A NEW ENHANCED GOAT ALGORITHM FOR FINDING OPTIMUM SWITCHING ANGLE AND HARMONIC REDUCTION

Ayyappa Srinivasan M G[1],J Reegan[2],S.Ebanezar Pravin[3],A.Soma Sundaram[4],M.Faustino Adlinde[5]

[1]*Assistant Professor, St.Mother Theresa Engineering College,*
Vagaikulam, Thoothukudi, Tamilnadu, India-628102,Email: ayyappa.srinivasan@gmail.com
[2]*Assistant Professor, St.Mother Theresa Engineering College,*
Vagaikulam, Thoothukudi, Tamilnadu, India-628102,Email:reegan.james@gmail.com
[3]*Assistant Professor, St.Mother Theresa Engineering College,*
Vagaikulam, Thoothukudi, Tamilnadu, India-628102,Email:ebanezar88@gmail.com
[4]*Assistant Professor, St.Mother Theresa Engineering College,*
Vagaikulam, Thoothukudi, Tamilnadu, India-628102,Email:somasundaram4ever@gmail.com
[5]*Assistant Professor, St.Mother Theresa Engineering College,*
Vagaikulam, Thoothukudi, Tamilnadu, India-628102,Email:faustinoadlin1.6@gmail.com

***Abstract:*-Multi level inverters are used now a days at large,because they have lesser harmonics than single level inverter. Several methodologies have been worked out in order to reduce the harmonics.It has been proved that the soft computing algorithms based switching angle calculation are more efficient than the conventional methods. In this paper a 7 level inverter has been used for DC to AC conversion.A new nature inspired Goat algorithm has been proposed in this paper.This algorithm has been applied for a single phase seven level inverter first. This algorithm has been tested by writing proper code in MATLAB-Mfile and it has been found that it consumes less computational time than the other algorithms since several goats explore solution space at a time. The results show that the harmonics obtained from inverter using the switching angles calculated from the algorithm are very much reduced and THD is almost around 12%.**
***Key Words*-7 level inverter, Goat algorithm, Switching angle, Total harmonic distortion**

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I.INTRODUCTION

In recent years, there is a large demand for high power output. For this multilevel inverters are one of the solution as prposed by Nabae etal.,.A survey of multilevel inverter topologies can be carried out by J.Rodreguz,Jih Sheng Lai et al[1].By using 6 H bridge cells a new topology was developed and the results were found to be satisfactory[2].A new Hbridge topology was proposed to produce any number of levels with reduced number of switches was proposed with commendable reduction in THD[3].By using same number of switching elements, a cascaded multilevel inverter was suggested and tested successful[4].Even though the cascaded multilevel inverters provide versatile output, they require large number of power sources. So, C.Cegila et al proposed a topology with lesser number of H bridge cascaded multilevel inverter which gave a new way for casced H bridge multilevel inverter[5].

In cascaded multilevel inverter the major disadvantage is that it has large number of power sources and switches. So, new topology with reduced number of switches was developed by kamaldeep and Jagadeesh kumar which was a7 level inverter[6].A new pathbreaking topology was invented by Sze Sing Lee which used Hbrdge inverter as base but with only one DC source[7].It requires total of 12 switches for a seven level inverter instead of conventional 28 switches.

Multilevel inverters have the advantage of lesser harmonics than single level inverters. However their THD is still larger. Conventionally sinusoidal pulsewidth modulation is used for switching inverter switches. When the level of inverter increases, the switching methodology also becomes complex. K.M.Kotb,A.El-Wahab Hassan,Essam M Rashid proposed a new simplified Sinusoidal Pulsewidth modulation wherein only one modulation by a carrier signal was proposed by using NI-PCI 6013 data acquisition controller[8].Results similar to conventional one were obtained. A special sinusoidal PWM technique for capacitor voltage balancing of nested T-Type 4 level inverter was proposed by Ahoora Bahrami which has lesser number of switches and useful for higher voltage applications[9].Earlier, the similar scheme was proposed for three phase Four wire inverter by Ning He etal.,It was Zero voltage switching based in nature[10].

