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A novel DSTATCOM with 5-level CHB architecture and selective harmonic mitigation algorithm

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ABSTRACT

This paper proposes a five level cascaded converter for Distribution Static Compensator (DSTATCOM) implementing a novel modulation algorithm with harmonic mitigation and a PI controller with phase shift modulation for reactive power control. The modulator operates at fundamental frequency and the whole system satisfies grid code requirements using a simple passive output filter tuned with 11th harmonic. The behavior of the proposed system has been successfully compared with another one with multilevel space vector pulse width modulation. Results show its capability of ensuring satisfactory dynamic response at low frequency operations, resulting improved efficiency and reduced output filter requirements over more conventional systems.

1. Introduction

Distribution Static Compensator (DSTATCOM) is a shunt-compensating device that provides an effective mean for improving power quality (PQ) in a distribution system by active control of the reactive power available in the grid. In fact, the active/reactive power regulations and the subsequent respect of grid codes limits regarding the maximum allowable harmonic levels, can be obtained by control of power flows through DSTATCOM device achieved by implementation of proper feedback control and modulation [1,2]. Typical DSTATCOM consists of a voltage source converter (VSC), output filter and/or transformer. The VSC is the key component of a DSTATCOM whose output voltage/current quality not only defines the filter type and its size to attenuate harmonics but is also responsible for the overall device efficiency. Therefore, a proper selection of DSTATCOM topology, control method and modulation technique are crucial for cost, efficiency and PQ optimization. In [3] different DSTATCOM topologies, state of the art, their performance, design considerations, future developments, and potential applications are investigated for power quality improvement. Paper [4] describes the design, implementation, and performance of a medium-size distribution-type static synchronous compensator with the simplest two-level three-leg voltage source converter topology. Reactive power control is achieved by phase-shift-angle control, and harmonics are eliminated by selective harmonic elimination (SHE) method. Paper [5] uses DSTATCOM for mitigation of current harmonics, load balancing with self supporting dc bus voltage of VSC. It proposes a control algorithm that is implemented in a digital signal processor (DSP) for switching of VSC under nonlinear loads. The controller performance is satisfactory under steady state and dynamic conditions. In [6] the performance of a reduced rating DSTATCOM has been thoroughly investigated for power quality improvement in three-phase, four-wire distribution systems. It uses a hybrid topology that consists of a three-phase, three-wire (3P3W) DSTATCOM, zigzag-delta transformer and a single-phase active power filter (APF). The simulation and experimental results show the efficacy of the hybrid configuration under unbalanced/distorted utility voltage conditions. Paper [7] proposes a new algorithm to generate reference voltage for a DSTATCOM operating in voltage-control mode. It is shown that the proposed

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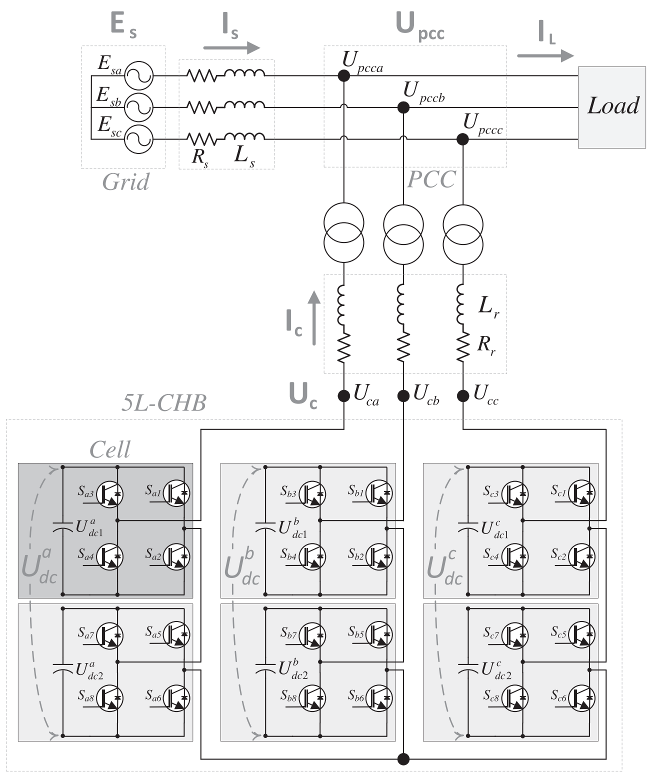

Fig. 1. Three phase diagram of DSTATCOM connected at the PCC.

scheme exhibits several advantages compared to conventional voltage-controlled DSTATCOM.

