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OPTIMAL SHE-PWM FOR VOLTAGE SOURCE MULTILEVEL PWM INVERTERS

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Abstract: In recent years, cascaded H-bridge multilevel inverters (CHB-MLI) are widely accepted in various industrial applications. Higher switching losses are one of the major concerns in the pulse-width modulation (PWM) techniques for CHB-MLIs. Selective harmonic elimination PWM (SHE-PWM) offers low switching losses owing to lower switching frequency. This dissertation aims of providing an efficient optimization technique for SHE- PWM based CHB-MLI. As this method is based on optimization algorithms, the switching angles are obtained without solving the non-Linear transcendental equations arithmetically. Comparative study is planned to find out efficient optimization technique for SHE-PWM equations. For validation, 7, 9-and 11-level inverters are to be selected and MATLAB software is being used for optimization and CHB-MLI simulation. The best suitable optimization technique shall be used in further research studies.

Keywords- Total harmonic distortion-THD, CHB-MLI-Cascaded H Bridge Multilevel Inverter, SHE-PWM-Selective Harmonic Elimination pulse width modulation, GA-Genetic Algorithm, PSO-Particle Swarm Optimization, FFT-Fast Fourier Transform**.**

I. INTRODUCTION

Several varieties of Applications in 21st Century uses Pulse width modulation inverters. The High Harmonic content is major operating consideration of the PWM inverters in their output waveform. To push the harmonics in their output spectra to higher frequencies, The inverters must be operated at High switching frequencies such that they can be easily filtered by a passive filter.[1] However, large power loss occurs due to high frequency. Therefore, we bring our Focus in investigating means to maintain low switching frequencies to suppress the harmonics in the output spectrum of the inverter at the same time. The SHE-PWM Technique is a possible solution to Mitigate the problems of the Harmonics, while maintaining low switching frequencies. the switching angles of the PWM output voltage waveforms are pre-calculated in programmed SHE-PWM Technique. In theFourier series

expansion of the PWM output voltage waveform, the values of the switching angles are such that, the magnitudes of all the undesired harmonics is reduced to zero. Thisis called selective harmonic elimination (SHE).[1,2] improved harmonics profile at the output end of the inverter is obtained by SHE-based Programmed PWM schemes as compared tocarrier-based PWM schemes. In carrier based PWM, there is no effective control over the magnitudes of the non-fundamental frequency components of the output voltage. considerably large coupling inductors are required for Inverters which operates using carrier-based PWM schemes to provide a similar attenuation in low order odd harmonics. The large coupling inductances are physically bulky and also have another drawback that they maintain the fundamental component of the output voltage. Also, programmed PWMschemes operate at much lower switching frequencies than carrier-based PWM schemes, the total power loss reduces by reducing the stress on the inverter switches. Also, The Advantage of using CHB-MLI is that less number of components are required in each level as well as the cascaded H-bride multilevel inverter uses capacitors and switches.This topology comprise a cascaded power conversion cells and power can be easily measured. The combination of capacitors and switches pair is called an H-bridge. Each H-bridge is given the separate input of DC voltage. Thus, In Multilevel PWM

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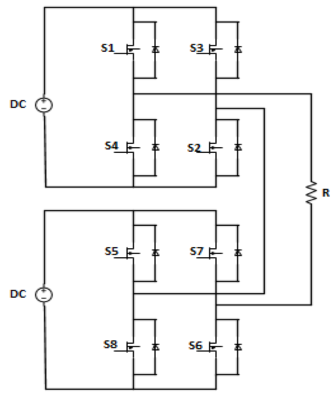
voltage source Inverters various Optimization Techniques are carried out and the best Possible output characteristicsare obtained by Simulation Results[3].

Cascaded H Bridge Multilevel Inverters

H-bridge's multi-level cascade inverter is one of the most advanced inverter topologies to convert the DC output from renewable energy sources such as photovoltaic arrays, fuel cells and solar thermal panels to an AC power source. It has gained wide acceptance due toits ability to produce a high-quality AC output waveform with a low switching frequency. However, the cascaded H-bridge inverter topology is unable to produce a good AC output voltage waveform if the switching angle placement techniques are not properly selected. The basic component of the cascaded H-bridge converter is an H-bridge called cells or modules. The CHB has many cells connected in series.[3] The intermediate circuit of each cellis isolated. Each cell produces the voltage level of (0, Vdc, Vdc). S1 is complementary to S2 and S3 complementary to S4. With 'n' cells, the number of levels is in Van is (2n+1). The voltage rating of each switch in each cell is 'Vdc'.

