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A NEW ALGORITHM WITH DIFFERENT MODULATION INDEX (MI) IN CASCADED H-BRIDGE MULTILEVEL INVERTERS (CHB MLIS)

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ABSTRACT

The output waveforms of the multilevel inverters must be maintained smooth and not highly contents of the harmonics.Due to that the research of the multilevel inverters is still relevant to explore. For maintaining sinusoidal of the output waveforms of the multilevel inverters the design of an appropriate controller is crucial, hence the best controllers must be chosen. The suitable and its performance of the controllers will determine whether the output waveforms of the multilevel inverters can reduce the harmonics contains or not. This research aimed to investigate the performance of the Firefly Algorithm (FFA) which is applied to the modified cascaded H-Bridge multilevel inverters (MCHBMLIs) for five levels for harmonics reduction of the MCHBMLIs output waveforms especially for the currents and the voltages with different modulation index (MI). FFA is considered as an easy way which is aims to compute of the switching angle to be optimized for harmonics reduction in the proposed inverters.The concept is based on the Selective Harmonics Elimination (SHE) and the FFA is capable to reduce the lower order harmonics in the output voltages and currents of the waveforms. In order to validate the effectiveness of the proposed algorithm a simulation model has been built up. The parametric model of the simulation to be a benchmark to build up a prototype. Finally the experimental results are a good agreement with the simulation results.
Keywords: Firefly Algorithm (FFA), harmonics, SHE, modulation index(MI).

1. INTRODUCTION

The contain of the harmonics of the inverter output totally depends on the inverter types in the cases for examples two or multilevel inverters. The low frequency harmonics can only be eliminated in two methods; The first method is that through an increasing the switching frequency in Sinusoidal Pulse Width Modulation (SPWM) and Space Vector Modulation (SVM). Another way is through computing the switching angles using SHE techniques. In CHB-MLI the total harmonic distortion depend on: The grid connected of a single phase of inverters has been detailed up in [1,2]. It is noted that among the benefits of the three levels of the inverters are that its switching is considerably high, however it have the problems in term of the losses of the switching. and the interference with other equipments as well. In[3,2] The harmonic levels of the inverters can be reduced by the way, through improving its waveforms. Others methods for reducing the harmonics contains are use of the filter size. The capabilities to solve the problems of the electromagnetic interference (EMI) generated by the inverters switching operation also contribute to reduce the harmonics, these can be found in [2,3].. he benefits of using the Multilevel inverters are that its output voltage waveforms almost sinusoidal. Meanwhile the current waveform output with better harmonic profile, less stressing of electronic components owing to decreased voltages. Others benefit its switching losses are lower compared to conventional two-level inverters, besides that the use of a smaller filter size, and lower EMI, all of which make them cheaper, lighter, and more compact [3], [4]. [5], [6], [7], [8], [9] All phases in diode clamped inverter is sharing each others to a common DC bus, which is considered gives an advantages to the diode clamped inverters.

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In practical the topology of this type of the inverter mostly uses in high voltage application. In term of its efficiency this inverter has high efficiency. The main problem faced by the diode clamped inverter is that the output limitation of the voltage waveform. [10-21].

Furthermore, other inverter is flying capacitor which is capable to operate at voltage higher than the blocking capacity of each power cell. Normally the power cell components are that a diode and switching element. Another advantage is that one DC source is used and it has switching redundancy within the phase in order to balance the flying capacitor. There is no transformer used in flying capacitor multilevel inverter so the power losses can be reduced. Hence, real and reactive power flow can be easily controlled. The disadvantages of this topology are that the uses of a large number of capacitors will cause short duration outages and deep voltage sags and pre charging of capacitors is important and difficult.

Practically the advantages of the Modified H-Bridge Multilevel Inverter is that the DC buses can easily regulates and its control of the modularity not difficult to operate. In this topology the component uses are less with the performance maintained as conventional topology. The issues such as bulky and lossy resistor-capacitor in Modified H-Bridge Multilevel Inverter practically can be solved by using the method of the diode Snubbers soft-switching.

The main purposes of this paper are that to implement an FFA algorithm to the modified CHBMLIs as this algorithm still not many researchers make towards the detailed up of the study in order to analyze the THD values with the different MI of the output of the inverter for the currents and the voltages.

2. THE MODIFIED CHB-MLIS TOPOLOGY'S

Figure 1A shows the topology of the Modified of CHBMLIs for five levels with reduces of the components The benefits of the proposed topology are that the components uses can be reduced without gives effect to the quality of the waveform In short it performs almost the same as conventional one evenhough the component uses have been reduced. The topology in this work consists of a DC Bus comprising two capacitors in series connected to DC source. Another part which is called an auxiliary circuit. This circuit consists of four diodes and a switch. They are placed between the DC bus capacitors and the full-bridge inverter and their function is to produce half-level DC bus voltage. An inductance L and resistance R is considered as a load.

