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Comparison of Cascaded H-bridge Inverters for Harmonic Mitigation Considering Various Loads

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ABSTRACT

This paper compares the reduction of harmonics in various level cascaded H-bridge inverters. The switching angles for the cascaded H-bridge inverter were calculated by evolutionary optimization technique. Fourier analysis is used to determine the switching angles for the desired electrical parameters. Lower order harmonics such as third, fifth, seventh, ninth and eleventh order harmonics were taken into consideration to reduce the total harmonic distortion. Simulation was done for thirteen, fifteen and seventeen level cascaded H-bridge inverters using Matlab. Total harmonic distortion of voltage and current for R, RL and Motor load were analyzed.

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1. INTRODUCTION

With the advent and development of new technologies, machine and devices has been designed to replace the work done by humans and also enable the sophisticated life of them. It is quite unfortunate that most of the instruments which the humans use in day to day life activities depend on electricity. Enormous amount of research is going on in the field of producing power from solar energy, fuel cells, wind energy etc Electricity produced by the solar cells, fuel cells are of direct current. Even though the voltage obtained from renewable energy resources are less, it can be boosted by DC-DC converters[1]. But most of the appliances used by the consumer utilizes electricity of alternating current type. So it is necessary to convert the direct current to alternating current for consumer as well as to transmit the power to long distances.

While converting the direct current to alternating current, inverters produces distortions in the output called as harmonics. A harmonic component in a power system is a sinusoidal component of a periodic waveform having a frequency that is an integral multiple of the fundamental frequency [2]. These harmonics creates undesirable effects to the machines [3]. One of the measures to determines the harmonic level is the Total Harmonic Distortion (THD). The other names for total harmonic distortion are Distortion Factor (DF), Harmonic Factor (HF) etc [4] Since the harmonics affects the operation of devices, it is essential to minimize or completely eliminate it.

Various inverters were proposed in the literature with aim to minimize total harmonic distortion. One such inverter is the multilevel inverter. Multilevel inverters are used for medium and high power applications. There are various topologies of multilevel inverter [5] such as Diode-clamped inverter, Capacitor-clamped inverter, Cascaded H-bridge inverter etc. Diode-clamped inverter and capacitor-clamped inverter produces more THD compared to the Cascaded H-bridge inverter for the same number of level [6] and hence found inferior. Cascaded-H-bridge inverter gets the input from multiple dc sources and converts it into stepped ac waveform. As the number of steps increases the waveform approaches smooth sinusoid. Each step of the waveform corresponds to a level. Hence the inverter output waveform with 15 steps is called 15-level inverter. If the number of steps are more, then the harmonics get reduced. An K level inverter requires (k-1)/2 H-bridges. Each bridge consist of four switching devices. Switching devices can be of IGBT, SCR, Power MOSFET etc. The circuit for 9-level cascaded H-bridge inverter and its associated waveform is shown in the Figure 1.

