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A Topology of Asymmetric Nine-Level Hybrid Bridge Multilevel Inverter

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ABSTRACT

In this paper, a single-phase asymmetrical 9-level hybrid bridge multilevel inverter is presented. It consists of seven switches, three diodes, and two unequal DC supplies. An asymmetrical configuration is considered because it provides more number of output voltage levels with a less number of switches. This inverter can be used for renewable energy application. The main goal is to decrease the THD without expanding the number of switches and levels. The THD is reduced by using different modulation techniques. The design of load parameters is explained using real time devices as load. The 9-level asymmetrical hybrid bridge multilevel framework has been developed in MATLAB/Simulink platform. The total harmonic distortion (THD) obtained from each modulation techniques is compared and the least THD value among the modulation techniques is considered the best method.

KEYWORDS: Multilevel inverter(MLI), phase disposition (PDPWM), particle swarm optimization (PSO), genetic algorithm(GA), half height method, total harmonic distortion (THD)

1. INTRODUCTION

In developing countries like Brazil, Malaysia, India etc. the use of electricity is increasing rapidly. The in conventional sources such as coal, natural gas and oil etc. the emission of carbon dioxide, methane, nitrous oxide are increasing which causes greenhouse effect. Already troposphere is greatly affected by air pollution which is the lower most region of earth atmosphere. Global warming must be controlled. This is because the world has already passed the danger zone[2-3]. Now is the perfect time to transition from conventional sources of energy to non-conventional sources of energy such as tidal, solar, geothermal, wind etc. India has the largest geographical solar energy potential. As the availability of solar energy is abundant and the cleanest form. The capture of solar energy and installation is easier than other renewable energy. A Photovoltaic system converts solar energy into electrical energy. The solar cell gives direct current which can be used in some applications but cannot be linked to the AC grid or used for AC appliances. The conversion of direct current to alternating current is done through a multilevel inverter (MLI) to match the gird voltage. MLI were chosen because of their benefits such as lower common-mode voltage, lower switching stress, lower THD, and better output power quality [4-5-6].

Flying Capacitor (FC), Diode Clamped or Neutral-Point-Clamped (NPC) and Cascaded H-Bridge (CHB) are the three primary structures of MLI [7-8]. The basic concept of FC is the use of a series connection of switching elements compressed by a capacitor, hence the inverter control is a very complicated task. NPC inverter uses multiple clamping diodes to boost the output voltage level. In both FC and NPC inverters, voltage balancing at high voltage levels is a complex task [9]. In CHB inverter consists of H-bridge elements and each element can provide three different output voltages such as zero, positive voltage and negative voltage. The major advantage of CHB is that, it requires less components compared to FC and NPC inverters. The drawback of the CHB inverter is that the number of a DC power supplies increases with the magnitude of the output voltage [10].

MLI has become a popular choice due to many advantages such as switchless architecture, high power quality signal and low switching loss. The problem of harmonics is a big challenge for this technology, this causes harmful effects on some appliances [11-14]. The harmonics can be reduced in two ways, firstly by increasing the number levels i.e. increasing the number of switches and DC supplies and secondly by different control techniques. Hence, this article presents a modified asymmetric hybrid bridge inverter (MAHB-MLI) to decrease the number of switches and power supplies used in the inverter circuit [1] and harmonics is reduced to a lower value by different control techniques.

This article is organized as follows. The analysis and implementation of a 9-level asymmetrical inverter topology is presented in Section-2. Elaborates the various control techniques and simulation result of each techniques are presented in section-3. The Simulink model are presented in section-4. Section-5 is followed by the conclusion.

2. 9-LEVEL ASYMMETRICAL INVERTER

A. Circuit Diagram and Description

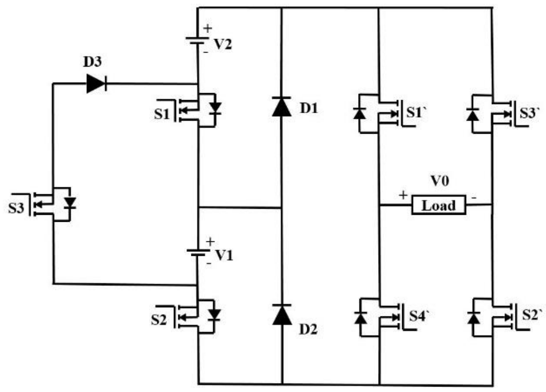


Figure 1: Modified Asymmetrical Hybrid Bridge Multi-level Inverter Topology for 9-level.

