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Research paper

Implementation of level shifted PWM and bee algorithm for cascaded multilevel inverters

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Abstract

This paper presents different modulation techniques to convert DC to AC voltage in multilevel inverter. In present scenario availability of fossil fuels are decaying day by day so importance of renewable energy sources are increasing for electric power generation. Solar energy is abandon in nature. The standalone solar PV system is used for water pumping system in Indian villages, where grid lines are not available. Cascaded H-bridge inverter (CHB) is suitable for renewable energy sources as it contains separate DC sources. The output voltage consists of predominant lower order harmonics. The various Sinusoidal PWM Techniques such as PD, POD and APOD were used to minimize the THD; it is a high switching frequency technique. Due to high switching frequency, high switching losses are occurred so filter requirement is more. To avoid this problem low switching frequency technique is used. The Selective Harmonic Elimination-Pulse Width Modulation (SHE-PWM) technique is utilised to eliminate the lower order harmonics and also to reduce the THD in multilevel inverters by solving the nonlinear equations. The non linear equations are solved by determining the proper switching angles using Bee algorithm. Bee algorithm is a metaheuristic nature inspired algorithm, based on the foraging behavior of honey bees. Simulation is carried out by using the MATLAB/SIMULINKK software for [5-7]-levels

Keywords: *Cascaded H-Bridge (CHB); SPWM; SHE-PWM; THD; Bee Algorithm (BA); Phase Disposition (PD); Phase Opposition Disposition (POD); Alternate PHSE Opposition Disposition (APOD).*

1. Introduction

The electricity demands lot of attention in day to day life. The renewable energy sources are the best choices to reach the demand of electricity. This can be achieved by employing micro grids and transferring the power with fewer losses, by monitoring of power frequently. The electricity delivered by the renewable sources is in the form of DC. But all appliances using now a days are work on the AC supply, and most of the power transmission is of AC. So it is better to convert DC to AC to fulfill the shortage of electricity[1]. For this purpose an inverter is used. The basic inverter is a two level inverter which produces the output in square wave. This leads to sudden on and off of electric equipments. It is important to generate the sinusoidal wave, this can be done by the multilevel inverter. The multilevel inverter can convert the DC supply to a stepped wave, which is nearer to sine wave [2].

The multilevel inverter provides the following advantages such as: (1) It can generate output voltage with less distortion. (2) It can decrease the stress on electronic switches. (3) It will decrease the use of bulky filters, since soft switching techniques can be applied and predominant harmonics can be removed so that filter requirement is reduced. (4) It can be operated at low switching frequency as well as high switching frequency. When multilevel inverter is used with renewable energy source, the whole system can be work as a standalone system. And it can be applied where there is no availability of grid lines, in agricultural fields for pumping of water, in fish & poultry, in farm houses for lightening.

Even though the THD is minimizing there are some lower order harmonics are presented in output of multilevel inverter. This leads to the high filter requirement, which in turn increases the cost of inverter. To avoid this problem selected lower order harmonics can be eliminated by applying some artificial intelligent based algorithms in SHE-PWM technique. The most probably used algorithm is Genetic Algorithm, But now a day's the research is going on increasing and many number of algorithms are introduced such as Be algorithm (BA), Particle Swarm Optimization (PSO) and Bat Algorithm.

This paper deals with the Bee Algorithm for the fundamental switching technique in section-IV. And also high switching frequency techniques like PD, POD and APOD in section-III. The Simulations were performed in MATLAB/SIMULINK environment and results were discussed for 5-level & 7-level CHB inverters in section-V.

2. Multilevel inverter

a) Multilevel Inverter

The multilevel inverter is start from the level three, and it was introduced in the year 1975. These are mainly of three types. They are:

1) Diode Clamped Multilevel inverter
2) Capacitor Clamped or Flying Capacitor Multilevel inverter.
3) Cascaded H-B ridge Multilevel inverter.

These inverters can be used for single phase as well as three phase applications. And by considering the application, voltage range requirements, the above inverters can be chosen. For renewable applications the CHB inverter is more suitable due to its modularity in structure, less number of switching devices used. The below table1 shows the number of power electronic devices used in various inverter topologies. Here 'm' is the level of inverter. The levels of CHB inverter can be found by number of DC sources 'S' by using "2S+1".