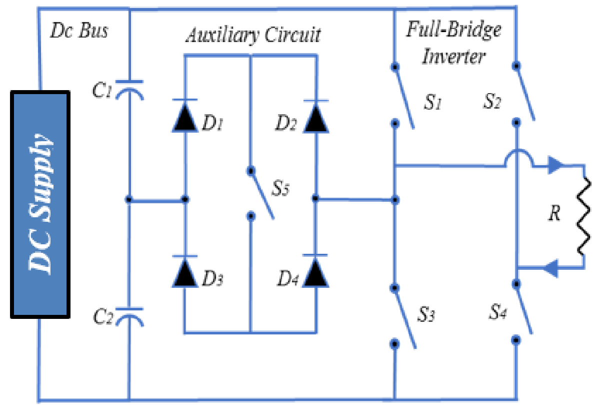

Fig 1: A Single-phase of a modified CHB-MLIs. for five levels.

3. ALGORITHM DEVELOPMENT OF A SINGLE PHASE OF MODIFIED CHB-MLIS FOR FIVE LEVELS

In practical the five levels of the multilevel inverter has a equations based on the Fourier series can be summarized as illustrayed below(Vijayakumar, 2015):

$f(t) = f_{\theta 1}(t) + f_{\theta 2}(t) =$

$\sum_{n=1,2,5}^{\infty} \frac{2Vdc}{n\pi} (V_{dc1} \cos(n\alpha_1) + V_{dc2} cos(n\alpha_2)$ (1)

where:

Vdc : Voltage of each voltage source that was in unity

θi : The switching angles

From (2-1), four equations were resulted in eliminating the 1st, 3th harmonic.

$$V_{AN} = V_{dc1} + V_{dc2}$$

$$b_n = \frac{2V_{dc}}{\pi} \begin{Bmatrix} \cos(n\alpha_1) + \cos(n\alpha_2) + \cos(n\alpha_3) + \cos(n\alpha_4) + \\ \cos(n\alpha_5) + \cos(n\alpha_6) \end{Bmatrix} n = 1,3,5,7,..$$

(2)

Eq. (2) has s variables $(\theta_1, \theta_2, \theta_3, \ldots, \theta_s)$, where 0 $< \theta_1 < \theta_2 < \theta_3 \ldots < \theta_s < \pi/2$, and a solution set is obtained by assigning a specific value to the fundamental component, Vf, and equating s-1 harmonics to zero as given below:

$V_1 cos(\theta_1) + V_2 cos(\theta_2) = 2m$

$V_1 cos(3\theta_1) + V_2 cos(3\theta_2) = 0$

(3)

where m = Vf /(2Vdc/ π), and it is related to the MI by MI = m/s, where 0 < mi <1.

An objective function is then needed for the optimisation procedure selected as a measure of effectiveness of eliminating selected order of harmonics while maintaining the fundamental component at a pre-specified value. Therefore, this objective function is defined as:

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$$F(\theta_1,\theta_2, \ ,\theta_s)=\left[\sum_{n=1}^{s} V_1\cos(\theta_n)\text{-m}\right]^2+ \left[\sum_{n=1}^{s} V_2\cos(3\theta_n)\right]^2+\ldots\ldots+ \left[\sum_{n=1}^{s} V_s\cos(2s-1)\theta_s\right]^2$$
(4)

The optimal switching angles are obtained by minimising Eq. (4) subject to the constraint $0 < \theta_1 < \theta_2 \quad \pi/2$, and consequently the required harmonic profile is achieved.

4. FIREFLY ALGORITHM

In fact that the concept of the Firefly algorithm has been introduced by Xian-She Yang In the late in 2007 and early 2008.. The concept of the Firefly algorithm more focused on the metaheuristic algorithms There are three rules of the metaheuristic algorithms namely social behavior, interaction and communication between fireflies. Fireflies generate bioluminescence flashes to communicate with mates or to attract prey. In [13] has discussed the details of the three rules of the firefly algorithm as follows;

There are no specific sex of the Fireflies ,they are known as unisex . One firefly will be attracted to other fireflies regardless of their sex..

The relationship between attractiveness and brightness is proportional to each others. When the distance of the Fireflies increases the attractiveness and the brightness decreases. The less brighter of the one firefly,, it will move to the brighter firefly,if all the fireflies have no brighter, 9n this situation they will move randomly.

The landscape of the objective function plays a vital role towards determining the brightness of the fireflies

An example of the Firefly Algorithm
Objective (cost) function
f(y), y=(y1,...............y ci)T
Generate initial population of fireflies yi (i=1,2,.........,n
Light intensity Ii
Define light absorption coeficient z
while(t<MaxGeneration)
for i =1 : n all n fireflies
for j=1 : i all n fireflies
if (II>iJ) / #in the case of maximization II < iJ
More firefly i toward j in d-dimension; end if
Attractiveness varies according to the distance r via exp[-r]
Evaluate new solutions and update light intensity end for I end for j
Rank the fireflies and find the current best end while postprocess results and visualization Figure 2 shows the fow chart of the Firefly algorithm