The circuit diagram of asymmetrical MLI which can generate nine levels in the output voltage waveform as shown in fig.1. This 9-level asymmetrical MLI topology consists of seven unidirectional switches, three diodes, and two DC supplies. The desired 9-level output voltage waveform is achieved by an asymmetric configuration of two DC supplies of 1:3 ratio chosen as V_1=1V_{dc}, V_2=3V_{dc}. The circuit consists of two different parts. First part consists of switches S_1, S_2 and S_3 and DC supplies V_1 and V_2 to create different levels in the output waveform, is known as level generation part. Second part consists of switches S_1`, $S_2$`, S_3`, $S_4$` in H-bridge for polarity changes in output waveform, is known as polarity generating part. The path for current flow and to prevent short circuits is done by five diodes (D_1, D_2 and D_3) in the circuit [1].

Table 1: Switching States for 9-level Asymmetrical Inverter

Mode	Voltage level	S1	S2	S3	S1`	S2`	S3`	S4`
0	0	0	0	0	1	1	0	0
1	V_1	0	1	0	1	1	0	0
2	V_2-V_1	0	0	1	1	1	0	0
3	V_2	1	0	0	1	1	0	0
4	V_1+V_2	1	1	0	1	1	0	0
5	-V_1	0	1	0	0	0	1	1
6	-(V_2-V_1)	0	0	1	0	0	1	1
7	-V_2	1	0	0	0	0	1	1
8	-(V_1+V_2)	1	1	0	0	0	1	1

B. Modes of Operation

The various operating modes of nine-level inverter is explained below. The function of the switches in mode-0 of the circuit is that S_1\` and $S_2$\` conduct to produce a load voltage of $0V_{dc}$, as shown in Fig 2(a). An operating switches in Mode-1 is S_2, S_1\`, and $S_2$\` conducting and produces a load voltage of $+1V_{dc}$ as shown in Fig 2(b). The mode-2 operating switches are S_3, S_1\` and $S_2$\` conducting and generate a load voltage of $+2V_{dc}$ as shown in Fig 2(c). The behavior of the switches in

Mode-3 is that S_1, S_1\` and $S_2$\` conduct to produce a load voltage of $+3V_{dc}$ as shown in Fig 2(d) and the operating switches in mode-4 is that S_1, S_2, S_1\` and $S_2$\` to produce load voltage of $+4V_{dc}$ as shown in Fig 2(e). The negative voltage levels are also determined according to the switching state shown in Table I.

