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Reduction of Total Harmonic Distortion of Cascade H-Bridge Inverter with Tuning Switching Parameters in Optimized Value

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Abstract

Multilevel inverters have become more convenient over the last years in electrical high power applications because, their outputs are closer to sinusoidal. The cascade H-bridge inverter (CHB) is very popular then other multilevel inverter because its control method is very easy when compared with others. In this paper new approach of seven levels Space vector modulation (SVM) is utilized to produce required fundamental voltage in CHB. For minimized total harmonic distortion (THD), switching parameters tuned by meta-heuristic algorithms and this value has been compared with arbitrary values. The simulation results have been carried out using MATLAB/SIMULINK Software.

1. INTRODUCTION

Multilevel Inverters divided the main dc supply voltage into several smaller dc sources which are used to compound an ac voltage into a stair case, or stepped, approximation of the desired sinusoidal waveform [1]. There are three main types of multilevel inverters: Diode clamped Inverter-Capacitor clamped inverter -cascade inverter.

To combine a multilevel waveform, the ac output of each of the different level H-bridge cells is connected in series [2]. the cascade multilevel converter consists of *m* full bridge topology which has been connected series to produce high level voltage. Figure1 illustrates the schematic diagram of single phase *m* level cascaded inverter using H-bridge cells and separate DC sources.

As been illustrated, value of output voltage in each phase is given as fallow:

$$V_o = V_{o1} + V_{o2} + ... + V_{om} \tag{1}$$

Cascade H-bridge converter classified into symmetrical and unsymmetrical, with consider of its input DC voltage. If all dc voltage source is equal to same value, it introduces symmetrical in other wise introduced as an asymmetrical. With consider *m* number of cell, converter output voltage level (N) shown as follow:

$$N = 2 \times m + 1 \tag{2}$$

One of major problem in multilevel inverter is utilization of great number of switching device to have high level inverter and output same to sinusoidal waveform.

This number of device raises the total cost of device. In order to has a tradeoff between cost and quality of multilevel inverter most of literature introduce new topology with reduced number of devices recently.in [3] new topology with reduced number of devices has been introduced which used in this paper. Figure 2 Illustrated basic unit for a sub-multilevel which proposed with author.

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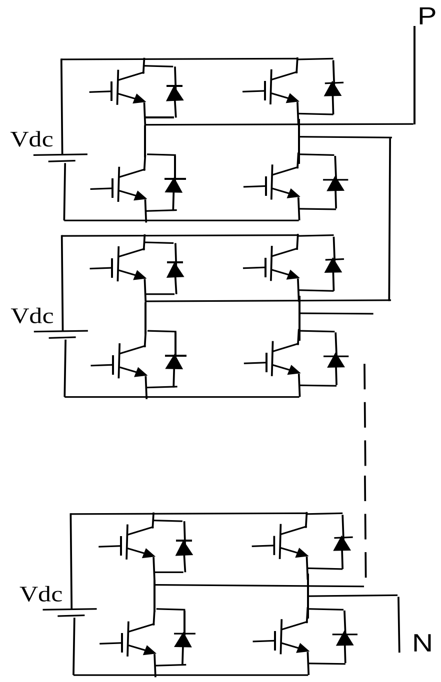

Figure 1. *Single Phase N Level Cascade H-Bridge Inverter*

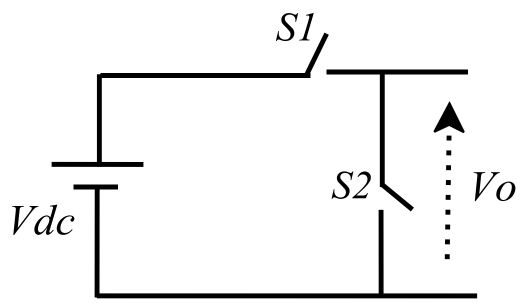

Figure 2. *Basic unit used in multilevel inverter*

Table I shows the value of V_o for feasible state of switches S1 and S2.

Table I. *FEASIBLE state of switches and their output voltage*

State	Switches State		Unit Output Voltage
1	S1	S2	Vdc
	1	0	
2	0	1	0

Figure 3 shows the single phase cascade H-bridge inverter with proposed base unit.