In this thesis, the results of operationand simulation of MATLAB for levels 7, 9 and 11 of CHBMLI are studied using different optimization methods.[3,4]



(Figure-1 circuit diagram and switching pattern of CHB-MLI)

V0	S1	S4S3	S2	S5	S8	S7	S6
2VDC	1	00	1	1	0	0	1
VDC	1	00	1	0	0	1	1
0	1	10	0	1	1	0	0
	0	01	1	0	0	1	1
-VDC	0	11	0	1	1	0	0
-2VDC	0	11	0	0	1	1	0

SHE-PWM Technique

The SHE-PWM method is used to optimize the stepped harmonic waveform for multilevel inverters using the genetic algorithm. It does not involve solving sets of nonlinear transcendental equations arithmetically that represent the relationship between the amplitude of the fundamental wave, the harmonic components, and the switching angles.The multi-level cascaded inverters with separate DC sources of Cascaded multilevel inverters as shown in Fig. 1 have many advantages such as amplitude of harmonics. The angles are obtained by below calculation, number of output voltage levels adding or subtracting an overall limit between zero and 90° ($0 < \alpha < 90$). Due to the bridge cells and the reduced number of components in an odd symmetrical quarter-wave characteristic, the harmonics with an even order becomes zero.[4,6]

The popular selective harmonic elimination method is also referred to as the fundamental switching frequency method**,** which is based on the technique developed by harmonic removal theory **.** As the equation shows, For example, a multi-level converter can produce a symmetrical stepped quarter-wave voltage waveform synthesized by various DC Source voltages. The output voltage equation can be expressed as follows:

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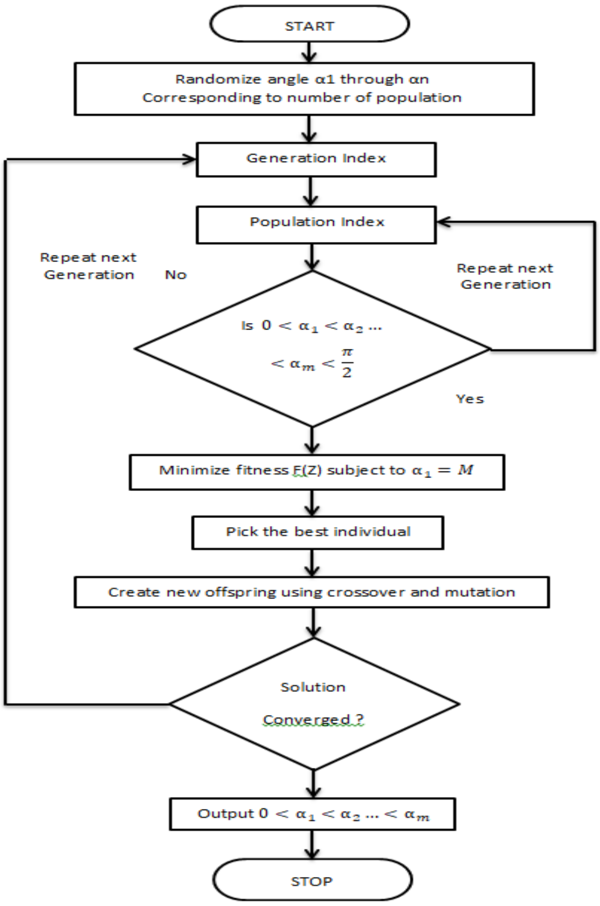
$$V(\omega t) = \sum_{n=1}^{\infty} Vn \sin(n\omega t)$$
$$Vn = 4\,Vdc/n\pi\left[\sum_{i=1}^{L} Vi\cos(n\theta i)\right], \text{ for } n = \text{odd}$$
$$0, \quad , \text{ for } n = \text{even}$$

II OPTIMIZATION METHODS

- **Genetic Algorithm**



(Figure-2 Flow chart of GA)

The genetic algorithm is classified into three types of operations: encoding, crossover, selection, and mutation. The evaluation usually starts from a population of randomly generated individuals and occurs in generation. At each generation, each individual in the generation is assessed for fitness, multiple individuals from the current generation are selected based on their fitness value are modified (recombined and possibly mutated) to form a new generation Generation is then used in the next th iteration of the algorithm. Typically, the algorithm ends when a maximum number of generations has occurred or a satisfactory level of fitness for the generation has been reached. If the algorithm has terminated due to a maximum number of generations, a successful solution may or may not have been reached. For each generation, the output voltage waveform at the multilevel inverter is generated using the switching angle in the population, and the required harmonic magnitude is , which is achieved using FFT techniques. The fitness score is calculated for each individual using a genetic algorithm configured to run through a defined number of generations to estimate the solution. Then the fitness values of the first generation are used to reach the new generation . It then goes through the crossover and mutation process that creates a newgeneration of the similar Cycle from the fitness

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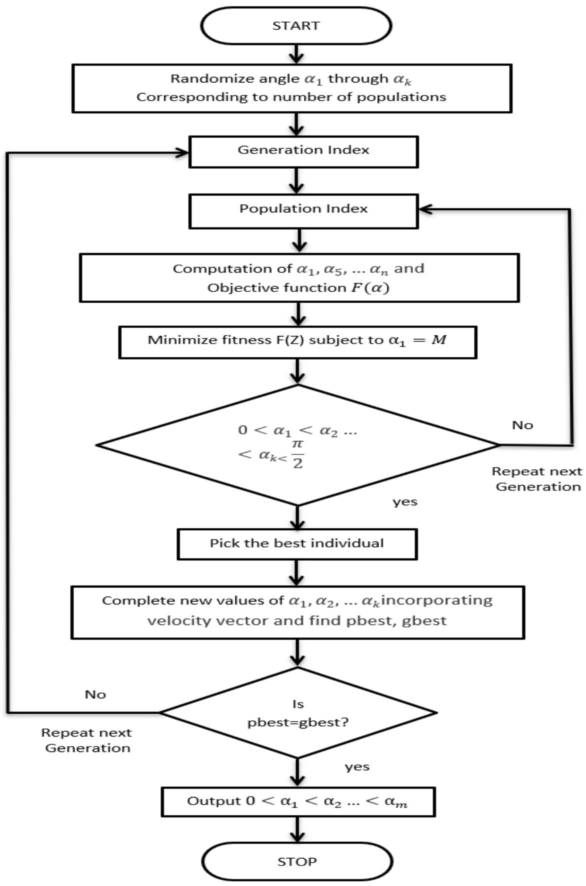
value estimate. Using MATLAB source code, find the optimal switching angle solution for a cascaded multilevel inverter with anynumber of output voltage levels and to eliminate any number of harmonics.[7]

