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P Satheesh Kumar
Associate Professor, Department of Electrical and Electronics Engineering, Mailam Engineering College, Tamil Nadu, India. India.

Dr. SP Natarajan
Professor & Head (Retd), Department of Instrumentation Engineering, Annamalai University, Tamil Nadu, India.

Dr. Alamelu Nachiappan
Professor & Head, Department of Electrical and Electronics Engineering, Pondicherry Engineering College, Tamil Nadu, India.

Dr. B Shanthi
Professor, Centralized Instrumentation and Service Laboratory, Annamalai University, Tamil Nadu, India.

Correspondence
P Satheesh Kumar
Associate Professor, Department of Electrical and Electronics Engineering, Mailam Engineering College, Tamil Nadu, India.

Analysis of switched inductor Z-source modified cascaded H-Bridge multilevel inverter

P Satheesh Kumar, Dr. SP Natarajan, Dr. Alamelu Nachiappan and Dr. B Shanthi

Abstract
To overcome the restriction of buck operation in VSI and to get extra boosting capability, with same set of switches, a new topology in the family of Z source fed multilevel inverter is developed and presented in this paper. An advanced dc-dc enhancement technique, called switched Inductor is included to develop this new topology. This topology is developed by replacing switched inductor cell instead of normal inductor in Z source modified cascaded multilevel inverter. This set up provide high boost factor compared to existing Z source cascaded H bridge multilevel inverter ZS CHB MLI. High voltage conversion ratio obtained by short shoot through helps in improving the quality of the output power of the main proposed circuit. Enlarged voltage boosting capability, from low ac voltages to higher ac voltages is possible in this topology. It has wide application in ac-ac, dc-dc, dc-ac, ac-dc power conversion.

Keywords: Switched Inductor (SL), Z source, Modified Cascaded Multilevel Inverter, Simple Boost control.

1. Introduction

Recent industrial development demands single power semiconductor switch to medium voltage grids in the range of 4.16KV which is very hard. Emergence of Multilevel inverters is a solution to this issue [1-3]. Multilevel inverter can be operated in both lower and higher switching frequencies. It draws current with low distortion and delivers low distortion output voltages. It generates smaller common mode voltages; thereby stresses in the motor bearings are reduced [4]. Cascade H-bridge has strong advantages when compared with the diode clamped and flying capacitor, for the power conditioning applications [5].

The main drawback of cascaded multilevel inverter is that, two switches of the same leg cannot be switched ON simultaneously, which will leads to short circuit. The another drawback is that it can perform only buck operation. The above limitations are overcome by integrating Z source with CHB multilevel inverter as shown in Figure.1.

By using the shoot -through both buck and boost ability is introduced, thereby narrow output voltage problem of multilevel inverter is also solved. Though the limitations of multi level inverter are surpassed by Z source multilevel inverter, this Z source has certain limitations.

$$\text{Boost factor}, B = \frac{V_{dc}}{V_{in}} = \frac{1}{1 - 2\mathrm{D_{sh}}} \quad (1)$$

$$\text{Duty Ratio}, \mathrm{D_{sh}} = \frac{\mathrm{T_0}}{\mathrm{T}} \quad (2)$$

Where T_o is the shoot-through zero state and T is the switching cycle.

It observed from (1) and (2), the Z source can perform boost operation. The large value of D_{sh} results in low value of Modulation index M is given in (3) and (4).

$$M \leq 1 - D_{sh} \quad (3)$$

$$M = \frac{Amplitude\ of\ modulation\ wave\ form}{Amplitude\ of\ carrier\ wave\ form} \quad (4)$$

The value of D_{sh} sets certain limitation on Z source, for applications which require strong boost inversion abilities for low voltage energy sources like fuel cell, batteries and PV systems [6]

To achieve extended boost operation, advanced dc-dc conversion enhancement techniques like switched capacitor (SC), switched inductor (SL), hybrid SC/SL, voltage multiplier cells and voltage lift (VL) techniques [7-13] are adopted.

