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Design & Development of Single Phase Multilevel Inverter (MLI) Using Coupled Inductor

Amisha Kumari[1], Venkatesha K[2]

M.Tech Student, Dept. of EEE, BNMIT-Bangalore, Visvesvaraya Technology University, Belagavi, India[1]

Associate professor, Dept. of EEE, BNMIT-Bangalore, Visvesvaraya Technology University, Belagavi, India[2]

ABSTRACT: In this paper, a novel single-phase 7 level inverter is proposed using coupled inductors. This inverter can output seven level voltages with only one DC source. Multilevel inverters with coupled inductors need only one source without input capacitors. For the inverter with coupled inductor, three limbs coupled inductors is the most desirable one; however, coupled inductor with high inductance value is not preferred. PWM control technique at 15 KHz switching frequency is generated using TMS320F28069 DSP controller. Simulation is carried out for a 5 KVA single phase inverter to check for 7 level output voltage and filter consideration in order to generate sine wave.12 switches are required to generate 7-level output. Finally, a prototype of 7-level inverter with 400 V input and 230 Vrms/5KW output is implemented.

KEYWORDS: Renewable energy source, inverter, multilevel inverter, single phase, coupled inductor

I. INTRODUCTION

Renewable energy sources must be incorporated because energy demand is increasing day by day. Now-a-days, non-conventional sources play a vital role as energy demand is increasing abruptly. Non-conventional sources like PV cells, fuel cells produce DC voltage. For house hold purpose and industrial purpose this DC voltage must be converted into AC voltage. For this, power electronic inverters are used to convert DC to AC form. Multilevel inverters have got wide spread acceptance to add more power and less harmonic content in the output voltage waveform.

In 1975, the concept of multilevel converter has been introduced. Multilevel began with the 3-level converter. After that, many MLI converter topologies have been developed. However, the elementary concept of a MLI to achieve high power is to use a series of power semiconductor switches with several lower voltage DC sources to perform the power conversion by synthesizing a staircase voltage waveform. MLI topologies have attracted a lot of attentions of energy control in the field for high power and medium voltage applications. Advantages of MLI include:

- Reduce voltage stresses on load and switching devices, that enhances lifetime of switches and reduces electromagnetic interferences.
- The output waveforms with higher quality output.
- Effective switching frequency is increased, that reduce the cost and size of the output filter.

For single phase MLI, the most common topologies are the cascaded h-bridge, capacitor clamped and diode-clamped and type. General, MLI topologies can be classified into two types: Type 1, Type 2. Type 1 uses multiple (split and clamping) dc voltage capacitors Type 2 uses dc voltage sources. Type 2 includes conventional diode-clamped, capacitor-clamped inverters Type 1 includes traditional cascade topologies.

In cascaded H-bridge is a single phase full-bridge connected with each separate DC source, or H-bridge, inverter. Each inverter level can generate 3 output voltages, $+V_{dc}$, 0, $-V_{dc}$ by connecting DC source to the ac output by different combinations of 4 switches S1, S2, S3 and S4. The cascaded H-Bridge is having some advantages and disadvantages:

Advantages:

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- The series of H-bridges makes for modularized packaging and layout. This will enable the manufacturing process to be done more cheaply and quickly.
- The number of possible output voltage levels are more than twice the number of DC sources.

Disadvantages:

- Separate dc sources are required for each of the H-bridges.

In diode-clamped, the dc bus capacitor is split into two, providing a neutral point Z, on the DC side of the inverter. The clamping diodes are the diodes connected to the neutral point, Dz1 and Dz2. The voltage across each of the DC capacitor is E, that is normally equal to half of the total DC voltage V_d. With finite value for Cd1 and Cd2, the capacitor can be charged or discharged by neutral current causing neutral point voltage deviation. The Diode-clamped MLI is having some advantages and disadvantages:

Advantages:

- In Diode-clamped, there is no dynamic voltage sharing problem.
- Low dv/dt and THD.

Disadvantages:

- The fluctuation of the DC bus midpoint voltage.
- Complicated the PWM switching pattern design.

