GENETIC ALGORITHM BASED SOLUTION IN PWM CONVERTER SWITCHING FOR VOLTAGE SOURCE INVERTER FEEDING AN INDUCTION MOTOR DRIVE

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ABSTRACT

This paper presents an efficient and reliable Genetic Algorithm based solution for Selective Harmonic Elimination (SHE) switching pattern. This method eliminates considerable amount of lower order line voltage harmonics in Pulse Width Modulation (PWM) inverter. Determination of pulse pattern for the elimination of some lower order harmonics of a PWM inverter necessitates solving a system of nonlinear transcendental equations. Genetic Algorithm is used to solve nonlinear transcendental equations for PWM-SHE. Many methods are available to eliminate the higher order harmonics and it can be easily removed. But the greatest challenge is to eliminate the lower order harmonics and this is successfully achieved using Genetic Algorithm without using Dual transformer. Simulations using $\text{MATLAB}_{\text{TM}}$ and Powersim with experimental results are carried out to validate the solution. The experimental results show that the harmonics up to 13^{th} were totally eliminated.

Index Terms: Inverter, Harmonics, Genetic Algorithm (GA), Pulse Width Modulation, Selective Harmonic Elimination.

1. INTRODUCTION

The use of power electronic equipments has increased in recent years in industrial and consumer applications. Such loads draw nonlinear sinusoidal current and voltage from the source and results in harmonics in the networks [1]. They occur frequently in variable frequency drives or any electronic devices using solid state switching method to convert AC or DC.

Pulse width modulation has been the subject of intensive research during the last few decades. Different types of feed forward and backward pulse width modulation schemes having relevance for industrial application have been widely discussed[2] .

The characteristic harmonics (h) are based on the number of rectifiers (pulse number) used in the circuit and can be determined by the equation (1).

$$h = (n \times p) \pm 1 \tag{1}$$

where, n is an integer

p is pulse number of rectifier.

For 6 pulse rectifier, the characteristic harmonics will be 5^{th},7^{th},11^{th} & 13^{th} and so on

The undesirable lower order harmonics of a square wave can be eliminated and then fundamental voltage can be controlled which is known as Selective Harmonic Elimination (SHE). In SHE method, notches are created on the square wave at predetermined angles to eliminate the significant harmonic components and control the fundamental voltage.

Programmed PWM eliminating lower-order harmonics [3] generates high quality output spectra, which in turn result in minimum current ripples, thereby satisfying several performance criteria and contribute to overall improved performance. Performance characteristics of a rectifier/inverter power conversion scheme largely depend on the choice of the particular Pulse Width Modulation strategy employed. Programmed PWM techniques optimize a particular objective function, such as selective elimination of harmonics and therefore are the most effective means of obtaining high performance.

An optimized PWM technique is used in [4], [5] to reduce harmonic distortion and to spread harmonic energy for high frequency inverters. Optimization algorithms are becoming increasingly popular in engineering design activities, where the emphasis is on the maximizing or minimizing a certain goal primarily because of the availability and affordability of high speed computers. They are extensively used in engineering design problems

The minimization of objective function used for SHE was done using traditional mathematical techniques such as Conjugate Gradient Descent method (CGD)[6] and Newton Raphson method (NR)[7]. These methods need initial values to obtain the objective function and are based on differential information, which in turn may produce local minimum solution which leads to undesirable pattern.

GA provides solution to nonlinear mathematical problems. GA is inspired by the mechanism of natural selection, in which stronger individuals are likely to survive in a competing environment. GA uses a direct analogy of such selection. GA is applied to eliminate the lower order harmonics in power converter with dual transformer and 12 pulse rectifier [8]. The 3^{rd} and other triplen harmonics can be ignored if the machine has an isolated neutral.

GA and CGD methods are used to find the switching pattern for Selective Harmonics Elimination to eliminate rectifier low input current harmonics without having initial guess for the switching pattern but initial values are provided by GA [9]. NR and GA are adopted to reduce the lower order line current harmonics by developing the 'N' number of pulse per half cycle [10]. GA technique was used to generate an optimal pulse pattern to suppress 5^{th} and 7^{th} harmonics in PWM inverter [11]. Random search methods [12] are used to eliminate 5^{th} and 7^{th} harmonics in diode clamped multilevel inverter where, the starting points are obtained by Newton Raphson algorithm.

The power circuit for Voltage Source Converter Drive system is given in Figure 1. DC voltage is obtained using 6 pulse Voltage Source Rectifier. The rectifier is connected to Voltage Source Inverter through DC link capacitor and Inductor.

This paper presents a new method of line voltage harmonics reduction in PWM converter without using dual transformer and GA. The use of dual transformer and 12 pulse rectifier were eliminated in the proposed method. The 5^{th} &7^{th} and 11^{th} & 13^{th} harmonics are the characteristic harmonics required to be eliminated for 6 pulse rectifier. The objective is achieved by determining the switching pattern for the three phase Inverter using GA. Simulations were carried out and validated using $\mathrm{MATLAB}_{\mathrm{TM}}$ and Powersim.

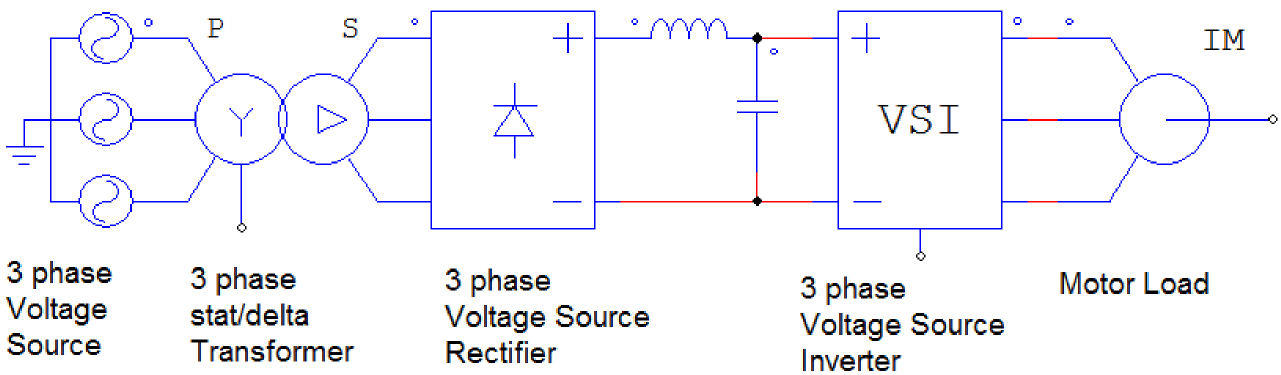

Figure 1. Power circuit of Voltage Source Converter Drive System

2. PWM-SHE SWITCHING TECHNIQUES

The Fourier coefficients of the PWM-SHE switching pattern for a three phase line to neutral voltages are given by the equation (2).

