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New digital reference current generation for shunt active power filter under distorted voltage conditions

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ABSTRACT

In this paper, a new reference current computation method suitable for shunt active power filter control under distorted voltage conditions is proposed. The active power filter control is based on the use of self-tuning filters (STF) for the reference current generation and on a modulated hysteresis current controller. This active filter is intended for harmonic compensation of a diode rectifier feeding a RL load under distorted voltage conditions. The study of the active filter control is divided in two parts. The first one deals with the harmonic isolator which generates the harmonic reference currents and is experimentally implemented in a DS1104 card of a DSPACE prototyping system. The second part focuses on the generation of the switching pattern of the inverter by using a modulated hysteresis current controller, implemented in an analogue card. The use of STF instead of classical extraction filters allows extracting directly the voltage and current fundamental components in the α–β axis without phase locked loop (PLL). The performances are good even under distorted voltage conditions. First, the effectiveness of the new proposed method is mathematically studied and verified by computer simulation. Then, experimental results are presented using a DSPACE system associated with the analogue current controller for a real shunt active power filter.

1. Introduction

Generally, harmonic currents are mostly generated by the AC/DC power conversion units and the power electronic equipments, used in domestic and industry applications. The harmonic currents are the source of adverse effects for many types of equipments such as heating in distribution transformer, perturbation of sensitive control equipments and resonances with the grid.

Many solutions are proposed and studied in the literature to compensate the harmonics such as filtering (passive, active, and hybrid) with various topologies (shunt, series) for two-wire single-phase, three-wire three-phase and four-wire three-phase systems [1]. These solutions have been proposed using current and voltage source inverters to improve the mains power quality.

The passive filtering is a simple way to eliminate the harmonic currents. However, it does not allow to completely eliminate all of them and has many drawbacks such as series or parallel resonance with the system impedance. Moreover, the compensation performances depend on the mains impedance. The active filters (series and shunt) were also developed and widely used to overcome the drawbacks of the passive filters and improve power quality. As well known, the parallel active filters are controlled to generate in real time the harmonic currents produced by the non-linear loads [2].

The performances of an active filter mainly depend on the reference current generation strategy. Several papers studied and compared the performances of different reference current generation strategies under balanced, sinusoidal, unbalanced or distorted alternating current (AC) voltages conditions [3–5]. In all of them, authors demonstrated that under balanced and sinusoidal AC voltages conditions, the strategies such as the so-called p–q theory and Synchronous Reference Frame Theory (SRF) provide similar performances. Differences arise when one works under distorted and unbalanced AC voltages. In real conditions, the mains voltages are distorted, which decreases the filter performances [6]. In this case, the p–q theory performances are poor, from the harmonics point of view, and the best results are obtained with the SRF. However, the SRF theory requires a phase locked loop (PLL) which increases the complexity of the control system: an additional card is usually used and the controller implementation is more complex. In this paper, we theoretically and experimentally studied a new reference current generation suitable for shunt active power filter control under distorted voltage conditions by using self-tuning filters (STF) for the reference current generation and a modified version of the classical p–q theory.

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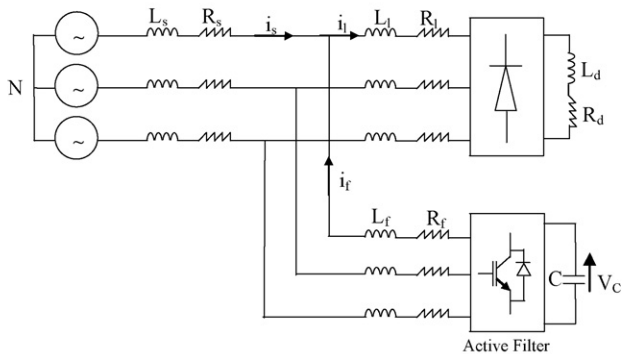

Fig. 1. Power system configuration.

The STF is dedicated to extract the fundamental component directly from electrical signals (distorted voltage and current) in α–β reference frame. In the following, the frequency and dynamic responses of the STF are mathematically analyzed and discussed. The major advantages of the STF are cited hereby:

- operating adequately in steady state and transient condition;
- no phase delay and unity gain at the fundamental frequency;
- no PLL required;
- easy to implement in digital or analogue control system.