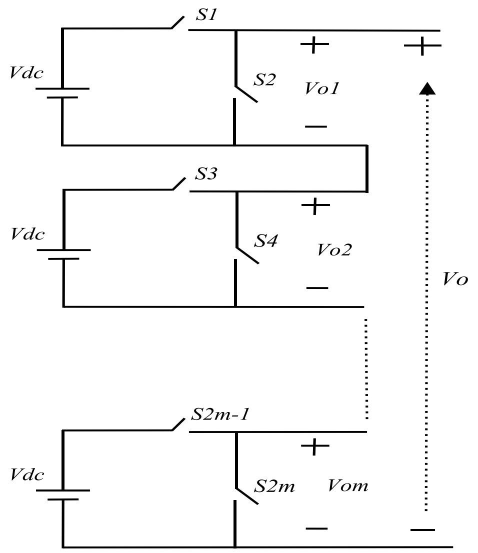

Figure 3. *Single Phase Cascade H-Bridge with basic proposed unit*

Output voltage for represented circuit with considers all feasible states to switches have been achieved like fig 4.

In this figure all dc voltage source of each unit considered in equal value.

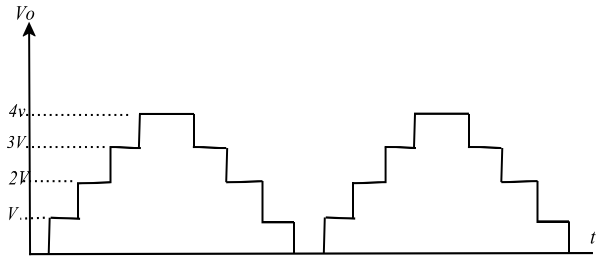

Figure 4. *Output Waveform of 5 Levels*

As be seen clearly achieved from figure 4, wave form for completion need to negative side.it is feasible by adding full bridge topology to indicated circuit. Figure 5 shows complete circuit. [4].

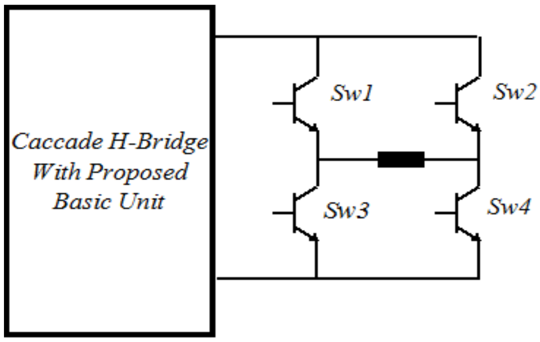

Figure 5. *Topology which has both positive and negative sides*

As author indicates in [3], needed IGBTs number in this topology achieved like (3) [5,6]:

$$N_{step} = m + 1$$
$$IGBTS\_Number = 2 \times N_{step} - 1 \quad (3)$$

Where:

N_{step} : inverter output levels

m : number of series unit

Figure 6 illustrates capabilities of the proposed converter in reduction of the number of the switches. [7,8].

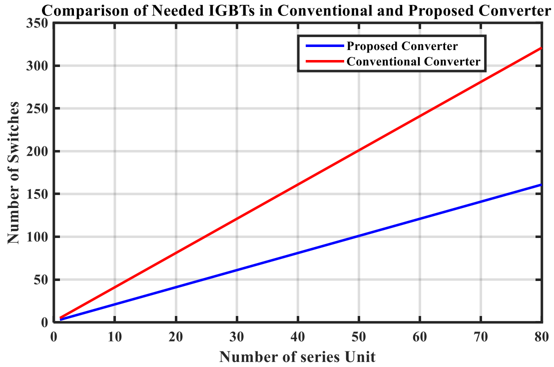

Figure 6. *Comparison Between Presented Cascade Multilevel with Conventional Multilevel Inverter*

2. SPACE VECTOR SWITCHING ALGORITHM

There is more kind of switching algorithms, such as: Sinusoidal pulse width modulation (SPWM), Hysteresis-band current control, space vector modulation (SVM) and etc. All of them have their advantages and disadvantages. They use in various implement with consider their proper features.

Among them, Space vector modulation provides more fundamental outage voltage as compared with other modulation methods. An advantage of the SVM is the instantaneous control of switching states and the freedom for select vectors in order to balance the NP. Space vector modulation used in three phase voltage source inverter in application such as: induction motors. It provides a constant switching frequency and therefore the switching frequency can be adjusted easily. The determination of the switching instant may be achieved using space vector modulation technique based on the representation of switching vectors in α , β plane.

The concept of space vector is derived from the rotating field of AC machine which is used for modulating the inverter output voltage. Space vector modulation which used in two levels inverter demonstrated in most number of literatures. But its application in high level inverters such as 3, 5… Levels are difficult because of switching pattern complication.

In next section space vector modulation for proposed seven levels Cascade H-bridge inverter described. [9].