Space Vector modulation is a new method in the generation of switching pulses. J.H Seo etal proposed a simplified space vector modulation technique for a 3 level inverter. The work used space vector algorithm of two level inverter into 3 level inverter and reduced the execution time to a very large extent[11]. The Space vector ethod is usually based on lookup tables. But this consumes memory of the programmable controller to great extent. Hence, a fractal based approach for space vector modulation was proposed which exploits the simplicity of fractal arithmetic by eliminating the need for look up table[12]. The same authors proposed a new space vector modulation technique for any general n-level inverter by determining centre of sub hexagon and thereby mapping the reference space vector into the centre of sub hexagon[13].This gives the switching sequence of two level inverter and by adding centre of sub hexagon with further next two level vectors.

Space Vector modulation and Sinusoidal Pulse width modulation are inter related with each other..The mathematical relationship between the two was analysed by W.Yao,H.Hu which was helpful design the switching strategy in an effective way[14].

However the methods of Sinusoidal Pulse width Modulation and Space Vector based Modulations suffer from the fact that they cannot provide exact switching angle and hence the THD is considerable. A best alternative to the above ethods is to calculate the switching angles by nature inspired algorithms and then to generate switching pulses fro Fuzzy based controllers. This gives exact value of switching angle by which inverter switches are turned on and off at those angles.

M.A.Meon etal.,tested imperialist Competitive algorithm, particle swarm optimisation, Differential Evolution, Bee algorithm and Genetic Algorithm for Selective Harmonic Eliination of PWM(SHEPWM)[15]. The performance of the inverter with these algorithms were analysed in terms of accuracy, computational complexity and convergence speed. A new Lightning search algorithm was used for switching the inverter switches in photovoltaic Inverter by eZDSP F28335 controller with inverter having low steady state error[16]. Another algorithm called Intelligent water drop algorithm was used to reduce the harmonics in a SHEPWM based Multilevel inverter by Akash Tyagi and GK Cheema and showed improved results[17].For the same SHEPWM bat algorithm was used to solve for switching angles to get improved resultswith THD reduced up to 9%[18].Real coded genetic algorithm, advanced version of GA was applied for selective Harmonic Elimination in Multi Level Inverter and THD was reduced to 5%[19].Firefly assisted Genetic algorithm is new in the era and it was tested for Selective Harmonic elimination in Reduced switch Multilevel inverter[20].However the THD was reported around 40% in that work.

In the present work a new nature inspired algorithm called goat algorithm has been introduced and tested for a single phase 13 level inverter. This algorithm is enhanced version of Ant colony optimisation algorithm, which was invented by Marco Dorigo and originally applied for Travelling salesman problem(TSP) by Christian Blum[21].But the Ant Colony optrimization technique takes larger time to find solution since solution space to be evaluated is larger.For this, modifications were proposed by S.Chowdhury etal[22] Also another algorithm called Sampled Ant Colony Optimization was proposed by Hu etal., which considered some sampled solutions alone[23]. However the sampled solutions part also took larger time as one ant is considered at one time. For this, the proposed Goat algorithm is better alternative since there is no random pheromone value but a factor called "smell factor" based on the value of switching angle.

II.THE GOAT ALGORITHM

The sheep or goat in and around Melakarandhai Village of Tuticorin District, Tamilnadu, India are capable of smelling the amount of grass through shortest path and able to eat the grass as much as possible. However, they do not eat grass or any other food mixed with soil and grass or food only on soil. While walking on the way they make a smell and move around. Wherever they smell larger amount of grass or food they start to eat. The place they have their grass food is ultimately with maximum amount of grass.

