Single Phase Two-Stage Transformerless Five-Level Inverter for PV Applications

P. Ravali
Research Scholar
Department of Electrical Engineering
NIT Warangal, INDIA
pr22eer1r01@student.nitw.ac.in

A. Kirubakaran, *Senior Member* IEEE
Associate Professor
Department of Electrical Engineering
NIT Warangal, INDIA
kiruba81@nitw.ac.in

***Abstract*—Recently, reduced device count multilevel inverter is getting more attention for PV applications due to high efficiency, modularity, simplicity and compactness. Therefore, in this paper, a new single input DC source based two stage transformerless five-level inverter with reduced devices is presented. The front-end boost converter is capable to maintain dc link voltage across the capacitors to obtain the desired output voltage. Whereas the T-type inverter is used to generate the five-level output voltage waveform by comparing a carrier waveform with two modulated sine signals. The proposed topology is tested for different conditions of load changes and modulation index in the MATLAB/Simulink software. Moreover, a comprehensive comparison is made with recently proposed topologies to highlight the merit of the proposed topology. Finally, concluding remarks are presented at the end.**

Keywords—Multilevel inverters, total harmonic distortion, pulse width modulation, modulation index

I. INTRODUCTION

Among all the renewable energy sources, photovoltaic (PV) energy is one of the most abundant and attractive energy sources which can support rising energy demands. Solar plays an important role among all the renewable energy sources. The use of power electronic interface based on single-stage and two stage system with boost converter and two-level voltage source inverter suffers due to poor efficiency, modularity, High harmonic content and not opted for higher power levels. Multilevel inverters (MLIs) got more attention in the recent years due to their superiority and capable to overcome the limitations of two-level voltage source inverters. It also finds applications in variable speed motor drives, HVDC, Electric vehicles, FACTs and for production of energy from renewable energy sources for standalone/grid connected operation [1]. Moreover, it is capable to deliver more power with reduced voltage stress, reduced switch count, high efficiency, less complex, low cost and large life span [2-5].

Therefore, recent research is focused on multilevel inverters with reduced device count to overcome the limitations of conventional topologies whereas better dc link voltage regulation and reduction in control complexity for higher levels [6-12]. Cascaded H-bridge multilevel inverter has merits like simple structure, less number of power semiconductor devices and flexible to control. The single-phase cascaded H-bridge Multi level inverter plays a major role in converting dc voltage generated by PV system into better sinusoidal AC waveform [7] resulting in reduced total harmonic distortion (THD). However, it required more number for dc sources for increased output levels. The topology based on the switched capacitor has an interesting feature of obtaining high efficiency and boosting capability [3]. A combination of single-phase five-level T-type inverter and a quasi-switched boost network can reach the efficiency to 97% and this topology has some benefits like good current profile, single DC input utilization, voltage gain and high boost factor. But it results in high voltage stress and discontinuous current in input [3]. A novel five-level multilevel inverter [2] for PV system is implemented by using five semiconductor power switches and level shifted-PWM technique is used for generating the gate pulses. Multi carrier APOD technique is used for generating switching signals. However, in practical applications, the use of more passive components and devices for boosting may reduce the efficiency [10]. For more output voltage levels, switched capacitor configuration is introduced with more device counts in [11]. However, the output are resulting in more THD due to the nature of stair case in waveforms.

In this work, the multilevel inverter with a front-end converter is implemented for photovoltaic applications. The main objective of this topology is to implement the MLI structure with minimum number of switches and have inherent voltage boosting capability so that it can be used for PV grid-connected applications. A pulse width modulation technique is proposed to generate gating pulses which results in five level output voltage. A comprehensive comparison is made with various five-level topologies with the proposed topology to highlight the merit of the proposed topology.

II. PROPOSED TOPOLOGY

In this paper, a two stage boost five level T-type inverter with single input dc source and reduced number of switches is proposed for PV applications as shown in Fig. 1. The proposed structure mainly consists of two parts: DC/DC boost converter and a five-level inverter. Here, the first stage consists of a DC/DC boost converter that is formed with one power switch (S_6), one capacitor (C_1), one power diode (D_a), and one inductor (L_a) [12]. The boost converter in proposed structure is used to adjust the voltage across the DC-link and the converter boosts the voltage to twice the input voltage. The output voltage of the DC-link is obtained from the mathematical expression:

$$V_{dc} = \frac{Vin}{(1-D)} \tag{1}$$

Where, V_{in} = dc input voltage, D= duty ratio.