$$a_n = \frac{4}{n\pi}[-1-2\sum_{k=1}^{N}(-1)^k \cos(n\alpha_k)] \qquad (2)$$

$$b_n = 0$$

Equation (2) has N variables $(\alpha_1\ to\ \alpha_N)$ and a set of solutions are obtained by equating (N-1) harmonics to zero and assigning a specific value to the fundamental amplitude α_1, through the equation (3).

$$f_1(\alpha) = \frac{4}{\pi}[-1-2\sum_{k=1}^{n}(-1)^k \cos(\alpha_k)] - M = \varepsilon_1$$

$$f_2(\alpha) = \frac{4}{5\pi}[-1-2\sum_{k=1}^{n}(-1)^k \cos(5\alpha_k)] = \varepsilon_2 \qquad (3)$$

....

$$f_N(\alpha) = \frac{4}{N\pi}[-1-2\sum_{k=1}^{n}(-1)^k \cos(n\alpha_k)] = \varepsilon_N$$

where, M is the modulation index and the variables ε_1 to ε_N are the normalized amplitude of the harmonics to be eliminated. The objective function of PWM-SHE technique is to minimize the harmonic content in the inverter line voltage and it is given in equation (4).

$$f(\alpha_1,\alpha_2,\alpha_3,.....,\alpha_N) = \varepsilon_1^2 + \varepsilon_2^2 + ...+\varepsilon_N^2 \qquad (4)$$

Subject to the constraint equation (5),

$$0 < \alpha_1 < \alpha_2 < \alpha_3 < \alpha_4 < \alpha_5 ....\alpha_N < \frac{\pi}{2} \qquad (5)$$

for Quarter-wave symmetric pulse pattern. In this method $\alpha_1, \alpha_2, \alpha_3, \alpha_4\ and\ \alpha_5$ solutions are expected with elimination of 5^{th}, 7^{th}, 11^{th} and 13^{th} harmonics.

3. GENETIC ALGORITHM METHOD TO SOLVE THE PROPOSED PWM SWITCHING PATTERN

Genetic Algorithms (GA) are numerical optimization algorithms based on the principle inspired from the genetic and evolution mechanisms observed in natural system and population of living beings. Binary encoding GA is dealing with binary strings, where the number of bits of each string simulates the genes of an individual chromosome, and the number of individuals constitutes a population. Each parameter set is encoded into a series of a fixed length of string symbols usually from the binary bits, which are then concatenated into a complete string called chromosome. Substrings of specified length are extracted successively from the concatenated string and are then decoded and mapped into the value in the corresponding search space. Generally, GA implementation comprises the procedures of initial population generation, fitness evaluation and genetic operations of selection, crossover and mutation.

In this paper, an attempt has been made to determine the most optimal switching pattern to eliminate the lower order line voltage harmonics in the Voltage Source Inverter using the implementation of GA is given below.

A. Initialization

The initial population (P_i) is generated after satisfying the equation (5) with randomly selected initial individual switching angle. The generated switching angles are distributed uniformly between their minimum and maximum limits by satisfying the equation (5).

B. Fitness of the candidate solutions

The Fitness Value (FV) in this case attempts to minimize the objective function using the equation (6).

$$FV = \frac{1}{1 + f(\alpha)} \qquad (6)$$

where, $f(\alpha)$ can be calculated using the equation (4).

The alpha limit violation can be dealt with the violation coefficient value using equation (7).

$$\text{Vio\_coeff} = (1 + [\alpha_{(i-1)} - \alpha_{(i)}]) \times \rho \qquad (7)$$

Where, ρ is the penalty parameter,

$\alpha_{(i)}$ is the i^{ih} value of α .

In such cases, the objective function is calculated by multiplying the Vio_coeff value. After computing the fitness of each individual, the parents then undergo the genetic operations of selection, crossover and mutation; as the result, each pair creates a child having two parents. The process of selection and mating of individuals continues until a new generation is reproduced.

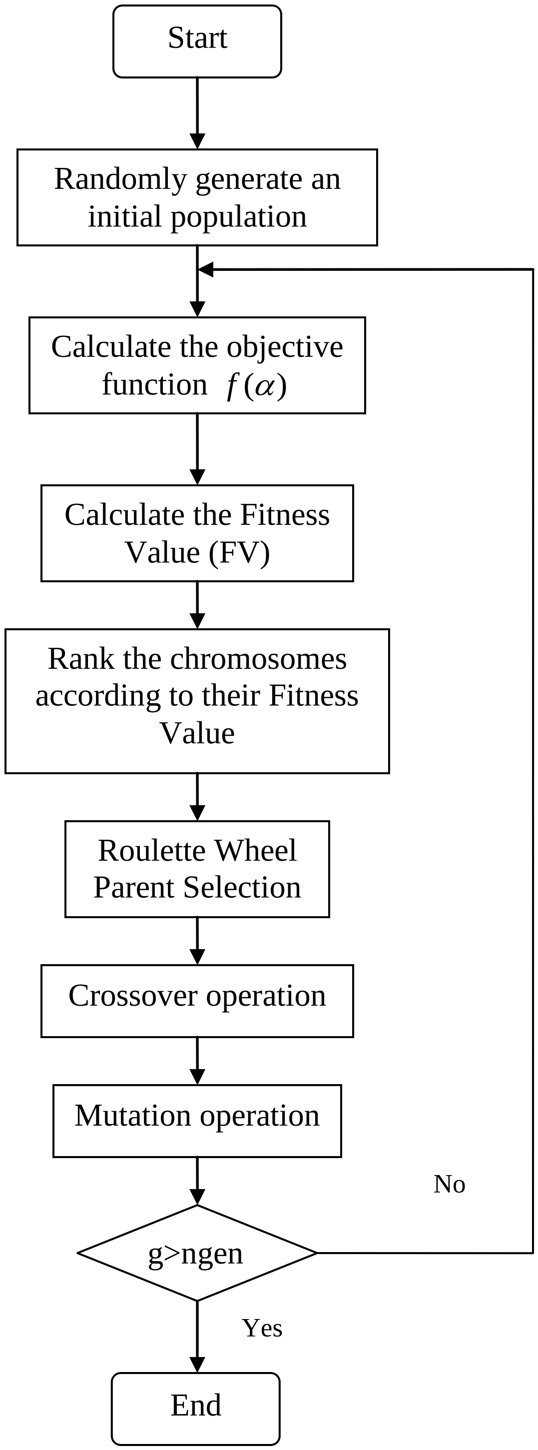

Figure 2. Operation of Proposed Genetic Algorithm method

C. Selection:

After the evaluation of initial randomly generated population, the GA begins to create new generation. Chromosomes from the parent population are selected in pairs with a probability proportional to their fitness in order to replicate and form offspring chromosomes. This selection scheme is known as Roulette wheel selection.