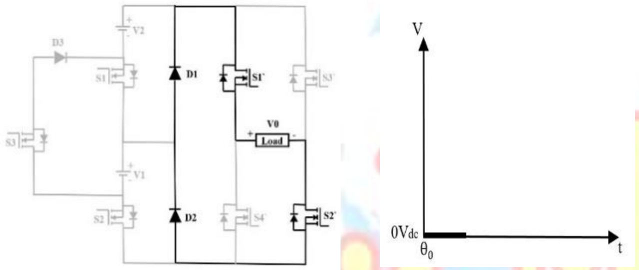


Figure 2(a): $V_o = 0V$

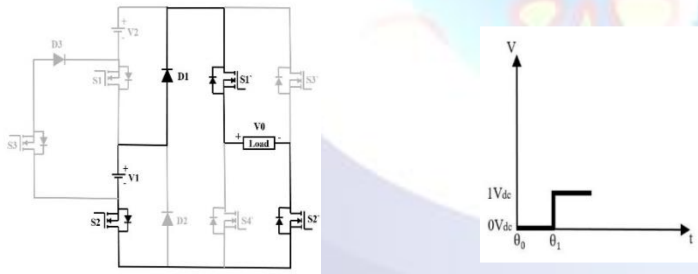


Figure 2(b): $V_o = V_1$

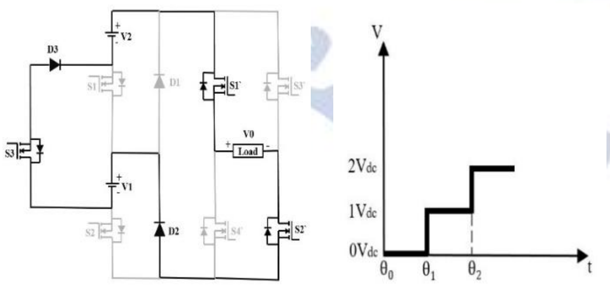


Figure 2(c): $V_o = V_1 – V_2$

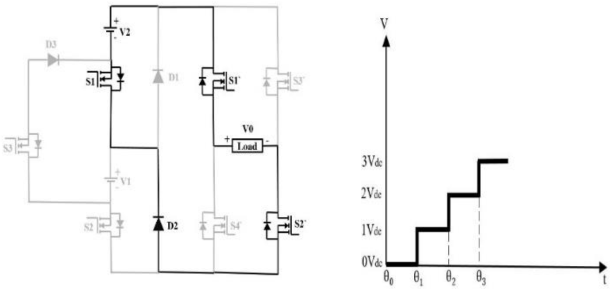


Figure 2(d): $V_o = V_2$

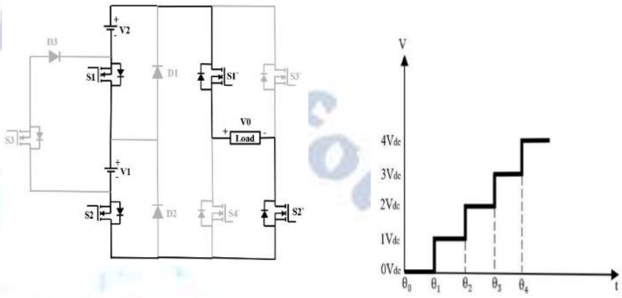


Figure 2(e): $V_o = V_1 + V_2$

The switching angle for θ_0, θ_1, θ_2, θ_3 and θ_4 is 0, 8.3078, 21.0848, 37.2995 and 60.2751 in degrees respectively.

C. Design of R Load

The load considered is the Oven of model HBG6753S1A.

The data specified in the datasheet is as follows,

Rated Voltage (V) = 240 V

Power output = 3600 W

Frequency (f) = 50 Hz

$P = VI$

$I = \frac{P}{V} = \frac{3600}{240} = 15$ A

Rated Current (I) = 15 A

$V = IR$

$R = \frac{V}{I} = \frac{240}{15} = 16\ \Omega$

3. MODULATION TECHNIQUES

Modulation technique generates a multilayer output waveform. Every modulation approach produces a unique switching pulse to generate the required output waveform.

A. Phase Disposition Pulse Width Modulation Technique

The Phase Disposition Pulse Width Modulation Technique (PD-PWM) strategy is used in multi-level inverters for controlling power switches because it provides the lowest harmonic distortion to the load [15]. PD-PWM consists of triangular carrier waves which have same phase sequence and the same frequency of 10 kHz, as shown in Figure 3.

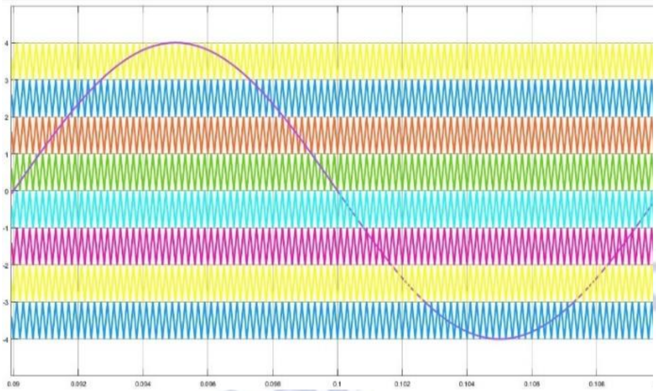


Figure 3. Generation of switching pulses by PD-PWM.

