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Reduction of Total Harmonic Distortion in Power Invertors Using Genetic Algorithm

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ABSTRACT
In this paper, Genetic Algorithm is developed as the favored solution algorithm of specific harmonic elimination (PWM-SHE) switching pattern. Genetic algorithms are a class of parallel processing learning techniques. In this paper first, the 7-level and 9-level cascaded inverter's structures are briefly described, and optimum switching angles are determined to eliminate low order harmonics and to reduce THD. Comparison has been done between the 7-level and 9-level with respect to the consideration of THD. Simulation results validate purpose method.
Keywords - Genetic algorithm, multilevel inverter, Selective harmonic elimination pulse width modulation (SHEPWM), Total harmonic distortion

I. INTRODUCTION

In recent years, Multilevel inverters have attracted a great deal of attention in medium –voltage and high power applications due to their lower switching losses , higher efficiency and more electromagnetic compatibility than those of conventional two-level inverters. Use of multilevel inverters is becoming popular for high power applications [1]-[5], especially in the distributed generation where a number of batteries, fuel cells, solar cell, and micro-turbines can be connected through a multilevel inverter to feed a load or the ac grid without voltage balancing problems. Another major advantage of multilevel inverters is that their switching frequency is lower than a traditional two-level inverter, which leads to reduced switching losses [1], [3], [6]. The cascaded inverter has the advantages that the DC-link voltage is balanced, circuit layout flexibility, and it has the least components per phase but require many separated dc sources in motor drive applications. The cascaded inverter has been largely studied and used in fields of SVCs (static VAR compensators), stabilizers, HVDC transmissions and so on [12]-[16]. Many switching strategies are applied to multilevel inverter to reduce harmonics, but SHEPWM is most well-known strategy. SHE-based methods have been proposed for both two-level [17]–[19] and multilevel inverters. The desired output of a multi level converter is synthesized with several methods including staircase modulation, sinusoidal pulse width modulation (PWM) with multiple triangular carriers, and multilevel space vector modulation. The elimination of specific low-order harmonics from a given voltage /current waveform generated by a voltage/current source inverter using

what is widely known as optimal , "Programmed" or selective harmonic elimination PWM (SHE-PWM) techniques has been deal with in numerous papers and for various converter topologies, systems, and applications [6]-[11].The general function of this multilevel inverter is to synthesize a staircase waveform from several separate dc sources (SDCSs), which may be obtained from solar cells, fuel cells, batteries, ultra capacitors, etc. For output staircase waveform, it is necessary to obtain the switching timing angles or the conducting angles of switching devices. The conventional method has the merit that the predominant low-order harmonics can be eliminated. However, it has to solve simultaneous equations, which are the set of nonlinear transcendental equations for the fundamental component and the harmonic ones. It is difficult to obtain the conducting angles because the conventional method needs an iterative method such as the Newton–Raphson one. Additionally, the switching angles are obtained by means of an off-line calculation to minimize the harmonics for each modulation index, which leads to increased use of look-up tables. Therefore, Genetic Algorithm (GA) [20]-[23] is adopted here to replace numerical algorithms to overcome this difficulty, because of its intrinsic ability to begin searching randomly, handle large amount data simultaneously and "jump" out of local optimum automatically. GA is kind of artificial intelligence approaches, and origins from optimizing problems. It has entirely different operation mechanism, comparing with numerical methods based on mathematical differential operation, which needs on some extent restrict requirements on objectives.