Table 1: Comparison of Multilevel Inverter Topologies

Type of MLI	No. of Diodes	No. of Switches	No. of Capacitors
1.Diode clamped MLI	(m^2-1)/2	2(m-1)	(m-1)/2
2.Flying Capacitor MLI	2(m-1)	2(m-1)	(1/2)* (m1)*(m-2) And (m-1) dc bus capacitors
3.Cascaded H-Bridge MLI	2(m-1)	2(m-1)	(m-1)/2

From the table, it can be observed that the number of power electronic devices required is less for CHB inverter. The CHB inverter can be operate as symmetrical and asymmetrical means for equal DC sources and unequal DC sources, depending on the DC input given.

The 5-level inverter is depicted in fig1, and switching states of that is given in table2.

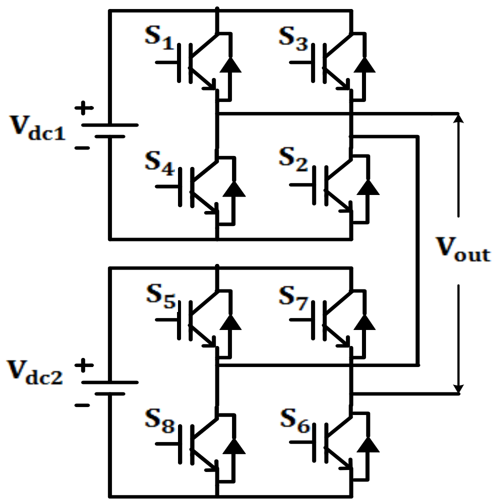

Fig. 1: 5-Level CHB Inverter Circuit

Table 2: Switching States of 5-Level CHB Inverter

Output Voltage	S1	S2	S3	S4	S5	S6	S7	S8
+2Vdc	1	1	0	0	1	1	0	0
+Vdc	1	1	0	0	0	0	1	1
0	0	1	0	1	0	1	0	1
-Vdc	0	0	1	1	0	1	0	1
-2Vdc	0	0	1	1	0	0	1	1

b) Modulation Techniques for Multilevel Iverter

The modulation techniques can be categorized based on the switching frequency that is[6]

1) High switching frequency techniques: These are carrier based pulse width modulation (PWM) techniques such as Sinusoidal PWM (SPWM) and Space Vector Modulation (SVM) technique. The mostly employed PWM technique is SPWM. The SPWM technique is further divided into

i) Phase Shifted SPWM

ii) Level shifted SPWM

a) Phase Disposition (PD)

b) Phase Opposition Disposition (POD)

c) Alternate Phase Opposition Disposition (APOD)

- (m-1) carriers are needed to produce the m-level output voltage.
- These carriers should be of same amplitude and switching frequency.
- The vertical shifting of carriers is to applied than the horizontal shifting of carrier signals.

2) Fundamental switching frequency techniques: These are based on the soft switching technique. They are Selective Harmonic Elimination PWM technique (SHE-PWM), Space Vector Control (SVC). The SHE-PWM technique consists of the non-linear equations, these equations will provide proper switching angles at which corresponding lower order harmonics are eliminated. But it is hard to find out the switching angles. To find out these switching angles Newton-Raphson method is used in the beginning. The NR method is a iterative method, the results of this are depends on the initial guess. If initial guess is incorrect then the results will incorrect[4]. By considering these difficulties some evolutionary algorithms are provided.

3. Sinusoidal PWM technique

The various types of SPWM technique are mentioned in section-II (B). In this section those types are going to be explained briefly for 5-level &7-level inverters.

a) Phase Disposition (PD-PWM)

In this technique, the carrier signals above the reference and below the reference are in same phase. This technique is applied to 5 & 7-levels of CHB inverter at modulation index of M=1, and carrier frequency is 2kHz. The depicted figures fig.2(a) & 2(b) shows the juxtaposition of carrier waves with reference wave[9].

