Electric Power Systems Research 146 (2017) 341–348

Contents lists available at ScienceDirect

Electric Power Systems Research

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

A transformerless STATCOM based on a hybrid Boost Modular Multilevel Converter with reduced number of switches

Ahmed A. Elserougi [a,b,*], Ahmed M. Massoud [c], Shehab Ahmed [b]

[a] Department of Electrical Engineering, Alexandria University, Alexandria, Egypt
[b] Electrical and Computer Engineering Department, Texas A&M University at Qatar, Doha, Qatar
[c] Department of Electrical Engineering, College of Engineering, Qatar University, Doha, Qatar

ARTICLE INFO

Article history:
Received 30 August 2016
Received in revised form 9 February 2017
Accepted 17 February 2017

Keywords:
Multilevel inverter
STATCOM
VAr compensation

ABSTRACT

This paper proposes a new three-phase transformerless STATic synchronous COMpensator (STATCOM) for shunt reactive power compensation in medium/high-voltage applications. The proposed STATCOM is based on a hybrid Boost Modular Multilevel Converter (hybrid BMMC) with a reduced number of Full-Bridge SubModules (FB-SMs). Operating with almost zero displacement factor at the ac terminals of the converter guarantees sufficient charging and discharging time intervals for the Half-Bridge SMs (HB-SMs) which ensures well-balanced capacitor voltages. Conventionally, each arm in a hybrid BMMC contains FB-SMs and HB-SMs with a ratio of 2:1 respectively. In this work, a new hybrid BMMC with a ratio of 1:2 is employed, which enables operating with a reduced number of FB-SMs with the same boosting capability, therefore, enabling transformerless operation. Nonetheless, the tradeoff is the loss of the dc fault blocking capability compared to the 2:1 configuration. This may be acceptable in STATCOM applications, as the possibility of having a dc side fault in such application is limited, compared to, for instance, MMC in high voltage dc network applications. In this work, detailed illustration of the proposed STATCOM configuration along with its controllers are presented. Finally, simulation case studies are considered to demonstrate the effectiveness of the proposed approach. The simulation results show promising and satisfactory performance.

1. Introduction

The STATic synchronous COMpensator (STATCOM) is an effective device in the family of flexible ac transmission system devices for controlling power flow and improving transient stability of power grids via shunt reactive power compensation [1–3]. Conventionally, a STATCOM is connected to the electrical network through an interfacing/coupling transformer [4–6]. Generally, the STATCOM can be operated in two different modes, namely, voltage regulation/control mode and VAr control mode. In the first mode, the voltage at the Point of Common Coupling (PCC) is regulated/controlled (ac voltage controller). While in VAr control mode, the STATCOM output reactive power is maintained constant at the desired level (reactive power controller). To ensure a successful STATCOM operation, it should be controlled to generate the desired reactive power based on the assigned functionality (ac voltage or VAr controller). Different converter configurations have been presented in the literature for STATCOM applications such as two-level Voltage Source Converters (VSCs) [7], three-level VSCs [8], multilevel cascaded H-bridge VSCs [9], and Modular Multilevel Converters (MMCs) [10,11].

Nowadays, MMCs are recognized in medium/high-voltage applications due to their modularity and scalability [12–15]. Different types of SubModules (SMs) can be employed to implement MMCs. Half-Bridge SMs (HB-SMs) and Full-Bridge SMs (FB-SMs) are the most common types of MMC SMs [16]. HB-SMs are able to generate zero voltage and positive voltage states, while FB-SMs are able to generate zero voltage, positive voltage, and negative voltage states as shown in Fig. 1. The negative voltage state of FB-SMs is not commonly used in the conventional MMC operation.

When HB-SMs (or FB-SMs) are employed in each arm, the converter is called HB (or FB) based-MMC, respectively [16]. Unlike the HB-MMC, an FB-MMC possesses dc fault blocking capability, which is a crucial feature in HVDC transmission applications, especially with the possibility of dc fault occurrence in transmission lines; mainly non-permanent faults [17]. Nevertheless, an FB-MMC has a

* Corresponding author at: Department of Electrical Engineering, Alexandria University, Alexandria, Egypt.
E-mail addresses: ahmed.elserogi@qatar.tamu.edu, ahmed.abbas@spiretronic.com (A.A. Elserougi).

