SELECTIVE HARMONIC ELIMINATION OF THE MULTI LEVEL INVERTER USING ANN

A thesis submitted to the department of Electrical Engineering in partial fulfillment of the requirements for the degree of Master of Technology

By

C.SIVARAMA RAJU

Roll No: 213EE3314

Under the guidance of

Dr. S. GOPALAKRISHNA

DEPARTMENT OF ELECTRICAL ENGINEERING

NATIONAL INSTITUTE OF TECHNOLOGY, ROURKELA

PIN-769008, ODISHA

(2013-15)

National Institute of Technology, Rourkela

Certificate

This is to certify that the dissertation entitled ***"*****Selective harmonic elimination of the multilevel inverter using artificial neural network*****"*** being submitted by **C. Sivarama Raju (213ee3314*)*** in partial fulfilment of the requirements for the award of Master of Technology degree in ***"*****ELECTRICAL ENGINEERING*****"*** with specialization of "**Control and Automation*"*** at the National Institute of Technology, Rourkela is an authentic work carried out by him under my supervision and guidance.

To the best of my knowledge, the matter embodied in the thesis has not been submitted to any other University/ Institute for the award of any degree or diploma.

Date:

Place:

Dr.S.GOPALAKRISHNA

Assistant professor

Department of Electrical Engineering

National Institute of Technology

Rourkela-769008

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C. Sivarama Raju

ROLL NO. - 213EE3314

Abstract

The multilevel Inverter is a powerful electronic device widely used for high power utility applications. The main purpose of the multilevel inverter is to provide sinusoidal waveforms with low level harmonic content to reduce distortion. Improving the inverter performance means improving the quality of the output voltage. Here we made an attempt of eliminating the desired harmonics in the output voltage waveform by solving the system of non-linear transcendental equations for getting the solution vector for different modulation index, here the solution of this system of equations was obtained using the method of least-squares (numerical method). After getting the solutions we have chosen the feed-foreword structure of ANN (artificial neural network). The ANN was made to learn by using the error-backpropagation algorithm. And finally we have obtained the weights to the corresponding neural network. The multilevel inverter chosen was three level cascaded inverter, which was simulated in the Matlab for different modulation indexes.

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CHAPTER-1
INTRODUCTION

1.1 INTRODUCTION OF MULTI-LEVEL INVERTERS

In general inverters are used to convert the DC power supply to AC power supply. In the application point of view the multilevel inverters are used mostly. the multilevel were implemented in different topologies in respective applications. Basically the inverter should consist of power semiconductor switches and DC voltage sources.

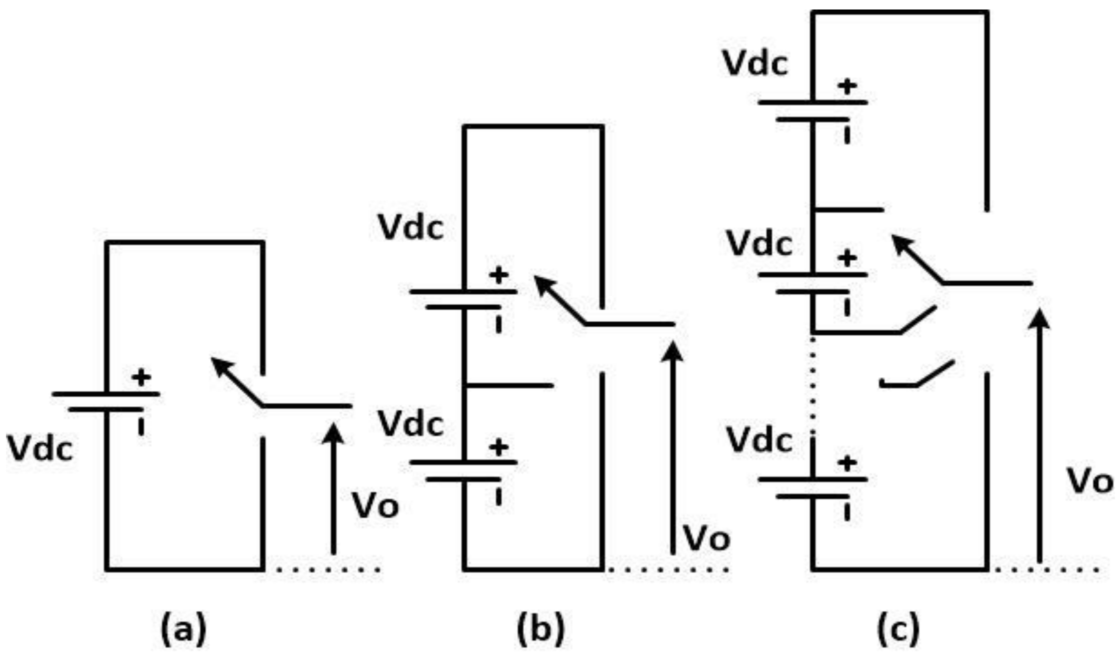

Fig. 1 Basic view of an inverter with (a)two levels (b)three levels (c)n levels

The semiconductor switches in the inverters half controlled in general. The control signals for this semiconductor switches will acquired from the relevant firing circuits. Fig. 1 shows the schematic diagram of one phase leg of inverter with different of levels in which the semiconductor device is represented by an ideal switch with several positions. In the above figure the basic view of the multilevel inverters with different number of voltage sources and voltage levels are shown briefly. From the above figure we can understand that as the number of the voltage sources is increased the number of the levels in the output voltage are also increased.

Some of the salient features of the multilevel inverters are :

i. The multilevel inverters can acquire the voltage and current with low THD.

ii. Efficiency of the inverter depends upon the switching frequency.

iii. Common mode voltages are reduced and hence the stresses on the motor bearings are reduced.

iv. The input current drawn by them has low distortion.

v. There exists no EMI problem

1.2 CASCADED MULTILEVEL INVERTER

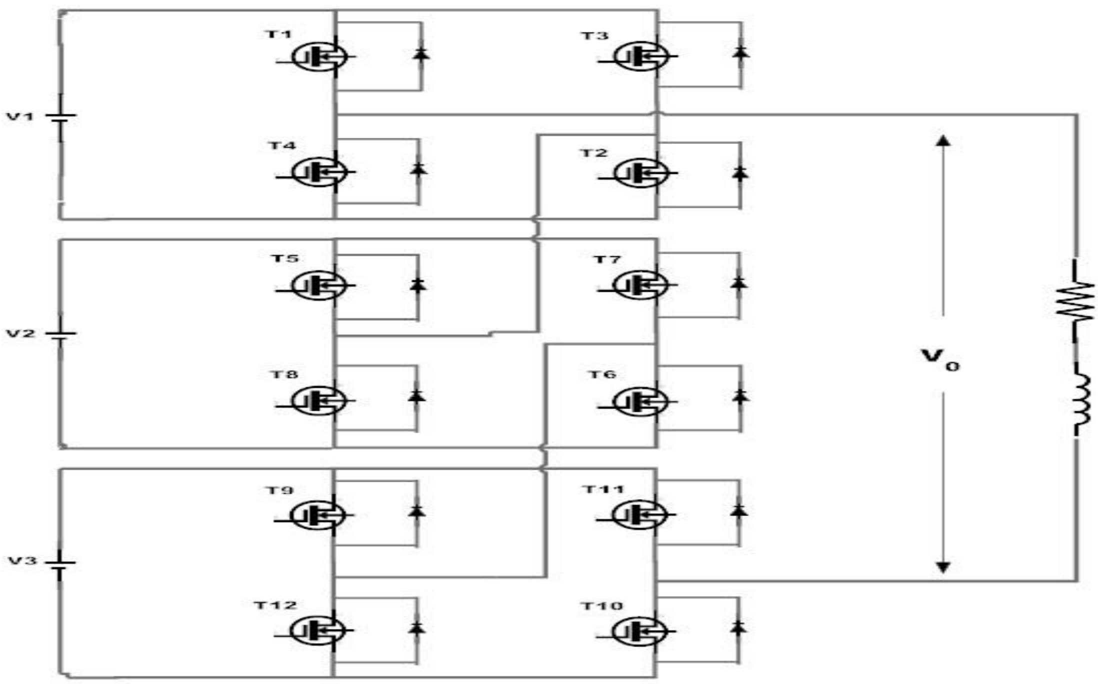

Fig. 2 circuit diagram of the cascaded H-Bridge inverter.

It is the series connection of the single phase H-bridge units with separate DC sources (SDCSs). These SDCSs may be batteries, capacitors, fuel cells or solar cells. Each unit produces three voltages at the output: + Vdc, 0 and – Vdc. The number of these units is decided by the manufacturing cost and operating voltage.

The cascaded multilevel inverter are recently, very popular in medium voltage, large power supplies and speed control applications. A cascaded MLI consists of a single phase full bridge inverter of each phases. Each H-bridge consist of one DC source separately. The each bridge consist single-phase full-bridge inverter having switches, S_1, $S_2, S_3\ and S_4$, each bridge can generate output voltages,V_{dc}, 0 and -V_{dc}. The outputs of each of its full-bridge converter are connected in series. So the output waveform is addition of individual converter outputs, which is staircase waveform. The number of total output voltage levels are $p = 2N + 1$.

Where $N = total\ number\ of\ DC\ sources\ of\ each\ bridge.$

Cascaded H-Bridge MLI are based on several single-phase inverter connected in series. So it is capable of reaching medium voltage levels. In case, any fault in one of these bridges, it can replace quickly and easily. With control strategy, it is possible to bypass the fault bridge without stop the load, with decrease output. Due to these features, the cascaded H-Bridge multilevel inverters has been more advantages than clamping diode, flying capacitor multilevel inverters.

Some of the advantages of the CHB converter can be summarized as below:

1. Modular in structure so packing and circuit layout is easier

2. No clamping diodes present as in NPC

3. No voltage balancing capacitors present in FC

4. Low voltage switching devices required

5. No EMI problem

6. Less common mode voltage and less

7. Suitable for medium voltage, high power applications

8. Separate DC sources eliminates the need of the voltage balancing circuits

9. With the increase in the number of the level, the staircase waveform approximates to a sinusoid

10. It can work at reduced power level when one of its cells is damaged

11. Soft switching techniques can be applied to CHB

12. No transformer required as in multi-pulse inverters

13. Number of possible output voltage levels is more than twice the number of DC sources

Its major disadvantage is the requirements of separate DC sources. It is thus limited to the applications where SDCSs are already present.

1.3 APPLICATION OF THE MULTILEVEL INVERTER

The cascaded multilevel converter can be utilized in wide range of applications. It is superior for medium and high power applications, likely (FACTS) Flexible ac transmission system controllers. The multilevel inverters are particularly because the as the number of levels are increased the quality of the power waveforms will become better and the harmonic distortion will get reduced. In advertently the multilevel inverters had their entry into the power electrical drive applications. The different topologies are used in the different applications. The cascaded multilevel inverters are mostly used in the FACTS and STATCOM applications. The neutral point converters has got their applications in the train drive systems particularly in trans-rapid maglev trains. In the similar fashion the diode clamped converters has got its applications in the real power conversion. A CHB-based and an NPC-based multilevel multistring photovoltaic topology have been developed. Hydro-pumped energy storage is one of the recent applications of multilevel converters. FC based converters have limited applications in photovoltaic topology, automotive applications, active filters, UPFC etc.

Also, these MLI can be reduces the size and weight of the compensator. And also improves the performance of the compensator during power system contingencies. The use of a large voltage DC-AC converter makes a possible direct connection to the large voltage distribution system, and to eliminating the low secondary voltage transformer and to reducing cost of the system. In addition, the harmonic ripples content of the inverter waveform can also be reduced with convenient modulation control techniques and thus the system efficiency can be improved. Some of the applications of MLI include (1) reactive power compensation, (2) back to back intertie, and (3) variable speed drives

1.4 WHY ARTIFICIAL NEURAL NETWORKS?

Artificial neural networks are developed to mimic the nature of the human brain. In the attempt of developing such networks mathematics related to the optimization methods were used. The idea of the artificial neural networks was first proposed by the inventor of the neuro computers, Dr. Robert hechet-nilson. He define artificial neural networks as

"...a computing system made up of a number of simple, highly interconnected processing elements, which process information by their dynamic state response to external inputs.''