By replacing either the top inductor arm or the bottom inductor arm of the Z source with the switched inductor unit, which consists of three diodes and two inductors, a new topology called switched inductor unit based Z source modified CHB MLI is derived. This topology overcomes the limitation of Z source by utilizing SL unit. The high voltage conversion ratios are obtained with short shoot-through zero state. This is beneficial in improving the output power quality of the main circuit [14].

This paper is organized as follows: Proposed topology description is provided in section II. The control strategy details are presented in section III and its simulation results are discussed in section IV. Finally, section V concludes the topology justification of the switched inductor Z source modified CHB multilevel inverter.

2. Topology description of SL-Z-source Modified CHB MLI

The proposed topology consists of three voltage sources, three input diodes, six equal valued inductors, six equal valued capacitors, ten switches and nine diodes. This topology consists of three modules, which are symmetrical in nature. One module is described in detail.

In the module-1 V_{in1} feeds the input to the Z network-1 through the input diode D_{in1}. In the top series arm of the Z network-1, switched inductor unit is connected. The switched inductor unit consists of L_1-L_2-D_1, D_2, D_3 connected as shown in the Figure.1. The switched inductor concept is brought into action by the two pairs of inductor-diode. The inductor diode pair1 (L_1, D_1) is formed by connecting the inductor L1 in series with diode D1.and the inductor diode pair 2 (L_2, D_2) is formed by connecting inductor L_2 in series with diode D_2. These two pairs L_1, D_1 and L_2, D_2 are connected in parallel. This entire setup is called switched inductor unit.

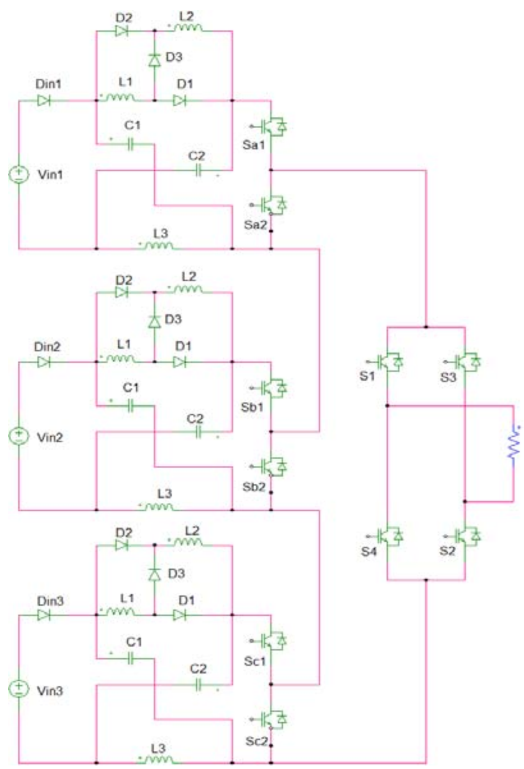

Fig 1: Circuit diagram of the proposed Topology

The role of switched inductor unit is store and transfer the energy from the capacitor to the dc bus. Based on the switching topology, the switched inductor unit comes into the play of boosting operation. i.e., the two inductors L_1 and L_2 of the switched inductor unit can be connected in series or parallel internally and finally connected to the main Z network. Thereby storage of energy can be raised to higher. The operation can be easily understood by the shoot-through state and non shoot-through state equivalent circuits.

2.1 Shoot-through state

This shoot-through zero state is similar to the additional zero state, produced by shoot-through action in classical Z source. During shoot-through zero state, input diode D_{in} and D_3 are OFF which is shown in Figure. 2. D_1 & D_2 are ON, in the top switched inductor unit, the inductors L_1 & L_2 are getting charged from the parallel connected capacitor C_1. In the bottom arm L_3 is charged by the capacitor C_2.

