Reduction of Total Harmonic Distortion (THD) on Multilevel Inverter with Modified PWM using Genetic Algorithm

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Abstract

In this research, modified PWM has been applied to the multilevel inverter (MLI) single-phase three-level diode clamp full bridge. Modified PWM is performed to produce minimum Total Harmonic Distortion (THD) the voltage because the quality of the good voltage is indicated by small THD. The THD indicates the quality of AC voltage source. The THD standard by the IEEE STD 519-1992 Harmonic Voltage Limits is 5% and the Pacific Corp standard is 8%, if the THD value is greater than the THD standard it can cause the electronic load to be damaged due to the damaged waveform. Modified PWM is applied by adding a 50 Hz sinusoidal reference signal with a sinusoidal signal which has a certain amplitude, frequency and phase shift angle. The frequency of the adder signal is the frequency at which the value of the individual harmonic voltage appears (n harmonic). To get maximum result, optimization using Genetic Algorithm (GA) method to determinate amplitude & phase shift angle done. The result of implementation hardware with modified PWM shows smaller THD voltage compared to the THD voltage with Sinusoidal Pulse Width Modulation (SPWM) switching up to 0.19 or decrease 65,51 % for modified PWM of harmonic injection n = 7 with GA optimization *ma*= 0.8 (A=0.0936 and ø = 0 rad) and up to 0.08 or decrease 12,30 % for modified PWM of harmonic injection n = 22 with GA optimization *ma* = 0.4 (A=0.1221 and ø = 0 rad).

Keywords: *Multilevel Inverter, Modified PWM, Genetic Algorithm.*

1. INTRODUCTION

The increasing need for electrical energy sources encourages people to use renewable electricity. The most popular renewable energy is photovoltaic. Photovoltaic is a component that utilizes sunlight to produce voltage. The resulting voltage of a photovoltaic is a DC voltage. DC voltage cannot be directly used because the existing electrical system is dominated by the electric load with AC voltage source. Thus, it requires a tool to convert DC voltage into AC voltage.

Many technological developments concerning the conversion of voltage from DC to AC voltage have been done by the researchers [2][3][7][14][23].

Inverter is a device used to convert DC voltage into AC voltage that utilizes the switching conditions of a switch component to produce AC voltage. The output voltage of the inverter still has a low voltage quality that is indicated by a very large Total Harmonic Distortion (THD). This voltage requires a filter to produce the output voltage with minimum THD voltage so as to generate a suitable sinusoidal wave for the voltage source [12]. THD is a measurement of the quality of voltage or current. In normal conditions the output voltage form is a sinusoidal wave where THD is close to or equal to 0 (zero). THD is the percentage value between the total components of harmonics with its fundamental components. The greater the percentage of THD, the greater the risk of equipment damage. In accordance with the standards by IEEE STD 519-1992, the standard Harmonic Voltage Limits on the general system is 5% [27], and 8% is for Pacific Corp standard [28]. If the THD value is greater than the THD standard, it can lead to the destruction of electrical equipment, the burning of cable/conductor, overheat on the electric motor, and error on the electromechanical measurement of KWH meter.

To overcome this, the multilevel inverter was built to improve the output voltage quality of the conversion. Multilevel inverter output has better voltage quality than inverter [2][3][7]. The voltage quality is indicated by smaller THD. This is because multilevel inverters emit voltage wave on stages according to a level that resembles a sinusoidal form. One type of multilevel inverter is a multilevel inverter clamp diode [16]. This type would be used for the conversion tool from DC voltage to AC voltage.

The output voltage form of the multilevel inverter depends on the switching method used. Much research has been done on the topic of the switching method [1][9][14][17][19]. Shared methods were tested including Pulse Width Modulation (PWM), Sinusoidal Pulse Width Modulation (SPWM) and Third Harmonic Pulse Width Modulation (THIPWM) to produce voltage with minimum THD voltage. With the results presented in various papers and journals [4][5][12][21], the researchers tried to research the switching method used in multilevel inverters to obtain a minimum or very small THD voltage. In this study, the researchers have made modified PWM for multilevel inverter switching so that the THD output voltage is minimum. Modified PWM is done by adding a 50 Hz sinusoidal reference signal with a sinusoidal signal having a certain amplitude & frequency. The frequency of the adder signal is the frequency at which the value of the individual harmonic voltage appears (n harmonic). To get maximum result done by the optimization using Genetic Algorithm (GA) method to determinate the amplitude & phase shift angle. Genetic Algorithm is a method that is done based on the biological principle that is natural evolution. This algorithm is based on the genetic processes that exist in living things, namely the development of generations from beginning to end. Therefore, whoever is strong, he is the one who survives. The Genetic Algorithm Method is used to obtain variable amplitude & phase shift angle.

2. RELATED WORKS

In a study by Ahmet M. Hava [1] with the title of A High Performance Generalized Discontinuous PWM Algorithm has been produced Discontinuous PWM algorithm that was tested on inverter three-phase as voltage source of motor. Discontinuous PWM test algorithm is performed in a laboratory under constant stress and frequency (constant) conditions on an induction motor with a capacity of 5 Hp 460 V 21 A. The dc voltage source used is 620 V. The frequency of the signal the keeper is 5 KHz. DSP was used in computing to compare the reference signal with the seeker signal. The Generalized Discontinuous PWM Algorithm (GDPWM) is generated from computing by applying the Switching Loss Function (SLF) algorithm ($\Psi = \varphi + \frac{\pi}{6} \leq \frac{\pi}{3} for\ motor$). In this study, the researcher compared various methods of PWM to produce Harmonic Distortion Factor or known as the minimum Total Harmonic Distortion. From the results of this study, it was obtained the best sequence of the type of Discontinuous PWM DPW M 3, DPW M 1, DPW M2, THIPW M 1/4, THIPWM 1/6; SVPWM, and SPWM. Using DGWM could lower harmonic distortion and losses on switching.

In a study by Xiaoming Yuan [26] with the title of Fundamentals of a New Diode clamping Multilevel Inverter has generated multilevel inverter topology with clamp diode type. Multilevel inverter on diode clamping type is designed for five-levels with one leg. Tests in this study were conducted on a laboratory scale with prototype generation of five-level clamping diode inverters with half bridges with 120 V DC voltage sources. In the test used inductor load of 8 mH connected in series with a resistor of 12 Ω that is connected between the outputs of the inverter with a neutral point. In the inverter modulation the harmonics of the 5th and 7th harmonics were performed and implemented. The research resulted that inverter with diode clamp type would help to form the level of inverter output voltage. In addition, the diode clamp type would reduce the unequal voltage between the voltage sources that were divided into the formation of the voltage level in the output inverter.

In a study by Olorunfemi Ojo [19] with the title of The Generalized Discontinuous PWM Scheme for Three Phase Voltage Source Inverter has generated signal modulation used for carrier signals on sinusoidal reference signals. Discontinue PWM was modulated to two-level on three-phase voltage generating inverters or so called Voltage Source Inverter (VSI). Modulation is generated by the inverter under balanced or unequal phase voltage conditions. In this research generation Generalized Discontinuous PWM was done by computing. The modulation function was generated by comparing high-frequency triangular (carrier) waves ranging from -1 to 1 with reference modulation waves. The Generalized Discontinuous PWM was indicated with $V_{pm} = 0.5\ V_d(1 - 2\alpha) - \alpha V_{min} + V_{max}(\alpha - 1);$ with $\alpha = 1 - 0.5 \left[1 + Sgn[Cos\ 3(\omega t + \delta)]\right];$ Sgn(X) =1, 0.0, and -1 if X is positive, 0 and negative.

In a study by Said Barkati [22] with the title of Harmonic Elimination in Diode Clamped Multilevel Inverter Using Evolutionary Algorithms generated comparison of results for harmonic optimization. The result was that the harmonic of multilevel inverter out was with a minimum value. The optimized method used was Genetic Algorithm (GA) and Particle Swarm that was applied for switching angle computing on three-phase seven-level inverter. In the optimization process using GA, the researchers did the optimization at the angle of the shift done on the reference signal that was $\alpha_1, \alpha_2, \alpha_3$. GA parameters used were Population = 100, Generation = 100, Crossover Probability = 0.33 and Mutation Probability = 0.33. It was observed that the maximum modulation (m) at 1.07. Parameter Particle Swarm run for 20 particles with w = 0.75, p_incr = 1.8 and g_incr = 1.8.

In a study by Reza Salehi [21] with the title Elimination of Low Order Harmonics in Multilevel Inverter Using Genetic Algorithm has been produced the process of eliminating harmonics with Selective Harmonic Elimination Pulse Width Modulation (SHEPWM) applied to multilevel inverter with cascade type of inverter with nine-level. SHEPWM was done using the Genetic Algorithm (GA) optimization method. GA was implemented on nine-level inverter for harmonic elimination of 5, 7, and 11. For fitness values less than or equal to 10-2, it was expected to eliminate harmonics. Ms expected (feasible) can be seen on M = 0.34 [0.44-0.47], 0.51 [0.54-0.6], 0.63 [0.67-0.69], [0.73-0.85] and 0.92.