D. Crossover and Mutation

Crossover operator is applied with certain probability, where the parent genotypes are combined to form two new genotypes that inherit solution characteristics from both parents. Crossover although being the primary search operator, cannot produce information that doesn't exist already within the population.

We propose to combine parameter values from the two parents into new parameter values for the children. A single point crossover method is used to combine the parents to produce the children.

Mutation operator is also applied with a small probability. Randomly chosen bits of the offspring genotype flip from 0 to 1 and vice versa to give characteristics that do not exist in the parent population. Generally mutation is considered as a secondary operator that gives a non-zero probability to every solution to be considered and evaluated. This operation can help in avoiding the possibility of taking a local minimum for a global optimum. A coin-toss optimum is employed to determine the genes to be mutated, if the random number between 0 and 1 is less than the mutation rate, the gene is mutated in the given region. This random scattering might find better optima, or even modify a part of the genetic code that will be beneficial in latter cross. On the other hand, it could produce a weak individual that would never be selected for cross.

E. Elitism:

The crossover and mutation for the two chromosomes are repeated until all the chromosomes of the parent generation are replaced by the newly formed chromosomes. The best chromosome of the parent generation and the best chromosome found in all of the previous generations were copied intact to the next generation, so that the possibility of their destruction through the genetic operator is eliminated.

F. Termination criterion for GA

The above procedure from the section [B-E] is repeated until the maximum iteration count is reached.

The main stages and operations of the proposed Genetic Algorithm technique including initialization, selection, crossover and mutation are shown in Figure 2.

4. OPTIMIZATION RESULTS

To obtain the best and optimum solution for the given non-linear transcendental equations, the following GA parameters were used.
Population size: 50
Number of generations: 100
Crossover rate: 0.8

Mutation rate: 0.01

After solving the five nonlinear functions of equations (3) simultaneously using $MATLAB_{TM}$ optimization toolbox, five angles were obtained. This process is repeated for the various modulation indices from 0.1 to 1.3. Figure 3 shows the Trajectory of calculated switching angles for the proposed PWM-SHE switching pattern using GA.

In Figure 3, the parameters represent five independent angles (3) used to construct the required PWM-SHE switching pattern as shown in Figure 4. In this approach, the trajectories of the angles are almost smooth for α_2 and α_3 over the whole range of possible modulation indices. There is an abrupt fall of 30^o for α_4 and α_5 and rise of about 5^o for α_1 for the modulation index 0.7. All five angles are smooth after M=0.8.

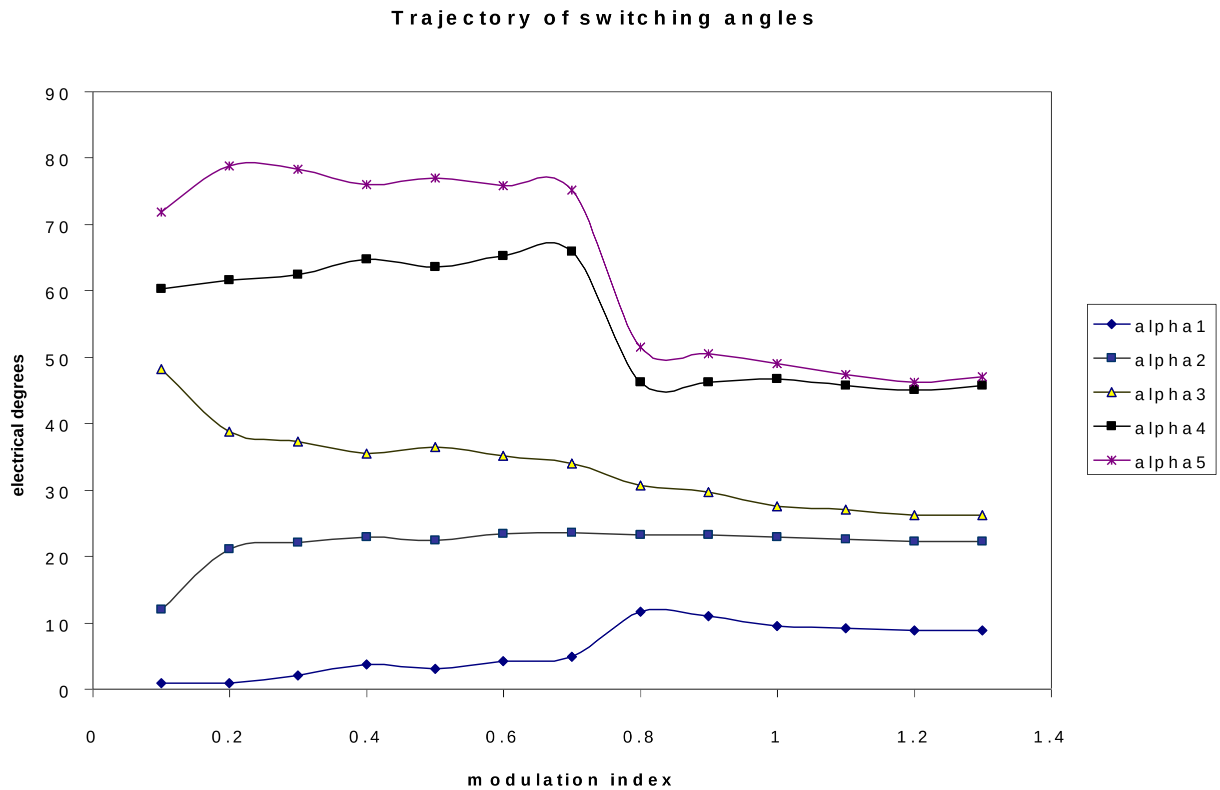

Figure 3. Trajectory of calculated switching angles of proposed PWM-SHE switching pattern using GA.

