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Transformer-Based Multilevel Inverter Design: Single Source Power Solutions

Journal of Electrical Systems

Abstract: - The transformer based Multilevel inverters with fewer power components are becoming increasingly popular because of their smaller size, increased efficiency and lower cost. In this paper, a novel transformer based multilevel inverter design with single power source is proposed which integrates three transformers with a four-leg inverter. A 15-level inverter design based on transformers is presented along with its switching operations. In this proposed topology the number of semiconductor devices, driver circuits, and sources decreased and the transformer galvanic isolation is also an advantage. The output voltage can be regulated by changing the turns ratio of transformer and leakage inductance also filters the harmonics in the load current. Consequently, the output voltage total harmonic distortion can be reduced. The simulation has been carried out for the proposed 15 level inverter and results were good agreement with the proposed design.

Keywords: based multilevel inverters, 15-level inverter, output voltage Total Harmonic Distortion (THD).

I. INTRODUCTION

The limitations of current energy sources and the growing need for more energy are the main causes to development of green energy. The wide spread use of PV and solar systems among Renewable energy sources is a result of recent advancements in the production of solar cells, photovoltaic systems are among the renewable energy sources that are used the most frequently. Because these systems produce DC power, power electronic inverters are required. In many industrial applications, voltage source inverters are utilized to attain three levels of load voltage by converting DC to AC. Multilevel inverters (MLIs) are gaining attention from researchers due to their advantages in high voltage and high-power applications.

Stepped voltage and low harmonic contents are provided by MLIs, and total harmonic distortion is decreased by raising the output voltage levels. In addition, switching loss is decreased and low dv/dt stress is reached, doing away with the necessity for highly rated devices. The three most popular types of MLIs are cascaded H-bridge multilevel inverters (CHBMLI), diode-clamped multilevel inverters (DCMLI), and flying capacitor multilevel inverters (FCMLI). However, DCMLIs face challenges with capacitor imbalance and regulation complexity. FCMLIs require more capacitors, increasing system noise and management difficulties. CHBMLIs, composed of series-connected H-bridge modules at low voltage with separate DC links, offer modular configuration flexibility but struggle with DC link cell charging and controlling the DC supply as levels increase.

II. BASE CASE: TRANSFORMER BASED7 LEVEL INVERTER

Fig. 1 represents circuit diagram of the suggested 7L inverter with common leg configurations by using single source. The offered topology is three half bridges with two transformers. The three half bridges terminals are coupled to two transformers primary side to produce multilevel output waveform from single source. It can clearly note that the offered inverter provides galvanic isolation. Moreover, presence of trans- formers in the suggested inverter can filters out the higher order harmonics in load voltage naturally.

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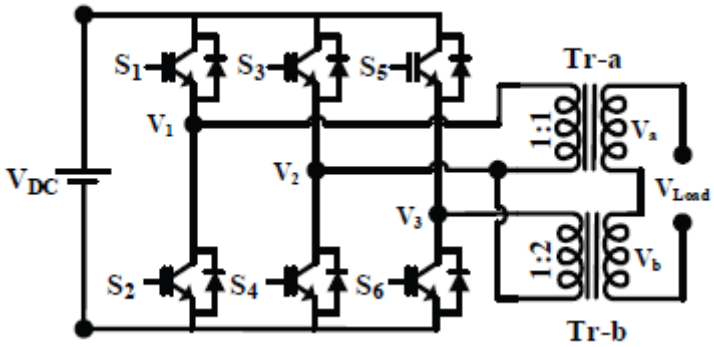


Figure1:7 Level Multilevel Inverter configuration

III. TRANSFORMER BASED MULTILEVEL INVERTER

To address the various conventional multilevel inverter issues, a transformer-based multilevel inverters have been developed. Rather of using more DC power supply, this design uses more transformers, which simplifies control and facilitates the galvanic separation of loads and sources. Inverters can be connected to the load using cascaded transformers, and by modifying the turn ratio, the transformer's output voltage may be altered. Transformer leakage reactance also filters harmonics in the inverter load current

A. Transformer Based 15-Level Inverter

To solve above problems, a new multilevel inverter topology with fewer switching components and more effective designs have been created.

A new fifteen-level inverter design based on transformers is proposed with single source. In contrast to the usual configuration, which calls for four switches per module, the recommended design need two switches only. By linking more than one module, fewer switches are needed overall, which simplifies operation and lowers energy consumption, space requirements, component counts, and prices.

B. Characteristics of the Proposed Circuit

A few characteristics of the proposed circuit include:

(i) Fewer driver circuits and power semiconductors.

(ii) Fewer necessary transformers with the recommended topology.

(iii) The advantage of galvanic isolation.

(iv) The inverter's solitary DC source.
(v) Variable load voltage through the turn ratio of the transformer.