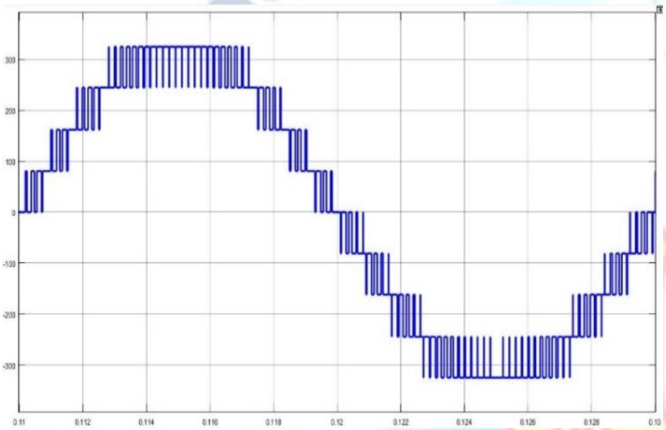


Figure 4. The waveform of output voltage for a 9-level inverter using the phase disposition PWM technique for R-load.

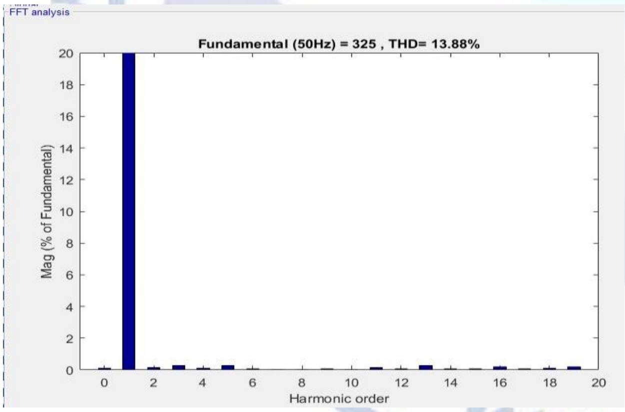


Figure 5. Output Voltage THD spectrum using phase disposition PWM technique for R-load.

B. Half-Height Method

The half-height method is adopted to reduce harmonic components on the output voltage side. The idea is that the switching angle is set when the fundamental rise halfway up the level. Half-height switching modulation technique divided into four quadrants for the full period (0^0 to 360^0) of the output waveform.

1. The main switching angle is from 0^0 to 90^0 which is calculated as follows,

$$b_k = \mathrm{Sin}^{-1}\frac{(2k-1)}{(M-1)} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (1)$$

Where, $k = 1, 2, 3, 4, \ldots\ldots\ldots, \frac{(M-1)}{2}$ and M = Number of output voltage levels.

2. The 2rd quadrant switching angle is from 90^0 to 180^0 which is calculated as follows,

$$b_{\frac{(M-1)}{2}} = 180^0 - b_{\frac{(M-1)}{2}}, 180^0 - b_{\frac{(M-2)}{2}}, \ldots\ldots, 180^0 - b_1 \ldots (2)$$

3. The 3rd quadrant switching angle is from 180^0 to 270^0 which is calculated as follows,

$$b_M = 180^0 + b_1, 180^0 + b_2, \ldots\ldots, 180^0 + b_{\frac{(M-1)}{2}} \ldots\ldots\ldots\ldots (3)$$

4. The 4th quadrant switching angle is from 270^0 to 360^0 which is calculated as follows,

$$b_{\frac{(3M-1)}{2}} = 360^0 - b_{\frac{(M-1)}{2}}, 360^0 - b_{\frac{(M-2)}{2}}, \ldots\ldots, 360^0 - b_1 \ldots (4)$$

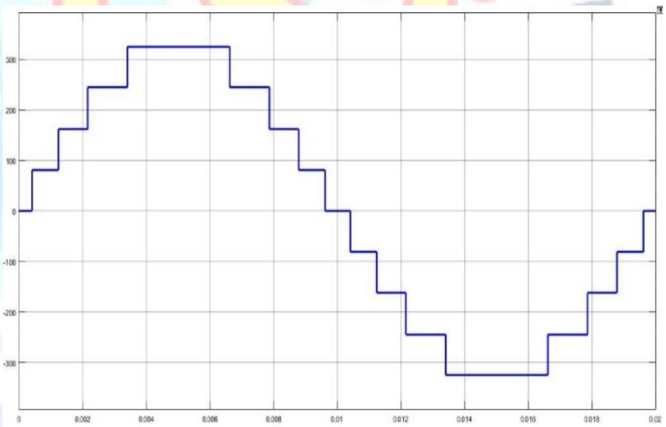


Figure 6. The waveform of output voltage for 9-level inverter using half height modulation technique for R-load.