This natural property of goats can be simulated to find solution from a solution space by using artificial goats. Our goats move over the solution space. Once they "smell" a solution to be fit, ,they further move and if the smell value of the adjacent solution is more optimal than older one, old solution is dropped from calculation list. This algorithm has following steps:

III.FORMULATION OF SOLUTION SPACE

As the solution space of switching angles is larger, the continuous solution space is sampled initially. Let us consider 25 goats move at a time over solution space. A lower and upper value for the solution space is selected as l_i and u_i and i=1,2,3,........D where D is number of variables required.The solution space is randomly sampled in the following way:

$$x_i^{(j)} = l_i + (u_i - l_i)(j - 1 + rand(0,1)) \quad (1)$$

Where Xi is the solution space and j=1,2,3.....P, where P is the number of goats which is 25 in our case. Thus the solution space is sampled according to the number of goats. More the number of goats, wider the solution space. Further, a random number between 0 and 1 has been added in order to make the solutions more accurate. Thus, the solutions are sampled between upper and lower values alone based on the range between which our solution can be fit.

A "smell factor" is assigned for each solution. It is the indicator of fitness of that solution into our application. When the Smell factor is more, the solution ,it "may fit" for the equation to be solved. Here, important point.to be noted is that the solution space is divided into 25 regions and each goat is made to sample the solution region at a time, which reduces computational time. Thus, the solution and smell factor are stored in the memory. Let the smell factor be α and then the solution and smell factor are given by the matrix S as,

$$S = \begin{bmatrix} \{x_1^{(1)}, \alpha_1^1\} & \{x_2^{(1)} \alpha_2^{(1)}\} & \{x_3^{(1)} \alpha_3^{(1)}\} & \ldots\ldots & \{x_D^{(1)} \alpha_D^{(1)}\} \\ \{x_1^{(2)}, \alpha_1^{(2)}\} & \{x_2^{(2)}, \alpha_2^{(2)}\} & \{x_3^{(2)}, \alpha_3^{(2)}\} & \ldots\ldots & \{x_D^{(2)}, \alpha_D^{(2)}\} \\ \{x_1^{(3)}, \alpha_1^{(3)}\} & \{x_2^{(3)}, \alpha_2^{(3)}\} & \{x_3^{(3)}, \alpha_3^{(3)}\} & \ldots\ldots & \{x_D^{(3)}, \alpha_D^{(3)}\} \\ & & \vdots & & \\ & & \vdots & & \\ \{x_1^{(k)}, \alpha_1^{(k)}\} & \{x_2^{(k)}, \alpha_2^{(k)}\} & \{x_3^{(k)}, \alpha_3^{(k)}\} & \ldots\ldots & \{x_D^{(k)}, \alpha_D^{(k)}\} \end{bmatrix} \quad (2)$$

a. Movement:

The goats move from one step to other partially in probabilistic and partially in deterministic manner. It has in its memory each of the previously visited local solution locations and the corresponding smell factors. It is stored as m x P where m is the number of the movements and P is the number of goats.

(i).Exploitation and Exploration:

The iteration factor f_i^k of a goat k for any ith variable is given by,

$$f_i^k = \begin{cases} 1, if\ q < q_0\ and\ j = j^* \\ 0,\ \ if\ q < q_0\ and\ j \neq j^* \end{cases} \quad (3)$$

Where q is random number between 0 and 1 and q_0 is threshold parameter fixed for each iteration and

$$j^* = \max(\alpha_i^{(1)}, \alpha_i^{(2)}, \alpha_i^{(3)} \ldots\ldots., \alpha_i^{(k)}) \quad (4)$$

The threshold parameter is fixed and used to determine whether exploration or exploitation is to be performed.

(a).Exploitation

If $q < q_0$,the goat decides to make local search that is searching the nearby solution for finding more accurate solution called as fine tuning. The solution is fine tuned by further exploiting the nearby solution space for a distance called radius "r_i".