3. PULSE GENERATING AND DWELL TIME CALCULATION

In this paper, SVM is used for pulse generating of seven levels cascade h-bridge inverter. In figure 7 space voltage diagrams for 3, 5 and 7 levels inverter is depicted in which triangle number for seven level space vector are 216. [10]

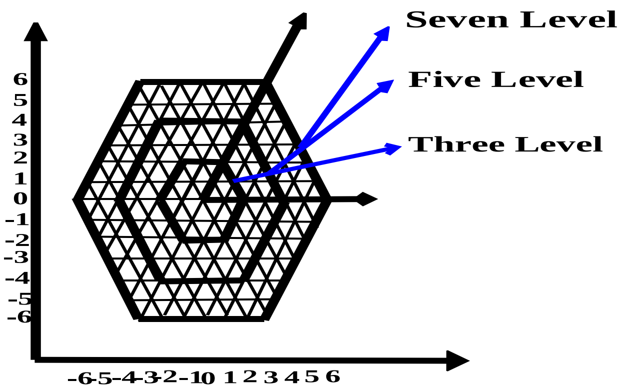

Figure 7. *Space Voltage Diagram for 3,5,7 Levels inverter*

In this algorithm to facilitate the calculation, all of them transferred to 60° coordinate system as show in figure7

$$\begin{cases} V_{\alpha} = V \times \cos\theta - \dfrac{V \times \sin\theta}{\sqrt{3}} \\ V_{\beta} = \dfrac{2 \times V \times \sin\theta}{\sqrt{3}} \end{cases} \tag{4}$$

Where V_{α} and V_{β} are the peculiarities of reference vector in the 60° tune system and V , θ are its amplitude and phase angle respectively. As clearly shown in equation (4), reference vector amplitude and angle have important role in space vector modulation. So, objective function in this paper considers tuning these two parameters in optimal value to achieve best switching pulse.

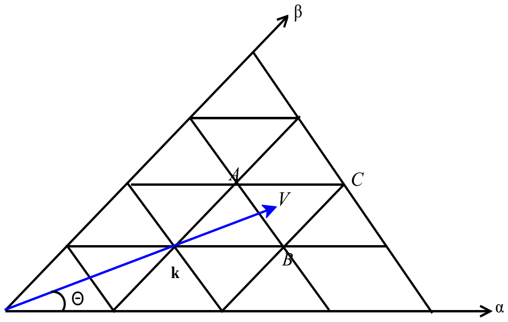

Figure 8. *Space Vectors in 60 Coordinate System (Sector I)*

For fast determination of reference vector location in this paper do as following way [11]:

If reference vector *V* lies in triangular ΔABC such as fig (8) and lower rounded value of specific vector detected with *lr(V)*, to determine the location of the reference vector, the coordinates of the space vector V_K, $V_{K\alpha}=lr(V_{\alpha}^{*})$ and $V_{K\beta}=lr(V_{\beta}^{*})$ will be used [12].

Based on V_K, the coordinates of space vector V_A, V_B, V_C can be calculated by:

$$\begin{aligned} (V_{B\alpha}, V_{B\beta}) &= (V_{K\alpha}+1, V_{K\beta}) \\ (V_{A\alpha}, V_{A\beta}) &= (V_{K\alpha}, V_{K\beta}+1) \\ (V_{C\alpha}, V_{C\beta}) &= (V_{K\alpha}+1, V_{K\beta}+1) \end{aligned} \tag{5}$$

If reference vector lies in ΔABC, with consider volt-second balancing principle, dwell time for each vector achieved like :

$$\begin{aligned} T_B &= (V_{K\beta}+1-V_{\beta}^{*}) \times T_s \\ T_A &= (V_{K\alpha}+1-V_{\alpha}^{*}) \times T_s \\ T_C &= T_s - T_B - T_A \end{aligned} \tag{6}$$

Where T_B, T_A, T_C are the dwell times of the vectors V_B, V_A, V_C respectively and T_s is sampling time.

The relationship between space vector and its switching states, is defined as follow:

$$\begin{aligned} V_a &= -k, -k+1, -k+2, \ldots, k-1, k \\ V_b &= V_a - \alpha \\ V_c &= V_a - \alpha - \beta \end{aligned} \tag{7}$$

Where α, β are indicates space vector.

K is obtained as follow:

$$k = \frac{n-1}{2} \tag{8}$$

Where *n* is the number of each phase levels.

For example, switches state for a 5-level inverter in sector I are given as table (II). By considering table (III), switching states for other sector can be obtained.

