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Indirect current controlled shunt active power filter for power quality improvement

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ABSTRACT

The paper deals with an indirect current controlled shunt active power filter (APF) for improving power quality by reactive power compensation and harmonic filtering. The proposed APF is based on a voltage source inverter (VSI). The VSI is controlled by two loops, the voltage control loop and the current control loop. The voltage control loop regulates the DC link capacitor voltage and the current control loop uses hysteresis band control to shape the source current such that it is in-phase with and of the same shape as the input voltage. The major advantage of the proposed APF is that the reference current for power quality improvement is generated from the DC link capacitor voltage. The proposed scheme has been verified through simulation and experimental investigations.

Introduction

There has been a continuous rise of nonlinear loads over the years due to intensive use of power electronic control in industry as well as by domestic consumers of electrical energy. The utility supplying these nonlinear loads has to supply large vars. Moreover, the harmonics generated by the nonlinear loads pollute the utility. The basic requirements for compensation process involve precise and continuous var control with fast dynamic response and on-line elimination of harmonics. To satisfy these criterion, the traditional methods of var compensation using switched capacitor and thyristor controlled inductor [1–6] coupled with passive filters are increasingly replaced by active power filters (APFs) [7–16] and hybrid APFs [17–22]. The hybrid APFs improve the characteristics of passive filters with smaller rated APFs. The majority of the reported APFs and hybrid APFs use a var calculator to calculate the reactive current drawn by the load and accordingly a reference current is generated. The compensator current is made to follow the reference current for the required compensation. This method exhibits good current profile and fast dynamic response; however the generation of reference current is a complicated process. In the proposed indirect current controlled APF, the reference current is generated from the DC link capacitor voltage directly, without calculating the reactive current drawn by the load. As the reference current in the proposed APF is generated from the DC link capacitor voltage, without calculating the reactive current drawn by the load, the compensation process is straight forward and simple as compared to the control techniques of conventional APFs.

For higher rated nonlinear loads; multilevel inverters (MLIs) can be used [23–27]. To control the output voltage and reduce undesired harmonics of MLIs, sinusoidal PWM, selective harmonic elimination or programmed PWM and space vector modulation techniques have been conventionally used in MLIs. The major complexity associated with such methods is to solve the nonlinear transcendental equations characterizing the harmonics using iterative techniques such as Newton–Raphson method [28,29]. However, this is not suitable in cases involving a large number of switching angles if good initial guess is not available. Another approach based on mathematical theory of resultant, wherein transcendental equations that describe the selective harmonic elimination problem are converted into an equivalent set of polynomial equations and then mathematical theory of resultant is utilized to find all possible sets of solutions for the equivalent problem has also been reported [30]. However, as the number of harmonics to be eliminated increases (up to five harmonics), the degrees of the polynomials in the equations become so large that solving them becomes very difficult. The evolutionary algorithm [31–35] can be applied for computing the optimal switching angles of the MLI with the objective of optimizing the individual harmonics to allowable limits.

The proposed indirect current controlled shunt APF is shown in Fig. 1. It has two control loops, the voltage control loop and the current control loop. The voltage control loop regulates the average

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Nomenclature

V_c	DC link capacitor voltage	i_{comp}	compensation current of the APF
$V_{c,min}$	minimum DC link capacitor voltage	i_{load}	load current
$V_{c,ref}$	reference DC voltage	i_s	source current
V_s	AC system voltage	i_{ref}	reference current
v_{comp}	compensating voltage	s	switching function
V_{comp1}	fundamental component in v_{comp}	ω	supply frequency
Q	var supplied by the APF	ω_s	switching frequency
L	inductor in series with the APF	$\omega_{s,max}$	maximum switching frequency
R	resistance of inductor L	HB	hysteresis band
C	DC link capacitor		

value of the DC link capacitor voltage (V_c). The sensed DC link capacitor voltage is sent to a low pass filter (LPF) to remove the ripples present in it. The voltage thus obtained is compared with a reference DC voltage ($V_{c,ref}$) and the error is fed to a PI controller. The output of the PI controller is the amplitude (k) of the current, which is used to derive the reference current. The derived reference current is compared with the source current in the current control loop for generating gate signals for the switches of the voltage source inverter (VSI) of the APF. Hysteresis band control [13,36] has been used in the current control loop of the proposed APF.

