Design of Square Wave Inverter with Reduced Harmonics Using SHE-PWM Technique.

Kushagra P[1], Kanishka M[1], Nalin J[1], Manan[1], Mangtiram P[1], Yusuf S[2], Ankit V[2]

[1]*Department of electrical Engineering, SKIT, Jaipur*
[2]*Assistant Professor Department of Electrical Engineering, SKIT, Jaipur*

---***---

Abstract - *Conventional inverter offers a square wave output which when applied to electrical appliances may damage the latter reducing its efficiency and life as the inverter's output waveform is not sinusoidal and contains lower and higher order harmonics in addition to fundamental frequency. On the other hand Selective Harmonic Elimination with Pulse Width Modulation (SHE-PWM) offers a fine control of the harmonic spectrum of a given voltage and current waveforms generated by a DC to AC converter (inverter). Inverters with this technique operate with low switching frequencies and due to capability of elimination of lower order harmonics, SHE-PWM is highly advantageous for high power inverters over other techniques that reduces the harmonics as a whole and generate high-quality output which in turn results in minimum current ripple, reduced torque pulsations, improved overall performance by increasing the life and efficiency of the electrical appliances. Thus in this paper we are going to design the pulse for SHE-PWM using certain optimization techniques to eliminate the lower order harmonics such as the dominant 3rd and 5th order harmonics. This will ensure reduced harmonic component and also the filter size would be reduced hence decreasing the overall size and cost of the inverter and at the same time improving the square wave inverter.*

Key Words: **Inverter, SHE-PWM, PSO, Harmonic Reduction**

1. INTRODUCTION

In high power applications, the harmonic content of the output waveforms has to be reduced as much as possible in order to avoid distortion in the grid and to reach the maximum energy efficiency [1]. On such applications, the thermal losses in power semiconductors limit the maximum switching frequency to a few hundreds of hertz. There are several methods used for harmonic elimination in inverter. If the switching losses in an inverter are not a concern (i.e., switching on the order of a few kHz is acceptable), then the sine-triangle PWM method and its variants are very effective for controlling the inverter output voltage . Newton-Raphson method is used in literature but this method has some drawbacks like divergence problems, require initial guess and gives no optimum solution. Another approach uses Walsh functions where solving linear equations, instead of non-linear transcendental equations, optimizes the switching angles. Traditional SHE PWM method is widely used [2]. This technique offers a tight control of the harmonic spectrum of a given voltage waveform generated by a power electronic converter along with a low number of switching transition. It involves the solution of non-linear transcendental equation sets representing the relation between the amplitude of the fundamental wave, harmonic components and the switching angles.

Selective harmonic eliminated PWM technique is one of the optimal PWM techniques. It can effectively reduce the harmonics content of inverter output waveform and generate higher quality spectrum through eliminating specific lower order harmonics. The technology has been investigated for more than three decades. A number of technical papers have appeared addressing the output waveform of a PWM inverter. Originally, such methods presented solutions regarding the angles that eliminate a number of harmonics. The main challenge associated with SHE-PWM techniques is to obtain the analytical solution of the resultant system of the non linear transcendental equations that contain trigonometric terms[3]. Several algorithms have been reported in the technical literature concerning methods of solving the resultant non linear transcendental equations which describe the SHE-PWM problem. algorithms include the well known iterative approach. Convergence is crucial for solving the nonlinear equations by using the numerical analysis. The iterative approach need a good initial guess that should be very close to the exact solution. Because the search space of the SHE problem is unknown, and one does not know whether a solution exists or not, providing a good guess is difficult in most cases.

A sequential homotopy-based computation that makes it possible to solve the SHE problem is proposed. The method is long and cumbersome. Recently, the walsh function and resultant theory were used for computing the solutions for SHEPEM. Specifically the transcendental equations that describe the harmonic elimination problem are converted into an equivalent set of polynomial equations or a matrix equation. However these methods can lead to a severe numerical difficulties.

Moreover the additional switching required to eliminate higher order harmonics will be considerably high, causing high switching losses. Recent approach of the harmonic elimination problem based on the soft computing technique has also been reported. A GA algorithm is used for harmonic optimization. However with the increase in number of harmonics to be eliminated, the cost function becomes more difficult to optimize and requires increased number of iterations.

In this project, Particle Swarm optimization (PSO) is used to minimize the 3rd and 5th harmonics of the output voltage of a H-bridge inverter. The objective function derived from the SHE problem is minimized, to compute the switching angles while lower order harmonics are controlled within allowable limits[9].