Flying capacitor topology involves series connection of the capacitor clamped switching cells. The topology has several attractive and unique features when that is compared to the diode clamped inverter. The flying capacitor inverters have switching redundancy within the phases that can be used to balance flying capacitors so that only one DC source is needed. One feature is that the added clamping diode is not needed.

This topology is a novel technique for multilevel inverter. All above discussed topology is having some disadvantages. This novel coupled inductor topology has having advantages which is overcoming the disadvantages of above discussed topology. This topology is working with voltage division concept, another advantage is having only one power supply for many number of level only number of switch and coupled inductors get increase as level increases. Coupled inductor used to improve output quality of the inverter by increasing, effective switching frequency & the number of output voltage levels, when eliminating the need for several DC sources and/or several bulky capacitors.

Additionally, this inverter compared to the other inverters with same no of voltage level, this requires fewer passive components and switches. And the voltage source MLI with coupled inductors can be easily extended, while the number of switches does not increase considerably, to any number of voltage levels.

Shrin et al [1], has mentioned five level inverters in this paper. John et al [2], large number diodes used to achieve number of levels. Zixin et al [3], has used 6 IGBTs for 5-level inverter, so is bulky. Sasan et al [4], in this paper, author has used MOSFET as a switch and clamp capacitor. Chi-Shen Wu et al [5], used 0.5mH inductor as output inductor.

II. PROPOSED STRUCTURE

The proposed 7-level inverter is illustrated in Fig.1. The structure of the proposed inverter is such that it provides single-phase 7-level voltage by using a dc voltage source, the switches S1 to S12 and two coupled inductors with three limbs at the output. All 12 switches S1 to S12 are switched by switching frequency and their current is half of the output current. The switches with lower current rating operate in higher frequency & higher current rating switches operate in low frequency. Output current increases or current reduction in the switches & generating of 7-level is achieved by the appropriate control of switches and the coupled inductors.

In illustrated figure total 6 legs are there and in one leg 2 switches. These 2switches can not be turned on simultaneously; otherwise, voltage source will behave as short circuit, it should be in complementary manner. Figure 2 shows the PWM (pulse width modulation) control method of the proposed converter. Control of the switches is obtained by comparing one carrier sine wave with triangle wave. The output voltage of the proposed 7-level inverter includes the voltage levels of V, 2V/3, V/3, 0, -V/3, -2V/3, -V. Switching modes to generate those voltage levels are given in Table1. In the table, 0 means that the corresponding switch is turned off and 1 means switch is turned on.

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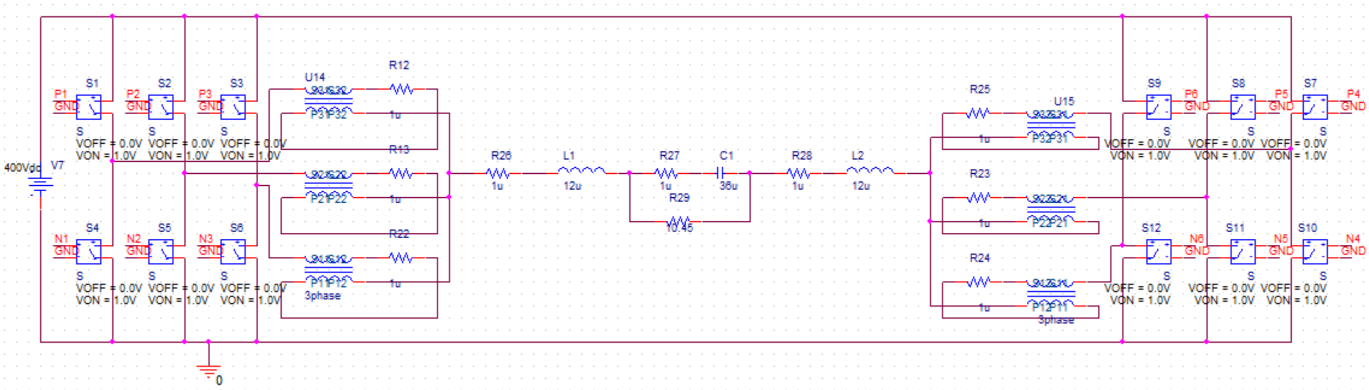