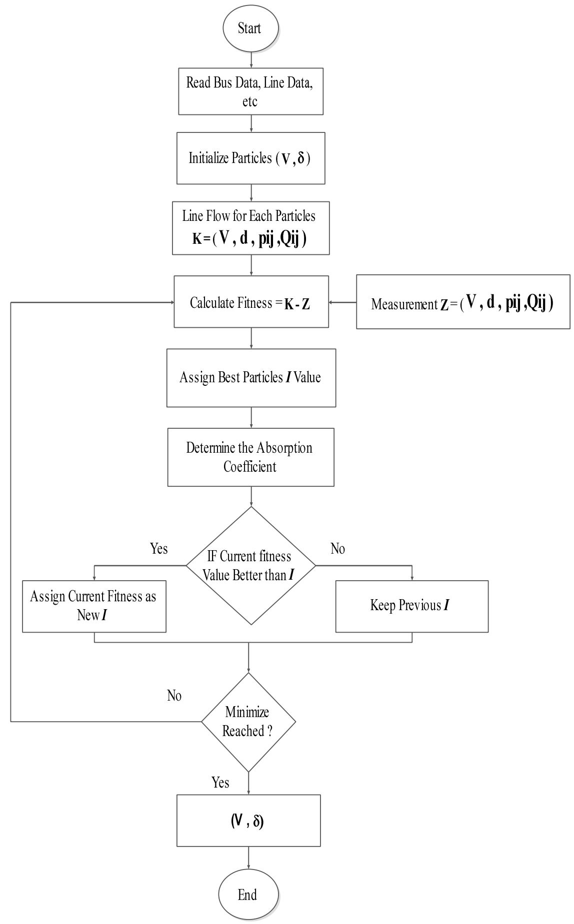

Fig 2. Shows the fow chart of the Firefly algorithm.

5. THE CONCEPT OF THE OPERATION OF THE MODIFIED CHB-MLIS FOR FIVE-LEVELS

As a solution, this work presents a five-level PWM inverter with output voltages zero, + l/2Vdc, Vdc, -l/2Vdc, and -Vdc as shown in Fig 3. Increased number of output levels reduces harmonic content.

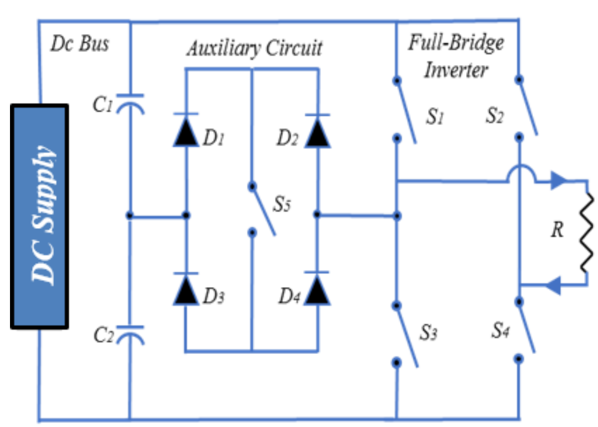

Fig 3. Proposal Modified of a CHB-MLI, Single-Phase Five- level Topology.

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Topology are explained in this section. Fig.4 State A shows the equivalent power circuit of proposed inverter to generate the output voltage level Vdc. Power switches S1 and S4 are in state 1 to achieve Vdc voltage level. Fig.4 State B shows the equivalent power circuit of proposed inverter to generate output voltage level Vdc/2. Power switches S4 and S5 are in state 1 to achieve Vdc/2 voltage level. Fig.4 State C shows the equivalent power circuit of proposed inverter to generate the output voltage level zero. To achieve zero level power switches S3 and S4 are in state 1. Fig.4 State D shows another possibility to obtain the zero, voltage level. Power switches S1 and S2 are in state 1 to generate the zero level. Fig.4 State E shows the equivalent circuit of proposed inverter to generate output voltage level -Vdc/2. To generate -Vdc/2 voltage level power switches S2 and S5 are in 1 state. Fig.4 State F shows the equivalent circuit of proposed inverter to generate output voltage level -Vdc. To generate -Vdc voltage level power switches S2 and S3 are in state 1. To depict each switch's switching pattern, represents the switch or diode in conducting mode, '0' for non-conducting mode.