The artificial neural networks are firstly used to simulate the behaviour of the neuronal structure of the mammalian cerebral cortex but on the lesser scales of the interconnections. Generally the mammalian brain has larger scale of the neurons in the order of billions, whereas the normal neural networks might have hundreds of thousands of the processing units. It is not necessary that the artificial neutral networks should accurately resemble the biological neurons. One of the major achievement of the researchers was mimicking the function of the eyes retina.

The mathematics involved in the neural networks was not too difficult even technical engineers can understand the behaviour or the operation of the neural networks.

There are different topologies proposed in the literature. In general the neural networks are typically organized in the layers and these layers consists of the nodes which are connected each other in different fashions for the respective topologies. Again the nodes consists of the activation functions which can be customised. The neural networks should be trained by applying the patterns to the network via the 'input layer', which are connected to the one or more hidden layers. The patterns are processed through the layers of the system by the weighted connections.

The schematic diagram of the artificial network has been shown in the fig.3 in this figure we recognize all the hidden, input and output layers of the network. Generally there are different types of the learning rules for the neural networks. Among all the learning rules we consider only the delta learning rule. The delta learning rule will update the weights of the network by applying the input patterns repeatedly many times.

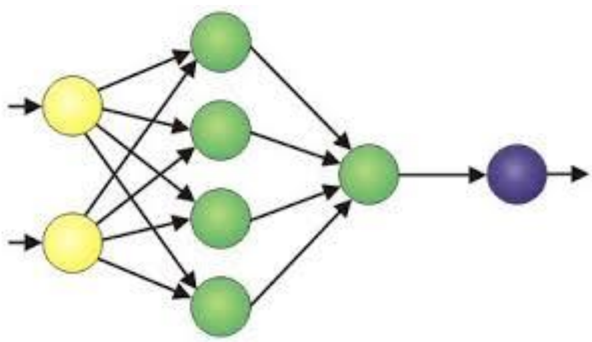

Fig. **3** schematic diagram of the artificial neural network.

The basic error back propogation algorithm was used in the delta learning. In this algorithm the weights are updated by minimizing the error function. Here in this context the error function is function of the weight vector. The updated weights for minimized error will be considered as the final weights for the neural network.

The main advantage of the error back propagation algorithm is that it can be coded easily without any complexities. In the algorithm we have to calculate the gradient of the error function. The gradient was calculated for each iteration in the code. The computational efforts of calculating the gradient will increase with the increase of the number weights of the artificial neural network. The calculation of the gradient gets simpler if the sigmoid is used as the activation function for the nodes in the neural network.

1.5 APPLICATIONS OF NEURAL NETWORKS

In the above section the description of the neural networks was discussed. Generally the neural networks are applied in the real world business problems. In fact they already been applied in the real world problems. In general the neural networks are typically organized in the layers and these layers consists of the nodes which are connected each other in different fashions for the respective topologies. Again the nodes consists of the activation functions which can be customised.

Actually the neural networks are best suited in the patterns recognizatoin or trends of the data, they are well suited for extrapolation which is called prediction used in the wheather forecasting. The following are the some areas where artificial neural networks are used.

- customer research
- industrial process controls
- sales forecasting
- data validation
- target marketing
- risk management

In the application point of view there many we can pose many examples for the artificial neural networks. Which we can explain in the following paradigms. Such as in communications for the recognition of the speakers, hepatitis diagnosis tests are done, recovering the telecommunications from the faulty software’s, understanding of multimeaning words in languages, undersea mine detection, analyses of the textures in the matters, recognizing three dimensional objects, facial and hand written word recognition.

1.6 LITERATURE REVIEW

In this paper [1] selective harmonic eliminated pulse width modulation technique was used. Here the study was done for making any angle number (odd or even) of switches composed the inverter, for purpose of comparison with the results found for only odd number. Here the resolution method is used for solving the nonlinear system of equations in order to achive the appropriate switching angles.

In this paper [2] the method of eliminating the active harmonic elimination for the desired higher order harmonics of the multilevel converters with equal or unequal dc sources was discussed in detail. Here in this paper the concept of resultant theory is used to the defining equations for the harmonic content of the output voltage and to evaluate the switching angles of the fundamental frequency switching scheme.

Here in this paper [3] Since the demand of the multilevel inverters was increased in this decade. It was explained that as they are able to produce output voltages with better harmonic spectrum, these converters are adaptable for higher output power and voltage applications. Numerous topologies were discussed and introduced and studied for utility and drive applications. It was concluded that among all the topologies the cascaded H-bridge multilevel inverter is innovative and simple which were used in the static VAR compensation. Here in this paper a new technique of the SHEPWM control strategy was implemented to eliminate the odd harmonics. The results were also shown in the matlab simulation environment in the seven level multilevel inveter.

In this paper the Genetic optimization method for harmonic elimination in a cascaded H-Bridge multilevel inverter and an optimal solution for eliminating desired order of harmonics from a output waveform for equal dc sources. Here the method of solving the nonlinear transcendental equations with multiple solutions was explained with relevant algorithm. The main objective of selective harmonic elimination pulse width modulation strategy is eliminating low-order harmonics by solving nonlinear equations. The two approaches of solving the transcendental equations which were newton raphsons method and the genetic algorithm were compared based on the computation of the switching angles. It was observed that a significant improvement in harmonic profile is achieved in the genetic algorithm method.

1.7 THESIS ORGANIZATION

The entire thesis consists of five chapters along with this current introductory chapter. In the second chapter basic understanding of the error back propogation algorithm was discussed form which the artificial neural networks are trained. And in this chapter the mathematical equations related to the algorithm are also discussed. The problems of the back propagation algorithm was also viewed.

In the third chapter the working of the multilevel inverter was discussed in detail where the operation of the inverter for each and every instant was shown in the figures from which we can understand the operation of the cascaded multilevel inverter very easily. In the second section of the chapter three the firing strategy for cascaded multilevel inverter was explained in the detailed fashion by which we can emphasize how to control firing angles of the cascaded multilevel inverter.

In chapter four the fourier analysis of the output voltage of the cascaded multilevel inverter has been analysed. In the fourier series expression of the output voltage we get the transcendental equations for eliminating the selected harmonics. These selected harmonics are eliminated by solving the transcendental equations, those equations are solved using the numerical technique with considerable amount of the error.

Finally in the chapter five the results are shown for work which we have done in the matlab Simulink.

Chapter-2
Artificial Neural Network

2.1 BACK PROPAGATION ALGORITHM

Neural networks which are widely used are broadly classified in to many small groups in which many other networks are based. These are Hopfield networks, back propagation network, competitive networks with spiky neurons. We can see many variations on these themes. Back propagation is a basic training algorithm which is used to train the artificial neural networks. In back propagation we learn the networks by examples. As just stated to train the neural network we need to give input patterns of what u want and the output patterns what particularly we want (target). The targets and the corresponding input patterns are called training pairs. After learning the network, it can produce the desired output for the given input with some error. Let us now understand the back propagation algorithm. In this algorithm the networks are initialised with weights which are randomly chosen numbers. Next for the input patterns applied to the network the outputs are calculated which is called forward pass. Generally in forward passes we get the output which is not exactly what we want. Then we calculate the error of each neuron. The error is mathematically a function of weights which are applied.

2.1.1WORKING OF ALGORITHM:

First apply the inputs to the network and work out the output – remember this initial output could be anything, as the initial weights were random numbers. Here we consider only the sigmoid activation function.

Next work out the error. The error is What you want – What you actually get.

$$[E_i] = [A_d – A_c] \ldots\ldots (2.1)$$

$$(e_i) = [E_i] \ldots\ldots (2.2)$$

The next step is to compute the deltas. In order to compute the delta we have to evaluate the gradient of the error function which is the function of the weights.

$$\Delta_{o-1} = [E_i].Y_o.(1 - Y_o) \ldots\ldots (2.3)$$

$$\Delta_{o-2} = \Delta_{o-1}.W_b.\ Y_{o-1}.(1 - Y_{o-1}) \ldots\ldots (2.4)$$

Change the weight. For updating the weights we have to multiply the output with the coefficient(η) which is called learning coeffecint. And in addition to that we use the momentum rate to improve the convergence.

$$W_b = W_b + \eta\ .\ Y_{o-1} + M\ .\ \Delta W_b \ldots\ldots (2.5)$$

$$Wa = W_a + \eta\ .X.\ Y_{o-1} + M\ .\ \Delta W_a \ldots\ldots (2.6)$$

Having obtained the Error for the hidden layer neurons now proceed as in stage 3 to change the hidden layer weights. By repeating this method we can train a network of any number of layers.

By doing the iterations repeatedly the weights will get updated. The differentiable activation functions makes the computational effort reduced. By which the time taking for the execution for each iteration. In this thesis the sigmoid activation function was used because the derivative can be calculated by having the information of the output for the respective nodes in the artificial neural networks. The no of iterations can be reduced by including the momentum coefficient.

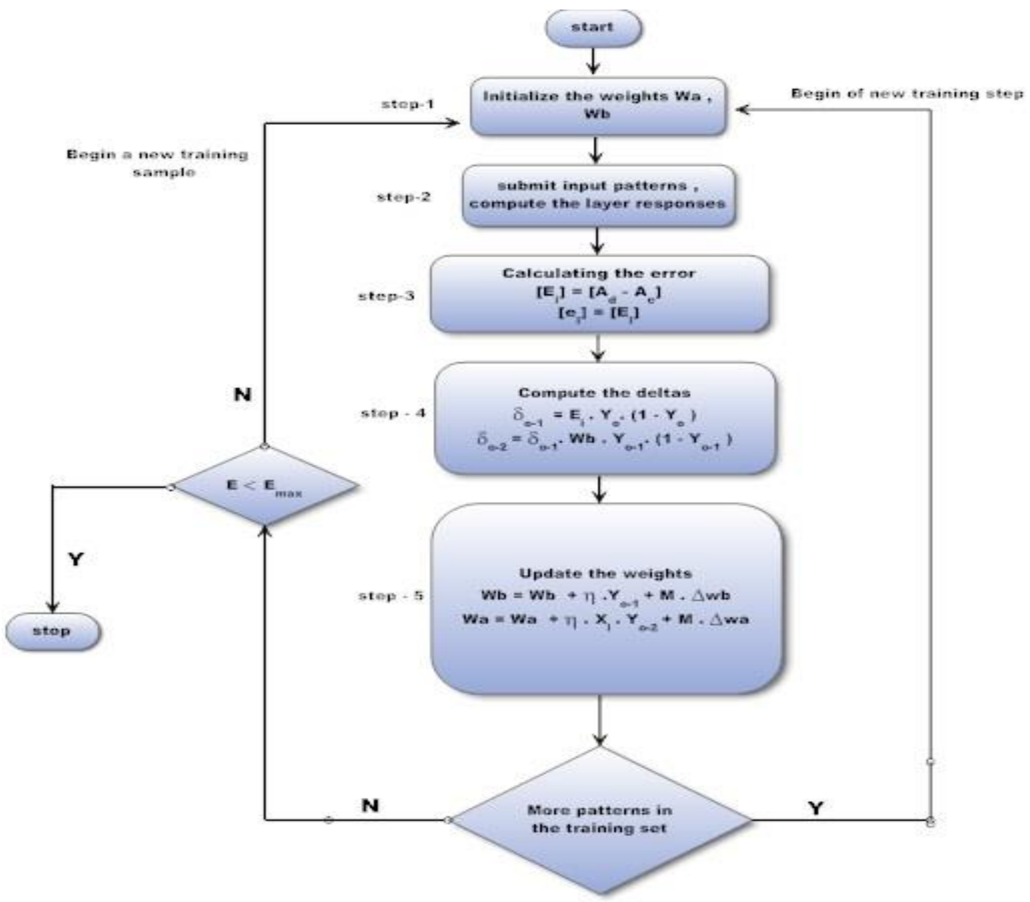

Fig. 4 Flow chart of the basic error back propagation algorithm

2.1.2 PROBLEMS WITH BACKPROPAGATION

Backpropagtion has some problems associated with it. Perhaps the best known is called “Local Minima”. This occurs because the algorithm always changes the Weights in such a way as to cause the error to fall. But the error might briefly have to rise as part of a more general fall, If this is the case, the algorithm will “gets stuck” (because it can’t go uphill) and the error will not decrease further. There are several solutions to this problem. One is very simple and that is to reset the weights to different random numbers and try training again (this can also solve several other problems). Another solution is to add “momentum” to the weight change. This means that the weight change this iteration depends not just on the current error, but also on previous changes. One of the main factors for choosing this technique is its generalization ability in nonlinear problems that are in nature complex and time consuming in calculation.