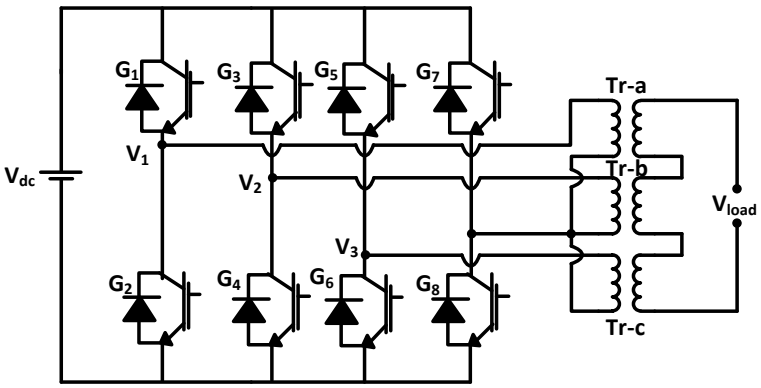
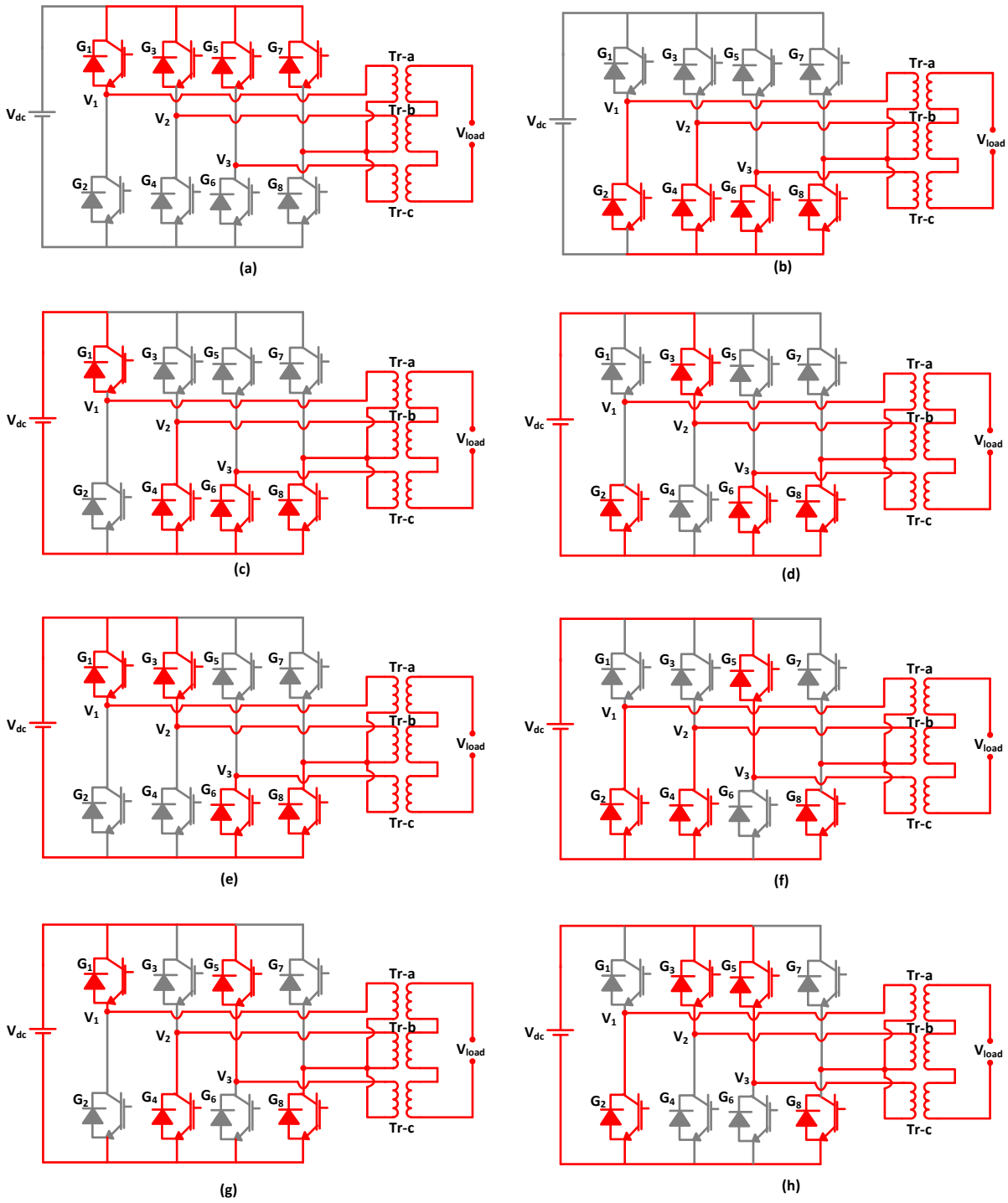


Figure 2: Proposed 15L inverter configuration

C. Modes of Operation

Fig. 2 shows An outline of the suggested 15-level circuit, which has a common arm powered by a single power source. Three transformers and four half-bridges make up the recommended topology. A multilayer output waveform is produced by connecting the terminals of the four switches to the primary sides of the three transformers. The galvanic isolation created by the inverter is easily obvious. Furthermore, higher order harmonics in the load voltage are automatically filtered out by the proposed inverter's usage of transformers.

To help comprehend the functioning of the proposed fifteen-level (15L) inverter, the states of its positive modes are shown. The several voltage-level switching modes are shown in Figure 3. Table II displays the various switching configurations of the suggested circuit.