3. ORIGINALITY
In this study, the research originality is modified PWM of the reference signal by adding a certain signal as well as doing the GA optimization on amplitude and phase shift angle value of the adder signal. GA optimization process was done with *Matlab* and *PSIM* simulation Off-line. After obtaining the amplitude and phase shift angle value, it was applied to hardware to generate a new reference signal. The modified PWM was done with the aim of getting the correct switching signal so that the multilevel inverter output voltage has minimum THD value.

4. SYSTEM DESIGN

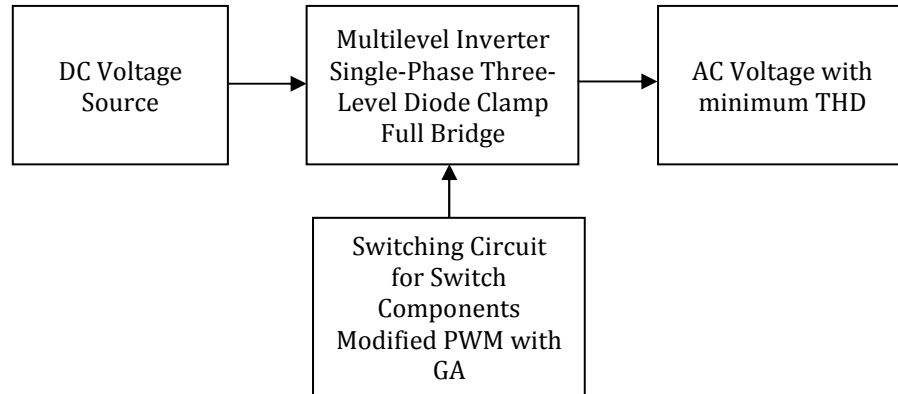Figure 1 shows the block diagram of the system reducing the THD output voltage of the multilevel inverter.

Figure 1. System Block Diagram

4.1 Multilevel Inverter

Multilevel inverter design is multilevel inverter single-phase three-level diode clamp full bridge according to the circuit in figure 2. The switching component used IRFP460 MOSFET. The voltage drive *Vgs* MOSFET was between 10 to 20 Volt dc. The IRFP460 *MOSFET* was used with current capacity = 20 Ampere with voltage *Vds* = 600 Volt dc. For the diode clamp, fast recovery diode with type R30120G2 was used. The fast recovery diode type was chosen because it adjusts to the magnitude of switching from the dc voltage entering the switching component, where the switching frequency for the carrier signal was 1 KHz. To provide Vdc/2 for multilevel inverter source, 220 uF capacitor mounted in series was used.
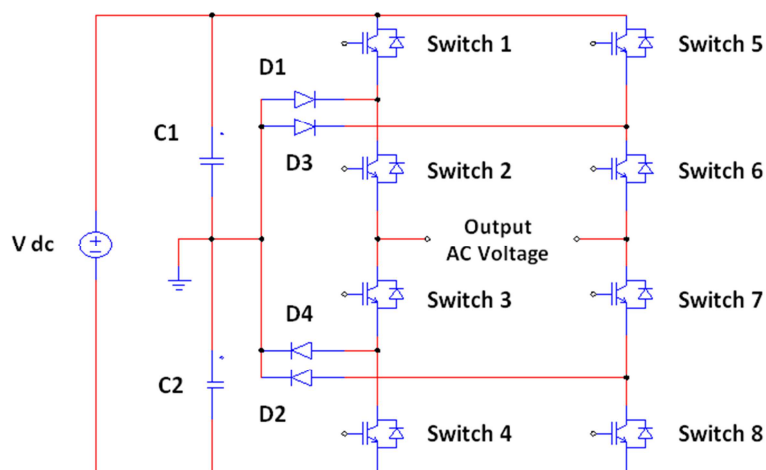

Figure 2. Multilevel Inverter Single-Phase Three-Level Diode Clamp Full Bridge

In multilevel inverters with diode clamp type, basically, the voltage of the clamping diode is used. The DC voltage source was divided into parts depending on the level, while the capacitor in pairs in series with a neutral point was between the capacitor in the middle. To know the parameters of multilevel inverter design with clamp diode type, observe the following:

$$Number\ of\ DC\ Capacitor = (m - 1) \tag{1}$$

$$Number\ of\ Diode\ Clamping = (m - 1) * (m - 2) \tag{2}$$

$$Number\ of\ switches = 2 * (m - 1) \tag{3}$$

$$Voltage\ on\ each\ component = \frac{V_{dc}}{m-1} \tag{4}$$

$$Minimum\ DC\ Voltage\ Source = 2 * \sqrt{2\ V_a} \tag{5}$$

Where :
   m is level for multilevel inverter
   Vdc is DC Voltage Source
   Va is Output Voltage Multilevel Inverter

The switching component condition in leg 2 was equal to leg 1 but there was an angular difference from the reference signal that was a sinusoidal signal of -120°. For Switch 3, it was complementary from Switch 1 while for Switch 4, it was complementary of Switch 2. Switch 1 and Switch2 were the reverses. In table 1 will be shown ON/OFF switching process for Multilevel Inverter Single-Phase Three-Level Diode Clamp for 1 leg.

Table 1.
Condition Switching for Voltage Each Leg

Level Voltage	Switch 1	Switch 2	Switch 3	Switch 4
Vdc/2	1	1	0	0
0 (Nol)	0	1	1	0
- Vdc/2	0	0	1	1

From table 1 above, condition 1 indicates switching condition ON, and condition 0 indicates switching condition OFF.

4.2 Switching Sinusoidal Pulse Width Modulation

The formation of the output voltage of the multilevel inverter depends on the switch components used by each leg. One of the switching methods of multilevel inverter is the method of Switching Sinusoidal Pulse With Modulation (SPWM). This method compares the sinusoidal signal   (A Sin ωt) as a reference signal with a triangle signal as a carrier wave. The carrier wave frequency must be greater than the frequency of the sinusoidal wave (*fc > fr*). In the process of forming switching with SPWM method there are two

important parameters namely amplitude and frequency modulation, which is denoted by *ma* and *mf.* Amplitude modulation index (*ma*) is the ratio between the amplitude voltage reference signal(V_{ref})and the amplitude voltage carrier signal($V_{carrier}$).

$$m_a = \frac{V_{ref}}{V_{carrier}} \tag{6}$$

While the frequency modulation index (*mf*) is the ratio between the frequency carrier signal($f_{carrier}$) and the frequency reference signal(f_{ref}).

$$m_f = \frac{f_{carrier}}{f_{ref}} \tag{7}$$

The switching condition ON/OFF was obtained by comparing sinusoidal signals with triangular stratified signals. The sinusoidal amplitude was 1 so as to have peak to peak = 2. As for the amplitude of triangular-level signal, the first level was -1 to 0 and the second level was 0 to 1. The frequency of the sinusoidal reference signal was 50 Hz and the frequency of the carrier signal was 1 KHz. In switching, microcontroller STM32F407 was used to generate signal switching to MOSFET. The signal was processed on microcontroller using signal generator function so that output from the microcontroller in the form of digital was in form of output condition of ON and OFF.

4.3 Switching Modified Pulse Width Modulation

Modified PWM signal was done by adding a certain signal with a reference signal that was a 50 Hz sinusoidal signal so that the output waveform of Multilevel Inverter resulted a minimum THD. This modified process was performed on switching method for Multilevel Inverter Single-Phase Three-Level Diode Clamp Full Bridge. Here was done a way to modify the PWM signal. Initially, we must know the magnitude of THD and the individual harmonic voltage to what appears on the output voltage wave Multilevel Inverter with SPWM switching. SPWM used the triangle carrier frequency of 1 KHz and the reference frequency of 50 Hz. The simulation would be taking data with *ma* which changes from 0.4 up to 0.8. The harmonics taken from n = 1 to n = 50 where the fundamental frequency was 50 Hz, so the range of frequency was between 0 Hz and 2500 Hz. After the data of THD and harmonics were obtained, it would be injected with the same signal on the frequency of the emergence of harmonics with the certain amplitude. Therefore, the modified PWM was done by adding a signal reference sinusoidal frequency 50 Hz with sinusoidal signal with frequency where the harmonics appeared. The circuit drawing is shown in figure 3.
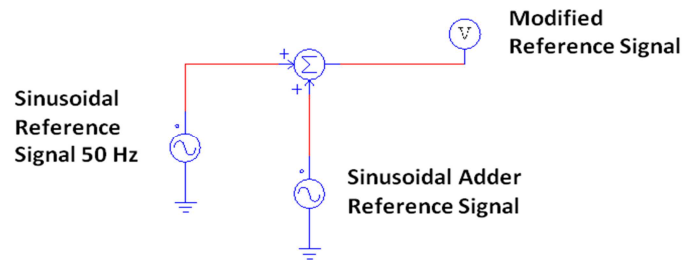
Figure 3. Modified Signal Reference