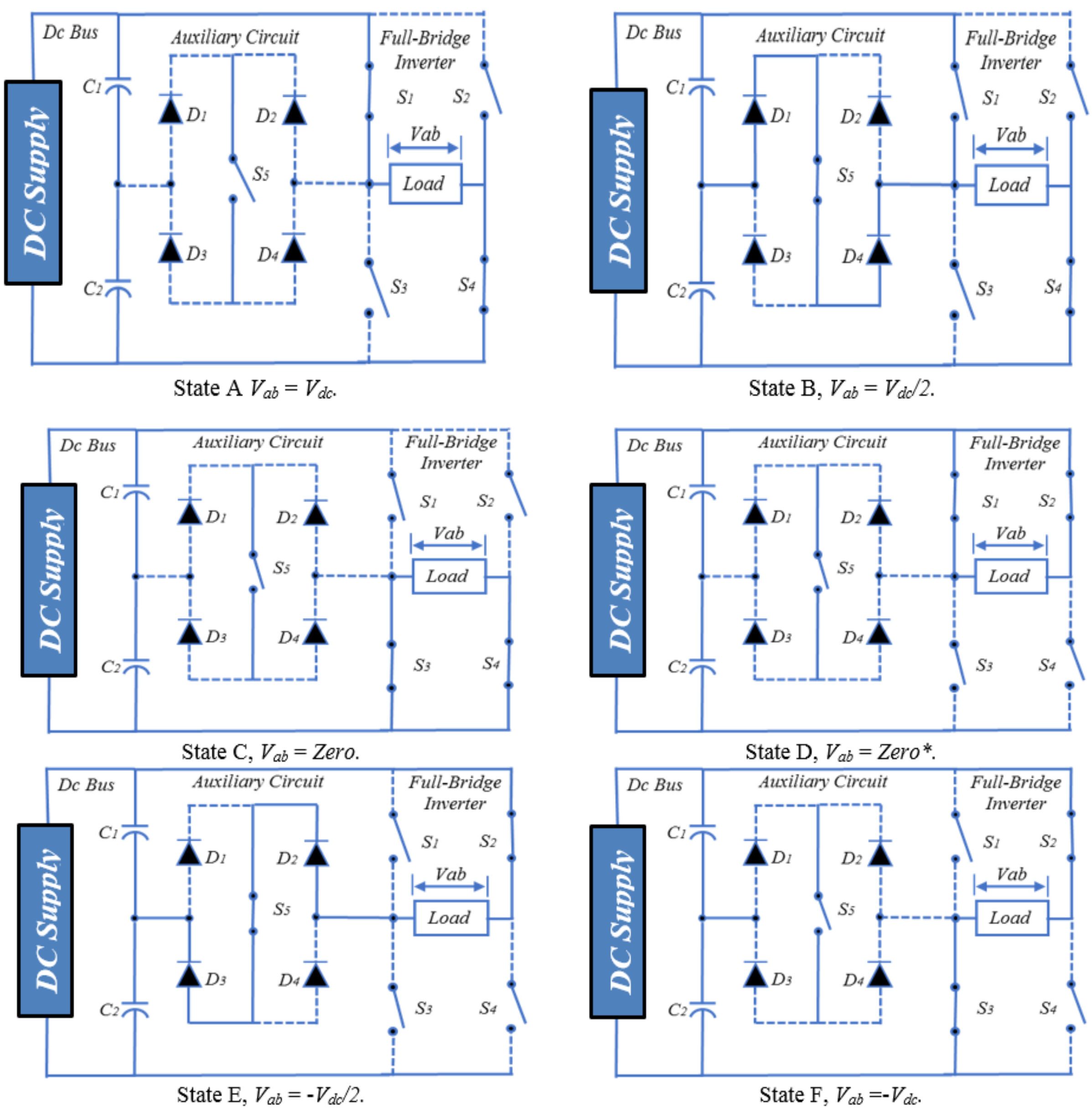

Fig 4. Switching operation modes of modified CHB-MLIs for five levels.

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The switching pattern or called the timing diagram of the proposed topology can be illustrated in Figure 5. As detailed up in Table 1,'l' represents switch or diode in mode operation and '0' is for the non-operation mode.

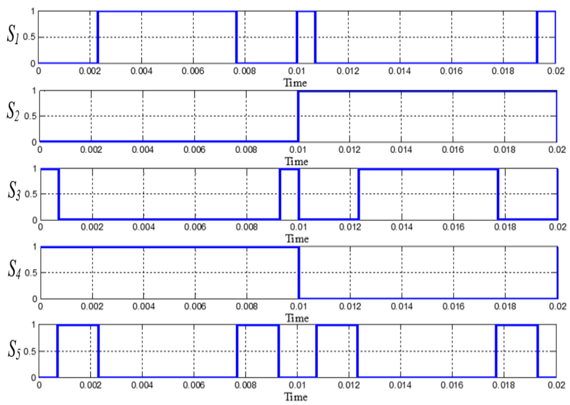

Fig 5. Switching pattern of a five-levels modified CHB-MLIs.

Table 1. Output Voltages O A Single Phase Of Modified CHB-Mlis For Five Levels

Voltage State	S_1	S_2	S_3	S_4	S_5	Vo
A	1	0	0	1	0	V_{dc}
B	0	0	0	1	1	$V_{dc}/2$
C	0	0	1	1	0	0
D	1	1	0	0	0	0*
E	0	1	0	0	1	$-V_{dc}/2$
F	0	1	1	0	0	$-V_{dc}$

The block diagram of the ovaerall proposed control of a modified CHB-MLIs by using firefly algorithm (FFA) as shown in Fig.6. Dc source has been supply to modified CHB-MLIs based on optimization FFA technique with in inductive load.

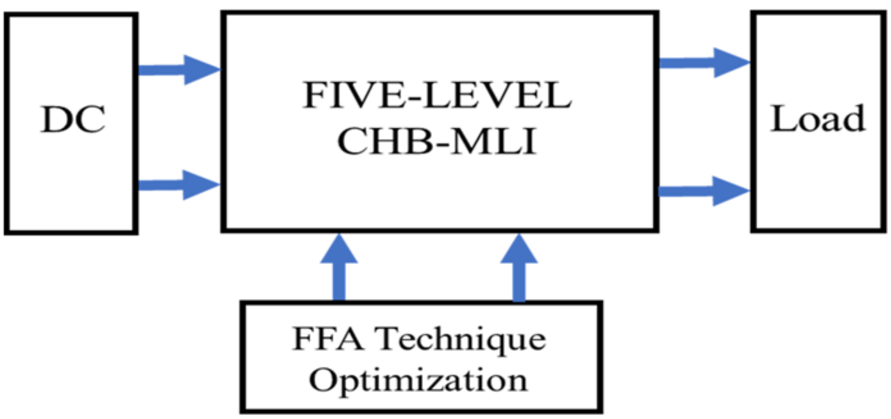

Fig 6.A Block Diagram Of Modified CHB-Mlis And Its Proposed Controller Using Firefly Algorithm.