$$fitness\ value(\alpha 1, \alpha 2, \alpha 3) = -100 * (V5 + V7)/(V1)$$

- **PSO Algorithm**



(Figure 3- Flow chart of PSO)

A PSO primarily based totally optimization approach is proposed to minimize the general THD of the output voltage of PWM inverter. The technique avoids the direct answer of nonlinear equations of the SHE problem. A PSO primarily based totally set of rules is evolved to compute the switching angles for minimization of typical voltage THD whilst the person decided on harmonics are optimized in the allowable limits.[6] The nonlinear equations of the traditional SHE problem show off a couple of answers. The proposed PSO set of rules searches for all feasible set of answers to make contributions the minimal THD. The gift technique is located to be very powerful in decreasing the typical THD for each unipolar and bipolar instances with different switching angles and ranging modulation index. The simulated consequences are also established via way of means of experiment. . In the proposed PSO method, the complexity of locating the answer of those nonlinear equations is averted by changing the SHE trouble to an optimization trouble. The %THD of the output voltage maybe computed using the formula.[6,7]

III PROPOSED WORK

Implementation of Optimization methods using

SHE-PWM based single phase CHB-MLI

By applying SHE-PWM Technique the Optimization of 7 Level Cascaded H Bridge MLI is carried out by using GA as explained in detail. In, the 7 level CHB MLI, 3 H-Bridges arerequired for the Operation of MLI. Hence, the switching Sequence is Given as S1, S2, S3,S4 in a single H-Bridge. Similarly, for another H-Bridge, S5, S6, S7&S8 Switches are used. Similarly, S6,S7,S8,S9 Switches are used for third H-Bridge converter. Hence, total 12 switches are required for the operation of cascaded 7 level H-Bridge MLI. The Circuit Diagram and Switching Pattern is as mentioned in

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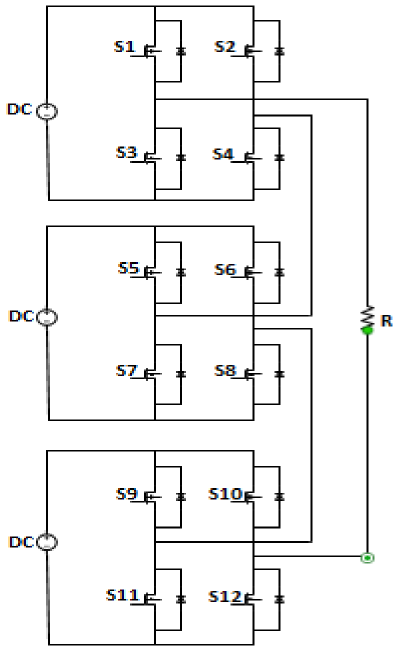

figure(4).

(Figure 4- 7 level CHB-MLI)

Based on the harmonic elimination theory[2,6], if one wants to eliminate the nth harmonic, thenthe voltage equation is given as follows:

$\cos(n\theta 1) + \cos(n\theta 2) + \cos(n\theta 3) + ... + \cos(n\theta s) = 0$

$V1 \cos(\theta 1) \pm V2\cos(\theta 2) \pm V3\cos(\theta 3) \pm ... \pm Vs\cos(\theta s) = m$

..

..

..

$V1 \cos(n\theta 1) \pm V2\cos(n\theta 2) \pm V3\cos(n\theta 3) \pm ... \pm Vs\cos(n\theta s) = 0$ where,

$m = \pi V1/ 4\, Vdc$

$V1\ max = (4 / \pi) * sVdc$

For 7 Level cascaded H Bridge MLI, The Equations for Output Voltage and Switching Angles are Given as Follows:

V1ref=m*12pi*Vdc; V1=4/pi*Vdc*(cos(x(1))+cos(x(2))+cos(x(3)));

V5=4/pi*Vdc/5*(cos(5*x(1))+cos(5*x(2))+cos(5*x(3)));

V7=4/pi*Vdc/7*(cos(7*x(1))+ cos(7*x(2))+cos(7*x(3)));

Angles=x*180/pi

Switching Time= Angles*5e-3/90

The Optimal Switching angles of seven level cascaded H bridge multilevel Inverter are calculated for modulation index m=0.8 using Genetic Algorithm in MATLAB simulation software are shown as follows:

The Total Harmonic Distortion Percentage is reduced to 12.55% for seven level as observedin the FFT analysis given in fig (4.5). As the number of level increases, the amount of percentage THD decreases.

Similarily, for validation the simulation for 9 and 11 level cascaded H Bridge multilevel inverter is carried out to find optimal switching angles[6].