2. CONTROL AND FUNDAMENTALS OF THE INVERTER TOPOLOGY SCHEME

SINGLE-PHASE DC-AC CONVERTER

A device that converts DC power into AC power at desired output voltage and frequency is called an Inverter. Phase controlled converters when operated in the inverter mode are called line commutated inverters. But line commutated inverters require at the output terminals an existing AC supply which is used for their commutation. This means that line commutated inverters can't function as isolated AC voltage sources or as variable frequency generators with DC power at the input. Therefore, voltage level, frequency and waveform on the AC side of the line commutated inverters can't be changed. On the other hand, force commutated inverters provide an independent AC output voltage of adjustable voltage and adjustable frequency and have therefore much wider application.

PWM

Pulse width modulation (PWM) techniques are effective means to control the output voltage frequency and magnitude. It has been the subject of intensive research during the last few decades. In this method a fixed dc input voltage is given to the inverter and a controlled ac output voltage is obtained by adjusting the on and off period of the inverter. Basically they can be classified into two main categories, one is carrier based PWM and the other is space-vector PWM. Especially, the space-vector PWM is used for three-phase converter applications. Here we mainly consider the carrier based PWM approaches that are often applied to the single-phase applications

The results are on the basis of MATLAB simulation. The conventional Regular Sampled PWM technique can be simply extended to allow Harmonic Minimization and also Harmonic Elimination PWM to be closely reproduced using simple algebraic equations. This survey paper will provide the insight of trends and technology of —Power Quality Improvement using PWM Technique.

The energy that a switching power converter delivers to a motor is controlled by Pulse Width Modulated (PWM) signals applied to the gates of the power transistors. There is one pulse of fixed magnitude in every PWM period. However, the width of the pulses changes from pulse to pulse according to a modulating signal. When a PWM signal is applied to the gate of a power transistor, it causes turn on and turn off intervals of the transistor to change from one PWM period to another PWM period according to the same modulating signal. The frequency of a PWM signal must be much higher than that of the modulating signal, the fundamental frequency, such that the energy delivered to the motor and its load depends mostly on the modulating signal[5].

PWM reduces the load current distortion induced in phase controlled circuits. Synchronization with the supply mains is not required. The THD can be reduced employing specified controlled PWM pattern. At high switching frequency, the largest harmonic can be reduced using simple capacitive filtering.

HARMONIC DISTORTION

Harmonic distortion is caused by nonlinear devices in the power system. A nonlinear device is one in which the current is not proportional to the applied voltage. Distorted waveform can be expressed as a sum of sinusoids. When a waveform is identical from one cycle to the next, it can be represented as a sum of pure sine waves in which the frequency of each sinusoid is an integer multiple of the fundamental frequency of the distorted wave. This multiple is called a harmonic of the fundamental.

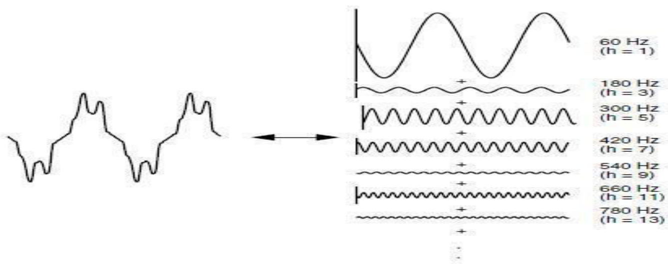

Fig 1: Harmonic distortion

The sum of sinusoids is referred to as a fourier series. The fourier series concept is applied in analyzing harmonic problems. Finding the system response of a sinusoid of each harmonic individually is much more straightforward compared to that with the entire distorted waveforms. The output at each frequency are then combined to from a new Fourier series, from which the output waveform may be computed

Often only the magnitude of the harmonics are of interest. When both the positive and negative half cycles of a waveform have identical shapes, the fourier contains only odd harmonics. Usually, the higher-order harmonics (above the range of the 25th to 50th, depending on the system) are negligible.

3. PROPOSED PARTICLE SWARM OPTIMIZATION

INTRODUCTION

Particle swarm optimization (PSO) is a population based stochastic optimization technique developed by Dr.

Eberhart and Dr. Kennedy in 1995, inspired by social behavior of bird flocking or fish schooling[8].

PSO shares many similarities with evolutionary computation techniques such as Genetic Algorithms (GA). The system is initialized with a population of random solutions and searches for optima by updating generations. However, unlike GA, PSO has no evolution operators such as crossover and mutation. In PSO, the potential solutions, called particles, fly through the problem space by following the current optimum particles[6].

