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Research Article

Parallel inductor multilevel current source inverter with energy-recovery scheme for inductor currents balancing

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Nik Fasdi Nik Ismail[1,2,3] ✉, *Nasrudin Abd. Rahim*[2], *Siti Rohani Sheikh Raihan*[2], *Yusuf Al-Turki*[4]

[1]*Faculty of Electrical Engineering, University Technology Mara (UiTM), Shah Alam, Malaysia*
[2]*UM Power Energy Dedicated Advanced Centre (UMPEDAC), University of Malaya, Level 4, Wisma R&D, Kuala Lumpur, Malaysia*
[3]*Department of Electrical Engineering, Faculty of Engineering, University Malaya (UM), Kuala Lumpur, Malaysia*
[4]*Department of Electrical and Computer Engineering, College of Engineering and Renewable Energy Research Group, King Abdul Azizi University, Jeddah, Saudi Arabia*
✉ *E-mail: nikfasdi@yahoo.com*

Abstract: Current source inverters (CSIs) have increasingly become popular because of their inherent advantages over voltage source inverter. In a single phase system, the operation of multilevel current source inverter (MCSI) requires large and bulky DC link inductor and the employment of switching state redundancy to balance the inductor currents limit the advantages of MCSI. This study proposed a new configuration for parallel MCSI. The proposed energy-recovery scheme provides a major path to release its stored energy in order to balance the sharing inductor currents and introduces a novel single state switching technique for the generation of MCSI output current. In addition, a chopper circuit with smaller inductor size is employed to replace the large and bulky input DC link inductor. An integration of five-level MCSI and a chopper based DC-current source with energy recovery scheme circuits produce a five-level MCSI with a simple converter structure. The performance of the proposed MCSI is analysed through MATLAB and is verified by constructing a prototype. The results demonstrate that the proposed circuit with the balancing inductor current scheme significantly reduces the input DC link inductor size, eliminate the control complexity in balancing the inductor currents and has excellent sharing inductor current characteristics.

1 Introduction

Multilevel inverter has drawn tremendous interest for medium and high voltage application by industry in recent years [1]. Multilevel inverters can be classified into two topologies; namely, multilevel voltage-source inverter (MVSI) and multilevel current-source inverter (MCSI). While the merits of these converters have been investigated, most of the current researches are focused on voltage structures. This is due to the fact that current source topology major drawback is the efficiency degradation [2, 3] and limited dynamic performance due to the use of large DC link inductor size [2, 4]. MVSI can be divided into three categories depending on their topology: diode-clamp (neutral-clamped) [5, 6], capacitor-clamped (flying-capacitor) [7, 8], and cascaded H-bridge with separate DC source [7, 9]. However, MCSI has advantages, where DC inductor has the reliability benefits compared with electrolyte capacitors that are used in MVSIs [10, 11]. Current source inverters (CSI) also offers short-circuit protection capabilities [1, 4], direct input current control [8, 12], a simple AC filtering structure [13], advantages in higher power applications especially power conditioning system for the superconducting magnetic energy storage system [1, 14], and recommended in application when boosting capabilities are required [13, 15, 16]. For these reason, there are more interest in the research works of MCSIs [17–19]. By improving performance and efficiency, MCSIs can be employed for applications that require high power, i.e. low voltage and high current, such as induction motor drives, fuel cell system, electric vehicles and grid connected of renewable energy sources [20–27]. A few MCSI structures have been reported and proposed by researchers [12, 28–32]. However, the requirement of many isolated DC current source added more complexity to the configurations such as the increment number of power switch devices, bulky and costly input DC link inductors.

Generally, traditional MCSIs use large input DC link inductor (100–1000 mH) that leads to a small input DC current ripple. According to Antunes *et al.* [28] and Vázquez *et al.* [30], the DC link inductor must be large to permit a good operation of the MCSIs and a low harmonic distortion at the output. However inductor with big inductance is bulky, large in size and expensive. Moreover, a large inductor also takes longer time to reach steady-state during transient analysis [2] and the inductance has a large leakage resistance which generates more conduction losses and degrades the converter efficiency. MCSI structures also employ current balance inductors or sharing inductors to separate a single current source into multiple current levels, while avoiding the requirement for isolation coupling transformers. Analogous to the voltage balancing issues in MVSIs, the currents in sharing inductors need to be balanced to ensure equal current stress in the inductors and low current harmonic distortion at the output. From the previous reported scheme, this current balancing has been attained by using their fundamental frequency switching [28], and many authors proposed natural current balancing using switching state redundancies [12, 28, 30–33]. However this method has a drawback of increasing the number of power switches and gate drives as the output levels increase and become more complicated when it been implemented for the three-phase system. Control complexity for balancing the intermediate level or sharing inductor currents also a problem of these topologies. As a result, there is a high chance of gating signal misfiring and gate drives malfunction [34, 35]. While several MCSIs have been reported, the parallel inductor MCSI topology as shown in Fig. 1 is particularly attractive [30]. This configuration is different from the previous published schemes and has the advantages of simple structure and fewer number of semiconductor switches. However this configuration uses redundancy balancing technique and the existing of large DC link inductor can reduce the attraction of this topology. In terms of reducing the size of DC link inductor,