The single phase 9-level CHB MLI has generated Nine step of output asmultiplication of it input voltage source (Vdc), such as 4Vdc, 3Vdc, 2Vdc, Vdc, 0, -Vdc, -2Vdc and -3Vdc, 4Vdc. The resulting AC output voltage swing from +4Vdcto -4Vdc through zero level. The Output Voltage Equation is given as follows:

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```
m =

    0.8000

Optimization terminated: minimum fitness limit reached
 and constraint violation is less than options.TolCon.

Angles =

   11.5045   28.7207   57.1096


SW_Time =

    0.0006    0.0016    0.0032
```

V1ref=m*16/pi*Vdc;

V1=4/pi*Vdc*(cos(x(1))+ cos(x(2))+ cos(x(3))+ cos(x(4))); V5=4/pi*Vdc/5*(cos(5*x(1))+ cos(5*x(2))+ cos(5*x(3))+ cos(5*x(4))); V7=4/pi*Vdc/7*(cos(7*x(1))+ cos(7*x(2))+ cos(7*x(3))+ cos(7*x(4))); V9=4/pi*Vdc/9*(cos(9*x(1))+ cos(9*x(2))+ cos(9*x(3))+ cos(9*x(4)));

The Total Harmonic Distortion Percentage is reduced to 10.81% for nine level as observedin the FFT analysis given in Fig( ). As the number of level increases, the amount of percentage THD decreases.

Similarly, The single phase 11-level CHB MLI has generated Nine step of output as multiplication of it input voltage source (Vdc), such as 5Vdc, 4Vdc, 3Vdc, 2Vdc, Vdc, 0, -Vdc, -2Vdc and -3Vdc, 4Vdc, 5Vdc. The resulting AC output voltage swing from +5Vdc to -5Vdc through zero level. The Output Voltage Equation is given as follows

Vdc=100;

V1=4/pi*Vdc*(cos(x(1))+ cos(x(2))+ cos(x(3))+ cos(x(4))+cos(x(5)));

V5=4/pi*Vdc/5*(cos(5*x(1))+ cos(5*x(2))+ cos(5*x(3))+ cos(5*x(4)) +cos(5*x(5)));

V7=4/pi*Vdc/7*(cos(7*x(1))+ cos(7*x(2))+ cos(7*x(3))+ cos(7*x(4)) +cos(7*x(5)));

V11=4/pi*Vdc/11*(cos(11*x(1))+ cos(11*x(2))+ cos(11*x(3))+ cos(11*x(4)) +cos(11*x(5)));

V13=4/pi*Vdc/13*(cos(13*x(1))+ cos(13*x(2))+ cos(13*x(3))+ cos(13*x(4)) +cos(13*x(5)));

The output Switching angles for 11 level chb-mli are obtained as follows:

```
m =

    0.8000

Optimization terminated: minimum fitness limit reached
 and constraint violation is less than options.TolCon.