Let the current solution obtained be

$$x = \{x_1, x_2, x_3 \ldots\ldots. x_D\} \quad (5)$$

Now fine tuning of the solution is done in the distance or radius of r_i and in the interval

$$|x_i - r_i,\ \ x_i + r_i,| \quad (6)$$

The value of ri is obtained as,

$$r_i = \frac{u_i - l_i}{2P} \quad (7)$$

The solution obtained is increased or decreased or unchanged as per the following criteria

$$x_{i\,new} = \begin{cases} \min(x_i + r_i, \sigma_i u_i),\ \ if\ \ 0 < q < \frac{1}{3} \\ x_i,\ \ if\ \ \frac{1}{3} < q < \frac{2}{3} \\ \max(x_i - r_i, \sigma_i l_i), if\ \ \frac{2}{3} < q < 1 \end{cases} \quad (8)$$

With σ is random number between 0 and 1.This solution set obtained is evaluated .If the solution is better than previous one then r_i has to be extended or otherwise it has to be reduced. This process is repeated for "v " number of times where v is the exploitation frequency determined initially. The new solution thus obtained in one iteration is denoted as g_i

(b).Exploration

It has to be performed when $q>q_0$ that is the solution in the region obtained is not fit for the switching angle equations, then the goat is removed from the population and number of goats reduce by one. In the mean time other goats are also searching the local space. So, the process of a goat moving to adjacent space is avoided and hence the process of exploration is avoided.

(c).Smell factor:

In nature, the goats search for solution in a region. If smell of grass nearby is more than the present one, then they move towards that area in that region. Likewise, our artificial goats smell a solution according to the smell factor. If the solution is not fit, it is to be removed. If it is fit, then the artificial smell factor is increased more. For this we add a factor called fitness factor, which lies between 0 and 1.The smell factor ρ is incorporated as,

$$\alpha_i^{(j)} \leftarrow (1+\rho)(\alpha_i^j) + \rho\alpha_{min} \qquad (9)$$

Where αmin is the minimum value of smell factor and ρ is the fitness factor .i=1,2,3.....D and j=1,2,3.....P. Thus, in each iteration, the most fit solutions are retained by increasing smell factor and least fit ones are removed out.

IV.H-BRIDGE CASCADED MULTI LEVEL INVERTER

A new cascaded H bridge Inverter for adjustable levels has been proposed by Annamalai Thiruvengadam and Udhayakumar[24].It is the one of the major breakthrough in Cascaded Multilevel inverter Topology as it requires 7 switches for 7 level where as conventional cascaded multilevel inverter requires 12 switches. When number of levels increases, the switches required is lesser than conventional cascaded multilevel inverters. However major disadvantage of this topology is that it requires 4 sources for 3 levels of voltages. So, we replace this by 2 sources and 4 capacitors as shown in fig.1

The Connected voltage sources are set to the value of 2Vdc/3.So, each capacitor charges to Vdc/3 volts. Hence, these capacitors and the seven switches are used to synthesize 7 level voltages in positive and negative levels each. The realization of voltages are given in Table I. Thus, it is found that this ulti level inverter in total is capable of synthesizing 13 levels of voltages. In any mode, three switches are on and remaining are off.

V.MATHEMATICAL MODEL OF SHEPWM

Output wave form of a 7 Level Inverter is shown in Fig.2.

