A STUDY OF A CASCADED H-BRIDGE MULTILEVEL INVERTER (CHB-MLI) PERFORMANCE BASED ON PARTICLE SWARM OPTIMISATION (PSO) AS A CONTROLLER

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2019

DECLARATION

I declare that this thesis entitled "**A STUDY OF A CASCADED H-BRIDGE MULTILEVEL INVERTER PERFORMANCE BASED ON PARTICLE SWARM OPTIMIZATION AS A CONTROLLER**" is the result of my own research except as cited in the references. The thesis has not been accepted for any degree and is not concurrently submitted in candidature of any other degree.

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APPROVAL

I hereby declare that I have checked this report entitled "A study of Cascaded H-Bridge Multilevel Inverter Performance Based On Particle Swarm Optimisation as a Controller" and in my opinion, this thesis it complies the partial fulfillment for awarding the award of the degree of Bachelor of Electrical Engineering with Honours

Signature : ....

Supervisor Name : ....

Date : ....

DEDICATIONS

To my beloved father, mother, brothers and sisters.

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In the name of Allah, the Most Beneficent and The Most Merciful. It is a deepest sense gratitude of the Almighty that give me strength and ability to complete the Final Year Project report.

Firstly, the most gratitude I would like to give to Prof Madya Ir. Dr. Rosli Bin Omar, my final year project supervisor that give a thorough guidance and helped me to coordinate the project especially in writing the report.

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ABSTRACT

The smoothness of the waveform of the multilevel inverter output, especially for the voltage waveform is crucial as can protect the electrical equipment from damage. In order to maintain the sinusoidal waveform of the voltage waveform of the multilevel inverter is totally dependent to the controller. This project aims to design and model of a single phase of a cascaded H-Bridge Multilevel Inverter (CHBMLIs) for five levels using Particle Swarm Optimization (PSO) for the better output of the waveforms for the voltages and currents. The performance of the proposed CHBMLIs for five levels will be monitored, evaluated and analyzed through simulation and experimental results in term of their THD values.

KEYWORDS : CHBMLIs, PSO, THD

ABSTRAK

Kelancaran gelombang bentuk output inverter bertingkat, terutamanya untuk bentuk gelombang voltan adalah penting kerana dapat melindungi peralatan elektrik dari kerosakan. Untuk mengekalkan gelombang sinusoidal bentuk gelombang voltan penyongsang bertingkat itu bergantung sepenuhnya kepada pengawal. Projek ini bertujuan untuk merekabentuk dan memodelkan satu fasa H-Bridge Multilevel Inverter (CHBMLIs) yang diselaraskan untuk lima tahap menggunakan Pengoptimuman Swarm Partikel (PSO) untuk keluaran gelombang yang lebih baik untuk voltan dan arus. Prestasi CHBMLI yang dicadangkan untuk lima peringkat akan dipantau, dinilai dan dianalisis melalui hasil simulasi dan eksperimen dari segi nilai THD mereka.

KATA KUNCI : CHBMLIs, PSO , THD

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

CHAPTER 1

INTRODUCTION

1.1 Research Background

Inverter is one the type of converter that change direct current (DC) power into alternating current (AC) power to get the desired frequency and output voltage. It is also known as two-level inverter. The multilevel converter has drawn many interest in power industry due to its structure that easier to produce an output of high voltage from medium voltage source. The main constraint of multilevel inverter lies to the usage of the switches to avoid the switching losses. Multilevel inverter allows the system to reach a high voltage output with low harmonic without the use of a transformer or a series-connected synchronised switching device. As the number of voltage level increase, the harmonic content of output voltage's waveform decrease significantly.

There are many topologies that has been proposed such as diode-clamped, flying capacitor and cascaded multilevel inverter [1]. Cascaded H- bridge has always been famous due to its feature that optimise the circuit layout and packaging as each level has the same structure. The advantage of cascaded H-bridge over other topologies is that its require less number of component to achieve the same voltage level. As each level has the same structure and there are no extra filtering circuit, it is possible to have an optimised circuit layout and packaging. The only drawback of this inverter is that its use a large number of semiconductor switches and its need separate dc sources for real power conversion.

The research in the area of power electronics especially in multilevel inverter is still relevant to explore as there are few areas in the multilevel inverter that can still be improved. Particle Swarm Optimisation (PSO) algorithm is proposed in this project to reduce the effect of non-triple harmonic from the output of multilevel inverter. This topology of inverter is important because multilevel inverter is better than conventional inverter which contain only 2 DC level as multilevel inverter produces lower switching losses, electromagnetic interference and harmonic distortion. As there are parameters that still can be improve in multilevel inverter, this project is still relevant to study. Multilevel inverters are promising as they have nearly sinusoidal output-voltage waveforms, output current with better harmonic profile, less stressing of electronic components owing to decreased voltages, switching losses that are lower than those of conventional two-level inverters, a smaller filter size, and lower EMI, all of which make them cheaper, lighter, and more compact [3], [4]. The controllers which are applied to the multilevel inverter play an important role in order to produce a smooth waveform of the multilevel inverter. There are so many types of the controllers which are applied to the multilevel inverter such as Pulse Width Modulation (PWM) technique, fuzzy, space vector PWM (SPWM) and Newton Raphson (NR) technique. All these types of the controller have the merit and demerit respectively. In this project, the Particle Swarm Optimization (PSO) algorithm will be used and it will be applied to the design of the Cascaded H-Bridge Multilevel Inverter (CHB-MLI) for five levels. Figure 2.1 shows the model of the Cascaded H-Bridge multilevel (CHB-MLI). Particle Swarm Optimisation is the most optimise algorithm to define the optimal solution of the non-linear problems and enhance the power quality when applied to a high voltage application system. Particle Swarm Optimisation (PSO) technique will compute the optimum switching angle which affect to get a lower percentage of harmonic distortion in term of THD.

1.2 Problem Statement

Nowadays, high power application system demands a better power quality supply to gain a better output. However, harmonic distortion in term of Total Harmonic Distortion (THD) is always the problem due to high switching losses which affected by switching angle in the inverter. It is important for the waveform of the inverter output to be maintained sinusoidal and free from the distortion. Cascaded H-Bridge Multilevel Inverter (CHBMLIs) will be proposed because it produce a lower percentage of THD as the harmonic distortion reduced.

1.3 Objective

- To study the concept of multilevel inverters and their controllers which are used for harmonics reduction of the output waveform of the multilevel inverters.

- To model and design a modified cascaded H-bridge multilevel inverter (CHB-MLI) based on particle swarm optimization algorithm by using MATLAB/SIMULINK software for the aims of the simulation.

- To implement and test the hardware prototype of a modified single phase five levels cascaded H-Bridge multilevel inverter and verify with the simulation results.

1.4 Scope of work

The scope of this project includes understanding and analysing the performance of the topology of the multilevel inverter that used in the project which is the cascaded multilevel inverter. The performance of the multilevel inverter is analyse by differentiate a few parameters which comprise of total harmonic distortion(THD) and switching losses. Particle Swarm Optimisation is used as a method to control the multilevel inverter to get the desired output. The simulation and the coding control are done by using MATLAB software and the implementation of the hardware is tested.

CHAPTER 2

LITERATURE REVIEW

2.1 Theory and basic principle

2.1.1 Cascaded H-Bridge Multilevel Inverter

Over the past decades, there are various type of topologies have been introduced for multilevel inverter as a respond to the increasing demand of high power applications in the industry. Multilevel inverter is more suitable to be use in the industrial area than two level inverter because of the advantages that being offered by the multilevel inverter's features. Multilevel inverter gives a higher efficiency, lower switching stress and electromagnetic interference which resulting in a better power quality. Multilevel inverter can be separated into three major topologies which is flying capacitors, diode-clamped and cascaded H-bridge. Among of these topologies, cascaded h-bridge multilevel inverter is the most convenient to be implement because of the simple modular and structure [2]. In 1970s, Baker and Bannister founded the first copyright for the converter topology which can produce multilevel voltages with various source of DC supply. In this topology, the cascaded multilevel inverter has several structure of single phase full bridge inverter that connected together. The voltage input is connected with the H-bridge which will produce output voltage. In cascaded multilevel inverter, the number of voltage level of output phase depends on the number of voltage supply which formulated through n = 2s+1 [3]. As the level of inverter increases, the stepped waveform become almost sinusoidal and reduce the harmonic distortions. The Figure 2.1 shows a single phase cascaded multilevel inverter model. The voltage output vary from $+V_{dc}$, 0 and $–V_{dc}$.

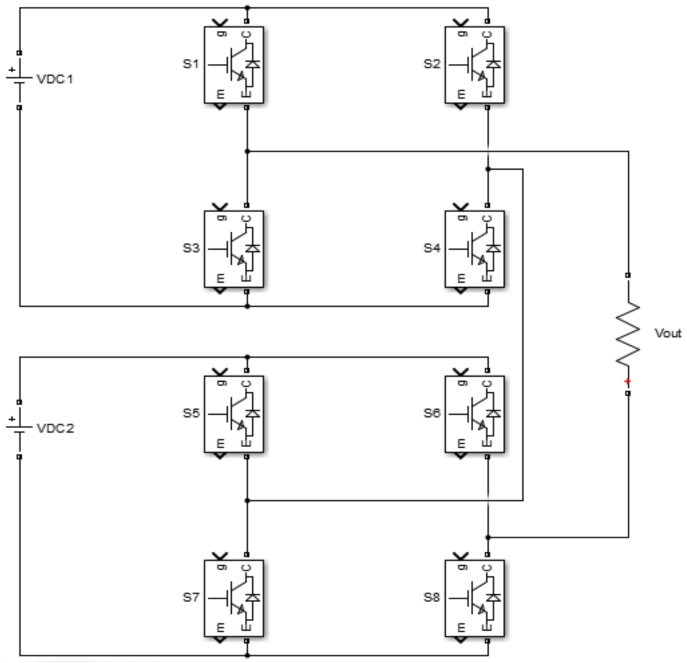

Figure 2.1: 5-level CHB-MLIs

2.1.2 Total Harmonic Distortion (THD)

Harmonic distortion in power system application is not a new case anymore. Every power system application has issues in their output regarding harmonics. Harmonic distortion will affect the power outcome as it produces a bad power quality [4]. The sudden demand of power electronic loads in a power system application starts in the early 1990. It has a good controllability and efficiency but the drawback is that the present of non-sinusoidal currents. Previous study shown that harmonic distortions in power system application will increase parallel with power electronic device continue to evolve [5]. Total Harmonic Distortion (THD) is the common term used to measure the harmonic distortions. Total Harmonic Distortion(THD) is apply to both the current and voltage and is varies from 0% to 100%. Normally the THD of the voltage is less than 5% whereas value above 10% is unacceptable and will damage the sensitive equipment and loads [6]. THD is defined as:

$$THD = \frac{100\sqrt{\sum_{h=2}^{k} U_{hrms}^2}}{U_{1rms}} \quad (2.1)$$

2.2 Comparison of previous work

There are few journals and articles about previous work related to this project that had been reviewed to help understand more about the performance parameter of the cascaded H-bridge multilevel inverter. In this review, the study about the configuration of the modulation technique to minimise the harmonic distortion will be discussed.