***Table II**. Switching States Sector I of 5-Level Inverter*

Switching States		
Va	*Vb*	*Vc*
-3	-3-α	-3-α-β
-2	-2-α	-2-α-β
-1	-1-α	-1-α-β
0	-α	-α-β
1	1-α	1-α-β

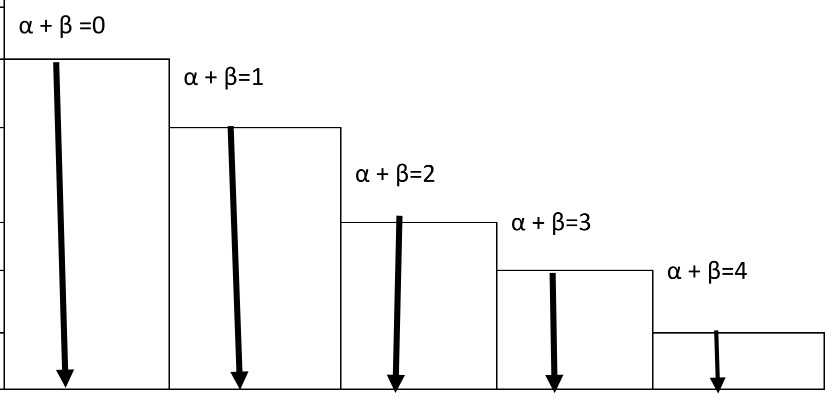

***Table III.** Relationship of Switching States in Various sectors*

Sector	Switching State			Example : Vector (1,1)
I	*Va*	*Vb*	*Vc*	[-1,-2,-3],[0,-1,-2],[1,0,-1]
II	*-Vb*	*-Vc*	*-Va*	[2,3,-1],[1,2,0],[1,0,-1]
III	*Vc*	*Va*	*Vb*	[1,-3,-2],[0,-2,-1],[1,0,-1]
IV	*-Va*	*-Vb*	*-Vc*	[2,3,-1],[2,1,0],[1,0,-1]
V	*Vb*	*Vc*	*Va*	[1,-3,-2],[0,-1,-2],[1,0,-1]
VI	*-Vc*	*-Va*	*-Vb*	[2,3,-1],[2,1,0],[1,0,-1]

A. Particle Swarm Optimization (PSO)

PSO is one kind of population based algorithm's which works with a population of potential solutions rather than with a single individual. The searching for the optimal solution continuations unless one of the stopping criteria arrives. Figure 8 illustrated flowchart of PSO. Each particle can be shown by its current speed and position, the most optimist position of each individual and the most optimist position of the surrounding. In this algorithm the speed and position of each particle change according the following equality.

$$\begin{aligned} V_j^{k+1} = & V_j^k + C_1 \times r_1^k \times (Pbest_j^k - x_j^k) \\ & + C_2 \times r_2^k \times (gbest^k - x_j^k) \end{aligned} \tag{8}$$

$$x_j^{k+1} = x_j^k + v_j^{k+1} \tag{9}$$

Where C1 is equal C2 and they are equal 2, r1, r2 represent random fiction between [0,1].

Objective function in this paper is defined as reduction of total harmonic distortion (THD) which is shown below:

$$OF = \int_0^{t_{sim}} t \times |THD|\, dt \tag{10}$$

Where: t_{sim} is the simulation time. In this simulation, values of THD in any time compared and minimized value is considerd as best value of objective function. By using PSO algorithm and tuning switching parameters objective function get its best value.

Table (IV) shows necessary information for PSO algorithms.

Table IV. *PSO Parameters*

Population Size	60
C_1	2
C_2	2
W	.93
Iteration	25

By minimizing objective function in minimized value, switching parameters tuned in the best value. [13,14].