6. SIMULATION RESULTS AND DISCUSSIONS

The circuit diagram as shown in Figure 6 has been modelled by using MATLAB/Simulink. The algorithm based on FFA has been created, then applied to the proposed topology. The modulation index (MI) is set at different values for examples its values is adjusted at 0.55 and 0.99 the calculation of the differences of MI will be solved by the FFA algorithm with the calculation of the correct angles In the case of the minimum value of the MI of 0.55 the output voltage and current waveform of the modified CHB-MLIs can be illustrated in Fig.7 . The THD values of the voltage waveform is about 32.29% as shown in Fig 8, moreover the values of THD for current can be illustrated in Fig 9.

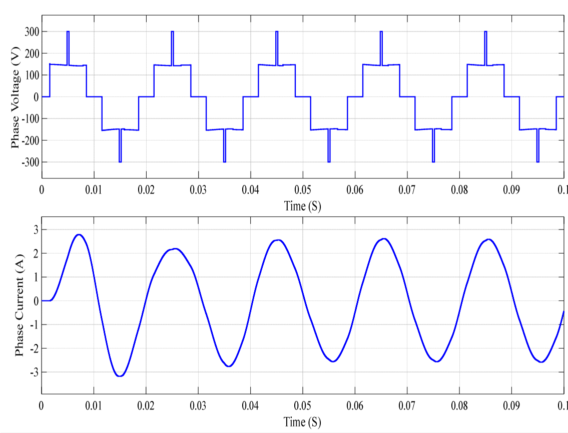

Fig 7. Non Optimization Voltage and Current Waveform Output of 5-level CHB-MLI with MI=0.55.using FFA technique.

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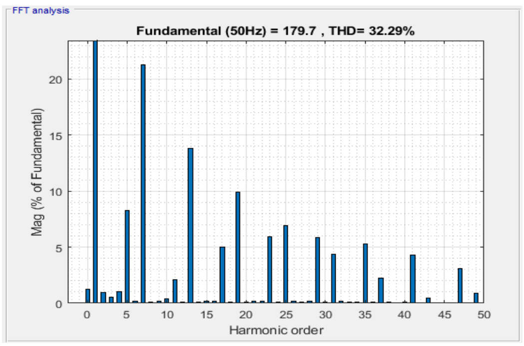

Fig 8. Non Optimization harmonic spectrum of single-phase output voltage waveform using FFA technique.

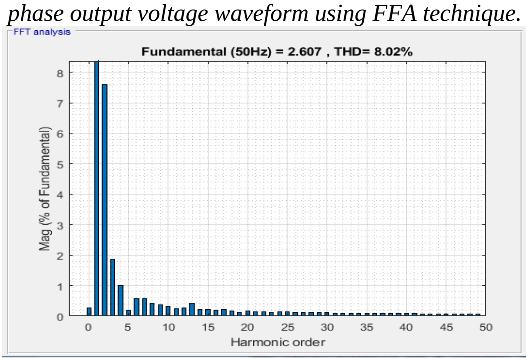

Fig 9. Non Optimization harmonic spectrum of single-phase output current waveform using FFA technique.

Further investigation of the simulation based on the FFA algorithm by calculating the correct angle for the optimal value. The MI is slightly increased through the correct switching angles of the calculation the maximum value of the MI supposed to be 0.99.As the outcome of the output voltage and current waveforms of the modified CHB-MLIs are smooth and to be optimized as shown in Fig.10. The THD values of the voltage waveform is about 14.93% as shown in Fig 11, moreover the values of THD for current can be illustrated in Fig 12.

Since the optimized values of the MI are obtained at 0.99 this value is considered a maximum value of the MI with the smooth waveforms of the voltage and current. This value of the MI also be a benchmark for the coding in the hardware implementation.

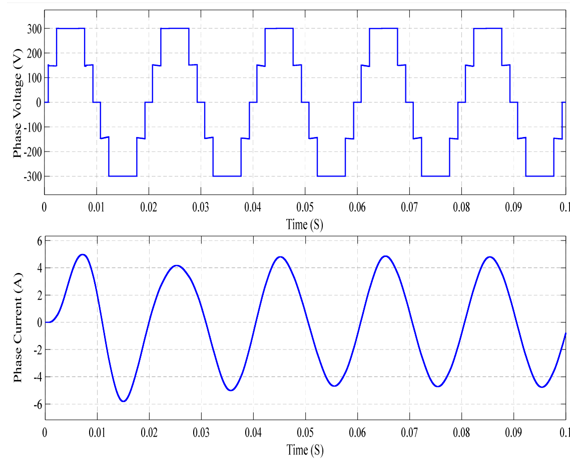

Fig 10. Optimization Voltage and Current Waveform Output of 5-level CHB-MLI with MI=0.99.using FFA technique.

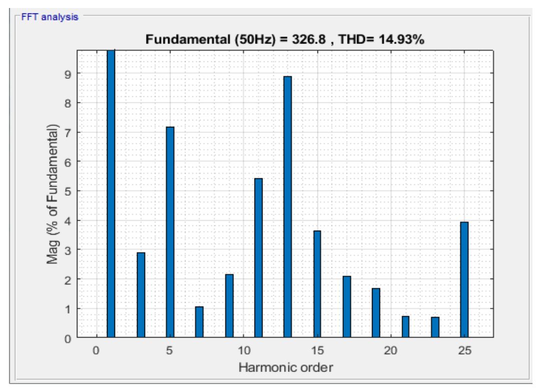

Fig 11. Optimization harmonic spectrum of single-phase output voltage waveform using FFA technique.