Each particle keeps track of its coordinates in the problem space which are associated with the best solution (fitness) it has achieved so far. (The fitness value is also stored.) This value is called *pbest*. Another "best" value that is tracked by the particle swarm optimizer is the best value, obtained so far by any particle in the neighbors of the particle. This location is called *lbest*. when a particle takes all the population as its topological neighbors, the best value is a global best and is called *gbest*.

The particle swarm optimization concept consists of, at each time step, changing the velocity of (accelerating) each particle toward its p*best* and *lbest* locations (local version of PSO). Acceleration is weighted by a random term, with separate random numbers being generated for acceleration toward *pbest* and *lbest* locations.

In past several years, PSO has been successfully applied in many research and application areas. It is demonstrated that PSO gets better results in a faster, cheaper way compared with other methods.

Another reason that PSO is attractive is that there are few parameters to adjust. One version, with slight variations, works well in a wide variety of applications. Particle swarm optimization has been used for approaches that can be used across a wide range of applications, as well as for specific applications focused on a specific requirement.

PSO ALGORITHM FLOWCHART

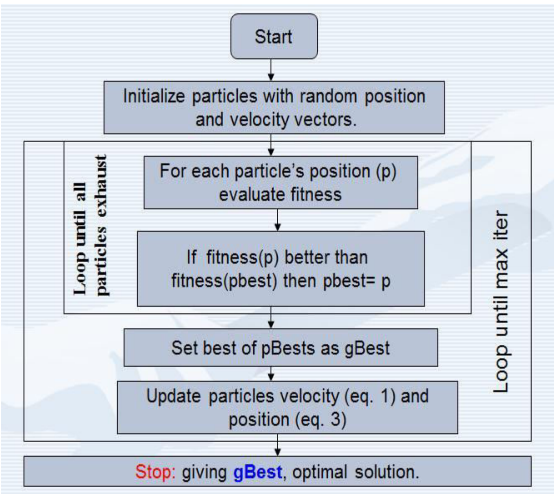

Fig 2: PSO algorithm flowchart

Each particle keeps track of its coordinates in the solution space which are associated with the best solution (fitness) that has achieved so far by that particle. This value is called personal best, ***pbest***.

Another best value that is tracked by the PSO is the best value obtained so far by any particle in the neighborhood of that particle. This value is called ***gbest***.

The basic concept of PSO lies in accelerating each particle toward its pbest and the gbest locations, with a random weighted accelaration at each time step as shown in the above figure.

Each particle tries to modify its position using the following information:

- the current positions,
- the current velocities,
- the distance between the current position and pbest,
- the distance between the current position and the gbest.

The modification of the particle's position can be mathematically modeled according the following equation :

$$V_i^{k+1} = wV_i^k + c_1\, rand_1(\ldots) \times (pbest_i - s_i^k) + c_2\, rand_2(\ldots) \times (gbest - s_i^k) \quad - (1)$$

Here, v_i^k : velocity of agent i at iteration k, w: weighting function, c_j : weighting factor, rand : uniformly distributed random number between 0 and 1, s_i^k : current position of agent i at iteration k, $pbest_i$: pbest of agent i, gbest: gbest of the group

Thefollowing weighting function is usually utilized in (1)

$$W = wMax - [(wMax - wMin) \times iter]/maxIter \quad - (2)$$

Where, wMax= initial weight, wMin = final weight, maxIter = maximum iteration number, iter = current iteration number

$$s_i^{k+1} = s_i^k + V_i^{k+1} \quad - (3)$$

Unlike in genetic algorithms, evolutionary programming and evolutionary strategies, in PSO, there is no selection operation. All particles in PSO are kept as members of the population through the course of the runPSO is the only algorithm that does not implement the survival of the fittest. No crossover operation in PSO. In EP balance between the global and local search can be adjusted through the strategy parameter while in PSO the balance is achieved through the inertial weight factor (w)[7].

4. SIMULATION

In this project the coding is done for both the algorithms PARTICLE SWARM OPTIMIZATION and the GENETIC

ALGORITHM algorithm. Here the results are obtained and a comparative study is made between both the algorithms.