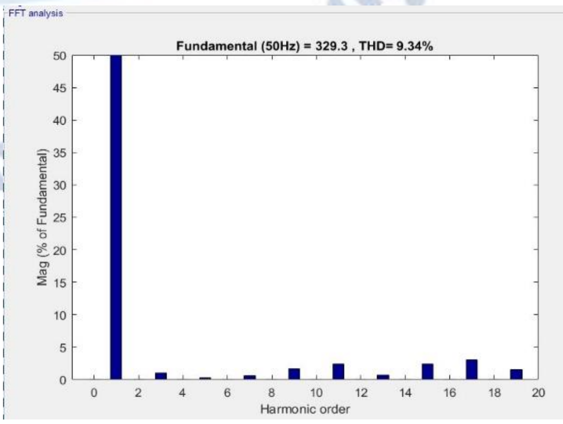


Figure 7. Output voltage THD spectrum using half height modulation technique for R-load.

C. Selective Harmonic Elimination Method

The Selective Harmonic Elimination (SHE) concept is based on multiple clipping of the square wave output to eliminate effective lower harmonics as well as control and regulate the fundamental voltage. By implementing SHE technique, the better power quality can be achieved by eliminating lower order harmonics and also network resonance can be avoiding by selecting certain harmonics to be mitigated [16]. Switching angles can be calculated by Particle Swarm Optimization, Genetic algorithm etc.

SHE-PWM is based on a Fourier series decomposition of the periodic PWM voltage waveform produced by a power electronics converter and calculation of the switching angle to reject/control selected low-order harmonics.

$$f(t) = a_0 + \sum_{n=1}^{\infty}(a_n \cos(n\omega t) d(\omega t) + b_n \sin(n\omega t)\, d(\omega t)) \ldots.(5)$$

Because of half-wave and quarter-wave symmetry of the output voltage waveform, there are no even harmonics (a_n and a_o), only odd harmonics (b_n).

$$b_n = \frac{2}{T}\int_0^T f(t)\sin(n\omega t)\, d(\omega t) \ldots\ldots(6)$$

The switching angles θ - θs must satisfy the following condition:

$$0 \le \theta_1 \le \theta_2 \le \ldots \le \theta_s \le \pi/2$$

a. Particle Swarm Optimization

Particle Swarm Optimization (PSO) is motivated by the simulation of social systems such as birds flocking and fish schooling [17]. The below steps are be followed to solve non-linear equation and to obtain the switching angle in PSO technique. The number of iteration is solved using MATLAB coding to get best switching angles.

Step-1: Set the parameters such as Inertia weight (w), Social parameter (C_1, C_2), Random values (r_1, r_2), Population size, Maximum iteration.

Step-2: Initialize the particle population with position vector (X_i) and velocity vector (V_i).

Step-3: Set the iteration count t=1.

Step-4: Check the conditions for social parameter C_1 and C_2.

$$0 < (C_1 + C_2) < 2$$

If the conditions is satisfied, then the system will converge to a stable point. If false, go to step-1.

Step-5: Calculate the Fitness function for every iteration, the particle moves according to changes in position and velocity.

Step-6: Set best previous position (P_{best}) and best particle for the whole swarm known as global best (G_{best}).

Step-7: Update Velocity ($V_{i,j}$) for jth current iteration of ith particle.

$$V_{i,j}^{t+1} = w \, X \, V_{i,j}^{t} + C_1 \, X \, r_1 \, X \left(Pbest_{i,j}^{t} - X_{i,j}^{t}\right) + C_2 \, X \, r_2 \, X \, (Gbest_{i,j}^{t} - X_{i,j}^{t}) \ldots\ldots(7)$$

Step-8: Update position ($X_{i,j}$) for jth current iteration of ith particle.

$$X_{i,j}^{t+1} = X_{i,j}^{t} + V_{i,j}^{t+1} \ldots\ldots(8)$$

Step-9: Update the G_{best} and P_{best} for the current velocity vector and position vector.