In this paper, we validated the STF performances in a real shunt active power filter. A theoretical and experimental study of a three-phase parallel active filter for harmonic compensation (Fig. 1) is presented. Improved harmonic isolator based on STF and three-phase modulated hysteresis current control are used. In Section 2, the system configuration is presented. Then, in Section 3, the filter control strategy is discussed. We used STF instead of classical harmonic extraction based on high pass filters (HPF) or low pass filters (LPF). A focus is made on the STF performances by mathematical analysis under distorted voltage conditions. The current controller is also presented [7]. In Sections 4 and 5, simulation and experimental results are presented, respectively.

2. System configuration

Fig. 1 presents the shunt active filter topology based on a three-phase voltage source inverter, using IGBT switches, connected in parallel with the AC three-phase three-wire system through three inductors L_F. The capacitor C is used in the DC side to smooth the DC terminal voltage. The non-linear load is a three-phase diode rectifier supplying a RL load. This load generates harmonic currents in the supply system.

The proposed control strategy can be divided in two parts. The first part is the harmonic isolator (reference current generation). It consists in generating the harmonic current references and uses STF instead of HPF or LPF usually used in the p–q theory first proposed by Akagi et al. [8]. This harmonic isolator will be implemented into a DSPACE system (DS1104 card) in the experimental study. The second part is the current control of the power converter. This controller generates the suited switching pattern to drive the IGBTs of the inverter by using a modulated hysteresis current controller. In the experimental study, this controller is implemented into an analogue card. Fig. 2 shows the schematic diagram of the active power filter system.

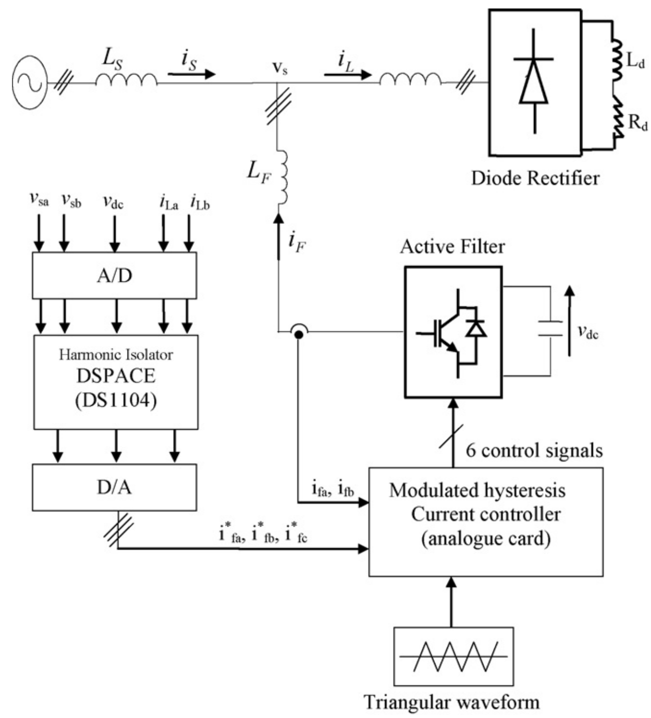

Fig. 2. Active filter system.

3. Control strategy

3.1. General control principle

According to Fig. 2, the voltage v_{dc}, the load currents i_{La} and i_{Lb}, and the source voltages v_{sa} and v_{sb} of the three-phase three-wire system are acquired and converted into digital signals at the inputs of the DSPACE system by Analogue-to-Digital converters. The sampling period for acquisition is equal to 30 μs. The current i_{Lc} is computed by $i_{Lc} = -(i_{La} + i_{Lb})$ and the voltage v_{sc} is calculated by $v_{sc} = -(v_{sa} + v_{sb})$. Then, we apply a modified version of the p–q theory (see Section 3.3) developed in our laboratory for generating the current references i^*_{fa}, i^*_{fb} and i^*_{fc} (see Fig. 2).

These digital references are the outputs of the DSPACE system and are converted into analogue signals by Digital-to-Analogue converters. By using an analogue card developed in our laboratory, we generate the switching pattern for the inverter by implementing the analogue modulated hysteresis current controller (see Section 3.4).

3.2. Self-tuning filter

3.2.1. Principle and frequency response of the STF

Hong-sock Song studied the integration in the synchronous reference frame [9]. He demonstrated that:

$$V_{xy}(t) = e^{j\omega t} \int e^{-j\omega t} U_{xy}(t) dt \quad (1)$$

where U_{xy} and V_{xy} are the instantaneous signals, respectively before and after integration in the synchronous reference frame. The previous equation can be expressed by the following transfer function after Laplace transformation:

$$H(s) = \frac{V_{xy}(s)}{U_{xy}(s)} = \frac{s + j\omega}{s^2 + \omega^2} \quad (2)$$