1.1 Structure of cascaded multi level inverter

The cascaded multilevel inverter is one of several multilevel configurations. It is shaped by connecting several single-phase H-bridge inverters in series as shown in Fig. 1 for 9-level inverter Each H-bridge has its own isolated DC source. Each separated DC sources is connected to H-bridge inverter and can produce voltages of 0, +Vdc and –Vdc, by different combination of the four switches, S1, S2, S3 and S4,where Vdc is the voltage of its DC bus.
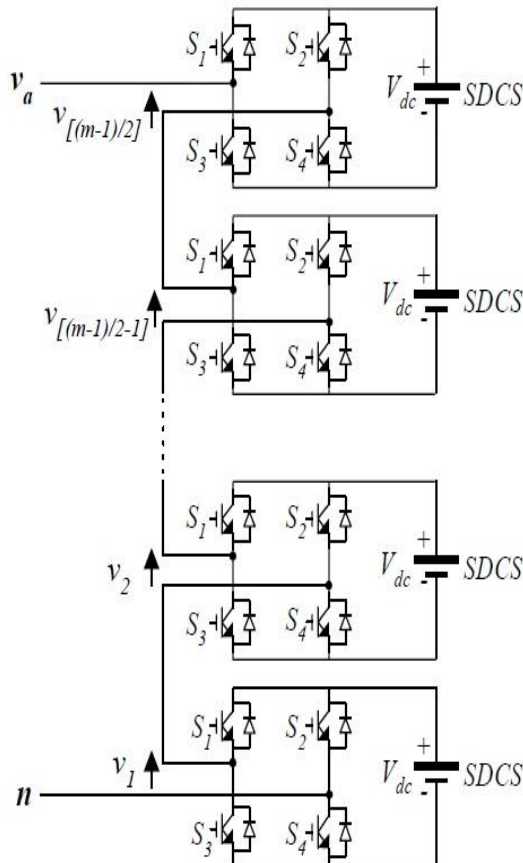

Fig. 1 Structure of cascaded multilevel Inverter

Each inverter generates quasi-square wave voltage waveform with different duty cycle ratios, which together form the staircase output voltage waveform as shown in Fig. 2 The synthesized voltage waveform is, therefore, the sum of the inverter outputs. The number of output phase voltage levels in a cascade multilevel inverter is then 2s+1, where s is the number of isolated dc sources.
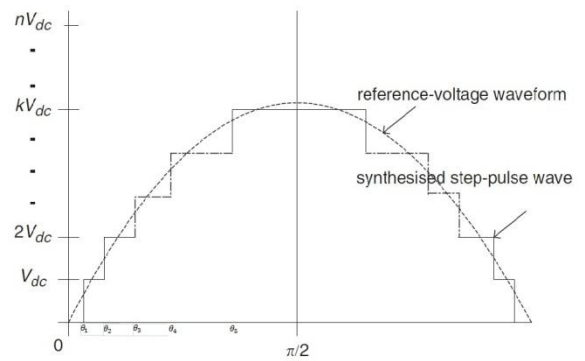

Fig. 2 Structure of cascaded multilevel Inverter

In this paper, a multilevel inverter based on the cascaded converter topology with 5 equal dc sources is studied. The key purpose of this paper is to commence a minimization technique assisted with Genetic Algorithm (GA) in order to decrease the computational burden associated with the solution of the nonlinear transcendental equations of the selective harmonic elimination method to reduce low order harmonics and to reduce THD.

1.2 Selective harmonic elimination method

The Selective Harmonic Eliminated PWM (SHE PWM) technique is used to find appropriate switching angles namely $\theta_1, \theta_2, \theta_3, \ldots, \theta_N$ so that the (N-1) odd harmonics can be eliminated and control of the fundamental voltage is also achieved. The Fourier series expansion for the quarter-wave symmetric staircase waveform as shown in Figure .1 is written as follows:

$$V_{\text{out}}(\omega t) = \sum_{n=1}^{\infty} \left[\left(\frac{4V_{dc}}{n\pi} \right) \sum_{k=1}^{s} \cos(n\theta_k) \right] \sin n\omega t \quad (1)$$

Where, θ_k is the switching angles, which must satisfy the following condition: $\theta_1, \theta_2, \theta_3, \ldots, \theta_s < \pi/2$ and s is the number of H-bridge cells.