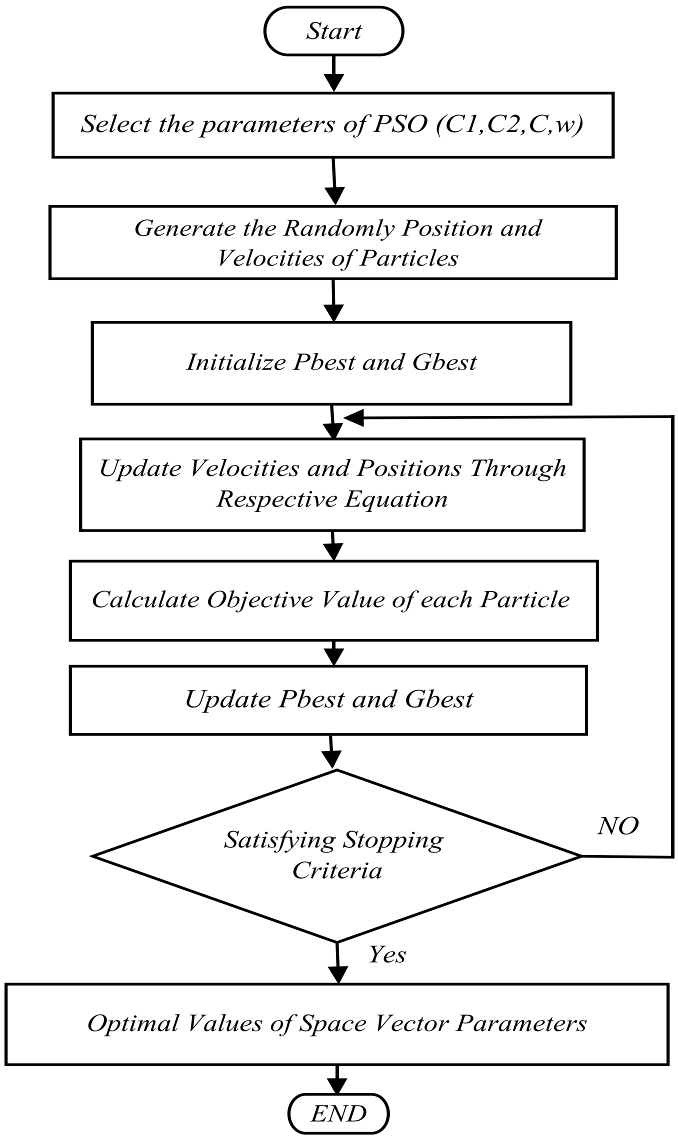

Figure 9. *PSO Flowchart*

B. Simulation Results

In SVM, reference voltage size and angles have important role in switching patterns. With tunes these parameters in optimal values, output voltage has minimal THD. Figure 10 shows pulse generating algorithm which demonstrated in previous section.

In table V angles and size of reference voltage illustrated with arbitrary value and with optimized value. In this paper input dc voltage considers 100 volts.

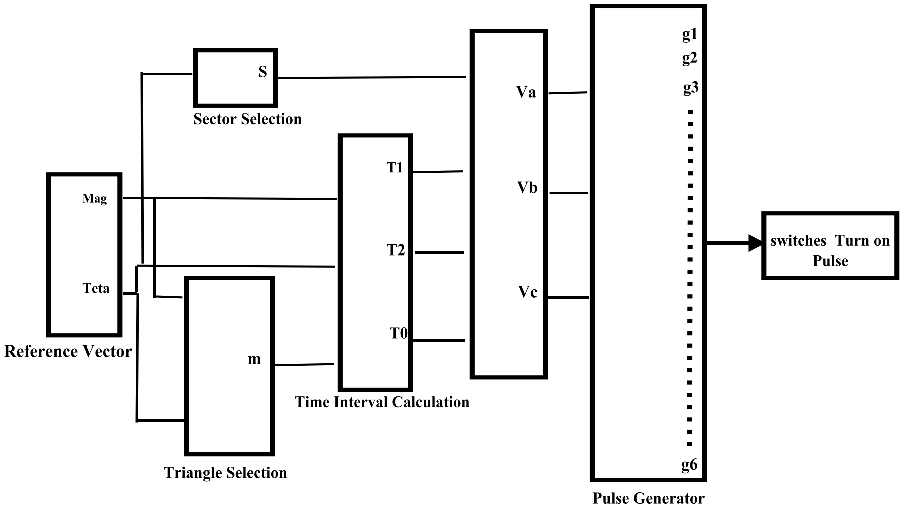

Figure 10. *Proposed Switching Algorithm*

Table.V. *Switching Parameters*

Optimization Algorithm	Reference voltage value	Reference voltage angle	Value of THD (%)
PSO algorithm	839	37	2.39
Arbitrary value	1000	0	12.79

As clearly seen from table V, by considering reference voltage and angle in optimized value (839 volt 37degree) value of THD decrease from 12.79% to 2.395%. Figure 11 shows switching states. The output voltage of proposed circuit with arbitrary switching values has been shown in figure 12. In figure 13 FFT analyses was shown for respected values.