2.2.1 Selective Harmonic Elimination PWM Method

The title of report should be as concise as possible, giving an accurate description of the In this study, there are many methods to minimise the harmonic but only SHE-PWM that select proper switching angles to eliminate low-order harmonics and minimise the THD of the output voltage from the system. In this method, the problem can be solved by three ways which is Newton-Raphson method, Genetic Algorithm (GA) and Particle Swarm Optimisation (PSO). Genetic Algorithm and Particle Swarm Optimisation are used to calculate the non-linear transcendental equation which will determine the best possible switching angle in cascaded H-bridge multilevel inverter. Selective Harmonic Elimination PWM used Fourier expansion to calculate critically the odd harmonic in the output phase voltage. The Fourier analysis is formulated as below [8]:

$$V(wt) = \sum_{n=1}^{\infty} V_n \cos(nwt) + V_n \sin(nwt) \tag{2.2}$$

V_n is the amplitude and the voltage waveform of n_{th} harmonic component. Selective Harmonic Elimination PWM will mitigate the low order harmonic whereas the other harmonic is eliminated by using filter. For example, this method can eliminate the odd harmonic such as 3rd, 5th and 7th harmonics and has been translated into transcendental non-linear equation as below [7]:

$$V_n = \frac{4}{n\pi} V_{dc}(na_1) + V_{dc}(na_2) + V_{dc}(na_3) \tag{2.3}$$

2.2.2 Genetic Algorithm

In the previous study, genetic algorithm is proposed where the switching angle is calculated in context of step modulation. This topology has the same purposed with other method which is to minimise the THD. Genetic algorithm reduces the computational calculation as well as the search time as it is inspired from the law of natural selection [9]. This method has been theoretically established to deliver solution in complex search spaces. Below shown the flow chart of the steps to minimise the total harmonic distortion (THD).

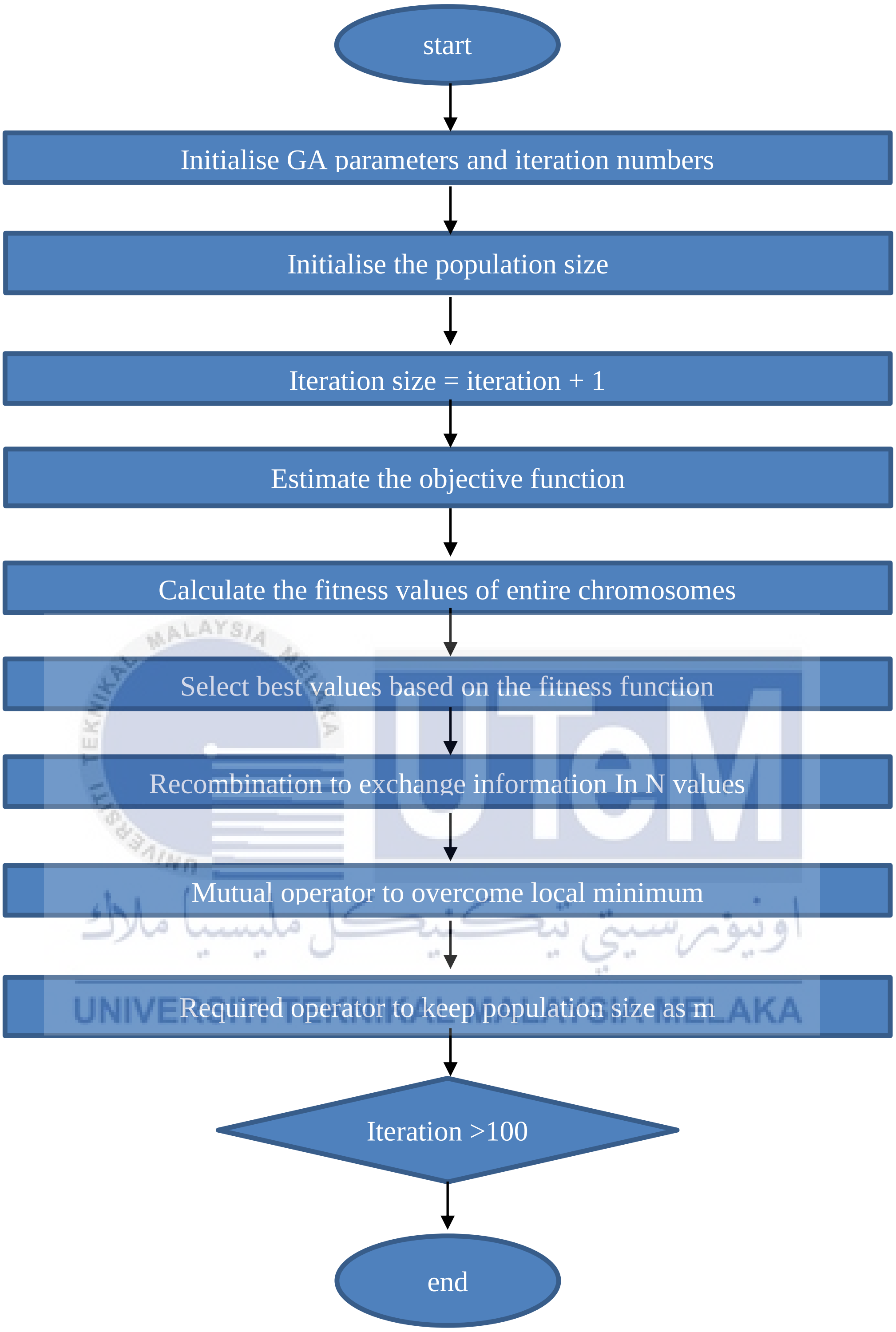

Figure 2.2: Flowchart of Genetic Algorithm

2.2.3 PSO

Particle swarm optimisation is more easy in concept and implementation compared to other algorithms and technique. It is consisting of velocity vector and position vector. This method is implemented to several level of the multilevel inverter to compute the best switching angles [2]. Other harmonic elimination methods have a number of limitation and also provided poor result. A simulation had been analyse and the result indicate that Particle Swarm Optimisation method produce a better outcome than other method as it produced a lower THD. Table 2.1 show the result of comparison of a few methods[10]

Table 2.1: Comparison of algorithm's result

Proposed method	Levels	Harmonics	THD (%)	Limitations
Artificial Neural Network	7-level 11-level	5,7,11,13	7-level = 14.57% 11-level = 9.79%	ANN produce higher THD than GA
Bee Colony Optimisation	7-level	5,7	9.57%	BCO produce higher THD than GA
Comparison of Newton Raphson and Genetic Algorithm	7-level	3,5,7	NR = 11.68% GA = 6.61%	GA consume high time
Simulated Annealing Algorithm	9-level	5,7	8.99% (consume less time than GA)	SA algorithm produce high THD% compare to GA

2.3 Summary and discussion review

The modelling of the modified cascaded H-bridge multilevel inverter with Particle Swarm Optimisation as the controller is developed and analysed using MATLAB/ Simulink software. This project aimed to minimise the harmonic distortion in term of Total Harmonic Distortion (THD) that present in power system application in order to produce a better power quality. A few parameters is analysed to get the best output performance as well as produce sinusoidal waveform at the voltage output.

CHAPTER 3

METHODOLOGY

3.1 Introduction

In this chapter, all related experimental and descriptive techniques used in the project were outlined and described thoroughly about the designation and the development of the cascaded multilevel inverter. This chapter will show the flow of work done from the beginning of the project till the end of project, regarding the methods which the software and hardware used to complete the project. It contains a work flow that clearly shows in the section in order to describe the overall work to be undertaken to complete this project.

The analysis of the proposed prototype of the modified five-level CHB-MLI has been implemented in order to compare the THD for different value of MI. The parameter for the prototype is similar to the simulation. The proposed coding for the prototype that has been created will be embedded in the DSP TMS320F2812 and will be analyse based on PSO technique controller. The overall proposed system can be described as shown in Figure 3.1.

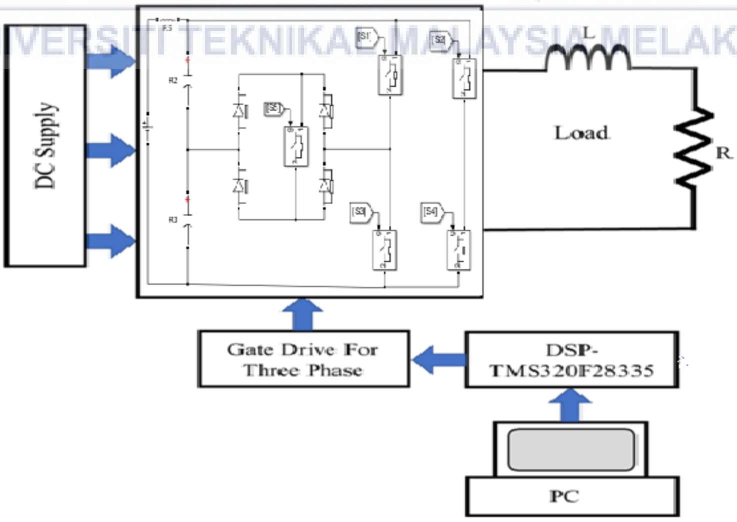

Figure 3.1: Block diagram of the overall proposed system

3.2 Research Methodology

The proposed system consists CHBMLIs for five level and the optimization of the controller based on PSO.