Figure 1: proposed single-phase 7-level inverter

Table1: Different operation mode of the proposed inverter

Modes	Switching states												Output voltage
	S1	S2	S3	S4	S5	S6	S7	S8	S9	S10	S11	S12	
1	0	1	0	1	0	1	0	0	1	1	1	0	2V/3
2	0	1	1	1	0	0	0	0	1	1	1	0	V/3
3	0	0	1	1	1	0	1	1	1	0	0	0	0
4	0	0	1	1	1	0	1	1	0	0	0	1	-V/3
5	1	0	1	0	1	0	1	1	0	0	0	1	-2V/3
6	1	0	1	0	1	0	0	1	0	1	0	1	-V
7	0	1	0	1	0	1	1	0	1	0	1	0	V

III. SIMULATION RESULTS

The proposed 7-level inverter has been simulated in the ORCAD/PSPICE to verify its operation. The DC link voltage is 400V. The inverter supplies a resistive load of 10.45. The self-inductance of the coupled inductor windings is 57mH and common mode inductance is 25μH. The fundamental frequency and switching frequency are 50Hz and 15 KHz respectively.

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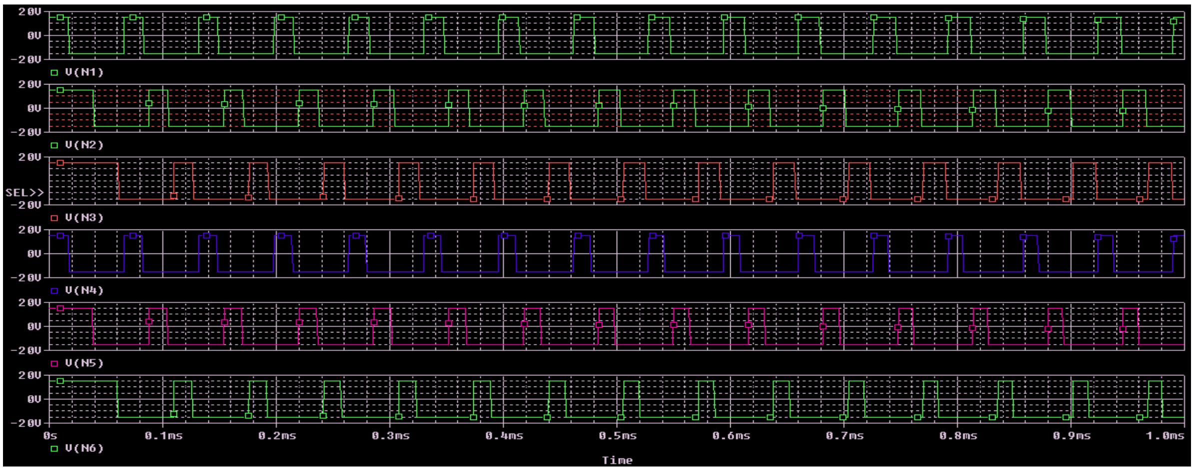

Figure2: PWM pulses of the proposed single-phase 7-level inverter

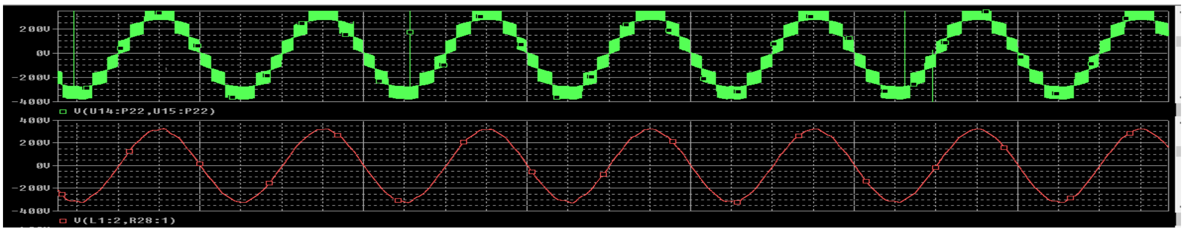

Figure3: multi-level output and sinusoidal output of Single-phase 7-level inverter