The modified was made by adding a sinusoidal signal with a certain frequency of each individual harmonic appearance. Thus, the merging of signals was done one by one to see the results of THD. Consequently, the mathematical equation of the signal incorporation is shown as in the following equation:

Sinusoidal reference signal is:

$$SignalRef = A_{ref} Sin\omega t \qquad (8)$$

Sinusoidal adder signal reference is :

$$SignalPe = A_{pen} Sinn\omega t \qquad (9)$$

So that the modified signal reference (Modified PWM) results is:

$$SignalModif = A_{ref} Sin\omega t + A_{pen} Sinn\omega t \qquad (10)$$

A_{ref} = Amplitude signal Reference

A_{pen} = Amplitude Sinusoidal adder signal

4.4 Optimization Amplitude and Phase Shift Angle with Genetic Algorithm for Switching Modified PWM

One of the solutions to get the best results on the system was done by using Genetic Algorithm method. The process of this method began with generating a number of populations randomly as an initial solution. The result of the initial random would be the parent of the next generation process. In this modified PWM process, the genetic algorithm method was used to get the best result that was minimum THD (very small). In this system there were two (2) variables of Amplitude (A) and phase shift angle (ø). The process of the Genetic Algorithm applied to this system is shown as in figure 4. The limitation of Amplitude (A) was between 0 to 1 while the phase shift angle (ø) was between 0 and 6.28 rad. Each chromosome contained a gene that encoded information stored in a chromosome. At the completion of the process using real number encoding with the gene value was at the interval of the numbers between 0 and 1. For real number encoding, a gen 'g' was used to represent a real number between 0 and 1. By

using a certain interval, the lower limit of r_b and the upper limit of r_a, the decoding could be done in the following way:

$$x = r_b + (r_a - r_b) * g \qquad (11)$$

After the chromosome encoding was done, the genetic algorithm was initialized for a population with N number of chromosomes. The genes on the chromosome were generated randomly with a uniform distribution. Each chromosome would be encoded into an individual with a fitness value of each. An individual was evaluated on the basis of a particular function as a measure of performance.
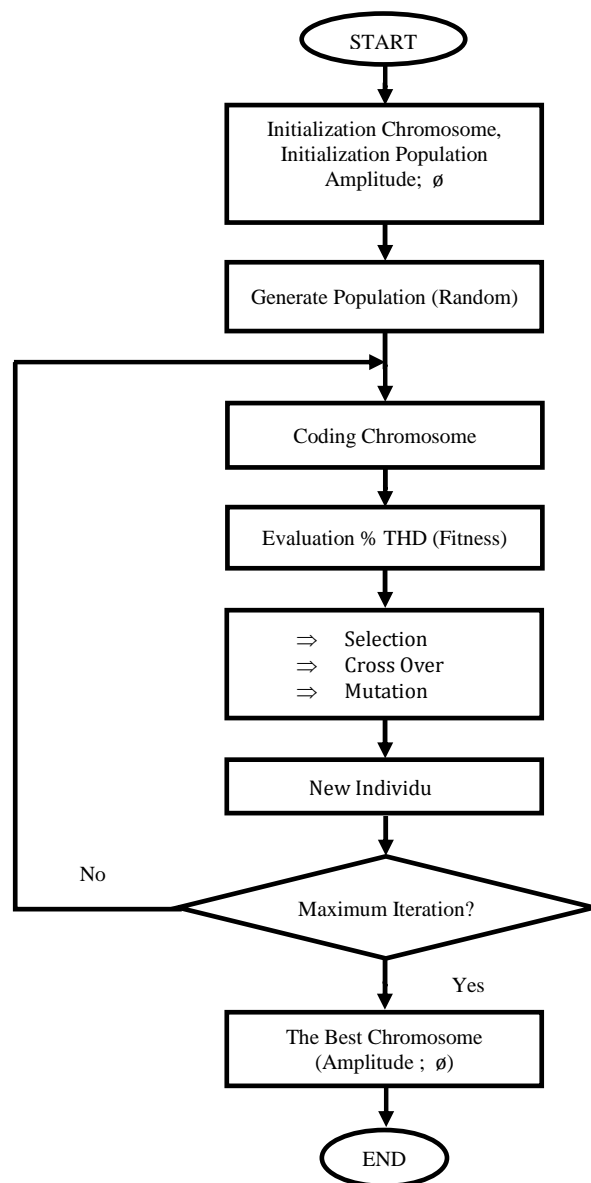
Figure 4. Flowchart Genetic Algorithm For System

In this system, evaluation was based on a small THD. In the evolution of nature, individuals who were of high fitness value would live so that these small THD were individuals who had great fitness values. This was due to the provision that individuals who had high fitness value could survive in the next generation. The fitness score reflected the measure of performance. Individuals with a large fitness value (*f*) were the best. In this system desired best results were with a very minimal size of THD. The value of THD was indicated by variable (*h*). In the Genetic Algorithm process, evaluation was indicated by the fitness value as in the equation :

$$f = \frac{1}{h} \tag{12}$$

In equation 12, the value of fitness (*f*) would be great if the value of *h* were smaller. Under certain conditions it is possible to $h = 0$ so that the fitness value becomes infinite. To avoid $h = 0$, it was added with a number that was considered very small i.e. *a*, so the value of fitness becomes the following equation:

$$f = \frac{1}{h+a} \tag{13}$$

A new population is produced by using natural selection mechanisms, choosing individuals proportionately to their fitness values, and natural genetics, namely cross breeding and mutation. Crossbreeding is done between population one with other population. This regards with population amplitude and population angle shift. In the process of crossbreeding it is known as the probability of interbreeding. In this genetic algorithm method we used crossbreed probability = 0.8 or 80%. It means cross-breeding between populations as much as 80% of data was done randomly. The number of chromosomes undergoing mutations in one population was determined by the mutation probability parameter. The applied mutation probability was 0.3 or 30%. The mutation process was performed by substituting one randomly selected gene with a new value obtained randomly. In the process of crossbreeding and mutation, the data performed were not actual data but the data was coded for each population. The coding data for each population was initialized between 0 and 1. Thus, after the cross-breeding process and mutation to know the actual data, the data calculation from the original encoding to the actual data was redone.

In this study, GA was used off-line. The process of determining the parameters (Amplitude and phase shift angle) was done by running GA program in *Matlab* software. For multilevel inverter system, the simulation was done with PSIM software. *Matlab* and *PSIM* software run simultaneously with *"Simcoupler"* module. In the process of simulation program path, then the simulation would run alone with GA method, so we obtained the parameters (Amplitude and phase shift angle). For GA method, the researcher used coding programming on m-file. For *Simulink Matlab* plant

system shown in figure 5 and the "*Simcoupler*" module on PSIM was plant system multilevel inverter shown as figure 6.
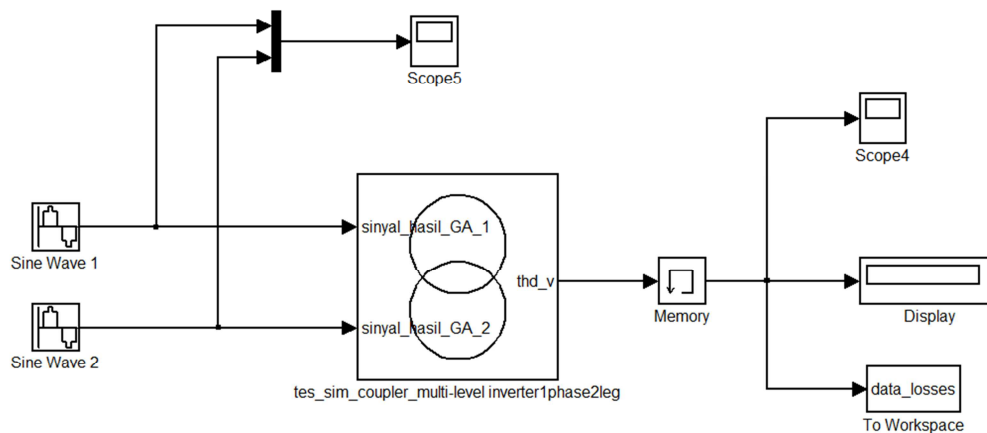

Figure 5. *Simulink Matlab* for Plant System

After obtaining the parameters (Amplitude and phase shift angle), parameters were included in microcontroller programming ("Waijung microcontroller STM32F407 ARM Cortex") as Amplitude and phase shift angle value to generate switching signal on switching component. The output voltage of the multilevel inverter was measured by using a power harmonic analyzer to determine the THD value.

