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Output feedback control strategy of parallel hybrid filters

S. Tnani*, P. Coirault

ESIP, Laboratoire d'Automatique et d'Informatique Industrielle, 40 Avenue du Recteur Pineau, 86022 Poitiers Cedex, France

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Abstract

In this paper, the authors propose a novel control strategy of active hybrid filters. The adopted hybrid filter consists of an active filter and a passive filter connected in parallel. The power rating of the converter is reduced compared with simple active filter. The control is introduced to allow active filtering of load harmonics and active damping of passive filter connected in parallel with the active filter. When connected in power grid, the complete system is adjusted to prevent risk of resonance as well as harmonic filtering. A complete modeling of the system is achieved using a simple structure and effective corrector is developed. An important characteristic of the proposed control scheme is that it results in a simple static output feedback controller. Complete simulation of the system validates efficiency of the control law.

Keywords: Active filters; Power quality; Control; Harmonics; Modeling

1. Introduction

Abundance of static power converters in industrial activities has led to serious concerns about the power quality of power distribution systems. The quality of electric power in commercial and industrial installations is undeniable decreasing. In addition to external disturbances, such as outages, sags, spikes due to switching and atmospheric phenomena, there are inherent, internal causes specific to each site and resulting from the combined use of linear and non-linear loads. Tripping of protected devices, harmonic overloads, high levels of voltage and current distortion, temperature rise in conductors and generators all contribute to reducing the quality and the reliability of a low-voltage ac system. The above disturbances are well understood and directly related to the proliferation of loads consuming non-sinusoidal current, referred to as "non-linear loads". This type of load is used for the conversion, variation and regulation of electric power industrial and residential installations. The prospect of a rapid return to linear-load conditions is illusory. The consumption of non-linear current will sharply increase in the years to come.

Today, a variety of classical approaches are used to minimize harmonic distortion, but all present disadvantages. All solutions will exhibit higher utility costs because of continued poor power factors. These solutions are listed here after.

- *Oversizing or derating of the installation*. This solution does not attempt to eliminate the harmonic currents flowing in the low-voltage (less than 1000VAC) electrical distribution system but rather to "mask" the problem and avoid the consequences. When designing a new installation, the plan is to oversize all elements likely to transmit harmonic currents, namely the transformers, cables, circuit breakers, engine generator sets and the distribution switchboards. The most widely implemented solution is oversizing of the neutral conductor. In existing installation, the most common solution is to derate the electrical distribution equipment subjected to the harmonic currents. The consequence is an installation that cannot be used to its full potential. The result is a major increase in the cost of electrical distribution system.
- *Specially connected transformers*. Two kind of transformer can be used. The first one called "zig-zag" transformer. This solution inhibits propagation of third-order harmonic currents and their multiples. It is a centralized solution for a set of single-phase

* Corresponding author. Tel.: +33 5 49 45 35 06; fax: +33 5 49 45 40 34.
E-mail address: slim.tnani@univ-poitiers.fr (S. Tnani).

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loads. However, it produces no effect on other harmonic orders that are not multiples of three (5th, 7th, etc.). On the contrary, this solution limits the available power from the source and increases the line impedance. The consequence is an increase in the voltage distortion due to the other harmonic orders. The second one is a combination of star and triangular connection of two transformers loaded by two three phase thyristor or diode converters. This solution inhibits propagation of 5th, 7th harmonics. This method is limited on a set of particular industrial applications as well as electric ships propulsion.

