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PI and fuzzy logic controllers for shunt active power filter — A report

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ABSTRACT

This paper presents a shunt Active Power Filter (APF) for power quality improvements in terms of harmonics and reactive power compensation in the distribution network. The compensation process is based only on source current extraction that reduces the number of sensors as well as its complexity. A Proportional Integral (PI) or Fuzzy Logic Controller (FLC) is used to extract the required reference current from the distorted line-current, and this controls the DC-side capacitor voltage of the inverter. The shunt APF is implemented with PWM-current controlled Voltage Source Inverter (VSI) and the switching patterns are generated through a novel Adaptive-Fuzzy Hysteresis Current Controller (A-F-HCC). The proposed adaptive-fuzzy-HCC is compared with fixed-HCC and adaptive-HCC techniques and the superior features of this novel approach are established. The FLC based shunt APF system is validated through extensive simulation for diode-rectifier/R–L loads.

1. Introduction

Recently a lot of research is being encouraged for power quality and custom power problems in the distribution system due to non-linear loads [1,2]. In practical application most of the loads are non-linear, such as power converters, SMPS, arc furnaces, UPS and ASDs [3]. These non-linear loads are introducing harmonic distortion and reactive power problems [4]. The harmonics in the system induce several undesirable issues, such as increased heating losses in transformers, low power factor, torque pulsation in motors, poor utilization of distribution plant and also affects other loads connected at the same Point of Common Coupling (PCC) [5,6]. In recent times Active Power Filters (APFs) or Active Power-Line Conditioners (APLCs) are developed for compensating the harmonics and reactive power simultaneously [7,8]. The APF topology can be connected in series or shunt and combinations of both (unified power quality conditioners) as well as hybrid configurations [9,10]. The shunt active filter is most popular than the series active filter, because most of the industrial applications required the current harmonics compensation [11,12].

The controller is the most significant part of the active power filter and currently various control strategies are proposed by many researchers [13–15]. There are two major parts of the controller, one is reference current extraction from the distorted line-current and another is the PWM-current controller to generate switching patterns for inverter [16,17]. Many control strategies are proposed in the literature to extract the harmonic components. However, the conventional PI controller requires precise linear mathematical model of the system, which is difficult to obtain under parameter variations and non-linear load disturbances. Another drawback of the system is that the proportional and integral gains are chosen heuristically [18,19]. Recently, Fuzzy Logic Controllers (FLCs) have been used in various power electronic applications and also in active power filters [20,21]. The advantage of FLCs over the conventional controllers is that it does not need an accurate mathematical model. It can handle nonlinearity and is more robust than conventional PI or PID controllers [22,23].

Similarly, various current control techniques are proposed for APF inner current control loop, such as triangular current controller, sinusoidal-PWM, periodical-sampling controller and hysteresis current controller [24,25]. The Hysteresis Current Controller (HCC) method attracts researchers' attention due to unconditional stability and simple implementation [26]. However, this control scheme exhibits several unsatisfactory features such as uneven switching frequency where the switching frequency varies within a particular band limit [27]. Adaptive-HCC (A-HCC) overcomes these fixed-HCC demerits. The adaptive-HCC changes the bandwidth according to instantaneous compensation current variation [28–31]. However, the adaptive-HCC is having more switching losses due to high frequency switching. These problems can be overcome by the proposed Adaptive-Fuzzy-HCC (A-F-HCC) in this paper. We focus on an adaptive-fuzzy-hysteresis current

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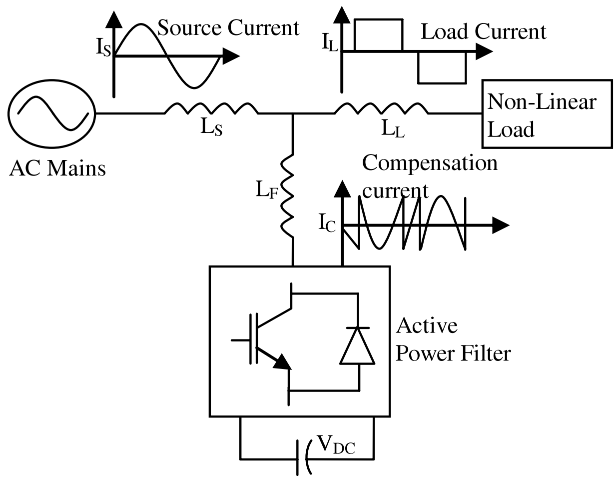

Fig. 1. Shunt active power filter system.

control scheme, where the hysteresis-bandwidth is calculated with the help of fuzzy logic [32–34]. This controller maintains the modulation frequency constant that facilitates reduction of switching loss. Furthermore, uneven switching does not occur that facilitates reduction in the high frequency ripples in the compensating current as well as load current. Therefore this control strategy for inner current loop improves the PWM–VSI performance and makes APF substantially.