The second stage consists of a five level T-Type inverter formed with five semiconductor switches (S_1 to S_5) and four diodes (D_1 to D_4). The switching states of the five-level inverter is shown in Table I. In order to generate any level of output voltage only two switches are used. The inverter circuit produces five levels of output voltage ($+2V_{dc}$, $+V_{dc}$, 0, $-V_{dc}$, $-2V_{dc}$).

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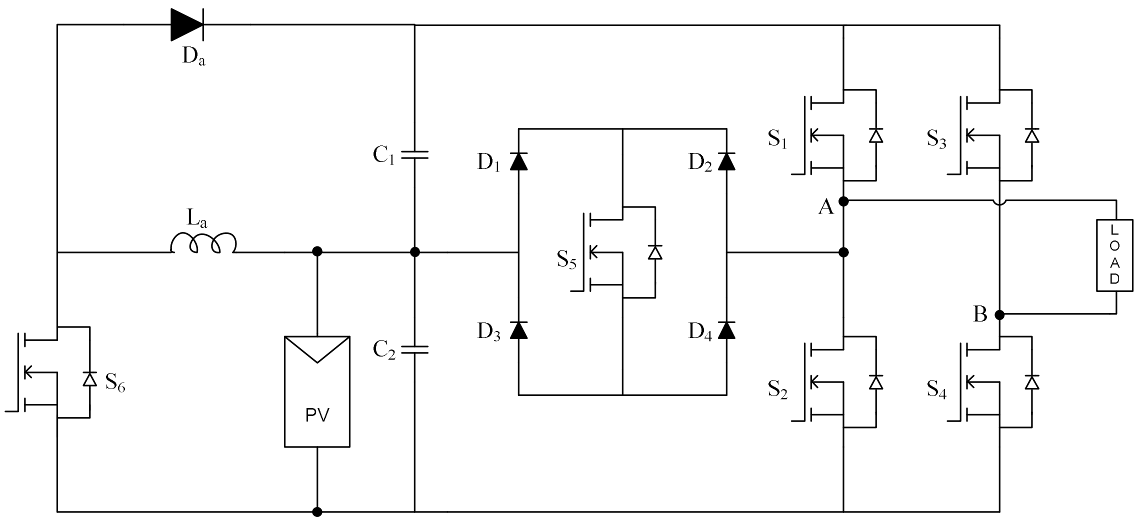


Fig. 1. Proposed Five-Level Inverter for Standalone Operation.

In the mode of operation of Fig. 2(a), the switches S_1 and S_4 are ON and remaining switches are in OFF state which works like normal H-bridge. During this state, the output level of $+2V_{dc}$ is produced. In the next configuration of Fig. 2 (b), the switches S_2 and S_3 are ON and remaining switches are in OFF state. During this state, the output level of $-2V_{dc}$ is produced. For the zero level, either S_1S_3 or S_2S_4 are in ON state that can be observed from the Fig. 2(c) & Fig. 2(d). In the configuration of Fig.2(e), the switches S_4, S_5 are ON and remaining switches are in OFF state. The diodes D_1 and D_4 conducts during this mode of operation. Hence, during this state, the output level of $+V_{dc}$ is produced. In the next configuration of Fig. 2(f), the switches S_3, S_5 are ON and remaining switches are in OFF state. The diodes D_2 and D_3 conducts during this mode of operation. Hence, during this state, the output level of $-V_{dc}$ is produced.