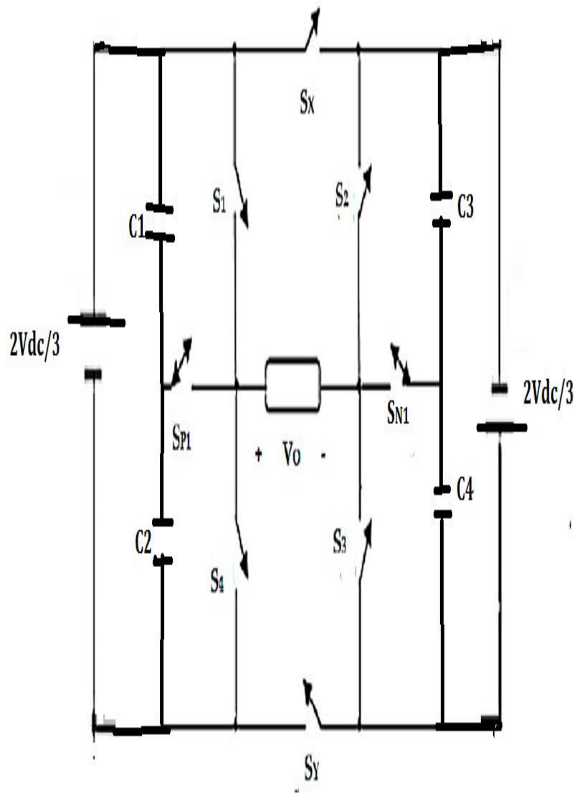

Fig.1.,Proposed Cascaded H Bridge Multilevel Inverter

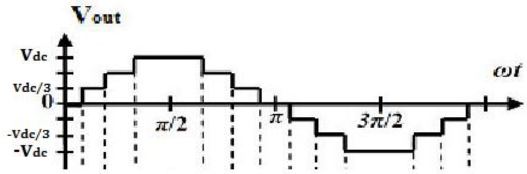

Fig.2.Output Waveform of 7 level Inverter

This waveform is called as staircase waveform. By applying Fourier transform it is found that, this wave for is combination of fundamental component and its harmonic components, which are multiple of fundamental components. Further this waveform is of quarter symmetry. So, it is represented by the following equation:

$$(\omega t) = \sum_{n=1,3,5...}^{\infty} \frac{4V_{dc}}{n\pi}\left(\cos(n\beta_1)+\cos(n\beta_2)+\cos(n\beta_3)+\cdots\cos(n\beta_S)\right)\sin(n\omega t) \qquad (10)$$

Where S is number of switching angles and n is Harmonic order .Further, in this triplen Harmonics cancel out each other and hence other odd harmonics are alone present. One switching angle is used to get desired fundamental output voltage and other switching angles are used to remove lower order harmonics. The fundamental output voltage of an inverter is given by,

Voltage	Switches Turned On
0	S_3,Sy,S_4
Vdc/3	S_{P1},S_3,Sy
2Vdc/3	S_1,S_3,Sy
Vdc	S_1,S_{N1},Sy
2Vdc/3	S_{N1},S_{P1},Sy
Vdc/3	S_y,S_{N1},S_4
0	S_1,S_X,S_2
-Vdc/3	S_{P1},S_2,S_X
-2Vdc/3	S_4,S_2,S_X
-Vdc	S_{N1},S_4,S_X
-2Vdc/3	S_{NI}.S_{P1},S_X
-Vdc/3	S_{NI},S_1,S_X
0	S_3,Sy,S_4

$$V(\omega t) = \sum_{n=1,3,5....}^{\infty} \frac{4V_{dc}}{\pi}\left(\cos(\beta_1) + \cos(\beta_2) + \cos(\beta_3) + \cdots \cos(\beta_S)\right) \tag{11}$$

The modulation index is defined in terms of fundamental and harmonic components as,

$$m_i = \frac{Fundemental\ voltage}{Maximum\ Obtainable\ Fundemental\ voltage}$$

$$= \frac{V_1}{V_{1max}} = \frac{V_1}{(4sV_{dc}/\pi)} = \frac{\pi V_1}{4sV_{dc}} \tag{12}$$

It's value lies between 0 and 1.
From this we find that, the fundamental voltage is given by,

$$V_1 = \frac{4sV_{dc}m_i}{\pi} \tag{13}$$

So, from equation (11) and (13), it is found that the switching angles are found from following transcendental equations :

