OPTIMAL MINIMIZATION OF THD AND LOSS ANALYSIS IN MULTILEVEL INVERTER USING CUCKOO SEARCH ALGORITHM

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ABSTRACT -Cascaded Multilevel Inverters with isolate DC source have proven to be extremely beneficial in medium voltage and high-power applications. Using fundamental switching technique for control and modulation of multilevel inverter minimizes power losses to a great extent. This paper proposes Cuckoo Search Algorithm (CSA) for determining the switching angles for optimal minimization of THD and power losses. The optimized switching angles are further used to generate the gating pulses for driving the switches of the multilevel inverter. The proposed technique is tested using 11-level cascaded H-Bridge inverter in the MATLAB/Simulink working platform. The effectiveness of the proposed Cuckoo Search Algorithm based switching scheme is evaluated by comparing the content of harmonics present in output voltage of the multilevel inverter using Sine Pulse Width Modulation (SPWM). The results indicate that switching angles obtained using CSA effectively minimize a number of specific harmonics, thus resulting in low THD with minimized power losses.

***Keywords*-Cascaded H-Bridge Multilevel inverter, Cuckoo Search Algorithm, Harmonics, Total Harmonic Distortion, Power Losses, Pulse Width Modulation.**

INTRODUCTION

As almost every electronic device used in industries is sensitive to power quality problems, there is increased need for high rating power source with low harmonics. So, cascaded multilevel inverters have appeared as a successful and pragmatic solution in the various power applications [1-3]. They are found superior for medium and high power applications, like Flexible AC Transmission System Controllers (FACTS). Multilevel inverters are particularly because as the number of level increases, the waveform quality becomes better and the harmonic distortion gets reduced. Inadvertently the multilevel inverters found their ingress into the power electrical drive applications [4]. There are different topologies which are used in the various applications.

Traditional PWM schemes employ high switching frequencies of the order of kHz which create undesirable harmonics. Increase in harmonic content brings many other problems like more heating losses, high temperature and insulation stress, reduced insulation lifetime, decreased power factor, decreased output, efficiency, and ability. Diverse techniques such as Sine Pulse Width Modulation [5] and Space Vector Modulation techniques [6, 7] have been investigated to decrease the problem of harmonics, but for specific higher order harmonics, Selective Harmonic Elimination (SHE) or programmed PWM methods are used [8].

SHE-PWM technique has replaced traditional PWM technique to a great extent. It refers to choosing switching angles such that specific higher order harmonics such as the 5th, 7th, 11th, and 13th are minimized from the output voltage of the inverter. Then the nonlinear transcendental equations containing trigonometric terms are required to be solved by iterative techniques such as the Newton–Raphson method. However, it becomes difficult to solve a large number of equations, if a good initial guess is not available. On the other hand, Optimal Minimization of THD (OMTHD) focuses on minimization of Total Harmonic Distortion [9, 10]. Therefore, the optimal values of switching angles are determined so as to reduce total harmonic content present in waveform without actually eliminating them completely. Also, the results obtained from OMTHD are far better than SHE-PWM. Various artificial intelligence methods, Genetic Algorithm (GA) [11, 12], Particle Swarm Optimization (PSO) [13, 14], Simulated Annealing (SA) [15], etc., have been recommended by different researchers for determining switching angles to optimize THD. But, most of these methods demand true selection of certain parameters such as population size, mutation rate, etc. Various existing works of literature discussed Particle Swarm Optimization technique (PSO) based multilevel inverter. But, it has propensity to early convergence in mid optimum points and slow convergence in refined search stage.

This paper proposes Optimal Minimization of THD using Cuckoo Search Algorithm (CSA) [16] for determining the angles at which switches of multilevel inverter are fired to get desired output. The control technique uses fundamental switching and thus minimizes power losses greatly as compared to high switching frequency methods like SPWM. An important benefit of Cuckoo Search algorithm is its simplicity. In fact, comparing with other population- or agent-based metaheuristic algorithms such as particle swarm optimization and harmony search, there is essentially only a single parameter ρ_a in CS, apart from the population size. Therefore, it is very easy to implement.