TABLE. I SWITCHING STATES FOR DIFFERENT LEVELS OF THE OUTPUT VOLTAGES FOR FIVE LEVEL T-TYPE INVERTER

Switching state					Output Voltage (V_{ab})
S1	*S2*	*S3*	*S4*	*S5*	
1	0	0	1	0	$+2Vdc$
0	0	0	1	1	$+Vdc$
0	1	0	1	0	0
1	0	1	0	0	0
0	0	1	0	1	$-Vdc$
0	1	1	0	0	$-2Vdc$

In order to generate the switching signals for the switches (S_1-S_5), a single carrier is compared with two modulating waveforms (Ma1, Ma2) as shown in the Fig. 3. The carrier frequency is 20 kHz and the fundamental modulating frequency is 50Hz. Two modulating waveforms with the magnitude of 0.95 and 0.4 are implemented in the PWM generation. The logic involved in the generation of switching pulses from S_1-S_5 is shown in Fig. 4.

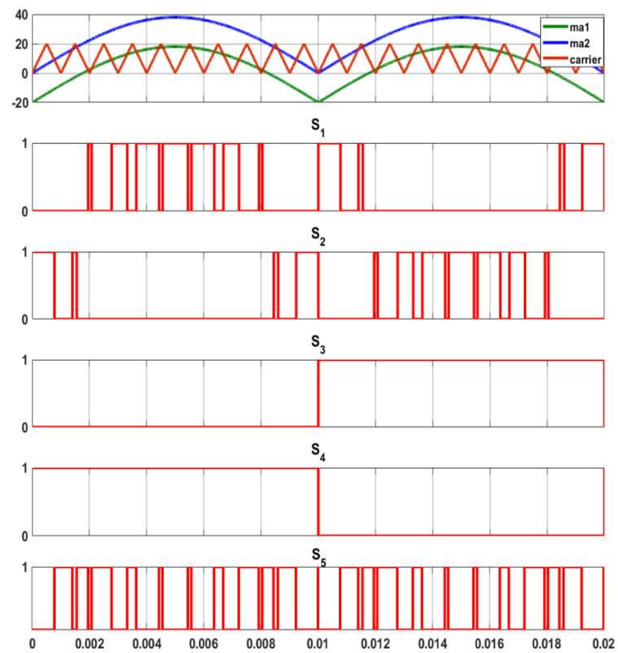


Fig. 3. Pulse generation for T-Type inverter.

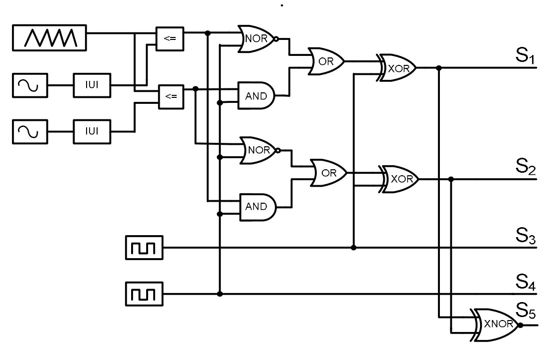


Fig. 4. Logic circuit for T-Type inverter.

