A NEW MULTI-LEVEL INVERTER WITH REVERSE CONNECTED DUAL DC TO DC BOOST CONVERTER MODELLING AND SIMULATION

Yerukala Shravani [1]

[1]*PG student/ Dept. of EPS, PVKK Institute of Technology, Andhra Pradesh, India*

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Abstract – It is very important to drive loads and control the electrical devices with changing electrical energy levels and change a voltage form. While DC-DC boost converters are used to change the value level of direct current (DC) electrical energy, inverters are used to change its form such as alternating voltage. Unlike these studies in the literature, for the first time, dc-dc boost converters are used to a new device structure to convert dc electrical energy into alternating current (AC) electrical energy and they can also change an amplitude of the multi-level voltage. So, the paper presents a multi-level inverter with reverse connected dual dc to dc converter. Firstly, the circuit structure and the signals that control the circuit are given and the operating logic is explained. Then, the proposed circuit is gradually modelling in MATLAB Simulink. After that, the circuit is operated in MATLAB Simulink and its performance is measured. According to the results obtained, the new circuit structure gives hıghly successful results.

Key Words: Reverse connected, Pulse Width Modulation, Multi-level inverter, new circuit structure, dual dc-dc boost converter, voltage form.

1.INTRODUCTION

DC-DC converters are used to drive a load and control performance depending on the character of the load by changing the level of the direct-current voltage on the load[1-4]. These converters can be multi-level and multi-output but have been used to change the dc voltage level so far[5-7]. They have never been used as an inverter. Inverters have been used for loads that require alternating energy by converting the dc voltage to alternating voltage[8-10]. These inverters have been involved in many studies as multi-level and none-level inverters. Z source inverters[11-13] can generate an output voltage higher than the input voltage on the load, while multi-level inverters convert the input voltage into alternating voltage in steps on the load[14-17]. Multilevel inverters cannot generate an alternating voltage higher than the input voltage on the load. Therefore, for the first time in this study, dc-dc converters are used for multilevel inverter design. In this proposed circuit structure, two dc-dc converters connected to the load create a much higher voltage than the source voltage as a second step voltage on the load. The voltage that creates a high level can be adjusted by changing the working rate of the switch of the dc-dc converter. Thus, a multi-level voltage can be generated by adjusting the high level of the multi-level voltage. In the first section, the inverter circuit with a double dc-dc converter is given via four different circuit models for four different runtimes. There are different timed PWMs that allow these four different circuit models to be created. Circuit operating logics and mathematical equations are created according to the operating conditions of these PWMs. In the second part, the proposed circuit structure is gradually modeled by creating subsystems in MATLAB Simulink and a multi-level inverter structure is introduced. After that, simulation of the proposed circuit is done in MATLAB Simulink according to the circuit structure and operating logic. At the application stage, a multi-level alternating voltage is produced on the resistive (R) load.

While the first step on the load occurs at the voltage input source levels, the voltage forming the second step is a much higher voltage than the input voltage created by the dc-dc converter. The results obtained show that for the first time in the literature, with the inverter structure with dc-dc converter, higher multi-level voltages than the input source are created on the load. A multi-level voltages of the inverter can be obtained by changing the operating rates of the switches of the converters of current and voltage on load are measured in different modulation indexes and presented in graphics. The converter and inverter structures in the circuit are modeled with subsystems and application is made for RL load. In the application made for RL load, the load is driven with the proposed inverter for different frequencies and different modulation indexes. The current and voltage formed at this load are measured and the harmonic distortion of the current measured and voltage is given. When the distortion values obtained are analyzed, the distortion value of the current is below 4%, which is the distortion rate of international standards. Looking at the results obtained, new multilevel inverter hardware is presented, which can generate second and third level voltages on the load depending on the operating rates of the converter switches after creating the first level voltage on the load at the source level. This situation is quite different from the studies presented in [18-21] up to this day and it is new. The circuit proposed for each modulation index have more voltage gain than conventional converters ever made in[22-25].

2. Circuit structure and control signals of Paper

Fig 1 shows the multi-level inverter circuit with the reverse connected double dc-dc converter. There are six switches in this inverter circuit. These power switches range from switch 0 to switch 5. There are two equal DC voltage sources. These dc voltage sources are V and V1. There are four ideal diodes. These ideal Diodes rank from diode to Diode 3. There are two equal capacitors. These capacitors are C1 and C2. As a load, there is an RL load formed by connecting the resistive (R) and inductive (L) elements in series. Fig 2 shows the pulse width modulation (PWM) signals that control the inverter circuit.

The four stages of PWM create four different circuits for four different times. While the first two stage PWM constitute the positive part of the alternating voltage, the third and fourth stage PWM constitute the negative part of the alternating voltage. Fig 3 demonstrates the four stages of PWM creating four different circuits for four different times. In order to better show the working logic of the circuit, the active elements of the circuit are given in black. Inactive ones are made transparent.