The search process of optimization by genetic algorithm method was done by using programming via *MATLAB* and *PSIM,* GA optimization process was done on *Matlab* and main system simulated with *PSIM*. The two would work together using the "*Simcoupler*" module.
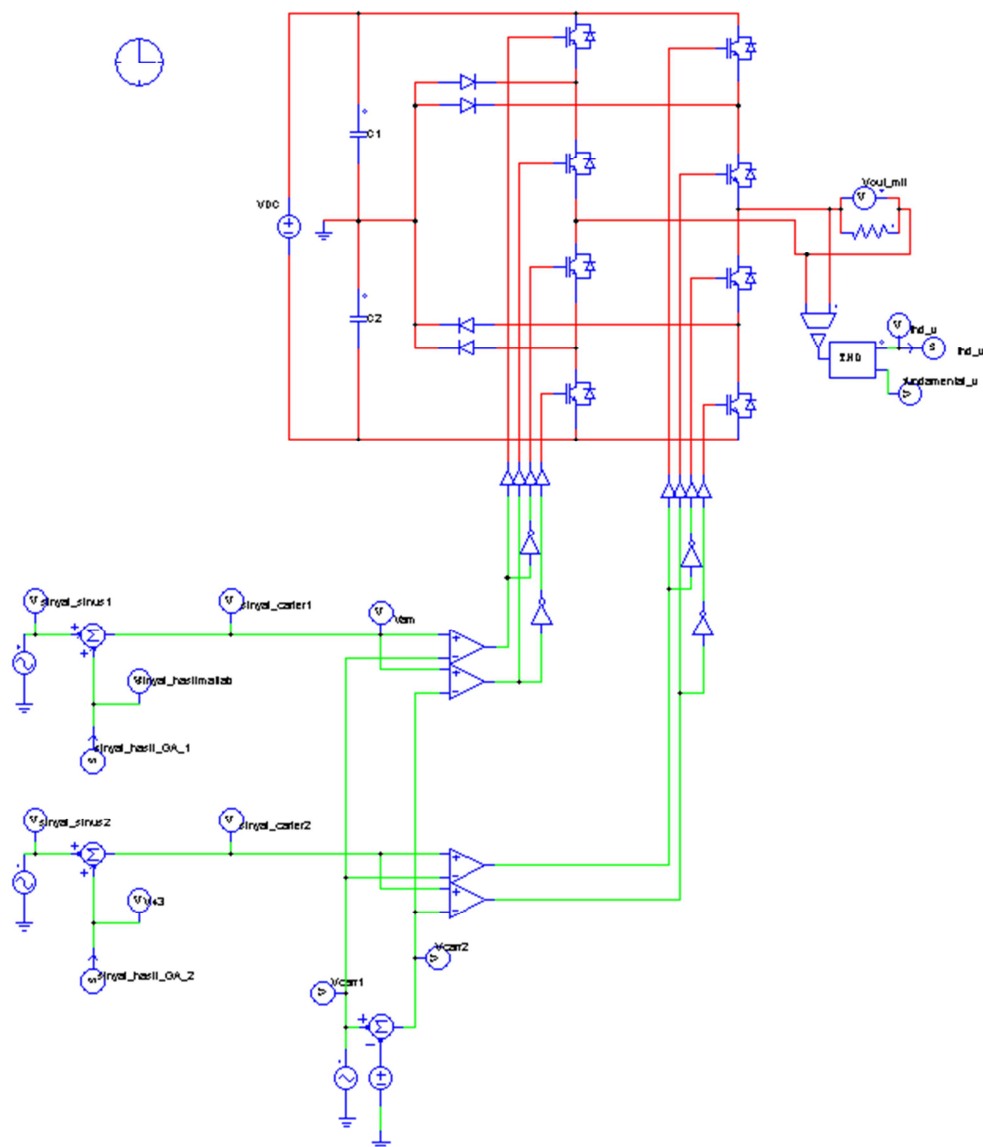
Figure 6. *PSIM* for Plant System Multilevel Inverter

5. EXPERIMENT AND ANALYSIS
5.1 Simulation Result Switching SPWM for Multilevel Inverter

In this system simulation design was done using *PSIM* as shown in Figure 7. In this simulation, we used the DC source voltage parameters of 30 Volt DC by using a switch component of MOSFET. The test is carried out with pure resistive load. Figure 8 is the condition of the switching *Mosfet* on the multilevel inverter. S1, S2, S3, S4 are switching components on leg 1 and S5, S6, S7, S8 are switching components in leg 2. The switching result is obtained from sinusoidal reference signal with frequency 50 Hz with amplitude 1 and triangular carrier signal with multilevel frequency 1 KHz with amplitude is 1.
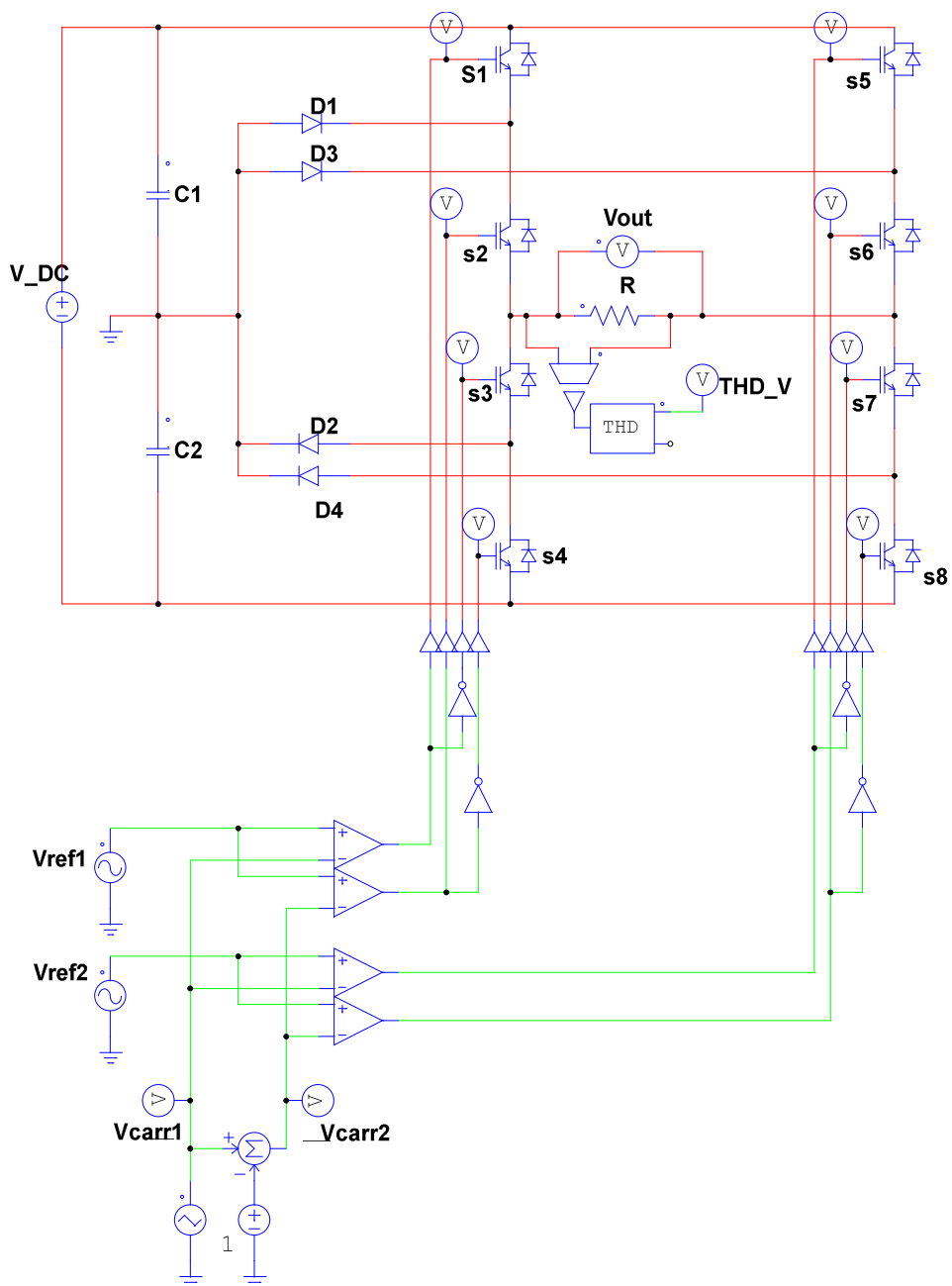
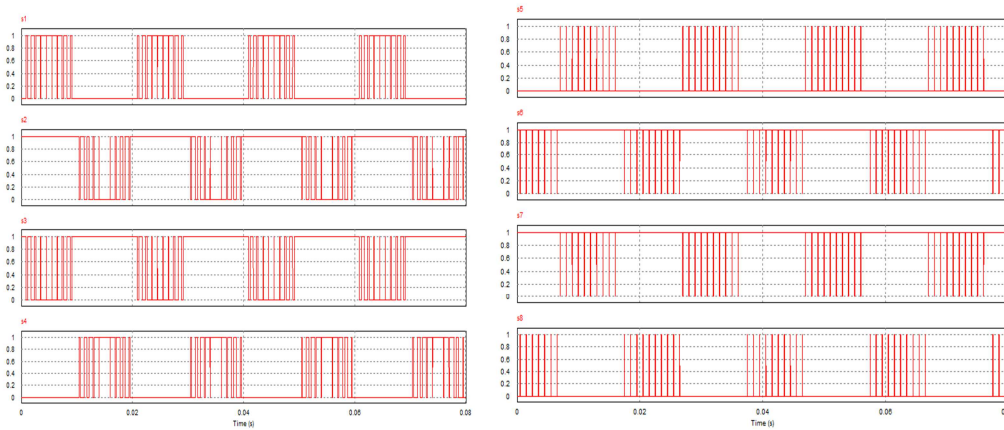**Figure 7.** Simulation PSIM Switching SPWM