n is odd harmonic order And, V is the amplitude of dc voltage The harmonic components in the waveform can be describes as follows:

• the amplitude of dc component equals zero
• the amplitude of the fundamental component, $n = 1$, and odd harmonic component are given by:

$$h_1 = \left[\left(\frac{4V_{dc}}{\pi} \right) \sum_{k=1}^{s} \cos(\theta_k) \right], \text{ and}$$

$$h_n = \left[\left(\frac{4V_{dc}}{n\pi} \right) \sum_{k=1}^{s} \cos(n\theta_k) \right] \quad (2)$$

• The amplitude of all even harmonics equals zero
Thus, only the odd harmonics in the quarter-wave symmetric multilevel waveform need to be eliminated. The switching angles of the waveform will be adjusted to get the lowest output voltage THD. The total harmonics distortion (THD) is mathematically given by:

$$THD = \sqrt{\Sigma h_n^2} / h_1 \quad (3)$$

In order control the fundamental amplitude and to eliminate the 5th, 7[th,] 11th, & 13th lower order harmonics, the nonlinear transcendental equations set (4) must be solved and the five switching angles $\theta_1, \theta_2,$

θ_3, θ_3 and θ_5 are calculated offline to minimize the harmonics for each modulation index in order to have a total output voltage with a harmonic minimal distortion rate.

$$\cos(\theta_1)+\cos(\theta_2)+\cos(\theta_3)+\cos(\theta_4)+\cos(\theta_5)= 3\pi M/4$$

$$\cos(5\theta_1)+\cos(5\theta_2)+\cos(5\theta_3)+\cos(5\theta_4)+\cos(5\theta_5) = 0$$

$$\cos(7\theta_1)+\cos(7\theta_2)+\cos(7\theta_3)+\cos(7\theta_4)+\cos(7\theta_5) = 0$$

$$\cos(11\theta_1)+\cos(11\theta_2)+\cos(11\theta_3)+\cos(11\theta_4)+ \cos(11\theta_5) = 0$$

$$\cos(13\theta_1)+\cos 13(\theta_2)+\cos(13\theta_3)+\cos(13\theta_4)+ \cos(13\theta_5)= 0$$

(4) the modulation index for the multilevel waveform is given as:

$$\mathbf{M} = \frac{h_1}{sV} \qquad (5)$$

Where, h1 is the amplitude of the fundamental component. From equation, varying the modulation index value can control the amplitude of the fundamental component and the other s-1 nonlinear equations, which are the undesirable harmonic components, can be eliminated. These equations are solved by Newton-Raphson method [11]. In the natural sinusoidal PWM strategy, a large number of switching is required, with the consequent increase of switching losses. With the method of Selective Harmonic Elimination, only selected harmonics are eliminated with the smallest number of switching. This technique is very suitable for inverters control. By employing this technique, the low THD output waveform without any filter circuit is possible. Another approach uses genetic algorithm to optimize switching angle to reduce THD.