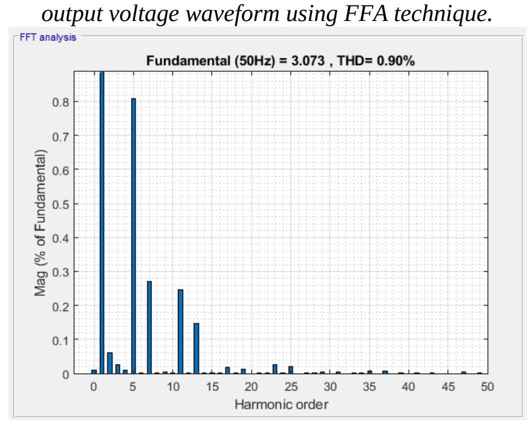

Fig 12. Optimization harmonic spectrum of single-phase output current waveform using FFA technique.

The THD values with the various switching angles for the currents and the voltages are obtained from the FFA algorithm as tabulated in Table 2.The voltages and the currents THD values have been plotted as described in Fig 13.

Table. 2. The values of switching angles and voltage and current THD for 5-level CHB-MLI and proposed FFA algorithm.

MI	θ_1	θ_2	THD_V	THD_I
0.55	36.668	72.668	32.29	8.02
0.99	12.915	42.156	14.93	0.90

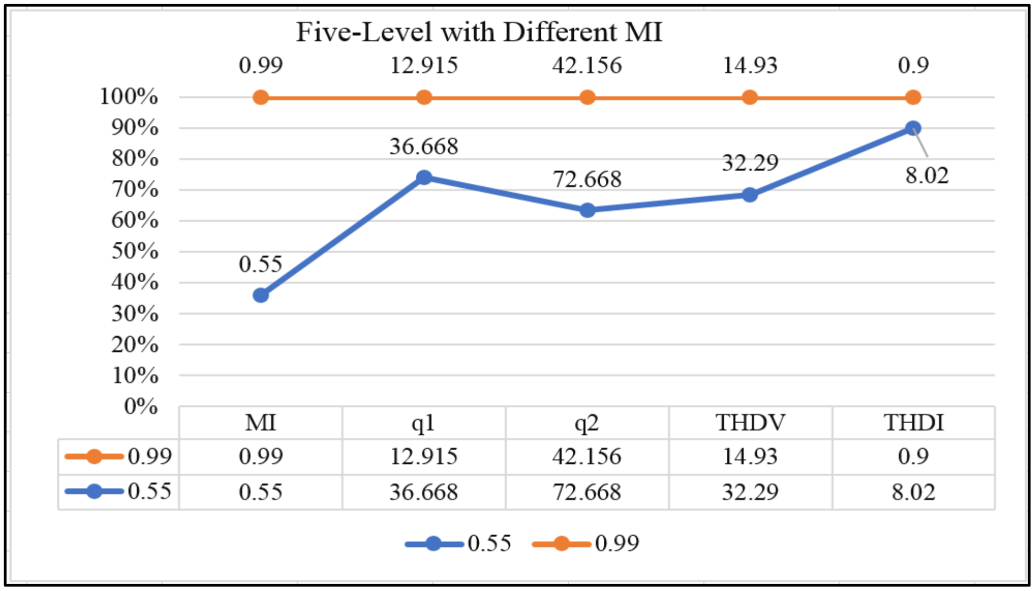

Fig 13. Overall values of MI, versus the switching angles and the values of THD for voltage and current.

Basically the switching angles of the Firefly algorithm always varies and its ranges within 0 to 90 degrees. Surprisingly the THD values obtained from the proposed algorithm are lower compared to the other iterative solution. From the analyzed found that the THD values of the highest voltage waveform are around 14.63%, meanwhile the lowest value of the voltage waveform is found to be 33.2%.

7. EXPERIMENTAL SET-UP

The construction of the five, levels of modified CHB-MLIs involves integrating the 5 pieces of power switching semiconductor IGBTs - IHW30N90T with snubber circuits, as shown in Fig 14 IGBT possessed the capability of operating up to 100 kHz switching frequency and in supplying electric current at 60 A at 25 ^oC, and in becoming 30 A when the temperature of the IGBTs reached 100 ^oC. Normally, it can operate at 600 volt DC towards the break down voltage at 900 volt DC.