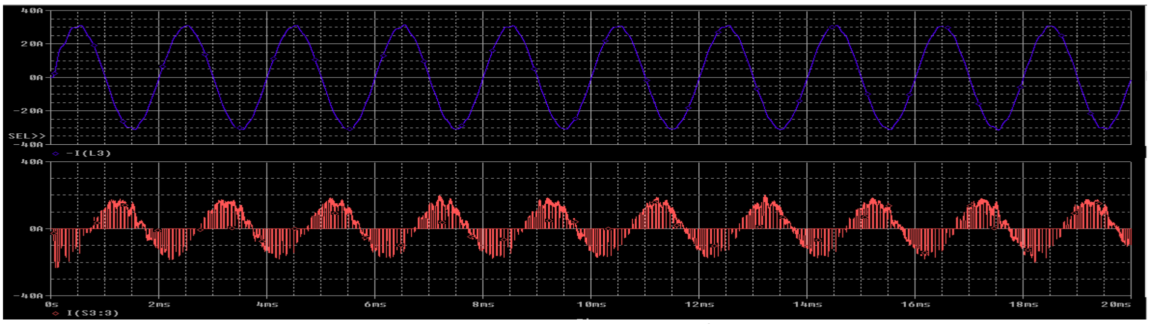

Figure 4: Current on switch S1 (similar for all switches)

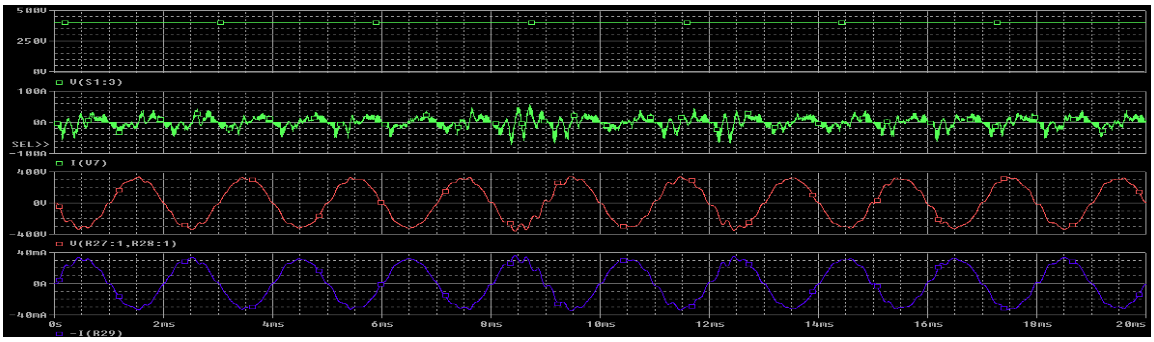

Figure 5: input and output voltage for 1-phase 5KVA inverter

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Table 1: Circuit specification

Input voltage	400V
Output voltage	230Vrms
Output power	5KVA
Switching frequency	15KHz
Output voltage frequency	50Hz

Table 2: Circuit parameter

Switch	STGIB15CH60TS-E
Coupled inductor	57mH; K=0.99
Output inductor	12uH
Output capacitor	36uF
Boot capacitor	10uF

The simulation results of the proposed single-phase inverter are shown in Fig. 2 to 5. As the fig. 3 shows, all the expected voltage levels are generated so that output voltage is a 7-level voltage. The sum of the inductor currents is the output current, second trace. The current of switch S1 is shown in fig. 4 to illustrate the current stress on switches is half of the output current and this is one advantage of the proposed inverter.

IV. RESULTS

The proposed single-phase 7-level inverter is implemented in the hardware. 12 switches are required to generate 7-level output. STIGB15CH69TS-E, IC is used, which is having 6 IGBTs and gate driver imbedded in single IC. The coupled inductor with three is made up of UMCEC-7 core with SWG-21 copper wire winding. Finally, a prototype of 7-level inverter with 400 V input and 230 Vrms/5KW output is implemented. PWM control technique at 15 KHz switching frequency is generated using TMS320F28069 DSP controller.