PARTICLE SWARM OPTIMIZATION – RESULTS

FOR 3rd and 5th SELECTIVE HARMONIC ELEMINATION PROBLEM

Total NO of Iteration = 150

Time need for all iteration = 0.344055 Sec

NO of Particle(swarm) = 30

Convergence occur at iteration = 59

minimum fitness = 0.001787

THE OPTIMUM FIRING ANGLES are-

ALPHA1 = 31.487 ; ALPHA3 = 54.586 ; ALPHA5 = 69.22

In this algorithm the parameters assigned and the results obtained are shown. As we can see that this algorithm converges at an iteration of 59 and requires very less time to converge its all because the parameters assigned and required in this algorithm are very few when compared to the other optimization techniques.

Simulink model

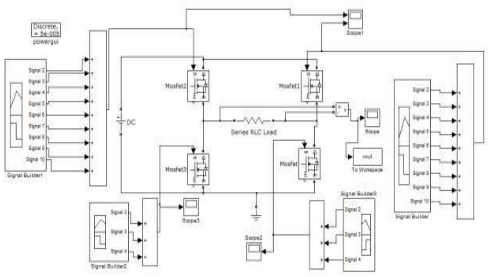

Fig 4: MATLAB SIMULINK MODEL

Here shown above is the MATLAB/SIMULINK model and the pulses are generated using the signal builder block implementing the values obtained from the optimization techniques. The pulses generated using these alpha values are given ahead.

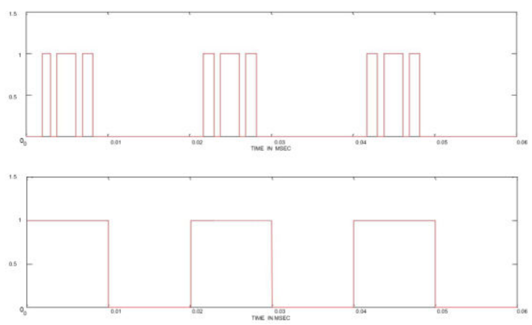

Fig 5: pulse to the switches S1 and S2

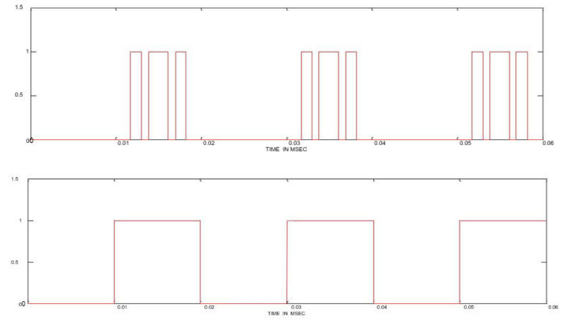

Fig 6: pulse to the switches S3 and S4

The output voltage waveform for the pulses given to the switches is shown below

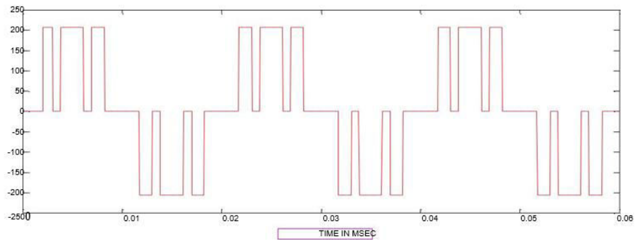

Fig 7: Output voltage waveform

5. RESULTS

FFT Analysis of the model

To do the Fast Fourier Transform analysis we will use the Powergui block available in the Simulink library and by opening this block we get various options and we will do the FFT analysis, so a new window opens and the output of FFT analysis can be seen as in the fig. 8(before injecting optimum values of switching angles) and Fig. 9(After injecting optimum values of switching angles).

```
Sampling time      = 0.000325203 s
Samples per cycle  = 62
DC component       = 1.935
Fundamental        = 152.7 peak (108 rms)
THD                = 46.31%

  0 Hz  (DC):        1.27%    270.0°
 50 Hz  (Fnd):     100.00%      1.5°
100 Hz  (h2):        2.53%    -90.0°
150 Hz  (h3):       33.19%      4.4°
200 Hz  (h4):        2.53%    -90.0°
250 Hz  (h5):       19.74%      7.4°
300 Hz  (h6):        2.53%    -90.0°
350 Hz  (h7):       13.92%     10.5°
400 Hz  (h8):        2.53%    270.0°
450 Hz  (h9):       10.64%     13.8°
500 Hz  (h10):       2.53%    270.0°
550 Hz  (h11):       8.52%     17.3°
600 Hz  (h12):       2.53%    -90.0°
650 Hz  (h13):       7.02%     21.2°
700 Hz  (h14):       2.53%    270.0°
750 Hz  (h15):       5.91%     25.4°
```