Multilevel converter is a powerful device originally developed for high voltage high power applications, but recently it is getting interesting also for low voltage applications. It improves the quality of the output voltage, in fact it provides output waveforms closer to sinusoid than two-level systems, ensuring low-level harmonic content to reduce distortion in the grid and maximize power efficiency, moreover allow to increase the voltage and power level up to kVA and MVA. These converters can be divided into three types: cascaded H-bridge (CHB), neutral point clamped (NPC) and flying capacitor (FC), being the CHB superior to the other topologies because of its simple, modular and flexible structure [8,9].

This paper is organized as follows: in Section 2 the operating principle of a five level CHB DSTATCOM topology is explained along with the introduction of proposed control scheme; Section 3 deals with the harmonic mitigation method (HMM) developed for achieving optimum selection of the CHB switching angles. In Section 4 the simulation results are presented in which the proposed system is compared with the one implementing a conventional proportional–integral (PI) current controller with a space vector pulse width modulator (SVPWM). Finally, the conclusions are given in Section 5.

2. DSTATCOM

The DSTATCOM is a shunt-connected voltage-source-converter based static compensator, which is used for voltage regulation and reactive power control. It is connected at the point of common coupling (PCC) injecting controlled amount of current of desired amplitude, frequency and phase into the grid. A DSTATCOM, consisting of a five level CHB inverter is connected to a load at the PCC, as shown in Fig. 1. A low voltage distribution system with a weak grid is considered, however, choosing power devices with different voltage rating, the obtained results can be extended to medium voltage grids.

2.1. Operating principle

A three phase balanced system is assumed; the dc link voltages are $U_{dc}^a = U_{dc}^b = U_{dc}^c = U_{dc}$. Fig. 2a shows the simplified single-phase Y-equivalent circuit model of the shunt connected VSC. The rms line-to-neutral ac grid voltage, referred to DSTATCOM side is denoted by E_s and it is considered with 0° phase angle; U_c is the rms line-to-neutral DSTATCOM fundamental voltage; δ is the phase angle between them; I_s, I_L and I_c represent the rms source, the rms load and the rms DSTATCOM fundamental currents, respectively. The phase angle between $\vec{U}_c$ and $\vec{I}_c$ is denoted by φ. The total series resistance R includes the internal resistance of the coupling transformer and the internal resistance of the input filter reactors and the total series reactance X includes the leakage reactance of the coupling transformer and reactance of input filter reactors. Q_s represents the source reactive power; Q_L the load reactive power and Q_c the DSTATCOM reactive power. As demonstrated in [10], for $R \ll X$, the power flow at the converter side can be written as:

$$P_c \simeq \frac{E_s U_c}{X} \sin(\delta) \tag{1}$$

$$Q_c \simeq \frac{E_s}{X}(E_s - U_c \cos(\delta)) \tag{2}$$

By introducing the modulation index m_1, the following relations are obtained for the considered five level DSTATCOM:

$$U_c = m_1 \frac{8U_{dc}}{\pi} \tag{3}$$

$$P_c = \frac{8m_1 E_s U_{dc}}{\pi X} \sin(\delta) \tag{4}$$

$$Q_c = \frac{E_s}{X}\left(E_s - \frac{8m_1 U_{dc}}{\pi} \cos(\delta)\right) \tag{5}$$

As described in [4] from (5), the reactive power of the DSTATCOM can be varied by either varying m_1, phase angle δ or dc link voltage U_{dc} or all three, depending upon the modulation technique. By assuming m_1 as constant value and varying U_{dc} and δ, the reactive power Q_c is varied, this is the phase shift modulation (PSM) technique. On the other hand, the reactive power Q_c can also be varied by assuming U_{dc} as constant and varying m_1 and δ, as in pulse width modulation (PWM) technique.

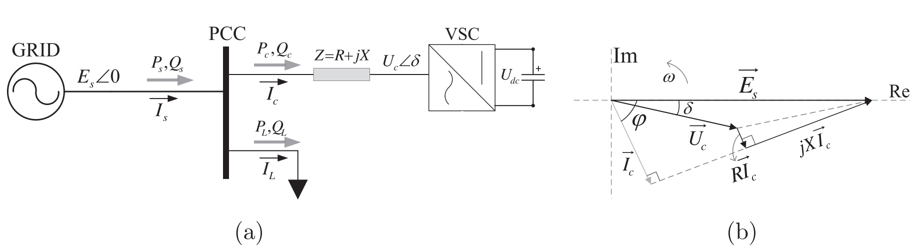

Fig. 2. (a) Single line diagram of shunt connected VSC and (b) phasor diagram lossy system.