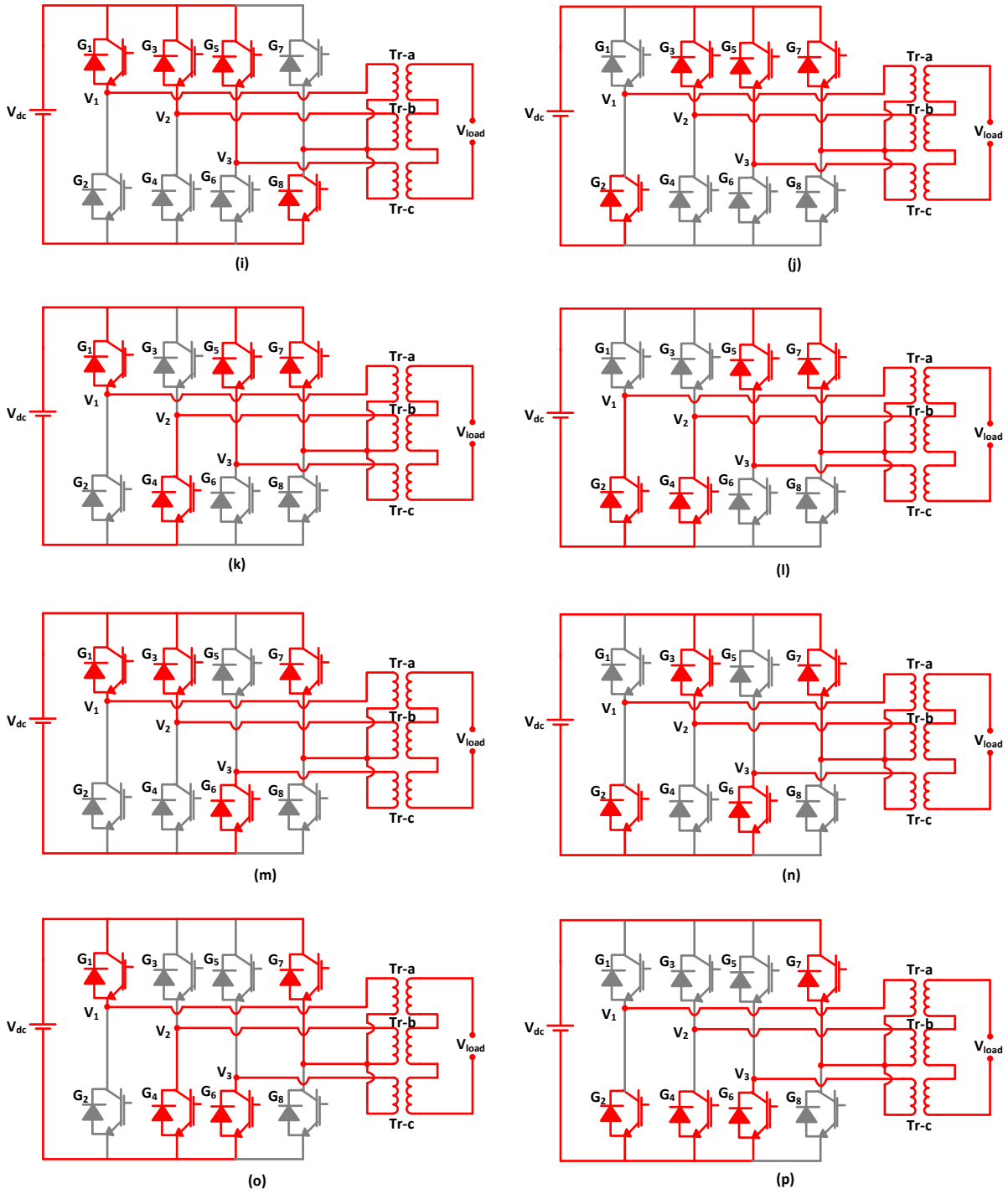


Figure 3. Modes of operation of 15-level inverter

- While the other switching devices are held in the OFF state, power electronic switches G2, G4, G6, and G8 are activated to provide a zero level (0VDC). The load is cut off from the input source by short-circuiting the primary sides of the three transformers. In Fig. 3(b), the precise route for producing this voltage level is displayed.

$$V_a = 0$$

$$V_b = 0$$

$$V_c = 0$$

$$V_o = V_a + V_b + V_c = 0V_{DC} \quad (1)$$

- Power electronic switches G1, G4, G6, and G8 must be activated in order to create the initial positive level (VDC), with the other switching devices being held in the OFF state. The input source provides VDC to transformer Tr-a's primary side, while the primary sides of the other transformers are short-circuited. In Fig. 3(c), the precise pathway for producing this voltage level is illustrated.

$$V_a = V_{DC}$$
$$V_b = 0$$
$$V_c = 0$$
$$V_o = V_a + V_b + V_c = V_{DC} \quad (2)$$

- To generate 2VDC, power electronic switches G2, G3, G6, and G8 must be activated; otherwise, all other switching devices stay in the OFF state. Transformer Tr-b's primary side receives 2VDC from the input source, while the primary side of the other transformers is short-circuited. Fig. 3(d) shows the precise pathway for producing this voltage level.

$$V_a = 0$$
$$V_b = 2V_{DC}$$
$$V_c = 0$$
$$V_o = V_a + V_b + V_c = 2V_{DC} \quad (3)$$

- To generate 3VDC, power electronic switches G1, G3, G6, and G8 must be activated; otherwise, all other switching devices stay in the OFF state. Transformer Tr-a receives VDC on its primary side, whereas Transformer Tr-b receives 2VDC from the input source. At the primary side, the remaining transformer has a short circuit. Fig. 3(e) depicts the precise pathway for producing this voltage level.

$$V_a = V_{DC}$$
$$V_b = 2V_{DC}$$
$$V_c = 0$$
$$V_o = V_a + V_b + V_c = 3V_{DC} \quad (4)$$

- To generate 4VDC, power electronic switches G2, G4, G5, and G8 must be activated; all other switching devices stay in the OFF condition. The primary sides of the other transformers are short-circuited, and transformer Tr-c's primary side gets 4VDC. Fig. 3(f) shows the specific route for producing this voltage level.

$$V_a = 0$$
$$V_b = 0$$
$$V_c = 4V_{DC}$$
$$V_o = V_a + V_b + V_c = 4V_{DC} \quad (5)$$

- The remaining switching devices are retained in the OFF state; in order to generate 5VDC, power electronic switches G1, G4, G5, and G8 must be activated. Transformer Tr-a gets VDC on its primary side, while Transformer Tr-c receives 4VDC from the input source. The residual transformer has a short circuit on its primary side. Fig. 3(g) shows the precise pathway for producing this voltage level.

