ESP-JETA
ESP Journal of Engineering & Technology Advancements
ISSN: 2583-2646 / Volume 4 Issue 1 February 2024 / Page No: 57-63
Paper Id: JETA-V4I1P107 / Doi: 10.56472/25832646/JETA-V4I1P107

Original Article

Five Level Inverter

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Received Date: 27 December 2023 Revised Date: 24 January 2024 Accepted Date: 22 February 2024

Abstract: *In this project, a single source five-level boost inverter has been proposed and analyzed. The proposed structure includes a five-level inverter and a single-input multi-output (SIMO) boost converter. In this structure, the DC link voltage has been controlled by controlling the implemented DC-DC boost converter. In addition, the inverter switching pattern has been obtained based on the pick current control (PCC) method. In order to test and prove the performance of the proposed structure, this system is tested with the local grid. Since the active and reactive powers have been controlled based on the PCC method, the generated energy in a renewable energy source can be transferred to the local grid with a controlled and high-quality current. In this project, the proposed structure has been introduced and its operation in different modes has been analyzed completely. Furthermore, the design considerations of the required elements have been investigated. Also, the power loss analysis and the comparison results of the proposed converter with other similar structures have been presented. Finally, in order to test the practical performance of the proposed structure and prove the theoretical analysis, a 620 W laboratory prototype of this structure has been assembled and its performance with the local grid has been tested.*

Keywords: *Inverter, DC-DC Boost Converter, Pick Current Control (PCC).*

I. INTRODUCTION

A. Inverters

A device that converts DC power into AC power at desired output voltage and frequency is called an Inverter. Phase controlled converters when operated in the inverter mode are called line commutated inverters. But line commutated inverters require at the output terminals an existing AC supply which is used for their commutation. This means that line commutated inverters can't function as isolated AC voltage sources or as variable frequency generators with DC power at the input. Therefore, voltage level, frequency and waveform on the AC side of the line commutated inverters can't be changed. On the other hand, force commutated inverters provide an independent AC output voltage of adjustable voltage and adjustable frequency and have therefore much wider application. Inverters can be broadly classified into two types based on their operation:

- Voltage Source Inverters (VSI)
- Current Source Inverters (CSI)

Voltage Source Inverters is one in which the DC source has small or negligible impedance. In other words VSI has stiff DC voltage source at its input terminals. A current source inverter is fed with adjustable current from a DC source of high impedance, i.e; from a stiff DC current source. In a CSI fed with stiff current source, output current waves are not affected by the load. From view point of connections of semiconductor devices, inverters are classified as under

- Bridge Inverters
- Series Inverters
- Parallel Inverters

B. Multi-Level Inverter

A multilevel inverter is a power electronic device which is capable of providing desired alternating voltage level at the output using multiple lower level DC voltages as an input. Mostly a two-level inverter is used in order to generate the AC voltage from DC voltage. Now the question arises what's the need of using multilevel inverter when we have two-level inverter. In order to answer this question, first we need to look at the concept of multilevel inverter.

a) Concept of Multi-Level Inverter

First take the case of a two-level inverter. A two-level Inverter creates two different voltages for the load i.e. suppose we are providing V_{dc} as an input to a two level inverter then it will provide $+ V_{dc}/2$ and $- V_{dc}/2$ on output. In order to build an AC voltage, these two newly generated voltages are usually switched. For switching mostly PWM is used as shown in the Figure 1.1, reference wave is shown in dashed blue line. Although this method of creating AC is effective but it has few drawbacks as it creates harmonic distortions in the output voltage and also has a high dv/dt as compared to that of a multilevel inverter. Normally this method works but in few applications it creates problems particularly those where low distortion in the output voltage is required.