When stage 1 PWM is initially running the circuit, the first stage circuit model occurs. Switch 0 of the circuit in Fig 3a is active to generate the first step.

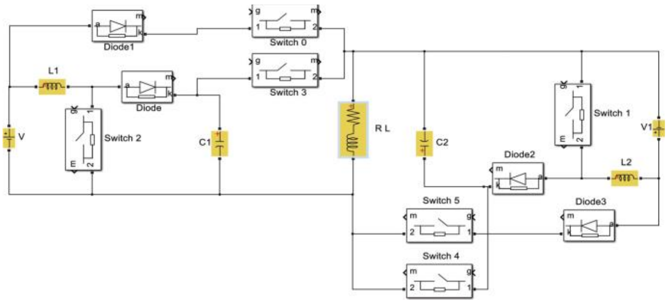

Fig -1: The multi-level inverter circuit with the reverse connected double dc-dc converter.

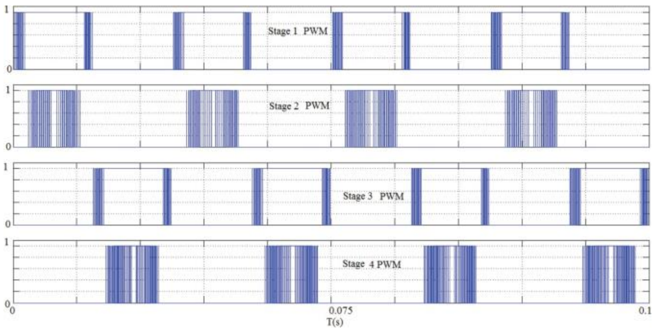

Fig -2: Shows the pulse width modulation (PWM) signals controlling the inverter circuit.

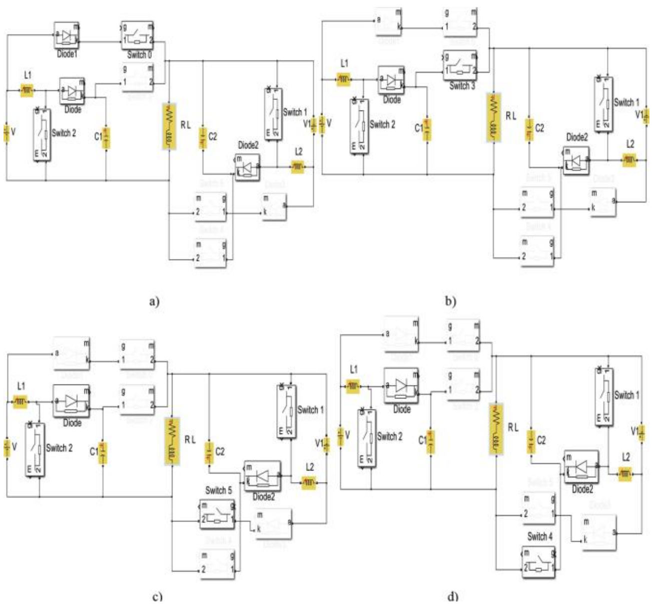

Fig -3: Four different circuits for four different times, a) stage1, b) stage 2, c) stage 3, d) stage 4.

Voltage of the positive cycle of alternating voltage. Switch 2 and switch 1 of the converter circuits are active with switching times of 0.01ms. The converter circuits store voltage in capacitors C1 and C2 for the second stage of alternating voltage.

When stage 2 PWM operates the circuit in Fig 1, the circuit model in Fig 3b occurs. Switch 3 is active for generating the second step voltage of the alternating voltage. Switch 3 activates the converter voltage which will form the high level of the positive side of the alternating voltage from capacitor C1 to the RL load. The converter voltage, which will constitute the second step of the negative side of the alternating voltage via switch 1, continues to be stored on the capacitor C2. In this phase, switch 0, switch 4 and switch 5 are not active.

After stage 3 PWM is running the circuit, the third stage circuit model in Fig 3c occurs. Switch 5 of the circuit in Figure 3c is active to generate the first step voltage of the negative side of alternating voltage. Switch 2 and switch 1 of the converter circuits are active with switching times of 0.01 ms. The converter circuits store voltage in capacitors C1 and C2 for the second stage of alternating voltage. When stage 4 PWM operates the circuit in Fig 1, the circuit model in Fig 3d occurs. Switch 5 is active for generating the second step voltage of the alternating voltage. Switch 5 activates the converter voltage which will form the high level of the negative side of the alternating voltage from capacitor C2 to the RL load. The converter voltage, which will constitute the second step of the positive side of the alternating voltage via switch 2, continues to be stored on the capacitor C1. In this phase, switch 0, switch 3 and switch 5 are not active.