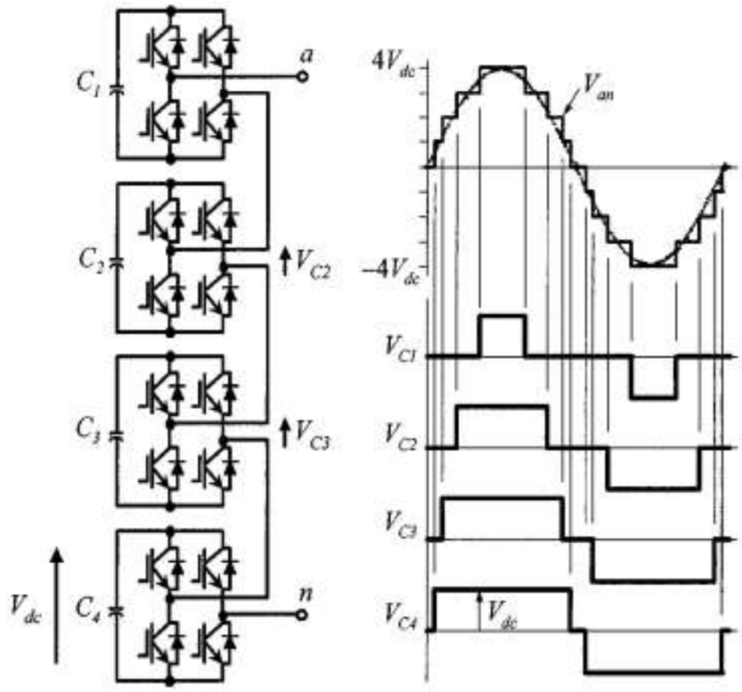


Figure 1. Nine level inverter and its associated waveform

The switching angles for the successful operation of the multilevel inverter is designed to minimize harmonics. This can be achieved by optimization algorithm. Many methods were proposed in the literature to estimate switching angles for multilevel inverter. Vector-optimized harmonic elimination for single phase Pulse-With Modulated inverter [7], considers dc-link ripple due to finite dc-link capacitance in optimized switching angle calculation. In application requiring capacitor size optimization, ripple capacitor filter can introduce lower order harmonics to flow in the ac load. Half-wave symmetry selective harmonic elimination method was implemented for five level inverter [8] with varying modulation index range 0 to 1.15SHEPWM can generate more solutions than quarter wave symmetrical method and asymmetry method. But complexity increases due to more number of equations. Shuffled Frog Leaping Algorithm has been utilized in [9] to calculate switching angles for eleven level inverter. In Optimal Pulse Width Modulation [10] based on har¬monic injection and equal area criteria has been applied for Selective Harmonic Elimination in multilevel con¬verters with unbalanced dc voltage source. Harmonic elimination and optimization of the stepped voltage of a 13-level inverter was made by Bacterial Foraging Algorithm [11] Based on the foraging behavior of a colony of ants, a novel algorithm for selective harmonic elimination in pulse width modulation was developed [12]. Bee algorithm has been applied to 7-level inverter to eliminate lower order harmonics by selective harmonic elimination pulse width modulation in [13]. The backlog of Bee algorithm is that the code is complex and the runtime is more compared to genetic algorithm. Genetic algorithm has been utilized to reduce harmonics in 9-level inverter [14]. Selective Harmonic Elimination Technique used in multilevel inverter by neural network [15]. Mitigation of harmonics in industrial motor drive have reported in [16].

Filters have been used to reduce harmonics in distribution system [17]. Most of the methods adopted in the literature, did not consider both the current harmonics and voltage harmonics. The number of levels used is less than 13 and they failed to describe about the harmonics characteristics for RL load and Motor load. In the proposed method, comparison is made with 13 level, 15 level and 17 level inverters. Current and voltage harmonics were simulated for R load, RL load and single phase induction motor load utilizing genetic algorithm to estimate switching angles.

2. GENETIC ALGORITHM

Genetic algorithm is a computational model that solves optimization problems by imitating genetic processes and the theory of evolution by using genetic operators like reproduction, crossover, mutation etc. Amounts of applications have benefited from the utilization of genetic algorithm. Genetic algorithm is still a novel technique for PWM-SHE technique. This algorithm is usually used to accomplish a near global optimum solution. Each iteration of the GA is a new set of strings, which are called chromosomes, with improved fitness is produced using genetic operators.

2.1. Chromosome representation

In GA, each chromosome is used as a feasible solution for the problem, where each chromosome is developed based on single dimensional arrays with a length of S, where S is the number of angles.

2.2. Initialize population

Set a population size, N, i.e. the number of chromosomes in a population. Then initialize the chromosome values randomly. If known, the range of the genes should be considered for initialization. Population size depends only on the nature of the problem and it must achieve a balance between the time complexity and the search space measure. The narrower the range, the faster GA converges. In this paper, population size is considered as 100.

2.3. Reproduction

The reproduction operator determines how the parents are chosen to create the offspring. This operator is a process in which chromosomes are copied according to their objective function values i.e. the degree of conformity of each object is calculated and an individual is reformed under a flat rule depending on the degree of conformity.

2.4. Crossover

Crossover is the most significant operation in GA. It creates a group of children from the parents by exchanging genes among them. The new offspring contain mixed genes from both parents. By doing this, the crossover operator not only provides new points for further testing within the chromosomes, which are already represented in the population, but also introduces representation of new chromosomes into the population to allow further evaluation on parameter optimization.

2.5. Mutation

Mutation is another vital operation. It works after crossover operation. In this operation, there is a probability that each gene may become mutated when the genes are being copied from the parents to the offspring. This process is repeated, until the preferred optimum of the objective function is reached.

2.6. Evaluation of fitness function

The most vital item for the GA to evaluate the fitness of each chromosome is the cost function. The purpose of this study is to minimize specified harmonics; therefore the fitness function has to be associated to THD. In this work the third, fifth and seventh harmonics at the output of 13 level, 15 level and 17 level inverter were minimized.

3. RESULTS AND DISCUSSION

Matlab software have been used to determine the switching angles for the 13-level, 15-level and 18-level cascaded H-bridge inverter by genetic algorithm. Fitness function equation and constraint equations were developed based on fourier analysis Here the constraints were designed to reduce 3rd, 5th, 7th, 9th and 11th order harmonics. The thirteen level inverter consist of cascaded six H-bridge inverters. Simulation circuit for the 13-level inverter with R load is shown in the Figure 2. Similarly fifteen and seventeen level inverters consist of cascaded seven and eight H-bridge inverters respectively.