The design process will be divided into four stages as follows:

Stage 1: In the initial stage, the previous works on multilevel inverter, regarding topologies, control scheme and applications will be reviewed. The project starts with identifying types of advanced digital control strategies for the control of modified CHB-MLI in recent years. Investigation on the modulation technique especially for modified CHB-MLI is necessary in order to improve a simple formulation of the control strategy using PSO.

Stage 2: In the second stage, formulation of new low switching frequency modulation approach to improve the output's harmonics profile. The new algorithm of optimization control will be designed and tested in simulation.

Stage 3: Experimental set up using digital signal processor. In the third stage is to implement the proposed controller for the modified CHB-MLI based on PSO. Program the designed optimization control in digital signal processing language using Digital Signal Processor (DSP) TMS320F2812. Wiring and integrate of hardware and others measurement equipment.

Stage 4: Evaluation and investigation performance of the systems. In the fourth stage is data capture and analysis. Examine and test the hardware under various operating THD conditions and load variations integrate of hardware and other measurement equipment. The construction of the complete inverter system with the proposed control strategy based on Super Capacitor is used to justify the simulation results.

3.3 Flowchart

The project methodology can be summarized in the project flow as shown in Figure 3.2. The factors in the flowchart are explained thoroughly about the steps taken in completion of this chapter.

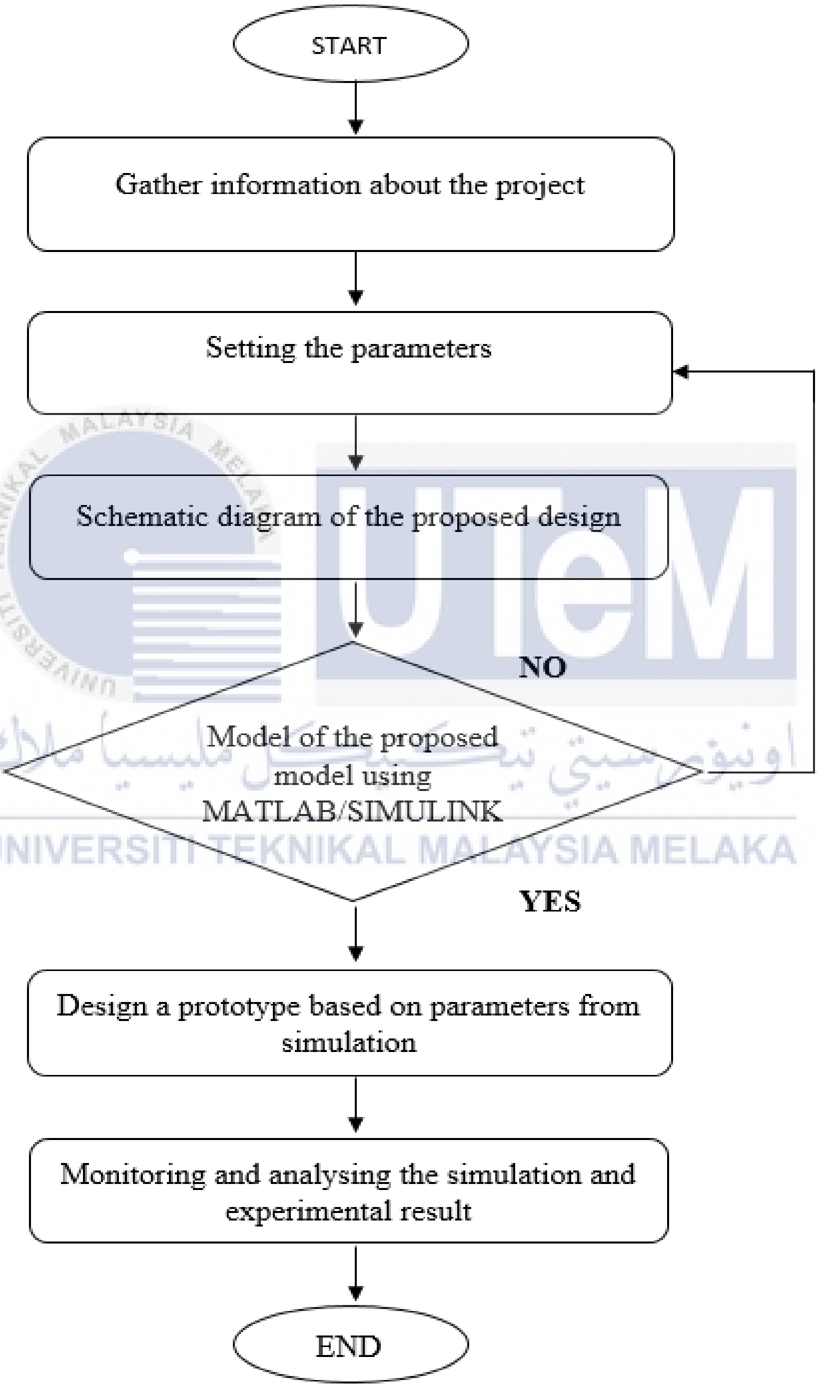

Figure 3.2: Project flow chart

Figure 3.2 shows the flowchart of the process upon completion of this project which summarises the methodology that have been practiced in this project. In order to conduct this project, the methodology of this project is categorized into several phases, which includes the first phase which is to gather all the data and information required through various resources and previous study.

Next stage of this project is to set the multilevel inverter's parameter to design the schematic diagram including parameter development to analyse the performance of the current and voltage output. Then, the simulation of the designed schematic diagram for cascaded multilevel inverter is implemented by using MATLAB Simulink software. If the simulation failed to obtain the desired result, the schematic diagram is designed again to achieve the desirable result.

The prototype is designed based on the output gain from the parameters obtained from the simulation to analyse the performance of the multilevel inverter practically. Last but not least, the data gathered from the simulation and the experimental result will be compared and analysed.

3.4 Particle Swarm Optimisation(PSO) Technique

The simulation of the model will be verified using the particle swarm optimization technique as the switching angles is calculated using particle swarm optimization algorithm. Particle swarm optimisation is a search algorithm which optimises a given problem by iteratively choosing the possible best solution with regards to the given constraints. The calculation of switching angles will be calculated using MATLAB code as shown in Appendices. Figure 3.3 shows the flow chart of the PSO technique.

Step 1 Initialise the system parameters such as position vector *Xi*, velocity vector *Vi*, personal best particle vector *Pi*, global best vector *Pg*, and particle inertia weight *C0*. Assign the values of generations as 100, population size as 40, cognitive parameter *C1* as 0.5 and social parameter *C2* as 1.25.

Step 2 Check for the conditions 0 < (C1 + C2) < 2 and (C1 + C2)/ 2 < C0 < 1, if the two conditions are satisfied then the system will be guaranteed to converge to a stable equilibrium point. If false, go to **Step 1**.

Step 3 Update the Velocity, Vi (t + 1).

$$Vij\ (t+1) = Vi(t) + \gamma_{1i}\,(P_i - x_i(t)) + \gamma_{2i}\,(G_i - x_i(t)) \quad (3.1)$$

Step 4 Update the Position, Xi (t + 1).

$$Xij\ (t+1) = Xij\ (t) + Vij\ (t+1) \quad (3.2)$$

where *i* is the particle index, *j* is the index of parameter of concern to be optimised, *x* is the position of the i^{th} particle and j^{th} parameter, *k* is the discrete time index, *v* is the velocity of the i^{th} particle and j^{th} parameter, *P* is the best position found by the i^{th} particle and j^{th} parameter (personal best), *G* is the best position found by swarm (global best), *c* is a random uniform number between [0,1] applied to the i^{th} particle, *u* is the inertia function, *a* is the acceleration constants.

Step 5 Now, evaluate the particles using the Fitness Function

F(Xi) = 100*(|f(2)|/ (|f(1)|) for harmonic elimination. Here the switching angles α_1 and α_2 are chosen in such a way that the selective harmonics 3th is eliminated.

$$F(1)=(\cos(\alpha_1) + \cos(\alpha_2)); \quad (3.3)$$

Step 6 Check the constraints $0 \leq \alpha_1 \leq \alpha_2 \leq \pi/2$.

Step 7 Check for the condition P(xi) < P(Pi), if not satisfied then

i = i + 1go to **Step 3**.

Step 8 Update the local best position of the particle if it is better than the previous local best position. Thus, the local best position is replaced as Pi = Xi.

Step 9 Update the global best position as Pg = min (P neighbour).

Step 10 Optimised switching angles are obtained. Terminate the problem.