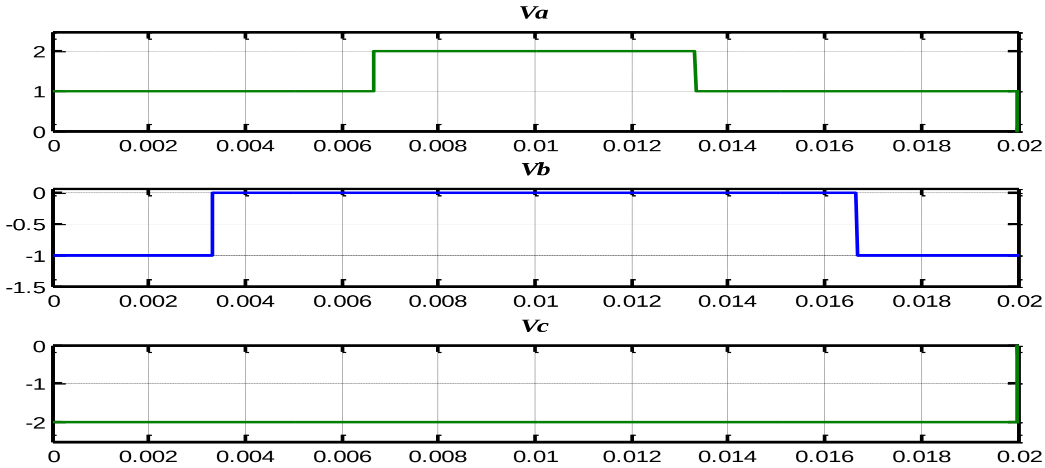

Figure 11. *Switching States*

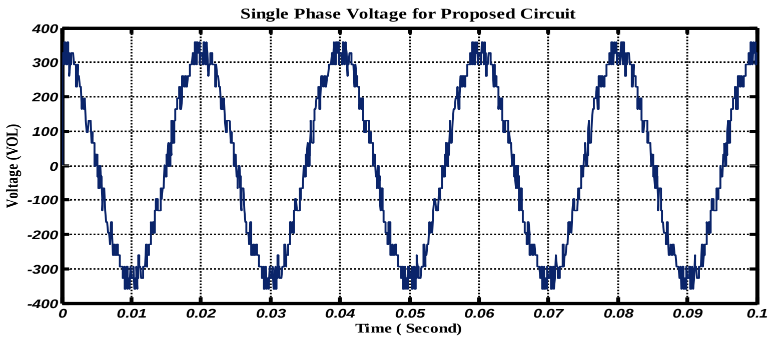

Figure 12. *phase voltage with arbitrary switching value*

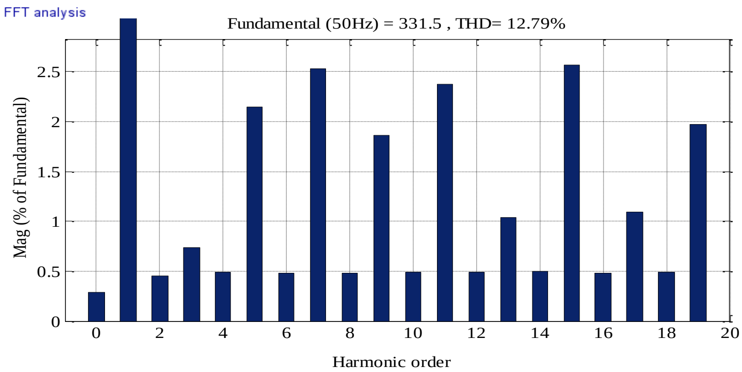

Figure 13.*FFT Analyzing of phase voltage in case 1*

If switching parameters is tuned in optimized value, output voltage has been shown like figure 14. [15].

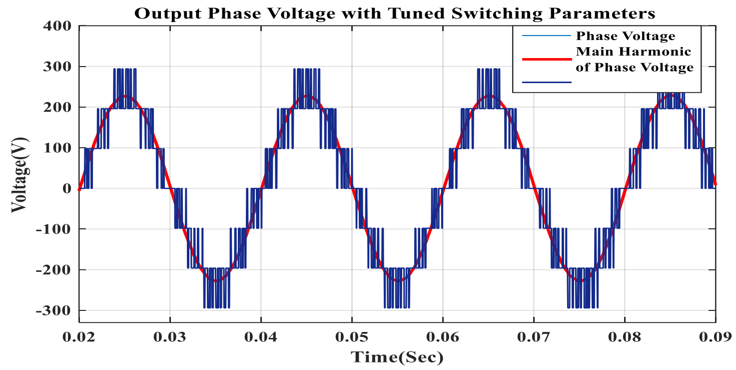

Figure 14. *Output phase voltage of multilevel with optimized tuned switching parameters*

Figure 15 shows FFT analysis for output phase voltage of proposed circuit. [16,17,18].