OPTIMAL MINIMIZATION OF THD

OMTHD technique refers to the selection of switching angles for THD minimization with no significance on the fundamental component. However, prime objective of an inverter is to keep the fundamental component of output voltage of multilevel inverter at desired value. So, the basic idea of the proposed method is to optimize the switching angles of multilevel inverter such that harmonic content present in the voltage output waveform is reduced and the fundamental component of output voltage equals the desired value. Therefore, this paper presents a control method that aims to reduce the deviation of fundamental component from desired value and minimize THD.

In this paper, a three-phase 11-level cascaded H-bridge configuration of multilevel inverter is used to evaluate the effectiveness of proposed method. If each H-Bridge is fired at switching angles α_1, α_2, α_3, α_4 and α_5, the phase output voltage of multilevel inverter given in Fig.1, can be expressed in terms of Fourier series expansion as:

$$V(t) = \sum_{n=1,3,5}^{\infty} \frac{4}{n\pi}(V_{dc1}\cos n\alpha_1 + V_{dc2}\cos n\alpha_2 + V_{dc3}\cos n\alpha_3 + V_{dc4}\cos n\alpha_4 + V_{dc5}\cos n\alpha_5)\sin n\alpha_n \quad (1)$$

Because of odd quarter-wave symmetric characteristic, even order harmonics become zero. While considering line voltage, triplen harmonics are also not required to be considered.

So, Total Harmonic Distortion of line voltage can be expressed as

$$\text{Line Voltage THD} = \frac{\sqrt{\sum_{n=5,7,11,13,\ldots}^{\infty} V_n^2}}{V_1} * 100 \quad (2)$$

And the fundamental component can be written as:

$$V_1 = \frac{4(V_{dc1}\cos\alpha_1 + V_{dc2}\cos\alpha_2 + V_{dc3}\cos\alpha_3 + V_{dc4}\cos\alpha_4 + V_{dc5}\cos\alpha_5)}{\pi} \quad (3)$$

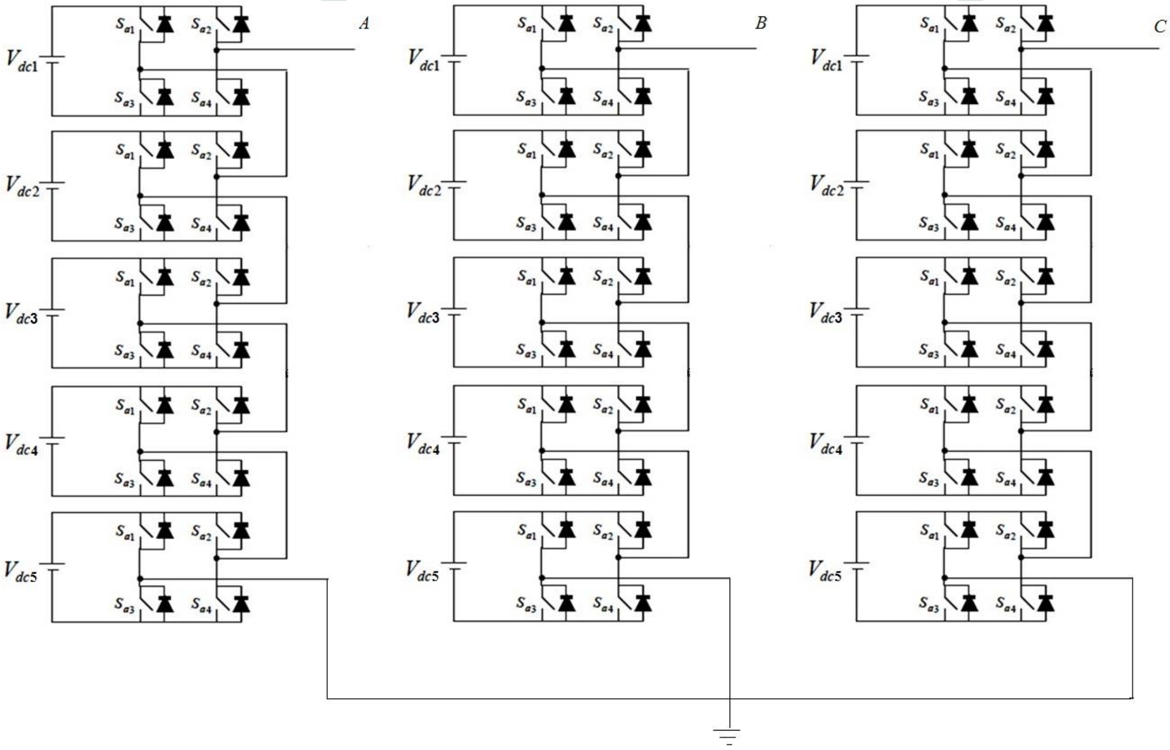

Fig 1: Three-Phase 11- level Cascaded H-Bridge Inverter

As the aim here is to minimize the voltage deviation of fundamental voltage from the reference value and reduce the total harmonic content to a minimal value. The objective function to be optimized is given as:

$$\text{Objective} = \text{Line Voltage THD} + (\text{Fundamental} - \text{Desired}) \quad (4)$$

$$\text{Objective} = \frac{\sqrt{\sum_{n=5,7,11,13,\ldots}^{49} V_n^2}}{V_1} * 100 + \left(m - \frac{V_1}{5 * V_{DC}}\right) \quad (5)$$

Here, m is the modulation index and V_{DC} is the value of DC voltage connected at the input of H-Bridge. The condition to obtain staircase waveform is that the switching angles should be within zero and $\pi/2$ ($0 < \alpha_1 < \alpha_2 < \alpha_3 < \alpha_4 < \alpha_5 < \pi/2$).

Artificial intelligence techniques have proven to be very helpful for solving optimizing function. But there are many limitations with the commonly used swarm intelligence techniques such as getting trapped at local mid-optimum points. And Genetic Algorithm requires selection of too many parameters. So, there is a need of an optimization algorithm that works efficiently with minimum parameters.

CUCKOO SEARCH ALGORITHM BASED OPTIMIZATION

Cuckoo search is a heuristic approach, proposed in 2009 by Xin-she Yang and Suash Deb, used for solving optimization problems in different fields of engineering. The algorithm is inspired by the behavior of cuckoo bird, also known as brood parasites, that it never builds its own nest and lays their eggs in the nests of other host birds (of different species). The eggs in a nest represent solutions, whereas egg of cuckoo bird is a new solution. Normally, each cuckoo lays one egg at a time in a randomly chosen nest. Numbers of host nests are fixed. So, each nest has one egg of cuckoo bird and rest of eggs of host bird. Sometimes host birds get involved in direct conflict with the intruding cuckoos. If the host bird recognizes the eggs as someone else's egg, they either throw them or move to build a new nest. The probability of cuckoo's egg being recognized is p_a, and is generally fixed at 25%. However, if cuckoo's egg matures, it moves to the next generations. The ability of algorithm to maintain balance between local and global random walks using switching parameter makes it suitable for global optimization problems. The flowchart used for optimizing switching angles using Cuckoo Search is given in Fig.2.