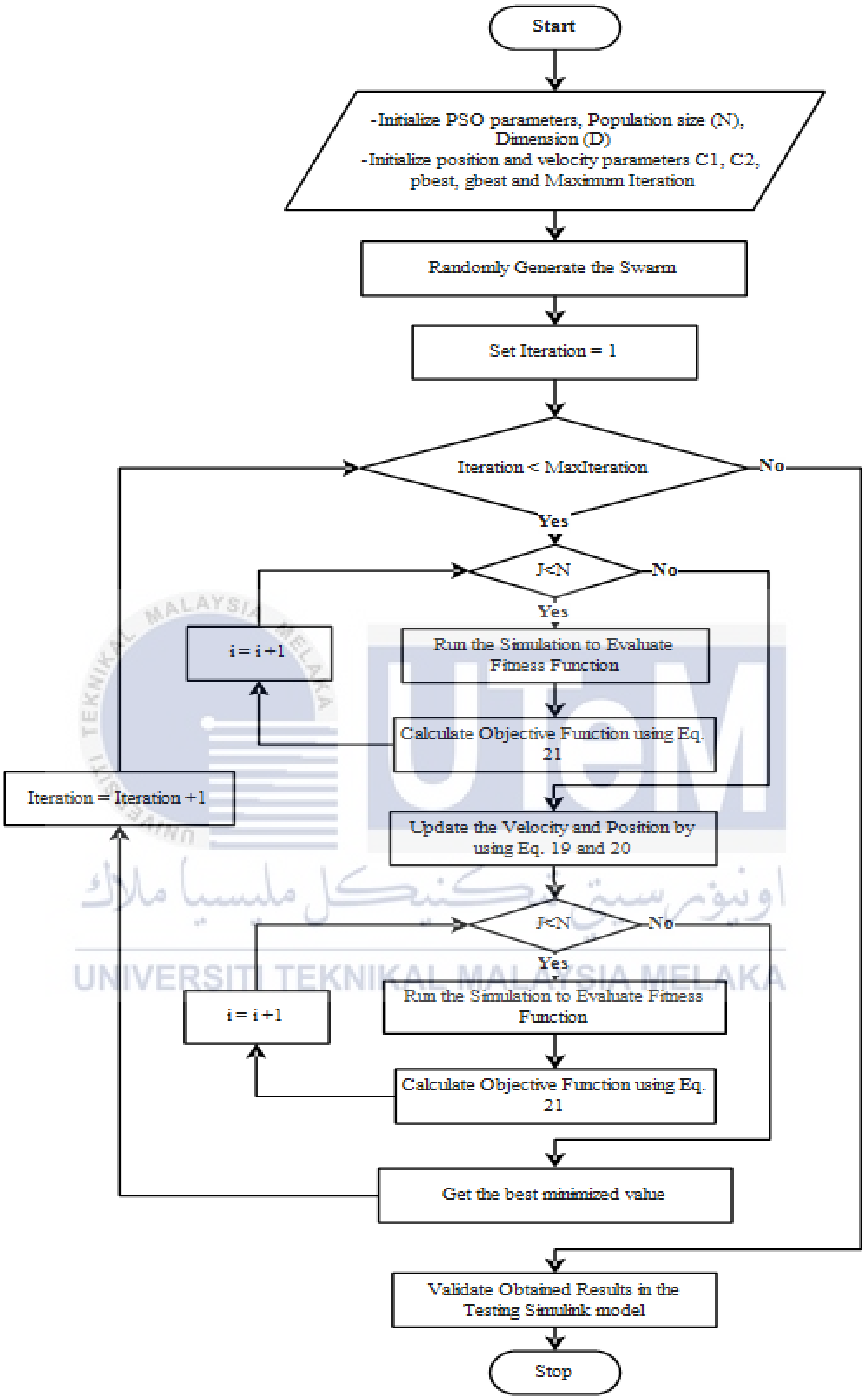

Figure 3.3: Flow chart of PSO technique

3.5 Switching operation of a modified CHB-MLI for five-level configuration

Figure 3.4 shows the timing diagram of switching pattern for the proposed multilevel inverter which explained the operating modes of switching process of modified CHB-MLI for five levels. Table 3.1 displays that each switch's and diode's switching combinations 'l' represents the switch or diode in conducting mode and '0' is for the non-conducting mode.

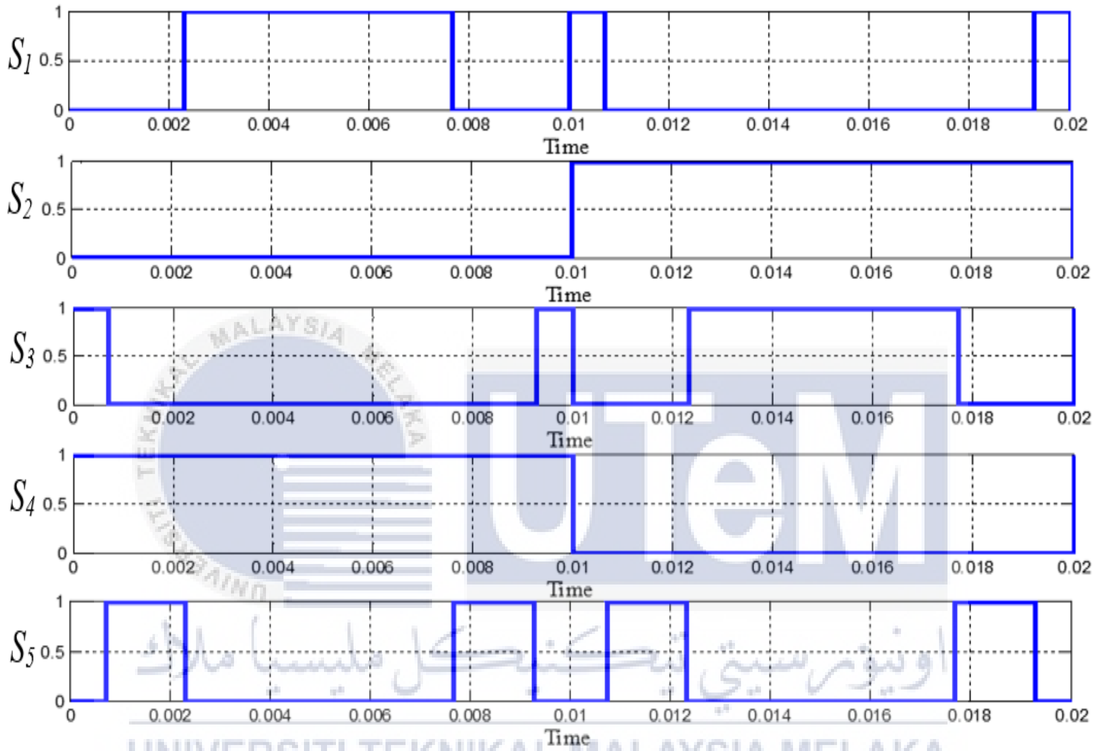

Figure 3.4: Switching pattern of a five-level modified CHB-MLI

Table 3.1: Switching combinations

S_1	S_2	S_3	S_4	S_5	Vo
1	0	0	1	0	V_{dc}
0	0	0	1	1	$V_{dc}/2$
0	0	1	1	0	0
1	1	0	0	0	0*
0	1	0	0	1	$-V_{dc}/2$
0	1	1	0	0	$-V_{dc}$

3.6 Modelling of the proposed five-level MLI using MATLAB/SIMULINK

MATLAB/SIMULINK software was used to model the simulation circuit of a modified CHB-MLI for five levels as illustrated in Figure 3.5. The MI value used for this model is 0.949 as it is the optimised value to gain the lowest harmonic distortion. The model consists of five switches and use PSO algorithm to obtain the optimal firing angle for the purpose of harmonic elimination. For this simulation model, one voltage supply is used which is a 300V direct current (DC) voltage source. This model used pulse generator block to conduct the switching pattern and control the multilevel inverter based on PSO algorithms. Other component used in this simulation model are ideal voltage and current measurement, R, L and C as loads. The parameter for the component of the model is shown in Table 3.2.

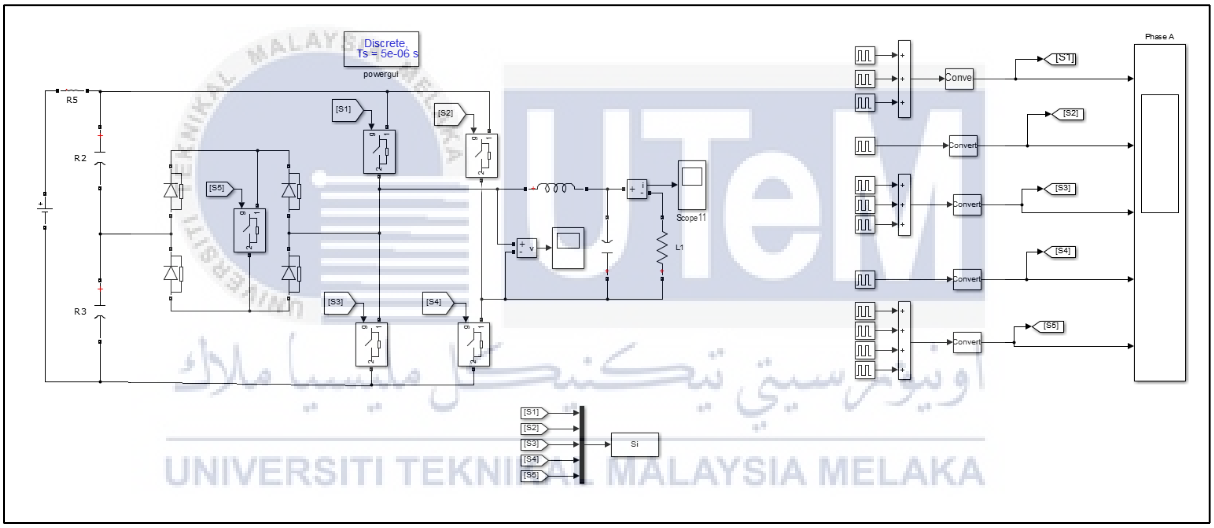

Figure 3.5: five-level CHB-MLI design using MATLAB/SIMULINK

Table 3.2: Parameter of the simulation model

COMPONENT	VALUE
Dc supply source	300V
Resistor	100kΩ
Frequency	50Hz
Capacitor	2500uF
Inductor	20e-3mH

3.7 Discussion on the Design for Proposed Hardware Implementation

3.7.1 Gate Drive for IGBT Switching

Figure 3.6 shows the construction of a gate drive for inverter which being utilise for switching the IGBT that comprises optocoupler HCPLA3120. The purpose of using optocoupler HCPL3120 is to interface the signal from DSP as low power voltage side to high voltage side. Moreover, it is a high-current output IGBT gate drive as the rating current and voltage supplied by HCPLA3120 made it ideally suitable for directly driving IGBTs with ratings up to 1200V/100A. For this research, the IGBT from Infineon IHW30N90Te was used with gate drive as the gate drive accepted +3.3volt input signal from DSP, and sent it with isolated $\pm 15\ volt$ to drive the IGBT that was connected to 100 volt DC. Some of the other component used in the gate drive are gate drive IC, resistors at different values, gate resistor and capacitor, boost Transformer and connectors.