Angles =

   11.5045   28.7246   57.1108   67.6210   88.8800


SW_Time =

    0.0006    0.0016    0.0032    0.0038    0.0049
```

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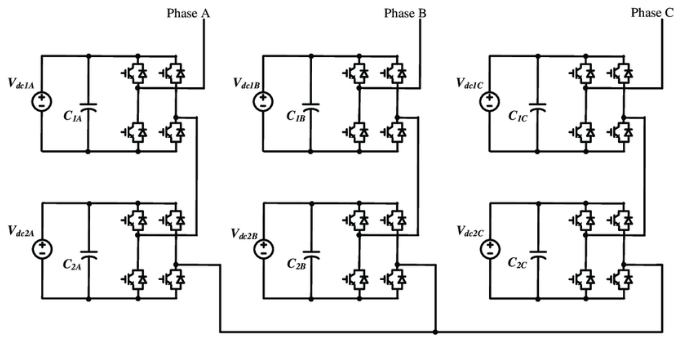
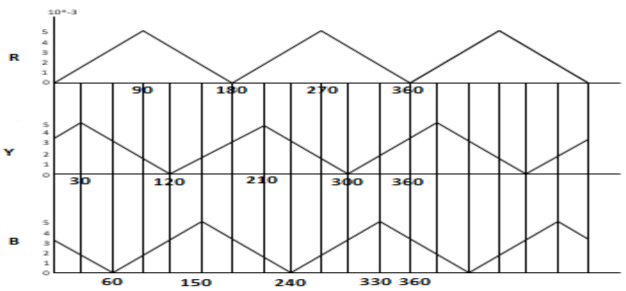
Implementation Of Optimization Methods For 3-Phase CHB-MLI

The model of three phase cascaded H Bridge multilevel inverter requires Three single phasecascaded H bridge multilevel inverters of each phase R, Y and B. All the three phase of cascaded H Bridge multilevel Inverters are given separate DC voltage Source. Each cell ofCHB-MLI are cascaded to one another. Hence, there are 3 cells in Each Phase of cascadedH Bridge multilevel Inverter. So, in Total there are 9 cells of H Bridges in the circuitry of three phase cascaded H Bridge multilevel Inverter. The three phases are connected parallelly with the help of neutral. The Output of three phase seven level cascaded H Bridgemultilevel Inverter is as shown. The Output waveforms of Line voltages andPhase Voltages are observed as shown in the MATLAB model of three phase 7 level CHB-MLI. The Calculation of Switching angles are carried out by considering the Triangular wave as reference having different values of switching Time for each Phase R, Y and B ofthe three phase 7 Level cascaded H Bridge Multilevel Inverter.[3,6]



(Figure 5- 3 phase CHB-MLI)

Calculation of Switching angles for 3 phase 7 level cascaded H bridge MLI



(Figure 7- Reference Diagram for Calculations of 3 Phase CHB-MLI)

As seen in the figure(5), the calculations are made according to the various values of firing angle theta (θ) during the time period (T) of two complete cycles i.e. 0 to 360 degree. Further the corresponding theta values are converted in to time values for simulation purpose based on the formulas mentioned below. From figure (5) it is known that for the value of theta for 180 degree. The equation for the corresponding output value i.e. switching time is derived mathematically as shown below.

At θ=180degree, corresponding time period is 10 ms,
then at θ= 30degree, corresponding time period is=?

$$\frac{60*10*10^{-3}}{180} = 1.67 \text{ ms}$$

Similarly,

At θ=180degree, corresponding time period is 10 msThen at θ= 60degree, corresponding time period is=?