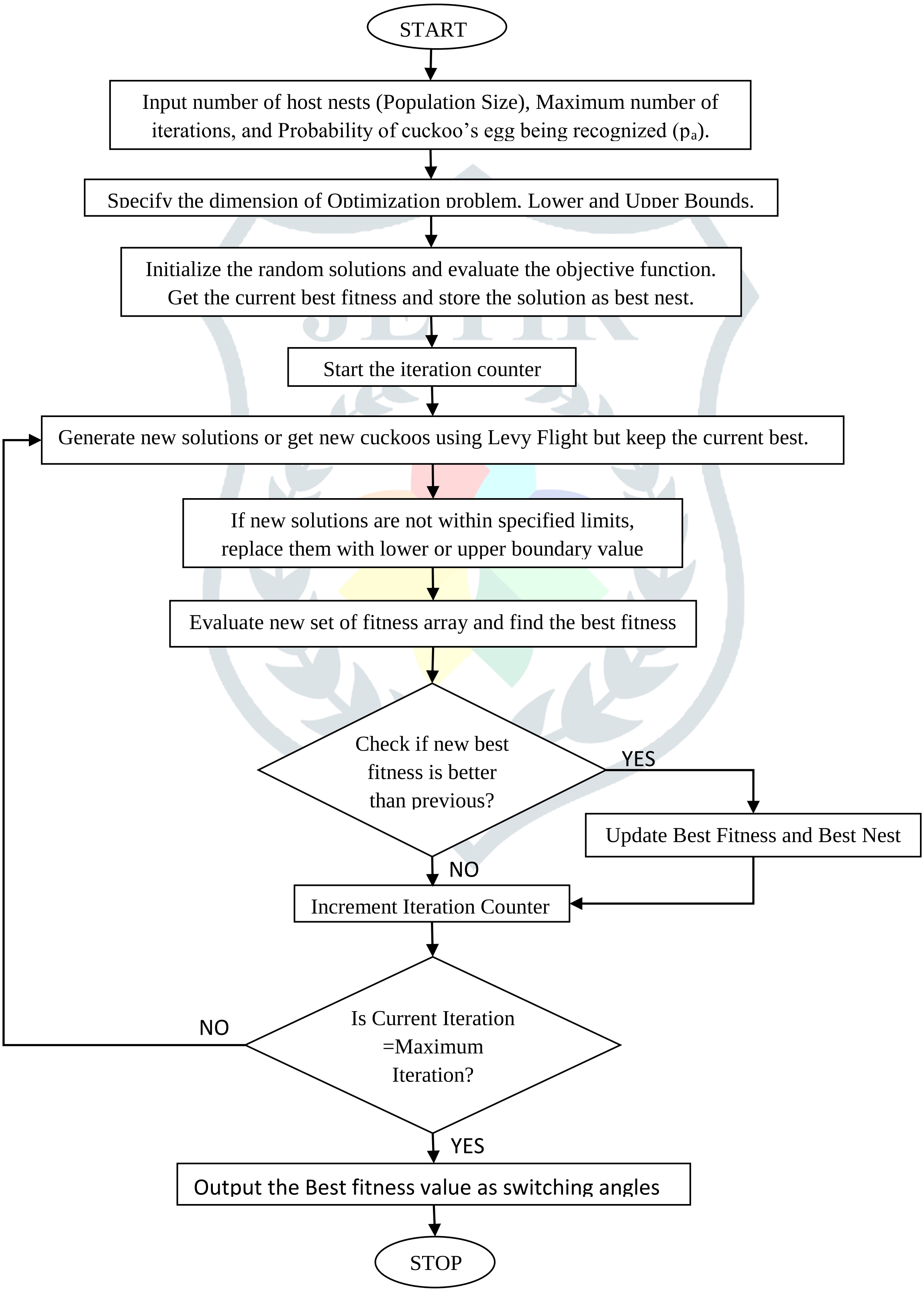

Fig 2: Flowchart of Cuckoo Search Algorithm as applied to Harmonic Minimization

SIMULATION AND RESULTS

A three-phase 11-level cascaded H-bridge inverter is modeled and simulated to obtain results accordingly using MATLAB as shown in Fig.3. It is assumed that the input side of inverter is connected to equal separate dc sources to give output voltage around 415V and three-phase non linear load with impedance Z=110.5ohm and load power factor 0.9 is connected at the output. CSA is implemented in MATLAB to optimize the values of angles at which switches of multilevel inverter are fired to get minimum THD. Maximum number of iterations is taken as 1000, discovery rate of alien's egg is 25% and number of host nests is 25. Harmonic Results and Power Loss obtained using OMTHD are compared with those of PWM at fundamental frequency.