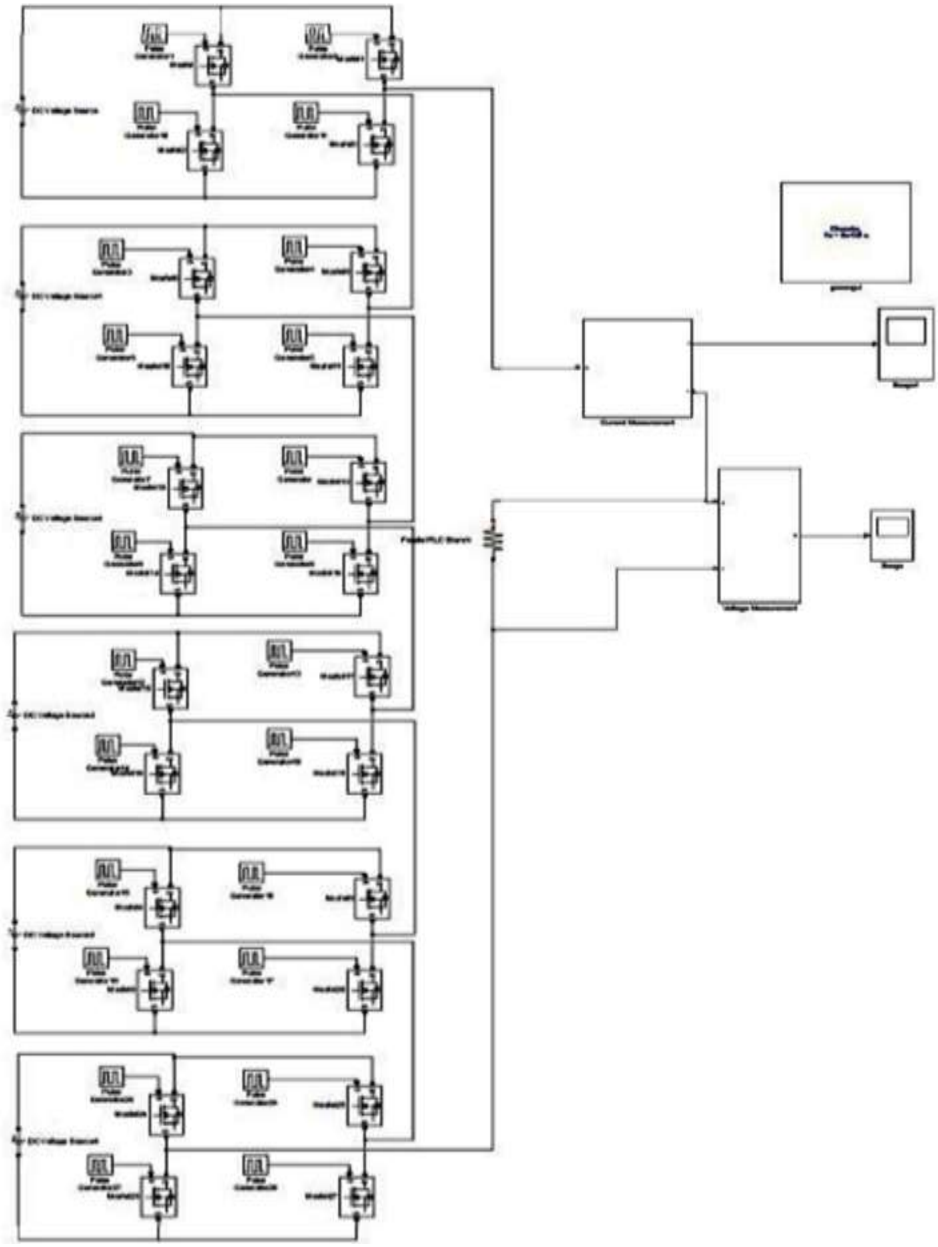


Figure 2. Thirteen level inverter with R load

The following equation represents fundamental component, third harmonics, fifth harmonics, seventh harmonics, ninth harmonics and eleventh harmonics for the 13-level inverter.