Figure 8. Condition Switching S1, S2, S3, S4, S5, S6, S7 and S8

From the switching conditions, it generated output voltage from Multilevel Inverter Single-Phase Three-Level Diode Clamp Full Bridge shown as in figure 9 and the parameters as shown in table 2.
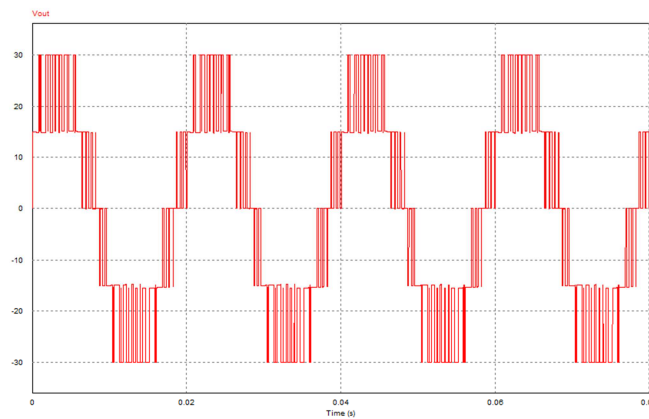

Figure 9.
Output Voltage Multilevel Inverter
Single-Phase Three-Level Diode Clamp Full Bridge

Table 2. Simulation Parameter

Parameter	Value	Parameter	Value
V DC	24 Volt	Frequency reference	50 Hz
Frequency	50 Hz	Frequency carrier	1 KHz

Figure 9 show that multilevel inverter voltage wave resulted THD data as in table 3. Data was taken with *ma* (modulation index) which changed from 0.4 up to 0.8. Harmonics were taken from n = 1 to n = 50 where the fundamental frequency was 50 Hz. Thus, the ranges of frequency were between 0 and 2500 Hz. As seen in table 3, the individual voltage harmonics that appeared were not the same as based on different *ma*.

Table 3.
THD MLI with SPWM Switching Method

Fundamental Frequency = 50 Hz	
ma	**THD**
0.4	0.92
0.5	0.69
0.6	0.49
0.7	0.44
0.8	0.42
0.9	0.39
1	0.35

The test was performed only on the change of the modulation index amplitude, because change the modulation index amplitude also affected the peak output voltage of the multilevel inverter in addition to the effect on THD. The modulation index amplitude is often used to get the output voltage from the multilevel inverter as needed. The modulation index frequency constantly used is the frequency of reference signal, that is 50 Hz and the frequency of carrier signal is 1 KHz. The value of the frequency will affect the switching capability of the component (MOSFET).

5.2 Testing Hardware Result Multilevel Inverter With SPWM

SPWM switching programming using *Simulink Matlab* with *Waijung* library on *Matlab* which was then downloaded to the microcontroller. The SPWM *Simulink* switching program is shown in Figure 10.
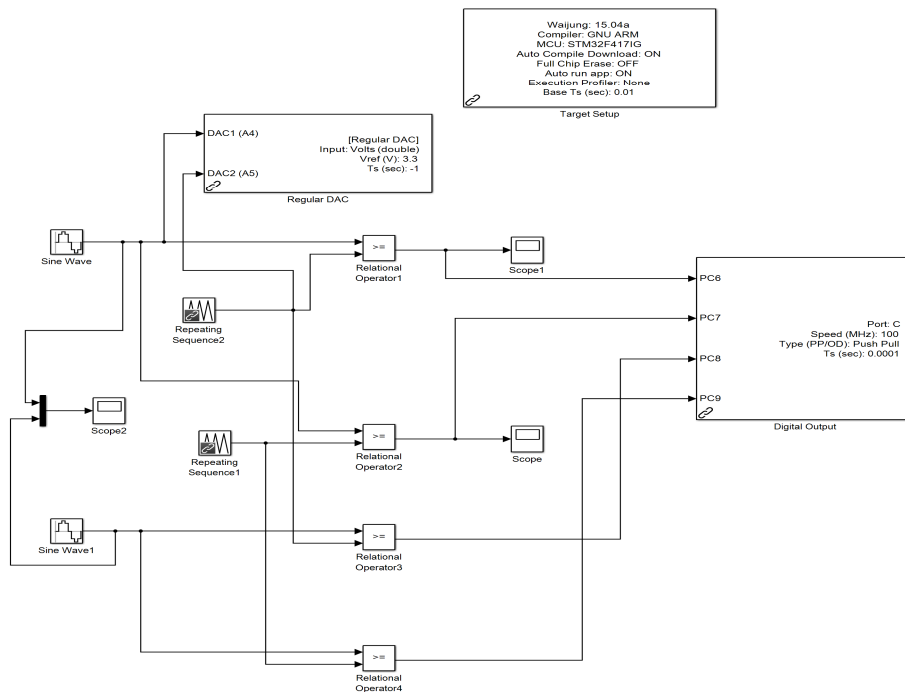

Figure 10. Program *Simulink* Switching SPWM

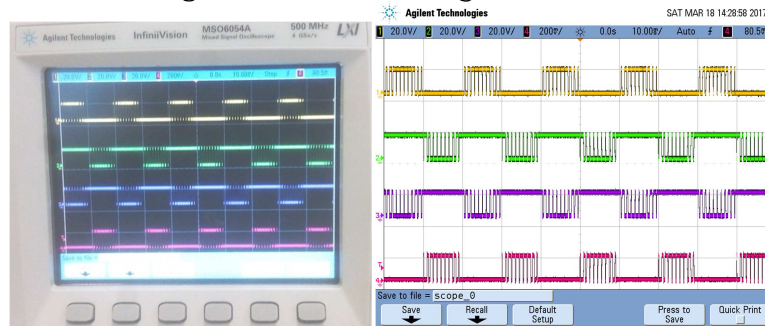Result of switching can be seen as in figure 11.

Figure11. Switching SPWM Leg 1

Figure 11 shows the output of the SPWM switching signal for 1 leg. There are 4 switching for 1 leg. Reference signal is sinusoidal with frequency 50 Hz and triangle carrier signal with frequency 1 KHz. In Figure 12 is the output waveform of the multilevel inverter. The output voltage is measured by an oscilloscope to determine the shape of the voltage with DC voltage source of 24 volts dc.
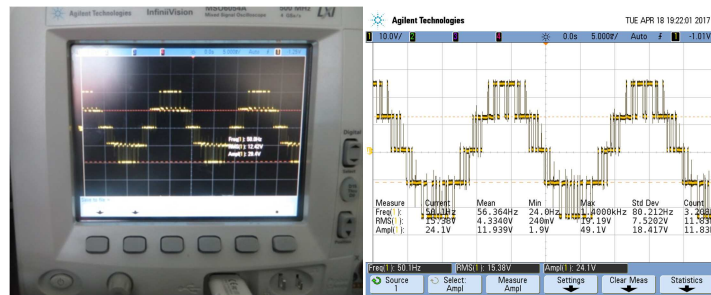

Figure 12. Output Voltage Multilevel Inverter with SPWM Method

In multilevel inverter testing the data retrieval is done repeatedly based on the modulation index (ma). The data were taken with a range of modulation index 0.4 to 0.8. For the measurement results are shown as in table 4. THD tests limited to n = 50 means that calculations on measuring devices were only until harmonics to 50.