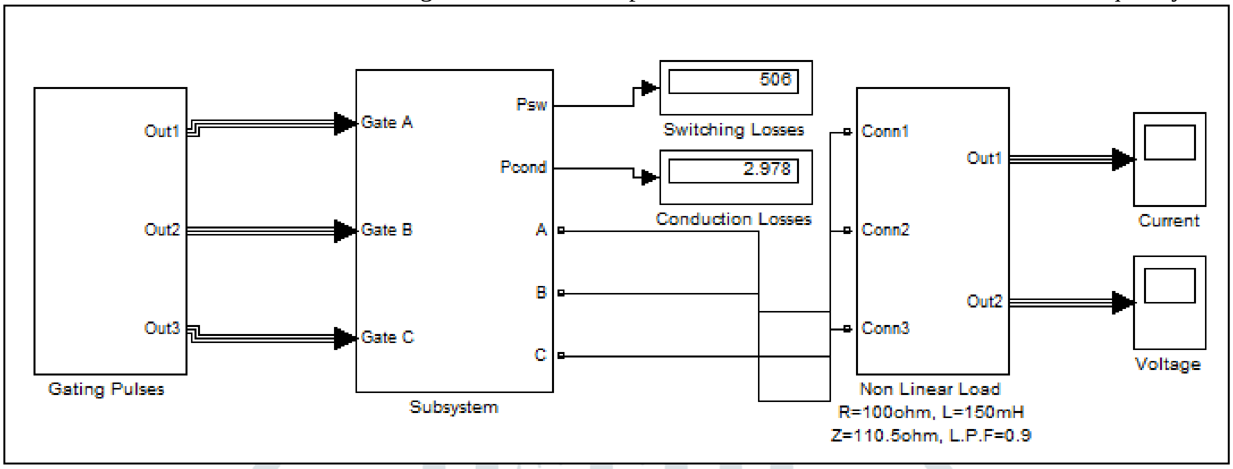

Fig 3: Simulink Model of 11-level Multilevel Inverter for THD and Loss Analysis

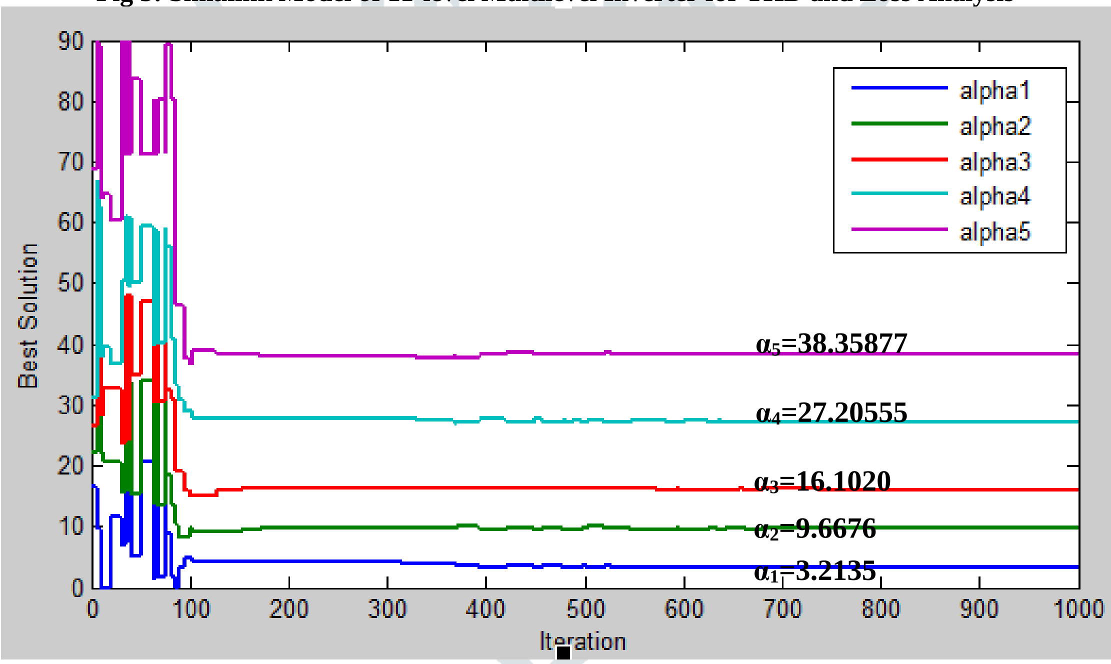

Fig 4: Optimization of switching angles using Cuckoo Search Algorithm

The 11-level cascaded H-bridge inverter has five H bridges and thus the five switching angles obtained using HS algorithm are α_1=3.2135, α_2=9.6676, α_3=16.1020, and α_4=27.2055, and α_5=38.3587 in degrees as shown in Fig.4. The computation time taken to optimize the switching angles is 2.47s. These switching angles are then used to generate the gating pulses for multilevel inverter. The output voltage obtained is shown in Fig.5, and FFT Analysis is given in Fig.6.