All these characteristics bring unpredictability to traditional algorithms that require precise initial values to guarantee convergence. In this approach GA is widely used because of discrete nature of harmonics to be eliminated.

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5. SIMULATION RESULTS

After obtaining the switching angles through the $MATLAB_{TM}$ using Genetic Algorithm, the proposed system was developed using Powersim. The circuit uses 230V single phase AC supply sources which was connected to the star connected primary winding of the 3 phase star/delta transformer. The 6 pulse voltage source rectifier was developed using six diodes as bridge. This rectifier is being connected to Voltage Source Inverter through the Inductor and Capacitor which was acting as a DC link between the rectifier and inverter. The load connected to the inverter is a three phase squirrel cage induction motor, where high capacity dual transformer and 12 pulse rectifier are not used to eliminate certain lower order harmonics in Genetic Algorithm approach. Simulations were carried out on a Pentium III 933-MHz, 256–MB RAM processor. The Coding was written using $MATLAB_{TM}$.
The rating of the proposed AC drive system was

1. Power supply: 400 (line to line) 50 Hz
2. DC link Inductance: 1 mH
3. DC link Capacitance: 470μF

The harmonics are to be observed in the output line to line voltage. With the five switching angles calculated, the whole switching pattern is constructed as shown in the Figure 4 using quarter wave symmetry method. The output line-to-line voltage waveforms for the modulation index, M=0.9 with RL load is shown in Figure 5(a).

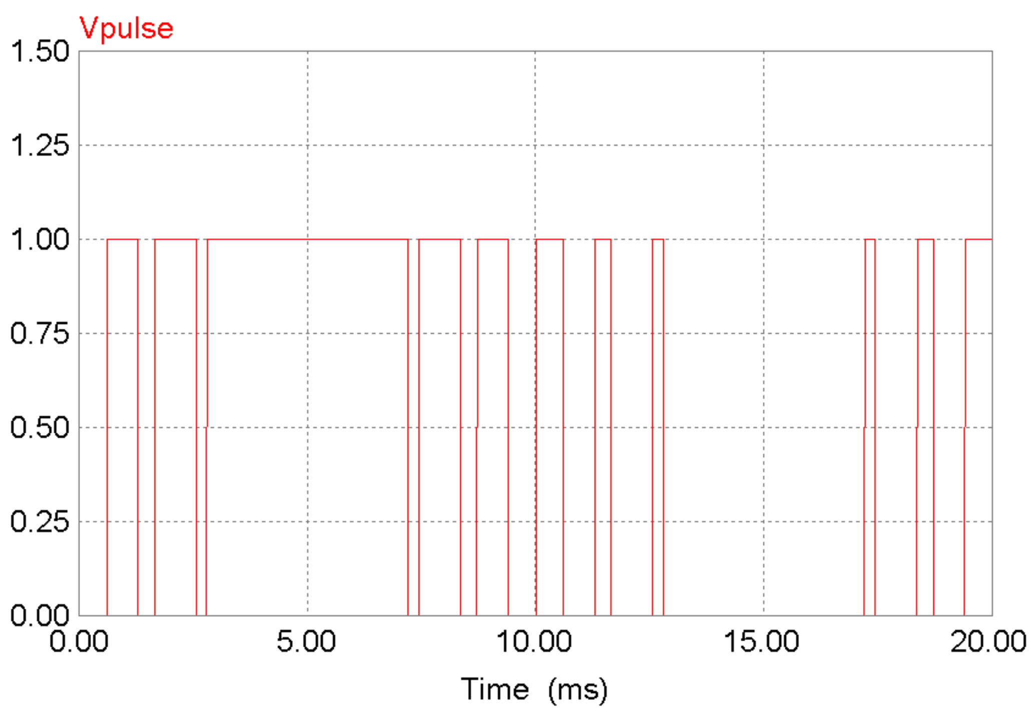

Figure 4. PWM-SHE switching pattern for 5^{th}, 7^{th}, 11^{th} and 13^{th} harmonics elimination.

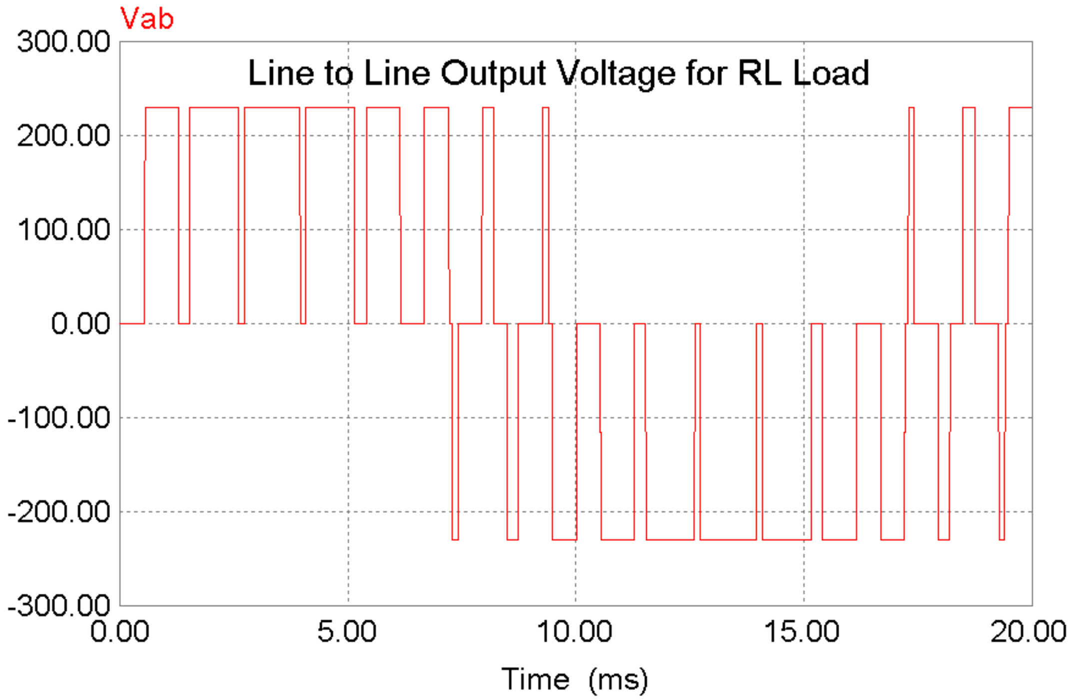

Figure 5(a). Inverter Output Voltage for RL Load

The Harmonic Spectrum of output voltage with RL load is shown in Figure 5(b).