Table 4. Result of SPWM Switching Testing

Data	Amplitude Sinusoidal	Amplitude Carrier (Triangular)	ma	THD
1	0.4	1.0	0.4	0.65
2	0.5	1.0	0.5	0.37
3	0.6	1.0	0.6	0.33
4	0.7	1.0	0.7	0.25
5	0.8	1.0	0.8	0.29
6	0.9	1.0	0.9	0.27
7	1	1.0	1	0.25

Measurement results with power harmonic analyzer and oscilloscope were shown as in figure 13. The measurement is done at ma = 1.
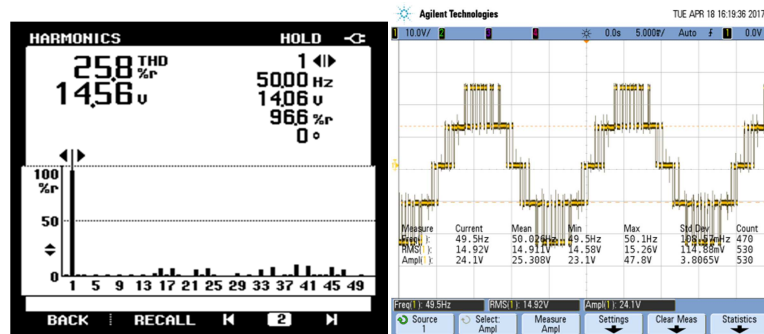

Figure 13. Result THD and Voltage of SPWM Switching Testing

On measurement with ma = 1 measured THD = 25.8% (0.258). In testing the tool was done using a measuring instrument in the form of oscilloscope and power harmonic analyzer. The image capture image is shown as shown in Figure 14.
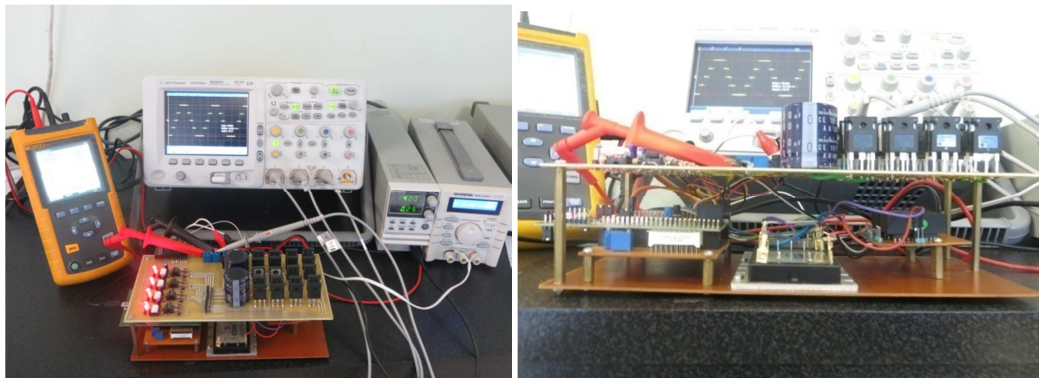

Figure 14. Testing Hardware Multilevel Inverter Single Phase Three Level Full Bridge

5.3 Simulation Result Multilevel Inverter with Switching Modified PWM
In the simulation the modified PWM was done with PSIM. The modified process was done by adding sinusoidal signal with certain amplitude and certain frequency on the 50 Hz sinusoidal reference signal. The added signal was sinusoidal with amplitude 0.1 and frequency 150 Hz for n = 3, 250 Hz for n = 5, 350 Hz for n = 7, 800 Hz for n = 16, 1100 Hz for n = 22, 1200 Hz for n = 24 and 2250 Hz for n = 45. The results of the simulation were THD data as shown in table 5.

Table 5. THD Modified PWM

ma	SPWM	THD						
		n = 3 f =150 Hz	n = 5 f =250 Hz	n = 7 f =350 Hz	n = 16 f =800 Hz	n = 22 f =1100 Hz	n = 24 f =1200 Hz	n = 45 f =2250 Hz
0.4	0.9167	0.9697	0.916	0.9003	0.9499	0.8504	0.9299	0.909
0.5	0.6857	0.7316	0.6834	0.6715	0.7274	0.6422	0.6944	0.6908
0.6	0.4925	0.5429	0.5233	0.524	0.5685	0.51	0.5492	0.5652
0.7	0.443	0.4628	0.4466	0.4128	0.4696	0.4382	0.4682	0.483
0.8	0.4201	0.4263	0.4421	0.3876	0.4264	0.4243	0.4297	0.4499
0.9	0.391	0.4025	0.416	0.3832	0.4031	0.4037	0.4036	0.4171
1	0.3542	0.3668	0.3762	0.3561	0.3735	0.3741	0.3594	0.3821

Table 5 shows the result of PWM modified without GA. The result was obtained from trial and error. Trial was done with PSIM simulation. PWM modified process was done by adding sinusoidal signal with amplitude and certain frequency at 50 Hz sinusoidal reference signal. The added signal was sinusoidal with amplitude 0.1 and frequency 150 Hz for n = 3, 250 Hz for n = 5, 350 Hz for n = 7, 800 Hz for n = 16, 1100 Hz for n = 22, 1200 Hz for n = 24 and 2250 Hz for n = 45. From the data shown in table 5, PWM modified that had been done did not all produce better THD values than SPWM. In general the better result was a modified PWM on the addition of a signal with a frequency of 350 Hz for n = 7 and 1100 Hz for n = 22. After obtaining better THD from SPWM that was in addition of signal with frequency 350 Hz for n = 7 and 1100 Hz for n = 22, it was done a process to get best THD result by using GA. GA was used to obtain the correct amplitude and phase shift angle variables for signal enhancement, so that PWM modified signal could produce the best THD voltage that was minimum.

5.4 Simulation Result Multilevel Inverter with Switching Modified PWM and Genetic Algorithm Optimization

The optimization process with genetic algorithm was performed on signal modified with frequency 350 Hz for n = 7 and 1100 Hz for n = 22. The optimization process was done using genetic algorithm with the help of *Matlab*. The data parameters in the genetic algorithm were chromosome = 2; Population = 100; Crossbreeding Mortality = 0.8; Probability of mutation = 0.3 and maximum generation = 50. With Genetic Algorithm, performance measures were indicated by the fitness values. From the fitness value shown by the graph in figure 15, it can be seen that the convergence conditions have been achieved for Modified PWM n=7 with optimization GA; ma = 0.8 and Modified PWM n=22 with optimization GA; ma = 0.4. Convergence conditions show that no change in fitness value means the best individual (variable amplitude and phase shift angle variables) has been found.
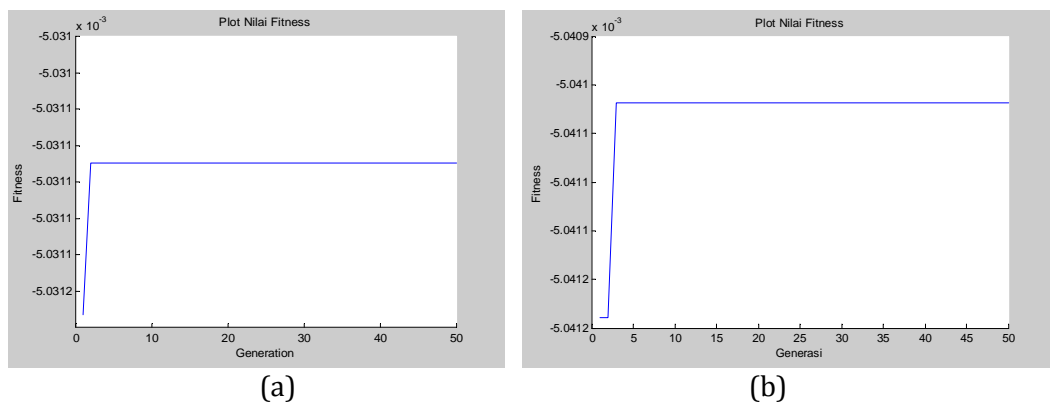
(a)   (b)

Figure 15. (a) Graph Fitness For Modified PWM n=7 With GA ; ma = 0,8
(b) Graph Fitness For Modified PWM n=22 With GA ; ma = 0,4

Genetic algorithm optimization data of amplitude and phase shift angle magnitude are shown in table 6.

Table 6. Result Parameter with Genetic Algorithm Optimization

ma	n =7 ; f = 350 Hz		n = 22 ; f = 1100 Hz	
	Amplitude	Phase Shift Angle (rad)	Amplitude	Phase Shift Angle (rad)
0.4	0.0811	0	0.1221	0
0.5	0.0518	0	0.0954	1
0.6	0.0096	3	0.0406	1
0.7	0.0469	0	0.0998	0
0.8	0.0936	0	0.0991	0

From the results in table 6 above, the amplitude and phase shift angle were applied to the system so that the results are obtained THD as shown in table 7.