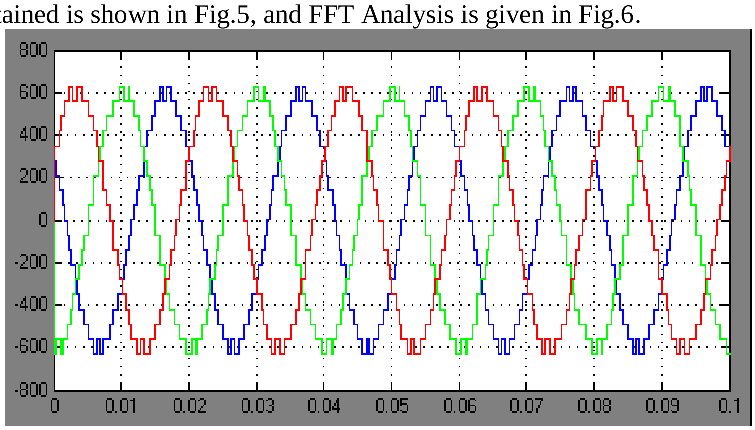

Fig 5a): Line Voltage using PWM

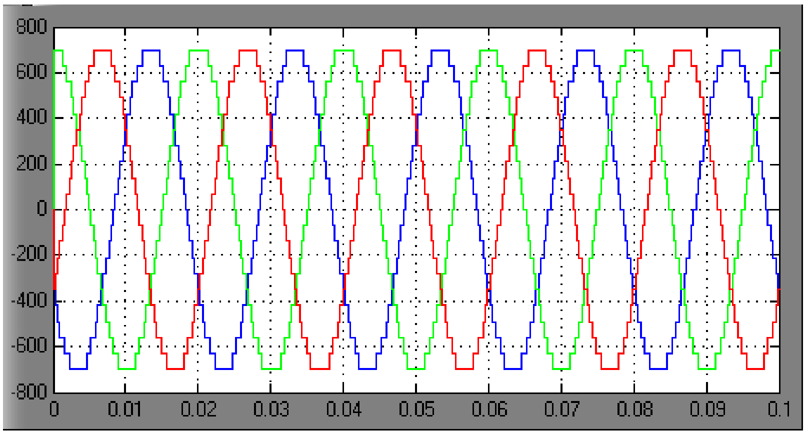

Fig 5b): Line Voltage using OMTHD using CSA

The Line Voltage THD is found to be 3.92% using optimal angles obtained using Cuckoo Search Algorithm. Comparison of FFT analysis clearly indicates that even order harmonics are reduced to negligible and much amount of harmonic content is reduced. Also the Table 1 and 2 shows the advantage of using OMTHD using CSA on the basis of various parameters.