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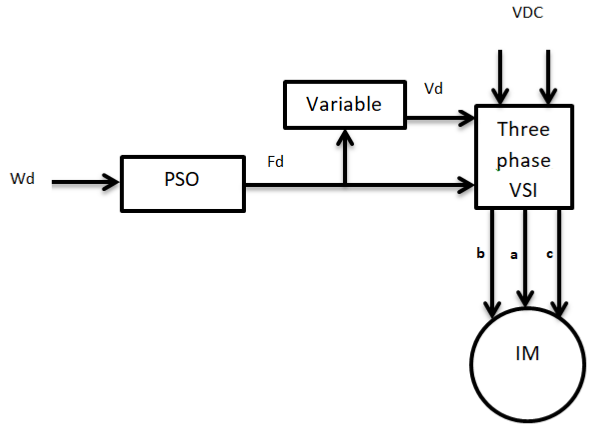
$$\frac{60*10*10^{-3}}{180} = 3.33 \text{ ms}$$

In the Simulation of three phase seven level cascaded H Bridge multilevel Inverter, voltageoutput of each phase R, Y and B are obtained by implementation of SHE-PWM method for 3 phase CHB-MLI. Similarly, the modification for more number of Levels can be done for validation and calculations are made accordingly. The output of Line voltages and Phase voltages are shown in Fig () for each phase of 3 phase cascaded H Bridge MLI.

V/F Control of Induction Motor by SHE-PWM



(Figure 6- Block Diagram of Open Loop V/F Control of IM)

Induction motor (IM) control is more important because most of the industry uses the induction motor and control at the cost of reduced machine efficiency and performance. When controlling the induction motor, the primary goal is to maintain the efficiency and performance of the machine. The constant V/f control method is variable speed control of the induction motor. Unfortunately, the control scheme is implemented at the cost of reducing the efficiency and performance of the motor. The IM slip also causes the speed error. With the V/f control method, we always try to keep the voltage and current ratio constant. To implement the V/F control method, we use the three-phase VSI and control the speed of the three-phase IM. We varied the frequency and frequency amplitude of the VSI to keep the V/f ratio constant and archive the motor at the reference speed. Figure 1 shows the block diagram of the IM speed control. Whenever three-phase current is supplied to the three-phase induction motor, a rotating magnetic field is generated which rotates at a synchronous speed given by: Ns = 120f/p. An emf is induced in the three-phase induction motor, which is given by,

$$V = 4.44ØKTf$$
$$Ø = V/(4.44KTf)$$

$$V/F = 4.44ØfKT$$

Here, frequency f=50 Hz and Vdc = 653V. Various parameters of 3 phase squirrel cage induction motor is taken as follows:

T= (4*1000)/n

Vph=(Vll*sqrt(2))/(sqrt(3))

Vph=(ma*(Vdc/2))

Vdc=Vph*2/ma

P=TW

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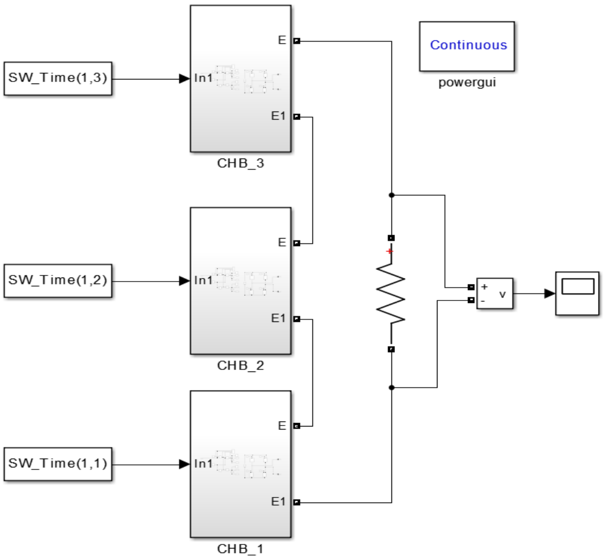