V = is V1; V and V1 are V. V is converter source. D is duty ratio of converter switches. V_C is converter output voltage. V_C is calculated as in Eq. (1).

$$V_C = \frac{V}{(1-D)} \qquad (1)$$

ω is the angular frequency. The first step voltage is dc source voltage V. The second step voltage is the converter output voltage and is added to the first step voltage value. Thus, the maximum value of the alternating voltage (V_m) to be produced can be expressed as in Eq. (2).

$$V_m = \frac{V}{(1-D)} + V\,Sin\omega t \qquad (2)$$

Equality (2) can be arranged as follows:

$$V_m = \left[\frac{V+V(1-D)}{(1-D)}\right] Sin\omega t \qquad (3)$$

$$V_m = \left[\frac{(1+(1-D)}{(1-D)}\right] V\,Sin\omega t \qquad (4)$$

$$V_m = \left[\frac{(2-D)}{(1-D)}\right] V\,Sin\omega t \qquad (5)$$

T is the period of alternating voltage. The average value of this voltage V_a can be expressed as in Equ. 6.

$$V_a = \int_0^{T72} \left[\frac{(2-D)}{(1-D)}\right] VSin\omega tdt \qquad (6)$$

Frequency f is the alternating voltage repetition. The angular frequency is in Eq. (7).

$$\omega = 2\pi f \qquad (7)$$

The frequency f is in Eq. (8).

$$f = \frac{1}{T} \qquad (8)$$

Equality (6) for average voltage (Va) can be arranged as follows:

$$V_a = \int_0^{T/2} \left[\frac{(2-D)}{(1-D)}\right] VSin\frac{2\pi}{T}dt \qquad (9)$$

$$V_a = \left[\frac{(2-D)}{(1-D)}\right] V(-\frac{2\pi}{T}\cos\frac{2\pi}{T}t\, I_0^{T/2} \qquad (10)$$

$$V_a = \frac{V}{\pi}\left[\frac{(2-D)}{(1-D)}\right] \qquad (11)$$

In conventional circuit converters and the inverters whose converter in [23–25] is connected to the input, the voltage gain (C_g) is as in Eq.12 while the proposed circuit gain (PC_g) is in Eq.13.

$$C_g = \frac{1}{(1-D)} \qquad (12)$$

$$PC_G = \left[\frac{(2-D)}{(1-D)}\right] \qquad (13)$$

If the voltage gains of the circuits are calculated for the 0.4 modulation index, results such as Equations 14 and 15 are obtained.

$$C_g = \frac{1}{(1-0.4)} = \frac{1}{(0.6)} = 1.66 \qquad (14)$$

$$PC_G = \frac{(2-D)}{(1-D)} = \frac{(2-0.4)}{(1-0.4)} = 2.66 \qquad (15)$$

Table -1: Voltage gains of circuits in different modulation indexes.

MI	Conventional circuit	Proposed circuit	MI	Conventional circuit	Proposed circuit
0.4	1.66	2.66	0.65	2.85	3.85
0.45	1.81	2.81	0.7	3.33	4.33
0.5	2	3	0.75	4	5
0.55	2.22	3.22	0.8	5	6.25
0.6	2.5	3.5	0.85	6.66	7.66

As shown at calculation, the voltage gain in the proposed circuit is 2.66, while the voltage gain of conventional dc-dc converters is 1.66. Voltage gains of circuits in different modulation indexes (MI) are given in Table 1. According to the values obtained in Table 1, the voltage gain of the circuit that is operated with 0.5 modulation index is 3 while the gain in conventional circuits is 2. In a high modulation index of 0.85, the voltage gain of the proposed circuit is 7.66 while the voltage gain of traditional circuits is 0.66.

The circuit proposed in the calculation for each modulation index appears to have more voltage gain than conventional converters ever made.

3. Application and performance of the circuit

Multi-level inverter with reverse connected dual dc- dc converter for simulation is in Fig 4. Six IGBT switches are used for the implementation of the circuit. There are four ideal diodes.

There are two equal capacitors and two equal inductors in the converter circuit; 0.1 ms are the switching times of the switches in the converter circuits. In the application of the circuit, 80 Hz alternating voltage and current are created. These voltages and currents are created for different modulation indices; 50 Ω of the resistive load is used as the first load. L1 = L2 = 1mH. Converter capacitors are 1mF.

When the modulation index of PWMs applied to converter switches is 0.7, the voltage and current on the load can be seen in fig 5.

In this modulation index, 360 V of alternating voltage is generated, while 7 A alternating current occurs as in figure 5. An alternating voltage of 350 Volts is successfully generated from the dc 100 Volt of the Input voltage. A voltage that is 160% higher than the input source voltage is obtained on the load. When the converter switches are operated in the 0.4 and 0.7 modulation indexes, the alternating voltage on the load can be seen in fig 6.

