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Full Length Article

Investigation on stacked cascade multilevel inverter by employing single-phase transformers

Y. Suresh [a,*], Anup Kumar Panda [b]

[a] Department of Electrical and Electronics Engineering, N.I.T. Karnataka, Surathkal India, 575025
[b] Department of Electrical Engineering, N.I.T. Rourkela, India, 769008

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ABSTRACT

In the present paper a new version of multilevel inverter is investigated. This new version is based on hybrid association of commutation cells with H-bridge cells. The association allows a significant reduction of the volume of the capacitors. In fact, presented topology allows us to work on higher input voltage levels with the same power switches. This new version is generally called as SCMI (stacked cascade multilevel inverter). The proposed inverter has potential to generate high quality waveforms, reduction in switching frequency, capable to operate at higher voltage levels and finally utilizes minimum number of switching components. The presented version of SCMI is simulated in Matlab-simulink and further, experimental validation is carried out in the laboratory with prototype setup.

1. Introduction

Multilevel converters gained popularity and increased attention in industry and academia as one of the preferred choices of electronic power conversion for high-power applications [1–3]. They have fruitfully made their way into the industry and thus can be considered a mature and proven technology. Currently, they are commercialized in standard and customized products that power a wide range of applications, such as pumps, fans, compressors, extruders, grinding mills, rolling mills, conveyors, crushers, blast furnace blowers, gas turbine starters, mixers, mine hoists, active and reactive power compensation, marine propulsion, high-voltage direct-current (HVDC) transmission, hydro pumped storage, wind energy conversion, and railway traction, to name a few [4–6]. Converters for these applications are commercially offered by a growing group of companies in the field [7,8]. Although it is a proven technology, still, multilevel converters present a great deal of challenges, and even more importantly, they offer such a wide range of possibilities that their research and development is still growing in depth and width. Researchers and industries all over the world are working hard in contributing to further improve the energy efficiency, simplicity, reliability, power density, and cost effectiveness of multilevel converters, and broaden their application field as they become more attractive and competitive than classic topologies.

In the recent past [9–11], different multilevel inverters came into existence. Some of the prominent multilevel based archetypes are Neutral point clamped (NPC), Flying capacitor (FC) and Cascade H-bridge (CHB) multilevel inverter and P2 multilevel inverter. Fig. 1 shows the classical and major multilevel topologies. Although these classes of inverter topologies are prominent in high power applications, they still have some demerits like usage of many switching components, reliability, and EMI problems. To evade these problems research community is in hunt of new kind of architectures and switching techniques. However, in this scenario, a new version of multilevel architectures is evolved, and this structure is quite versatile when compared with traditional multilevel inverter. The origin of this structure is from SMC (stacked multicell) converters. After major modifications in FC converters, SMC is evolved. However, after finite modification in the SMC and cascade multilevel inverter a new version is introduced, i.e. SCMI (stacked cascade multilevel inverter). This paper is completely devoted to investigate SCMI performance. The key reasons for the investigation on this archetype are as follows: (1) they have the capability to handle high voltage power applications, (2) the architecture is modular (in case of any fault it is easily replaceable), (3) generation of high quality waveform (as storage elements are involved). In fact, all these features make this structure to be a good competitor for other multilevel inverters in the power market.

Aforementioned, SCMI is based on a hybrid association of commutation cells and allows a significant reduction of the volume of the capacitors. Thus SCMI gains an inherent potential to allow us to work on higher input voltage levels with the same power switches. As SCMI uses imbricate cell topology, we obtain a strong

* Corresponding author. Tel.: +91 0824 2473460, fax: +91 0824 2473460.
E-mail address: ysuresh.ee@gmail.com (Y. Suresh).
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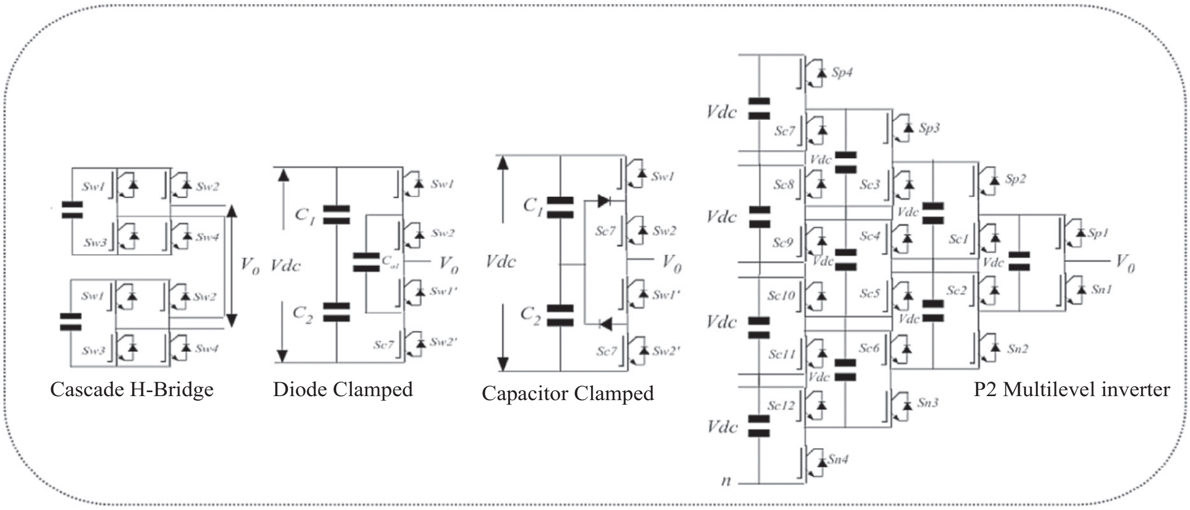

