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Research on cascade multilevel inverter with single DC source by using three-phase transformers

Anup Kumar Panda, Yellasiri Suresh *

Department of Electrical Engg., NIT Rourkela, Rourkela 769 008, India

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ABSTRACT

One of the most significant recent advances in power electronics is the multilevel inverter. Using this concept the power conversion is performed with enhanced power quality. In this scenario cascade H-bridge multilevel inverter (CHBMLI) is an exceptional one and it has many inherent benefits like: (1) its modular structure, (2) it can be easily implemented through the series connection of identical H-bridges, (3) generate near sinusoidal voltages with only fundamental frequency switching and finally and (4) no electromagnetic interference or common-mode voltages. This flexibility has resulted CHBMLI topology in various applications like medium-voltage industrial drives, electric vehicles and the grid connection of photovoltaic-cell generation systems. But one of the major limitations of the cascade multilevel converters is requirement of isolated dc voltage sources for each H-bridge, this increases the converter cost and reduces the reliability of the system. This drawback is the key motivation for the present work. The present paper investigates different cascade multilevel inverter (CMI) based topologies with reduced dc sources and finally the proposed CMI with single dc source by employing low frequency transformers is presented. Proposed topology significantly reduces size when compared with conventional topologies and increases the reliability. To verify the performance of proposed architecture, prototype experiments are carried out and adequate results are presented.

1. Introduction

Multilevel converter gives massive advantages compared with conventional and very well known two level converters like; high power quality waveforms, low switching losses, high voltage capability, low electromagnetic compatibility (EMC) etc. [1–3]. Fig. 1 shows the most common multilevel power converters and the classical two level converters. But one of the most significant multilevel topology is cascade H-bridge multilevel-inverter (CHBMLI) [4,5]. CHBMLI has numerous advantages over diode-clamped (DCMC), flying-capacitor (FCMC) and p2 multilevel converters (P2MC) [6,7]. All these converters are compared in terms of feasibility of their utilizations and applications [8].

According to the MIL-HDBK-217F standard, the reliability of a system is indirectly proportional to the number of its components [9], so less the components more the reliability. Compared to *m-level* DCMC, FCMC, and P2MC, which use $m-1$ capacitors on the dc bus, the CMC uses only $(m-1)/2$ capacitors for same *m-level*. Clamping diodes are not required for FCMC, P2MC and CMC [10]. In overall P2MC undeniably require too many components as compared to other multilevel converters, so it is not suitable for higher voltage levels. However comparing CMC with DCMC, FCMC and P2MC, it requires least number of components and its dominant advantage is circuit layout with flexibility. According to recent survey CHBMLI are extensively used in compressors (82%) [11,12], synchronous motors (92%) [13,14], converters (98%) [15–17] and power generation plants (47%) [18]. In addition it is best suited for the power quality devices like, STATCOMs and universal power quality conditioners [19–21,24]. Although this inverter topology is more preferable still there are some aspects that require further development and research. The primary issue that strikes about conventional CHBMLI is that, it uses separate dc source for each H-bridge, this not only yield significant cost but also drastically effects efficiency and reliability of a converter. This issue becomes the core motivation for this paper. In the present paper we have investigated different cascade multilevel inverter (CMI) based topologies, which use reduced number of dc sources and attains high power quality waveforms. Finally our proposed CMI with single DC source is presented. The relative performance is evaluated with prototype experiments.

The rest of the paper is organized as follows. The conventional CMI structures, working principles, their advantages and disadvantages are described in Section 2. Proposed CMI with single dc source using three-phase transformers is introduced in Section 3.

* Corresponding author.
E-mail addresses: akpanda.ee@gmail.com (A.K. Panda), ysuresh.ee@gmail.com (Y. Suresh).