Fig 8: FFT analysis of model (before implementation of optimum switching angles)

```
Sampling time      = 0.000227273 s
Samples per cycle = 88
DC component       = 5.936e-08
Fundamental        = 102.8 peak (72.66 rms)
THD                = 65.26%

    0 Hz   (DC):          0.00%     90.0°
   50 Hz   (Fnd):       100.00%      0.0°
  100 Hz   (h2):          0.00%    270.0°
  150 Hz   (h3):          0.47%      0.0°
  200 Hz   (h4):          0.00%    -89.9°
  250 Hz   (h5):          2.31%    180.0°
  300 Hz   (h6):          0.00%    270.0°
  350 Hz   (h7):         45.04%    180.0°
  400 Hz   (h8):          0.00%     90.0°
  450 Hz   (h9):          7.67%      0.0°
  500 Hz  (h10):          0.00%     89.9°
  550 Hz  (h11):         30.94%      0.0°
  600 Hz  (h12):          0.00%    270.0°
  650 Hz  (h13):         13.57%    180.0°
  700 Hz  (h14):          0.00%     90.2°
  750 Hz  (h15):          5.42%      0.0°
  800 Hz  (h16):          0.00%    -89.7°
  850 Hz  (h17):          1.98%      0.0°
  900 Hz  (h18):          0.00%    270.0°
  950 Hz  (h19):         21.28%    180.0°
```

Fig 9: FFT analysis of model (After implementation of optimum switching angles)

Thus we can see from the outputs that the 3rd (150Hz) and the 5th (250 Hz) harmonic contribution with respect to the fundamental component is 0.47% and 2.31% respectively which earlier was 33.14% and 19.74% respectively and these new values are well within the allowed limits of 3% by IEEE standards.

6. FUTURE SCOPE

This project has a great scope of future enhancement and implementation. first of all the optimum values of the switching angles can be calculated by various other optimization techniques and then a comparison can be done to find the best one. Also a hardware can be constructed using different equipment such as IGBT's or MOSFET's and a microcontroller can be used to design the firing pulse according to the switching angles found by the optimization techniques, also a comparison can be done between various microcontrollers for the same.

REFERENCES

[1] H. S. Patel and R. G. Hoft, —Generalized techniques of harmonic elimination and voltage control in thyristor inverters: Part 1—Harmonic elimination,|| *IEEE Trans. Ind. Appl.*, vol. IA-9, no. 3, pp. 310–317, May/Jun. 1973.

[2] Selective Harmonic Mitigation Technique for High Power Converters Javier Napoles,Jose I. Leon, *Member, IEEE*, Ramon Portillo, *Student Member, IEEE*, Leopoldo G. Franquelo, *Fellow, IEEE*, and Miguel A. Aguirre, *Member IEEE*,

[3] Selective Harmonic Mitigation Technique for Multilevel Cascaded H-bridge Converters Javier Napoles, Jose I. Leon, Leopoldo G. Franquelo, Ramon Portillo and Miguel A. Aguirre Electronic Engineering Department, School of Engineering University of Seville.Seville, Spain 41092.

[4] Power System Stabilizer Design Based on Optimization Techniques Mahdiyeh Eslami, Hussain Shareef, Azah Mohamed .Department of Electrical, Electronic and Systems Engineering Universiti Kebangsaan Malaysia, Bangi, Selangor, Malaysia.

[5] Harmonic Elimination for Constrained Optimal PWM The 30th Annual Conference of the IEEE Industrial Electronics Society, November 2 - 6, 20Q4, Busan, Korea

[6] PSO – MODELS, ALGORITHMS AND APPLICATIONS 1J.R. Al-Enezi, 1M.F. Abbod & 2S. Alsharhan **1**Electronic and Computer Engineering Department, School of Engineering and Design, Brunel University, UK. **2**Computer Science Department, Gulf University for Science and Technology, P.O. Box: 7207, Hawalli, 32093, Kuwait

[7] R.N. Ray, D. Chatterjee, S.K.Goswami, —Harmonics elimination in a multilevel inverter using the particle swarm optimisation technique||,IET Power Electron., 2009, Vol. 2, Iss. 6, pp. 646–652

[8] Kennedy, J., & Eberhart, R. (1995), —Particle swarm optimization||,IEEE international conference on neural networks, Perth, Australia (Vol.IV, pp. 1942–1948).

[9] Loh, P. C., Holmes, D. G., & Lipo, T. A. (2005),—Implementation and control of distributed PWM cascaded multilevel inverters with minimum harmonic distortion and common mode voltages||, IEEE Transactions on Power Electronics, 20(1), 90–99.