Converter switches are operated at 0.7 modulation index for up to 0.075 secs. After 0.075 secs, they are operated at 0.4 modulation index. The circuit working with 0.7 modulation index creates 430 V of multilevel alternating voltage on the load.

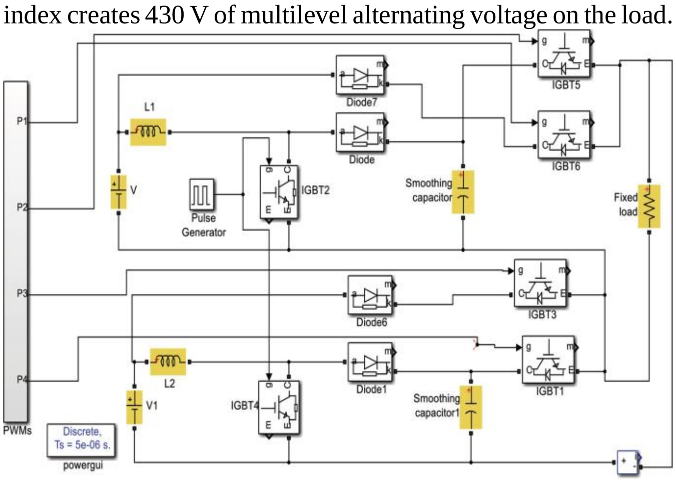

Fig -4: Multi-level inverter with reverse connected dual dc-dc converter for simulation.

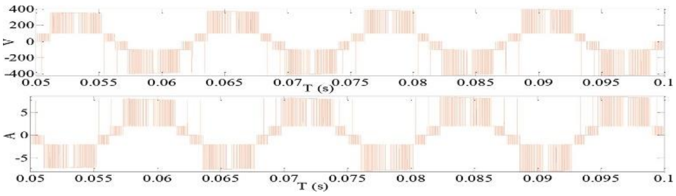

Fig -5: The voltage and current for 0.6 of modulation index on the load.

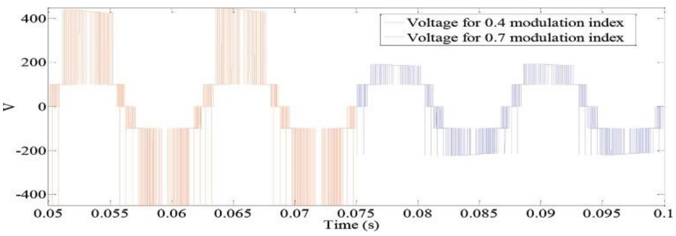

Fig -6: Alternating voltage for the 0.4 and 0.7 modulation indexes.

While the modulation index decreases to 0.4, it creates 260 V on the load after 0.075 secs. When the converter circuits in the inverters work with different modulation indexes, the voltages on the load can be seen in Fig 7.

A multi-level alternating voltage of 300 V in the proposed circuit is generated on the load from the100 V input source for the 0.5 modulation index. A voltage gain of 200% occurs. The multi-level alternating voltage on the load for the 0.6 modulation index is 350 V, while the load voltage on the 0.7 modulation index is 433 V. The voltage gains are 250% and 333%, respectively. A multi-level alternating voltage of 600 V is generated on the load from the 100 V input source for the 0.8 modulation index. Conventional circuit voltage on load is 198

V at 0.5 of modulation index while it is 500 V at 0.5 of modulation index.

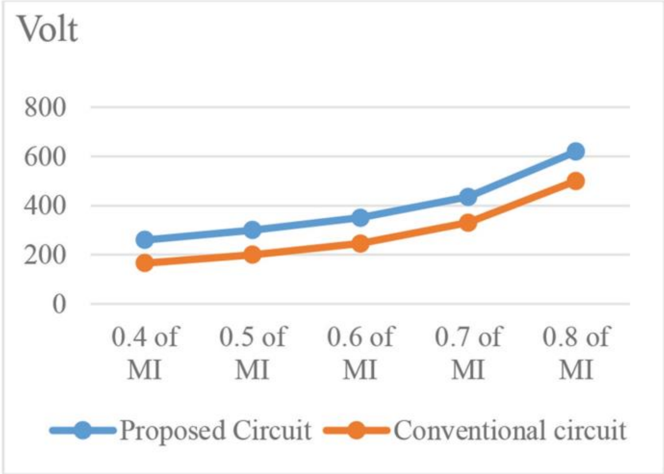

Fig -7: Voltages on load for modulation index.

When the converter circuits in the inverter work with different modulation indices, the current values on the load can be seen in Fig 8.

An alternating current of 5.2 A for in the proposed circuit is generated on the load for the 0.4 modulation index. The alternating current on the load for the 0.6 modulation index is 7 A, while the load current on the 0.7 modulation index is 8.66 A. The multi-level alternating voltage of 600 V is generated on the load from the 100 V input source for the 0.8 of modulation index. Conventional circuit current on load is 4 A at 0.5 of modulation index while it is 10 A at 0.5 of modulation index.