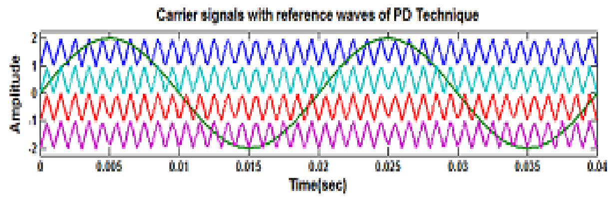

Fig. 2: A): Juxtaposition of Reference and Carrier Signals for 5-Level CHB Inverter.

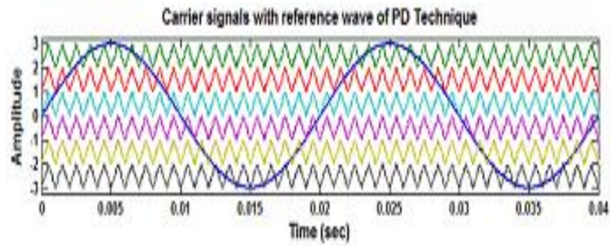

Fig. 2: B): Juxtaposition of Reference and Carrier Signals for 7-Level CHB Inverter.

b) Phase Opposition Disposition (POD-PWM)

In this technique, the carrier signals above the reference is in phase and below the reference are out phase with them. This technique is simulated for both 5 & 7 level inverters at M=1and Fc=2kHz. And all carrier signals are of equal amplitudes, that is 1. Hereunder the corresponding figures for POD-SPWM technique in fig.3(a) & 3(b).

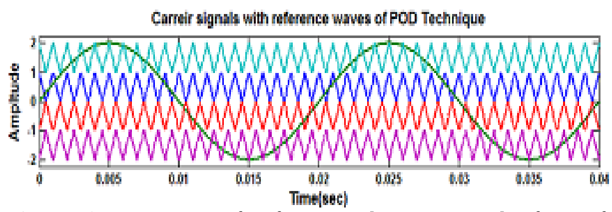

Fig. 3: A): Comparison of Reference and Carrier Signals of POD for 5-Level CHB Inverter.

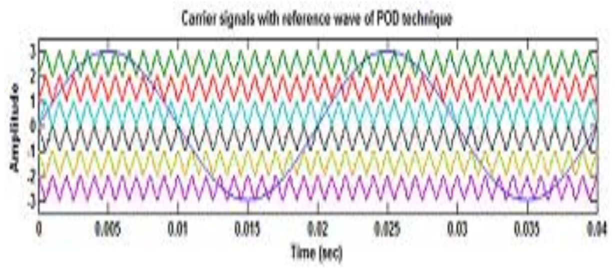

Fig. 3: B): Comparison of Reference and Carrier Signals of POD for 7-Level CHB Inverter.

c) Alternate Phase Opposition Disposition (APOD-PWM)

In this technique, one carrier wave is in out of phase to its prior carrier. The carrier signals are of same amplitude and simulated at M=1 & Fc=2kHHz. The depicted figures fig.4 (a) & 4(b) will shows for 5& 7 levels.

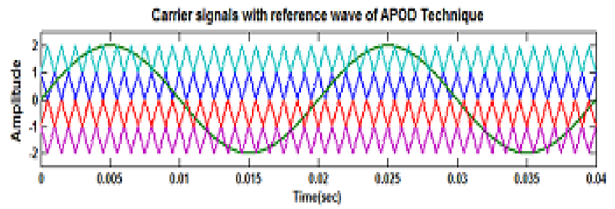

Fig. 4: A): Comparison of Reference and Carrier Signals of APOD for 5-Level CHB Inverter.

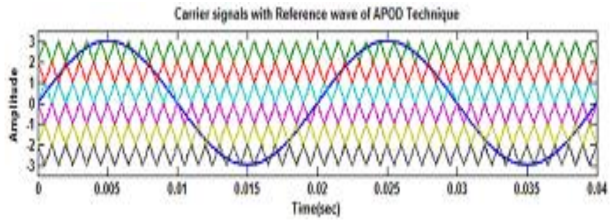

Fig. 4: B): Comparison of Reference and Carrier Signals of APOD for 7-Level CHB Inverter.