$$V_a = V_{DC}$$
$$V_b = 0$$
$$V_c = 4V_{DC}$$
$$V_o = V_a + V_b + V_c = 5V_{DC} \quad (6)$$

- To generate 6VDC, power electronic switches G2, G3, G5, and G8 must be activated; otherwise, all other switching devices stay in the OFF state. The input source provides 4VDC to the primary side of transformer Tr-c and 2VDC to transformer Tr-b. At the primary side, the remaining transformer has a short circuit. Figure 2(h) provides a comprehensive method that generates this voltage level.

$$V_a = 0$$
$$V_b = 2V_{DC}$$
$$V_c = 4V_{DC}$$
$$V_o = V_a + V_b + V_c = 6V_{DC} \quad (7)$$

- To generate 7VDC, power electronic switches G1, G3, G5, and G8 must be activated; all other switches stay in the OFF position. Transformer Tr-a provides VDC on its primary side, Transformer Tr-b provides 2VDC from the input source, and Transformer Tr-c provides 4VDC. In Fig. 3(i), the precise pathway for producing this voltage level is illustrated.

$$V_a = V_{DC}$$
$$V_b = 2V_{DC}$$
$$V_c = 4V_{DC}$$
$$V_o = V_a + V_b + V_c = 7V_{DC} \quad (8)$$

- Power electronic switches G2, G3, G5, and G7 must be activated in order to produce the initial negative level (−VDC), while the other switching devices must stay in the OFF-state. Transformer Tr-a's primary side receives −VDC from the input source, while the primary side of the other transformers is short-circuited. The entire process for producing this voltage level is shown in Fig. 3(j).

$$V_a = -V_{DC}$$
$$V_b = 0$$
$$V_c = 0$$
$$V_o = V_a + V_b + V_c = -V_{DC} \quad (9)$$

- Power electronic switches G1, G4, G5, and G7 must be activated in order to produce -2VDC; all other switching devices must stay in the OFF state. While the other transformers' primary sides are short-circuited, transformer Tr-b's primary side receives -2VDC from the input source. This voltage level's detailed journey is shown graphically in Figure 3(k).

$$V_a = 0$$
$$V_b = -2V_{DC}$$
$$V_c = 0$$
$$V_o = V_a + V_b + V_c = -2V_{DC} \quad (10)$$

- Power electronic switches G2, G4, G5, and G7 must be activated in order to produce -3VDC, while the remaining switching devices must remain in the OFF position. Transformer Tr-a's primary side delivers −VDC, while transformer Tr-b's primary side receives −2VDC from the input source. The primary side of the remaining transformer is shorted. Fig. 3(l) shows the schematic depiction of this voltage level creation.

$$V_a = -V_{DC}$$
$$V_b = -2V_{DC}$$
$$V_c = 0$$
$$V_o = V_a + V_b + V_c = -3V_{DC} \quad (11)$$

- Power electronic switches G1, G3, G6, and G7 must be activated in order to produce -4VDC; all other switching devices must stay in the OFF state. While the other transformers are short-circuited at the primary side, transformer Tr-c's primary side receives -4VDC from the input source. A graphic illustration of the whole path for producing this voltage level may be found in Fig. 3(m).

$$V_a = 0$$
$$V_b = 0$$
$$V_c = -4V_{DC}$$
$$V_o = V_a + V_b + V_c = -4V_{DC} \quad (12)$$

- Power electronic switches G2, G3, G6, and G7 must be activated in order to produce -5VDC, while the remaining switching devices must remain in the OFF position. Transformer Tr-c receives -4VDC from the input source, while its primary side receives -VDC. The primary side of the remaining transformer is shorted. Figure 3(n) provides a graphic representation of the whole procedure used to produce this voltage level.

$$V_a = -V_{DC}$$
$$V_b = 0$$
$$V_c = -4V_{DC}$$
$$V_o = V_a + V_b + V_c = -5V_{DC} \quad (13)$$

- Power electronic switches G1, G4, G6, and G7 must be activated in order to produce -6VDC; all other switching devices must stay in the OFF state. Transformer Tr-b delivers -2VDC from the input source, while the primary side of Tr-c supplies -4VDC. The primary side of the remaining transformer is short-circuited. This voltage level's detailed course is shown graphically in Fig. 3(o).

$$V_a = 0$$
$$V_b = -2V_{DC}$$
$$V_c = -4V_{DC}$$
$$V_o = V_a + V_b + V_c = -6V_{DC} \quad (14)$$

- Power electronic switches G2, G4, G6, and G7 must be activated in order to produce -7VDC; all other switching devices must stay in the OFF state. Transformer Tr-a's primary side delivers -VDC, whereas transformer Tr-b receives -2VDC from the input source and transformer Tr-c produces -4VDC. The full method for creating this voltage level is shown graphically in Fig. 3(p).

$$V_a = -V_{DC}$$
$$V_b = -2V_{DC}$$
$$V_c = -4V_{DC}$$
$$V_o = V_a + V_b + V_c = -7V_{DC} \quad (15)$$

TABLE 1. SWITCHING STATES

V_{DC}	G_1	G_2	G_3	G_4	G_5	G_6	G_7	G_8
$7V_{DC}$	1	0	1	0	1	0	0	1
$6V_{DC}$	0	1	1	0	1	0	0	1
$5V_{DC}$	1	0	0	1	1	0	0	1
$4V_{DC}$	0	1	0	1	1	0	0	1
$3V_{DC}$	1	0	1	0	0	1	0	1
$2V_{DC}$	0	1	1	0	0	1	0	1
V_{DC}	1	0	0	1	0	1	0	1
$0V_{DC}$	1	0	1	0	1	0	1	0