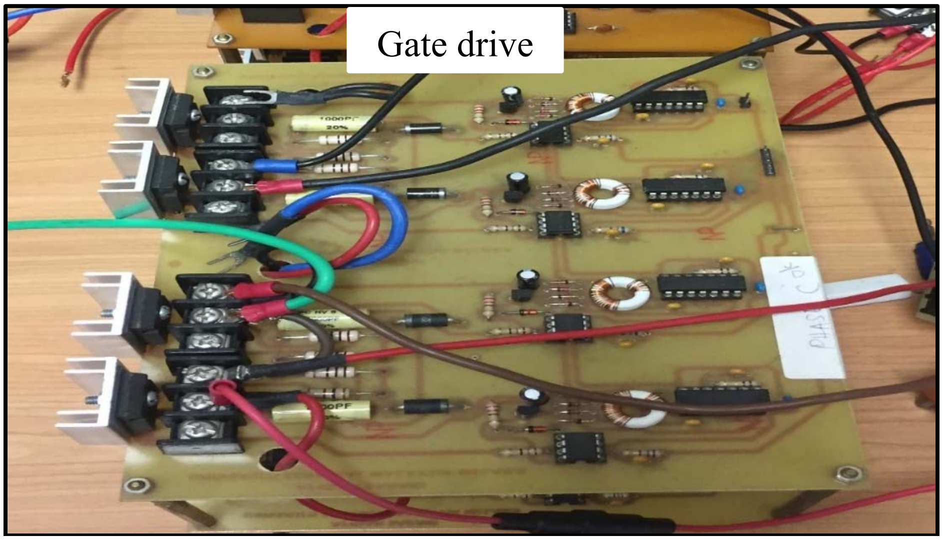

Fig 14. The development of a Gate drive for single-phase of modified CHB-MLIs for five-levels.

All the parameters obtained from the model of the simulations were used towards to develop a prototype in order to validate whether the proposed algorithm is applicable or not. The source code creation using FFA algorithm. The created source code, then integrated and stored into the DSP-TMS320F2812. The control signals based on FFA algorithm were created and running with the DSP TMS320F2812. The MI used for the optimized value of 0.99 with the correct calculation switching angles based on FFA algorithm. Fig 14 showed that the proposed prototype and its components with the switching frequency of 2500Hz. As the same with the parameters used in the simulation model by using the MI about 0.55. The switching angles based on MI=0.55 are inaccurate level or not optimized will causes non optimization of the produced waveform of the voltage and the current as shown in Fig.16. In the case of the the non-optimisation of phase output voltage waveforms, the nonaccurate calculation of the switching angles obtained are θ_1=36.668^0 and θ_2 =72.668^0 with MI=0.55 as shown in Fig 15. as shown in Figure 16, Figures 17 and 18 show the non-optimisation harmonic spectrum of the output voltage and current waveform of a single-phase modified CHB-MLIs for five levels using FFA with THD voltage and current values equivalent to 34.3% and 8.2% respectively.

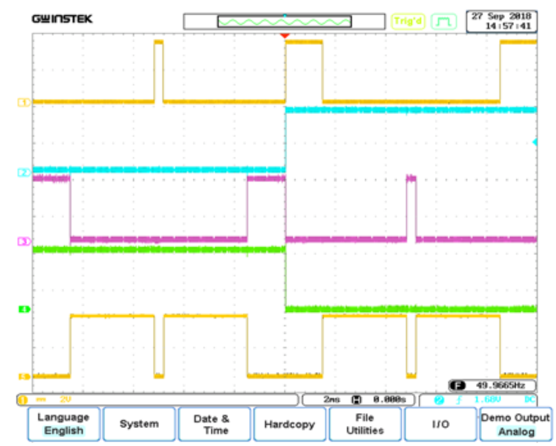

Fig 15. Timing diagram of a modified CHB -MLIs with MI=0.55 using FFA technique.

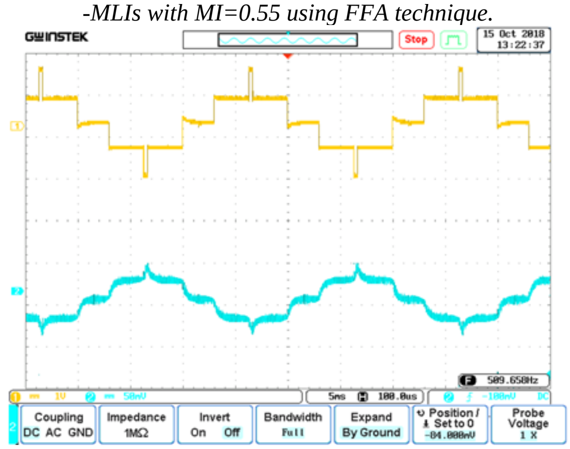

Fig 16. Non-optimisation of output voltage a and current waveform of a five-level CHB-MLIs with MI=0.55 using FFA technique.

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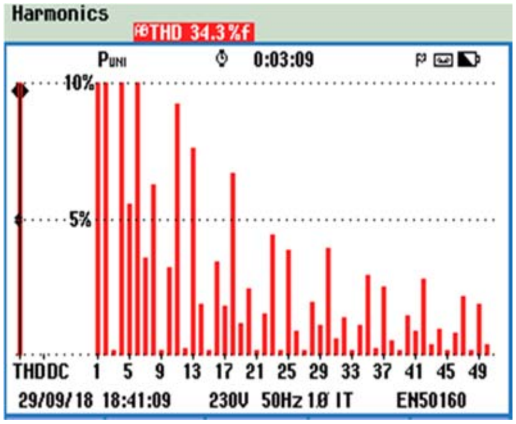

Fig 17. Non-Optimisation harmonic spectrum of a single -phase output voltage waveform using FFA technique.