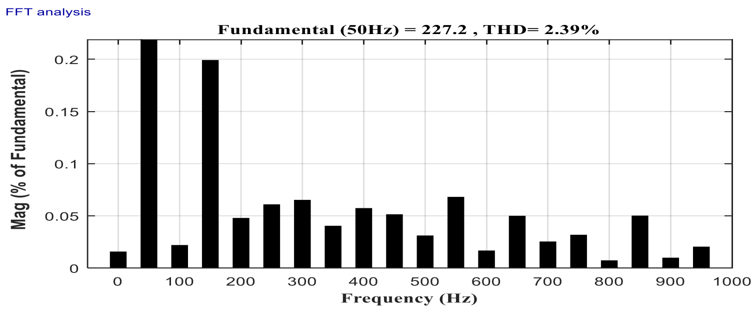

Figure 15. *FFT Analyzing of Voltage in Case 2*

C. Experimental Results

In this section results which achieved from experimental measurements by considering optimal tuned switching parameters has been illustrated. The circuit parameters of experimental results, are shown in table VI. Value of each input dc voltage adjusted in 30 volts. figure 16 shows output voltage of single phase H-bridge inverter. Figure 17 illustrates experimental view of proposed topology. [19,20].

Table VI. *Principle Parameters in the Prototype*

Parameter	Value
Input voltage	30 (V)
Load	R-L (160Ω-33mH)
Switches	IRFP450 MOSFET's with Internal Antiparallel Diodes
Gate drivers	TLP250 kind and diodes are based on MUR460

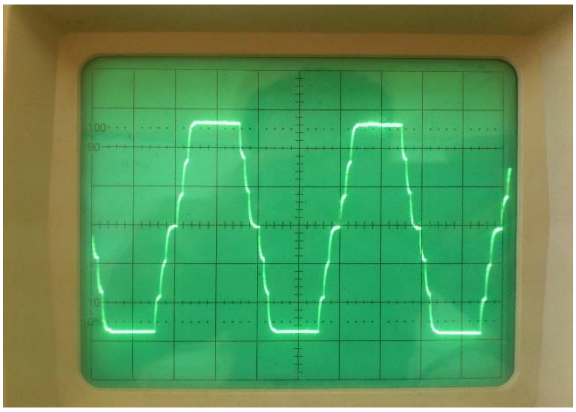

Figure 16. *Output Voltage with Tuned Switching Parameters*

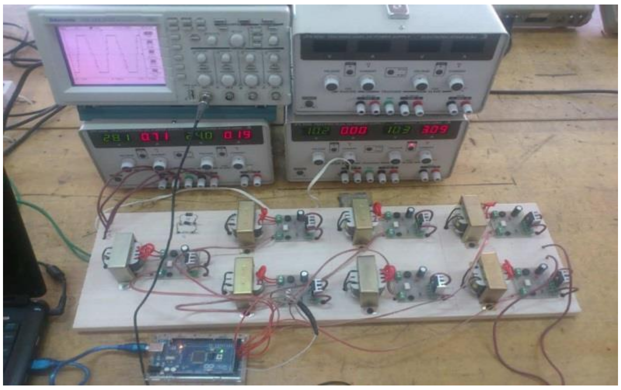

Figure 17. *Experimental schematic of proposed circuit*

4. CONCLUSION

Recently some meta-heuristic algorithms such as: particle swarm optimization (PSO) and genetic algorithm (GA) is introduced for solving optimization problems. As it can be find out from results, by utilizing PSO algorithm, switching parameters has been tuned in optimal value. With implement this values in proposed topology distortion harmonic of output voltage reduced significantly. The comparison of the results in this paper with similar work in other literature proves PSO efficiency in minimization of THD in cascade h-bridge (CHB) multilevel inverters.

CONFLICT OF INTEREST

No conflict of interest was declared by the authors

REFERENCES

[1] Sung-Jun Park, Feel-Soon Kang, et al. “A New Single-Phase Five- Level PWM Inverter Employing a Deadbeat Control Scheme,”IEEE Trans. on Power Electronics, Vol. 18, No. 3, MAY 2003, Page 831-843.

[2] G. Gateau, M. Fadel, P. Maussion, R. Bensaid, and T. A. Meynard, “Multicell converters: Active control and observation of flying capacitor voltages,” IEEE Trans. Ind. Electron., vol. 49, no. 5, pp. 998–1008, Oct. 2002.

[3] E.Babaei,S.H.Hosseini,"New Multilevel Converter Topology with Minimum Number of Gate Driver Circuits, "International Symposium on Power Electronics,Electrical Drives, Automation and Motion, 2008,pp1-6.

[4] Ajami, A.; Reza Jannati Oskuee, M.; Toopchi Khosroshahi, M.; Mokhberdoran, A.E," Cascade-multi-cell multilevel converter with reduced number of switches,,"IET Journal and Magazines,Vol.7,Issue .12,pp.2914-2924.

[5] Boobalan, S.; Dhanasekaran, R.," Hybrid topology of asymmetric cascaded multilevel inverter with renewable energy sources," Advanced Communication Control and Computing Technologies (ICACCCT) International Conference on 2014,pp 1046-1051.