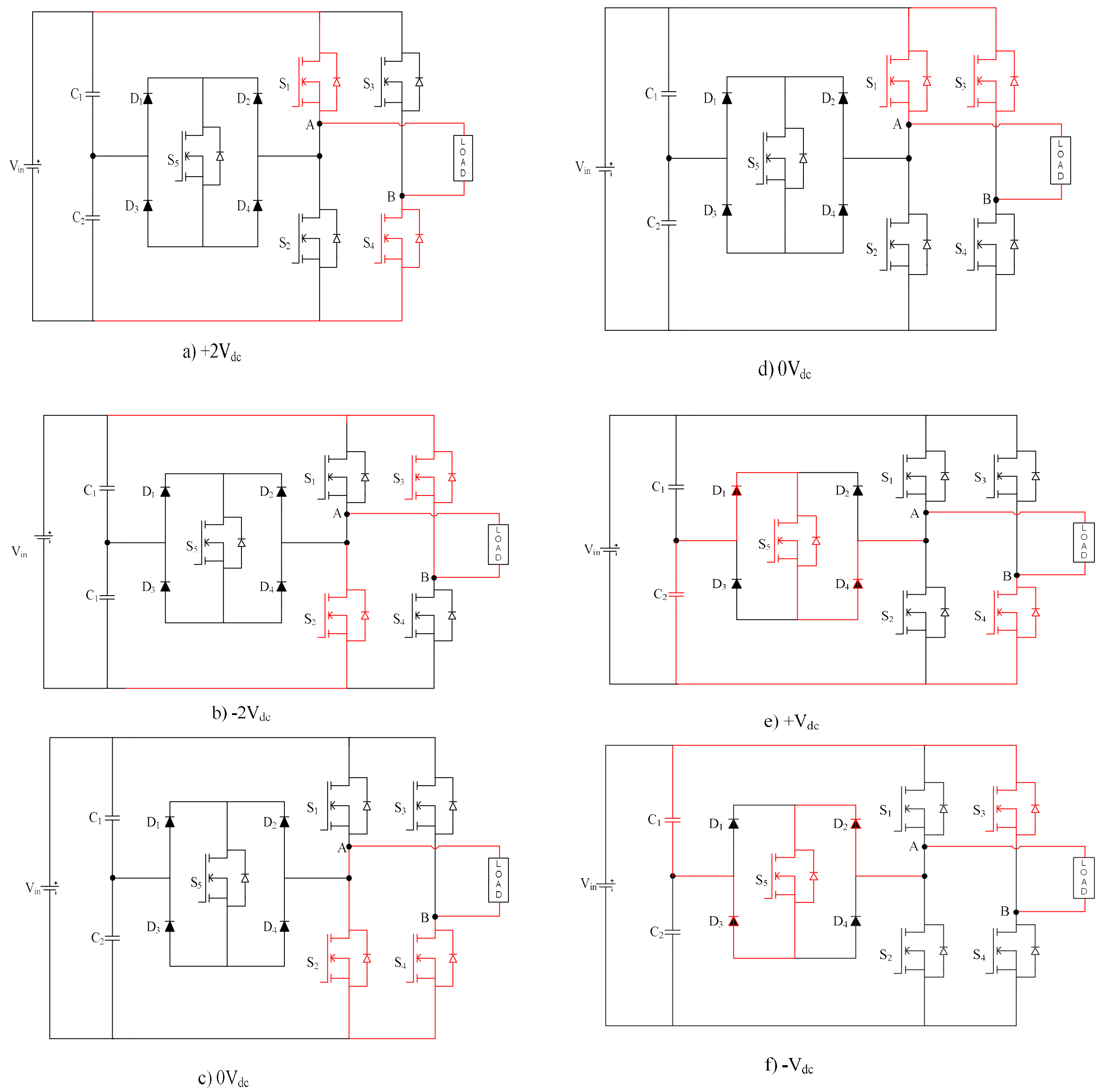


Fig. 2. Switching states for five level output voltage generation.

TABLE. II COMPARISON OF DIFFERENT FIVE-LEVEL INVERTER TOPOLOGIES

Parameters		Neutral Point Clamped Topology	Flying capacitor Topology	Cascaded H-Bridge Topology	Ref. [2]	Ref. [3]	Ref. [4]	Ref. [5]	Proposed
Components	Diodes(excluding body diodes)	6	0	0	6	4	2	1	5
	Switches	8	8	8	5	10	10	8	6
	Capacitors	4	10	2	4	2	1	2	2
	Inductors	0	0	0	2	1	0	0	1
	Input sources	1	1	2	1	1	1	1	1
Shoot through states		No	No	No	Yes	Yes	No	No	No
Output voltage		Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes

* Yes- Buck/Boost Capability

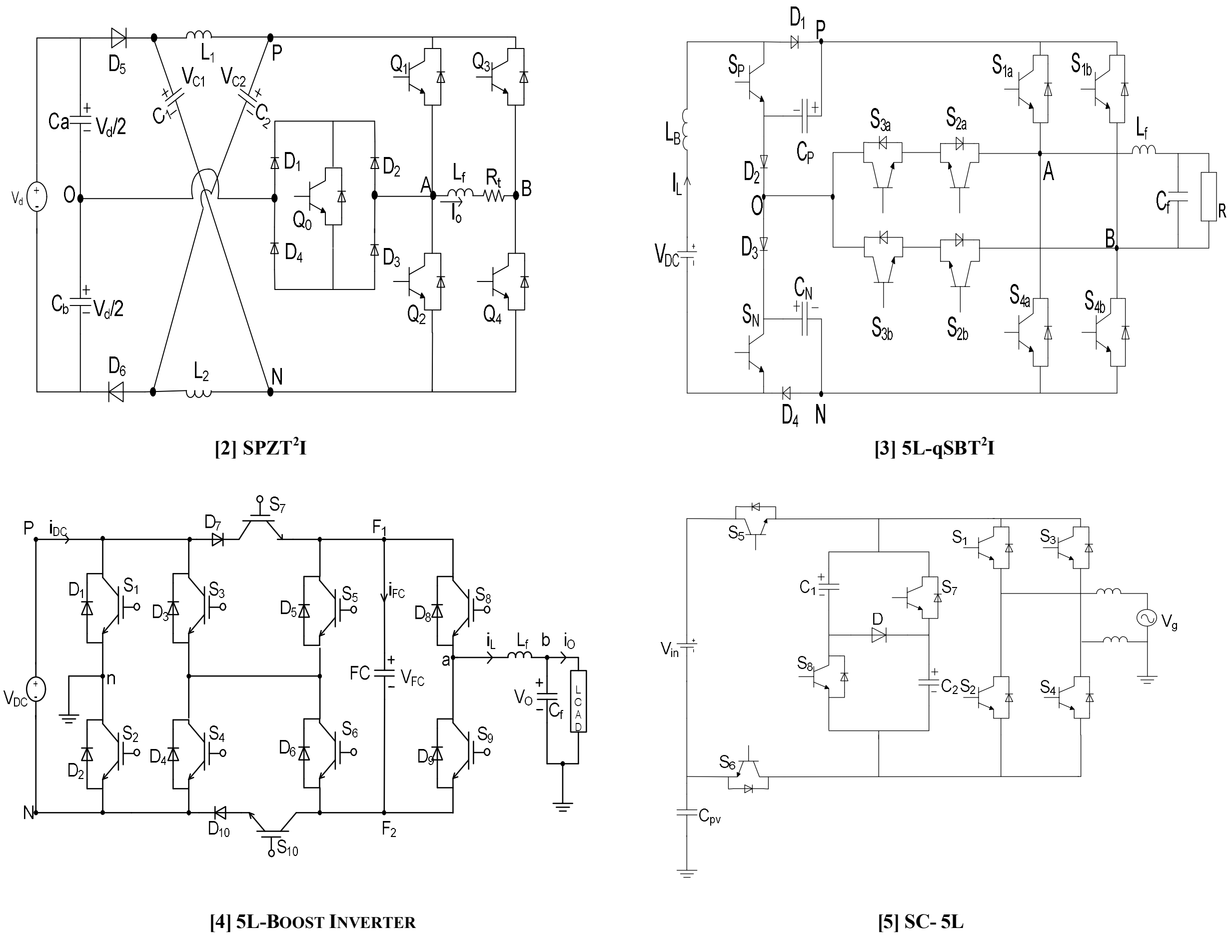


Fig. 5. Various single phase five-level inverter topologies.

III. Comparison Analysis

Table II shows the comparison study of the different topologies of five-level inverters recently proposed by various researchers. The comparison mainly consists of components like diodes, switching devices, inductors, capacitors, no. of sources. The proposed topology has a voltage boosting capability when compared with the conventional multilevel inverter topologies of NPC, FC, and CHB MLIs. The number of switching devices in proposed system is less when compared with the recently proposed topologies in [2], [3], [4] & [5] are shown in Fig. 5. Therefore, it results in the higher efficiency of the proposed topology.

IV. Simulation Results

The proposed topology is developed by using the MATLAB/Simulink to study the performance under different conditions of load changes and modulation index. The parameters used in the topology are: boost inductor of 1mH, two capacitors of 2000µF and switching frequency of 20 kHz, R=120 Ω and RL= (100 Ω +j200 mH). The input voltage given is 100V and the voltage across DC-link capacitors is 100V. As the load varies from R to RL, we can observe the output voltage remains constant as shown in Fig. 6. It can be noticed that the DC link voltage across capacitors C1 and C2 is maintained as constant for the fixed duty ratio of 0.5 as shown in Fig. 7.