Selective Harmonic Elimination-PWM Technique

From the Fourier analysis, the output voltage is

$$V(\omega t) = \sum_{n=1}^{\infty} V_n \sin(\omega t) \quad (1)$$

Here Vn is the nth harmonic component, Now Vn becomes

$$V_n = \begin{cases} \frac{4V_{dc}}{n\pi} \sum_{i=1}^{S} \cos(n\theta_i) \ \ for\ odd \\ \quad 0\ for\ even \end{cases} \quad (2)$$

The range of switching angles 0 to π/2. Even harmonics are not presented due to quarter wave symmetry. And also triplen harmonics were suppressed in the three phase loads. The odd ordered harmonics can be omitted by using below equations.

ordered harmonics can be omitted by using below equations.

$$V_1 = \frac{4Vdc}{n\Pi}[\cos(\theta 1) + \cos(\theta 2) + \cos(\theta 3)] \quad (3)$$

$$V_5 = \frac{4Vdc}{n\Pi}[\cos(5\theta 1)\cos(5\theta 2) + \cos(5\theta 3)] \quad (4)$$

$$V_7 = \frac{4Vdc}{n\Pi}[\cos(7\theta 1)\cos(7\theta 2) + \cos(7\theta 3)] \quad (5)$$

The eqn (3) is to satisfy the fundamental component, eqn(4) is to find out the magnitude of 5th harmonic and eqn (5) is to find out the magnitude of 7th harmonic. For 5-level inverter eqn (3) & (4) were solved. For 7-level inverter eqn (3) to eqn (5) were solved. So eqn (4) and eqn (5) considered to be zero and by solving them switching angles were calculated.

$$M = \frac{1}{3}[\cos(\theta_1) + \cos(\theta_2) + \cos(\theta_3)] \quad (6)$$

$$0 = [\cos(5\theta_1) + \cos(5\theta_2) + \cos(5\theta_3)] \quad (7)$$

$$0 = [\cos(7\theta_1) + \cos(7\theta_2) + \cos(7\theta_3)] \quad (8)$$

The modulation index M is find out by the below equation

$$M \triangleq \frac{V_1}{12V_{dc}/\pi} \quad (0≤□≤□) \quad (9)$$

To solve above non-linear equation, Bee Algorithm is used in this paper.

4. Bee algorithm

The Bee Algorithm is an artificial intelligent based algorithm depending on the food foraging behavior of honey bees [7].

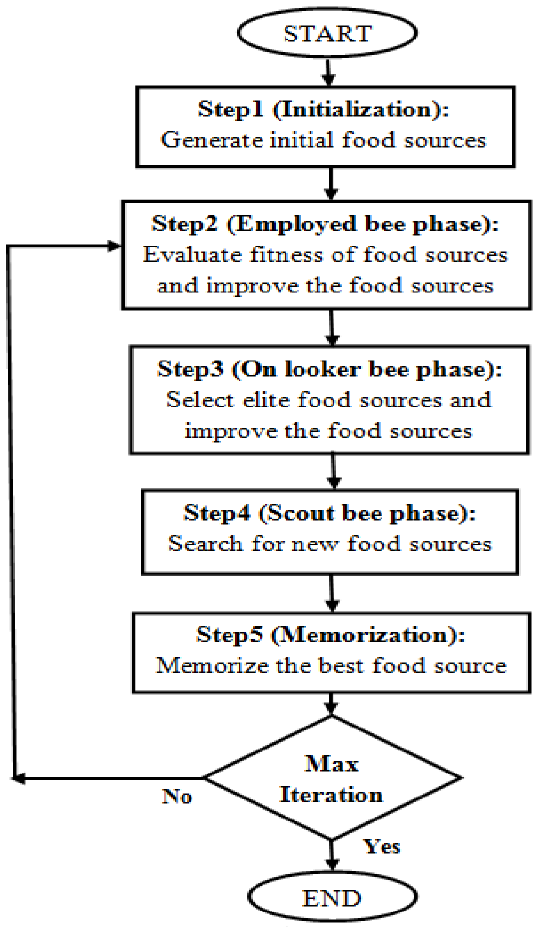

Fig. 5: Flowchart of Bee Algorithm.

Step1: the random food sources were generated which are theta values between 0to π/2. These were one half of bee colony.