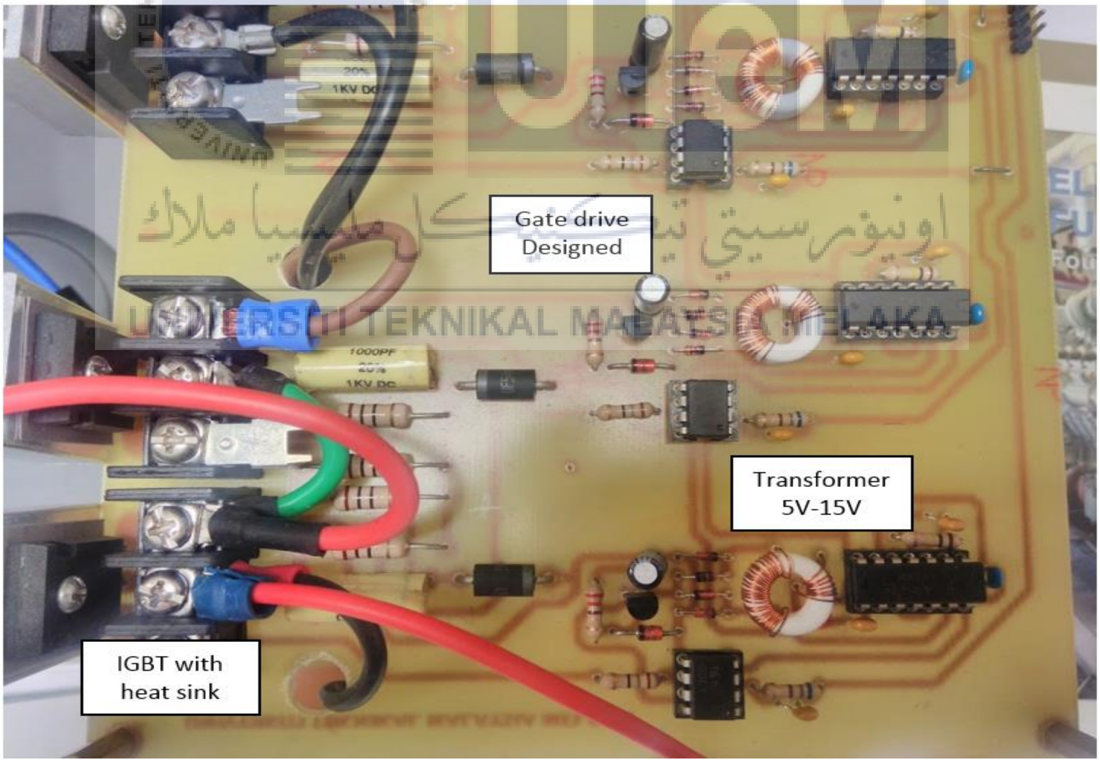

Figure 3.6: Prototype of gate drive for CHB-MLI

3.7.2 The hardware of modified five-level CHB-MLI

The construction of the modified five-level CHB-MLI involves integrating part of semiconductors switching, transformer coils and optocoupler HCPLA3120 as shown in Figure 3.7 and Figure 3.8. Gate (G), collector (C) and emitter (E) are the terminal that contain in IGBT. The IGBT is capable of operating up to 100 kHz switching frequency and supply the electric current of 60 A at $25\ ^{o}$C, and become 30 A when the temperature of the IGBT reached $100\ ^{o}$C. Furthermore, the IGBTs can accept a maximum of $\pm 30V$ gate to emit voltage pulse.

Figure 3.7: Front view of five-level CHB-MLI

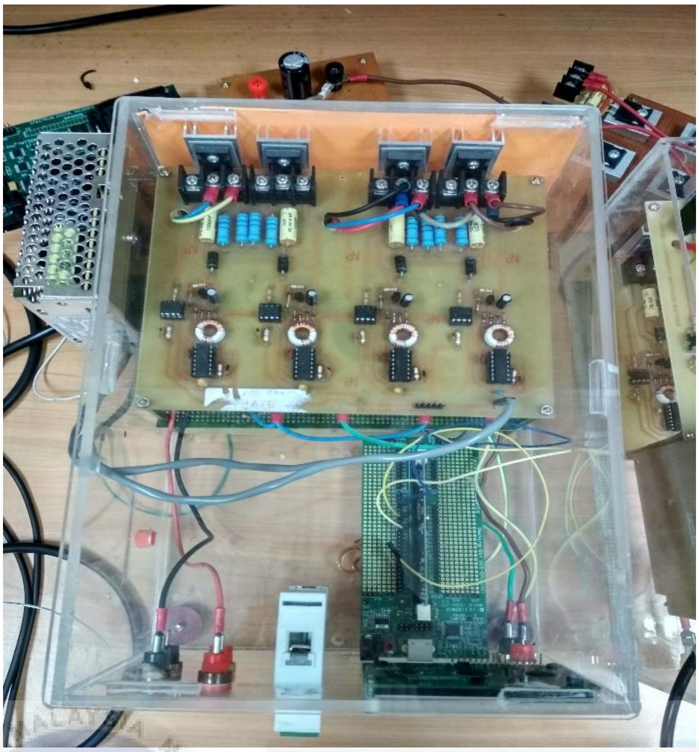

Figure 3.8: Upper view of five-level CHB-MLI

3.7.3 The hardware of modified five-level CHB-MLI

In this research, DSP TMS320F2812 is represented that function as a microprocessor to measure, filter or compress the signal in order to get the output result for the CHB-MLI. Figure 3.9 display the model of DSP TMS320F2812 which used a frequency of 150MHz for the hardware. DSP TMS320F2812 consist of time sampling, control system, analogue to digital conversion (ADC). The system used in the DSP could generate the controller to produce pulse width modulation (PWM). Some of the beneficial feature of DSP TMS320F2812 for the research are 12-bit A/D module handling 16 channels and two on-chip event manager peripherals which provide a broad range of functions, particularly useful in applications of control. The coding based on PSO technique is developed to be coded and stored in the DSP in order to carry out the inverter.

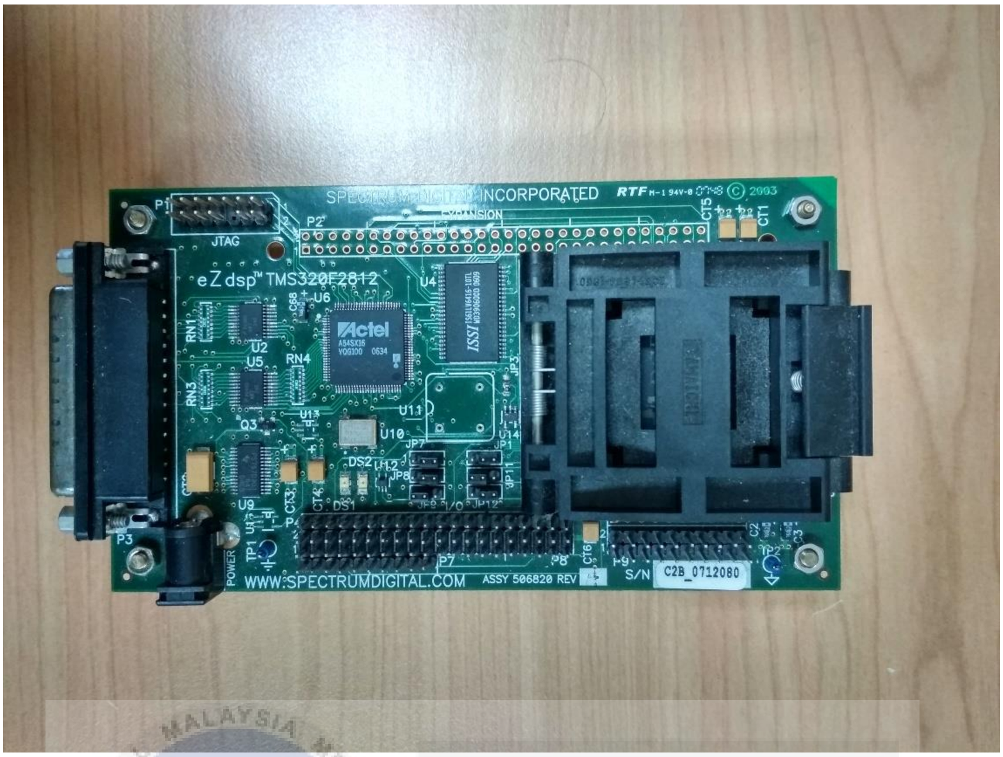

Figure 3.9: Model of DSP TMS320F2812

3.8 Summary of methodology

In order to get a better understanding of the study and meet the objectives, a detailed research methodology has been discussed. The proposed method can be categorized into a few phase. Firstly, the data collection from the previous study is discussed to design the proposed topology using MATLAB/SIMULINK software. The parameter from the simulation is being utilize to develop and implement the hardware configuration. The proposed five-level CHB-MLI was tested and the results were analyzed by comparing the simulation and experimental result in the last phase.

CHAPTER 4

RESULTS AND DISCUSSIONS

4.1 Overview

In this chapter, the discussion about simulation and experimental results will be discussed in details. The simulation results of a modified CHBMLI for five levels, then will be compared with the experimental results which is obtained from the design of a modified CHBMLI for five levels using PSO.

4.2 Result of the Simulation

The result of the simulation will be presented in this section. In order to validate the performance of the proposed scheme, the model of the modified cascaded multilevel inverter was developed as illustrated in Figure 3.5. The proposed model then simulated by using the MATLAB / SIMULINK program.

4.2.1 Simulation Result of 5-level CHB-MLI with MI= 0.949 based on PSO technique

Based on the simulation model as shown in chapter 3, the simulation starts with the calculation of Modulation Index (MI) of 0.949 which is the optimum value of the MI can achieve. Figure 4,1 shows the switching pattern of a modified CHBMLI for five levels at the switches S1- S5 which is obtained by calculating the switching angles for optimisation using the PSO technique.