Table 7.
Result of THD with Genetic Algorithm Optimization

ma	THD	
	n =7; 350 Hz (GA)	n = 22 ; 1100 Hz (GA)
0.4	0.89	0.84
0.5	0.67	0.63
0.6	0.48	0.48
0.7	0.41	0.43
0.8	0.38	0.42

In figure 16 the sinusoidal signal image with amplitude of 0.0936 and a frequency of 350 Hz for n = 7 are added to the sinusoidal amplitude signal 0.8 and 50 Hz. Mathematically it can be shown like the following equation:

$$SignalModified = 0.8\ Sin\omega t + 0.0936\ Sin\ 7\omega t \qquad (14)$$

$$\omega = 2\pi * f = 2\pi * 50$$

In figure 17 the picture of the sinusoidal signal with amplitude of 0.0991 and the frequency of 1100 Hz for n = 22 are added to the sinusoidal signal amplitude 0.8 and 50 Hz. Mathematically it can be shown like an equation:

$$SignalModified = 0.8\ Sin\omega t + 0.0991\ Sin\ 22\omega t \qquad (15)$$
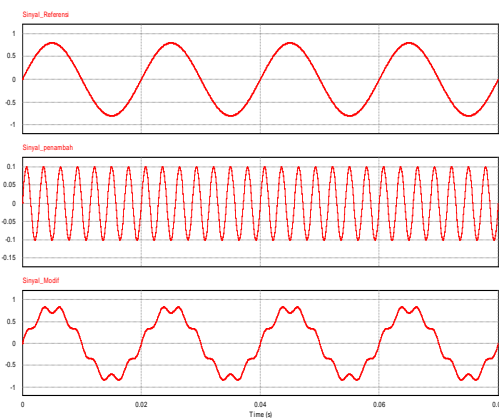$$\omega = 2\pi * f = 2\pi * 50$$

Figure 16.
Modified PWM
Signal Reference n =7
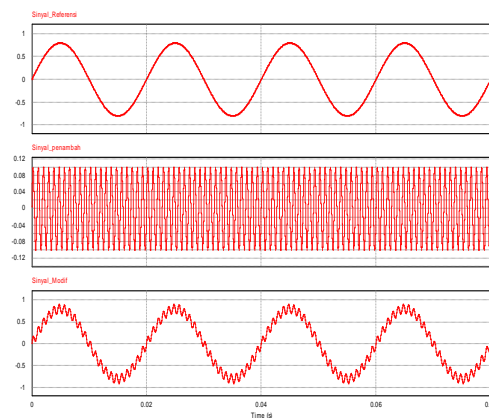(Frequency = 350 Hz)

Figure 17.
Modified PWM
Signal Reference n =22
(Frequency =1100 Hz)

5.6 Testing Hardware Result Multilevel Inverter With Switching Modified PWM And Genetic Algorithm Optimization

Programming switching Modified PWM was done using *Simulink* with library *Waijung* on *Matlab* that was then downloaded to microcontroller. The *Simulink* program switching modified PWM is shown in figure 18. The test was done by taking the data and entering the result parameters of genetic algorithm method. The test results are shown in Table 8. The measurements were performed with an oscilloscope and a power harmonic analyzer according to figure 19.
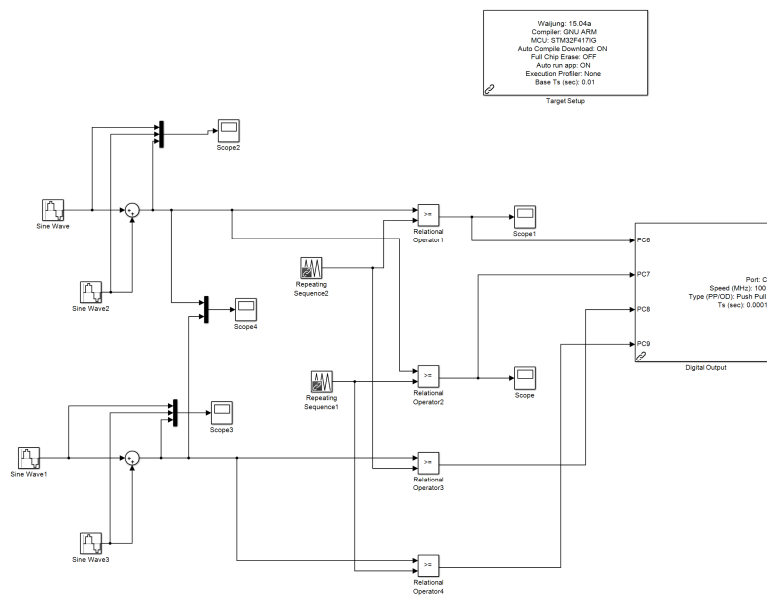
Figure 18. Program Switching *Simulink* Modified PWM

Table 8.
Result of Testing Hardware Multilevel Inverter
With Genetic Algorithm Optimization

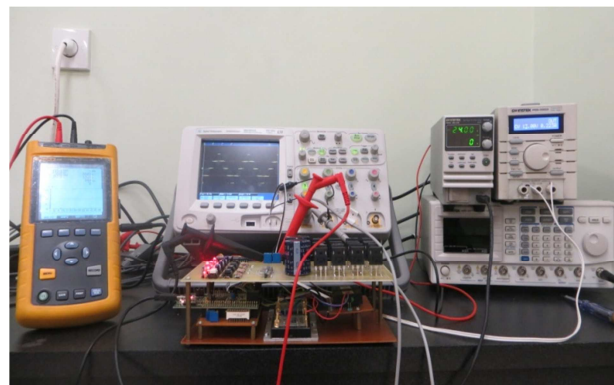| n=7; f = 350 Hz				n =22; f = 1100 Hz			
ma	Amplitude (Volt)	Phase Shift Angle (rad)	THD	ma	Amplitude (Volt)	Phase Shift Angle (rad)	THD
0.4	0.0811	0	0.55	0.4	0.1221	0	0.57
0.5	0.0518	0	0.34	0.5	0.0954	1	0.43
0.6	0.0096	3	0.32	0.6	0.0406	1	0.33
0.7	0.0469	0	0.20	0.7	0.0998	0	0.30
0.8	0.0936	0	0.10	0.8	0.0991	0	0.29

Figure 19. Testing Hardware Modified PWM

Here is one example of the measured results as shown in figure 20 for PWM modified PWM n = 7 (f = 350 Hz) With Genetic Algorithm Optimization and figure 21 for modified PWM n = 22 (f = 1100 Hz) With Genetic Algorithm Optimization.
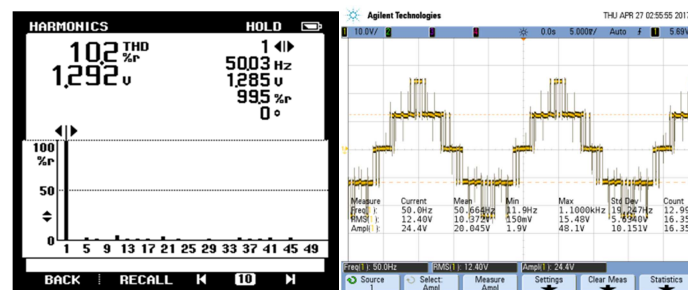

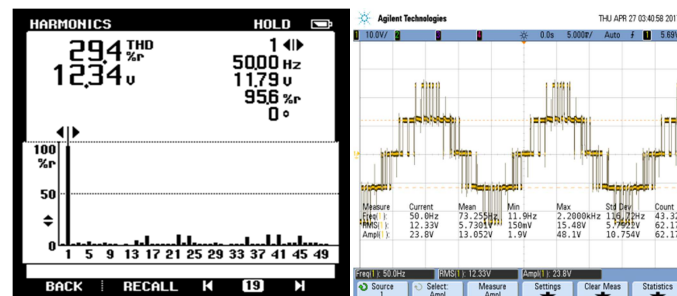**Figure 20.** Result Output THD Voltage Modified PWM n = 7 (f=350 Hz) With GA Optimization

Figure 21. Result Output THD Voltage Modified PWM n = 22 (f=1100 Hz) With GA Optimization

5.7 Comparison SPWM, Modified PWM n = 7 (Frequency= 350 Hz) With Genetic Algorithm Optimization and Modified PWM n = 22 (Frequency =1100 Hz) With Genetic Algorithm Optimization

The simulation of comparison data is shown in table 9 and graph in figure 22. Comparison of THD simulation for PWM Modified n = 7 (Frequency = 350 Hz) with Genetic Algorithm Optimization and PWM Modified n = 22 (Frequency = 1100 Hz) with Genetic Algorithm Optimization is better than SPWM. However, there are certain conditions in which *ma* results the same result. Modified PWM n = 7 (Frequency = 350 Hz) Genetic Algorithm Optimization has maximum result, so minimum THD at m condition between 0.4 to 0.6 and modified PWM n = 22 (Frequency = 1100 Hz). Genetic Algorithm Optimization has maximum result, so THD Minimum at *ma* conditions were between 0.6 to 0.8. The data was taken with *ma* (modulation index) which varies from 0.4 to 0.8. This modulation index was chosen because the multilevel inverter implementation was used in DC voltage source that did not change significantly.