This paper presents a shunt APF that uses PI or fuzzy logic controller for reference current extraction. The active filter is implemented with VSI and switching patterns are generated from the proposed novel adaptive-fuzzy-HCC. The shunt APF system is validated through extensive simulation under non-linear load conditions. Comparative assessments of the different PWM-current controller are presented. In Section 2, the design of shunt APF system architecture is presented. Section 3 describes about control strategies for reference current extraction and PWM-current controller proficiencies. Section 4, system performance has been modeled and analyzed from the obtained results under non-linear load conditions. Finally, Section 5 describes the conclusions of this work.

2. Design of shunt APF system

Shunt APF is connected in the distribution-grid at PCC through filter inductance that is shown in Fig. 1. The filter inductance suppresses the harmonics caused by the switching operation of the power inverter. The current harmonic compensation is achieved by injecting equal but opposite current harmonic components at PCC, there by canceling the original distortion and improving the power quality on the connected power distribution system [8].

The instantaneous source current is represented as

$$i_s(t) = i_L(t) - i_c(t). \tag{1}$$

The instantaneous source voltage is

$$v_s(t) = V_m \sin \omega t. \tag{2}$$

The nonlinear load current contains the fundamental component and harmonic current components, which is represented as [20]

$$\begin{aligned} i_L(t) &= \sum_{n=1}^{\infty} I_n \sin(n\omega t + \Phi_n) \\ &= I_1 \sin(\omega t + \Phi_1) + \left(\sum_{n=2}^{\infty} I_n \sin(n\omega t + \Phi_n) \right). \end{aligned} \tag{3}$$

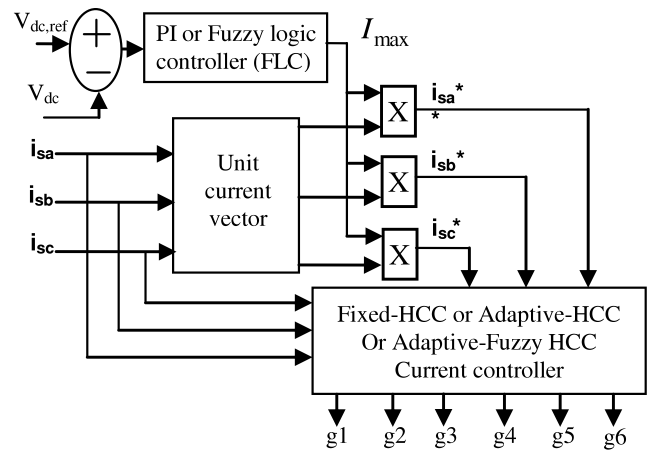

Fig. 2. Block diagram of the control strategy.

The instantaneous load power can be computed from the source voltage and load current and the calculation is given as

$$\begin{aligned} p_L(t) &= i_s(t)^* v_s(t) \\ &= V_m \sin^2 \omega t^* \cos \varphi_1 + V_m I_1 \sin \omega t^* \cos \omega t^* \sin \varphi_1 \\ &\quad + V_m \sin \omega t^* \left(\sum_{n=2}^{\infty} I_n \sin(n\omega t + \Phi_n) \right) \\ &= p_f(t) + p_r(t) + p_h(t). \end{aligned} \tag{4}$$

This load power contains fundamental (active power), reactive power and harmonic power. From this Eq. (4), the real (fundamental) power drawn from the load is

$$p_f(t) = V_m I_1 \sin^2 \omega t^* \cos \varphi_1 = v_s(t)^* i_s(t). \tag{5}$$

If the active power filter provides the total reactive and harmonic power, the source current $i_s(t)$ will be in phase with the utility voltage and sinusoidal. The three-phase source currents after compensation can be expressed as

$$\begin{aligned} i_{sa}^*(t) &= p_f(t)/v_s(t) = I_1 \cos \varphi_1 \sin \omega t \\ &= I_{\max} \sin \omega t. \end{aligned} \tag{6}$$

Similarly,

$$i_{sb}^* = I_{\max} \sin(\omega t - 120°) \tag{7}$$

$$i_{sc}^* = I_{\max} \sin(\omega t + 120°). \tag{8}$$

This peak value of the reference current $I_{\max}$ is estimated by regulating the DC-bus capacitor voltage of the inverter using PI or fuzzy logic controller.

3. Control strategies

The block diagram of the proposed control system is shown in Fig. 2 that consists of two parts. One is reference current extraction controller using unit current vector along with PI or fuzzy logic controller. Another is PWM-current controlled voltage source inverter switching control method using fixed-HCC or adaptive-HCC or adaptive-fuzzy-HCC.

3.1. Reference current extraction controller

The reference current is extracted from distorted line-current using unit current vector with PI or FLC. Conventional PI and PID controllers have been used to estimate the required reference current, and to control the dc-bus capacitor voltage of the inverter [18,19]. When load is non-linear or reactive, it is