a. **Fundamental Component Equation**
0.9003*(v(1)*cosd(x(1))+v(2)*cosd(x(2))+v(3)*cosd(x(3))+v(4)*cosd(x(4))+v(5)*cosd(x(5))+v(6)*cosd(x(6)))-230;

b. **Third Harmonic Equation**
v(1)*cosd(3*x(1))+v(2)*cosd(3*x(2))+v(3)*cosd(3*x(3))+v(4)*cosd(3*x(4))+v(5)*cosd(3*x(5))+v(6)*cosd(3*x(6));

c. **Fifth Harmonic Equation**
v(1)*cosd(5*x(1))+v(2)*cosd(5*x(2))+v(3)*cosd(5*x(3))+v(4)*cosd(5*x(4))+v(5)*cosd(5*x(5))+v(6)*cosd(5*x(6));

d. Seventh Harmonic Equation
v(1)*cosd(7*x(1))+v(2)*cosd(7*x(2))+v(3)*cosd(7*x(3))+v(4)*cosd(7*x(4))+v(5)*cosd(7*x(5))+v(6)*cosd(7*x(6));

e. Ninth Harmonic Equation
v(1)*cosd(9*x(1))+v(2)*cosd(9*x(2))+v(3)*cosd(9*x(3))+v(4)*cosd(9*x(4))+v(5)*cosd(9*x(5))+v(6)*cosd(9*x(6));

f. Eleventh Harmonic Equation
v(1)*cosd(11*x(1))+v(2)*cosd(11*x(2))+v(3)*cosd(11*x(3))+v(4)*cosd(11*x(4))+v(5)*cosd(11*x(5))+v(6)*cosd(11*x(6));

Where

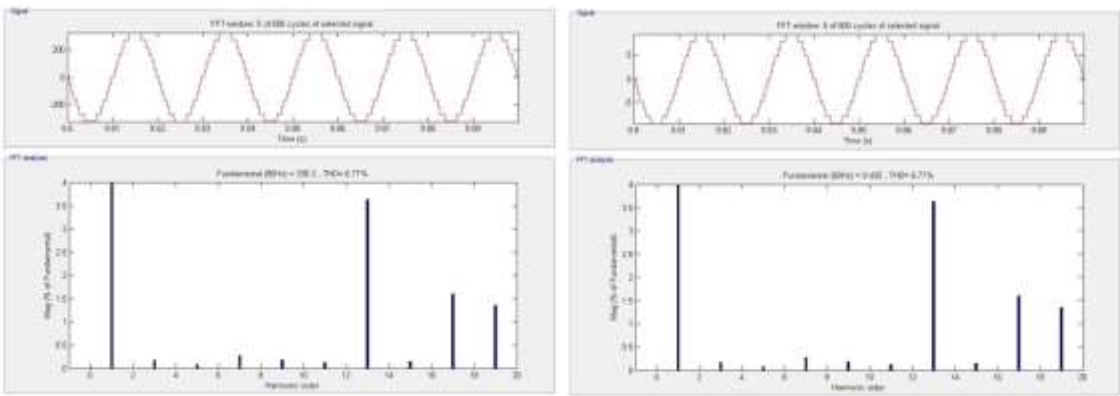
v(1), v,(2), v(3), v(4), v(5) and v(6) represent the input DC voltages for six H-bridge inverters.
x(1), x(2), x(3), x(4), x(5) and x(6) represent the switching angles for six H-bridge inverters
Here rms voltage is kept as 230V

The Total Harmonic Distortion for R load, RL load and motor load considering voltage as well as current for 13, 15 and 17 level inverter is shown in Table 1. From the table it is clear that as the level of the inverter increases total harmonic distortion increases

Table 1. THD % for R load, RL load and Motor load

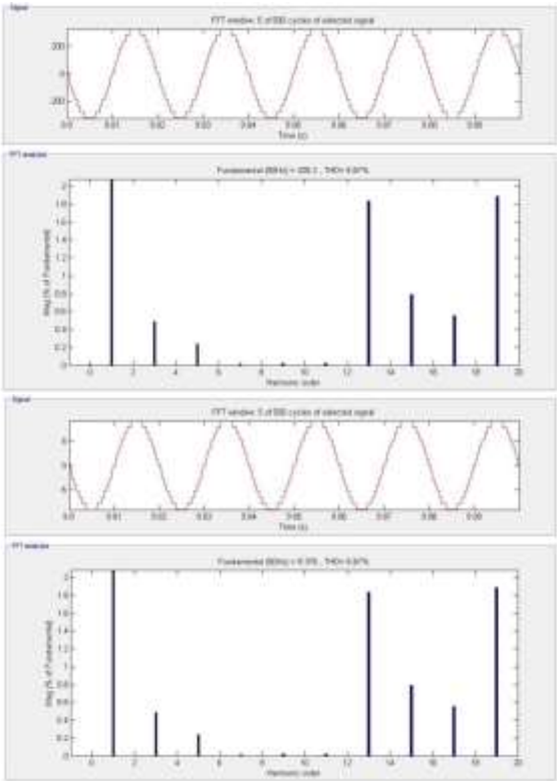
Cascaded H-Bridge inverter	R load		RL load		Motor Load	
	Voltage THD %	Current THD %	Voltage THD %	Current THD %	Voltage THD %	Current THD %
13level	6.77	6.77	6.92	3.01	6.82	3.33
15 level	5.67	5.67	5.82	2.16	5.70	2.65
17 level	4.78	4.78	4.93	1.55	4.84	2.80