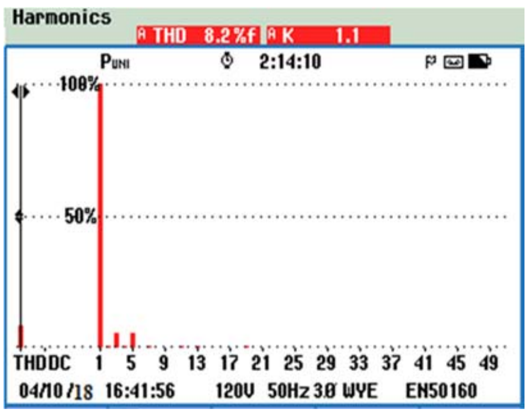

Fig 18. Non-Optimisation harmonic spectrum of a single-phase output current waveform using FFA technique.

The optimized waveforms in term of the voltage and current output of a single-phase modified CHB-MLIs for five levels can be illustrated in Figure 20. The optimization of phase output voltage waveforms based can only be produced through the corrent calculation of the switching angles. The correct switching angles are obtained are θ_1=12.9154^0 and θ_2 =42.1565^0 with MI=0.99 as shown in Fig 19. Figures 21 and 22 show the optimal harmonic spectrum of the output voltage and current waveform of a single-phase modified CHB-MLIs for five levels using an FFA algorithm with THD voltage and current values equivalent to 14.8% and 3.9% respectively.

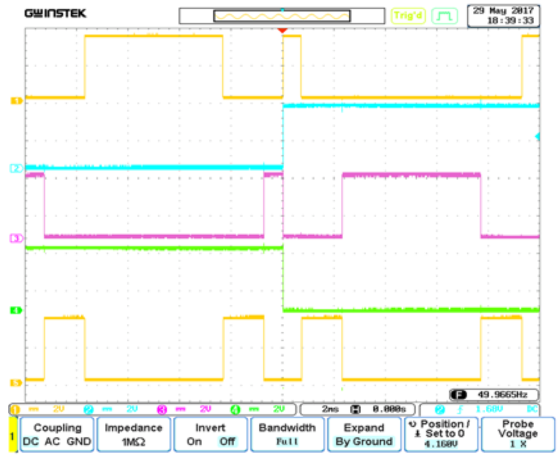

Fig 19. Timing diagram of a modified CHB-MLIs with MI=0.99 using FFA technique.

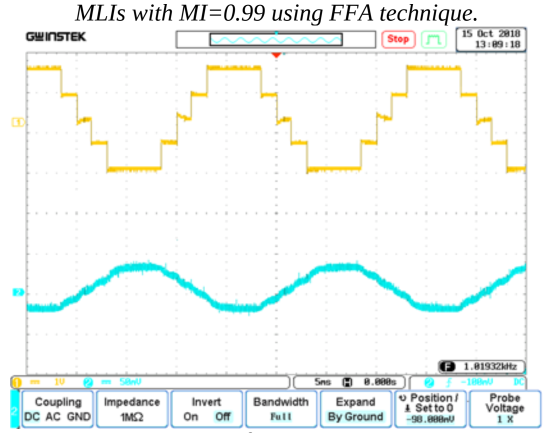

Fig 20. Optimisation of output voltage a and current waveform of a five-level CHB-MLIs with MI=0.975 using FFA technique.

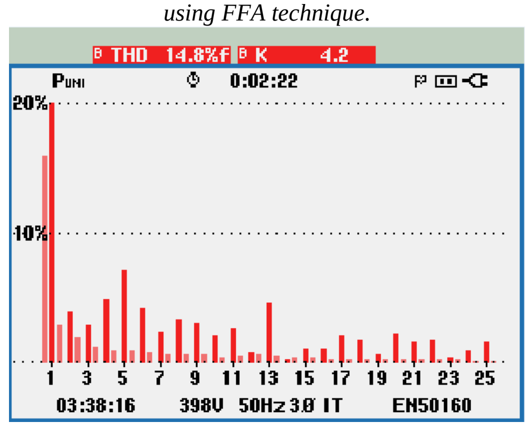

Fig 21. Optimisation harmonic spectrum of a single-phase output voltage waveform using FFA technique.

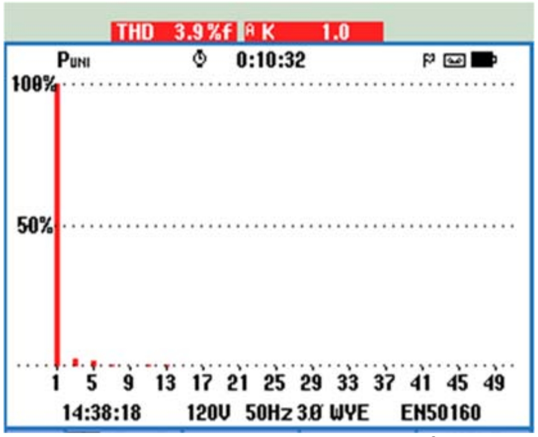

Fig 22. Optimisation harmonic spectrum of a single-phase output current waveform using FFA technique.

8. CONCLUSION

The performance of the CHBMLIs for five levels can be observed through the output waveforms obtained especially for the currents and the voltages. The output of the waveforms is totally depending on the MI values. The proposed algorithm has capabilities in reducing the harmonics contain of the output waveforms of the CHBMLIs compared with others algorithms such as Newton Raphson (NR) and Particle Swarm Optimization (PSO).Simulation and experimental results proved that the FFA algorithm is suitable in reducing the harmonics contain bases on the International Electrical Committee (IEC) standard.

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