Electrical Power and Energy Systems 51 (2013) 298–306

Contents lists available at SciVerse ScienceDirect

Electrical Power and Energy Systems

journal homepage: www.elsevier.com/locate/ijepes

Three-level H-bridge and three H-bridges-based three-phase four-wire shunt active power filter topologies for high voltage applications

Sushree Sangita Patnaik *, Anup Kumar Panda

Department of Electrical Engineering, National Institute of Technology, Rourkela, India

ARTICLE INFO

Article history:
Received 28 January 2013
Accepted 27 February 2013
Available online 9 April 2013

Keywords:
Active power filter
Current harmonics
$i_d - i_q$ scheme
Multilevel inverter
Real-time analysis

ABSTRACT

In a three-phase four-wire distribution system, presence of current harmonics, unbalanced loading, reactive power and excessive neutral current play the most important role in deciding power quality. Main culprits behind these are the disturbances caused due to non-linear and unbalanced loads. Here a new three-level H-bridge (3L-HB) topology of three-phase four-wire shunt active power filter (APF) has been developed for load compensation. This can be connected to the distribution lines directly, and does not require any bulky and expensive coupling transformers. Furthermore, this topology of shunt APF has been compared with two-level three H-bridges (3HB) based topology. The performances of APFs are investigated with the help of real-time performance analysis in Opal RT-Lab. A comparison has been made between the two configurations showing their topological differences and load compensation capabilities under ideal, distorted and unbalanced supply voltage conditions. Observations are done taking into consideration the unbalanced loading scenario that is when both three-phase and single-phase loads are present in the system.

1. Introduction

Active power filters (APFs) have gained great popularity in solving the power quality issues encountered in power systems. Mostly, APFs use voltage source inverters (VSIs) with capacitor acting as an energy storage device supplying the dc voltage. Pulse width modulation (PWM) is used to generate gating signals for the semiconductor switches inside VSI. The VSI in turn produces required compensation currents to be injected into the point of common coupling (PCC) for compensation of harmonics and reactive power. The shunt APFs are being extensively used on account of their ability to compensate for current harmonics, unbalance and reactive power simultaneously [1–3].

Conventional two-level VSI configurations used as APFs are split capacitor three-leg and four-leg topologies [4–6]. These configurations are only suitable for low to medium power applications. However, another two-level VSI that is, three single-phase H-bridges (3HB) topology is suitable for high voltage, and medium to high power applications [6]. Three-level inverters are now becoming very popular for power conditioning applications [7–9]. The cascaded H-bridge (HB) multilevel inverter was first introduced for motor drive applications [10]. It has also been used for reactive and harmonic compensation [11]. Further, work has been reported on universal power conditioning of power systems, especially for medium-voltage systems [12,13]. It has several advantages over the conventional two-level inverters as they result in reduction of (i) harmonic content of output voltage, (ii) voltage stresses across the semiconductor switching devices, and (iii) switching power loss due to low switching frequency. It also provides lower costs, higher performance, less electromagnetic interference (EMI), and higher efficiency than two-level VSIs for power line conditioning applications, both series and shunt compensation [14]. The cascaded HB inverter has inherent self-balancing characteristics. A simple control scheme, which ensures dc voltage balance, has been proposed for reactive and harmonic compensation [11].

APF performs the required actions under the command of APF control strategy, which involves VSI dc-link voltage regulation and generation of compensation currents. Inverter dc-link voltage in both the configurations is regulated using proportional–integral (PI) controller, whose gains have been extracted using particle swarm optimization (PSO). An assessment of several control schemes for generation of reference compensation currents establish the instantaneous active and reactive current components ($i_d - i_q$) method to be the most appropriate for use in three-phase systems on account of its proficiency under all kinds of supply voltage [15,16]. Since, any unbalance and/or distortion in supply voltage may result in partial harmonic compensation, which certainly imposes a limitation on other APF control schemes.

In this paper, three-level H-bridge (3L-HB) and 3HB based VSIs have been selected to be used for load compensation in three-phase four-wire power systems and are described clearly in Section 2. Section 3 illustrates the control strategy involved in dc-link

* Corresponding author.
E-mail address: sspatnaik.ee@gmail.com (S.S. Patnaik).