Step-10: If t < maximunm iteration then t = t+1 and goto step-5 else go to step-11.

Step-11: Print optimum solution as G_{best}.

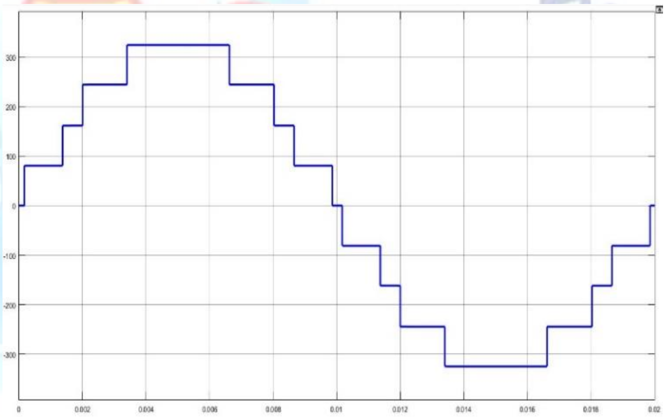


Figure 8. The waveform of Output voltage for 9-level inverter using the PSO technique for R-load

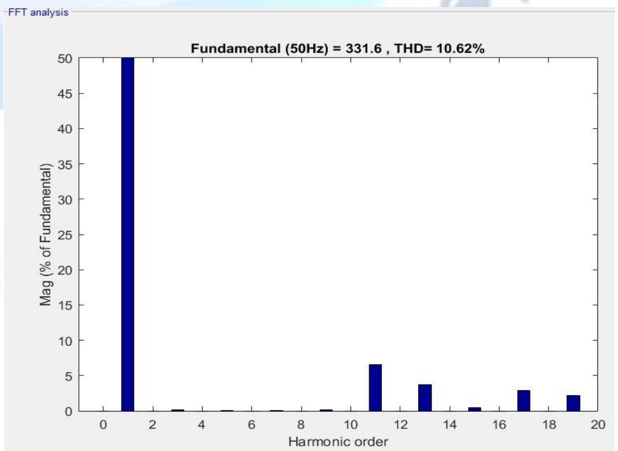


Figure 9. Output voltage THD spectrum using PSO technique for R-load.

b. Genetic Algorithm

A genetic algorithm is inherently parallel because multiple points in the search space are analyzed simultaneously. Therefore, GA reduced the possibility of approach local optima and more opportunities to approach the global optima [18].

The fitness function is formulate as follows:

Fitness function = $(\frac{m-F1}{F1})^2 + (F_5)^2 + (F_7)^2 + (F_{11})^2$ ………....(9)

Where, M = desired modulation index

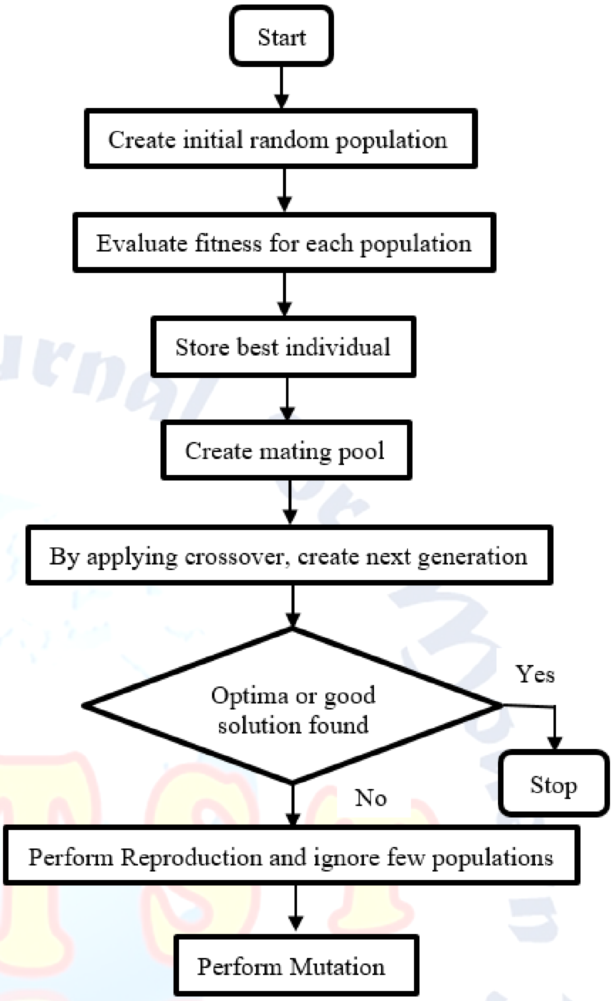
$F_1 = 4\pi\,(\cos\theta_1 - \cos\theta_2 + \cos\theta_3 - \cos\theta_4)$