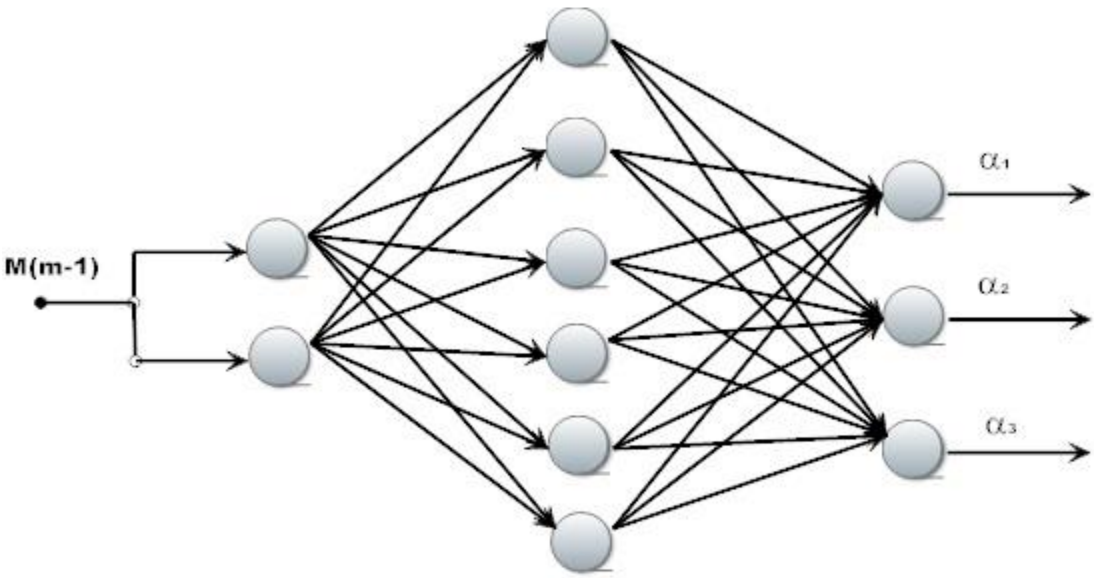

Fig. 5 feedforward structure of the artificial neural network

In the proposed Artificial neural network there is one hidden layer, the sigmoid activation function is choosen in the node of the hidden and output layer. We had set two weight vectors, one exist between the input layer and the hidden layer mentioned as W_a and the other weight vector mentioned as W_b is between the hidden layer and the output layer. We have used the error back propagation algorithm in the learning process of the proposed artificial neural network the flow chart of the error backpropagation algorithm is shown in the fig below. In the training of the ANN we have set the threshold level of the error in the algorithm of (0.15). The matlab code was written for the following algorithm, the plot between the error and the no of the training iterations was given below. The weights obtained after the learning process are written below.

$$W_a = \begin{bmatrix} -185.1586 & -374.6793 & -24.6388 & -23.8734 & -11.3679 & -19.3264 \\ 211.2957 & 104.7059 & -122.6368 & -64.1352 & 6.5472 & 14.4102 \end{bmatrix}$$

$$W_b = \begin{bmatrix} 1.9602 & 1.6336 & -2.5266 \\ 2.9462 & -1.2377 & -2.0570 \\ -3.4795 & -2.3770 & 7.3682 \\ 3.6820 & 1.7240 & -6.7634 \\ 13.0491 & 36.0413 & 7.8594 \\ -93.3583 & -85.2298 & 6.8163 \end{bmatrix}$$

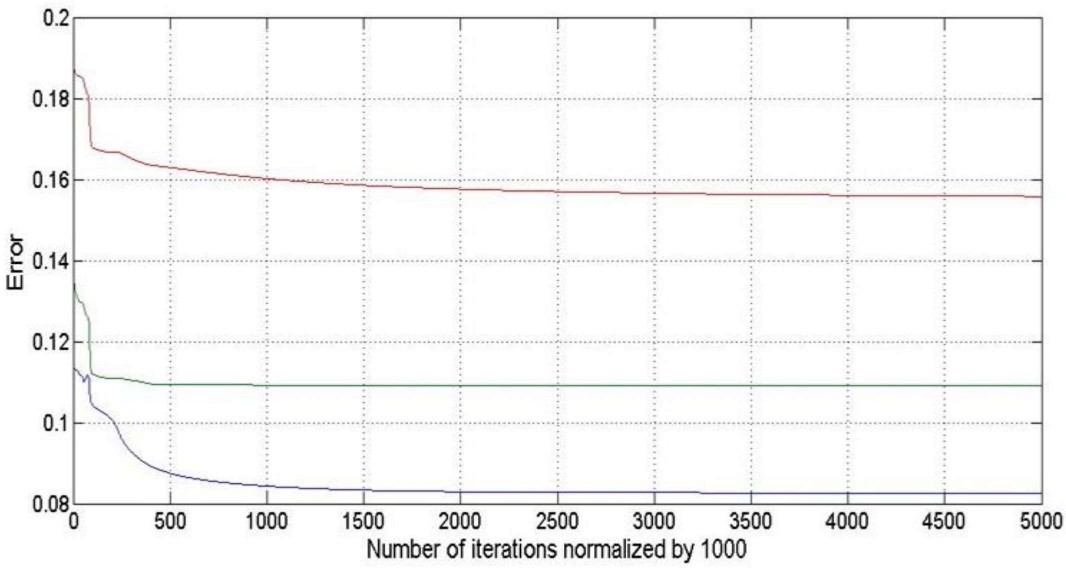

Fig. 6 The plot between the error and the number of iterations

In the above figure the plot between the mean square error and the number of the iterations were plotted the lesser the error the greater the accuracy in the output of the artificial neural network.

CHAPTER -3

Cascaded multilevel inverter

3.1 WORKING OF THE MULTILEVEL INVERTER

Here the modulation technique of the cascaded inverter is explained. The firing angles $\alpha_1, \alpha_2, \alpha_3$ of the individual H-bridges are controlled individually by using simple modulation technique. The modulation technique used is triangle pulse modulation with suitable logic used to control the respective H-bridge of the cascaded inverter. The firing angle is controlled by varying the DC value of the carrier waveform. This Dc value comes from the artificial neural network to which it is trained to eliminate the harmonics in the output voltage of the multilevel inverter.

The general schematic diagram of the H-bridge inverter is shown below, here it consist of four switches T1,T2,T3 and T4. The dc source connected may be a battery or pv module where energy comes from.

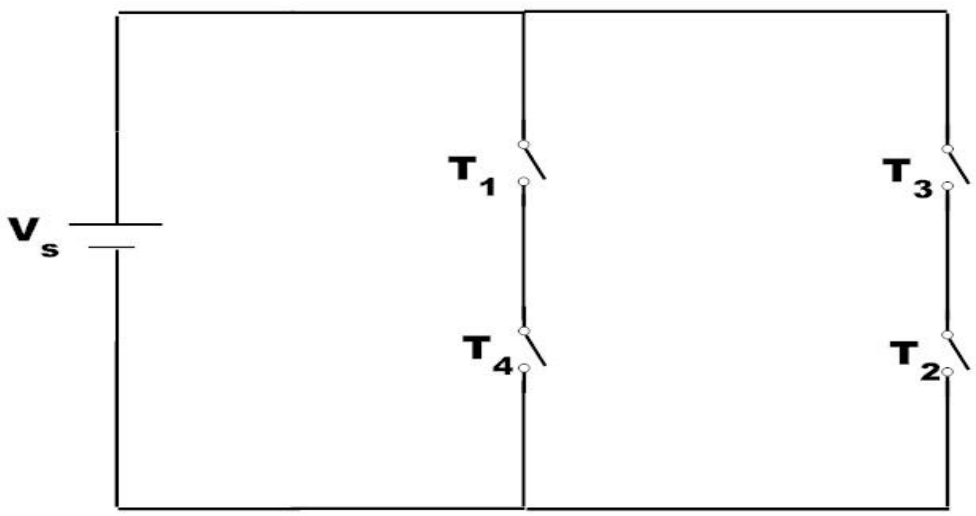

Fig. 7 switching diagram of the H-Bridge inverter.

The output voltage of the output voltage is shown below consists of the four switching instants named 1,2,3 and 4. In each particular switching instant the combination of the switches which should turn on will vary. There are some instants for which the combination of the switches which should turn on was not unique.

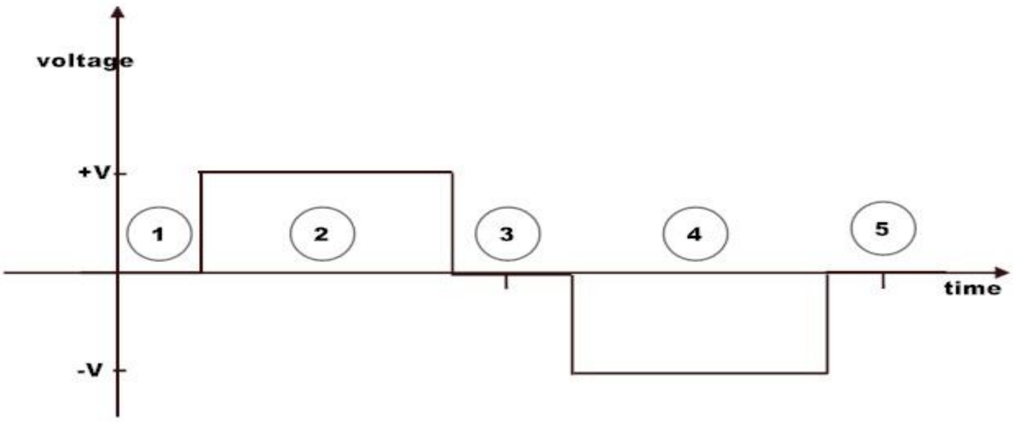

Fig. 8 The output voltage synthesized by the H-bridge.

Among the four instants in the first instant the switches T1 and T3 are turned on . the schematic was shown below.

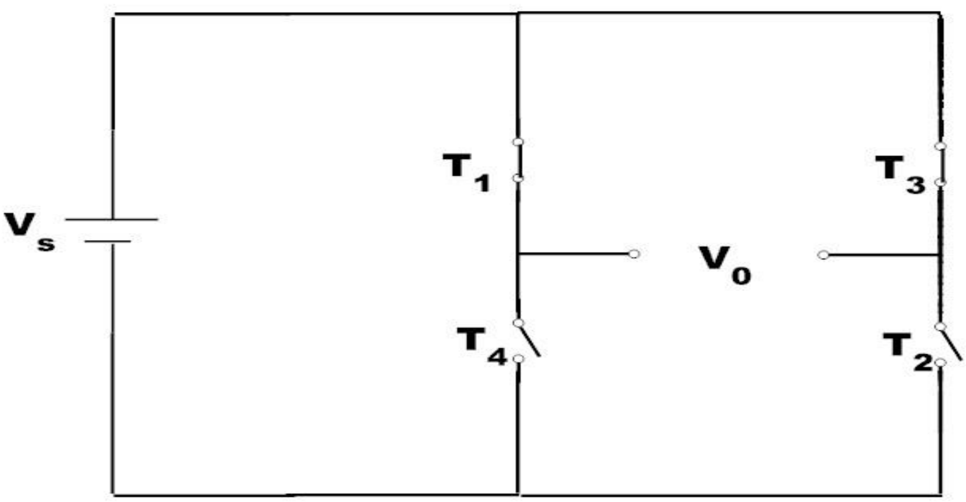

Fig. 9 First instant of the H-bridge

In the second instant the switches T1 and T4 are turned on , here the thing which we should take care about is in the second leg of the bridge the T2 should be turned on when the T3 is confirmed off or else the dead short circuit will occur.