The V/F control of three phase induction motor is Implemented by using the SHE-PWM technique in three phase cascaded H Bridge multilevel Inverter and the Simulation results Obtained are indicated as follows. The Output characteristics of Stator current Is, motor Speed N and Load Torque T is obtained by simulation Results which is shown in figure( ), ( ), ( ) .

IV SIMULATION AND RESULTS



(Figure 8-1 phase Seven Level CHB-MLI Simulation Model)

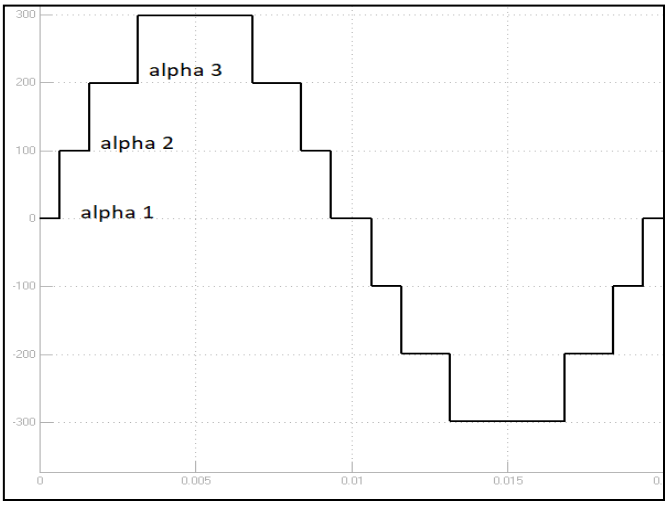


Figure 10- Simulation output of 7 level CHB-MLI

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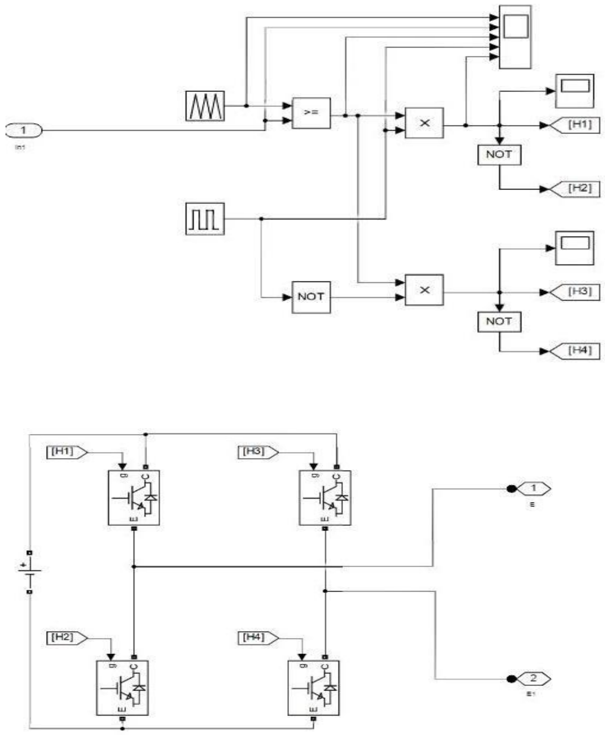
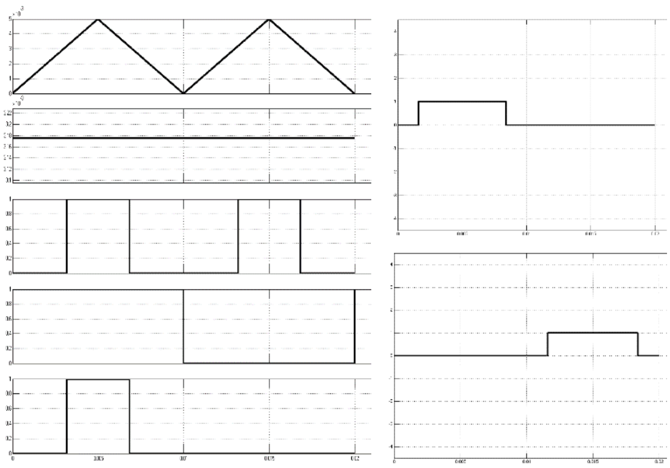


(Figure 9- 1 phase Seven Level CHB-MLI Subsystem Model)



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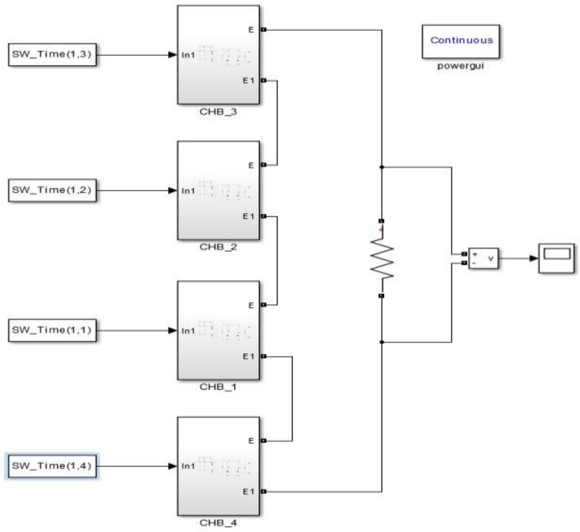

Figure 11- MATLAB Model of 9 level CHB-MLI

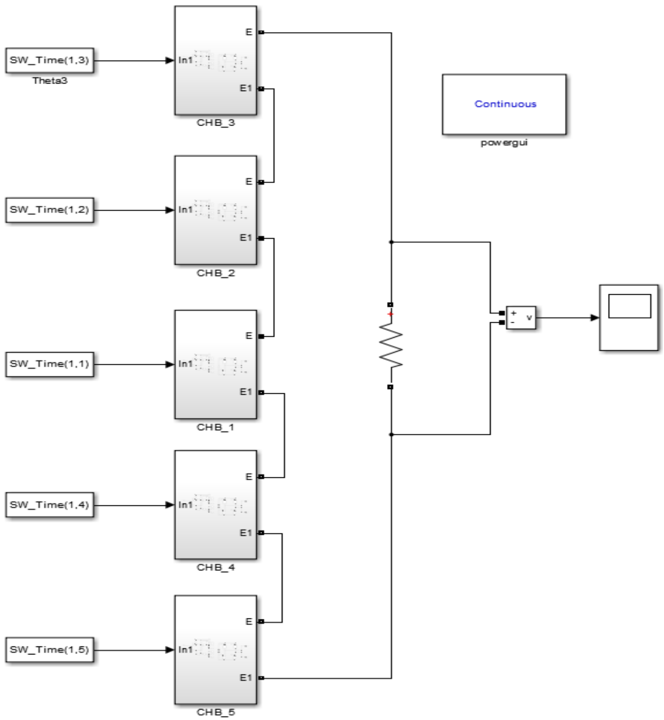

Figure 12- MATLAB Model of 11 level CHB-MLI

The MATLAB Simulation of 7,9, and 11 level single phase CHB-MLI is carried out as shown in the matlab model above The respective simulation results as as shown below in Figure(13) and (14).

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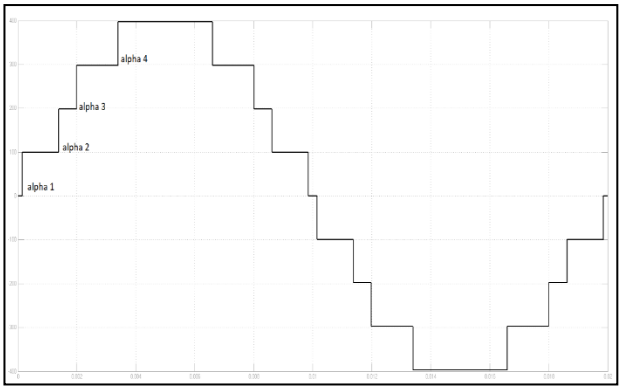

Figure 13- Simulation output of 9 level CHB-MLI

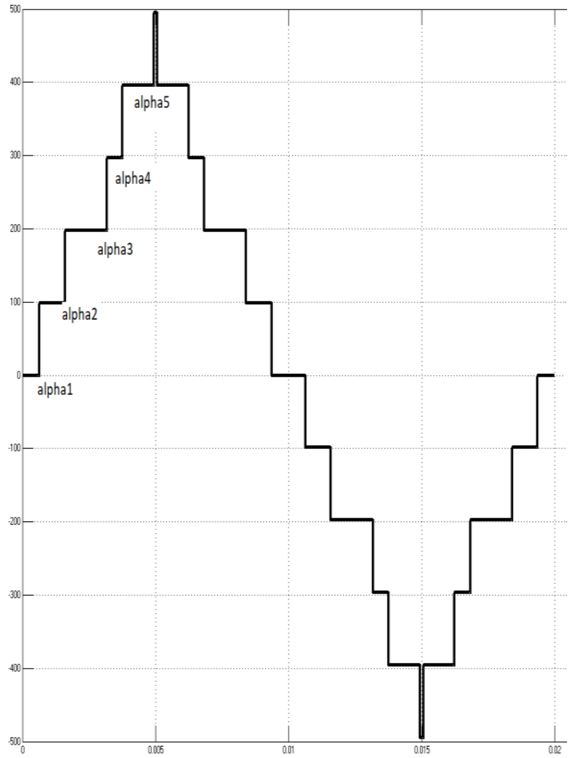

Figure 14- Simulation output of 9 level CHB-MLI

Hence, The Single phase SHE-PWM based CHB-MLI is implemented to find Optimal switching angles α1, α2, α3 as indicated in the Simulation Resultsin Figure(10),(13)and (14).

FFT Analysis

The Total Harmonic Distortion Percentage is reduced to 12.55% for seven level as observed in the FFT analysis given in fig (15). The Total Harmonic Distortion Percentage is reduced to 10.81% for nine level as observedin the FFT analysis given in Fig(16). The Total Harmonic Distortion Percentage is reduced to 10.44% for seven level as observedin the FFT analysis given in Fig (17). As the number of level increases, the amount of percentage THD decreases.

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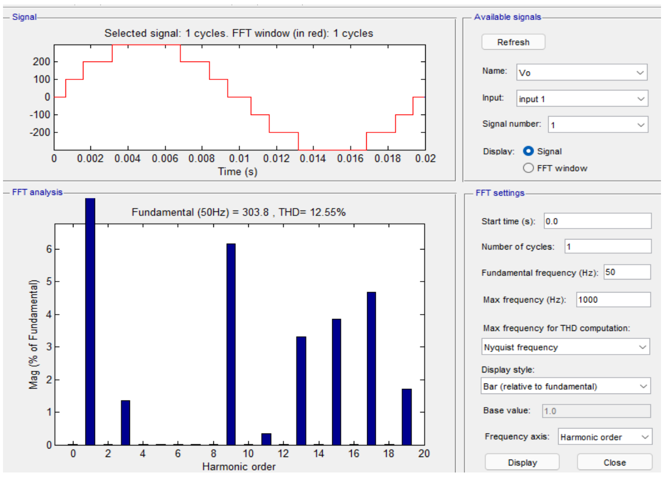

Figure 15- FFT Analysis of 7 level CHB-MLI

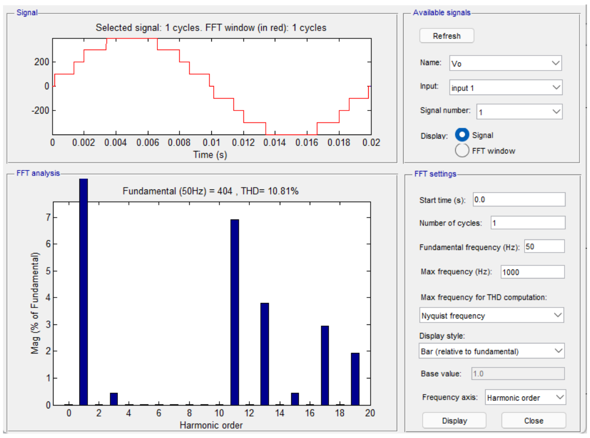

Figure 16- FFT Analysis of 9 level CHB-MLI

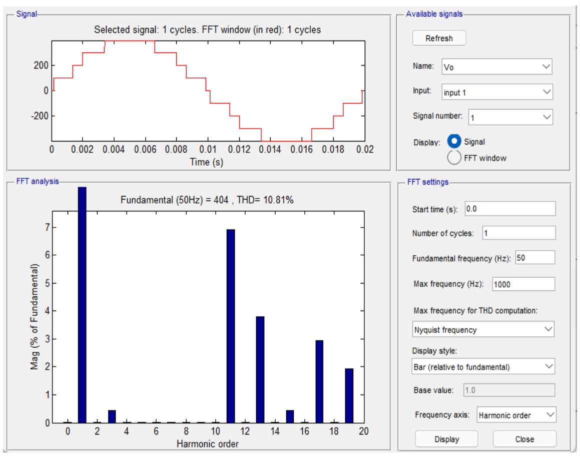

Figure 17- FFT Analysis of 11 level CHB-MLI

Comparision of GA and PSO Algorithms