II. Genetic Algorithm

Genetic algorithm is a computational model that solves optimization problems by imitating genetic processes and the theory of evolution by using genetic operators like reproduction, crossover, mutation etc. Amounts of applications have benefited from the utilization of genetic algorithm. Genetic algorithm is still a novel technique for PWM-SHE technique.
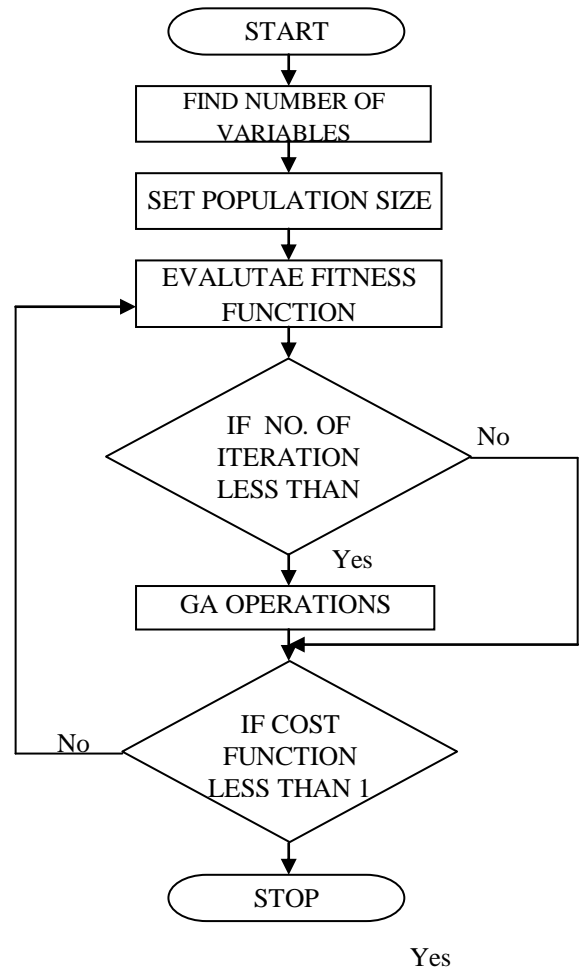

Fig. 3 Flowchart of Genetic Algorithm

This algorithm is usually used to accomplish a near global optimum solution. Each iteration of the GA is a new set of strings, which are called chromosomes, with improved fitness, is produced using genetic operators.

2.1 Chromosome representation

In GA, each chromosome is used as a feasible solution for the problem, where each chromosome is developed based on single dimensional arrays with a length of S, where S is the number of angles.

2.2 Initialize population

Set a population size, N, i.e. the number of chromosomes in a population. Then initialize the chromosome values randomly. If known, the range of the genes should be considered for initialization. Population size depends only on the nature of the problem and it must achieve a balance between the time complexity and the search space measure. The narrower the range, the faster GA converges. In this paper, population size is considered as 100.

2.3 Reproduction

The reproduction operator determines how the parents are chosen to create the offspring. This operator is a process in which chromosomes are copied according to their objective function values i.e.

the degree of conformity of each object is calculated and an individual is reformed under a flat rule depending on the degree of conformity.

2.4 Crossover

Crossover is the most significant operation in GA. It creates a group of children from the parents by exchanging genes among them. The new offspring contain mixed genes from both parents. By doing this, the crossover operator not only provides new points for further testing within the chromosomes, which are already represented in the population, but also introduces representation of new chromosomes into the population to allow further evaluation on parameter optimization.

2.5 Mutation

Mutation is another vital operation. It works after crossover operation. In this operation, there is a probability that each gene may become mutated when the genes are being copied from the parents to the offspring. This process is repeated, until the preferred optimum of the objective function is reached.

2.6 Evaluation of fitness function

The most vital item for the GA to evaluate the fitness of each chromosome is the cost function. The purpose of this study is to minimize specified harmonics; therefore the fitness function has to be associated to THD. In this work the fifth, seventh, eleventh, and thirteenth harmonics at the output of an eleven-level inverter are to be minimized.

$$FV = \frac{\sqrt{\sum_{n=5,7,11,13}\left(\frac{1}{n}\sum_{k=1}^{5}\cos\left(n\,\alpha_k\right)\right)^2}}{\sum_{k=1}^{5}\cos\,\alpha_k} \qquad (6)$$

For each chromosome a multilevel output voltage waveform

is produced using the switching angles in the chromosome and the required harmonic magnitudes are calculated using FFT techniques.

GA is typically set to run for a certain number of iterations (100 in this case) to get an answer. After the first iteration, FV's are used to determine new offspring. These go through crossover and mutation operations and a new population is created which goes through the same cycle starting from FV evaluation. Sometimes, GA can converge to a solution much before 100 iterations are completed. To save time, in this paper, the iterations have been stopped when the cost function goes below 1.