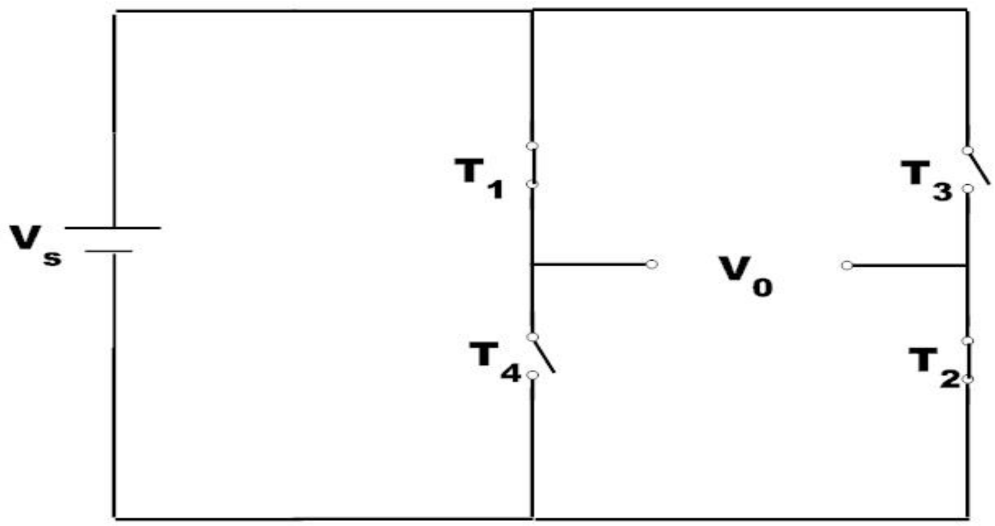

Fig. 10 Second instant of the H-bridge inverter

In the third instant of the H-bridge inverter T1 and T3 are turned on which is same as the switches turned on in the instant-1 , here in this instant we turn on the T4 and T2 but we choose only the odd numbered switches at the zero voltage of the H-bridge inverter.

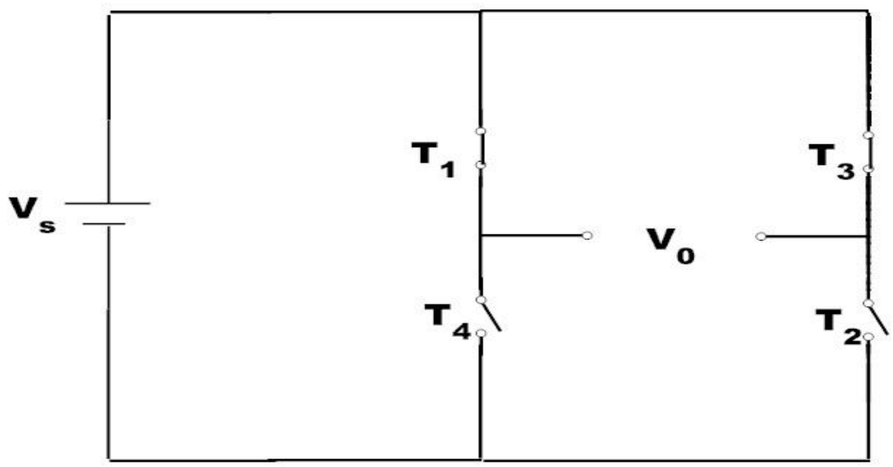

Fig. 11 Third instant of the H-bridge inverter

In the four instant the switches T1 and T4 are turned on , here the thing which we should take care about is in the first leg of the bridge the T1 should be turned on when the T4 is confirmed off or else the dead short circuit will occur. The following is the out.

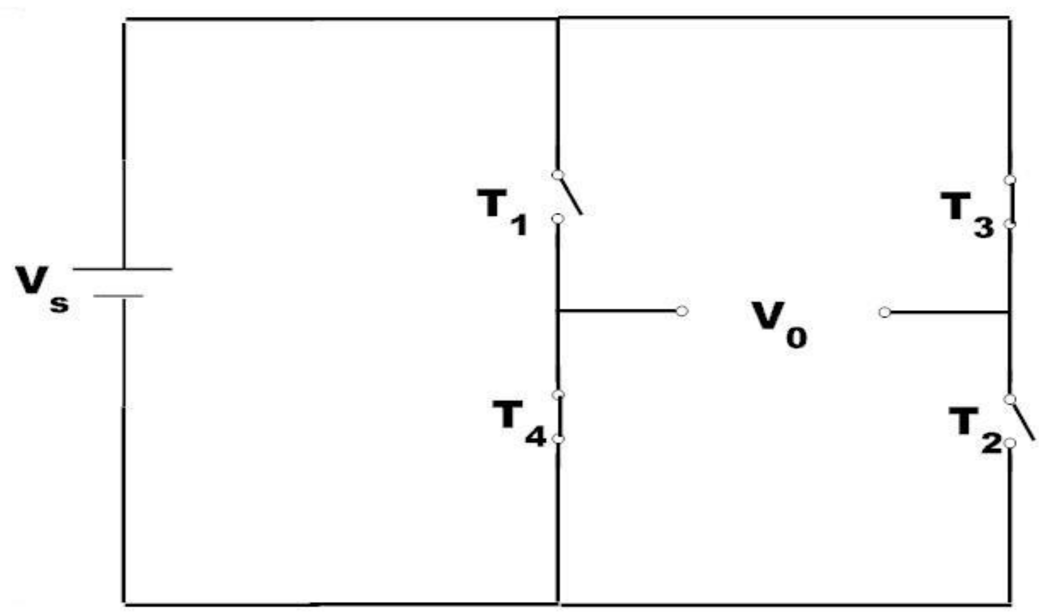

Fig. 12 fourth instant of the H-bridge inverter.

3.2 FIRING STRATEGY OF THE MULTILEVEL INVERTER

The carrier and reference signals which were used to fire the different switches in the H-bridge inverter are shown below, here in this context voltage is synthesized by controlling the switches of the two legs in the H-bridge inverter for different instants by considering the two different sets of the controlling carrier and reference signals. The signals Vc and Vr are used to synthesize the positive part of the output voltage and the signals Vc' and Vr' are used to synthesize the negative part of the output voltage.

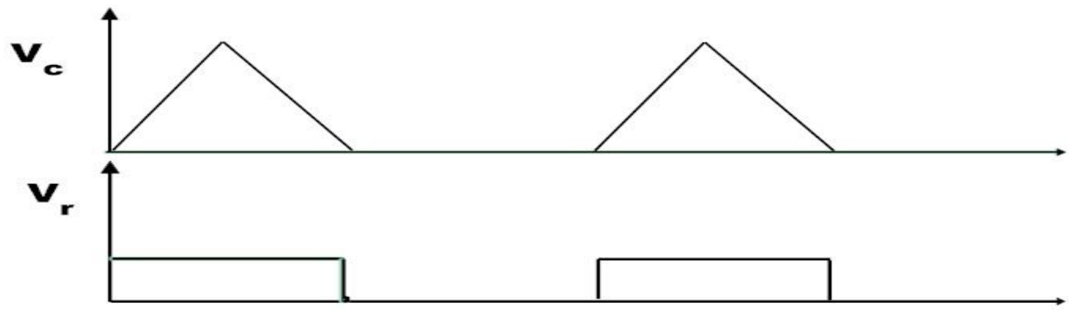

Fig. 13 first set of the carrier and reference signal.

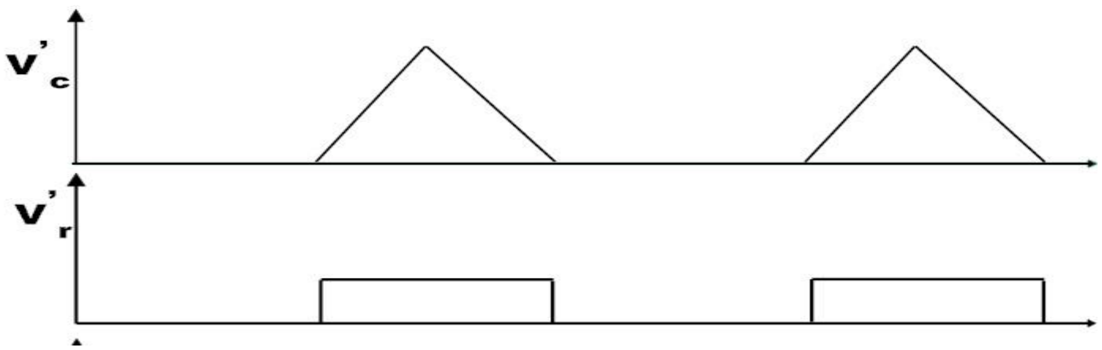

Fig. 14 second set of the carrier and reference signal.

The above two signals are compared to get the switching signal for the devices in the H-bridge to get the output of the inverter module. After the signals are compared we get the signals X1, X2, X3 and X4 which are sent through the adders and given to the each of the switches in the H-bridge.

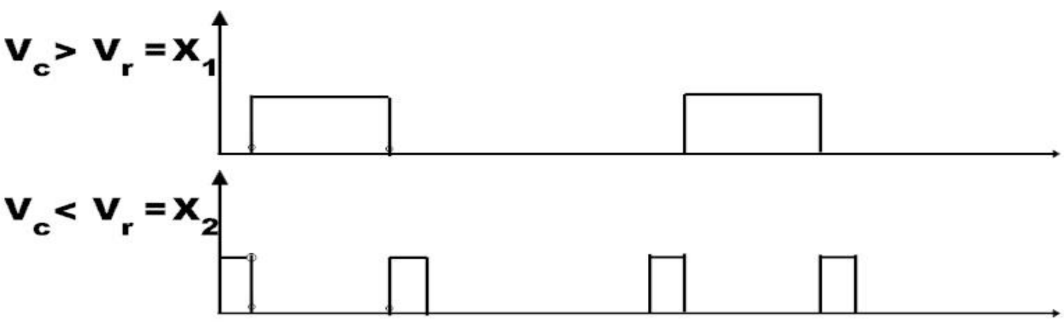

Fig. 15 The signal X1 and X2

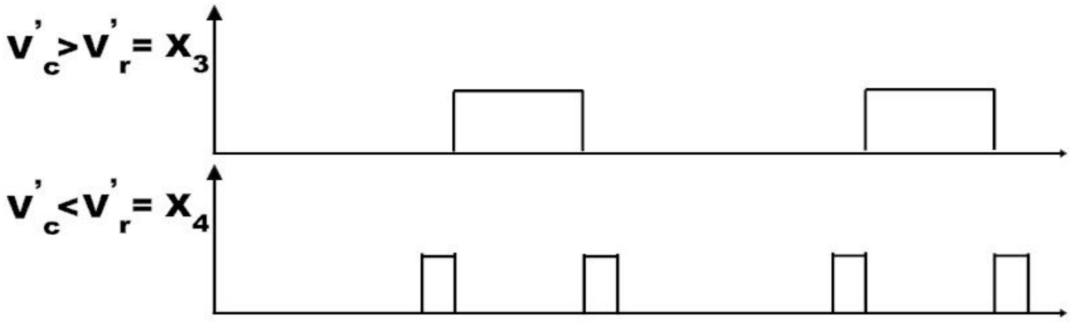

Fig. 16 The signals X3 and X4

The firing angle strategies for the H-bridge inverter is shown below the signals are coming from the firing circuit in which the switches are turned on according to the logic which was planned. Here in this context of the firing scheme the switching and conduction losses are more in the odd numbered IGBT's so we have to design the H-Bridge inverter in such a way that the on resistance of the switches should be very less for reducing the damage and increasing the reliability of the inverter. In the figure shown below the

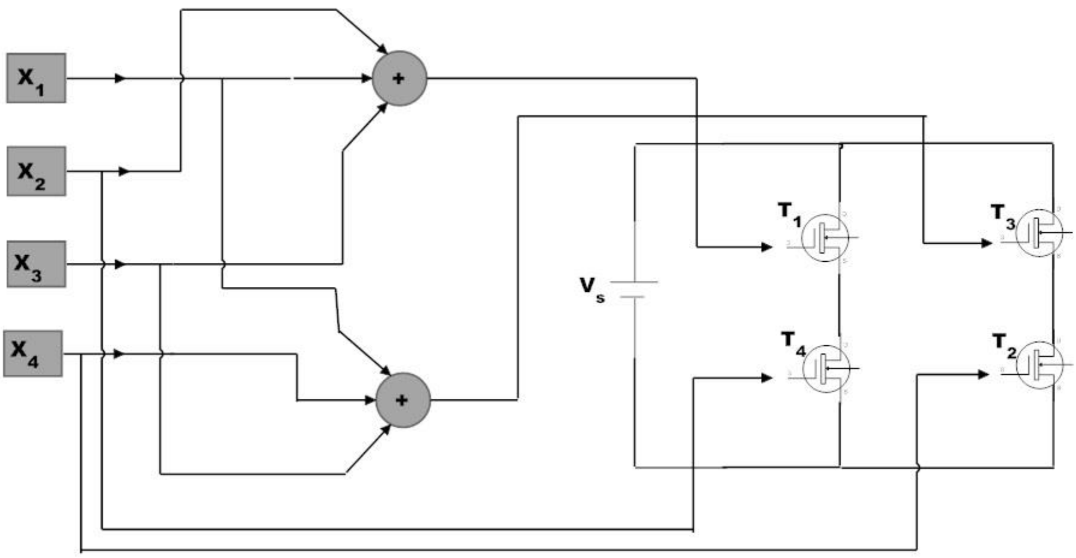

Fig. 17 firing strategy of the single H- Bridge inverter.