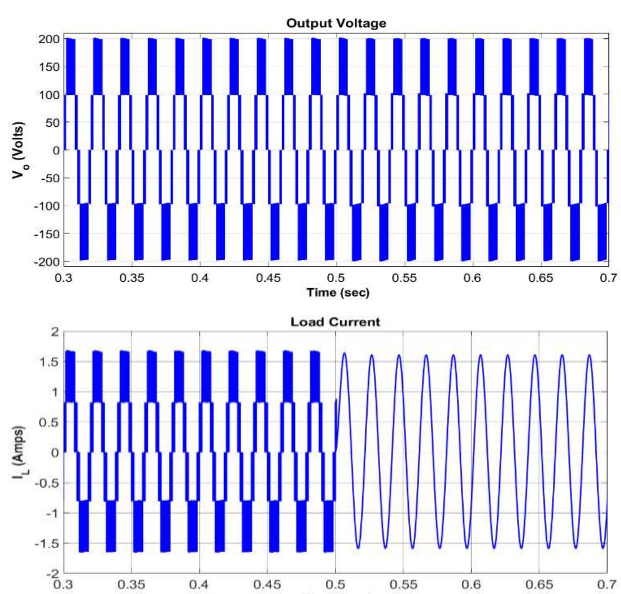


Fig. 6. Simulation results of Output voltage and output current.

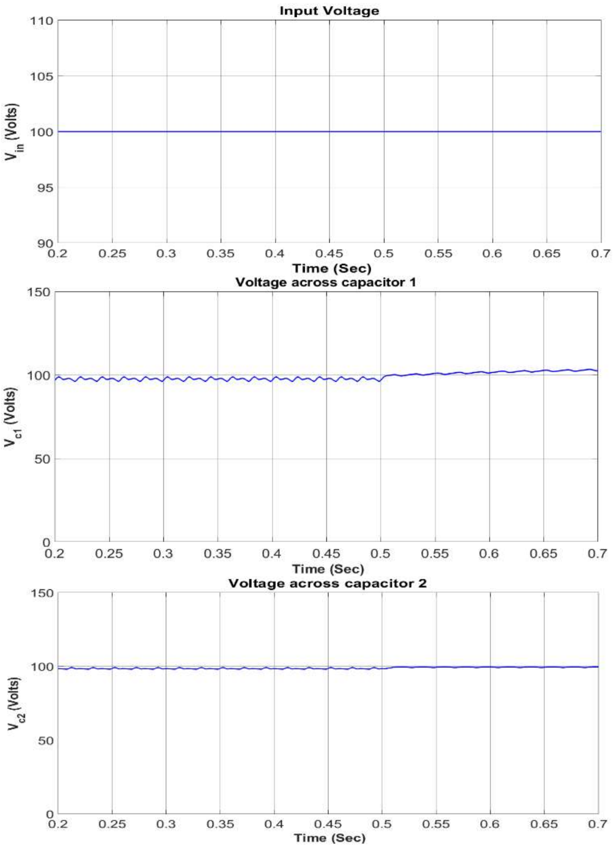


Fig. 7. Waveforms of input voltage and dc link voltages.