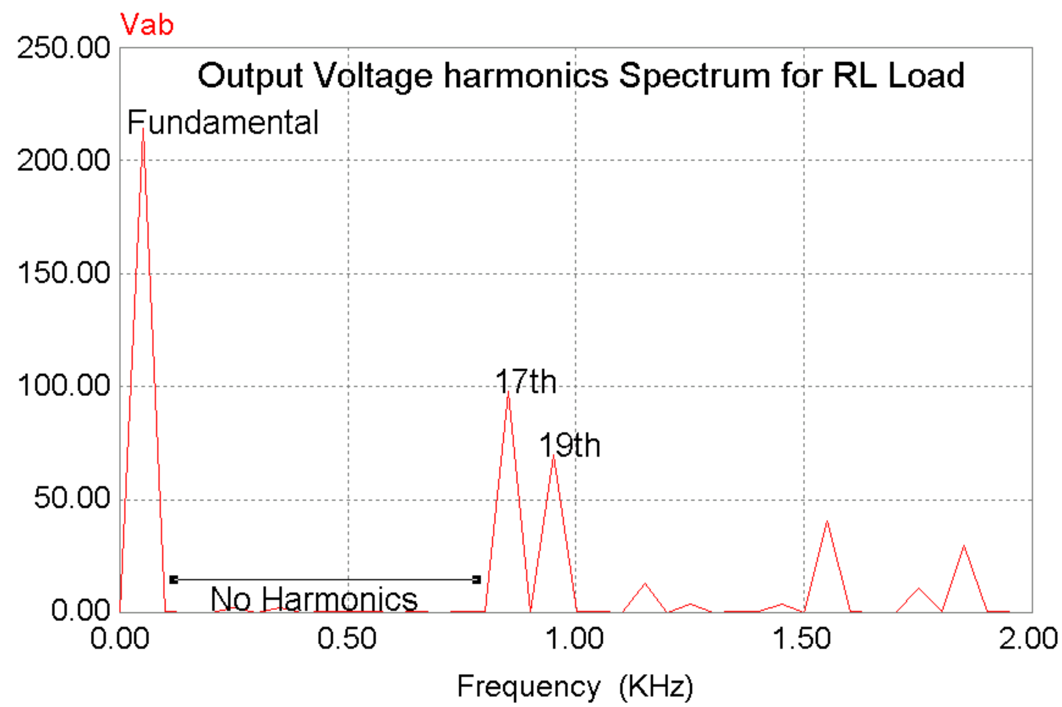

Figure 5(b). Harmonics Spectrum for Inverter Output Voltage for RL Load (after eliminating 5^{th}, 7^{th},11^{th} and 13^{th} harmonics using GA) at M=0.9

The waveform for the load current with RL load and harmonics spectrum for load current are shown in Figure 6(a) and 6(b).