- *Series reactors*. This solution, used for variable speed drives and three phase rectifiers, consists in connecting a reactor in series upstream of a non-linear load. But a reactor has limited effectiveness. Only, 11th, 13th harmonics are limited. One must be installed for each non-linear load. Current distortion is divided by a factor of approximately 2.
- *Tuned passive filter*. The idea is to "trap" the harmonic currents in L/C circuits tuned to the harmonic orders requiring filters. A filter therefore comprises a series of "stages", each corresponding to a harmonic order. Orders 5, 7, 11 and 13 are the most commonly filtered. A filter may be installed for one load or a set of loads. Its design requires in-depth study of the ac system. This is particularly difficult in case of electric ships. Sizing depends on the harmonic spectrum of the load and the impedance of the power source which varies according to the speed. Rating also must be coordinated with reactive power requirements of the loads, and it is often difficult to design the filter to avoid leading power factor operation for some load conditions. This solution is moderately effective and its design depends entirely on the given power source and the loads. When appropriately designed, this type of filter may also be used to eliminate harmonic distortion already present on the electrical network of the power distributor, provided a significant overrating for harmonic absorption from the power system.

  The major inconvenient of this solution is that it is not flexible and is very difficult to upgrade. It must be re-tuned if circuit environment changes. Moreover damping of passive filters is generally performed with a resistive component in parallel with the inductors. This method decreases efficiency of the system in term off losses.

  The active harmonic filter concept uses power electronics to introduce current components, which cancel the harmonic components of the non-linear loads. A number of different topologies are being proposed and are discussed below. Within each topologies there are issues of required components ratings and method of rating the overall filter for the loads to be compensated [4,1,3,9].
- *Series filters*. This type of filter is connected in series with the ac distribution network and compensates both the harmonic currents generated by the load and the voltage distortion already on the ac system. This solution is technically similar to line conditioners and must be sized for the total load rating [2]. For low-voltage ac systems, less than 1000VAC, it is suitable to choice active parallel filter. Indeed, series topologies contain transformers which are not useful in low voltage.
- *Parallel filters*. The active filter is connected in parallel with the ac line, and constantly injects currents that precisely correspond to the harmonic components drawn by the load. The result is that the current supplied by the power source remains sinusoidal [6,8]. Then, the source supplies the load with the fundamental component of the current only. The normal power source provides the fundamental current, and the active harmonic filter supplies the harmonic currents required by the load. If the harmonic currents drawn by the load are greater than the rating of the active harmonic filter, the filter can automatically limits the injected current to its rated output current. Easy to implement, an active filter may be installed at any point on a low-voltage ac system to compensate the power drawn by one or several non-linear loads, thus avoiding the circulation of harmonic currents throughout the low-voltage ac system.
- *Hybrid filters* [12,10]. This solution, combines an active filter and a passive filter, and may be either of the series or parallel type. It gives the advantages of passive filter low cost and modularity of the active one.

Different control methods of simple or hybrid active filters are well known and used in industrial applications [9,5]. We can divide these methods in two families: the first one is based on overlapping control loops as used in vector control of electrical machines. The second one uses sliding mode control technique. These methods are difficult to implement in case of hybrid filters and require several current sensors.

In this paper, a hybrid active filter consisted of an active filter and a passive filter connected in parallel is analyzed and presented. The authors propose an original method of control using the state space modeling. A complete mathematical design of one hybrid filter structure is achieved and introduce a feedback control witch minimize the number of sensors. The control scheme generate a PWM reference for the voltage source inverter (VSI). One use only two current sensors and two voltage sensors. The global simulation results highlight the interest and the efficiency of these method of control.

2. System description

In case of a non-linear load as three-phase diode or thyristor converters, usual harmonics are 5th, 7th, 11th and 13th ones. Passive filters must be used to eliminate most important harmonics. Within the framework of loads which we consider, the 5th and 7th are the most ones. It is thus suitable to tune passive filters on these ranks. The IGBT converter filter the other existing harmonics on the grid. Electrical structure of the hybrid filter is shown in Fig. 1.

The hybrid filter is connected in parallel with the non-linear load. The VSI consist of a 6 IGBT converter with a L/C lowpass filter tuned at 1 kHz. Passive filters are tuned on the 5th and 7th harmonic ranks. The considered load is a 6 pulses thyristor converter