Simulation were done keeping Vrms =230V and Irms= 6.5A approx. Figure 3, 4 and 5 represents the FFT window depicting the THD % for R load of 13. 15 and 17 level inverter. Figure 7, 8 and 9 represents the FFT window depicting the THD % for RL load of 13. 15 and 17 level inverter. Similarly Figure 11, 12 and 13 represents the FFT window depicting the THD % for single phase induction motor load of 13. 15 and 17 level inverter.



(a) (b)

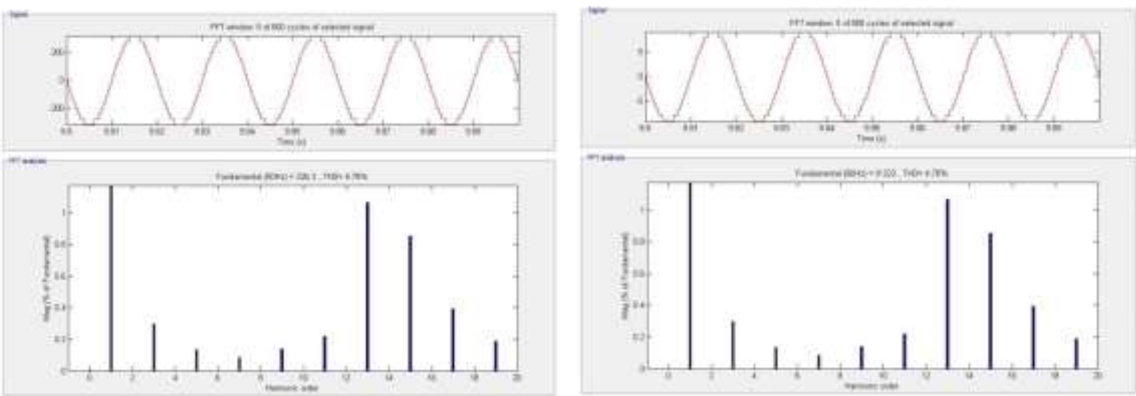
Figure 3. 13-level inverter R load (a) Voltage THD% (b) Current THD%



(a) (b)

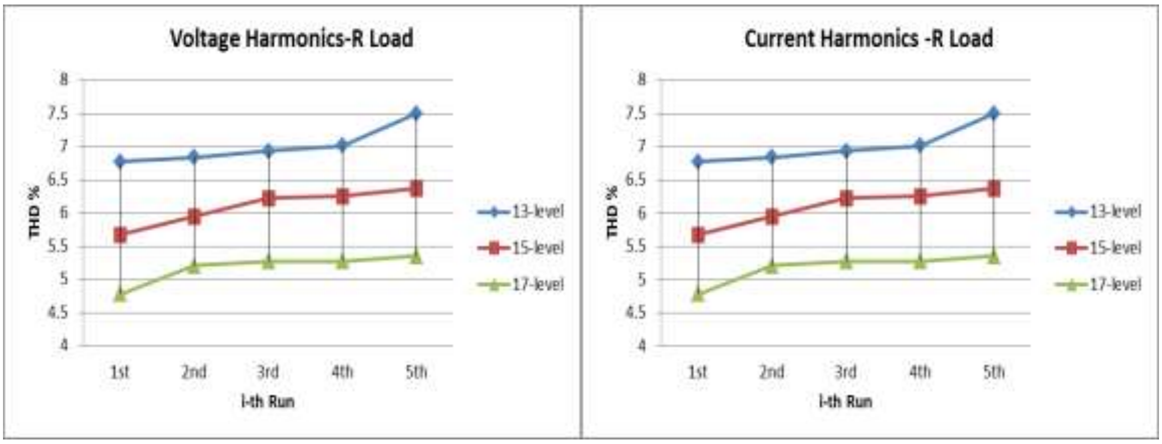
Figure 4. 15-level inverter R load (a) Voltage THD% (b) Current THD

Genetic algorithm has been used to calculate the switching angles for the multilevel inverter. But the switching angles determined by the algorithm varies for different run leading to variation in the THD. So the algorithm has been run for 5 times and its results were plotted in graph. Figure 6 shows the THD comparison for 5 times run of 13, 15 and 17 level inverter of R load. Similarly Figure 10 and 14 shows the THD comparison for 5 times run of 13, 15 and 17 level inverter of RL load and motor load respectively. The results indicate that as the level of the inverter increases the THD decreases. From Figure 9(b) it is also clear that for certain run, THD of 15 level inverter is less than 17-level inverter. It is due to the fact that the genetic algorithm has been used to calculate switching angles, considering the reduction of 3rd, 5th, 7th, 9th and 11th order harmonics. But other higher order harmonics were not taken into account. Such high order harmonics might have contributed to the increase in THD. The results show that for seventeen level cascaded- H bridge inverter the THD was well within the IEEE 519 standard.