0142-0615/$ - see front matter © 2013 Elsevier Ltd. All rights reserved.
http://dx.doi.org/10.1016/j.ijepes.2013.02.037

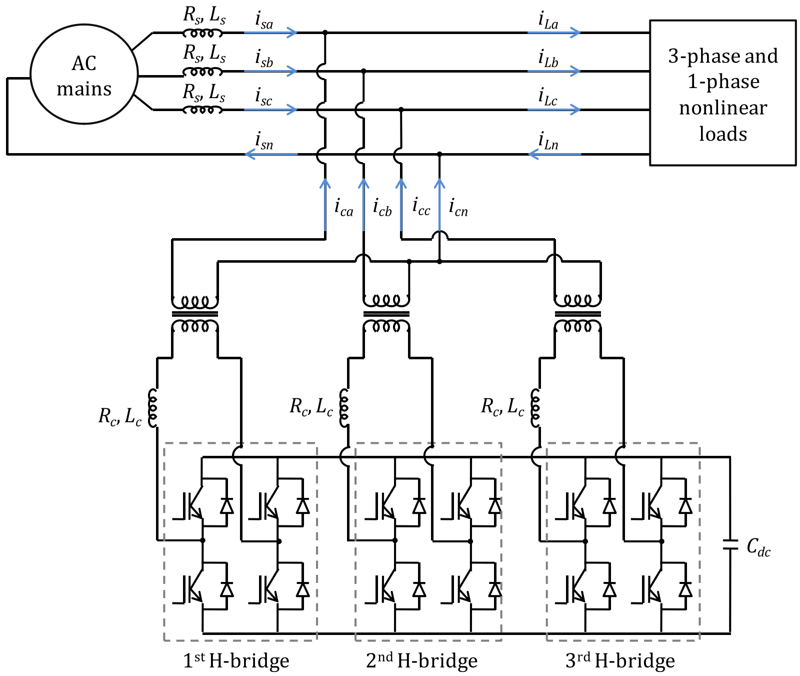

Fig. 1. System configuration of three single-phase H-bridges (3HB) based shunt APF.

voltage regulation and generation of reference compensation currents using $i_d - i_q$ scheme, followed by production of gate pulses for the IGBTs constituting VSI. A critical comparison of APF performance with 3HB and 3L-HB VSIs has been done in the next section. Adequate real-time results have been presented to find out the effectiveness of the two topologies in load compensation under ideal, distorted and unbalanced supply voltages with unbalanced loading condition. Finally the conclusion is summarized in last section.

2. Configurations of shunt APF

Though both voltage-source and current-source inverter (CSI) configurations of APF can be employed in three-phase power systems, VSI-type is the most preferred and widely used. In three-phase four-wire systems, the popular shunt APF topologies being used for low to medium power applications are three-leg split capacitor and four-leg VSI-based topologies. However, these two-level VSI configurations of shunt APF are inappropriate for high voltage, medium to high power applications. In view of that, this concept has been extended to multilevel inverters. Alternately, another two-level VSI i.e. the 3HB configuration is suitable for high voltage, medium to high power systems. In this paper, the two-level 3HB and three-level 3L-HB shunt APF configurations have been discussed thoroughly.

2.1. 3HB configuration

Fig. 1 depicts the system configuration of 3HB APF along with the three-phase and single-phase non-linear harmonic producing loads. In 3HB configuration of shunt APF, three single-phase H-bridges are connected to a single dc-link capacitor (C_{dc}). The generated compensation currents are injected into the ac lines at PCC via coupling transformers and series impedance (R_c,L_c). The source impedance is represented by (R_s,L_s).

Since the 3HB VSI is comprised of twelve number of semiconductor devices compared to six switches in case of conventional two-level VSIs, it suffers from heavy switching power loss. This accounts for a significant amount of the total power loss in the APF system. This can be minimized by maintaining the dc-link voltage constant, which is described elaborately in the following section.

2.2. 3L-HB configuration

The system configuration of 3L-HB APF topology is presented in Fig. 2. Each dc-link capacitor (C_{dc}) is connected to a single-phase H-bridge inverter. As a result, each H-bridge of the three-level inverter generates a quasi-square wave with three-level outputs, $+V_{dc}$, 0 and $-V_{dc}$. Harmonic content of output voltage in case of three-level VSI is very less compared to two-level VSI. Moreover, modular structure of H-bridges makes the manufacturing process simple, cheap and quick. This VSI can make direct connection with distribution lines without the use of any additional transformers. A series impedence (R_c,L_c) is used for coupling it to the ac system. To control the average voltage of all three dc-link capacitors of 3L-HB APF configuration, only one capacitor voltage needs to be tracked and fed back [12]. Therefore, this lessens the complexity of voltage regulation of all the capacitors, reduces the necessity of voltage sensors and increases the reliability.

3. Control strategy for generation of compensation currents

3.1. Regulation of dc-link voltage

During steady state operation of APF,

$$\textit{Real power supplied by the source} = \textit{Real power demand by loads} + \textit{Small power to compensate the APF losses} \quad (1)$$

But the above equation does not hold good during transient condition, and the real power difference is compensated by charging/discharging of C_{dc}. To achieve quality performance of APF, the dc-link capacitor voltage (V_{dc}) should be maintained constant at a particular reference value (V^*_{dc}). A PI controller has been employed for this purpose. The actual V_{dc} is tracked using voltage sensor and compared with its reference V^*_{dc}, and the error is processed in a PI