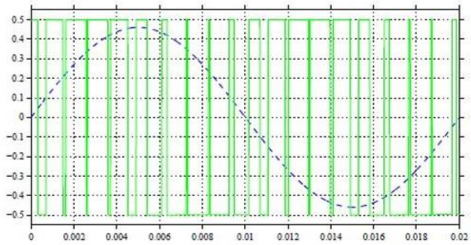

Figure 1: PWM Voltage Output of a Two-Level Inverter

The concept of multilevel Inverter (MLI) is kind of modification of two-level inverter. In multilevel inverters we don't deal with the two level voltage instead in order to create a smoother stepped output waveform, more than two voltage levels are combined together and the output waveform obtained in this case has lower dv/dt and also lower harmonic distortions. Smoothness of the waveform is proportional to the voltage levels, as we increase the voltage level the waveform becomes smoother but the complexity of controller circuit and components also increases along with the increased levels. The waveform for the three, five and seven level inverters is shown in the Figure 1.2 where we clearly see that as the levels are increasing, waveform becoming smoother.

II. SYSTEM AND IMPLEMENTATION

A. Existing System

A much simpler existing multilevel inverter topology with less power devices requirement compared to the previously mentioned ones is known as the cascaded H-bridge multilevel inverter (CHMI). The main drawback of this topology is the isolated DC power supply requirement for each of its stages which on the other hand makes it attractive for use in applications related to renewable or alternate energy sources that can offer readily available DC output. Various literatures in recent years have reported the utilization of the single-phase and three-phase CHMI in both static and drive applications. However, detail analysis on the performance of the three-phase CHMI in particular has not been clearly revealed.

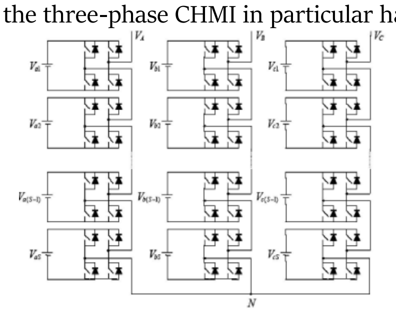

Figure 2: Existing Topology CHB Multilevel Inverter

A three-phase system, the output of three identical structure of single-phase CHMI can be connected in either wye or delta configuration. Fig.3.1 illustrates the schematic diagram of a wye-connected m-level CHMI with separate DC sources. For a three-phase 5-level CHMI, two H-bridge cells with eight switches are needed per phase. Thus a total ofsix H bridge cells involving 24 power switches are required for this circuit configuration. This means that twelve pairs of gating signals have to be generated to be fed to the switches. For each H-bridge cell, the switching's designed in such a way that only one pair of switches operate at the carrier frequency while, the other pair operates at the reference frequency, thus having two high-frequency switches and two low-frequency switches.

B. Proposed System

This project proposes a structure is a modified version of the presented inverter in. The proposed structure is a combination of a SIMO DC-DC boost converter and a multilevel inverter. Since the inverter side is a five-level inverter, in the DC side, a single-input two-output DC-DC converter is required. The implemented five-level inverter is a six-switch inverter and this inverter is connected to the two output capacitors of the DC side. In this structure, two DC side output capacitors are the connection link between the DC side and inverter side. Therefore, by implementing a DC voltage source (Vin = V dc), two non-isolated DC voltage sources have been obtained in the output of DC side. Since, autonomous control of the output DC voltages is possible, even with unequal power delivery from the output capacitors; the proposed structure can provide the desired performance. As a result, the mentioned feature is vital for the performance of the proposed structure. In Fig. 1, the implemented five-level inverter contains six power switches (S1-S6). The power switches S1 and S2 have been implemented to generate the output voltage levels.

a) Proposed Inverter

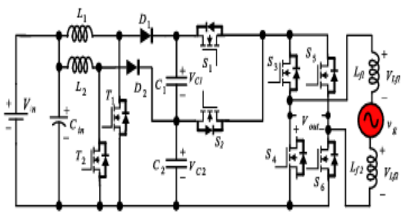

Figure 3: Five Level-Boost Inverter

b) Proposed Topology

This structure is a modified version of the presented inverter. The proposed structure is a combination of a SIMO DC-DC boost converter and a multilevel inverter. Since the inverter side is a five-level inverter, in the DC side, a single-input two-output DC-DC converter is required. The implemented five-level inverter is a six-switch inverter and this inverter is connected to the two output capacitors of the DC side. The implemented DC-DC converter contains two MOSFETs (T1 and T2), two inductors (L1 andL2), two power diodes(D1 andD2),and two output capacitors (C1 and C2). In this structure, two DC side output capacitors are the connection link between the DC side and inverter side. By controlling the implemented DC-DC converter, both the DC side output voltages (VC1 andVC2) can be controlled autonomously.