$F_5 = \cos5\theta_1 - \cos5\theta_2 + \cos5\theta_3 - \cos5\theta_4$

$F_7 = \cos7\theta_1 - \cos7\theta_2 + \cos7\theta_3 - \cos7\theta_4$

$F_{11} = \cos11\theta_1 - \cos11\theta_2 + \cos11\theta_3 - \cos11\theta_4$

A detailed flowchart of GA is shown below.



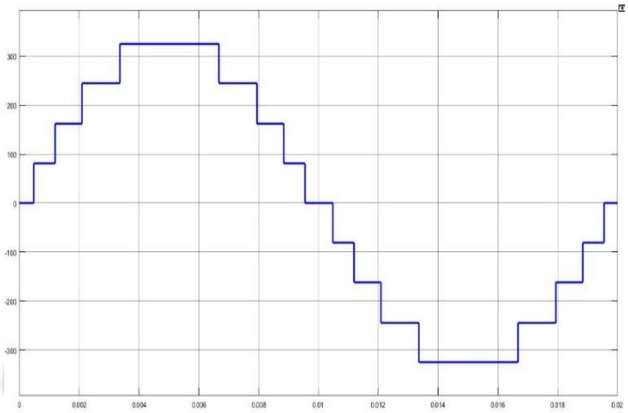


Figure 10. The waveform of Output voltage for 9-level inverter using Genetic algorithm for R-load

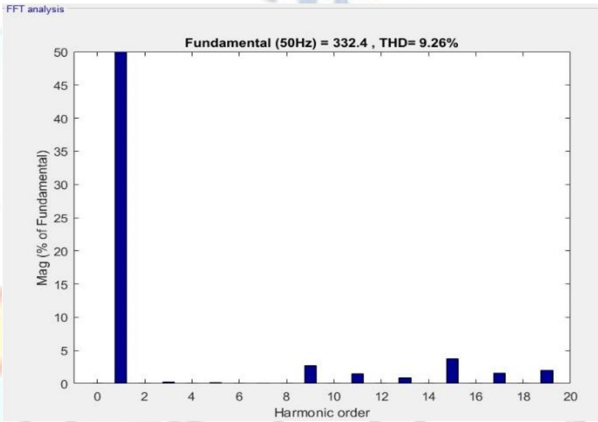


Figure 11. Output voltage THD spectrum using Genetic algorithm for R-load.

4. MATLAB SIMULINK MODEL

The input Dc supplies of asymmetrical switching pattern, is given as V_1=84V and V_2=252V. The switches used are unidirectional MOSFET semiconductor switches of model number FQA30N40 of 400V, 30A with internal resistance (R_{on}) of 0.14ohm.