2.2 Non shoot-through state

This non shoot-through state is similar to the six active states and two zero states of the classical z source. During this state, the input diode D_{in} and D_3 are ON shown in Figure. 3. In the top switched inductor unit, the inductors L_1 & L_2 get connected in series and delivers energy to the main circuit. The bottom inductor arm delivers energy to the main circuit. In the same time, the Capacitor C_1 is charged by V_{in} through bottom arm. The capacitor C_2 is charged by source V_{in} through the top switched inductor unit.

3. Control strategy

In this paper, the special feature of this topology called, extended boost operation is obtained through shoot-through operation. PD-PWM technique with simple boost control strategy is used to generate switching pulses for the proposed topology. During the shoot-through period, in addition to the existing PWM technique an additional constant line called shoot-through line, whose magnitude is greater than or equal to the reference wave is utilized to generate switching pulses with shoot-through to obtain the boost functionality.

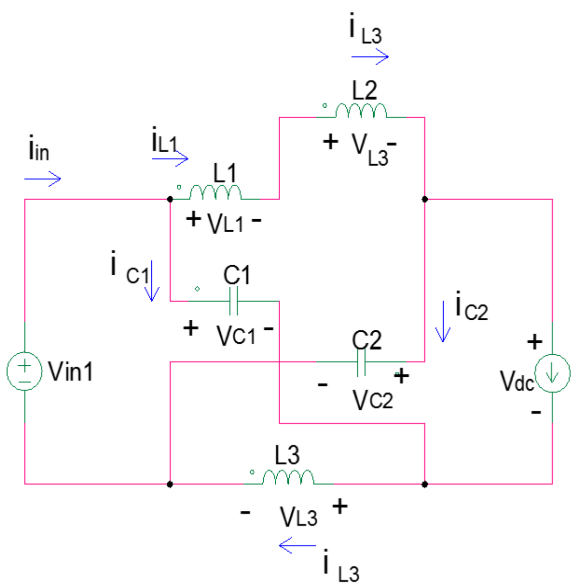

Fig 2: Equivalent diagram of the shoot through state

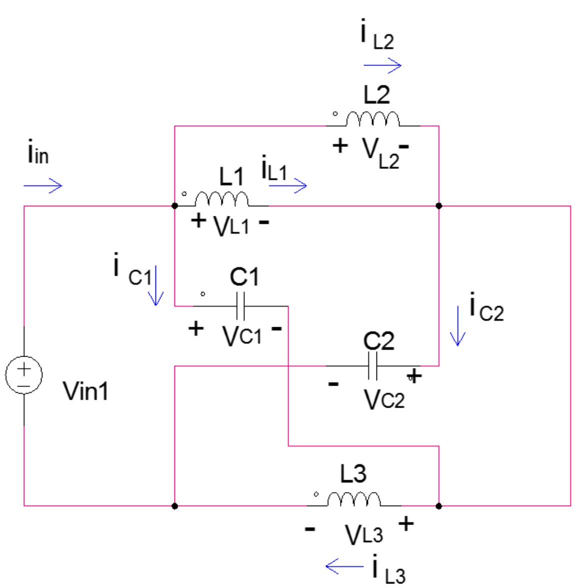

Fig 3: Equivalent diagram of the non-shoot- through state.

For comparing the boost ability, the graph of the boost factor versus the duty cycle is shown in Figure. 4. The boost ability of the proposed SL-Z-M-CHB-MLI is significantly high and its boost factor is higher than the traditional Z-source network.