Signals X1, X2, X3 and X4 are synthesized by the digital logic which was implemented in the previous chapter. The total seven level cascaded inverter in which the three H-bridge inverters are controlled in the decoupled fashion for respective desired firing angles are controlled in the same fashion which was represented in the above figure. The firing angles vectors which are the solution vectors of the nonlinear transcendental equations are coming from the artificial neural network. In general the neural network output will be in radians the main task is how to get the desired firing angle which is exactly same as the value of the neural network output. This task is performed using the triangle pulse modulation which we referred from the basic power electronic textbook.

Controlling of the firing angle in the individual converter will synthesize the individual output waveform duty cycle, upon super imposing the output voltages of the each H-Bridge inverter the final output voltage of the seven level cascaded inverter will be synthesized as per the requirement of eliminating the selected harmonics in the output voltage of the cascaded inverter. The following fig gives the brief block diagram view of the control hierarchy of the present context which we discussed earlier.

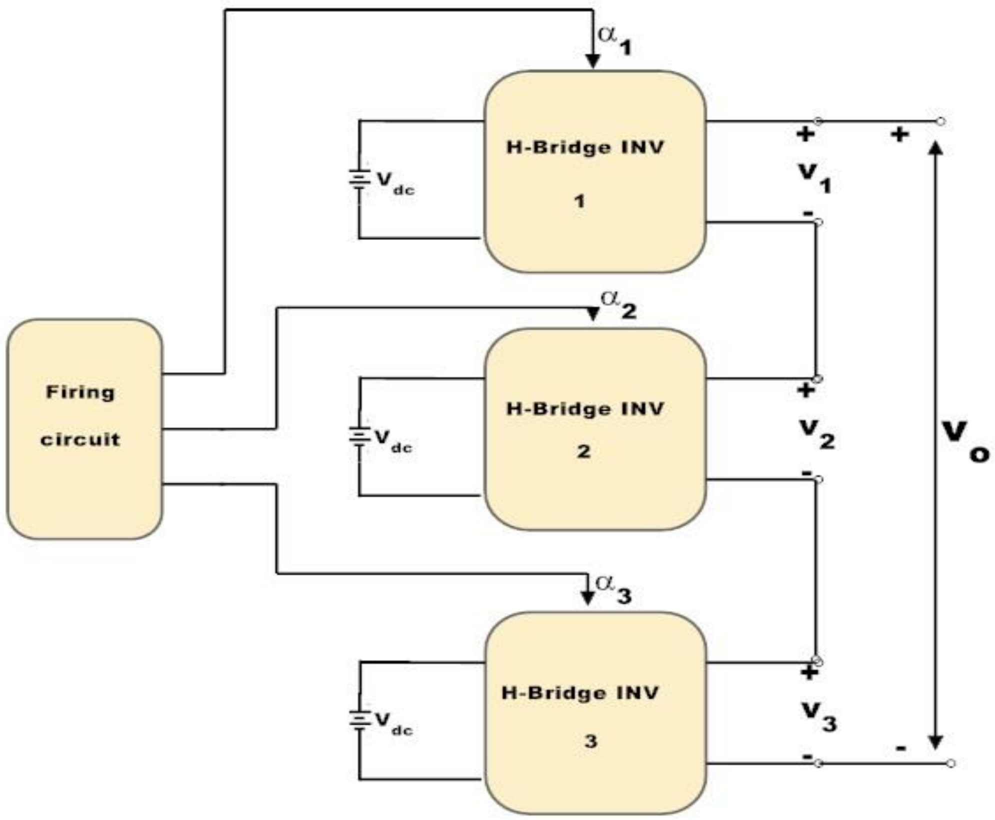

Fig. 18 block diagram of the firing scheme of the cascaded multilevel inverter

Here in the above block diagram the firing angles are given to the individual H-bridge inverters. The individual H-bridge inverter has its own sources which the output voltages of them comes from. The main advantage of the firing scheme which we used was their no constraint in switching angles such the order of the magnitudes of the individual H-bridge inverters.

CHAPTER – 4
Analysis of the Output

4.1 SOLVING EQUATIONS

Here the circuit topology of three level cascaded inerter is shown the output voltage of this inveter will have seven steps per half cycle ($m = 4$).

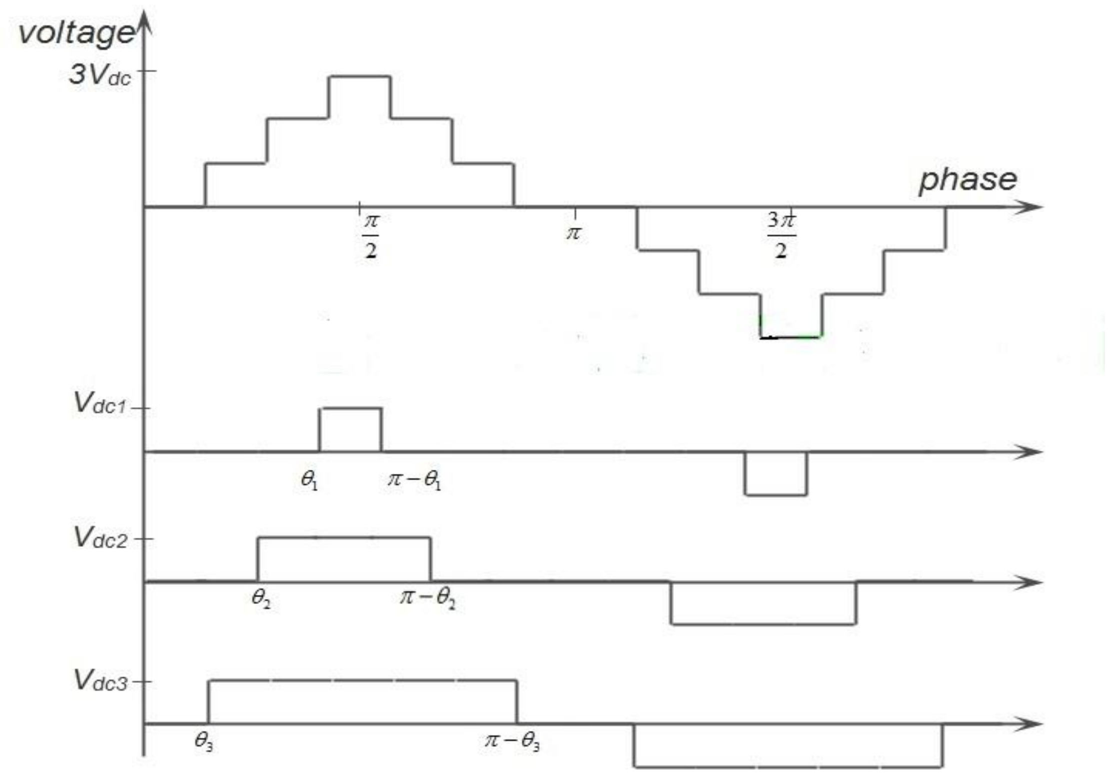

Fig. 19 four level cascaded multilevel inverter

The output voltage is given by the equation

$$V_o = V_{dc1} + V_{dc2} + V_{dc3} \quad \text{...(4.1)}$$

This output voltage equation can be resolved in the fourier series components. Due to the quarter wave symmetry along the x-axis both fourier coefficients A_0 and A_n are zero.

$$B_n = \frac{4V_{dc}}{n\pi} \sum_{j=1}^{m-1} \cos(n\alpha_j) \quad \text{...(4.2)}$$

Which gives the instantaneous voltage v_{0n} as

$$v_{on} = \left[\frac{4\,V_{dc}}{n\pi}\sum_{j=1}^{m-1}\cos(n\alpha_j)\right] * \sin(nwt) \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots..(4.3)$$

The output voltage equation of the three-level cascaded inverter is given below

$$v_{on} = \frac{4v_{dc}}{\pi}(\cos(\alpha_1) + \cos(\alpha_2) + \cos(\alpha_3)) * \sin(wt)$$
$$+ \frac{4v_{dc}}{3\pi}(\cos(3\alpha_1) + \cos(3\alpha_2) + \cos(3\alpha_3)) * \sin(3wt)$$
$$+ \frac{4v_{dc}}{5\pi}(\cos(5\alpha_1) + \cos(5\alpha_2) + \cos(5\alpha_3)) * \sin(5wt) + \cdots \ldots\ldots (4.4)$$

Here we made an attempt in eliminating the third and fifth harmonics in the output voltage. To simplify the equations a new modulation index is defined as

$$M = \frac{V_1}{12\frac{V_{dc}}{\pi}} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (4.5)$$

Here the value of M lies in between 0 and 1, but we considered for 0.2 to 0.8 only

The systems of the nonlinear transcendental equations are

$$M = \frac{1}{3}(\cos(\alpha_1) + \cos(\alpha_2) + \cos(\alpha_3)) \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots..(4.6)$$

$$0 = (\cos(3\alpha_1) + \cos(3\alpha_2) + \cos(3\alpha_3)) \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots..(4.7)$$

$$0 = (\cos(5\alpha_1) + \cos(5\alpha_2) + \cos(5\alpha_3)) \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots..(4.8)$$

Here the equations $(6), (7)$ & (8) are solved numerically using the method of least squares, and finally we have founded the solution vector. The algorithm which we have implemented is given below .