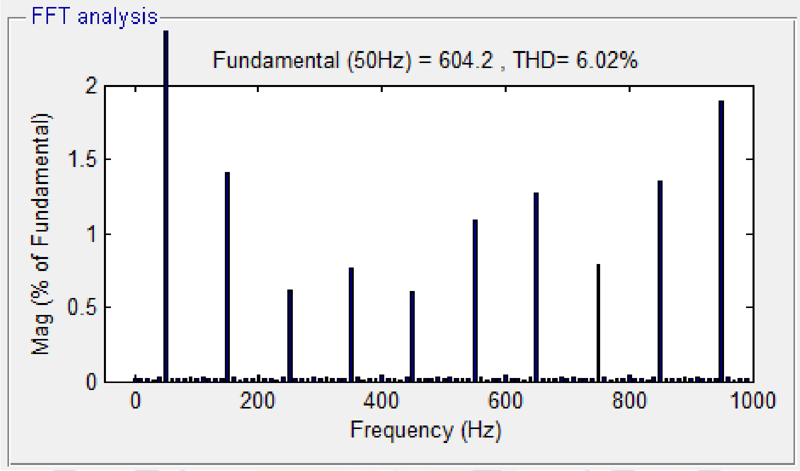

Fig 6a): FFT Analysis of Line Voltage using PWM

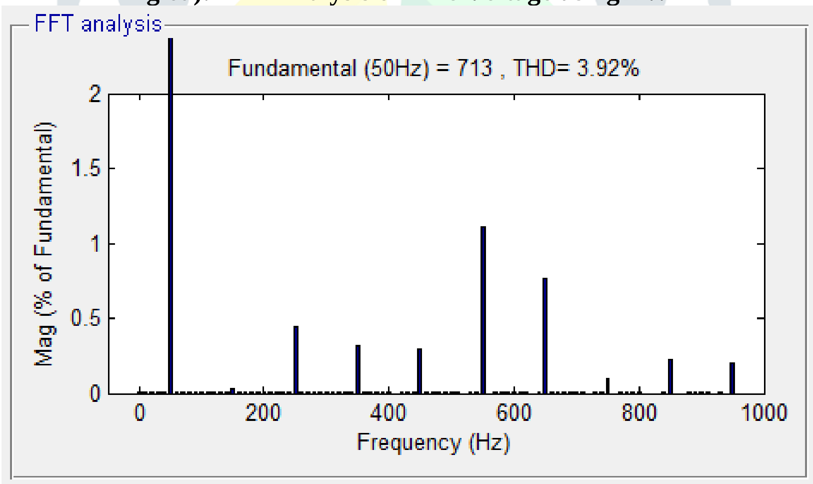

Fig 6b): FFT Analysis of Line Voltage using OMTHD using CSA

Table 1. Comparison of Performance Parameters between PWM and OMTHD

Performance Parameters	PWM	OMTHD using CSA
Line Voltage (r.m.s.)	427 V	504 V
Line Voltage THD	6.02 %	3.92 %
DC Component of Voltage	0.105 V	0 V
Current (r.m.s.)	1.13 %	0.39 %
Current THD	3.86 A	4.56 A
Switching Loss	903 W	506 W
Conduction Loss	5.429 W	2.978 W

Table 2. Comparison of Performance Parameters between PWM and OMTHD

Harmonic Order (%)	3rd	5th	7th	9th	11th	13th	15th	17th	19th
PWM	1.41	0.61	0.76	0.60	1.08	1.27	0.79	1.35	1.90
OMTHD using CSA	0.03	0.44	0.32	0.30	1.11	0.77	0.10	0.23	0.20

Table 1 shows that all the parameters improves with OMTHD as compared to PWM. It is very much clear from the harmonic spectrum and harmonic order chart that the lower order harmonics reduces significantly and THD is also reduced as compared to that obtained in PWM.

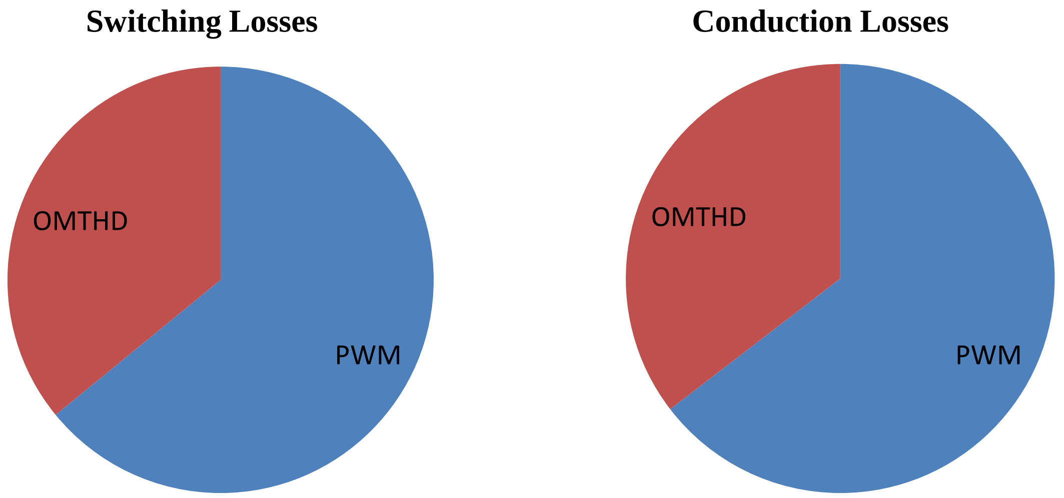

Fig 7: Comparison of Power Loss using PWM and OMTHD

Fig.7 shows the comparison of switching loss and conduction loss in multilevel inverter using PWM and OMTHD method at fundamental frequency. Moreover, the losses are reduced by 45% by firing the switches at optimal values rather than PWM compared values. Hence, the quality of output voltage and thus multilevel inverter is better using CS algorithm applied OMTHD method as compared to PWM technique.

