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An adaptive hysteresis band current controller for shunt active power filter

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Abstract

In this paper, an adaptive hysteresis band current controller is proposed for active power filter to eliminate harmonics and to compensate the reactive power of three-phase rectifier. The adaptive hysteresis band current controller, proposed by Bose [An adaptive hysteresis band current control technique of a voltage feed PWM inverter for machine drive system, IEEE Trans. Ind. Electron. 37 (5) (1990) 402–406] for electrical machine drives, is adapted to active power filter (APF). The adaptive hysteresis band current controller changes the hysteresis bandwidth according to modulation frequency, supply voltage, dc capacitor voltage and slope of the i_c^* reference compensator current wave. The hysteresis band current controller determines the switching signals of the APF, and the algorithm based on an extension of synchronous reference frame theory (d-q-0) is used to determine the suitable current reference signals. The results of simulation study of new APF control technique presented in this paper is found quite satisfactory to eliminate harmonics and reactive power components from utility current. All of the studies have been carried out through detail digital dynamic simulation using the MATLAB Simulink Power System Toolbox. The APF is found effective to meet IEEE 519 standard recommendations on harmonics levels.

Keywords: Hysteresis band current controller; Shunt active power filter; Harmonic current compensation

1. Introduction

Recent wide spread of power electronic equipment has caused an increase of the harmonic disturbances in the power systems. The nonlinear loads draw harmonic and reactive power components of current from ac mains. Current harmonics generated by nonlinear loads such as adjustable speed drives, static power supplies and UPS. The harmonics causes problems in power systems and in consumer products such as equipment overheating, capacitor blowing, motor vibration, excessive neutral currents and low power factor. Conventionally, passive LC filters and capacitors have been used to eliminate line current harmonics and to compensate reactive power by increasing the power factor. But these filters have the disadvantages of large size, resonance and fixed compensation behavior so this conventional solution becomes ineffective.

The concept of using active power filters to mitigate harmonic problems and to compensate reactive power was proposed more than two decades ago [1,2]. Since then, the theories and applications of active power filters have become more popular and have attracted great attention [6–8]. Without the drawbacks of passive harmonic filters, such as component aging and resonant problems, the active power filter appears to be a viable solution for reactive power compensation as well as for eliminating harmonic currents.

There are various current control methods proposed for such active power filter configurations, but in terms of quick current controllability and easy implementation hysteresis band current control method has the highest rate among other current control methods such as sinusoidal PWM. As in most PWM applications the interval between two consecutive switching actions varies constantly within a power frequency cycle. It means that the switching frequency is not constant but varies in time with operation point and conditions. In principle increasing inverter operation frequency helps to get a better compensating waveform. However there

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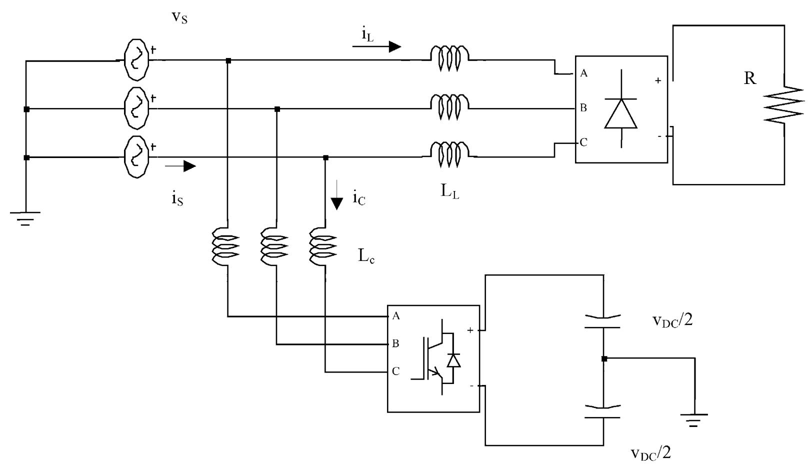

Fig. 1. Basic principle block diagram of a three-phase shunt active power filter.

are device limitations and increasing the switching frequency cause increasing switching losses, audible noise and EMF related problems. The range of frequencies used is based on a compromise between these two different factors. In this paper, the control of switching frequency is realized by introducing an adaptive hysteresis band current control algorithm.

The main aim of this study is to investigate the effects of hysteresis bandwidth to THD of supply current and switching frequency of APF. Adaptive hysteresis band current controller changes the hysteresis bandwidth as a function of reference compensator current variation to optimize switching frequency and THD of supply current. In this paper, the synchronous d-q-0 reference frame theory is first briefly reviewed. Next, the proposed adaptive hysteresis band current control based compensation strategy for the three-phase active power filter is described. Then, simulation results are presented followed by the conclusion.

2. Shunt active power filter

The shunt active power filter (APF) is a device that is connected in parallel to and cancels the reactive and harmonic currents from a nonlinear load. The resulting total current drawn from the ac main is sinusoidal. Ideally, the APF needs to generate just enough reactive and harmonic current to compensate the nonlinear loads in the line.

In an APF depicted in Fig. 1, a current controlled voltage source inverter is used to generate the compensating current (i_c) and is injected into the utility power source grid. This cancels the harmonic components drawn by the nonlinear load and keeps the utility line current (i_s) sinusoidal. A variety of methods are used for instantaneous current harmonics detection in active power filter such as FFT (fast Fourier technique) technique, instantaneous p-q theory, synchronous d-q reference frame theory or by using suitable analog or digital electronic filters separating successive harmonic components. In this paper, the synchronous d-q-0 reference frame theory based algorithm is proposed.

3. Synchronous d-q-0 reference frame based compensation

The three phase load currents shown in Fig. 2, have already been transformed to the synchronous reference frame (a-b-c to d-q-0 transformation). A high pass filter is used to extract the dc component representing the fundamental frequency of the currents. The coordinate transformation from three-phase load currents (i_{La}, i_{Lb}, i_{Lc}) to the synchronous reference frame based load currents (i_{Ld}, i_{Lq}, i_{L0}) is obtained as follows:

$$\begin{bmatrix} i_{Ld} \\ i_{Lq} \\ i_{L0} \end{bmatrix} = \sqrt{\frac{2}{3}} \begin{bmatrix} \cos(\omega t) & \cos(\omega t - (2\pi/3)) & \cos(\omega t + (2\pi/3)) \\ -\sin(\omega t) & -\sin(\omega t - (2\pi/3)) & -\sin(\omega t + (2\pi/3)) \\ 1/\sqrt{2} & 1/\sqrt{2} & 1/\sqrt{2} \end{bmatrix} \cdot \times \begin{bmatrix} i_{La} \\ i_{Lb} \\ i_{Lc} \end{bmatrix} \quad (1)$$

The high pass filter to remove the dc component of load current should only be applied to the i_{Ld} current. Q axis current (i_{Lq}) is applied to inverse transformation to compensate reactive power. Zero axis current (i_{L0}) must be used when the voltages are distorted or unbalanced and sinusoidal current are desired. In this study, it is not investigated. The dc side voltage of APF should be controlled and kept at a constant value to maintain the normal operation of the inverter. Because there is energy loss due to conduction and switching power losses associated with the diodes and IGBTs of the inverter in APF, which tend to reduce the value of V_{dc} across capacitor C_{dc}. A feedback voltage control circuit needs to be incorporated into the inverter for this reason. The difference between the reference value, V_{ref} and the feedback value (V_{dc}), an error function first passes a PI regulator and the output of the PI regulator is subtracted from the d axis value of