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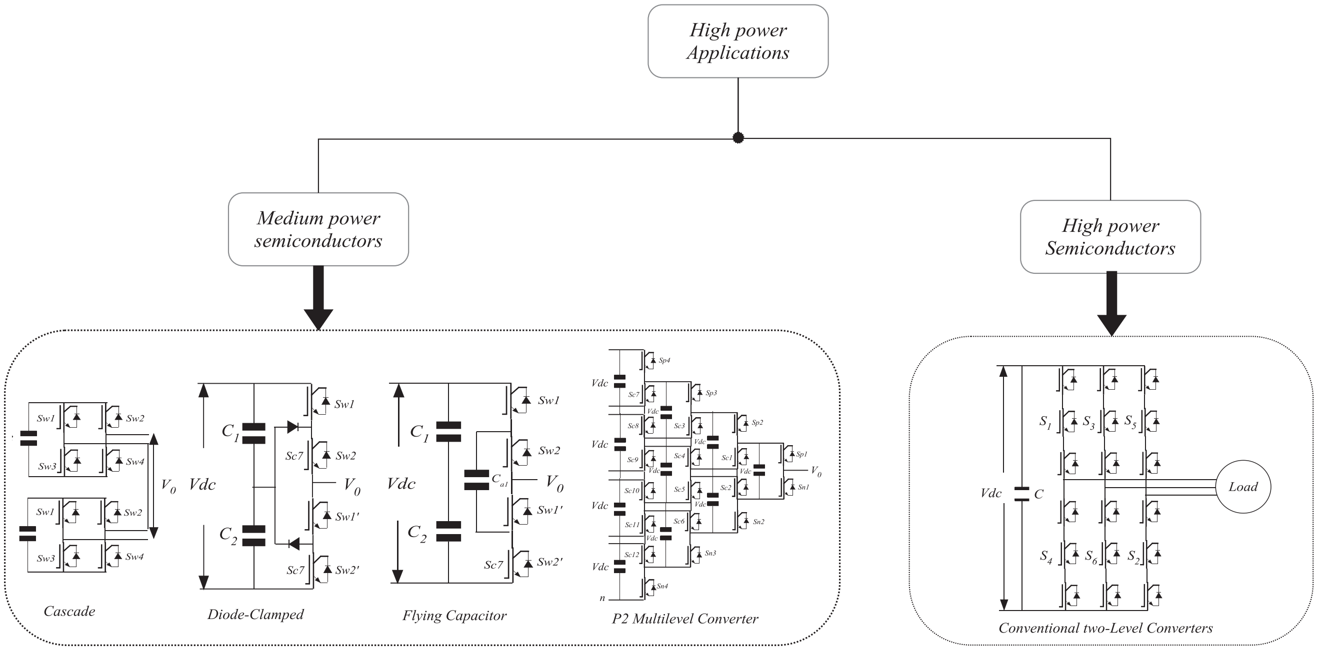

Fig. 1. Classical two level power converters versus most common mutlilvel power converters.

Comparative study between conventional and proposed converter is discussed in Section 4. Finally conclusions and discussion are presented in Section 5.

1.1. Switching techniques

Recurrently three major PWM techniques are applied in multilevel inverters: (1) sinusoidal PWM (SPWM), (2) third harmonic injection PWM (THPWM), and (3) space vector PWM (SVM) [29–31]. Lezana et al. [21] had reported about multicarrier based PWM techniques. To be specific, sinusoidal carrier based PWM approaches are quite good to handle. According to literature survey two major carrier based PWM approaches are available. Namely, phase shifted PWM and level shifted PWM techniques. Fig. 2 demonstrates the carrier based PWM approaches. However an in-depth assessment between PWM methods can be found in [22,23].

In brief, rather than level shifted PWM, phase shifted PWM technique had finite merits like; no rotation in switching, less switching losses and easy to implement. However, in present article all productive topologies are implemented with sinusoidal PWM approach. Next sections provide the details of conventional topologies and their operating principles and finally figure out the merits and demerits.

2. Conventional cascade H-bridge topologies

2.1. Cascade H-bridge with separate dc sources

Architecture shown in Fig. 3a demonstrates three-phase series H-bridge inverter appeared in 1975 [20], but several recent patents have been obtained for this topology as well. Since this topology consist of series power conversion cells, the voltage and power

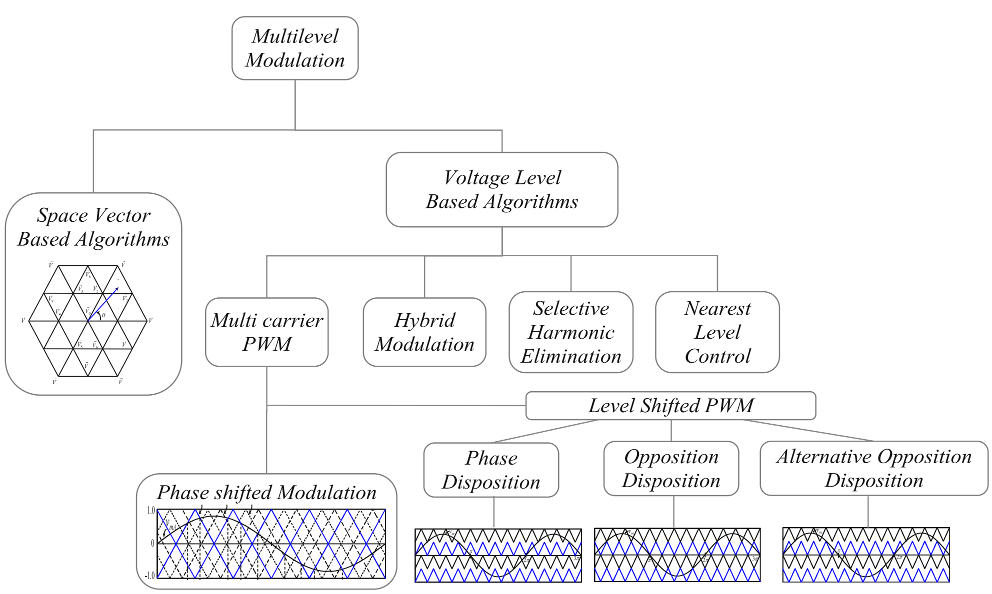

Fig. 2. Details of phase shifted and level shifted PWM techniques (top to bottom).