Table 1: Switching Table of the Proposed Five Level Inverter

S_1	S_2	S_3	S_4	S_5	S_6	Switch / Voltage
1	0	1	0	0	1	V_{dc}
0	1	1	0	0	1	$V_{dc}/2$
0	0	1	0	1	0	0
0	1	0	1	1	0	$-V_{dc}/2$
1	0	0	1	1	0	$-V_{dc}$

C. Mode of Operation

Our Proposed Project Types of Modes:

a) FIRST OPERATIONAL MODE (power switches S2, S3, and S6 are in on state)
b) SECOND OPERATIONAL MODE (power switches S3 and S5 are in on state)
c) THIRD OPERATIONAL MODE (power switches S1, S3, and S6 are in on state)
d) FOURTH OPERATIONAL MODE (Power switches S2, S4, and S5 are in on state.)
e) FIFTH OPERATIONAL MODE (power switches S3 and S5 are in on state)
f) SIXTH OPERATIONAL MODE (switches S1, S4, and S5 are in on state)

a) First Operational Mode

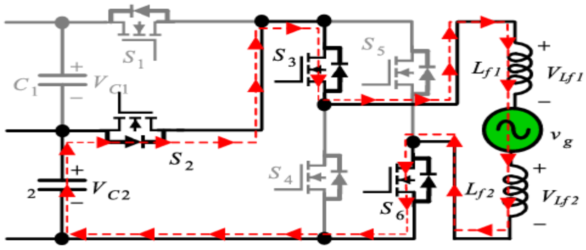

Figure 4: First Operational Mode

The equivalent circuit of the proposed inverter in the first operational mode. In this mode, the power switches S2, S3, and S6 are in on state. Therefore, the stored energy in the capacitor C2 transfers to the output side and the current of the output inductor increases linearly. Also, due to off state of the power switch S1, the capacitor C1 does not conduct. As a result, the magnitude of the output voltage is equal to the voltage of the capacitor C2 (V out = +V dc/2).

b) Second Operational Mode

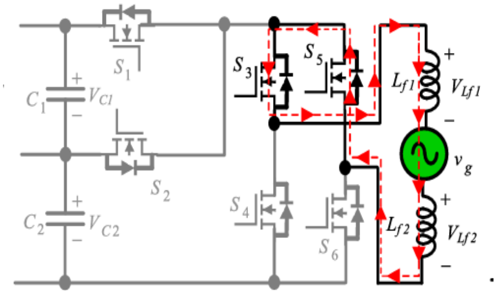

Figure 5: Second Operational Mode

The equivalent circuit of the second operational mode in this mode, the power switches S3 and S5 are in on state. Therefore, the output current is reduced and the zero-voltage level has been generated in the output voltage waveform.

c) Third Operational Mode

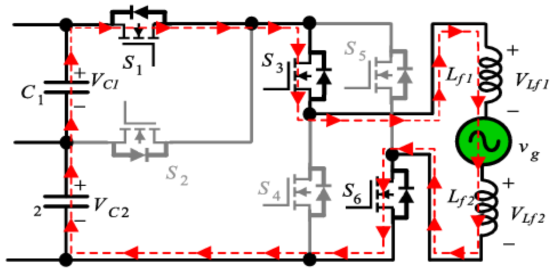

Figure 6: Third Operational Mode

The equivalent circuit of the proposed structure in the third operational mode. In this mode, the power switches S1, S3, and S6 are in on state. Furthermore, the capacitors C1 and C2 transfer energy to the output side simultaneously. As a result, the output voltage magnitude is equal to the DC link voltage (V out = +V dc)