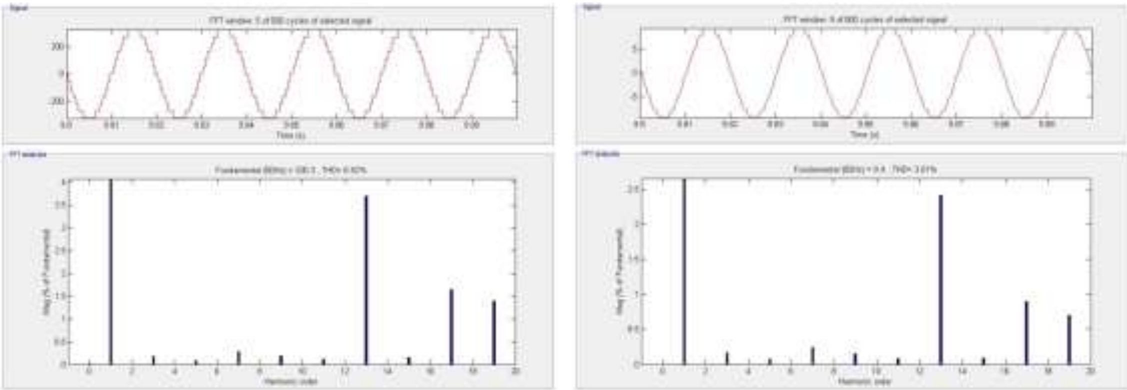
(a) (b)

Figure 5. 17-level inverter R load (a) Voltage THD% (b) Current THD%



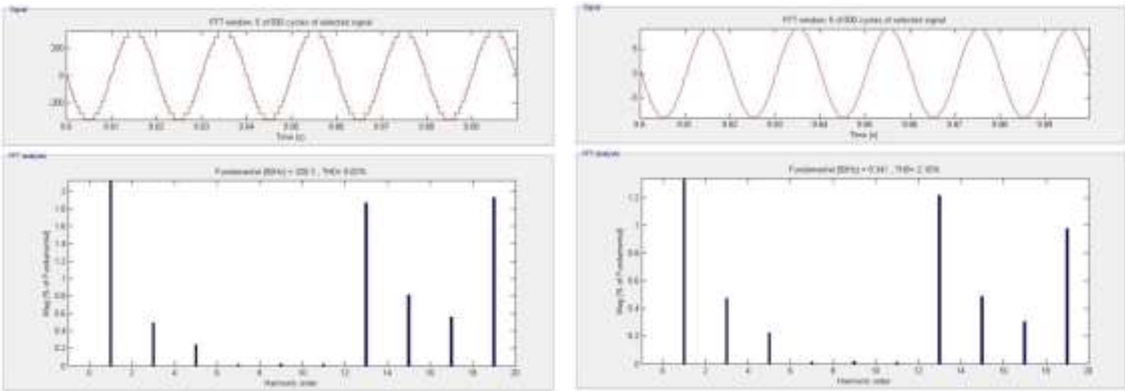
(a) (b)

Figure 6. 13, 15, 17 Level inverter R load (a) Voltage THD% comparison (b) Current THD% comparison



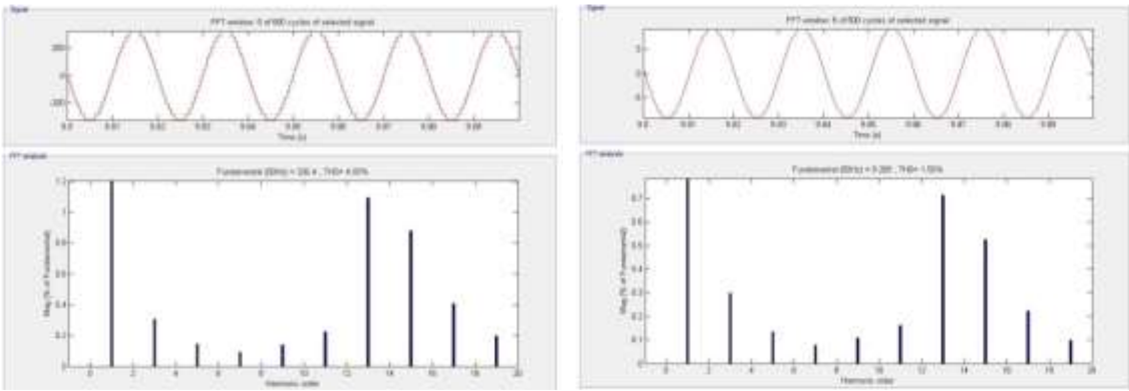
(a) (b)