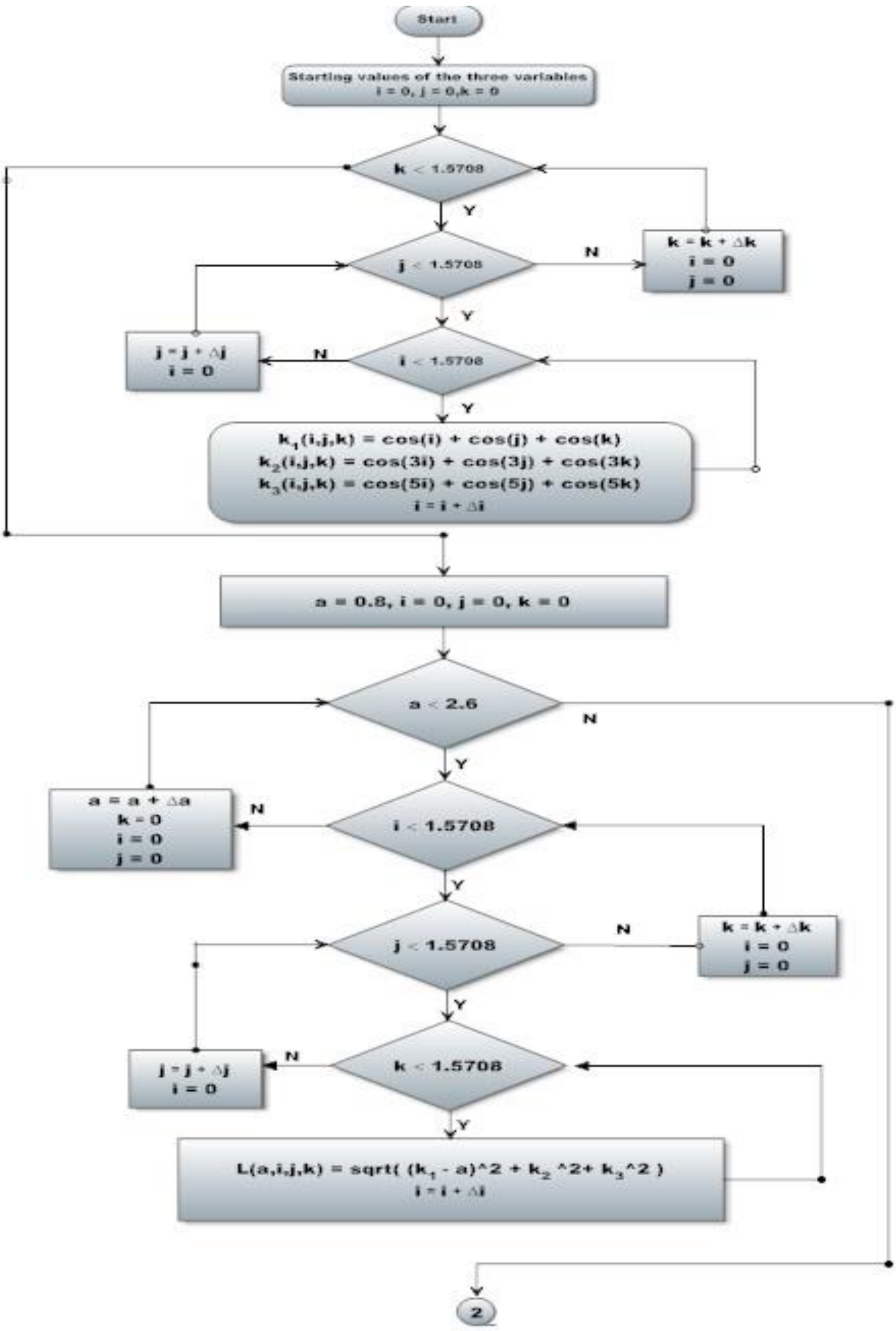

Fig. 20 Flowchart of the least squares algorithm

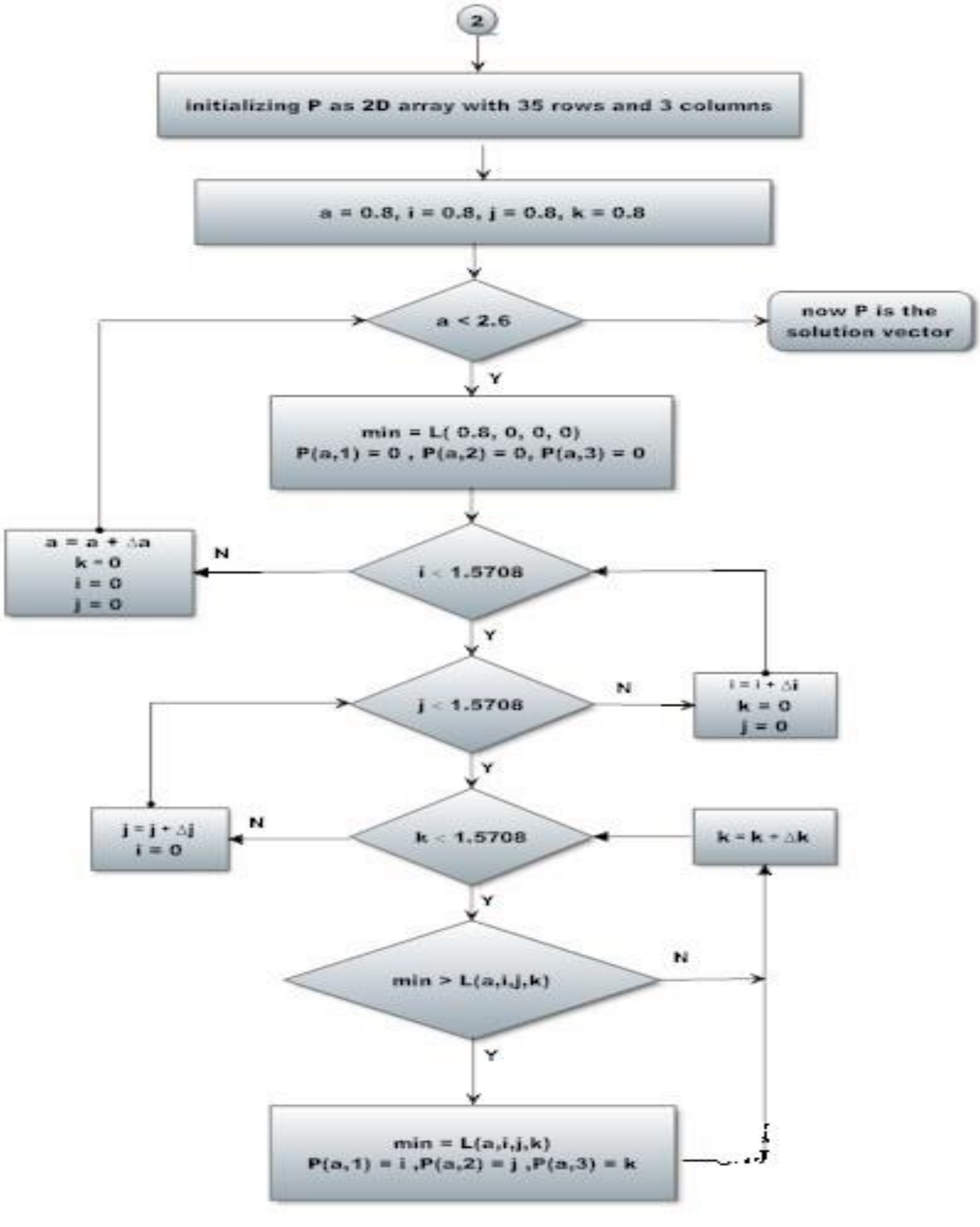

Fig. 21 Flowchart of the least squares algorithm

In the algorithm which we have used the solutions are constrained in the ranges of

$$0 < \alpha_1 < \frac{\pi}{2} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots(4.10)$$

$$0 < \alpha_2 < \frac{\pi}{2} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots(4.11)$$

$$0 < \alpha_3 < \frac{\pi}{2} \quad \text{......................(4.12)}$$

The matlab code was written for proposed algorithm and the solution vectors are plotted between firing angles and (M(m-1))

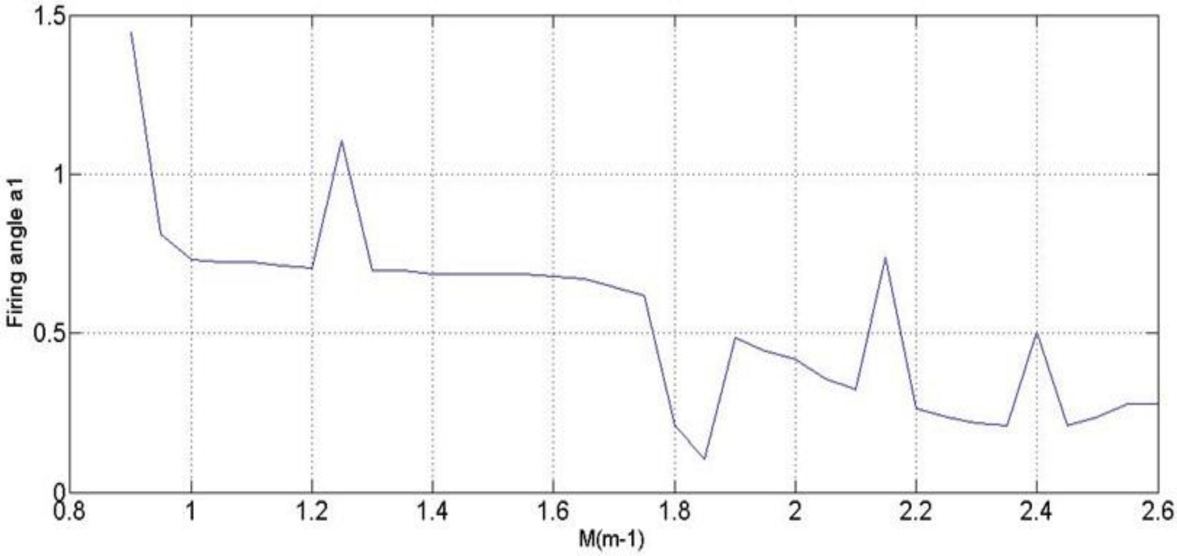

Fig. 22 Matlab plot between Firing angle $\boldsymbol{\alpha_1}$ and (M(m-1))

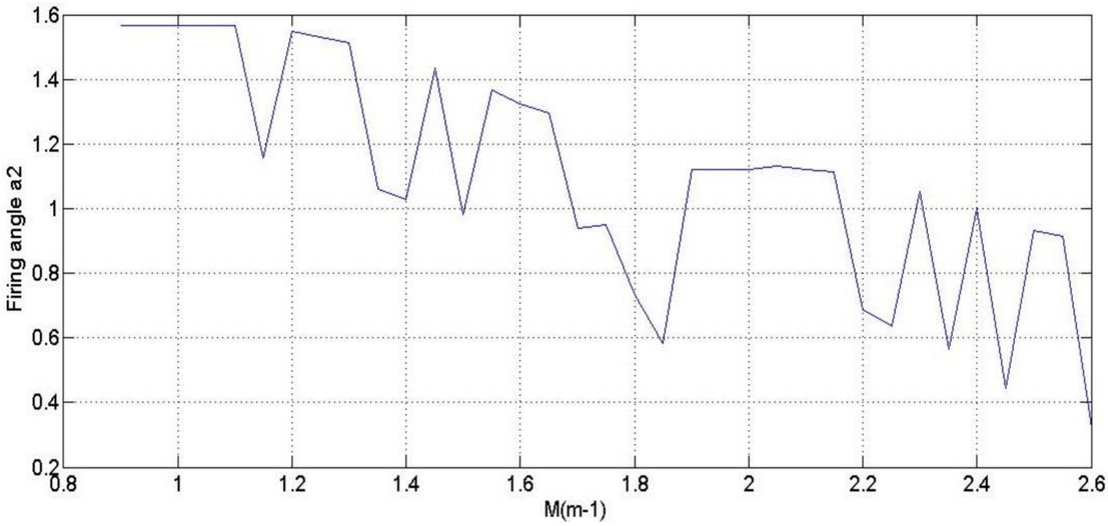

Fig. 23 Matlab plot between Firing angle $\boldsymbol{\alpha_2}$ and (M(m-1))

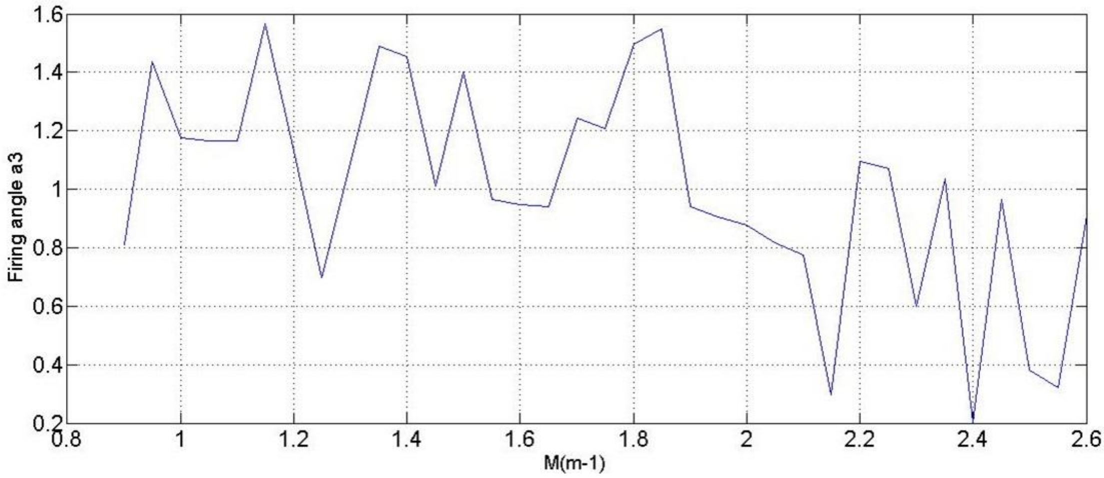

Fig. 24 Matlab plot between Firing angle $\boldsymbol{\alpha_3}$ and (M(m-1))

CHAPTER- 5

5. RESULTS

The circuit topology was given in the fig. 1. In the given circuit there are twelve switching devices connected with diodes in anti-parallel. Among the three H-bridges in the circuit the thyristors are classified into two, which are upper thyristors and lower thyristors. We have numbered the upper thyristors with the odd numbers and the lower thyristors with the even numbers. Actually there fourteen instants in the synthesized output voltage. For each instant particular devices should only work and the rest should turned off. Here the thyristors are turned on only in the presence of the gate signal.