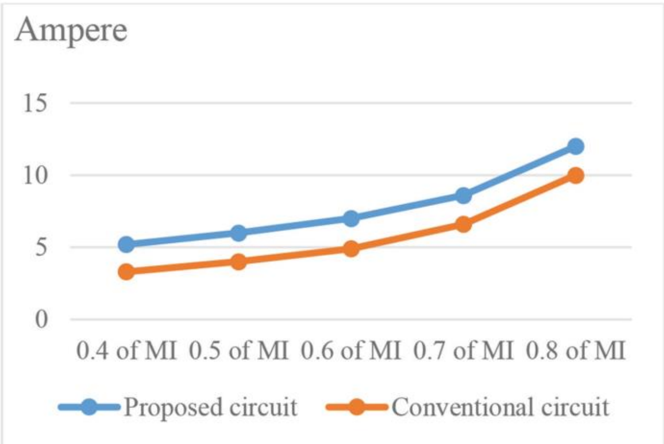

Fig -8: Currents on load for modulation index.

While the converter circuits in the inverter work with different modulation indices, the power values on the load can be seen in Fig 9.

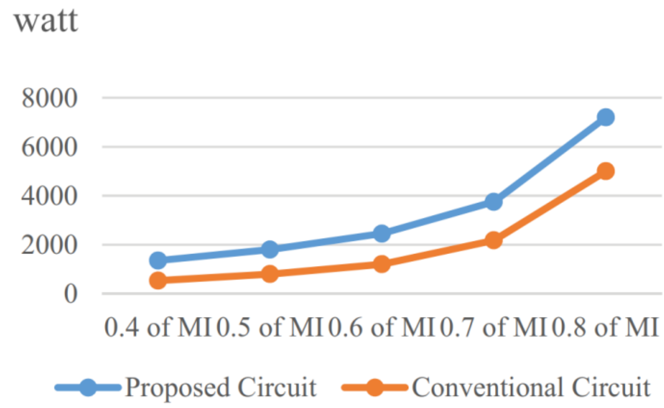

Fig -9: Powers on load for modulation index.

The power generated on the load in the modulation index of 0.4 is 1352 W for the proposed circuit. The power generated in the 0.5 modulation index is 1800 W. When the 0.8 modulation index controls the switches in the converter circuit, the power on the load is 7200 W. As the modulation index increases, the growth rate of the power on the load increases. While the power generated by the conventional converter on the load is 531 W in the 0.4 Modulation index, the power it provides to the load when working with the 0.8 modulation index is 500 W. As a result of the work done and comparisons, the proposed circuit has a higher performance than traditional and known circuits [24,25].

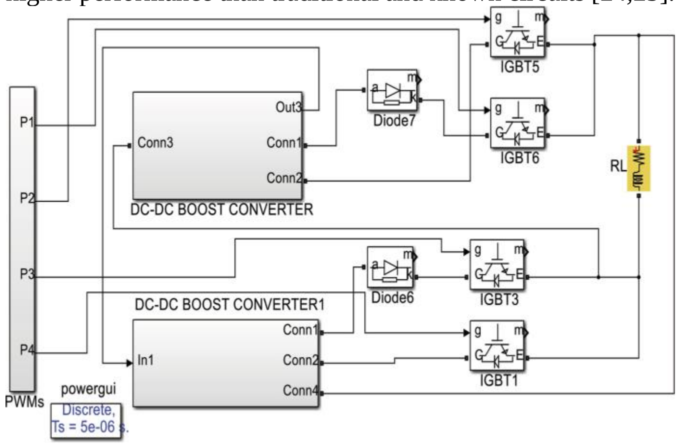

Fig -10: The subsystem created for the converter circuits in the proposed circuit at the Matlab Simulink.

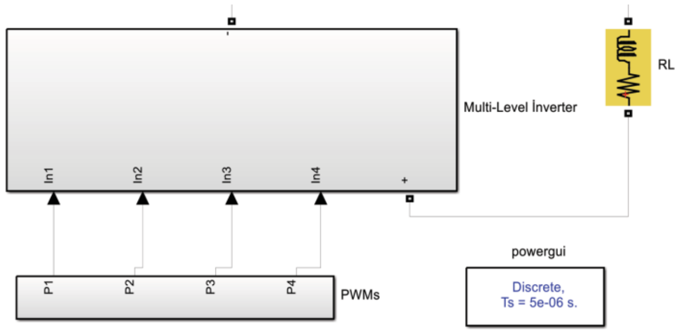

Fig -11: The subsystem created for multilevel inverter in the proposed circuit at the Matlab Simulink.