The boost factor of this topology is given in (5)

$$B = \frac{1}{1-2D} \ to \ \frac{1+D}{1-2D-D^2} \quad (5)$$

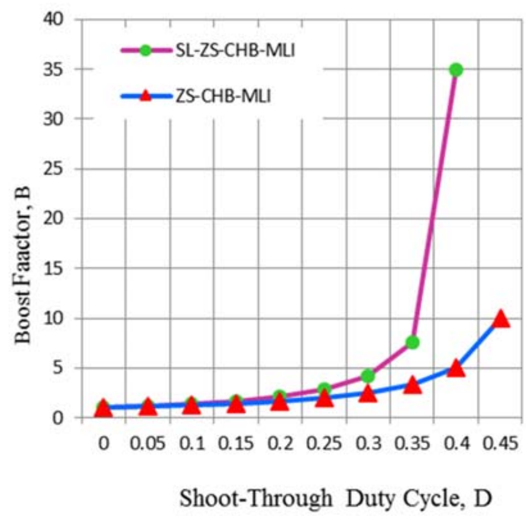

Fig 4: Comparison of Duty Cycle Vs Boost Factor for ZS-CHB-MLI and SL-ZS-M-CHB-MLI

Figure.5. shows the graph of gain vs modulation index under the simple boost control strategy, for SL-Z-M-CHB-MLI and the traditional inverter. The tradeoff of maximum shoot-through duty ratio of simple boost is (1-M), so it reaches zero when going to one [15]. At M<1, voltage boosting are gradually increased when compared to Z-CHB-MLI. During shoot-through state, the value of D_{sh} is limited by (1-M). For any given gain, a higher modulation index is available in the proposed inverter to improve the performance. The voltage gain G is expressed in (6)

$$G = M.B \ (6)$$

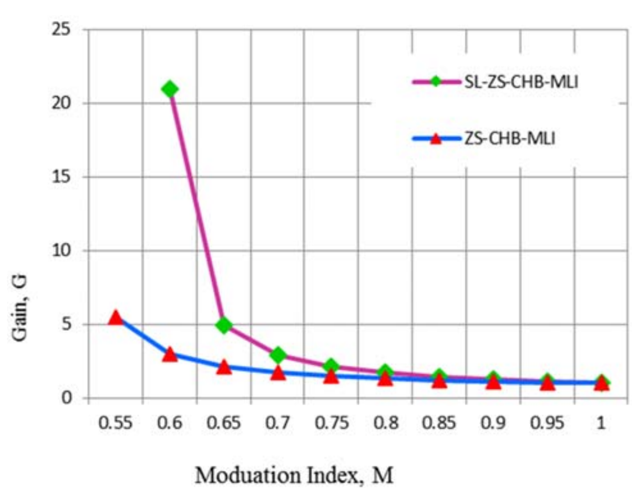

Fig 5: Comparison of Modulation Index Vs Gain for ZS-CHB-MLI and SL-Z-M-CHB-MLI

According to (3) Low modulation index M will result in poor inversion ability, with high harmonic distortion values at the fundamental frequency. In Z-source multilevel inverter, to have an optimum design, the values of modulation index must be chosen, to be close to 1, and therefore the duty cycle has a small upper limit accordingly. Thus, the boost factor of Z-source network is usually restricted seriously by (1). The observation from Figure.5, clearly demonstrates that SL-Z-M-CHB-MLI has higher gain as well as, its corresponding modulation index closer to 1 when compared to the Z-CHB-MLI.

4. Simulation Results

Simulation study using MATLAB software is carried for the proposed SL-Z-M-CHB-MLI topology. The circuit parameters for simulation are as follows: $L_1 = L_2 = L_3 = 40mH$ and $C_1 = C_2 = 6000\mu F$. The Switching frequency is equal to $f_s = 5\ kHz$ and the input voltage is V_{in} = 100 V and $R_{Load} = 50\Omega$. As shown in Figure.8, during the steady state, the dc-link voltage is boosted to 140V for the input dc voltage of 100V. The capacitor voltages V_{C1} & V_{C2} of C_1 and C_2 respectively for the proposed topology are boosted to 140V and 140V approximately, which are same with analysis and shown in Figure.6 & Figure.7.