$0V_{DC}$	0	1	0	1	0	1	0	1
$-V_{DC}$	0	1	1	0	1	0	1	0
$-2V_{DC}$	1	0	0	1	1	0	1	0
$-3V_{DC}$	0	1	0	1	1	0	1	0
$-4V_{DC}$	1	0	1	0	0	1	1	0
$-5V_{DC}$	0	1	1	0	0	1	1	0
$-6V_{DC}$	1	0	0	1	0	1	1	0
$-7V_{DC}$	0	1	0	1	0	1	1	0

D. Comparison of Topology

Recent studies on multilevel inverters have explored various topologies based on transformers or coupled coils. Table II compares the characteristics of these proposed circuits with previously known structures. Principal Objectives of Transformer-Based multilevel inverters are to provide galvanic isolation, boost the output voltage, and achieve high load voltage levels to enhance waveform quality. In contrast to earlier designs, the recommended configuration offers galvanic isolation and consistent voltage levels independent of the turn ratio, while also requiring fewer components. As indicated in Table 2, this proposed structure is cost-effective and enables the generation of a 15L load voltage with minimal complexity and volume.

The Table 3 expresses in detail the necessary design parameters simulation for the

Table 2. Comparison analysis

Topology	Switches	Drives	Transformers	sources
Conventional	12	12	2	1
7 level	6	6	2	1
15 level	8	8	3	1

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IV. SIMULATION AND RESULTS

Here is an example of how the pulse width modulation (PWM) approach is used to create the switch pulses for each of the recommended circuit IGBTs. The reference signal (Vref) is represented by a sinusoidal wave, while the carrier signals (Vc) are triangle waves. The triangular waves and a reference wave are contrasted in Figure 3. The formula may be used to find the required carrier flux for producing a given load voltage.

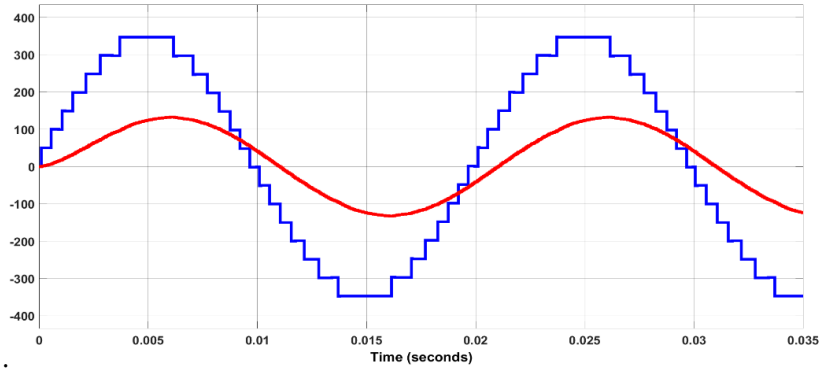

Figure 4: pwm technique

A. Simulation Diagram

The fifteen-level inverter is design by connecting the transformers and dc source is given as the supply and this circuit is drawn in the MATLAB/SIMULINK as shown in the above figure 5. In the Simulation the input supply is the DC Source and the eight IGBT's are connected as the four half-bridge inverter, and the three transformers is the connected to the inverter. By using this circuit, we can generate the fifteen-level output voltage waveform. And the primary side of the transformer is connected to the inverter and the secondary side of the connected to the load. In the below figure 5 the output voltage of the transformer is shown. In the first transformer the on/off switch time period is less. And in the second transformer the time period of on/off switch is greater than the first transformer. And in the third transformer the time period is more.

The Table 3 expresses in detail the necessary design parameters simulation for the 15 Level Inverter

Table 3. Simulation Details

Items	Simulation
DC Voltage	50 V
Transformers	3
Switching Frequency	2000 Hz
Load Frequency	50 Hz
Output Voltage	350 V, 50 Hz
Load	R=30 Ω , L=50 MH

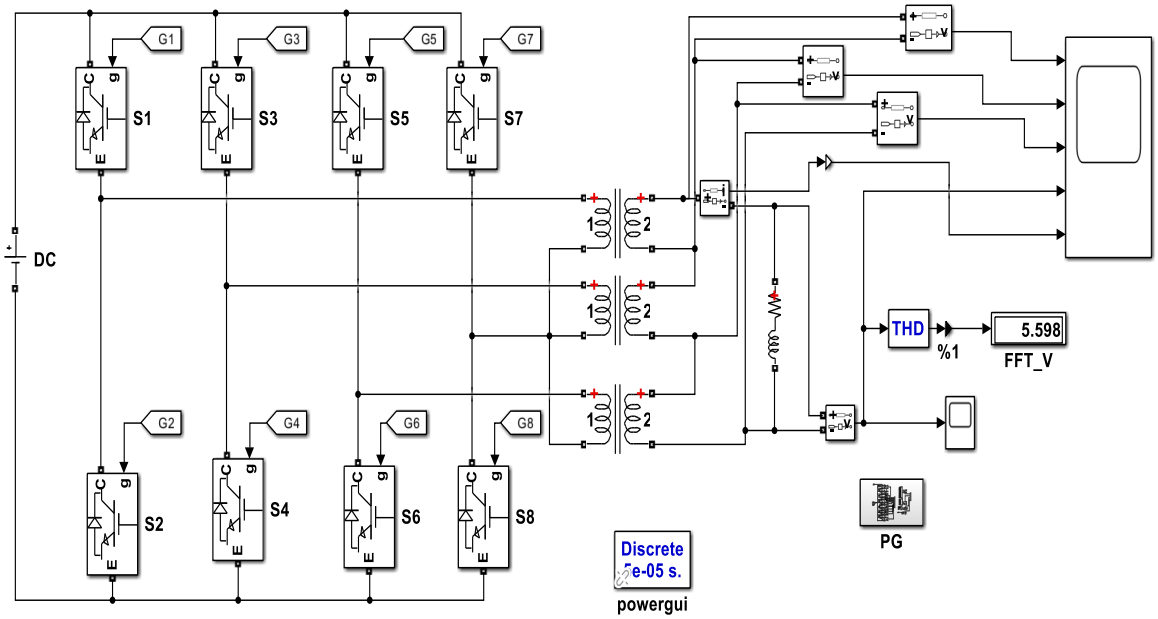

Figure 5: By interconnecting the transformer, the fifteen-level inverter's simulation diagram