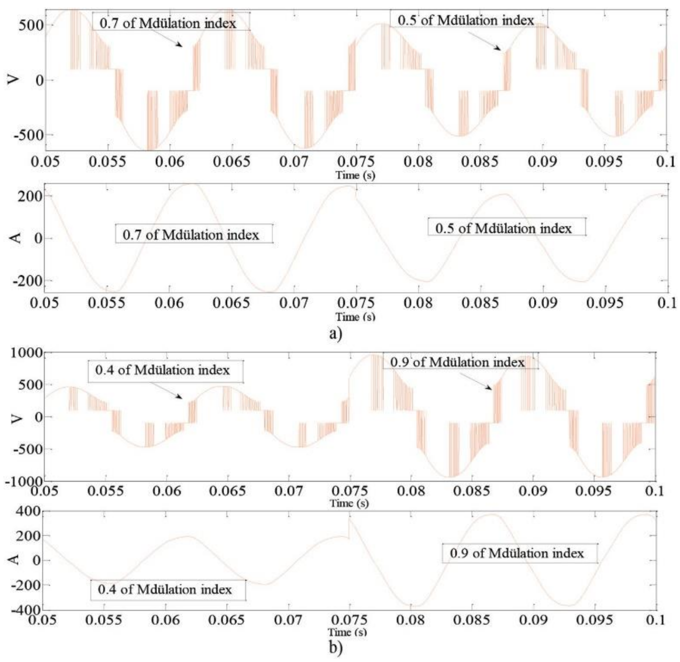

Fig -12: The voltage and current on RL load a) for 0.7 and 0.5 modulation indexes b) for 0.7 and 0.5 modulation indexes.

The voltage and current obtained on RL load in simulation for different modulation indexes are as given in fig 12. R = 0.2Ω, L = 5mH. Input voltage is100 V of DC voltage. In order to drive RL loads, when the subsystem is created for the converter circuits in the proposed circuit, the circuit in Fig 9 is created. When the subsystem is created for the multi-level inverter in the proposed circuit at the MATLAB Simulink, the circuit in Fig 11 is created.

Up to 0.075 secs, the load current in fig 12a is 280 A while converter circuits run with 0.7 modulation index. When the modulation index of the converters decreases by 0.5, the current on the load is 234 A after 0.075 sec. Until 0.075 seconds, the load current in fig 12b is 200 A while converter circuits run with 0.5 modulation index. When the modulation index of the converters decreases by 0.9, the current on the load is 370 A after 0.075 seconds. The voltage and current obtained on RL load for different frequencies are as given in Fig 13.

Up to 0.075 seconds, the load current is 280 A while converter circuits run with 80 Hz of alternating voltage. When the frequency of alternating voltage increases to 160 Hz after 0.075 sec, the current is 140 A. According to the results obtained. Up to 0.066 secs, the load current is 180 A while converter circuits run with 60 Hz of alternating voltage. When the frequency of alternating voltage increases to 120 Hz after 0.066 sec, the current is 320A. According to the results obtained. The proposed circuit performs successfully both in modulation index changes and frequency changes. Total Harmonic Distortions (THD) of the current and voltage formed on the RL load can be seen in Figs 14 and 15.

The distortion of the 514 V alternating voltage created at 80 Hz at the RL load is 18.43% as in Fig 14. If a normal PWM inverter is used instead of the recommended circuit or if the converter is disabled, the distortion value will be close to 100%. Therefore, the proposed method has performed better than conventional inverters. The disturbance of the alternating cur- rent of 204.4 A generated at 80 Hz at RL load is 3.53% as in Fig 15. According to international IEEE standards, the acceptable distortion value in the current is below 4%. Therefore, the performance of the proposed method is acceptable. Total Harmonic Distortions (THD) of the currents formed on the RL load in different modulation indexes are given in Fig 16.

When the converter circuits are working with 0.4 modulation index, the current disruption on the RL load is 3%. With a 0.6 modulation index, the converter creates voltage steps on the RL load while THD is 3.8%.

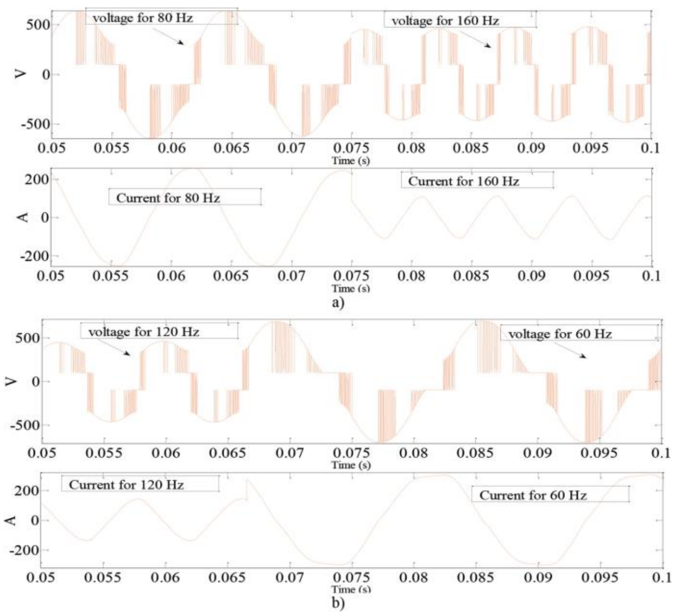

Fig -13: The voltage and current on RL load: a) for 80 Hz and 160 Hz b) for 120 and 160 Hz.