III. Simulation results

From the simulation results using genetic algorithm, it is clear that for 9-Level cascaded multilevel inverter the 5th, 7th, and 11th harmonics and for 7-Level inverter 5th and 7th, harmonics and their magnitudes are negligible relatively to the fundamental component. The obtained switching angles for various values of modulation index using GA for 7-level inverter and 9-Level inverter is shown in Table1 and Table 2 respectively. Fig.4 shows the

simulation results for the output voltage waveform of 9-level inverter for M = 0.8, Fig.6, Fig. 8 shows the FFT spectrum of THD of an 9- level multilevel inverter, Optimal switching angles for various values of M and THD of 9-level multilevel inverter. Fig.7 shows the simulation results for the output voltage waveform of 7-level inverter for M = 0.8, Table. 3 shows THD for 9-level and 7- level inverter.

Table.1 Switching angles generated by GA for 7-level

Modulation Index (M)	Switching Angles		
	θ_1 (rad.)	θ_2 (rad.)	θ_3 (rad.)
0.1	0.215	0.373	0.621
0.2	0.212	0.356	0.602
0.3	0.225	0.358	0.61
0.4	0.19	0.524	0.723
0.5	0.348	0.633	0.907
0.6	0.475	0.777	0.896
0.7	0.041	0.236	0.592
0.8	0.098	0.299	0.514
0.9	0.154	0.419	0.721
1.0	0.324	0.655	0.968

Table.2 Switching angles generated by GA for 9-level

Modulation Index (M)	Switching Angles			
	θ_1 (rad.)	θ_2 (rad.)	θ_3 (rad.)	θ_4 (rad.)
0.1	0.525	0.859	0.997	1.274
0.2	0.20	0.5	0.99	1.568
0.3	0.194	0.46	0.793	1.117
0.4	0.094	0.609	0.774	1.367
0.5	0.091	0.605	0.774	1.374
0.6	0.312	0.666	0.954	1.169
0.7	0.082	0.354	0.49	0.95
0.8	0.628	0.89	1.133	1.48
0.9	0.09	0.589	0.781	1.382
1.0	0.292	0.64	1.107	1.563