$$\mathrm{Cos}(\beta_1) + \cos(\beta_2) + \cos(\beta_3) = 3m_i \tag{14a}$$

$$\mathrm{Cos}(5\beta_1) + \cos(5\beta_2) + \cos(5\beta_3) = 0 \tag{14b}$$

$$\mathrm{Cos}(7\beta_1) + \cos(7\beta_2) + \cos(7\beta_3) = 0 \tag{14c}$$

TABLE I
VOLTAGE SYNTHEZISATION IN PROPOSED MULTILEVEL INVERTER

Total Harmonic distortion of any inverter is given by,

$$THD = \sqrt{\sum_{i=5,7,9...}^{49} \frac{V_i^{\,2}}{V_1^{\,2}}} \tag{15}$$

VI.IMPLEMENTATION

The equations (14a),(14b) and (14c) were solved in MATLAB R2014b. The number of goats chosen were 25 with 150 iterations were carried out .While calculating solutions, the value of m_i was incremented by 0.02 from 0 to 1.In order to determine the fitness of the value of switching angle, a fitness function as in [25] is used given as follows:

$$f = \min_{\alpha_i}\left[\left(100\,\frac{V_1^* - V_1}{V_1^*}\right)^4 + \sum_{s=2}^{S} \frac{1}{h_s}\left(50\,\frac{V_{hs}}{V_1}\right)^2\right] \tag{16}$$

In each iteration the solutions of switching angles are assessed by the above fitness function and solved values of solutions of these switching angles were taken into account. These angles were used to turn on and off the switches of 7 level inverter. The switches were of MOSFET and 50z and mi=0.9 were chosen. The calculated switching angles were converted into time and accordingly pulses were generated by using dsPIC30F4011 processor for switching MOSFET.

VI.RESULTS

Fig.2 shows the variation of fitness function with respect to modulation index varying from 0.1 to 2.5.

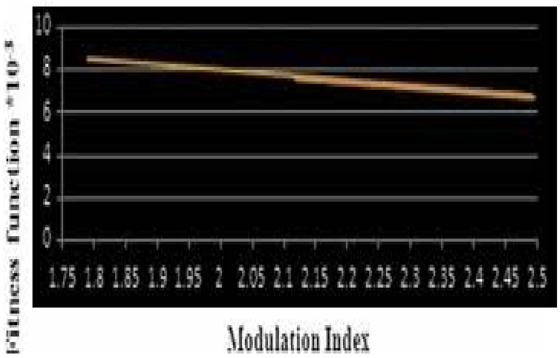

Fig.2.Fitness function vs modulation Index

Fig.3 represents the curve between switching angles and modulation index.

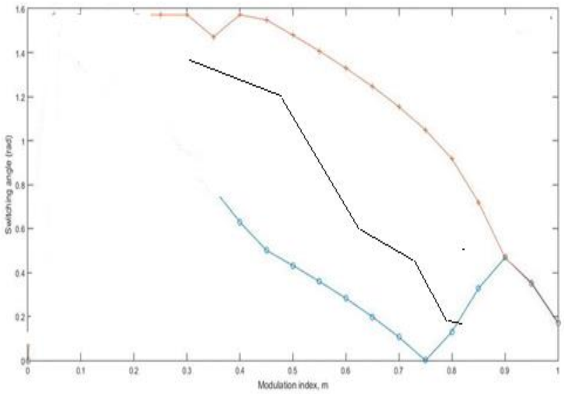

Fig.3.Switching angle Vs Modulation Index

Curve in red colour indicates the variation of β_3 and blue colour is that of β_2 with respect to modulation index. The black colour curve indicates the variation of β_1.It is found that there is no solution between m_i=0 to m_i=0.2.

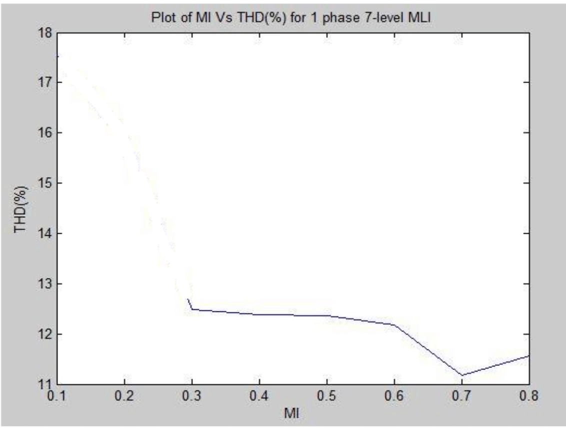

Fig.4.THD Vs Modulation Index

Fig.4.Shows THD Vs modulation Index curve. It is found that THD is around 12%.