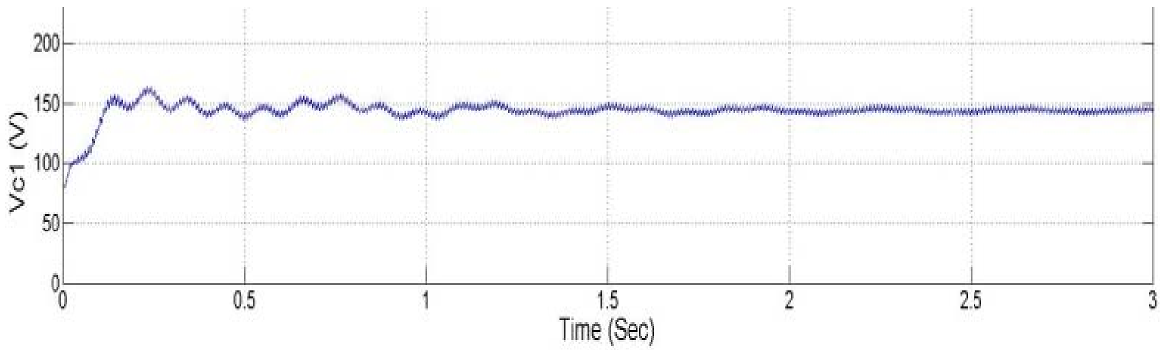

Fig 6: Capacitor (C_1) voltage of the proposed SL-Z-M-CHB-MLI Topology

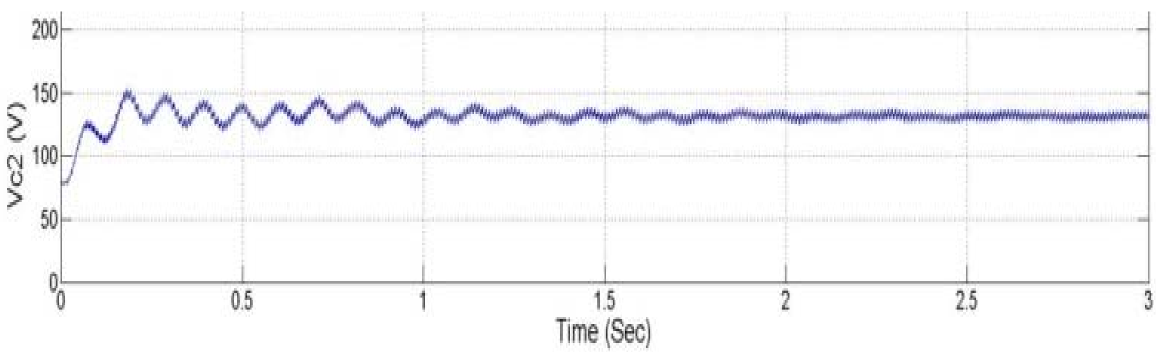

Fig 7: Capacitor (C_2) voltage of the proposed SL-Z-M-CHB-MLI Topology

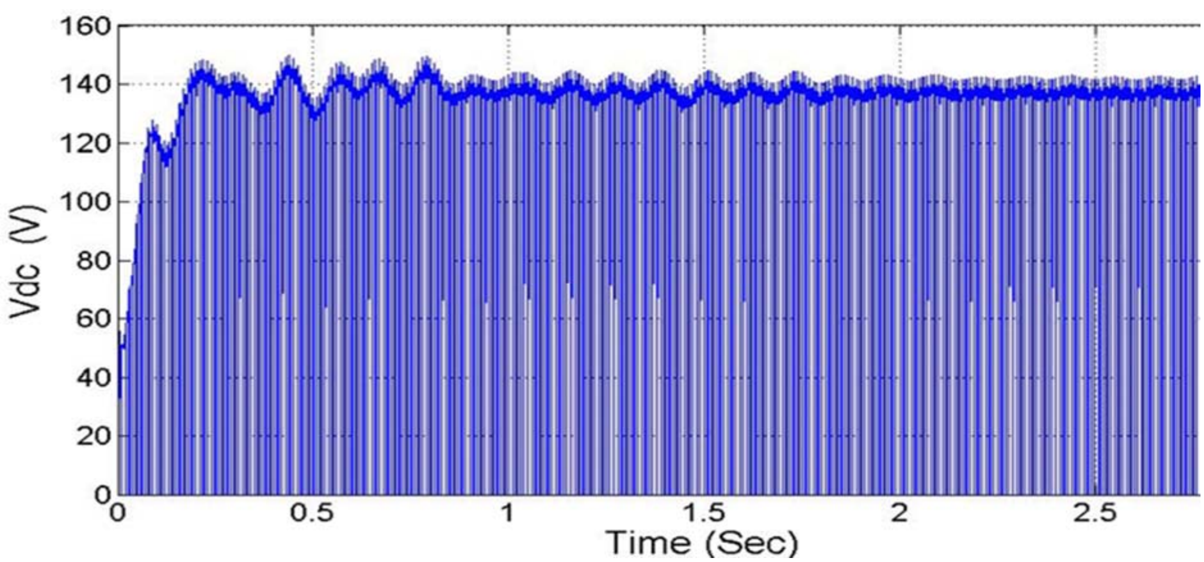

Fig 8: DC Link voltage of the proposed SL-Z-M-CHB-MLI Topology

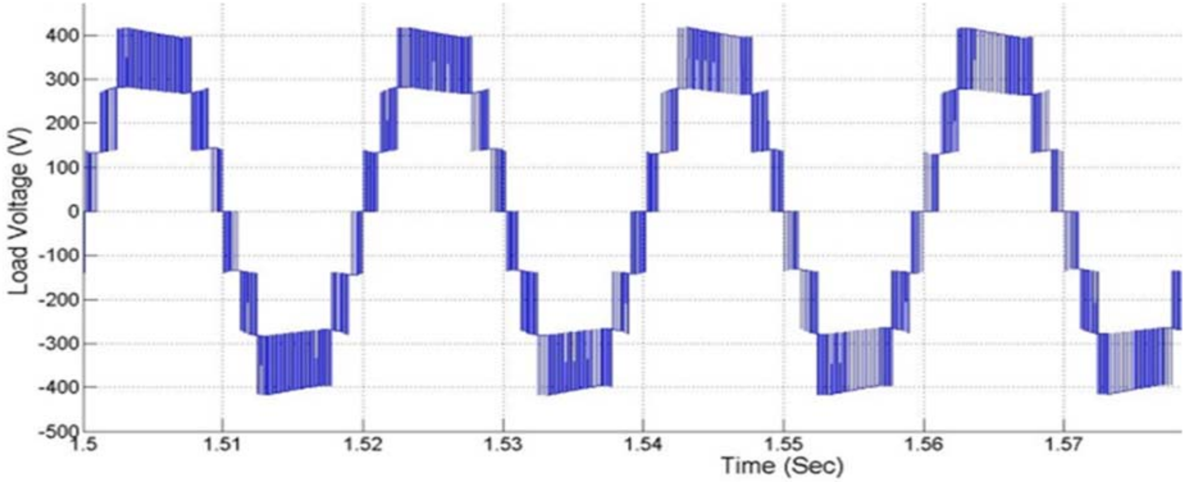

Fig 9: Output Voltage of the proposed SL-Z-M-CHB-MLI Topology

The output voltage waveform of the proposed SL-Z-M-CHB-MLI topology is shown in Figure.9. From the Figure.9 it can be observed that the output voltage is boosted to 410V for the given DC input voltage, 100V. The model is examined for various applicable modulation indexes. As the modulation index increases, the output voltage decreases, because of reduction in shoot-through period.

5. Conclusion

The new SL-Z-M-CHB-MLI topology presented in this paper provides better boosting ability over the classical Z-source MLI. It also provides better gain than the classical Z-source inverter. Both inversion and boost operation is obtained in single stage, thereby reducing component count and reduces cost. This proposed topology finds application in distributed renewable energy systems and can also be applied in all areas of dc-ac, ac-dc, ac-ac, and dc-dc power conversion.

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