d) Fourth Operational Mode

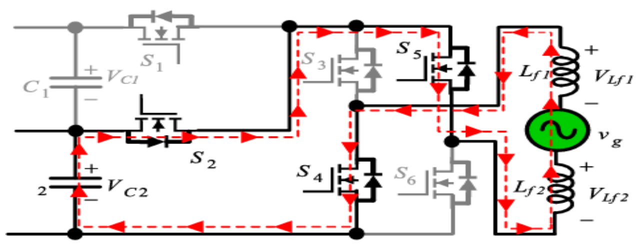

Figure 7: Fourth Operational Mode

The proposed inverter in the fourth operational mode. In this mode, the switches S2, S4, and S5 are in on state. Consequently, the first negative voltage level in the negative half cycle has been generated and the output voltage is equal to−V dc/2(V out=−V dc/2).In this mode, the direction of the output current has been changed.

e) Fifth Operational Mode

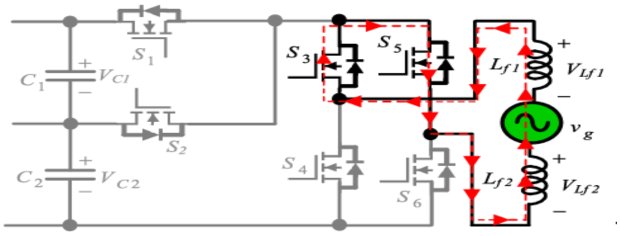

Figure 8: Fifth Operational Mode

The proposed inverter in the fifth operational mode. The power switches S3 and S5 are in on state. As a result, the zero voltage level of the output voltage has been generated in the negative half cycle.

f) Sixth Operational Mode

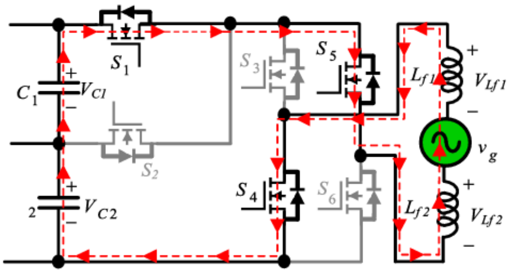

Figure 9: Sixth Operational Mode

The equivalent circuit of the proposed inverter in the sixth operational mode. In this mode, the switches S1, S4, and S5 are in on state. The output voltage is negative and these voltage level of the negative half cycle has been generated .Therefore, the output voltage is equal to−V dc (V out=−V dc).