http://dx.doi.org/10.1016/j.epsr.2017.02.014
0378-7796/

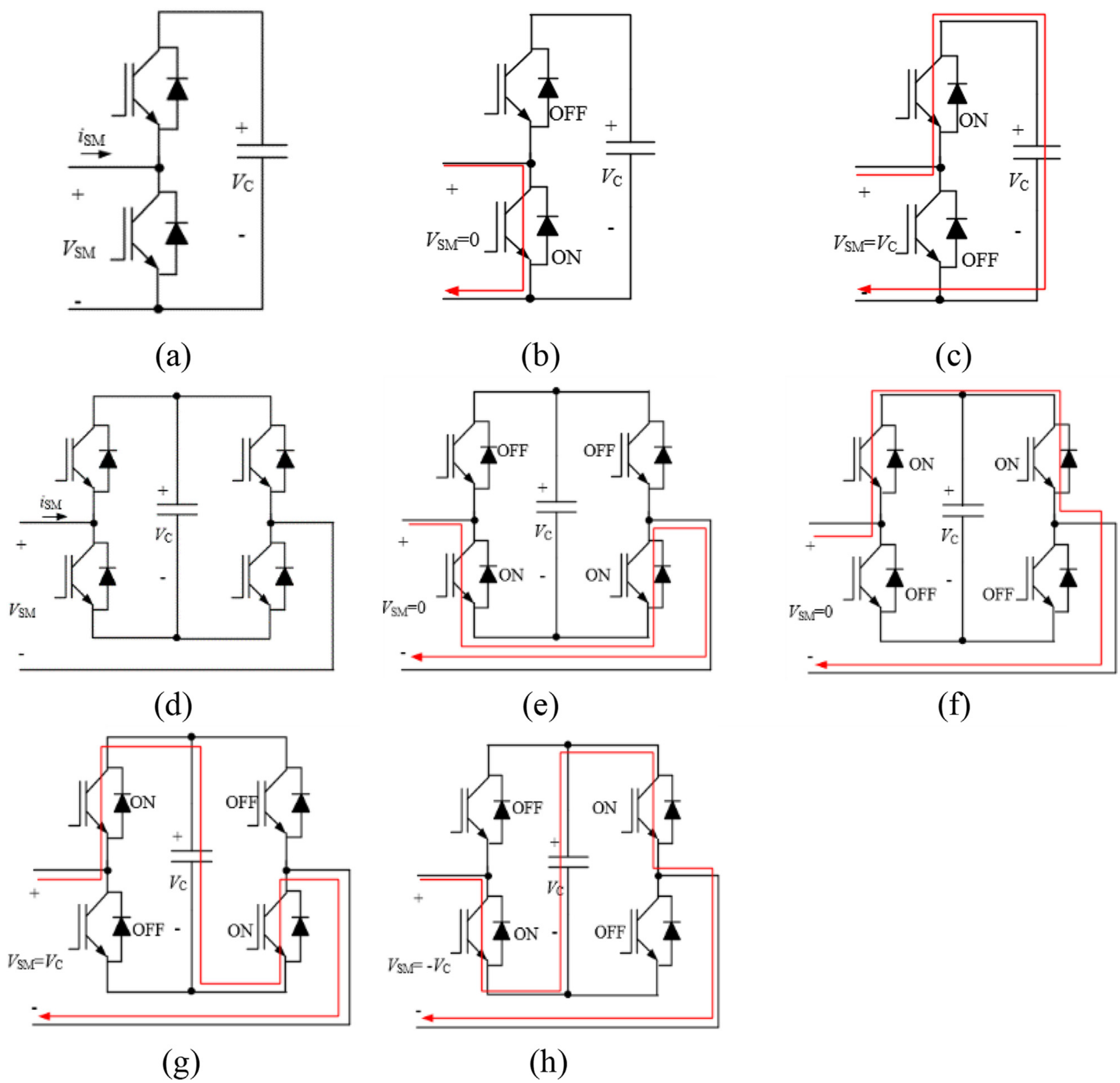

Fig. 1. Operating principles of HB-SMs and FB-SMs, (a) HB-SM construction, (b) HB-SM zero voltage state, (c) HB-SM positive voltage state, (d) FB-SM construction, (e) and (f) FB-SM zero voltage state, (g) FB-SM positive voltage state, and (h) FB-SM negative voltage state.

large number of semiconductor devices and high conduction losses. An MMC is called hybrid MMC when both HB-SMs and FB-SMs are employed in each arm [18,19]. In Ref. [18], half of the SMs is HB-SMs while the other half is FB-SMs, i.e. 1:1 ratio. This type of MMC has no boosting capability, but it provides dc fault blocking capability with a reduced number of FB-SMs, when compared with the FB-MMC, which reduces system complexity and losses.

As mentioned earlier, the negative voltage state in FB-SMs is not commonly utilized in conventional FB-MMC operation, but it can be employed to increase the utilization of the dc-link voltage as in the Boost MMC (BMMC) [20], where by increasing the number of FB-SMs by 50%, the ac output voltage can be increased by 100% compared to conventional control without using the negative voltage state. A BMMC has a boosting capability, as it can generate an ac output voltage with a magnitude up to the dc-link voltage. It has also a dc fault blocking capability, yet with a high number of FB-SMs, which increases system complexity and cost. In Refs. [19,20], a hybrid BMMC has been proposed with FB-SMs:HB-SMs per arm ratio of 2:1 to provide the same performance of the BMMC (the same boosting capability and dc fault blocking capability), but with a reduced number of FB-SMs.

In this work, a 1:2 (FB-SMs:HB-SMs) hybrid BMMC is investigated for STATCOM applications. The main advantages of the proposed 1:2 hybrid BMMC-based STATCOM system are:

- Unlike the conventional types of voltage source multilevel converters, it can generate an ac output voltage with a magnitude up to the dc-link voltage, i.e. it has the same boosting capability as the BMMC, but with a reduced number of FB-SMs.
- Its boosting capability enables transformerless operation which results in dispensing with the low-frequency and bulky transformer, i.e. reducing the weight, losses, and footprint of the STATCOM.