Certain values of switching angles obtained as solution are given in TABLE II:

TABLE II

Switching Angles in degree for 7-Level Inverter

Modulation Index	β1	β2	β3
0.45	23.8	52.9	90
0.793	20.4	46.8	79.8
0.683	18.5	43.4	61.8

It is evident that there is no multiple solution problem in 7 Level inverter when goat algorithm is applied.The simulated voltage as well as current output of the multilevel inverter is shown in Fig.4 and Fig.5 respectively.

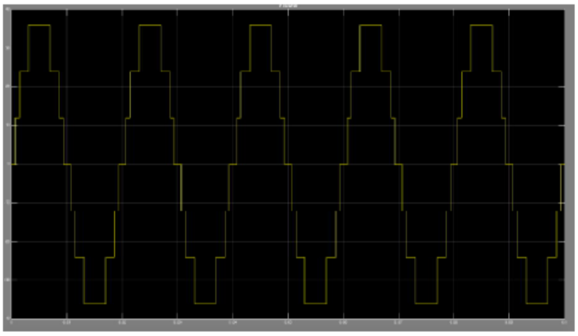

Fig.5.Simulated Output of 7 Level Inverter

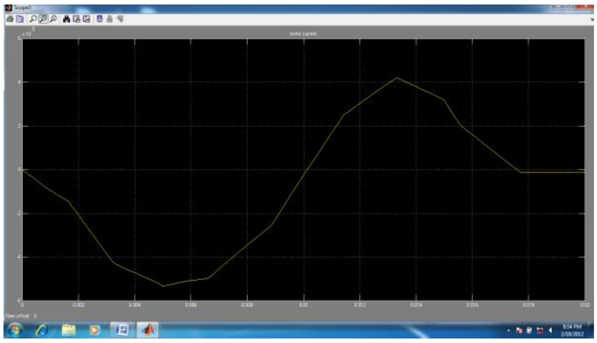

Fig.6.Load Current of &-level Inverter(Resistive Load)

Fig.7 shows the experimental setup and fig.8. shows output voltage of 7 level inverter hardware.

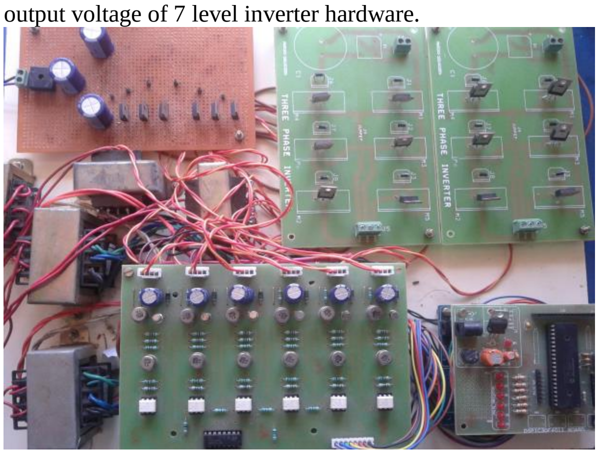

Fig.7.Experimental Setup

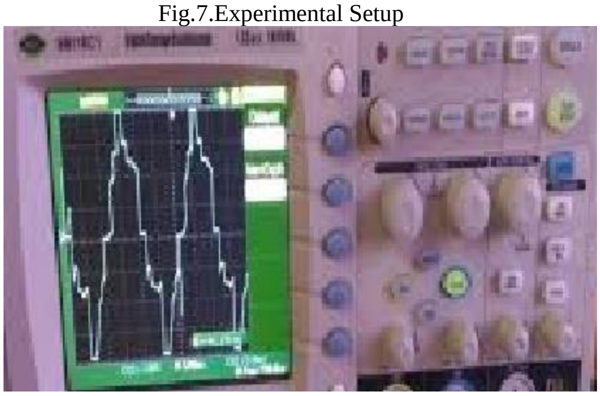

Fig.8.Output Voltage of Experimental setup.