CONCLUSION

In this paper, a method (OMTHD) for calculation of the optimal values of switching angles is presented using Cuckoo Search algorithm, to minimize the total harmonic distortion (THD) of cascaded H-bridge multilevel inverter. Simulations using PWM technique and OMTHD using CSA have been carried out for 11-level cascaded H-bridge inverter in MATLAB/Simulink and a comparison on the basis of different performance parameters has been done. It has been observed that OMTHD reduces total harmonic distortion of line voltage as well as individual harmonic content in multilevel inverter. The FFT analysis confirms that the lower order harmonics are controlled within allowable limits and comply with IEEE 519-1992 harmonic guidelines. Both voltage and current THD has been effectively reduced. Also, switching and conduction loss are decreased significantly by almost 50% using OMTHD. As there is only a single parameter ρ_a required in Cuckoo Search, apart from the population size, it makes it easy to implement. The computational time required for determining switching angles is only 2-3sec approx. The algorithm can be easily implemented for any level of inverter.

REFERENCES

[1] Jih-Sheng Lai, Fang Zheng Peng. Multilevel converters-a new breed of power converters. IEEE Transactions on Industry Applications. 1996; 32(3):509-517.

[2] Rodriguez J, Jih-Sheng Lai, Fang Zheng Peng. Multilevel inverters: a survey of topologies, controls, and applications. IEEE Transactions on Industrial Electronics. 2002; 49(4):724-738.

[3] Malinowski M, Gopakumar K, Rodriguez J, Pérez M. A Survey on Cascaded Multilevel Inverters. IEEE Transactions on Industrial Electronics. 2010;57(7): 2197-2206.

[4] Fang-Zen, P., & Zhao-Ming, Q. Applications of cascade multilevel inverters. Journal of Zhejiang University-SCIENCE A, (2003). 4(6), 658-665.

[5] D.Mohan D, B.Kurub S. A Comparative Analysis of Multi Carrier SPWM Control Strategies using Fifteen Level Cascaded H bridge Multilevel Inverter. International Journal of Computer Applications. 2012 ; 41(21):7-11.

[6] Mondal S, Bose B, Oleschuk V, Pinto J. Space vector pulse width modulation of three-level inverter extending operation into overmodulation region. IEEE Transactions on Power Electronics. 2003; 18(2):604-611.

[7] Gupta A, Khambadkone A. A Space Vector PWM Scheme for Multilevel Inverters Based on Two-Level Space Vector PWM. IEEE Transactions on Industrial Electronics. 2006;53(5): 1631-1639.

[8] N D, Kaur D. Selective Harmonic Elimination PWM Technique Implementation for a Multilevel Converter. International Journal of Engineering Research. 2015; 4(6):303-308.

[9] TOODEJI H. An improved OMTHD technique for an n-level cascaded multilevel inverter with adjustable DC sources. Turkish Journal Of Electrical Engineering & Computer Sciences. 2017: 25:4841-4853.

[10] Ozpineci B, Tolbert L, Chiasson J. Harmonic Optimization of Multilevel Converters Using Genetic Algorithms. IEEE Power Electronics Letters. 2005; 3(3):92-95.

[11] Salami A, Bayat B. Total Harmonic Distortion Minimization of Multilevel Converters Using Genetic Algorithms. Applied Mathematics. 2013; 04(07):1023-1027.

[12] Rupali Mohanty, Comparison Study of Harmonic Elimination in Cascade Multilevel Inverter Using Particle Swarm Optimization And Genetic Algorithm. IOSR Journal of Electrical and Electronics Engineering. 2013; 5(1):43-49.

[13] Mythili M, Kayalvizhi N. Comparison of GA and PSO algorithms in cascaded multilevel inverter using selective harmonic elimination PWM technique. International Journal of Advanced Research in Electrical,Electronics and Instrumentation Engineering. 2014 Apr;3(4):8621-.

[14] Ali S, Kannan R, Kumar M. Exploration of Modulation Index in Multi-level Inverter using Particle Swarm Optimization Algorithm. Procedia Computer Science. 2017; 105: 144-152.

[15] Napoles, Javier, et al. "Selective harmonic mitigation technique for cascaded H-bridge converters with nonequal DC link voltages." IEEE Transactions on Industrial Electronics60.5 (2013): 1963-1971.

[16] Gandomi, A. H., Yang, X. S., & Alavi, A. H. (2013). Cuckoo search algorithm: a metaheuristic approach to solve structural optimization problems. Engineering with computers, 29(1), 17-35.