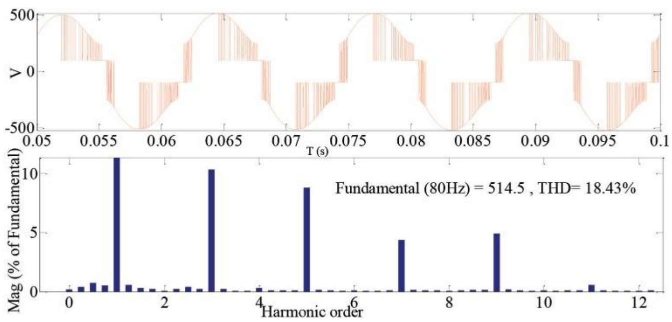

Fig -14: Alternating voltage and THD.

In the 0.8 modulation index, the distortion of the cur- rent on the load decreases by 2.8%. Total Harmonic Distortions (THD) of the currents formed on the RL load in different frequencies are given in Fig 17.

When the converter circuits are working with 60 Hz of frequency, the current disruption on the RL load is 4, 2%. With an 80 Hz of frequency, the converter creates voltage steps on the RL load while THD is 3.5%. In 80 Hz of

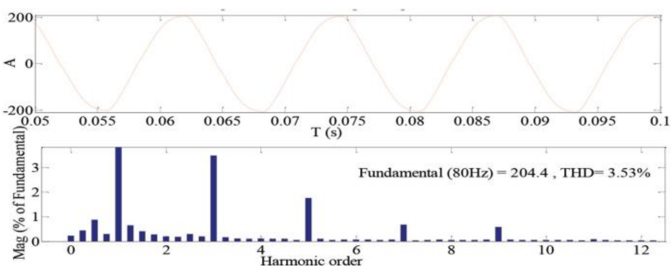

Fig -15: Alternating current and THD.

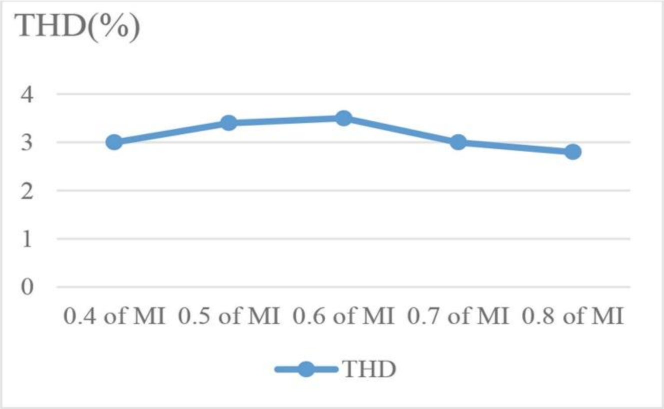

Fig -16: Total Harmonic Distortions of the currents formed on the RL load in different modulation indexes.

Different voltages are obtained as in Fig 18 and 19 when the load values are replaced by 0.1 ohms for R and 5 mH for L.

Fig 18 shows the alternating currents at 80 Hz when the converter units are working with the modulation index of 0.8 and 0.5. For the 0.8 modulation index, alternating currents of 500 A with 120 degree of phase different occur on the load, for the 0.5 modulation index, alternating currents of 300 A with 120-degree phase different occur on the load.

Fig 19 shows the alternating currents for 80 Hz and 160 Hz when the converter units are working with the modulation index of 0.8 for the 160 Hz of frequency, alternating currents of 500 A with 120 degree phase different occur on the load, for the 80 Hz of frequency, alternating currents of 150 A with 120 degree phase different occur on the load frequency, the distortion of the current on the load decreases by 4.2%. The multi-level inverter circuit tested in different modulation indices and at different frequencies is at acceptable values for the distortion of the currents it creates on the load. Thus, unlike the inverter circuits studied in [22,26] so far, an inverter circuit model with a dc-dc converter structure has been successfully presented. One hundred and twenty degrees of phase.