In case of the zero level there are two possible switching patterns to synthesize the zero level. Example 1) upper thyristors or 2) lower thyristors

We enumerated the switching possibilities for each switching instant of the output voltage. And firstly we considered the firing angles spaced symmetrical to the π/2 and the twelve switching waveforms for the devices are shown below.

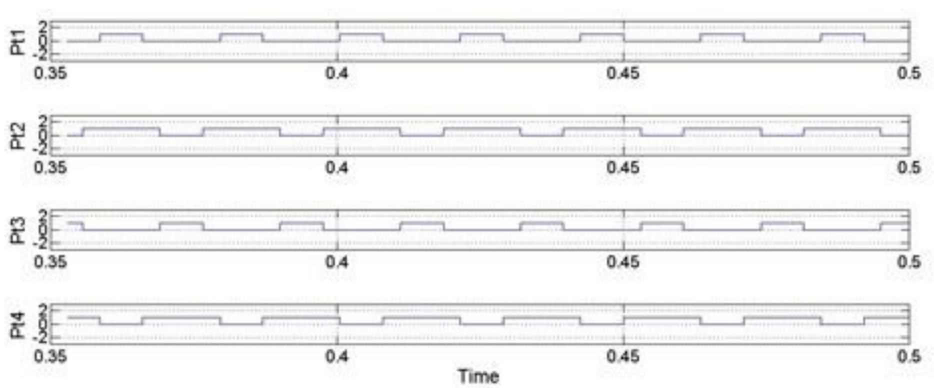

Figure 25 switching signals for the devices t1,t2,t3,t4

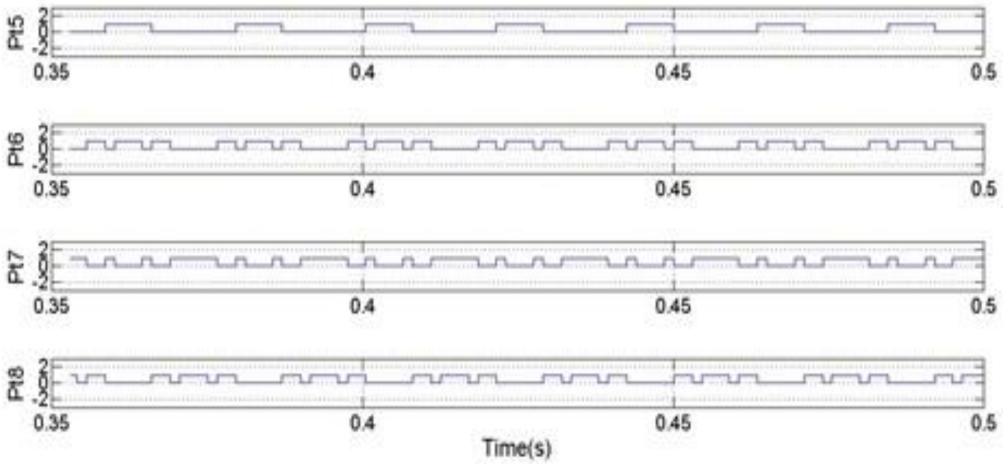

Figure 26 switching signals for the devices t5,t6,t7,t8

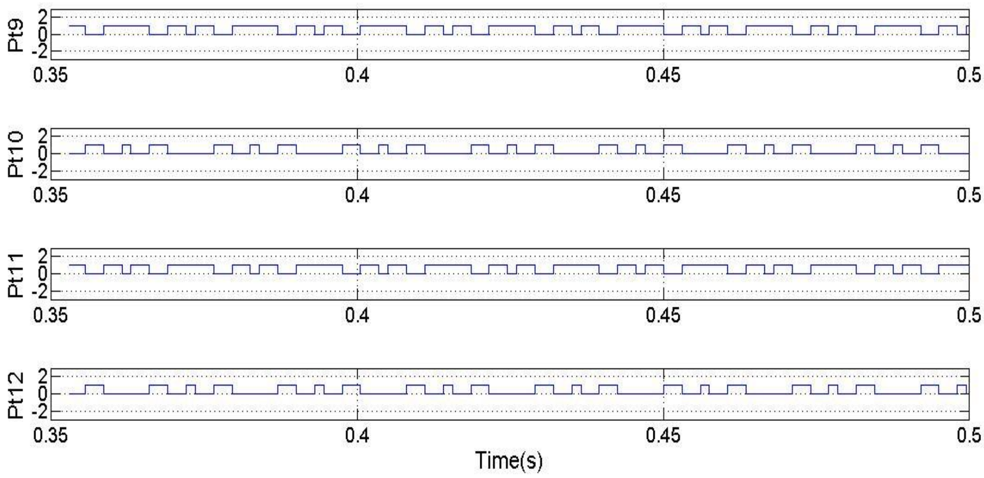

Figure 27 switching signals for the devices t9,t10,t11,t12

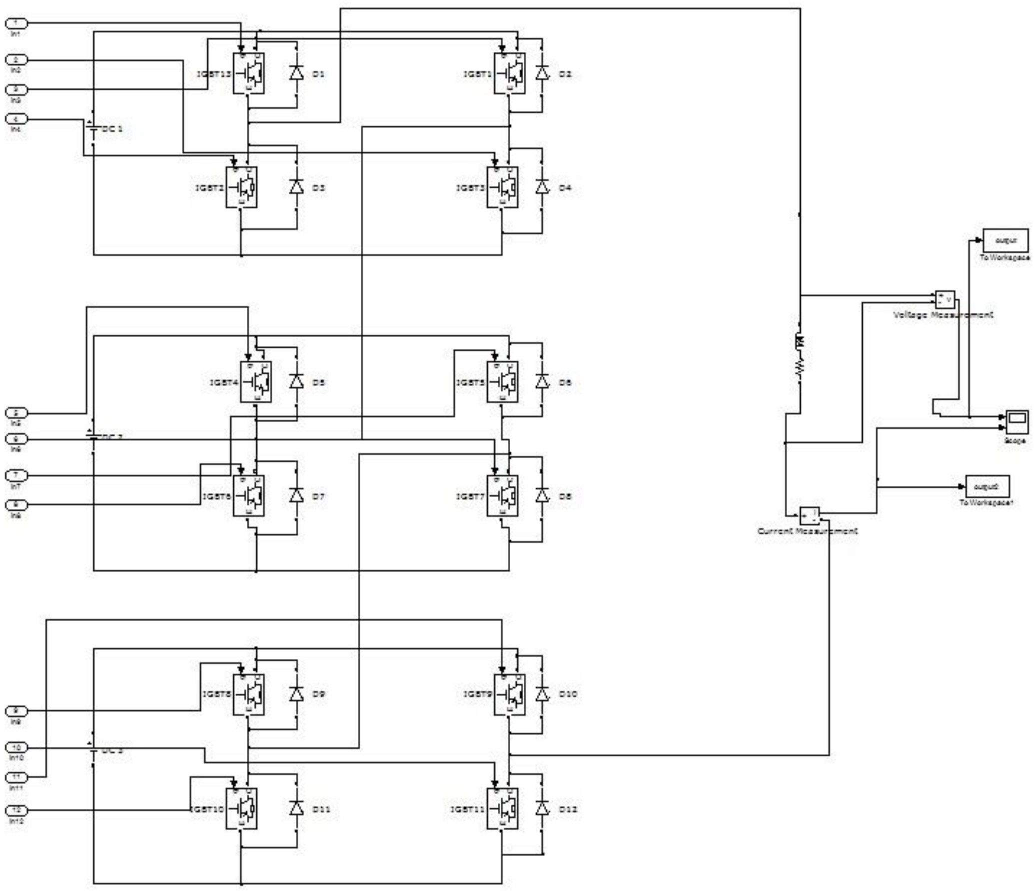

Figure 28 Simulatoin diagram of the cascaded inverter

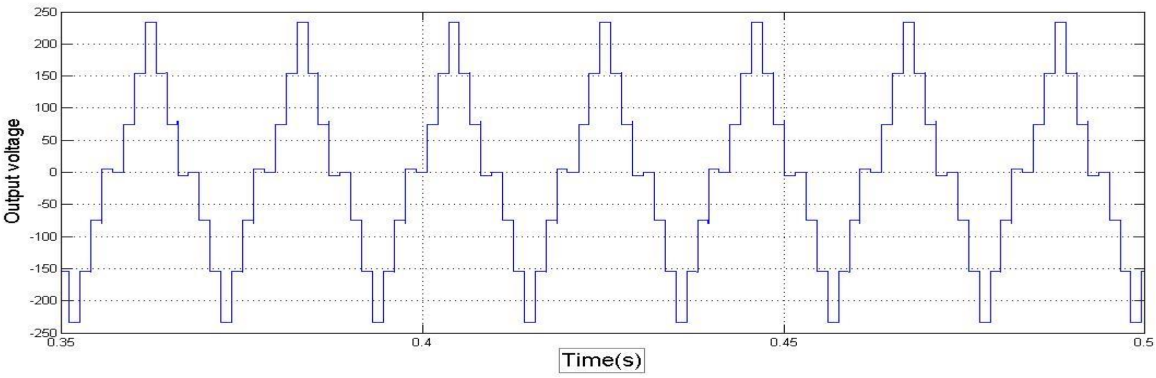

Figure 29 output voltage of the cascaded multilevel inverter

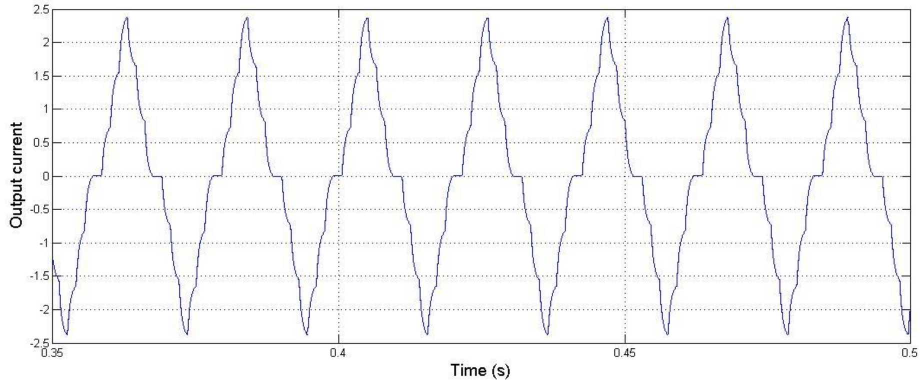

Figure 30 output current of the cascaded multilevel inverter

Here the simulations were done on the matlab Simulink, the above diagrams show the output voltage and current waveform of the cascaded multi-level inverter. In the simulation that we performed for the seven levels cascaded multilevel inverter with the voltage of 80 volts to each H-bridge inverter and lagging load is considered to include the effect of the practical situations.