Table 9. Simulation Result Comparison THD

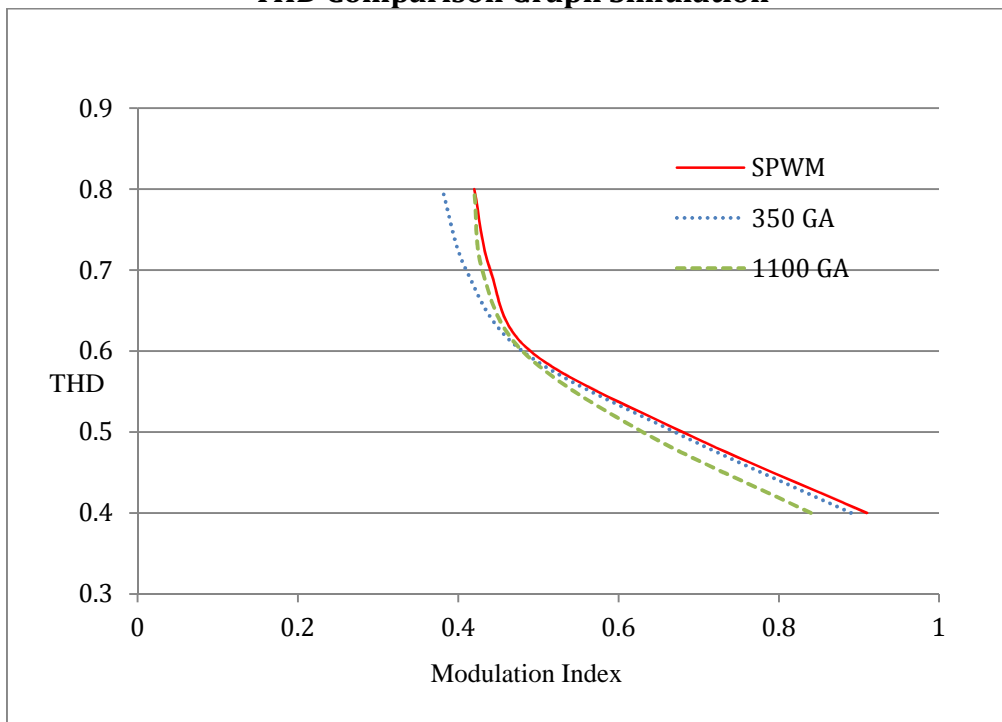| ma	THD		
	SPWM	**n =7 ; f =350 Hz With GA**	**n = 22 ; f=1100 Hz With GA**
0.4	0.91	0.89	0.84
0.5	0.68	0.67	0.63
0.6	0.49	0.48	0.48
0.7	0.44	0.41	0.43
0.8	0.42	0.38	0.42

THD Comparison Graph Simulation

Figure 22. Simulation Result THD Comparison Graph SPWM, Modified n = 7 (Frequency = 350 Hz) With GA Optimization and Modified n = 22 (Frequency = 1100 Hz) With GA Optimization

By testing the hardware, we obtained better THD results compared with SPWM. The results compare the data shown in Table 10 and the graph in Figure 23.

Table 10. Testing Hardware Result Comparison THD

ma	THD		
	SPWM	n =7 ; f =350 Hz With GA	n = 22 ; f=1100 Hz With GA
0.4	0.65	0.55	0.57
0.5	0.37	0.34	0.43
0.6	0.33	0.32	0.33
0.7	0.25	0.2	0.29
0.8	0.29	0.1	0.26

Comparison of THD between SPWM, Modified PWM n = 7 (Frequency = 350 Hz) with Genetic Algorithm Optimization and modified PWM n = 22 (Frequency = 1100 Hz) with Genetic Algorithm Optimization was better than SPWM. Modified PWM n = 7 (Frequency = 350 Hz) with Genetic Algorithm Optimization resulted better results than SPWM, while Modified PWM n = 22 (Frequency = 1100 Hz) with Genetic Algorithm Optimization generated better THD under certain m conditions. The data was taken with ma (modulation index) varying from 0.4 to 0.8. Each ma has a different difference. The great decrease is at ma 0.8 where the THD decrease was with modified PWM n = 7 (Frequency = 350 Hz) with Genetic Algorithm Optimization up to 0.19 compared to SPWM While the biggest decrease was in modified PWM n = 22 (Frequency = 1100 Hz) with Genetic Algorithm Optimization When ma = 0.4 where the THD decrease to 0.08 compared with SPWM.
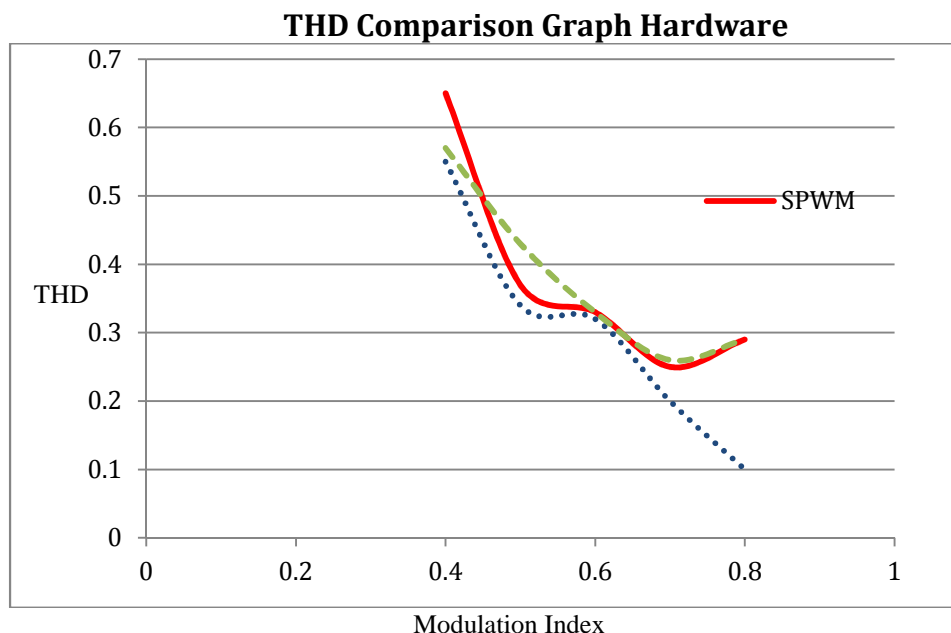
THD Comparison Graph Hardware

Figure 23. Testing Hardware Result THD Comparison Graph SPWM, Modified n = 7 (Frequency = 350 Hz) With GA Optimization and Modified n = 22 (Frequency = 1100 Hz) With GA Optimization

Harmonic measurement and THD hardware test resulted different result because real measurement was done using power harmonic analyzer which have limitations in harmonic measurement that is only until harmonics to n = 50, whereas simulation of harmonic calculation can reach infinite frequency, that is until harmonic does not appear.

6. CONCLUSION

The modified PWM process using genetic algorithm method resulted in smaller THD voltage than SPWM switching. The optimization process was achieved by obtaining amplitude and phase shift angle variable of the established reference signal. The form of switching signal for reference signal was obtained by using genetic algorithm optimization method. Genetic Algorithm method is very effective in determining the best amplitude and angle variables used in the system since the optimum value can be selected from the many variables tested with Genetic Algorithm method on the computer. Genetic Algorithm method does not need many mathematical needs related to optimization because it will seek solutions based on natural evolution. By hardware testing, the result of modified PWM n = 7 (Frequency = 350 Hz) with Genetic Algorithm Optimization resulted in smaller THD compared with SPWM. The result of modified PWM n = 7 (Frequency = 350 Hz) with Genetic Algorithm Optimization got the best result of THD of 0.1 with modulation index 0.8 whereas modified PWM n = 22 (Frequency = 1100 Hz) with Genetic Algorithm Optimization got the best result of THD of 0.26 with modulation index 0.8. Each *ma* had a different difference. The great decrease was at ma 0.8 where the THD decrease with modified PWM was n = 7 (Frequency = 350 Hz) with Genetic Algorithm Optimization up to 0.19 compared to SPWM While the biggest decrease was in modified PWM n = 22 (Frequency = 1100 Hz) with Genetic Algorithm Optimization was at *ma* = 0.4 where the THD decrease was to 0.08 compared with SPWM.

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