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switch time period is less. And in the second transformer the time period of on/off switch is greater than the first transformer. And in the third transformer the time period is more.

In the below figure 6 shows the switching pulse of the switches of 1-4 (G1-G4). If the waveform of the pulse is at 1 then the switch is in ON condition. If the pulse is at 0, then the switch is in OFF condition. And in the figure 6 shows the switching pulse of the switches 5-8 (G5-G8).

G_1-

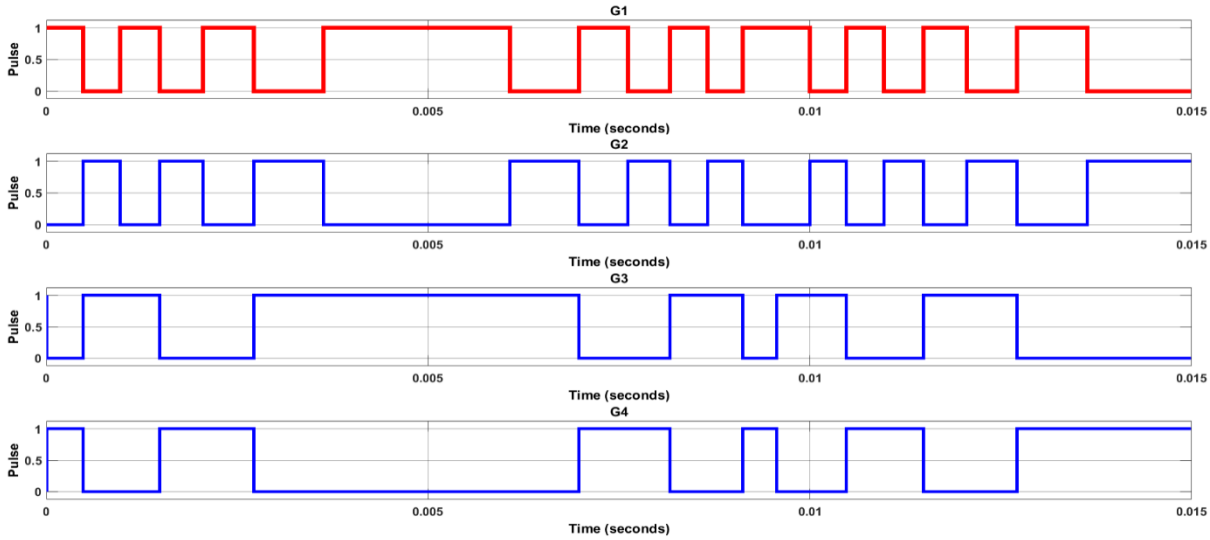


Figure 5: Pulse waveform of G_1-G_4

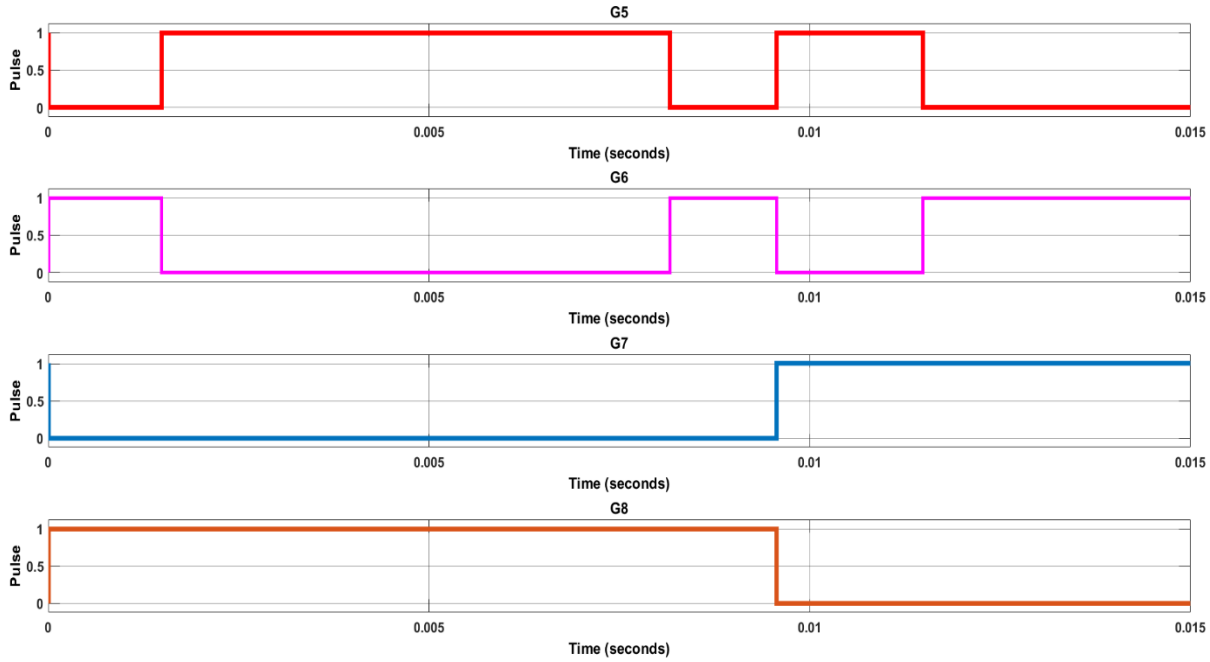