Here the concept of the selective harmonic elimination is applied in the firing circuit which was not shown which is hard to understand at this moment but the main observation which we should consider is in the output voltages for different modulation indexes is due to the error in the solution vectors of the switching angles and the truncation and the rounding off errors in this digital simulation results the improper functioning of the total simulation circuit that is the desired harmonics which should be eliminated are not completely getting eliminated.

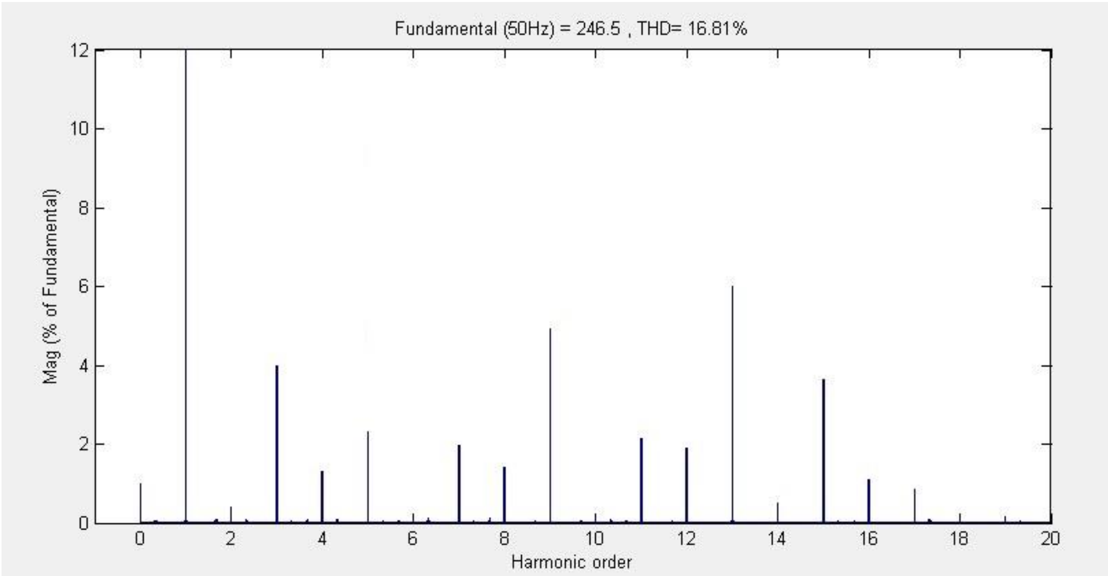

Figure 31 FFT analysis of the output voltage for M(m-1) equal to 2.2

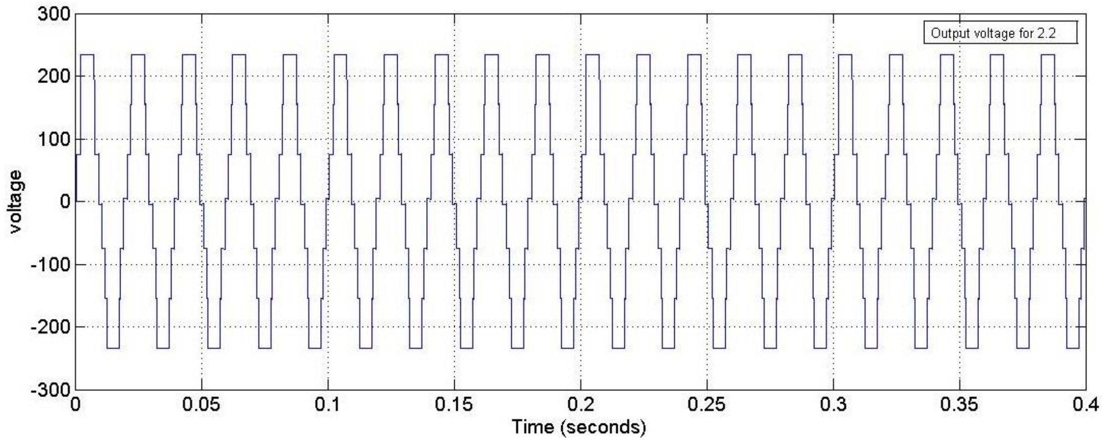

Figure 32 The output voltage for M(m-1) equal to 2.2

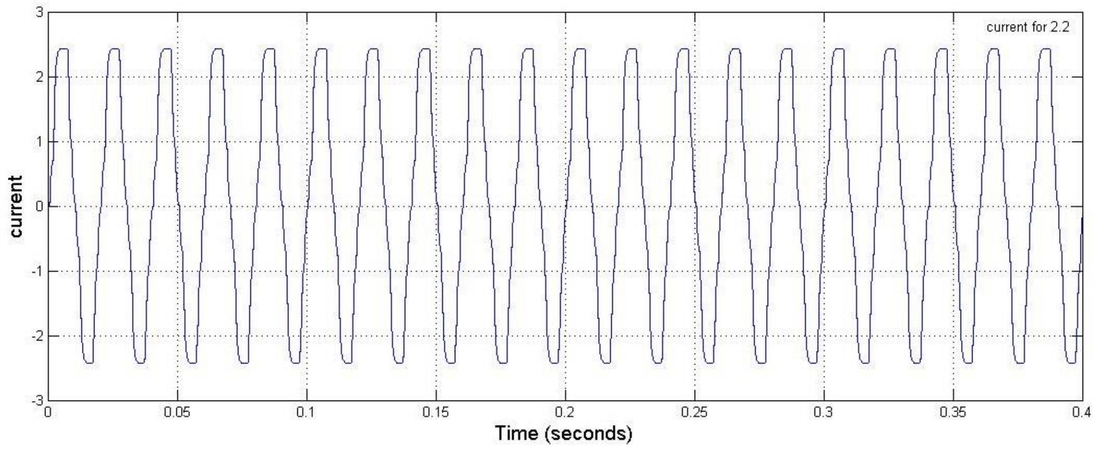

Figure 33 The output current for M(m-1) equal to 2.2

In this page the FFT analysis for different modulation is observed.

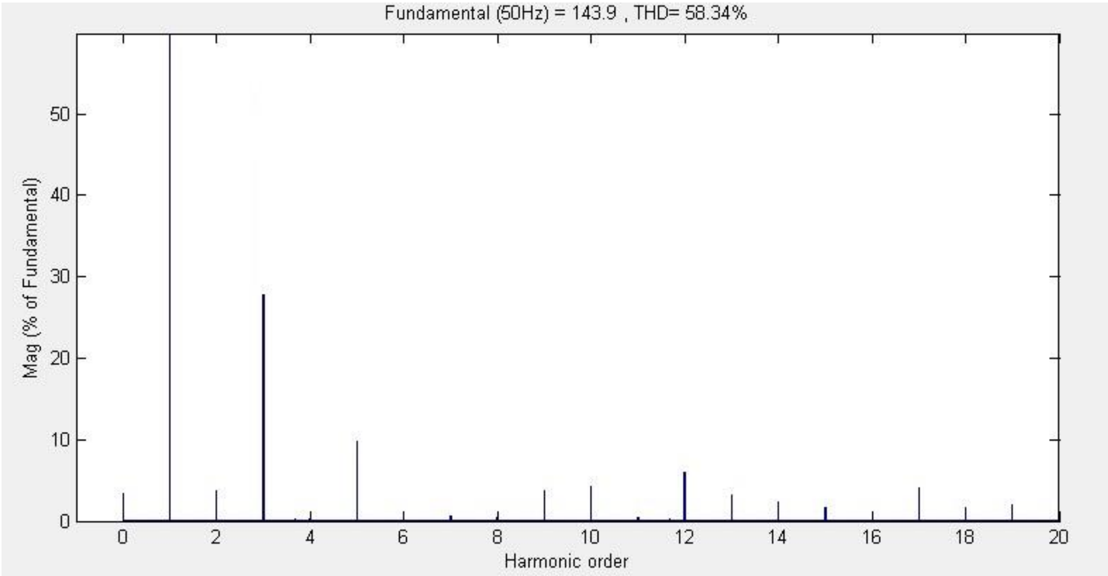

Figure 34 FFT analysis of the output voltage for M(m-1) equal to 1.5

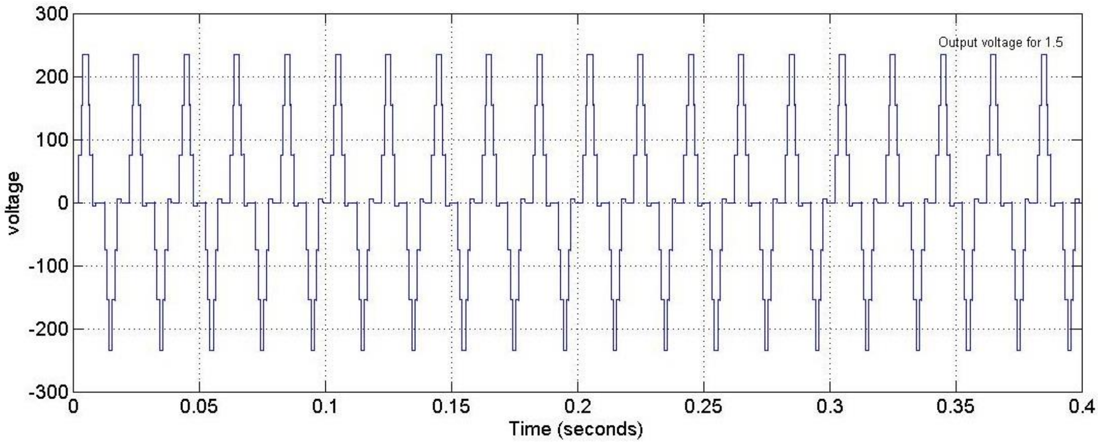

Figure 35 The output voltage for M(m-1) equal to 1.5

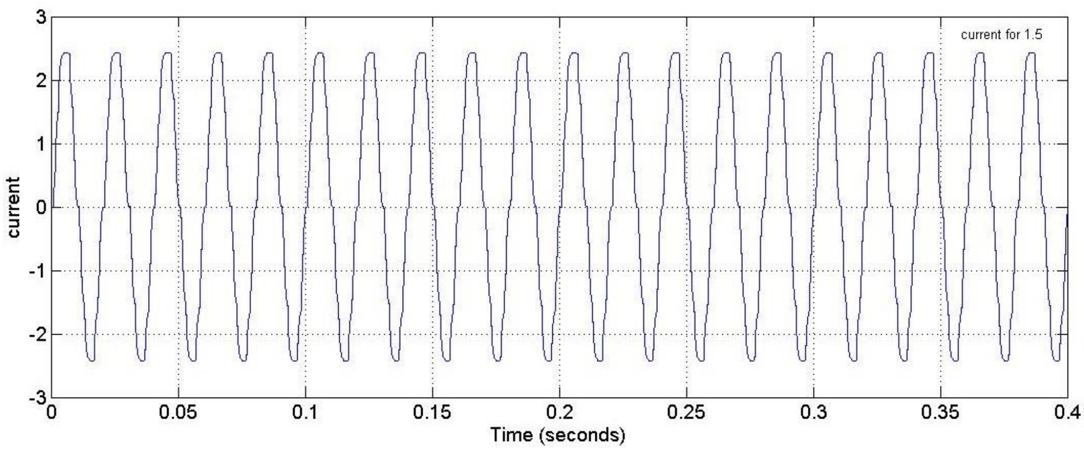

Figure 36 The output voltage for M(m-1) equal to 1.5

CHAPTER- 6

6.CONCLUSION:

Here in this thesis, a detailed analysis of the three level cascaded inverter has been done and the control of the H-Bridge inverters in the decoupled fashion was designed and implemented with the new firing strategy which was not proposed yet and the thing which we had recognized is that there is considerable amount of error in the output voltage. It was observed that the accumulated error is due to the artificial neural network and in the solution vectors of the firing angles of the individual H-bridges. The control circuit for the cascaded multilevel inverter is was simulated in the matlab Simulink. For large output current levels, the power supply can be developed using power MOSFETs low voltage and small current ratings. And the main advantage of the firing strategy which we used is simplicity in the control for large number of the inverter modules in the cascaded multilevel inverter.

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