While the Particle Swarm Optimization (PSO) algorithm has a fitness of 0.099 over 25 iterations, with a running time of 61.95 seconds.[7,8] From several tests it was obtained that thefitness score of PSO exceeded that of GA, so PSO tends to have a better fitness score than GA. and the simulation results of both the methods (GA and PSO) are compared.

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Comparative study is carried out to find out efficient optimization technique for SHE-PWM equations. Also, the comparative results concluded that PSO hasbetter rate of convergence with lower %THD than that of GA. So, for the best value of Optimal Switching angles PSO is selected. For validation, 7-, 9-and 11-level inverters are selected and MATLAB software is being used for optimization and CHB-MLI simulation.[9]

Modulation Index (ma)	GA			PSO			%THD	
	$\alpha 1$	$\alpha 2$	$\alpha 3$	$\alpha 1$	$\alpha 2$	$\alpha 3$	PSO	GA
0.1	72.4264	89.9543	89.9544	72.4225	89.9543	89.9543	56.60	129.16
0.2	55.0466	89.0917	89.1720	89.1328	55.0436	89.1328	76.06	75.50
0.3	44.6224	79.3811	89.9544	44.6238	79.3796	89.9543	56.60	56.60
0.4	40.5395	65.1692	88.9251	40.5408	65.1273	88.8863	75.46	48.38
0.5	39.4231	56.2610	80.1119	20.4527	56.1210	89.6748	56.60	56.60
0.6	11.8688	41.7672	85.7035	33.4959	54.7593	67.1012	48.39	41.34
0.7	18.3395	44.1634	64.3685	64.3621	44.1133	18.3048	22.97	22.19
0.8	11.5045	28.7207	57.109	28.7151	11.5066	57.1051	41.31	12.55
0.9	13.1998	13.2069	40.6292	40.6281	13.2004	13.2035	22.16	19.27
1.0	9.2278	9.2310	9.2355	9.23193	9.23170	9.2319	19.27	20.93

V CONCLUSION

This Dissertation ends of providing an efficient Optimization Technique and Optimal switching angles (α_1, α_2, α_3,) for SHE-PWM based CHB-MLI. As this method is based on optimization algorithms, the switching angles are obtained without solving the non-Linear transcendental equations arithmetically and the simulation results of both the methods (GAand PSO) are compared. Comparative study is carried out to find out efficient optimizationtechnique for SHE-PWM equations. Also, the comparative results concluded that PSO hasbetter rate of convergence with lower %THD than that of GA. So, for the best value of Optimal Switching angles PSO is selected. For validation, 7-, 9-and 11-level inverters are selected and MATLAB software is being used for optimization and CHB-MLI simulation.

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