Figure 6: Pulse waveform of G_5-G_8

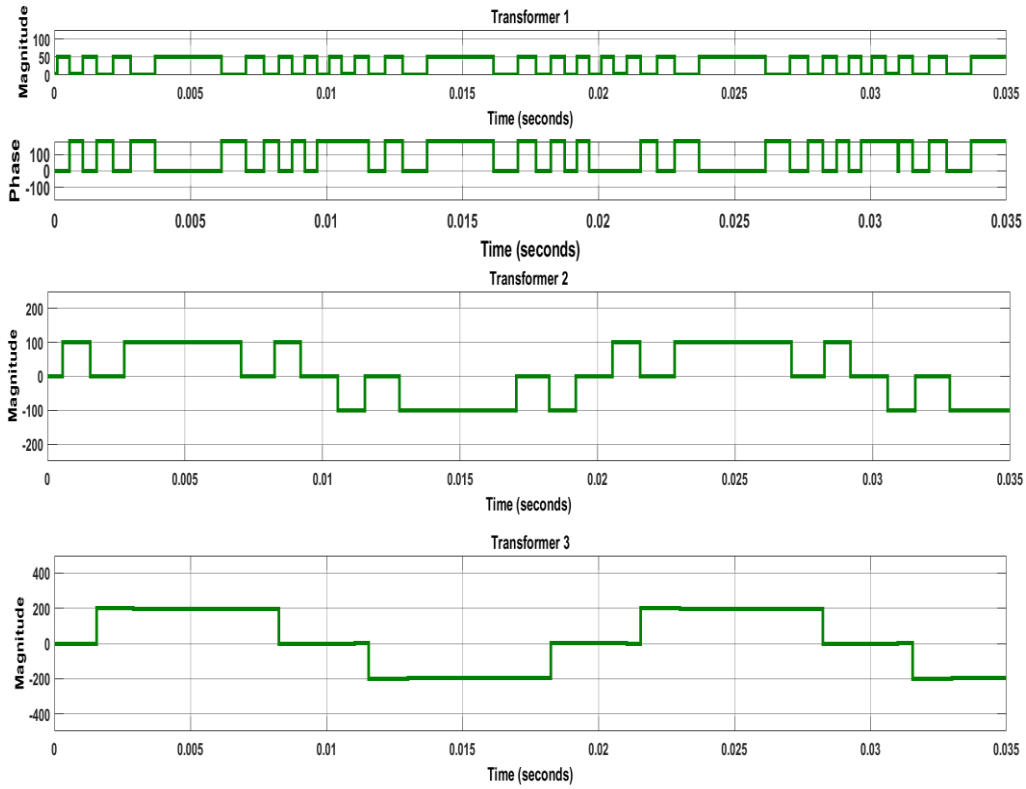


Figure 7: The Output Voltage of the transformer

The below figure 8 shows the output voltage waveform of the fifteen-level inverter. In the waveform the sine wave is converter in to the fifteen step of the waveform. The positive waveform having the seven level, at zero it is one level, and in the negative waveform having another seven levels. If the input of this inverter is 50 V. Then the output voltage will be the seven times of the input i.e., if the input is 50 V, then the seven times of the input is the 350V. So, then the output voltage waveform peak voltage is 350V.

