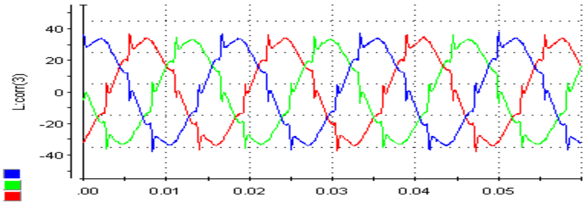


Fig. 14.Waveform of source current with parallel hybrid filter

Fig. 15 depicts a comparison between waveform of source current with hybrid filtering using simulation and real implementation.

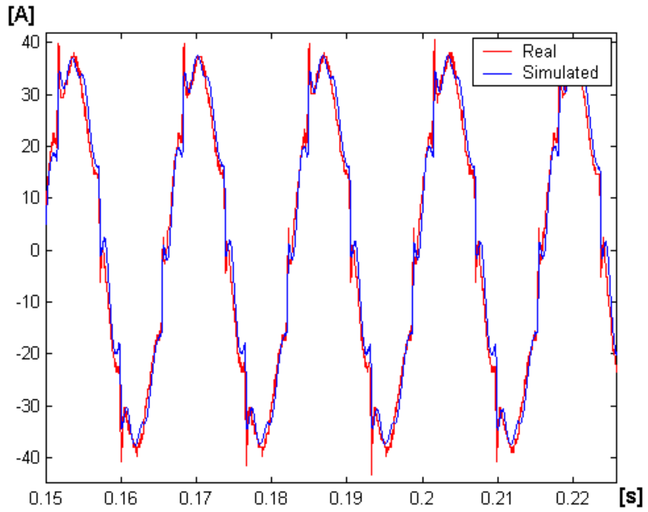


Fig. 15. Comparison of source current waveform for simulated and practical result.

A simplified representation of series hybrid filter with characteristics values implemented in laboratory is illustrated in Fig. 16.

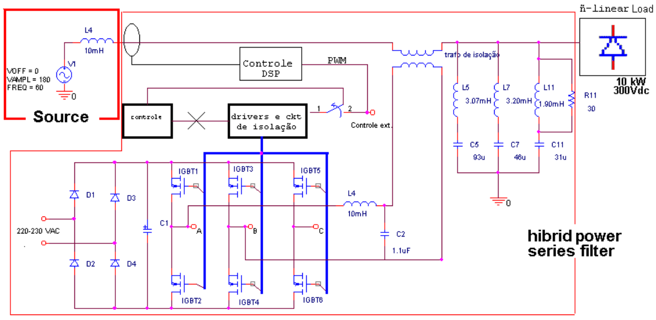


Fig. 16. . Simplified power circuit of an experimental series hybrid filter.

Fig. 17 depicts waveform of voltage and current after start up of active part of series hybrid filter. It can be observed a reduction of resonance produced for parallel passive filters, which result in the waveform close a sinusoidal waveform.

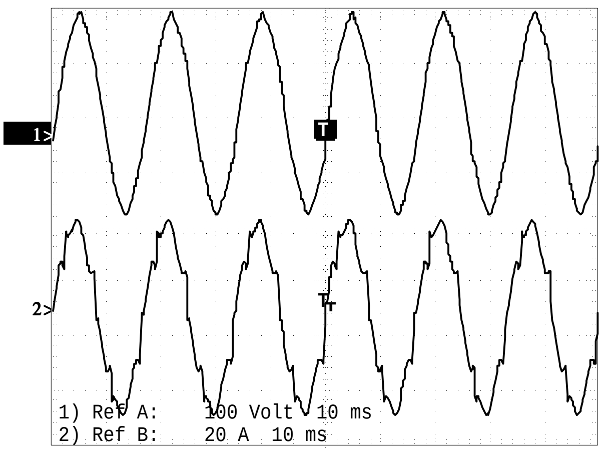


Fig. 17. Waveform of voltage and source current with series hybrid filter.

Fig. 18 depicts a comparison between waveform of source current with hybrid series filtering using simulation and real implementation.

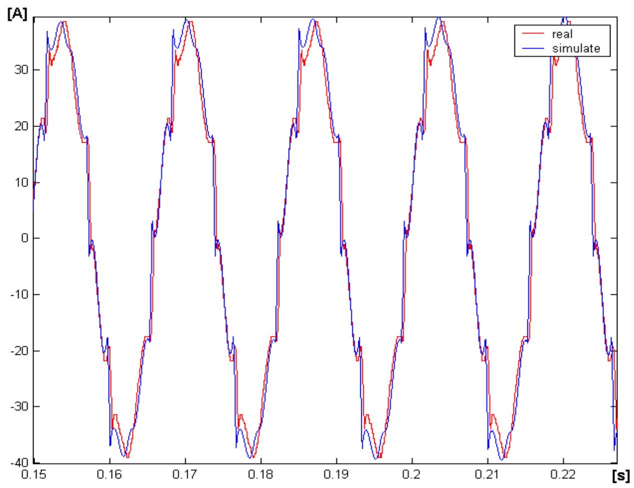


Fig. 18. Comparison of source current waveform for simulated and practical result.

## VI. Conclusions

This paper has presented a discussion illustrated of comparison for two main power hybrid filters topologies and practical implementation using Matlab® and dSpace® DSP.

Analyzing results of simulations is possible verify that hybrid series filter have presented better results then of hybrid parallel filter. It is important to observe that practical implementations presents some limitations towards start up operation and protection of active part of hybrid series filter. This subject is still on investigation.

The hybrid parallel filter has an inferior performance than hybrid series filter, however, this kind of filter not present difficult in start up and protection. The main limitation is on fast derivative compensation of source current. Despite of limitation the results are satisfactory with good perspective for power conditioners of high power non-linear loads.

Another contribution refers to validate of computational models of filter, which has present good performance when compare with experimental result.

## VII. References


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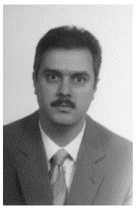
## VIII. Biographies

**Flávio Antonio Becon Lemos** – received his degree in Electrical Engineering from Universidade Federal of Santa Maria, Brazil in 1988, and the M. Sc. and Ph.D. degrees in Electrical Engineering from Universidade Federal of Santa Catarina, Brazil in 1994 and 2000 respectively. From 1996 to 1997 he was a research fellow in Brunel Institute of Power System, London, UK. His main research interests are in the area of voltage stability, power system dynamics and control, power system operation and non-linear systems.



**Fausto Bastos Líbano** was born in Porto Alegre, Brazil, on November 7, 1960. He obtained the Electrical Engineering Diploma from the Pontifícia Universidade Católica do Rio Grande do Sul, MSc degree from the Universidade Federal de Santa Catarina and Dr. Ing. degree from Universidad Politécnica de Madrid. Since 1980, he has been with Department of Electrical Engineering of the Pontifícia Universidade Católica do Rio Grande do Sul. His main interest are in Power Electronics, Power Quality and Electrical Drives.

**Rodrigo Antonio Marques Braga** was born in Porto Alegre, Brazil, on April 18, 1973. He obtained the Control and Automation Engineering Diploma from the Pontifícia Universidade Católica do Rio Grande do Sul, in 1998, M. Sc. degree from Pontifícia Universidade Católica do Rio Grande do Sul, Brazil in 2001. His main interest are in Control Systems, Power Electronics, Power Quality and Electrical Drives.