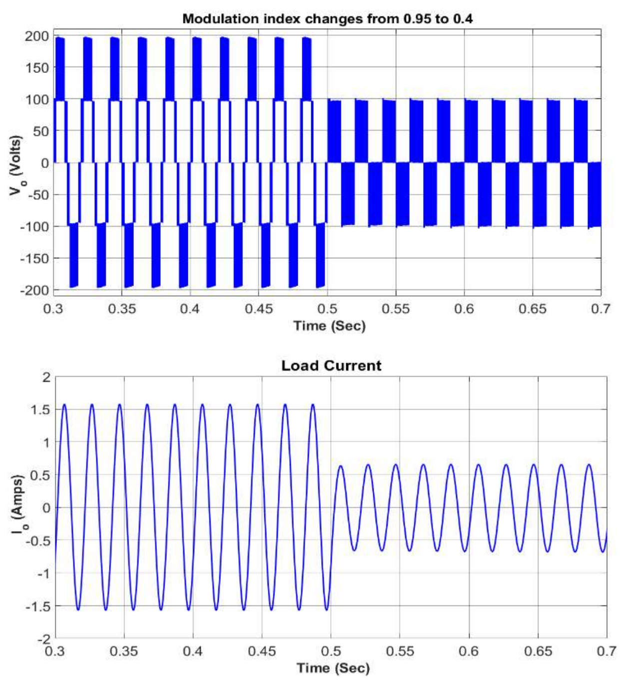
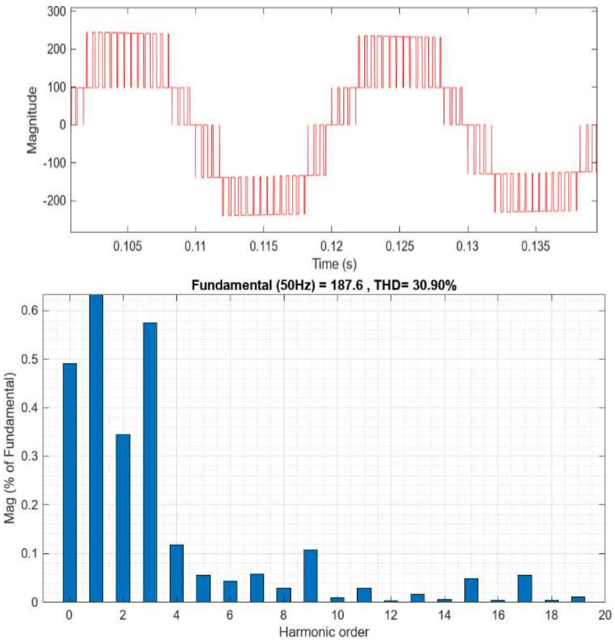
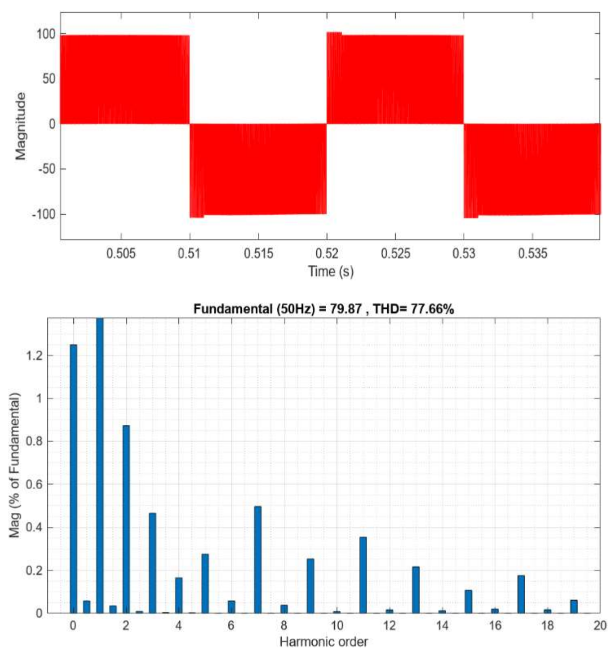


Fig. 8. Waveforms of output voltage and current with varying modulation index.



(a)



(b)

Fig. 9. FFT analysis for (a) m_a=0.9 and (b) m_a=0.4.

It can be well regulated with the introduction of simple PI controller. Fig. 8 shows the variation of modulation index results in variation of the output voltage. As the modulation index (m_a) decreases from 0.95 to 0.4, the output voltage is decreased from five level output into two level. Moreover, Fig. 9 shows the total harmonic spectrum for five level output and two-level output voltage waveforms. It is observed that the THD of the waveforms reduced for an increase in output voltage level with reduced component is an additional merit of the proposed system for PV applications.

V. Conclusion

This paper presents a new two-stage five level T-type inverter in which boost converter is used to adjust the capacitor voltages. By using the boost converter, the voltage is boosted to twice the input voltage and five voltage levels are generated with reduce number of devices. The advantage of the proposed topology is showed in comparison with the other existing topologies in terms of device counts and its boosting capability. Moreover, the proposed topology is tested for the change in modulation index and load changes in MATLAB software. We can observe that as the number of levels increases, the %THD decreases which contributes to reduce the output filter size. The accuracy of the proposed system is validated by using the simulation and experimental results. From the above analysis, the proposed system is best suitable for PV applications.

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