Figure 7. 13-level inverter RL load (a) Voltage THD% (b) Current THD%



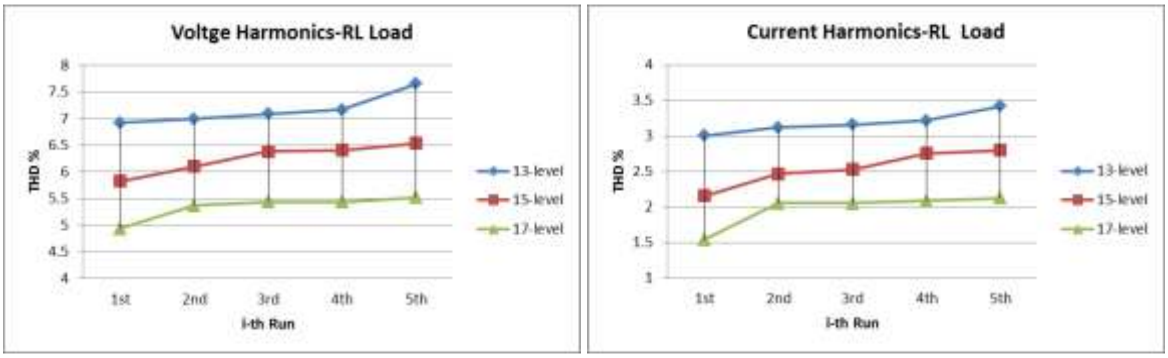
(a) (b)

Figure 8. 15-level inverter RL load (a) Voltage THD% (b) Current THD%



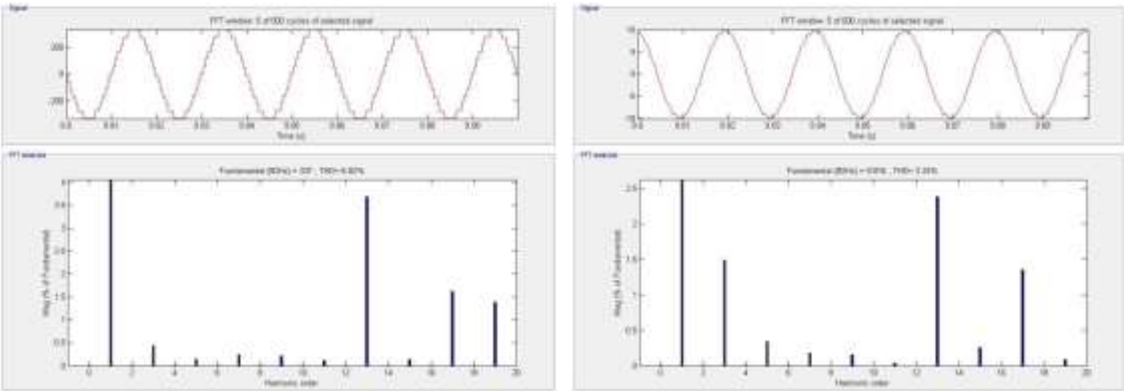
(a) (b)

Figure 9. 17-level inverter RL load (a) Voltage THD % (b) Current THD%



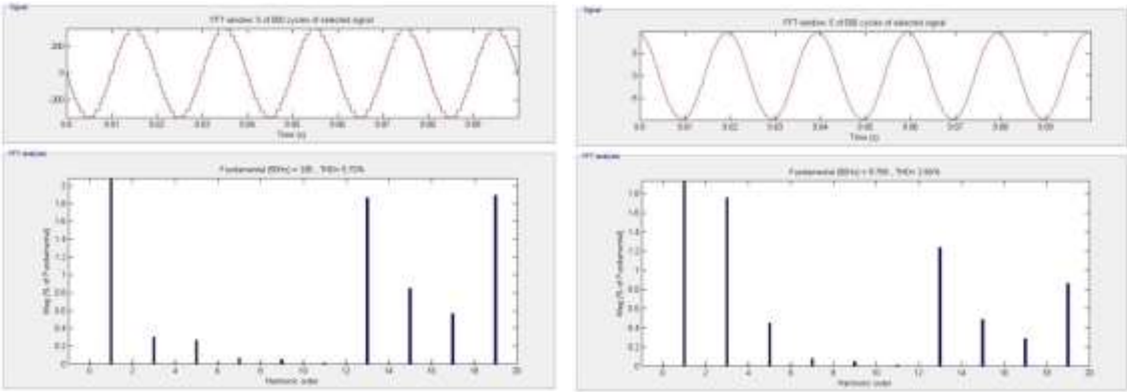
(a) (b)