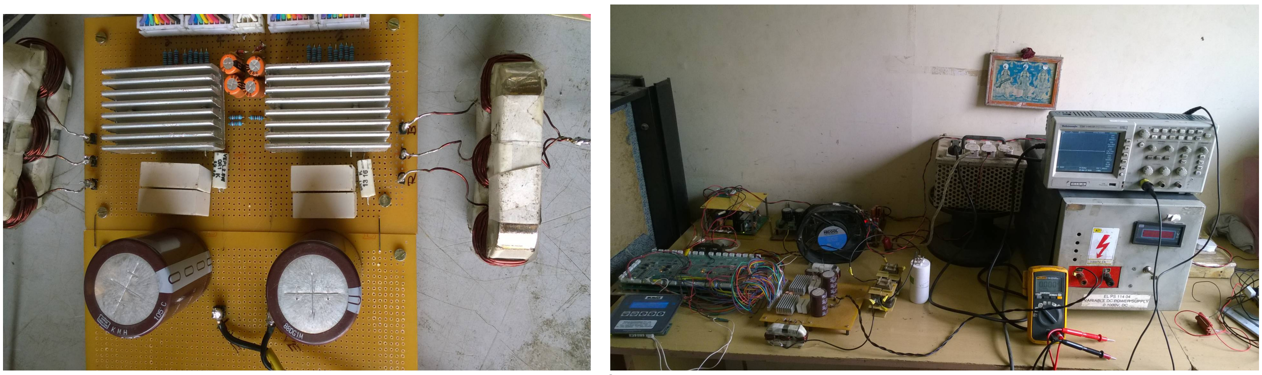

Figure 6: Hardware set up for single-phase 7-level inverter

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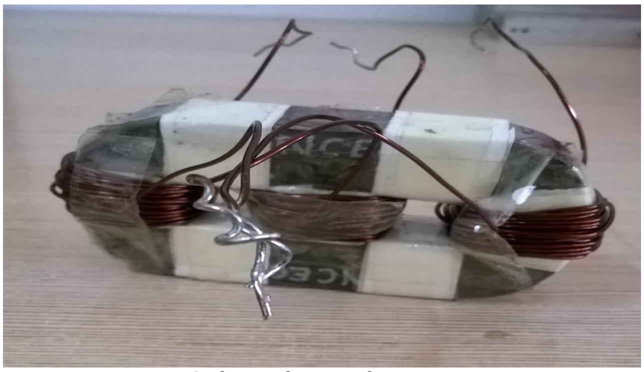

Figure 7: 3-phase inductor with umncec-7 core

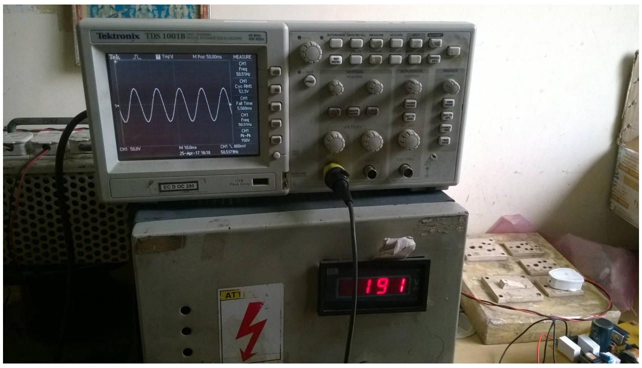

Figure 8: experimental result of prototype for 200 input dc and 115 output ac

V. CONCLUSION AND FUTURE ENHENCEMENT

Prototype of 5 KVA single-phase multilevel inverter is prepared in laboratory and simulation is done in ORCAD with PWM control technique at 15 KHz switching frequency is generated using TMS320F28069 DSP controller**.** Simulation is done with 400V dc and 230V ac output. Experiment results is carried out with 200V input and 115V ac output. Future enhancement is to make a prototype for 400V input and 230V ac output.

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