[6] Ajami, A.; Oskuee, M.R.J.; Mokhberdoran, A.; van den Bossche, A. ," Developed cascaded multilevel inverter topology to minimize the number of circuit devices and voltage stresses of switches, "Power Electronics IET, Vol.7, Issue.2, pp.459-466.

[7] R. Shalchi Alishah, D. Nazarpour, S. H. Hosseini, M. Sabahi," Novel Single-Phase Multilevel Inverter Topology Based on Cascaded Connection of Basic Units," Asian Power Electronic Journal," Vol.8. No.1, June2014, pp24-29

[8] Bharatiraja, C. ; SRM Univ., Chennai, India ; Jeevananthan, S. ; Latha, R. ; Dash, S.S.," Simplified structure - A mapped space vector pulse width modulation for three level neutral point diode clamped multilevel inverter," Sustainable Energy and Intelligent Systems (SEISCON 2011), International Conference on 2011.pp266-271.

[9] Jwu-Sheng Hu ; Dept. of Electr. Eng., Nat. Chiao-Tung Univ., Hsinchu, Taiwan ; Keng-Yuan Chen ; Te-Yang Shen ; Chi-Him Tang," Analytical Solutions of Multilevel Space-Vector PWM for Multiphase Voltage Source Inverters ,"Power Electronic IEEE Transaction on Vol.26,Issue 5,2011,pp 1489-1502.

[10] Benny, A.; Ruban Deva Prakash, T.," Space vector based pulse density modulation scheme for multilevel inverter control with zero voltage switching," Emerging Research Areas: Magnetics, Machines and Drives (AICERA/iCMMD), 2014 Annual International Conference on July 2014, pp 1-6.

[11] D. Lee and G. Lee, "A Novel Over modulation technique for space-vector PWM inverters," IEEE Trans. Power Electron., Vol. 13, No. 6, pp. 1144-1151, 1998.

[12] A. K. Gupta and A. M. Khambadkone, "A general space vector PWM algorithm for multilevel inverters, including operation in over modulation range," IEEE Trans. Power Electron., Vol. 22, No. 2, pp. 517–526, Mar. 2007.

[13] Xiaobing Zhao ; Coll. of Autom. Eng., Nanjing Univ. of Aeronaut. & Astronaut., Nanjing, China ; Zewang Chen ; Jiang Cui ; Yuntao Jia ," Research on fault prediction method of power electronic circuits based on particle swarm optimization non-homogenous grey model ," Prognostics and System Health Management Conference (PHM-2014 Hunan), 2014 pp.24-27.

[14] Sreejeth, M. ; Dept. of Electr. Eng., Delhi Technol. Univ., Delhi, India ; Singh, M. ," Particle swarm optimization in efficiency improvement of vector controlled surface mounted permanent magnet synchronous motor drive, "Power Electronic,IET.Vol.8,Issue 5,2015.pp.760-769.

[15] Pan Z.; Peng F. Z.: Harmonics Optimization of the Voltage Balancing Control for Multilevel Converter/Inverter Systems. IEEE 39th Annual Industry Applications Conference, Oct. 2004, vol. 4, pp. 2194- 2201

[16] B. P. McGrath and D. G. Holmes, "Analytical modeling of voltage balance dynamics for a flying capacitor multilevel converter," IEEE Trans. Power Electron., vol. 23, no. 2, pp. 543–550, Mar. 2008.

[17] Hamed.Hosseinnia, et al, "Simple Boost Control Method Optimized withGenetic Algorithm for Z-Source Inverter" JEPECS VOL. 1, NO. 1, PP. 32-36, AUTUMN 2013.

[18] Hosseinnia, Hamed, and Murteza Farsadi. "Utlization Cat Swarm Optimization Algorithm for Selected Harmonic Elemination in Current Source Inverter." International Journal of Power Electronics and Drive Systems 6.4 (2015).

[19] G. P. Adam, S. J. Finney, A. M. Massoud, and B.W.Williams, “Capacitor balance issues of the diode-clampedmultilevel inverter operated in a quasi-two-state mode,” IEEE Trans. Ind. Electron., vol. 55, no. 8, pp. 3088–3099, Aug. 2008.

[20] Z. Du;L. M. Tolbert, B. Ozpineci, and J. N. Chiasson, “Fundamental frequency switching strategies of a seven-level hybrid cascaded H-bridge multilevel inverter,” IEEE Trans. Power Electron., vol. 24, no. 1, pp. 25–33, Jan. 2009 .

[21] M. M. Prats, R. Portillo, J. M. Carrasco, L. G. Franquelo. New fast space-vector modulation for multilevel converters based on geometrical considerations. *IECON Proceedings (Industrial Electronics Conference)*, 2002, Vol.4: 3134-3139.