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Original article

A DSP-based implementation of an instantaneous current control for a three-phase shunt hybrid power filter

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Abstract

This paper presents the design and implementation of an instantaneous current control technique for a three-phase shunt hybrid power filter (SHPF) to compensate harmonics generated by non-linear loads. The control of the SHPF is based on synchronous reference frame (SFR) method. The SHPF consists of a small-rated voltage source inverter (VSI) in series with an LC passive filter. The proposed control algorithm of the SHPF requires less number of current sensors compared to the instantaneous reactive power theory based current control algorithm, which resulting in an overall cost reduction. Proportional–Integral (PI) controller is used to control the SHPF dc-bus voltage. The inner loops ensure the shaping of the ac currents, through the control of dq current components. The outer loop regulates the dc-bus voltage to its set reference and provides the current reference to the inner current loops. The SHPF can maintain the low level of dc-bus voltage at a stable value below 50 V, which is one of its advantages in comparison to the conventional hybrid power filter. The systems performance, during both nominal and severe operating conditions, are then evaluated in real-time using the dSPACE DS1104 controller board, supported by a Matlab/Simulink Real-Time Workshop environment.

Keywords: Hybrid power filter; Nonlinear load; Real-time control; Harmonics; Power quality

1. Introduction

Nonlinear loads inject wide spread current harmonics into the power grid even if the supply is harmonic free sinusoidal voltages. The circulation of current harmonics through the grid impedance involves the appearance of voltage harmonics at the point of common coupling of different loads. These voltage harmonics propagate over grid, are sensed by all connected equipments, consequently it disrupt sensitive equipment and controllers [21]. Conventionally,

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passive filters (PFs) are used to eliminate harmonic currents and compensate reactive power. However, these PFs have some drawbacks such as bulky and heavy devices, series and parallel resonance with source and load impedances, etc. [4]. Active power filters have been developed to mitigate the problems of passive filters [1,3,9,15]. But the initial and operational costs of these filters are too high and are not suitable on high- or medium-voltage situations [2,7,14,19]. Combining the advantages of both passive and active filters, hybrid filter topologies are appealing [5,12,13]. Hence, various kinds of topologies of hybrid filter with different complex control techniques have been suggested for compensation of load harmonics [20,22]. These structures enable the design of small rated active filter with respect to the use of parallel/series active filter separately. Harmonic extraction techniques used for detecting current and voltage harmonic components and sub-harmonics are mostly based Direct or Indirect control method based on instantaneous reactive power theory [6,16]. Also synchronous rotating reference frame, adaptive notch filters, flux based controller, sliding Mode Control, power balance theory, and nonlinear controller have been used to improve performance of the active power filters [8,10,11,17,18]. However, most of these control techniques include a number of transformations and are difficult to implement.

In this paper, an instantaneous current control scheme is used, in order to ensure ac current shaping and dc voltage regulation for a three-phase shunt hybrid power filter. The control scheme of the SHPF is based on synchronous reference frame and is simpler and easier to implement. The SHPF can maintain the low level of dc-bus voltage at a stable value below 50 V. The lower dc bus voltage is one of the advantages of the SHPF in comparison to the conventional hybrid power filter. Moreover, a Proportional–Integral (PI) controller is used to control the SHPF dc-bus voltage. Two loops have been implemented, the inner loop ensure the shaping of the ac currents, through the control of dq current components. The outer loop regulates the dc-bus voltage to its set reference and provides the current reference to the inner current loops. The control method is experimentally verified on a 2.5 kVA prototype of the SHPF, using the DS1104 controller board of dSPACE and real-time workshop of Matlab. The systems performance is evaluated in terms of source current Total Harmonic Distortion (THD), dc-bus voltage regulation and robustness toward any type of nonlinear load under distorted source conditions. Experimental results during static and dynamic operations validate the theoretical and simulated proposed method. The total harmonic distortion of the supply current gets less than 5%.

2. Three-phase shunt hybrid filter topology

Fig. 1 shows the shunt hybrid power filter configuration connected to the power system feeding the nonlinear loads. The SHPF consists of three phase voltage source inverter connected in series with a 5th-tuned passive filter. Different nonlinear loads (diode bridge rectifiers with R-L load or R-C load are considered) are connected to the point of common coupling which represent the possible industrial loads to be compensated.

3. Current control technique of shunt hybrid filter

To determine the set of the instantaneous active current of the load, the synchronous reference frame method is used. The measurement and/or calculation of the harmonics are not required, making the proposed control scheme very simple and easier to implement. The Phase Locked Loop (PLL) allows synchronizing the frequency of synchronous reference frame with that of the grid. In the current control technique, the switching signals for SHPF devices are obtained by comparison of reference (i^*_{s1}, i^*_{s2} and i^*_{s3}) and sensed (i_{s1}, i_{s2} and i_{s3}) supply currents. The determination of the active component (d-component) i_d is done with the help of the so-called dq-transformation. The sensed three-phase load currents i_{L1}, i_{L2} and i_{L3} in the stationary reference frame are transformed into the rotating reference frame dq by using the following transformation:

$$i_d = \frac{2}{3}\left[\cos\,\theta \quad \cos\left(\theta - \frac{2\pi}{3}\right) \quad \cos\left(\theta + \frac{2\pi}{3}\right)\right] \cdot \begin{pmatrix} i_{L1} \\ i_{L2} \\ i_{L3} \end{pmatrix} \tag{1}$$