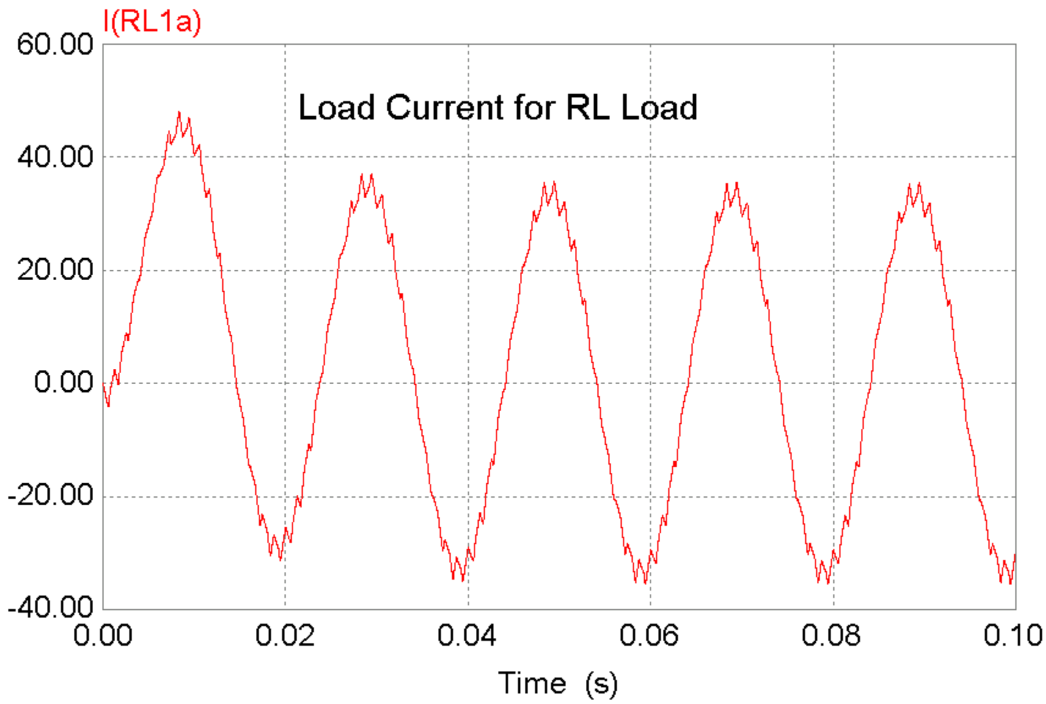

Figure 6(a). Load current waveform for RL load

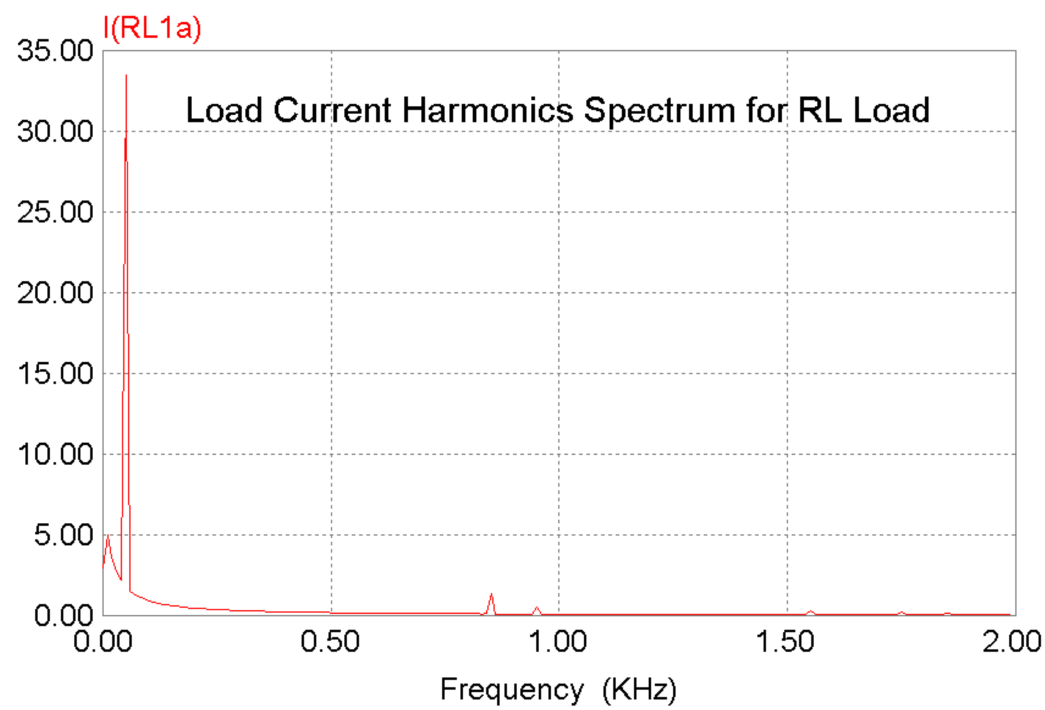

Figure 6(b). Load current Harmonics Spectrum for RL load.

The output line-to-line voltage waveforms for the modulation index, M=0.9 with Induction Motor Drive load is shown in Figure 7(a). The Harmonic Spectrum of output voltage with Induction Motor Drive load for M=0.9 is shown in Figure 7(b).

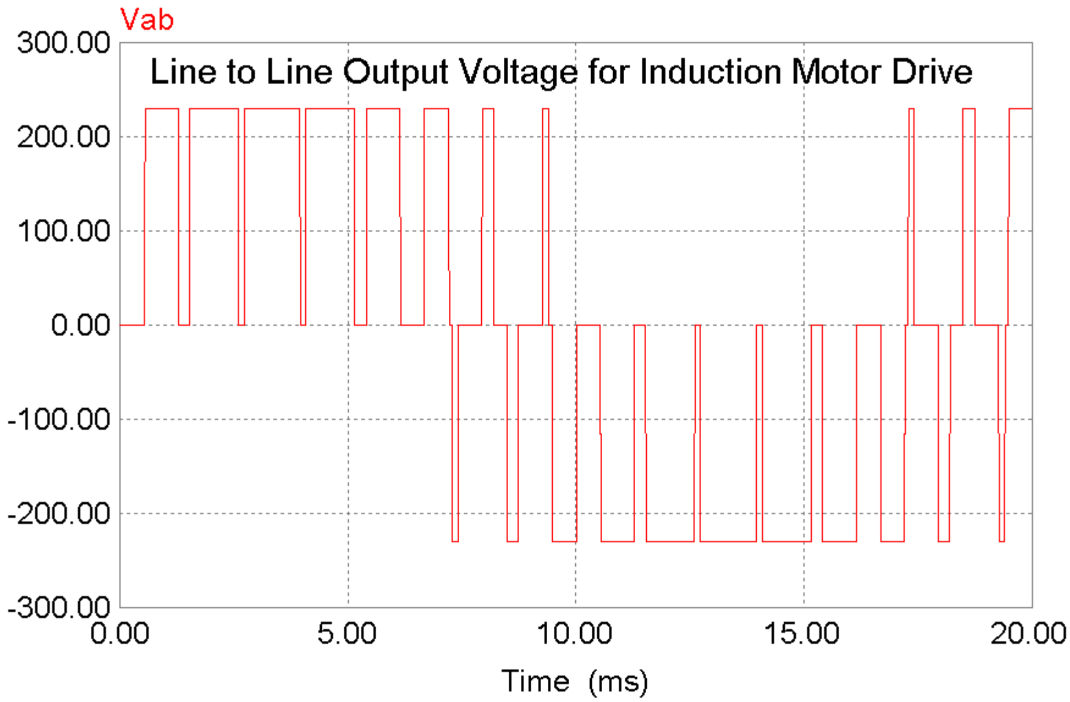

Figure 7(a). Output Line to Line Voltage with Induction Motor Drive at M=0.9

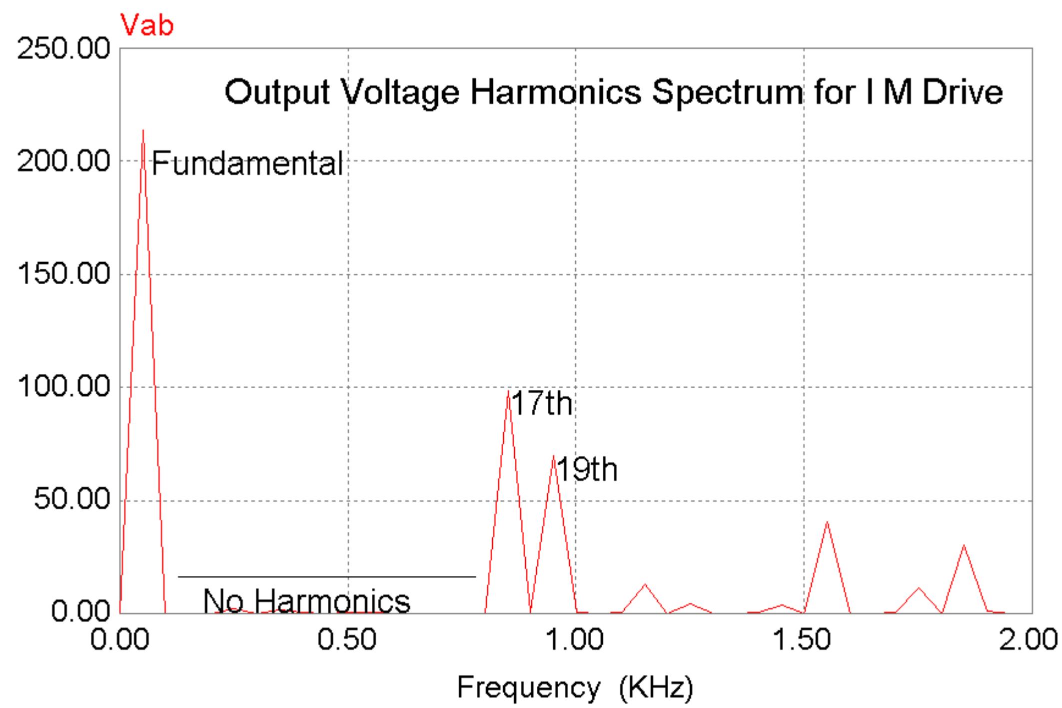

Figure 7(b). Output Voltage Harmonics Spectrum for Induction Motor Drive at M=0.9