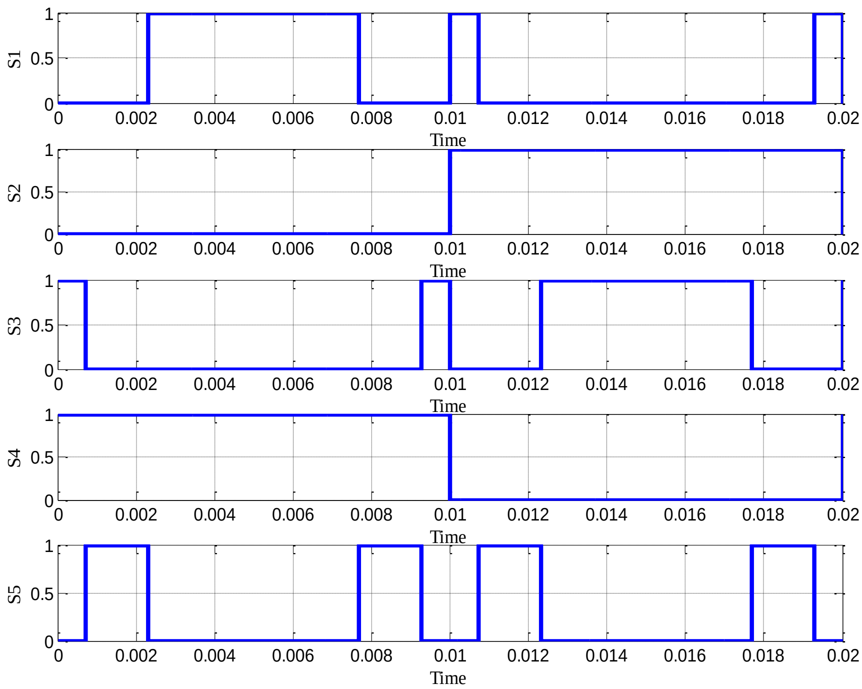

Figure 4.1: output switching waveform S1- S5 for MI= 0.949

The combination of the switches of S1, S2, S3 and S4 will produce the output voltage for five levels CBH-MLI for the simulation as shown in Figure 4.2. At this MI of 0.949, the perfect and smooth output waveform is obtained with the optimal value of MI. The analysis of the harmonic spectrum for the voltage output waveform is displayed in Figure 4.3. The THD value for the optimised voltage output waveform is 15.34%.

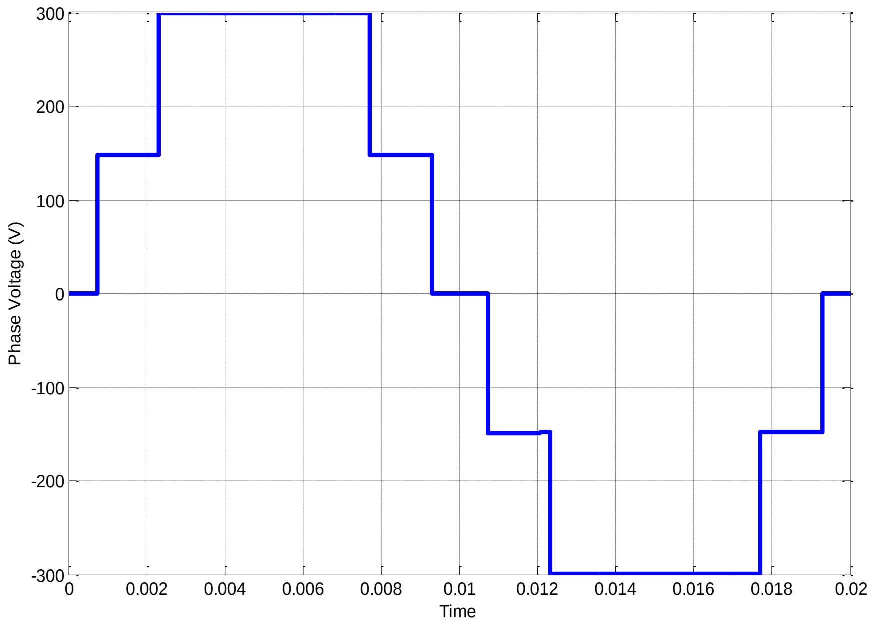

Figure 4.2: Output voltage waveform of five level CHB-MLI with MI = 0.949

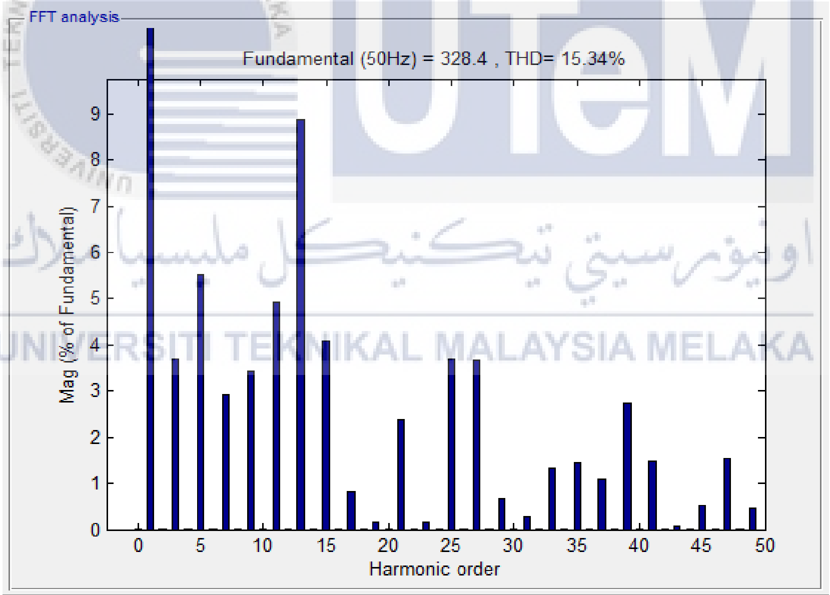

Figure 4.3: Harmonic spectrum for voltage at output 5-level CHB-MLI with MI = 0.949

Figure 4.4 described the optimisation of output current waveform for five- level CHB-MLI. It can be shown from the Figure 4.4 that the current waveform is smooth and sinusoidal due to perfect calculation of switching angle using PSO technique. Based on the harmonic spectrum, the value of THD for the current is 0.9% as shown in Figure 4.5.

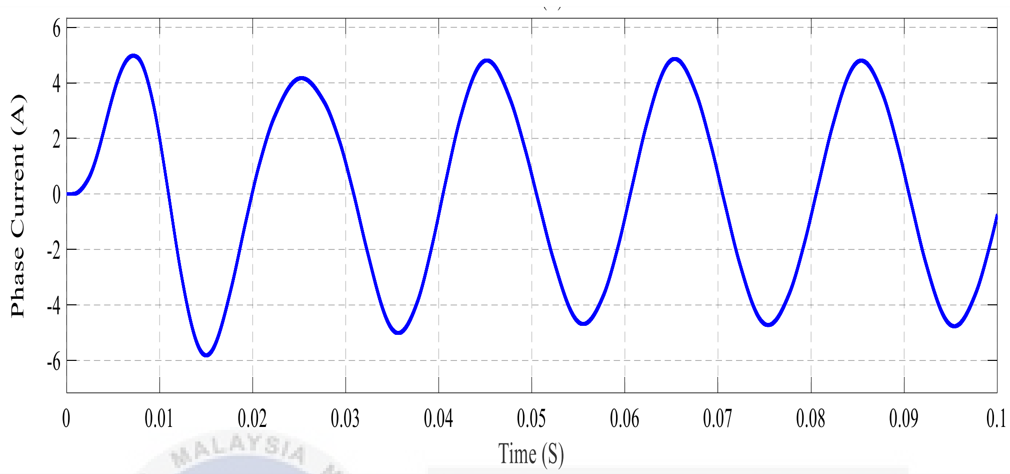

Figure 4.4: Output current waveform of five level CHB-MLI with MI = 0.949

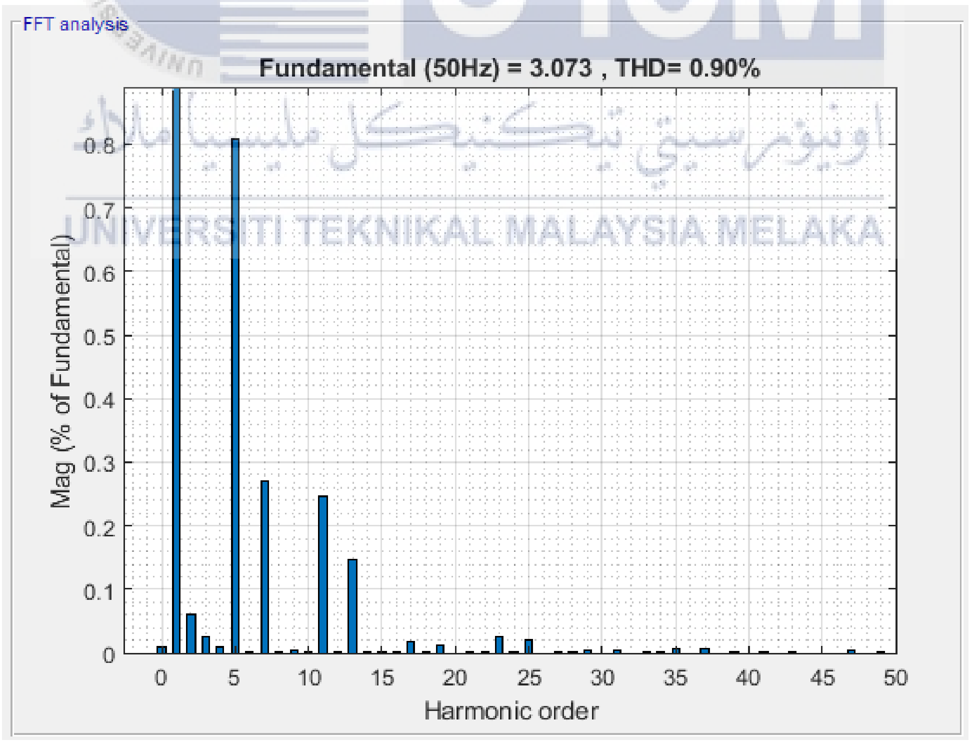

Figure 4.5: Harmonic spectrum for current at output 5-level CHB-MLI with MI = 0.949

4.2.2 Simulation Result of 5-level CHB-MLI with MI= 0.75 based on PSO technique

Using PSO technique, the value of MI such 0.75 is used for the purpose of simulation for five-level modified CHB-MLI. Figure 4.6 illustrates the switching waveform where there are five switches which comprises switches S1, S2, S3, S4 and bi-directional S5. Each switch produces different waveform in order to produce output voltage and current waveform as shown respectively in Figure 4.7 and Figure 4.9 using MI value of 0.75.