III. SIMULATION RESULT

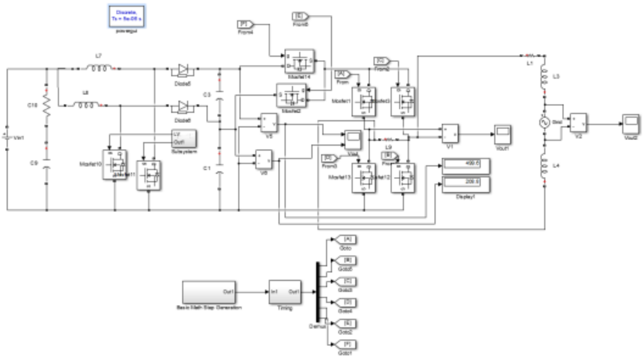

Figure 10: Simulation Model for Five Level Inverter

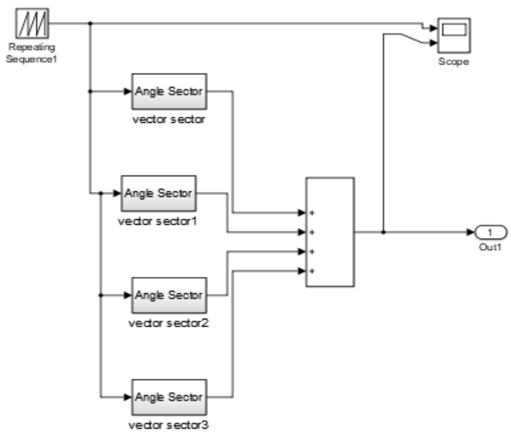

Figure 11: Simulation Model for Control System

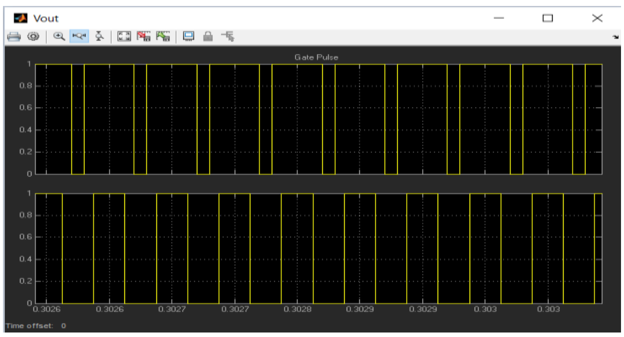

Figure 12: Simulation Result for Gate Pulse

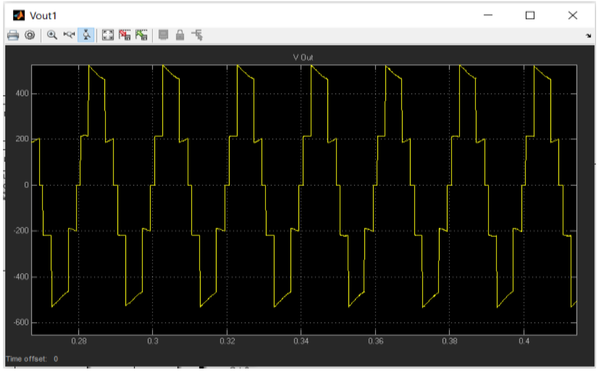

Figure 13: Simulation Result for Square Wave AC Output

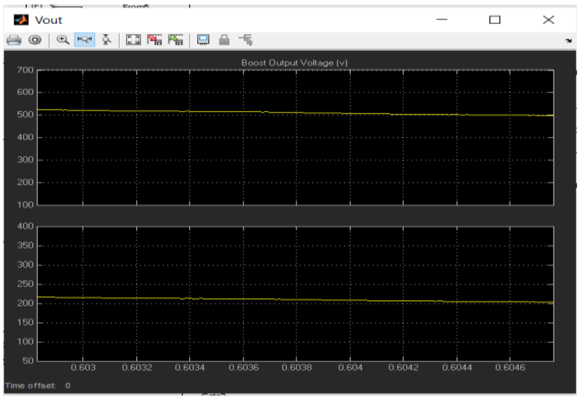

Figure 14: Simulation Result For Boost Voltage in 100v to 500v and 200v DC

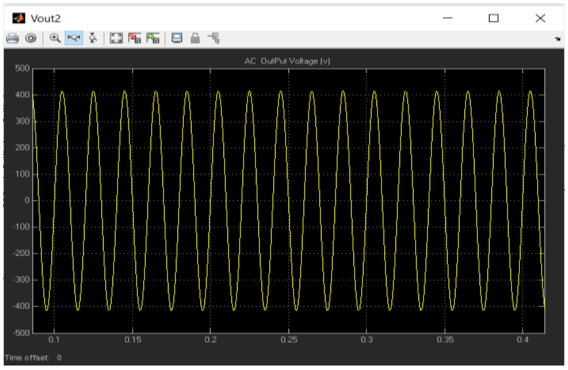

Figure 15: Simulation Result of Grid AC Output Voltage

IV. CONCLUSION

In this paper, a five-level boost inverter with single DC source has been proposed. In the DC side of the proposed structure, a DC-DC boost converter has been implemented to transfer the required DC voltage from the single input DC source to the capacitors C1 and C2. In this structure, the implemented PCC method to derive the switching pattern has been explained. In addition, design of the implemented components and power losses analysis have been presented. The performance of the proposed inverter in terms of different parameters have been compared to similar structures. Furthermore, in order to verify the claimed advantages of the proposed structure, a laboratory prototype of the proposed structure has been tested with the local grid. Both the injected active and reactive powers have been controlled based on the PCC method.

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