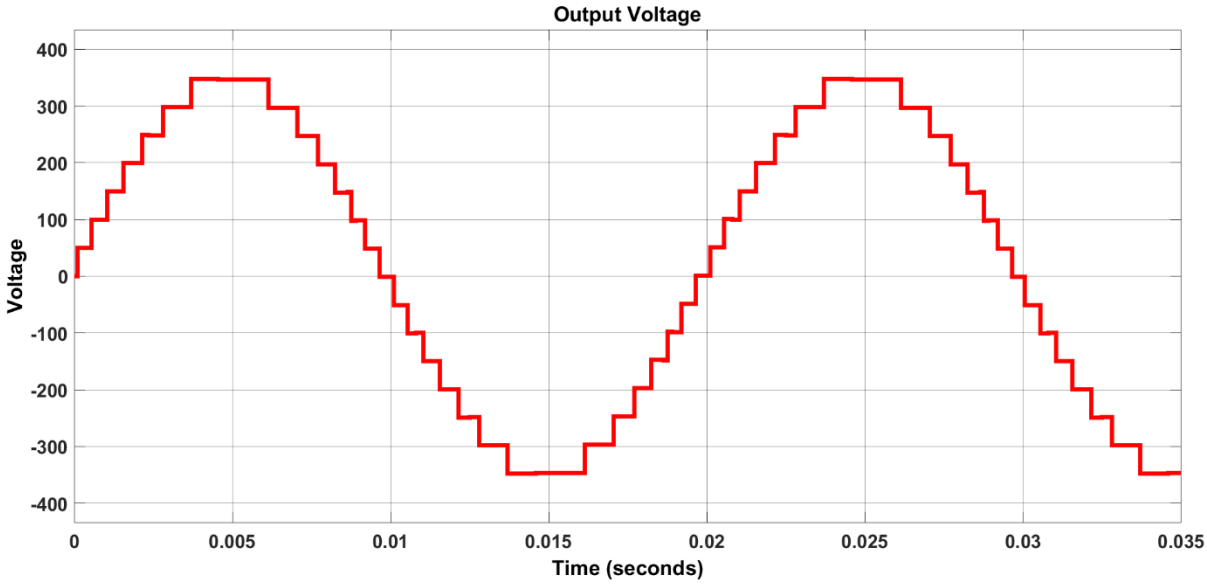


Figure 8: The output Voltage Waveform of 15 level inverter

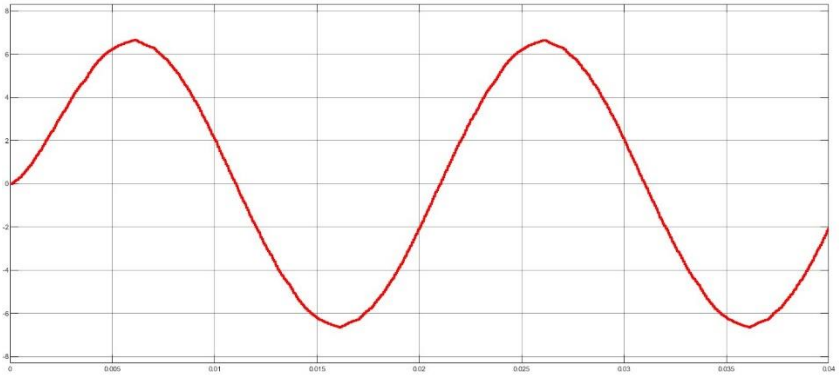


Figure 9: Output current waveform

FFT Analysis of 15 Level Transformer based inverter

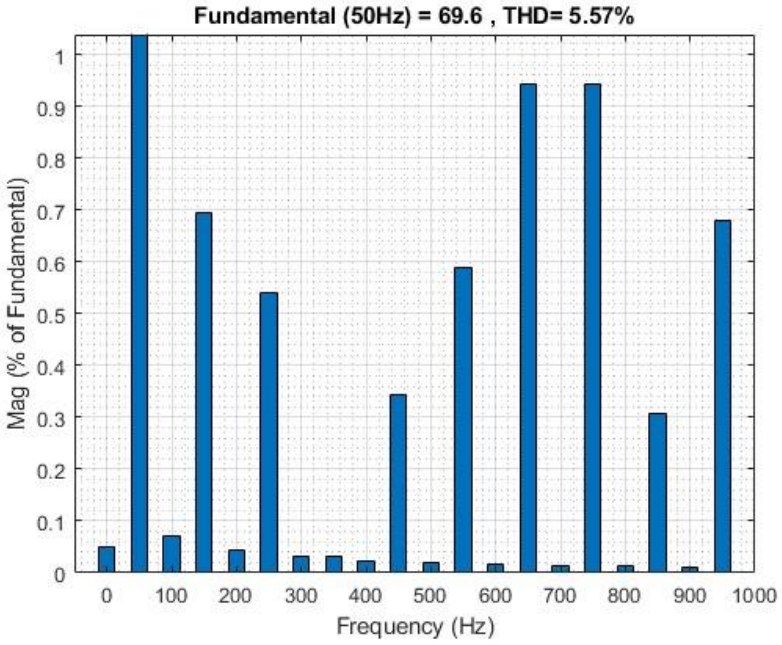
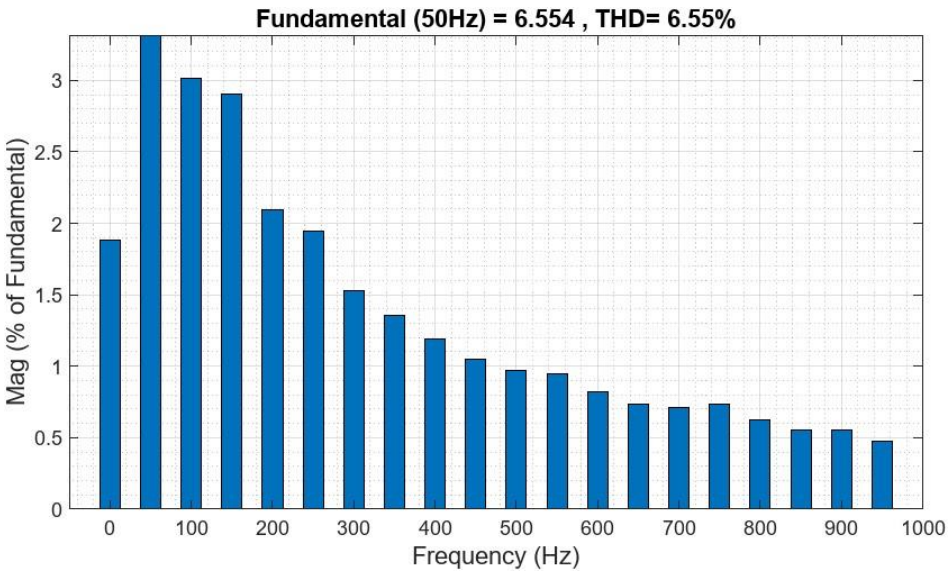


Figure 10: voltage THD



V. CONCLUSION

This topology described a novel Transformer-Based 15-level Inverter Design: Single Source Power Solutions presents a ground breaking 15L Multilevel inverter structure incorporating three transformers and eight switches. This innovative architecture significantly minimizes the number of inverter switches, transformers, and drives while maintaining the advantages of traditional configurations. The transformers not only facilitate galvanic isolation but also contribute to enhanced performance and reduced costs due to the streamlined component requirements. Additionally, a straightforward PWM approach is outlined for switch pulse generation. Simulation results affirm the effectiveness of the proposed inverter design, promising notable efficiency in practical applications.

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