θ_i, i = 1, 2 ...N

Step2: This is employed bee phase, every employed bee is allotted to one food source to calculate fitness value by eqn(10) and to estimate the amount of nectar. The employed bee saves the solution if the fitness is better in the colony.

$$Vij = \theta ij + \varphi ij\ (\theta ij - \theta kj) \quad (10)$$

Here k € {1, 2 ...N},

j € {1,2,......D}

Φ is a random number between [-1, 1]

D = Number of optimization parameters

After estimating the eqn 10, Greedy selection process is applied to choose the best value from the estimated solutions.
Step3: This is onlooker bee phase, now onlooker bee selects the food source by calculating the probability as given in eqn(11).

$$Pi = \frac{fit_i}{\sum_{i=1}^{100} fit_i} \quad (11)$$

Where, fit is selected based on the fitness value

$$fit_i = \begin{cases} \frac{1}{1+f_i} \; if \; f_i \geq 0 \\ 1 + abs(f_i) \; if \; f_i < 0 \end{cases} \quad (12)$$

Where, $\boldsymbol{f_i}$ is defined as

$$f = \min_{\theta_i} \left\{ \left(100 \frac{V_1^* - V_1}{V_1^*}\right)^4 + \sum_{S=2}^{S} \frac{1}{h_s} \left(50 \frac{V_{h_S}}{V_1}\right)^2 \right\} \text{ i=1, 2..S} \quad (13)$$

Where,

V_1^*= Desired fundamental voltage

V_1= estimated from eqn (3)

S=number of switching angles

In multilevel inverters BA is used to mitigate or eliminate the harmonics so f value is considered if it is less than or equal to zero. The onlooker bees are the other half of bee colony. The best food source attracts more onlooker bees. Onlooker bees generate new food sources by eqn(10) and estimate the fitness value, if present fitness value is good than the prior one then she update the present solution in her memory. Again greedy selection process is applied.
Step4: The employed bee which is not improved till now is considered as abandoned one, and it is send to seek the new food sources as a scout bee by the use of eqn(14).

$$\theta_i^j = \theta_{min}^j + rand[0,1](\theta_{max}^j - \theta_{min}^j) \quad (14)$$

Step5: The Best fitness value achieved so far is memorized. If best value is not attained in one cycle, the process will starts from step2.

5. SPWM simulation results

The simulation results for 5 & 7-level inverter using Sinusoidal PWM technique are shown in this section. The simulation was finished in MATLAB/SIMULINK environment, at RL load of R=10ohm and L=10mH. And at Modulation index of M=1.
The figures from Fig6(a) to Fig6(d), shows 5-level CHB inverter's output voltage profile with PD, POD and APOD techniques with their FFT Analysis.

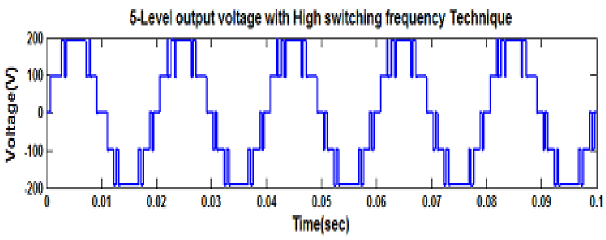

Fig. 6: A): 5-Level Output Phase Voltages of CHMLI Using PD, POD and APOD Techniques.

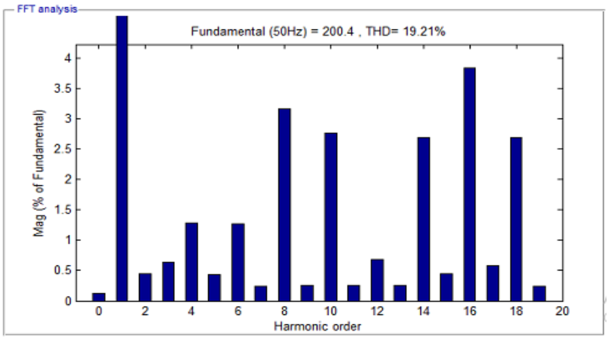

Fig. 6: B): FFT Analysis of 5-Level Inverter with PD-SPWM.