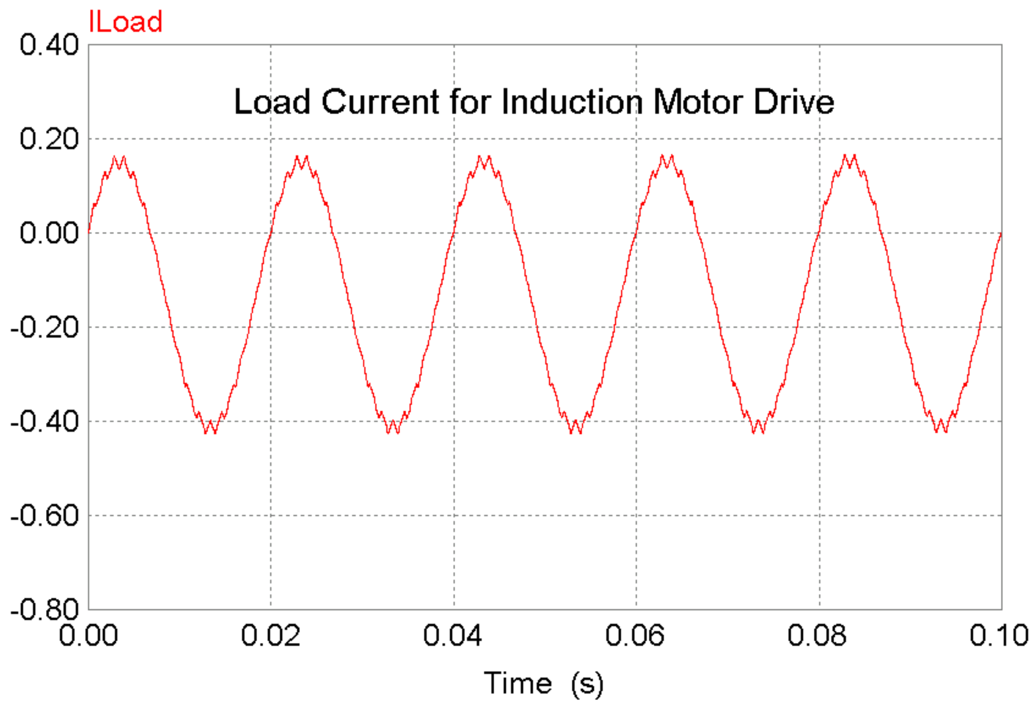

Figure 8(a). Load current waveform for Induction Motor Drive

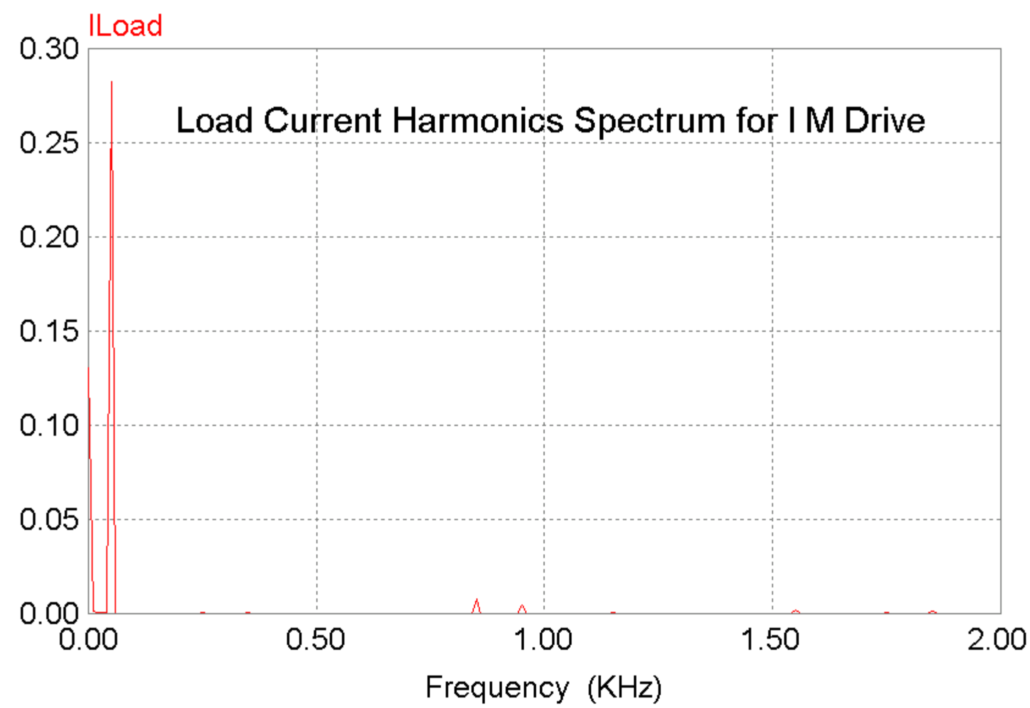

Figure 8(b). Load Current Harmonics Spectrum for Induction Motor Drive

The waveform for the load current with Induction Motor Drive and harmonics spectrum for load current are shown in Figure 8(a) and Figure 8(b).