4. Conclusions

This paper presented a new multi-level inverter with reverse connected dual dc to dc converter. Firstly, signals controlling the circuit structure, and the operation algorithm of the circuit were given. The circuit's logic of operating was explained and the mathematical equations of the circuit were created in line with this logic. In the application of the circuit for 50 Ω of resistive load, 80 Hz alternating voltage and current are created. These voltages and currents are created for different modulation indices. A multi-level alternating voltage of 300 V was generated on the load from the 100 V input source for the 0.5 of modulation index. A voltage gain of 200% occurred. The multi-level alternating voltage on the load for the 0.6 modulation index was 350 V, while the load voltage on the 0.7 modulation index was 433 V. The voltage gains were 250% and 333%, respectively. A multi-level alternating voltage of 600 V was generated on the load from the 100 V input source for the 0.8 modulation index. After that, the voltage and current were obtained on RL load in simulation for different modulation indexes. Up to 0.075 sec, the load current was 280 A while converter circuits operated with 0.7 modulation index. When the modulation index of the converters decreased by 0.5, the current on the load was 200 A after 0.075 sec

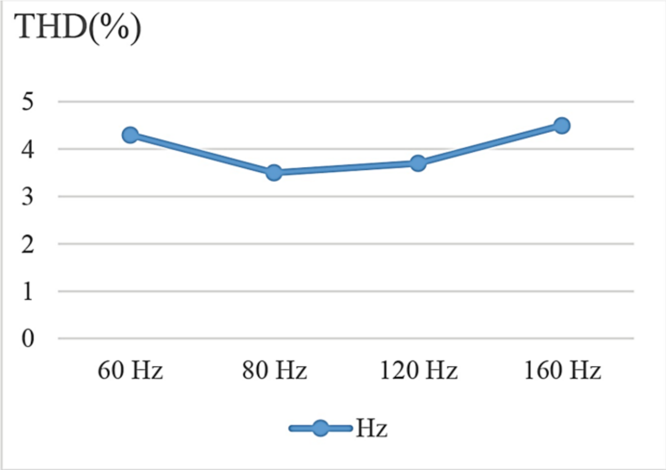

Fig -17: Total Harmonic Distortions of the currents formed on the RL load in different frequencies.

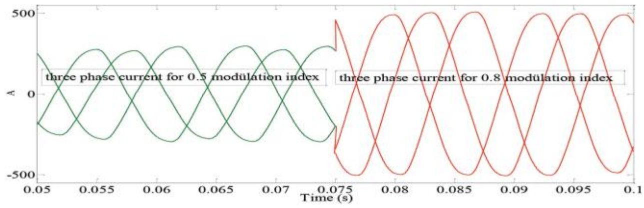

Fig -18: The alternating currents at 80 Hz when the converter units working with the modulation index of 0.8 and 0.5.

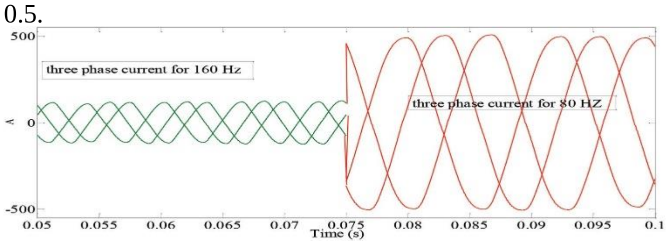

Fig -19: The alternating currents for 80 Hz and 160 Hz when the converter units working with the modulation index of 0.8.

The voltage and current were obtained on RL load for different were obtained on RL load for different frequencies. Up to 0.075 seconds, the load current was 280 A while converter circuits operated with 80 Hz of alternating voltage. When the frequency of alternating voltage increased to 160 Hz after 0.075 sec, the current was 140 A. According to the results obtained, the proposed circuit performed successfully both in modulation index changes and frequency changes. Total Harmonic Distortions (THD) of the current and voltage formed on the RL load were analyzed. The distortion of the 514 V alternating voltage created at 80 Hz at the RL load was 18.43%. If a normal PWM inverter was used instead of the recommended circuit or if the converter was disabled, the distortion value would be close to 100%. The disturbance of the alternating current of 204.4 A generated at 80 Hz at RL load was 3.53%. According to international IEEE standards, the acceptable distortion value in the current is below 4%. By considering the results obtained, the proposed method is quite successful and acceptable.

ACKNOWLEDGEMENT

The satisfaction and euphoria that accompany the successful completion of any task would be incomplete without the mention of people who made it possible, whose constant guidance and encouragement crowned our efforts with success. It is a pleasant aspect that we have now the opportunity to express our gratitude for all of them.

It is with immense pleasure that we would like to express our indebted gratitude to our Guide **Mr. E Nagabhushana, Assistant Professor, Electrical Power System**, who has guided us a lot and encouraged us in every step of the journal work. We thank him for the simulating guidance, constant encouragement and constructive criticism which have made possible to bring out this journal work.

We thank all other faculty and non-teaching staff, and our friends who had directly or indirectly helped and supported us in completing our research in time.

We also express our sincere thanks to **MANAGEMENT of PVKK institute of Technology** for providing excellent facilities.

Finally, we wish to convey our gratitude to our family who fostered all the requirements and facilities that we need.

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