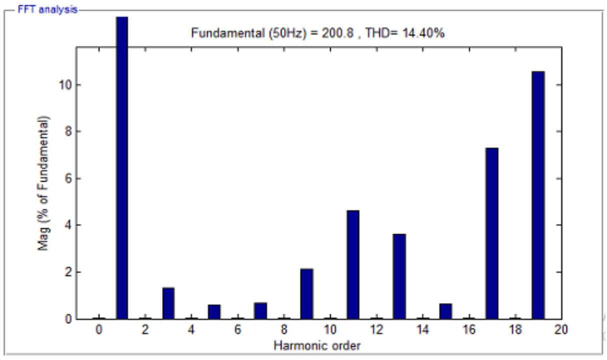

Fig. 6: C): FFT Analysis of 5-Level Inverter with POD-SPWM.

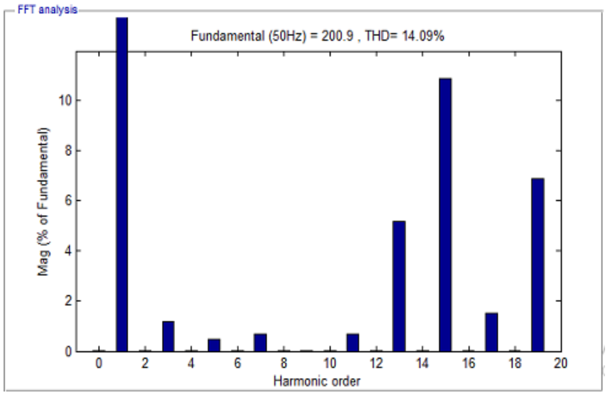

Fig. 6: D): FFT Analysis of 5-Level Inverter with APOD-SPWM.

The THD's of 5-level inverter with PD-SPWM technique is 19.21%, POD-SPWM technique is 14.40% and APOD-SPWM is 14.09%.

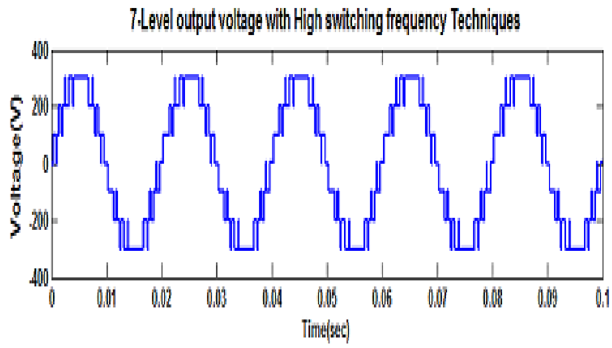

Fig. 7: A): 7-Level Output Phase Voltages of CHMLI Using PD, POD and APOD Techniques.

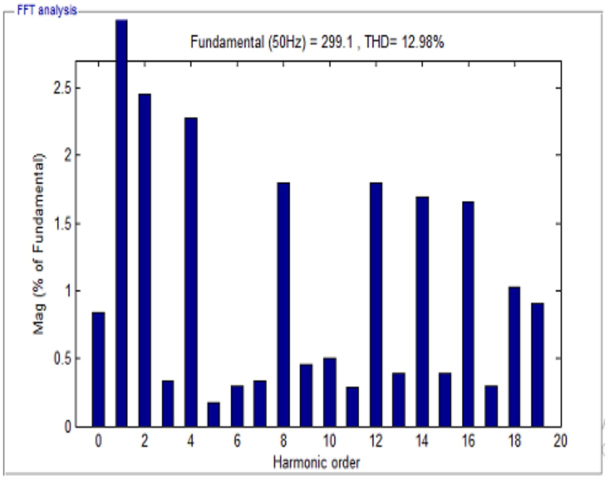

Fig. 7: B): FFT Analysis of 7-Level Inverter with PD-SPWM.