Table.3 THD for 9-level and 7-level inverter

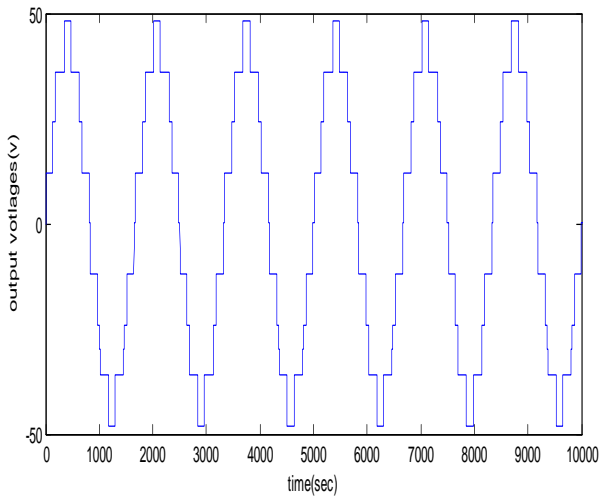| Level	THD(%)
nine	15.13
Seven	17.29

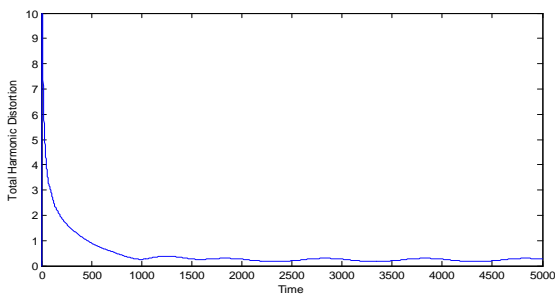Fig. 4 Output Voltage of 9-Level Inverter
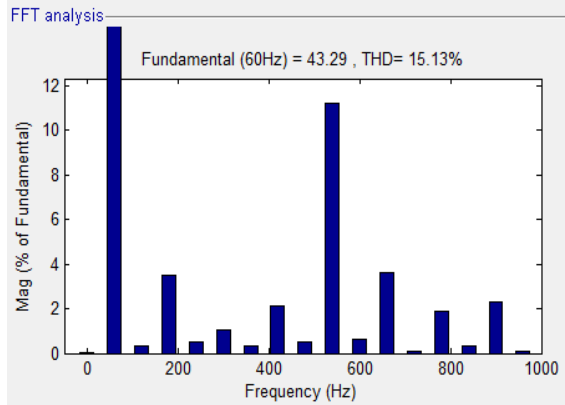

Fig.5 THD of a 9- level multilevel inverter

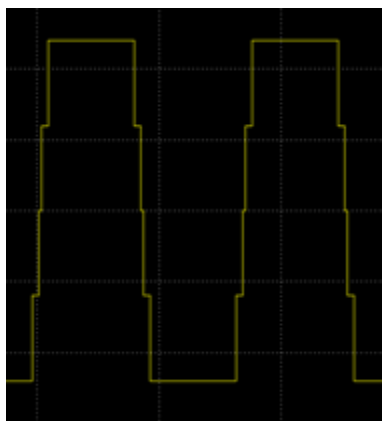Fig. 6 FFT analysis of 9-Level Multilevel inverter
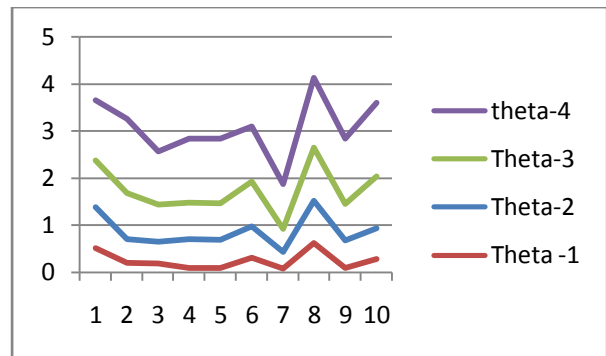

Fig. 7 Output Voltage of 7-Level Inverter

Fig.8 Optimal switching angles Vs M.

IV.   CONCLUSION

In this work, genetic algorithm optimization technique is applied to find the switching angles of the cascaded inverter for the reduction of harmonics. The use of the GA is proposed to solve the selective harmonics elimination problem in PWM inverters. The paper successfully demonstrates the validity of genetic algorithm for the estimation of optimum switching angles of staircase waveform generated by multilevel inverters, and Comparison has been done between the 7-level and 9-level with respect to the consideration of THD. As number of level increases THD decreases; therefore THD of 7-level inverter is greater than THD of 9-level.As in this approach, GA can be applied to any problem where optimization is required; therefore, it can be used in many applications in power electronics.

REFERENCES

[l]   P.M. Bhagwat and V.R. Stefanovic, "Generalized structure of a multilevel PWM inverter", IEEE Trans. On I.A., Vol. IA-19, n. 6. 1983, pp. 1057-1069.

[2]   J. Lai and F.Z. Peng, "Multilevel converters - A new breed of power converters", IEEE IAS Annual Conference Records, 1995, pp. 2348-2356.

[3]   F.Z. Peng, J. Lai, J. McKeever and J. VanCOevering, "A multilevel voltage-source inverter with separate dc sources for static var generation", IEEE IAS Annual Conference Records, 1995, pp. 2541-2548.

[4]   H. L. Liu and G.H. Cho, "Three-level space PWM in low index modulation region avoiding narrow pulse problem", IEEE IAS Annual Conference Records, 1993, pp. 257-262.