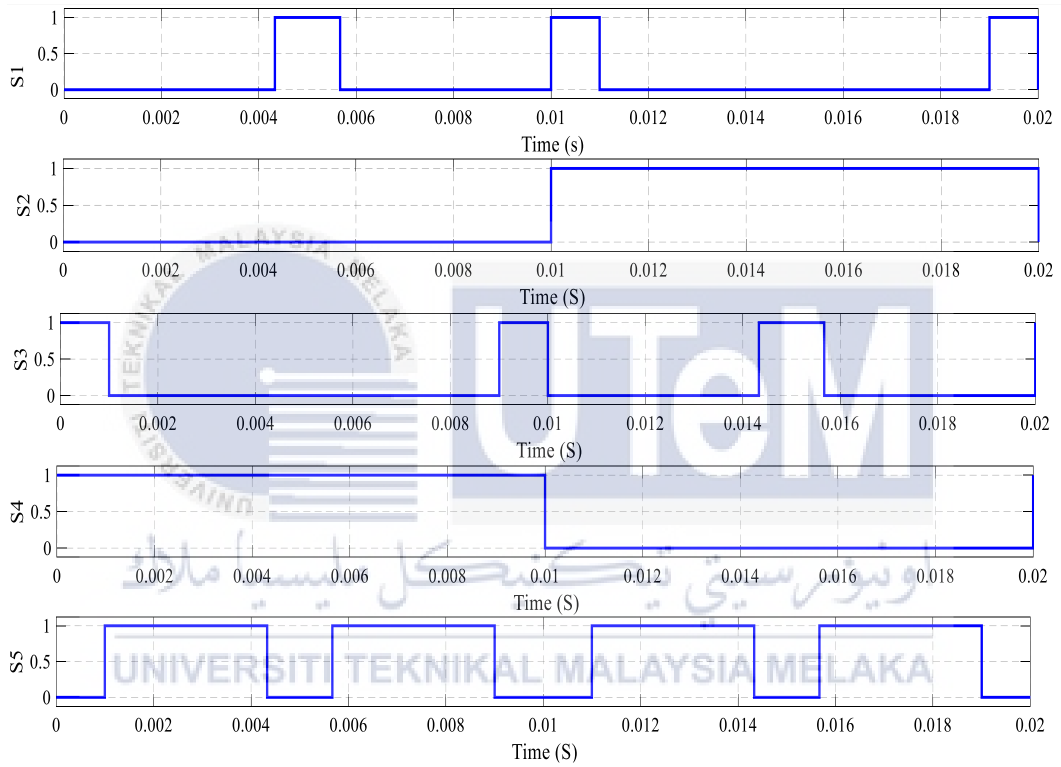

Figure 4.6: output switching waveform S1- S5 for MI= 0.75

In the cases, if the MI is changed from 0.949 to 0.75, the output of the inverter for the voltage can be seen as shown in Figure 4.7. The waveform of the voltage obtained is not so smooth as compared with the waveform of voltage obtained from Figure 4.2 due to the non-optimisation value of MI which is 0.55. Figure 4.8 represent the harmonic spectrum for the output voltage waveform. Based on the harmonic spectrum, the value of THD for voltage output is 28.93%.

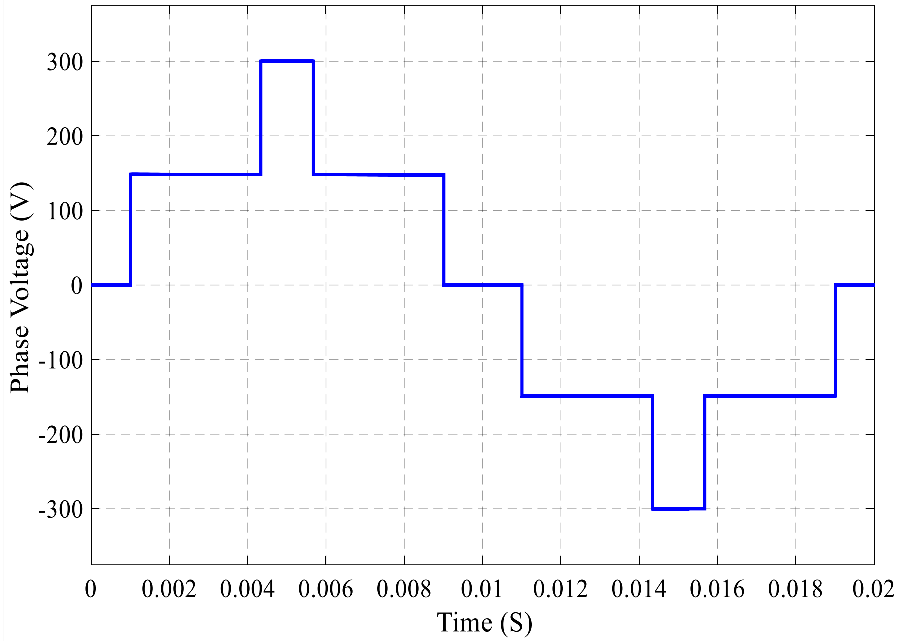

Figure 4.7: Output voltage waveform of five level CHB-MLI with MI = 0.75

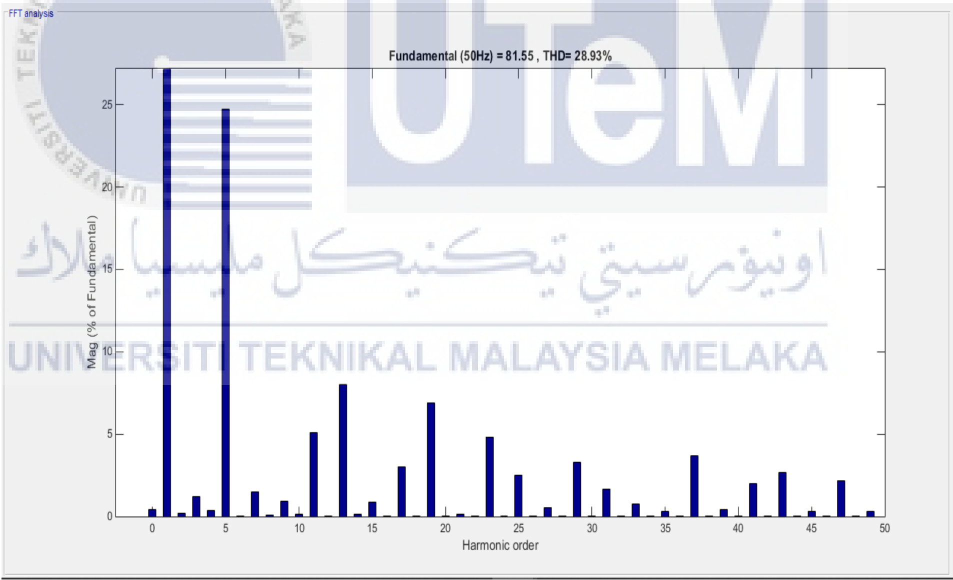

Figure 4.8: Harmonic spectrum for voltage at output 5-level CHB-MLI with MI = 0.75

The non-optimisation of output current waveform of a single-phase modified CHB-MLI of five levels using PSO can be described in Figure 4.9. The output current waveform is not very smooth compared to output current waveform in Figure 4.4 due to non-optimise value of MI which affect the calculation of switching angles. Figure 4.10 display the value of THD for the current waveform which is 3.83%. The harmonic content in the simulation was refer to the value of THD obtained.

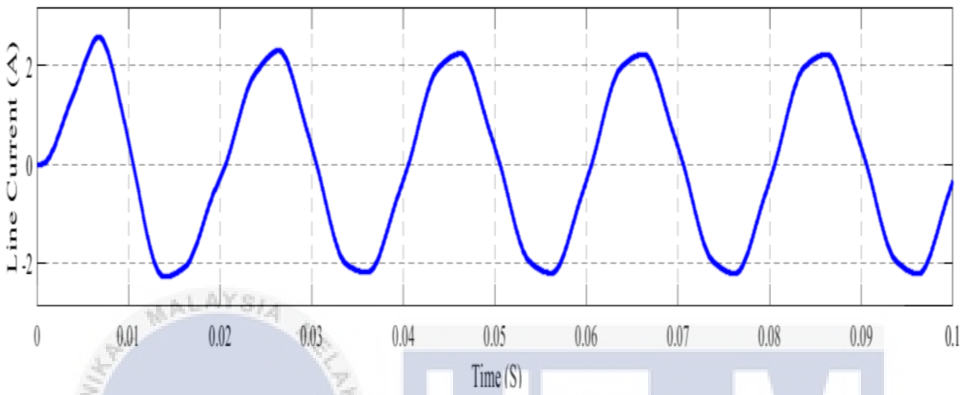

Figure 4.9: Output current waveform of five level CHB-MLI with MI = 0.75

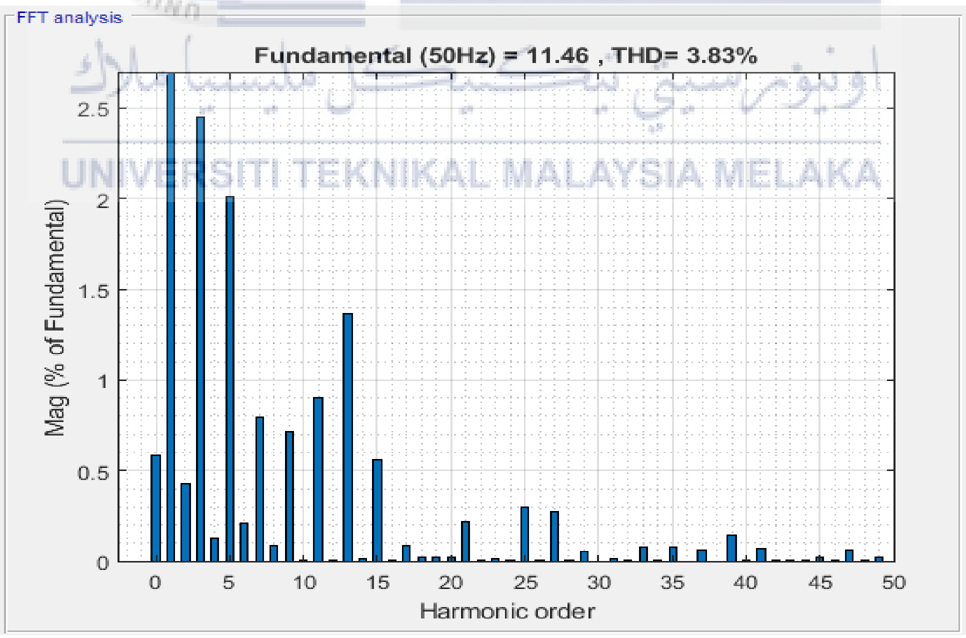

Figure 4.10: Harmonic spectrum for current at output 5-level CHB-MLI with MI = 0.75

4.2.3 Simulation Result of 5-level CHB-MLI with MI= 0.55 based on PSO technique

By referring to the simulation model in figure in chapter 3, the simulation is then compared with another value of non-optimise MI which is 0.55. The switching waveform can be illustrated using the switches in timing diagram in Figure 4.11. The switching angle is obtained by using PSO algorithm to calculate the phase delay and period for each switches in the timing diagram.