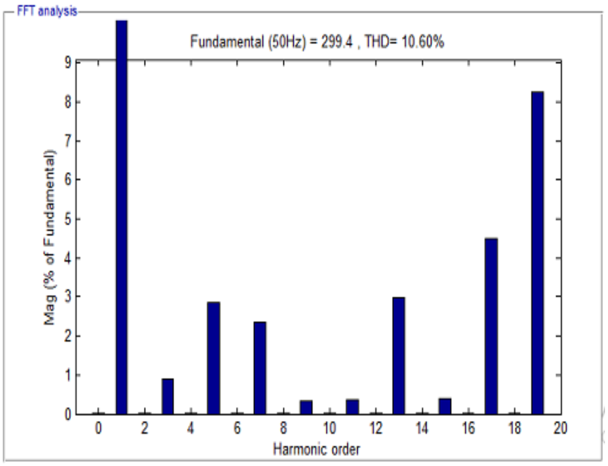

Fig. 7: C): FFT Analysis of 7-Level Inverter with POD-SPWM.

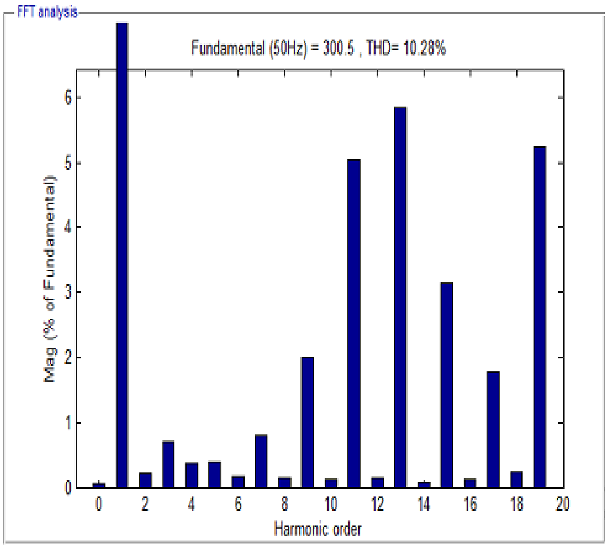

Fig. 7: D): FFT Analysis of 7-Level Inverter with APOD-SPWM.

The THD's of 7-level CHB inverter with PD-SPWM technique is 12.98%, POD-SPWM technique is 10.60% and APOD-SPWM is 10.28%.

6. SHE-PWM simulation results

The non-linear equations of SHE-PWM were solved by using the Bee Algorithm. This algorithm was applied for both 5 &7-levels of CHB inverter. This algorithm is simulated at M=0.55 and for RL load of R=10ohm & L=10mH. Some of the optimization values with their THD's and percentage of harmonic content was given in table3.

Table3: Switching Angles with THD and Harmonic Component for 5-Level

Θ1	Θ2	Fitness Value	THD (%)	Harmonics 5^{th} (%)
38.9297	70.58877	0.0121	17.15	5.45
40.0678	72.2386	0.0021	15.78	4.34
32.2862	70.7717	1.0508×10^{-7}	20.7	2.61
37.1169	72.2885	7.8149×10^{-5}	16.96	1.49
36.0766	72.5749	2.5168×10^{-5}	17.79	0.49

The highlighted optimum theta values eliminates 5th harmonic in 5-level inverter to 0.49%. And THD is 17.79%.
Table 4 displays Optimization values for 7-level inverter. In this 5th & 7th harmonics were eliminated. The highlighted optimum theta values eliminate 5th & 7th harmonics to 3.86% & 0.39% respectively.

Table.4: Switching Angles with THD and Harmonic Component for 7-Level

Θ1	Θ2	Θ3	Fitness value	THD (%)	Harmonics (%)	
					5^{th}	7^{th}
38.0339	53.8891	73.2591	1.0000	14.08	9.05	1.78
17.5087	49.7422	86.2649	1.0000	18.03	9.69	1.52
35.1044	57.8861	71.3817	0.4201	13.69	7.89	2.54
22.1481	52.351	82.3206	0.4042	14.03	6.76	0.08
33.0218	55.65	75.3932	0.3698	12.72	3.86	0.39

The output voltage profiles and FFT Analysis of 5 & 7-level inverter with fundamental frequency technique is shown in Fig. 8 (a)-8 (d).