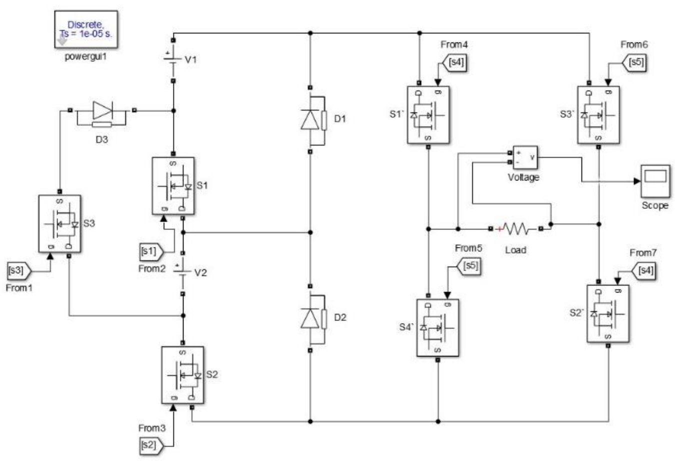
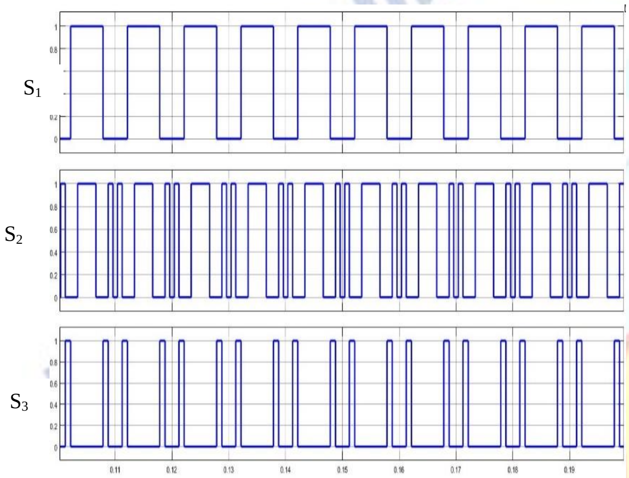


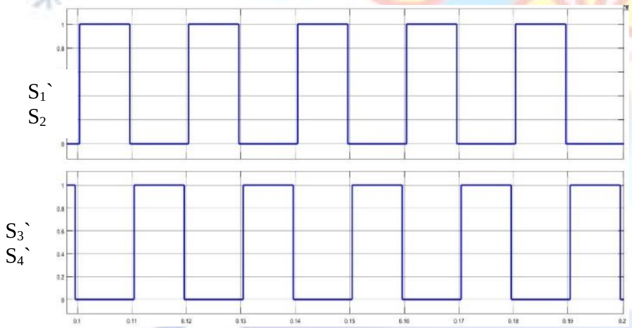
Figure 12. MATLAB/Simulink circuit for 9-level Asymmetrical Multilevel inverter

The 9-level asymmetrical hybrid bridge multilevel inverter is simulated for the Half Height method, Particle Swarm Optimization technique, Genetic Algorithm and Phase Disposition PWM method in MATLAB/Simulink platform. The analyses are done for R-load.

The simulation circuit of 9-level asymmetric MLI is shown in Figure.12, the circuit is built of 7 MOSFET switches and 3 diodes. The Resistive load of value 16 ohms with unequal DC input voltage of ratio 1:3.



(A)



(B)

Figure 11. (A and B) Switching pulse of switches.

Table 2. Comparison of THD with Different Modulation Techniques

Modulation technique	THD%
Phase Disposition PWM	13.88
Half Height method	9.34
Genetic Algorithm	9.26
Particle Swarm Optimization	10.62

5. CONCLUSION

This paper introduces an asymmetric hybrid bridge multi-level inverter that generates 9-level output voltage waveforms. This 9-level asymmetrical inverter produces four positive, four negative and 1 zero level in the output waveform. Due to low circuit complexity, few number of components, less cost and voltage stress on switches are less compared to conventional multilevel inverter topologies. The MATLAB simulation is done for Phase Disposition PWM, Particle Swarm Optimization technique, Half Height modulation technique and Genetic Algorithm. Table II. shows the comparison between different modulation techniques in terms of simulation results with THD parameter considering R-Load. Thereby concluding that THD using the Genetic algorithm is low compared to other modulation techniques and the THD is reduced to a lower value compared to the base paper [1]. THD obtained in base paper is 13.53% by PD-PWM technique which is reduced to 9.26% by GA. Thus simulation results validate the better performance and superiority of the Modified Asymmetrical Hybrid Bridge Multilevel Inverter Topology for 9-level topology over the conventional multilevel inverter topologies.

Conflict of interest statement

Authors declare that they do not have any conflict of interest.

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