Fig. 1. Details of traditional multilevel inverter.

improvement of the waveforms at the output of the converter. Another remarkable issue is, this new version has the capability to generate higher number of levels with less number of switching components. To confirm the theoretical findings presented, adequate simulations are performed with Matlab-Simulink and further, experimental validation is carried out in the laboratory with Prototype setup.

2. Traditional multilevel inverter

2.1. Cascade multilevel inverter

Architecture shown in Fig. 2 is a series H-bridge inverter that appeared in 1975, but a number of recent patents have been obtained for this topology as well. Since this topology consists of series power conversion cells, the voltage and power level may be easily scaled. Numerous advantages have been figured out using this topology, which are extensively used in medium and high power applications. Examining Fig. 2b, the output phase voltage can be expressed as $v = v_1 + v_2 + v_3$; this is because all the inverters are connected in series. Each single-phase full bridge inverter can generate three level

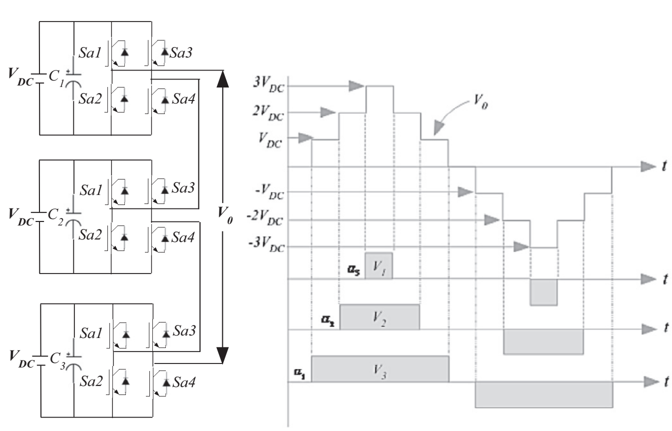

Fig. 2. (a) Cascade H-Bridge multilevel inverter. (b) Key waveform for seven-level inverter.

outputs v_{dc}, 0 and $-v_{dc}$, and this is made possible by connecting the DC sources sequentially to the AC side via the four switching devices. Minimum harmonic distortion can be obtained by controlling the conducting angles at different inverter levels. Further, to improve the quality of the synthesized output waveform several PWMs are also available.

Thus this structure is quite renowned and gained popularity for its functions and features. Some of the attributes of this converter, to name a few, are its being cost-effective, efficient, possible to modularize circuit layout and easy to pack, because each level has the same structure, and there are no extra clamping diodes or voltage balancing capacitors. However, CHB has the greatest disadvantage, i.e. it uses separate DC source for each H-bridge cell. Provision of separate DC source for each H-bridge cell not only increases cost but also affects the reliability of the converter.

2.2. Flying capacitor

Before going to new version, let's have an idea about the flying capacitor and stacked multicell inverter. Fig. 3 shows five-level flying capacitor (FC) architecture. On observing this architecture, large numbers of capacitor are utilized in the structure. The Flying Capacitor topology was introduced by Meynard in 1992 [12] ; this topology is based on the connection of two level cells, as shown in Fig. 4. Due to this reason the maximum number of levels at the output of this converter is:

$$m = n + 1 \tag{1}$$

where m is number of levels and n is the number of cells connected.

For a proper operation, the DC-link voltage on each cell must be accomplished with

$$V_{ci} = \frac{i}{n} * V_{dc} \tag{2}$$

where i represents the number of capacitors and n is the number of cells.

Fortunately, this condition is reached by the inverter itself if the modulation strategy applies the redundancy states in an alternate way. A main advantage of FC over CMI (shown in Fig. 2) converter is that FC does not require a complex input transformer, in case of internal fault.