[5]   Rodriguez J, Bernet S, Wu B, Pontt J.O, Kouro S. "Multilevel voltage-source-converter topologies for industrial medium-voltage drives". IEEE Trans. Ind. Electron. Vol. 54, Dec. 2007, 2930 – 2945

[6]   A. Nabae, I. Takahashi, H. Agaki "A New Neutral-Point-Clamped PWM, Inverter," IEEE Transactions on Industry Applicaitions. Vol.IA-17, No.5, Sep./Oct 1981, pp.518-523.

[7]   B. Wu, P. G Song, "Comprehensive Analysis of Multi-Megawatt Variable Frequency Drives", Transaction of China Electrotechnical Society, Vol.19, No.8, pp. 40-52, 2004

[8]   L. M. Tolbert, F. Z. Peng, and T. G. Habetler, "Multilevel converters for large electric drives," IEEE Trans. Ind Applicat., Vol. 35, pp. 36-44, Jan./Feb.1999.

[9]   P.W. Hammond, "A New Approach to Enhance Power Quality for Medium Voltage AC Drives,' IEEE Trans. on Industry Applications," Vol.33, No.1, pp202-208,1997.

[10]   W A Hill, and C D Harbourt, Performance of Medium Voltage Multi-level Inverter, IEEE Industry Application Society Annual Meeting (IAS), pp.1186-1192, 1999.

[11]   Sirisukprasert, Siriroj. (1999) "Optimized Harmonic Stepped-Waveform for Multilevel Inverter", Msc thesis, available at http://www.worldcatlibraries.org

[12]   F. Z. Peng, J. S. Lai, J. McKeever and J.VanCoevering, "A Multilevel Voltage-Source Inverter with Separate DC Sources for Static Var Generation," IEEE-IAS Con$ Rec., pp2541 -2548.

[13]   G. Joos, X. Huang and B. T. Ooi, "Direct-coupled Multilevel Cascaded Series VAR Compensators," IEEE-IAS Con$. Rec., pp. 1608-1615, 1997.

[14]   F. Huang, P. I. Lim and E. K. Goh, "Design and Implementation of a 3- Phase Voltage Stabilizer Using 1 1-Level Voltage Source Inverter," IEEEIECON Con$ Rec., pp. 722-725, 1997.

[15]   Lai Y S, Shyu F S. (2002) "Topology for hybrid multilevel inverter," IEE Proceedings-Electric Power Applications, , vol.149, pp.449-458.

[16]   P.P. Bhagwat, and V. R. (1983) "Generalized structure of a multilevel PWM inverter," IEEE Transactions in Industry Applications, vol.19, pp.1057-1069.

[17]   J. Sun, S. Beineke, and H. Grotstollen, "Optimal PWM based on realtime solution of harmonic elimination equations," IEEE Trans. Power Electron., vol. 11, no. 4, pp. 612–621, Jul. 1996.

[18]   J. R. Wells, X. Geng, P. L. Chapman, P. T. Krein, and B. M. Nee, "Modulation-based harmonic elimination," IEEE Trans. Power Electron., vol. 22, no. 1, pp. 336–340, Jan. 2007.

[19]   J. Wang, Y. Huang, and F. Z. Peng, "A practical harmonics elimination method for multilevel inverters," in Conf. Rec. IEEE IAS Annu. Meeting, Oct. 2005, vol. 3, pp. 1665–1670.

[20]   L. Chambers.(1995) "Practical handbook of genetic algorithms" Boca Raton, CRC Press.

[21]   S.N.Sivanandam, & S.N.Deepa (2011). Principles of Soft Computing, Second edition page(s):385-401

[22]   Goldberg D.E. (1989). Genetic Algorithm in Search, Optimization and Machine Learning, MA: Addison Wesley

[23]   Davis.L. (1991). Handbook of Genetic Algorithm, New York: Van Nostran