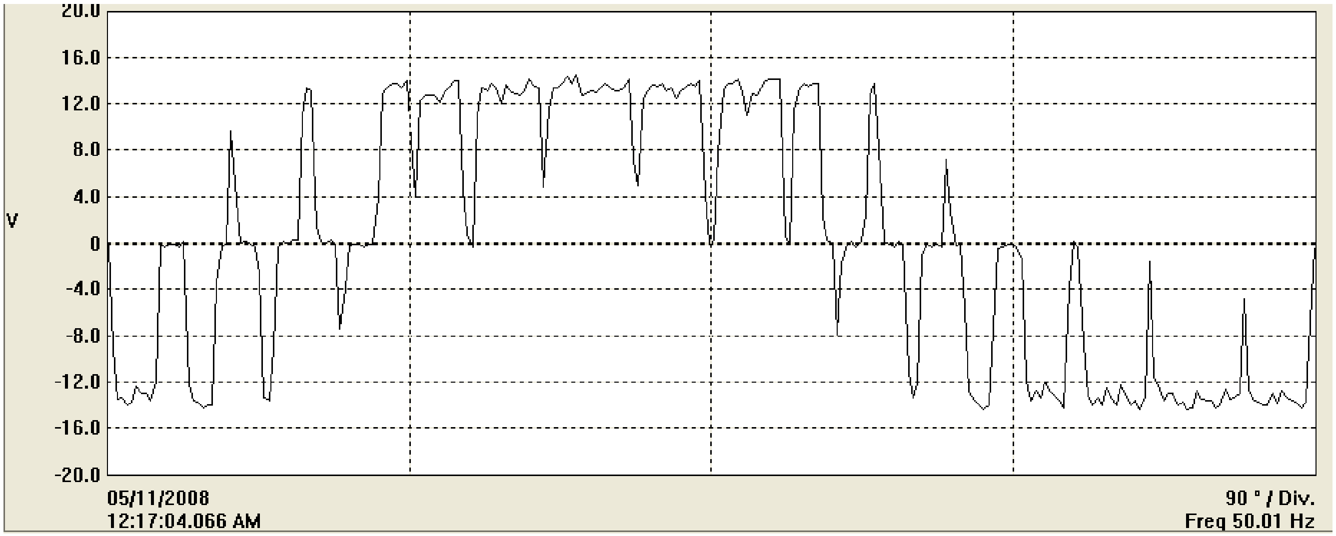

Figure 9(a) Experimental results: Line to Line voltage with RL Load with low input DC voltage.

Figure 9(a) and 9(b) shows the experimental results, where the Line to Line voltage with RL load with low input voltage is given in the Figure 9(a) and the harmonics Spectrum of the Line to Line voltage with RL load is given in the Figure 9(b), are absorbed using the Portable Energy & Harmonics Analyzer ALM30. This shows that the lower order harmonics up to 13^{th} are fully eliminated using Genetic Algorithm approach. The higher order harmonics can easily eliminated by ordinary LC filters.

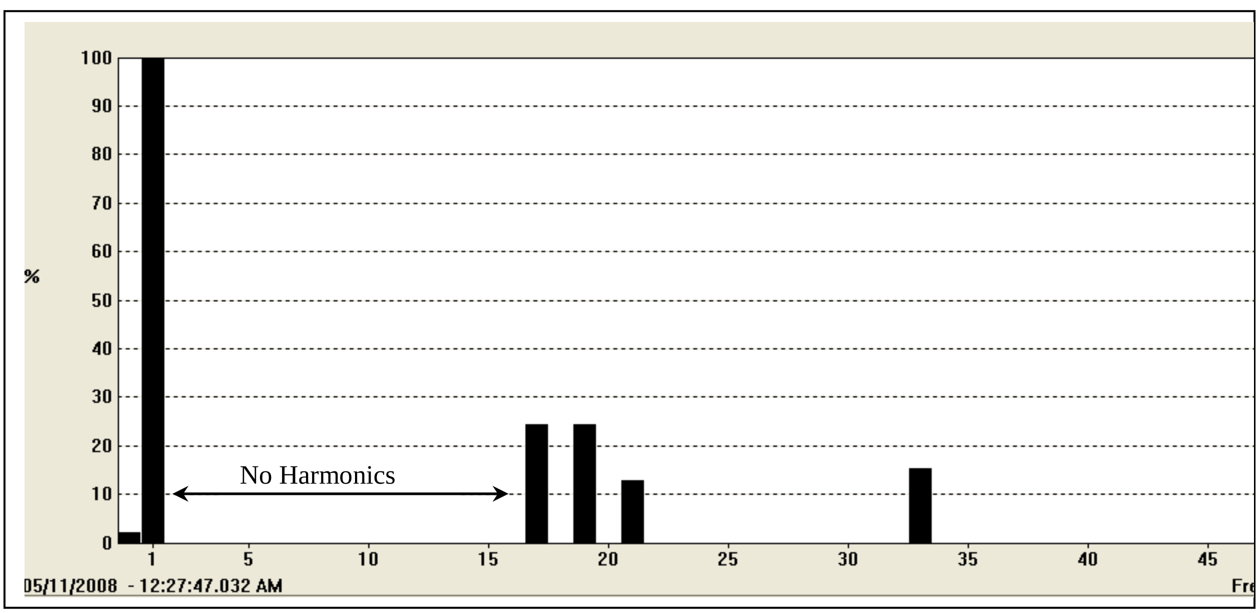

Figure 9(b). Harmonics Spectrum of the load voltage with RL Load.

The harmonics spectrum Figures shows that almost all 5th,7th,11th and 13th harmonics are eliminated for the modulation index value 0.9. These are the characteristic lower order harmonics to be eliminated for the 6 pulse converter.

Maswood, A.I. et. al. have suggested a method to eliminate the 5th and 7th harmonics using dual transformer. But in this paper, 5th, 7th,11th and 13th harmonics are eliminated without using dual transformer and 12 pulse rectifier. Shi, K.L. et. al. have proposed an optimized PWM strategy based on Genetic Algorithm for inverters. However, this method is applicable for the power line frequency inverters with lower switching frequency. Sayyah, H. et. al. have suggested a method to minimize the total harmonic distortion by suppressing only 5th and 7th order Harmonics. But, selective harmonic elimination method eliminates harmonics up to 13th using Genetic Algorithm for Voltage Source Inverter.

6. CONCLUSION

An efficient technique of calculating switching angles through the Genetic Algorithm method is illustrated. An optimized PWM-SHE switching method is proposed for 3 phase Inverter circuit with 6 pulse converter as the power circuit for 3 phase drive system. This method avoids usage of 12 pulse rectifier and the traditional complex calculations. Analysis of the Harmonics spectrum shows that, all the harmonics up to 13th are eliminated. According to the experimental and simulated results, the characteristic harmonics of six pulse rectifier, 5th, 7th, 11th and 13th are totally eliminated by Genetic Algorithm without using high capacity dual transformer connections. It remains to be a topic for further investigations to design similar real-time PWM systems.

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