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A line-interactive UPS system implementation with series-parallel active power-line conditioning for three-phase, four-wire systems

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Abstract

This paper presents a three-phase line-interactive uninterruptible power supply (UPS) system with active series-parallel power-line conditioning capabilities. Synchronous reference frame (SRF)-based controller is used to harmonic and reactive power compensation generated from any configuration of non-linear load. Under normal line conditions the UPS system works with universal filtering capabilities, such as compensating the input currents and output voltages. Two three-phase pulse width modulation (PWM) converters, called series and parallel active filters, are used to perform the series and parallel active power-line compensation. The series active power filter works as sinusoidal current source in phase with the input voltage, drawing from utility sinusoidal and balanced input currents with low total harmonic distortion (THD). The parallel active power filter works as sinusoidal voltage source in phase with the input voltage, providing regulated and sinusoidal output voltages with low THD. Operation of a three-phase phase-locked loop (PLL) structure, used in the proposed line-interactive UPS implementation, is presented and experimentally verified under distorted utility conditions. The performance of the UPS system is evaluated in three-phase, four-wire systems. Digital simulations and experimental results are presented to confirm the theoretical studies.

Keywords: Active power filters; Harmonics; Uninterruptible power supply system; Power factor correction; Synchronous reference frame controller

1. Introduction

The large use of non-linear loads, such as, personal computers, UPS, etc., has increased in the last years, causing problems to the power supply systems. The harmonic currents drawn by non-linear loads from utility have contributed to reduce the power factor and to increase the total harmonic distortion (THD) in the utility input voltages. The problem increases when single-phase non-linear loads are connected in three-phase, four-wire systems. In this case, as the phase currents are not sinusoidal, even perfectly balanced single-phase loads can result in significant neutral currents and its amplitude can exceed the amplitude of the line currents [1]. If the non-linear loads are unbalanced, the input currents will be unbalanced in terms of fundamental and harmonic components, and a very large third component and its multiples will flow in the neutral wire. The excessive neutral currents can cause damage both in the neutral conductor and in the transformer to which it is connected [2]. Thereby, active filter topologies have been used to compensate neutral harmonic currents [2–4].

Uninterruptible power supply (UPS) systems have enabled the improvement of power source quality, providing clean and uninterruptible power to critical loads such as industrial process controls, computers, medical equipment, data communication systems, and protection against power supply disturbances or interruptions [5–10]. In Refs. [9,10] a three-phase parallel processing UPS has been presented with harmonic and reactive power compensation, but the output voltages and the input currents cannot be controlled simultaneously. Three-phase UPS systems with series-parallel active power-line conditioning have been proposed using different control strategies [5–6]. In Ref. [6] the three-phase UPS system was employed for three-wire systems, and in Ref. [5], albeit it can be employed for three-wire and four-wire systems, the UPS was used to feed a non-linear load composed by a three-phase non-controlled rectifier, in which neutral currents do not exist.

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This paper presents a three-phase line-interactive UPS system with active series-parallel power-line conditioning capabilities using an SRF-based controller, for three-wire and four-wire systems in which three single-phase loads are fed. In UPS standby operation mode, the series active power filter acts as a sinusoidal current source and the parallel active power filter acts as a sinusoidal voltage source [6]. The output voltages are controlled to have constant rms values and low THD and the source currents are controlled to be sinusoidal and balanced with low THD. Both input currents and output voltages are simultaneously controlled to be in phase with respect the input voltages. Therefore, an effective power factor correction is carried out.

Operation of a three-phase phase-locked loop (PLL) structure, used in the line-interactive UPS implementation, is presented and experimentally tested under distorted utility conditions. A PLL model is shown and design procedures to achieve the PI controller gains are presented. The control algorithm using SRF method and the active power flow through the UPS system are described and analytically studied. Design procedures, digital simulations and experimental results for a prototype are presented in order to verify the good performance of the proposed three-phase line-interactive UPS system.

2. Description of the line-interactive UPS topology

The topology of the line-interactive UPS system is shown in Fig. 1. Two pulse width modulation (PWM) converters, coupled to a common dc-bus, are used to perform the series active filter and the parallel active filter functions. Capacitors and a battery bank are placed in the dc-bus and a static switch 'sw' is used to provide the disconnection between the UPS system and the power supply when an occasional interruption of the incoming power occurs. The center-tap of the dc-bus is connected to the utility neutral.

A control algorithm using synchronous reference frame (SRF) based controllers is used to control the series PWM converter to make the active filter to compensate the currents of a non-linear load, such that balanced, sinusoidal currents (i_{sa}, i_{sb}, i_{sc}) are drawn from the power source. The parallel active filter acts as sinusoidal voltage sources, such that balanced and sinusoidal voltages are provided to the load. The output UPS voltages v_{fa}, v_{fb} and v_{fc} are controlled to be in phase with respect to the input voltages v_{sa}, v_{sb} and v_{sc}, respectively. Both the parallel and the series filter use three independent controllers acting on half-bridge inverters.

3. Synchronous reference frame and state feedback controllers

3.1. Current SRF-based controller (standby mode)

An SRF-based controller is used to provide and to control the compensating reference currents (i^*_{ca}, i^*_{cb}, and i^*_{cc}) for the series PWM converter shown in Fig. 1. The block diagram of the control scheme for current compensation is shown in Fig. 2. The three-phase load currents (i_{La}, i_{Lb}, i_{Lc}) are measured and transformed into a two-phase stationary reference frame $(dq)^s$ quantities (id^s, iq^s) based on the transformation (1). Then, these quantities are transformed from a two-phase stationary reference frame $(dq)^s$ into a two-phase synchronous rotating $(dq)^e$ reference frame, based on the transformation (2), where $\theta = \omega t$, is the angular position of the reference frame. The components of the unit vectors, sin θ and cos θ, are obtained from PLL system that will be discussed in Section 3.2. The currents at the fundamental frequency ω (id^e and iq^e) are now dc values and all the harmonics, transformed into non-dc quantities, can be filtered using a low pass filter (LPF) as shown in Fig. 2. Now, id^e_{dc} represents the fundamental active component of the load current and iq^e_{dc} represents

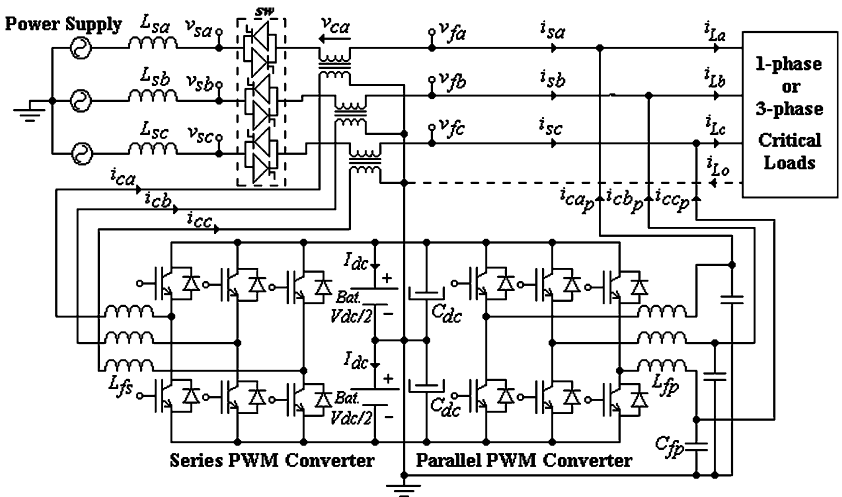

Fig. 1. Line-interactive UPS system toplogy.