Indirect current controlled APF

The VSI of a single-phase indirect current controlled shunt APF is shown in Fig. 2. The VSI is controlled to produce a fundamental terminal voltage in-phase with the AC system voltage. When the fundamental inverter terminal voltage is more than the RMS value of AC system voltage V_s, a leading current is drawn from the AC system and when the inverter terminal voltage is less than V_s, a lagging current is drawn from the AC system. The magnitude of the inverter terminal voltage depends on the DC link capacitor voltage V_c. By controlling the gate signals of the switches, the inverter terminal voltage can be made to lag or lead the AC system voltage, so that real power flows into or out of the inverter circuit. By suitable operation of the switches, a voltage v_{comp} having a fundamental component V_{comp1} is generated at the output of the inverter. When $V_{comp1} > V_s$, leading current (with respect to V_s) will be drawn and the inverter supplies lagging vars to the system. When $V_{comp1} < V_s$, the inverter draws lagging current and it supplies leading vars to the system. When $V_{comp1} = V_s$, no current will flow into or out of the system. The var supplied by the APF is given by

$$Q = \frac{V_s|V_{comp1} - V_s|}{\sqrt{\omega^2 L^2 + R^2}} \quad (1)$$

where L is the inductor in series with the APF, R is the resistance of inductor L and ω is the supply frequency. By controlling V_{comp1}, the reactive power can be controlled.

Control principle

The switches S_1, S_2, S_3 and S_4 (Fig. 2) are operated in such a way that total current drawn from the source is of the same shape as that of the source voltage V_s. The source voltage V_s can be expressed as $V_s = L\frac{di_{comp}}{dt} + R\ i_{comp} + sV_c$. This gives

$$\frac{di_{comp}}{dt} = \frac{V_s - R\ i_{comp} - sV_c}{L} \quad (2)$$

where i_{comp} is the compensation current of the APF and V_c is the DC link capacitor voltage. $s = 1$, if the switches S_1 and S_4 conduct; $s = -1$, if the switches S_2 and S_3 conduct and $s = 0$, if the switches S_1, S_3 or S_2, S_4 conduct.

The DC link capacitor voltage V_c can be expressed as $C\frac{dV_c}{dt} = si_{comp}$. This gives

$$\frac{dV_c}{dt} = \frac{si_{comp}}{C} \quad (3)$$

where C is the DC link capacitor.

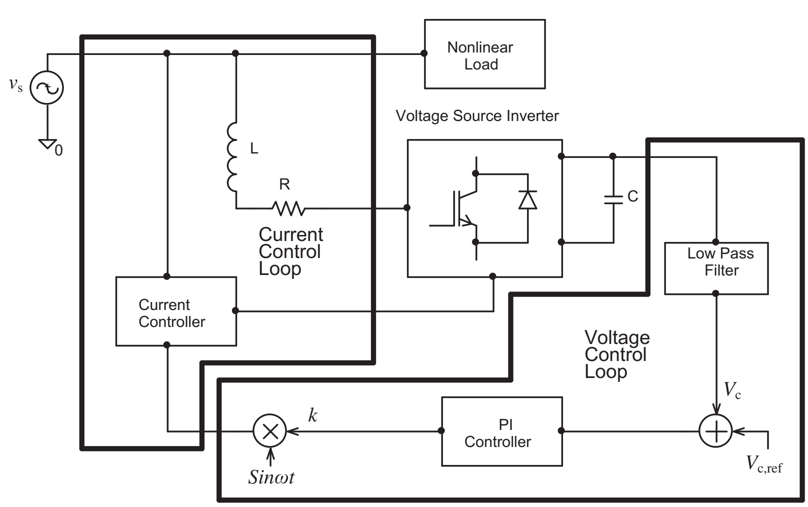

Fig. 1. Indirect current controlled shunt APF.