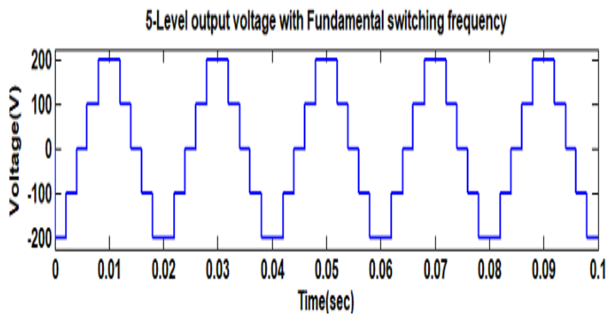

Fig. 8: A): 5-Level Output Phase Voltage Profile.

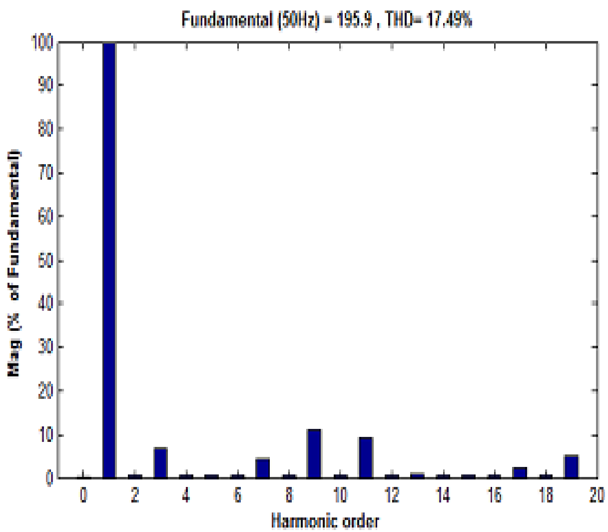

Fig. 8: B): FFT of 5-Level CHMLI Using Bee Algorithm.

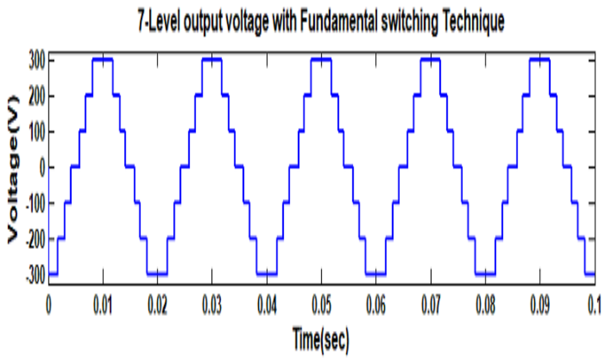

Fig. 8: C): 7-Level Output Phase Voltage Profile Using Bee Algorithm.

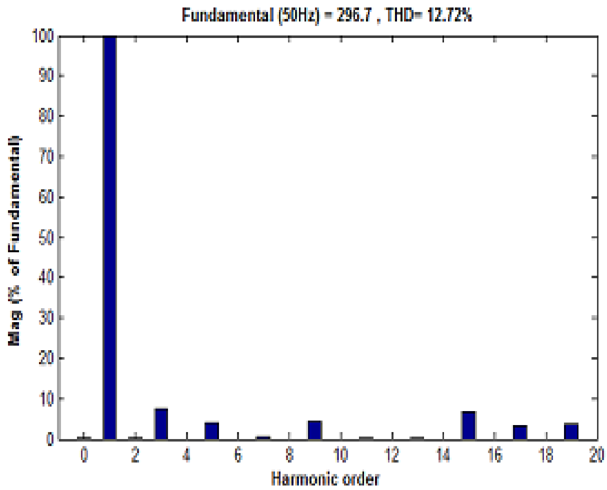

Fig. 8: D): FFT of 7-Level CHMLI Using Bee Algorithm.

Table 5: The Percentagethd's of Different Modulation Techniques

Proposed Methods	THD (%)	
	5-Level	7-Level
PD	19.21	12.98
POD	14.40	10.60
APOD	14.09	10.28
Bee Algorithm	17.49	12.72

7. Conclusion

The Sinusoidal PWM technique and SHE-PWM technique were studied and simulated in MATLAB/SIMULINK for 5-level and 7-level CHB inverters. And the Results were depicted and explained. Both techniques are showing minimum THD values, among these APOD technique gives less THD in both 5 & 7-level inverters. But using these SPWM technique lower order harmonics were not eliminated In SHE-PWM lower order harmonics were eliminated by using the Bee Algorithm. So that switching losses were minimized.

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