Figure 10. 13, 15, 17 Level inverter RL load (a) Voltage THD% comparison (b) Current THD% comparison



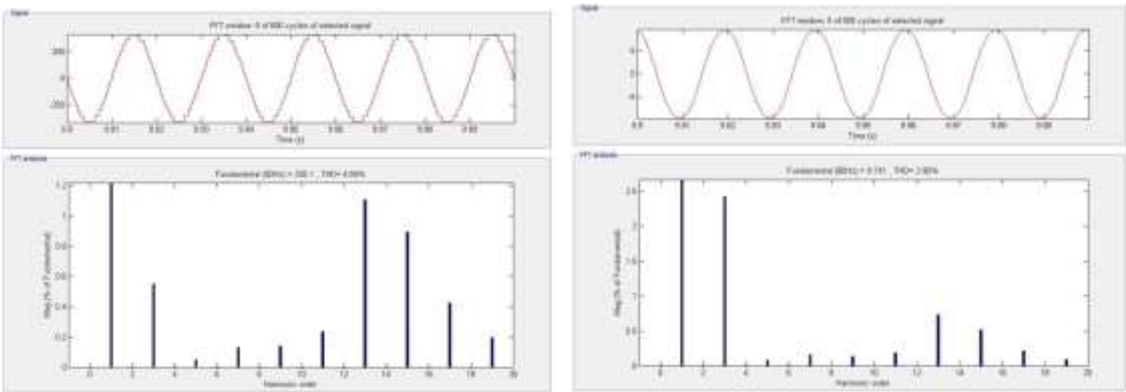
(a) (b)

Figure 11. 13-level inverter M load (a) Voltage THD% (b) Current THD%



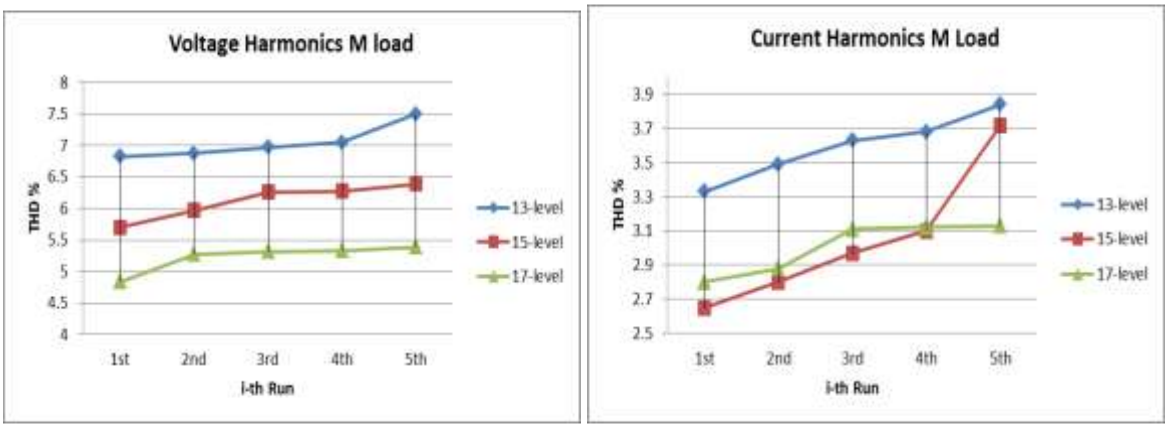
(a) (b)

Figure 12. 15-level inverter M load (a) Voltage THD% (b) Current THD%



(a) (b)

Figure 13. 17-level inverter M load (a) Voltage THD% (b) Current THD%



(a) (b)

Figure 14. 13, 15, 17 Level inverter M load (a) Voltage THD% comparison (b) Current THD% comparison

4. CONCLUSION

The comparison between thirteen, fifteen and seventeen level of cascaded H-bridge inverter has been done using Matlab. The results indicate when the number of level increases the total harmonic distortion decreases. For RL load the current harmonics are minimized to a greater extent. But as the number of level increases, more switching devices has to be incorporated which results in more switching losses and reduced efficiency. Depending upon the application of load, cascaded H-bridge inverter can be suitably designed, utilizing genetic algorithm for switching angle estimation, with minimum total harmonic distortion.

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