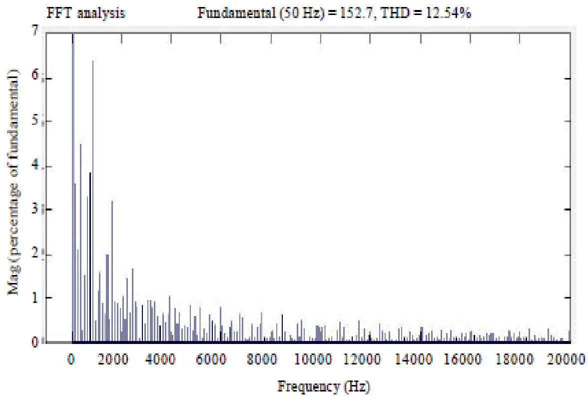

Fig.9.FFT Analysis of output Voltage of 7 level Inverter

It is evident that third order harmonics have value of voltage around zero and lesser number of 5^{th} order and 7^{th} order harmonics. They are around 0.01% and 0.3%.The 13^{th} order harmonic is around 4.25%.

VII.CONCLUSION

A New algorithm called Goat Algorithm has been proposed in the paper and it has been applied to equations used to solve for switching angles in a 7 level enhanced H Bridge 7 level Inverter. This algorithm has new approach of dividing solution space into regions and each goat searching for solution in that region alone simultaneously and thereby reducing computational time considerably than any other algorithm. The THD is around 12%.It has been proposed to implement this algorithm to higher level inverter in future.

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AUTHOR PROFILE

Mr.Ayyappa Srinivasan M G received his B.E.Degree in Electrical and Electronics Engg., from Manonmaniam Sundaranar University, Tirunelveli in 1999 and M.E. in Power Electronics and Drivesfrom Anna University, Chennai. He has been working with St. Mother Theresa Engineering College, Thoothukudi. He has published 5 research papers in various reputed journals. His fields of interest include Multilevel converters, Soft computing Algorithms

Mr.J Reegan received his B.E. Degree in Electrical and Electronics Engineering and M.E.in Embedded Systems both from Anna University, Chennai . He has been working with St. Mother Theresa Engineering College, Thoothukudi. He is currently pursuing PhD Degree in Anna University. He has published 15 research papers in various reputed journals. His research interest include various Converter topologies, BLDC motors etc.,

Mr.S.Ebanezar Pravin received his B.E.Degree in Electrical and Electronics Engineering and M.E.in Power Electronics and Drives both from Anna University, Chennai . He has been working with St.Mother Theresa Engineering College, Thoothukudi. He has published 8 research papers in various reputed journals. His research interest include various Multilevel converters, Soft computing Algorithms

Mr.A.Soma Sundaram received his B.E.Degree in Electrical and Electronics Engineering and M.E.in Power Electronics and Drives both from Anna University,Chennai . He has been working with St.Mother Theresa Engineering College, Thoothukudi .He has published several research papers in various reputed journals.His research interest include various DC-DC converter topologies and THD reduction

Ms.Faustino Adlinde received her B.E. Degree in Electrical and Electronics Engineering and M.E.in Power Electronics and Drives both from Anna University, Chennai . She has been working with St. Mother Theresa Engineering College, Thoothukudi. She is currently pursuing PhD Degree in Anna University. She has published several research papers in various reputed journals. Her research interest include various Converter topologies, BLDC motors etc.,

Ms.M.Faustino Adlinde received her B.E.Degree in Electrical and Electronics Engineering and M.E.in Power Electronics and Drives both from Anna University, Chennai . She has been working with St. Mother TheresaEngineering College,Thoothukudi. She is currently pursuing PhD Degree in Anna University. She has published 15 research papers in various reputed journals. Her research interest include