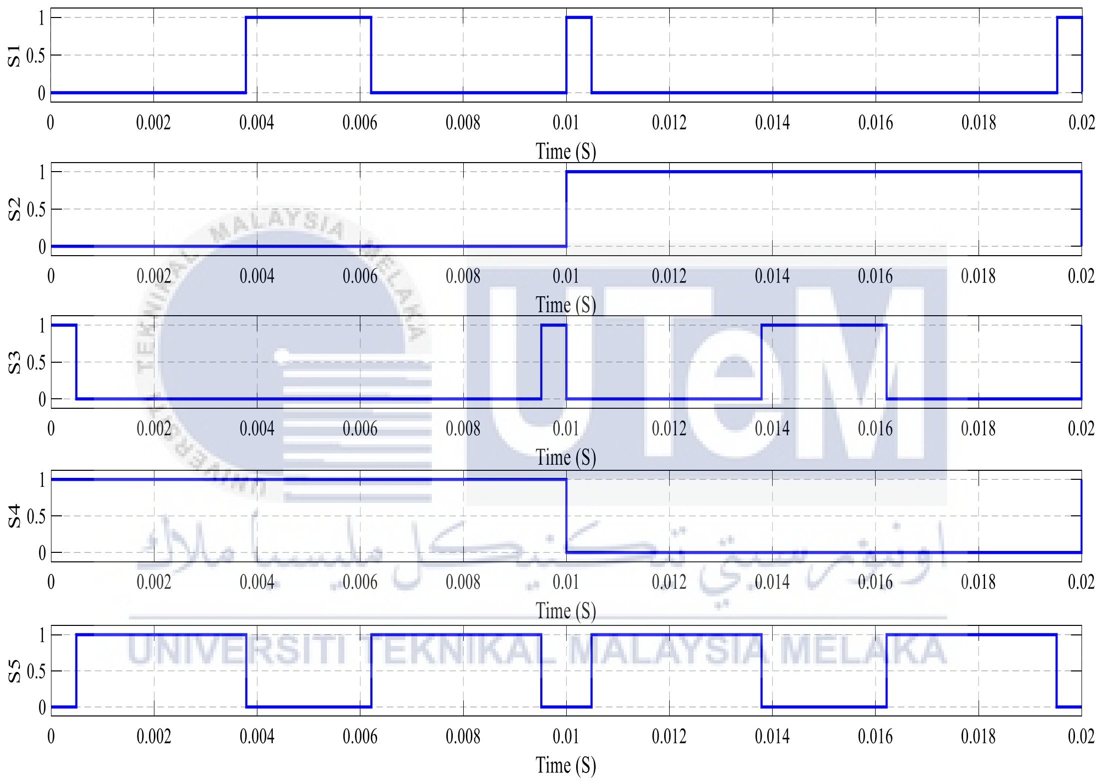

Figure 4.11: Output switching waveform S1- S5 for MI= 0.55

The non-optimization five-level CHB-MLI has been simulated with MI value of 0.55. The simulation using optimized value of MI which is 0.9 prove the output voltage waveform to be smooth but the output voltage waveform for MI= 0.75 shown to be less smooth. Whereas, another non-optimized value of MI which is 0.55 proven the smoothness of output voltage waveform to be worse than waveform of MI= 0.75 as displayed in Figure 4.12.

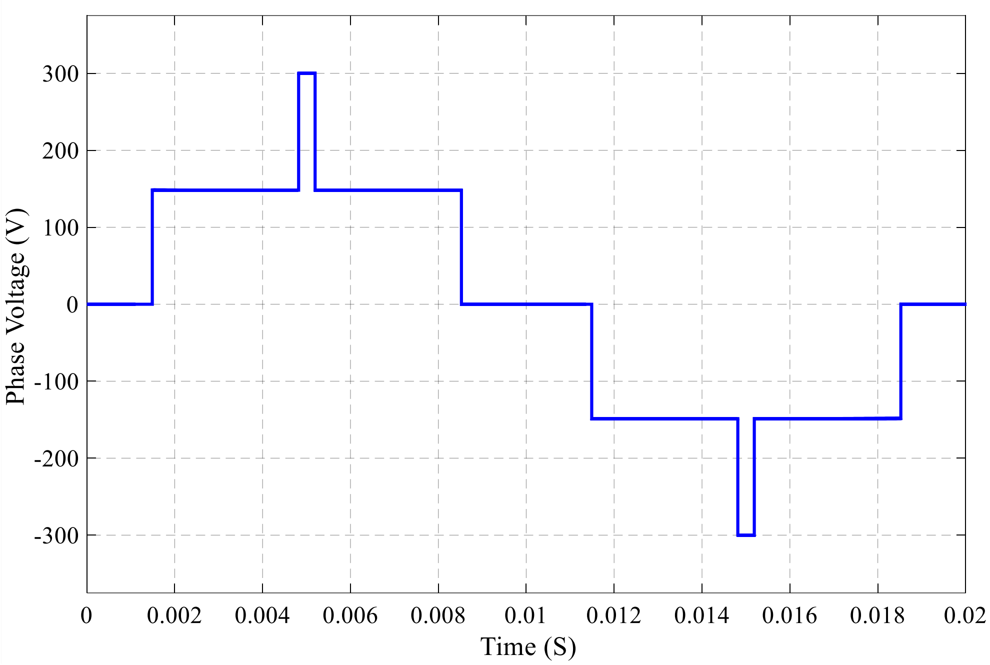

Figure 4.12: Output voltage waveform of five level CHB-MLI with MI = 0.55

The Figure 4.13 shows the harmonic spectrum for the output voltage waveform for MI= 0.55. Based on the harmonic spectrum, the value of THD which obtained for the output voltage is equal to 32.87%.

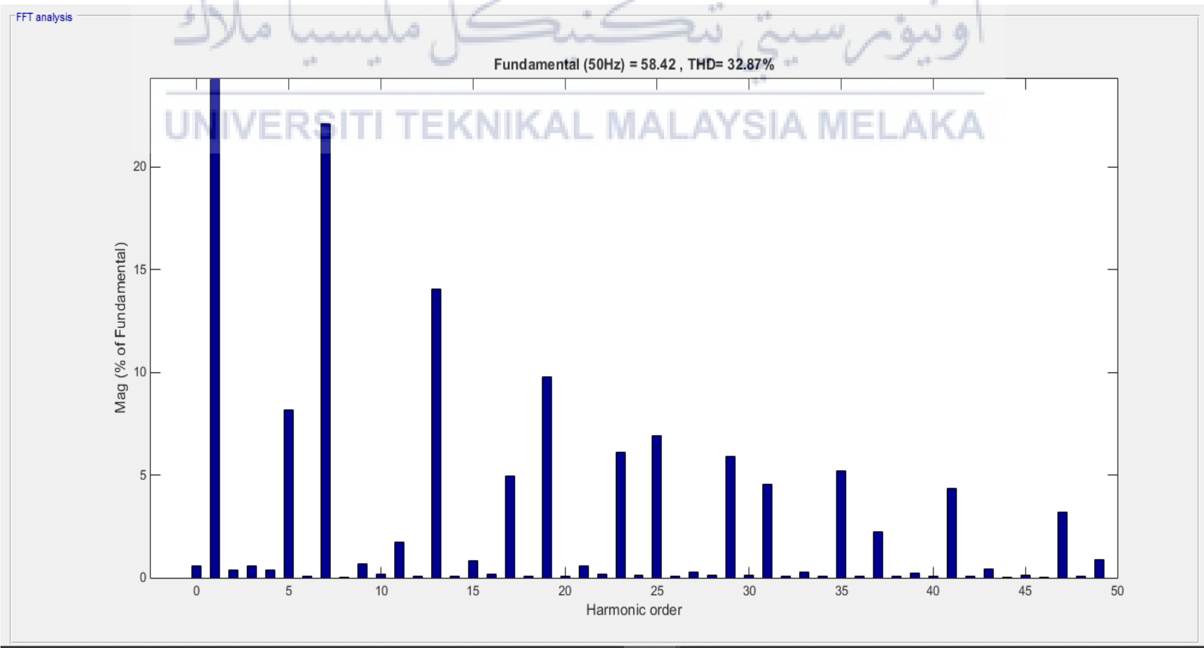

Figure 4.13: Harmonic spectrum for voltage at output 5-level CHB-MLI with MI = 0.55

Figure 4.14 shows a lesser sinusoidal output current waveform of a graph current against time obtained from 5-level CHB-MLI with the modulation index that is set at 0.55. The waveform is not smooth and sinusoidal because of the value of MI used for this simulation is not optimised. The value of THD for this MI is equal to 6.43% as being displayed in harmonic spectrum in Figure 4.15.

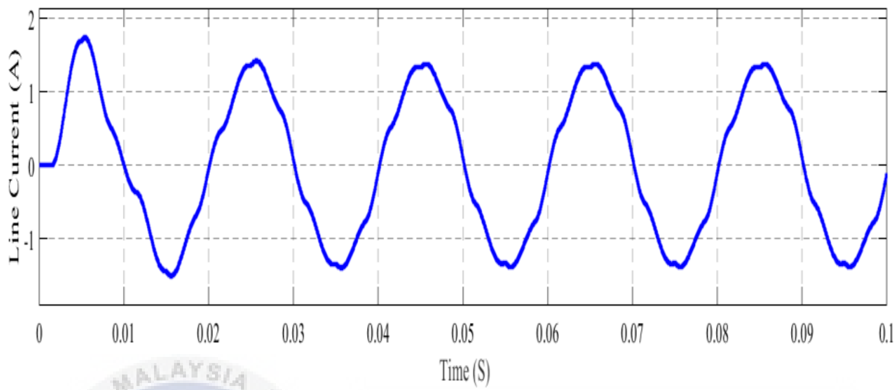

Figure 4.14: Output current waveform of five level CHB-MLI with MI = 0.55

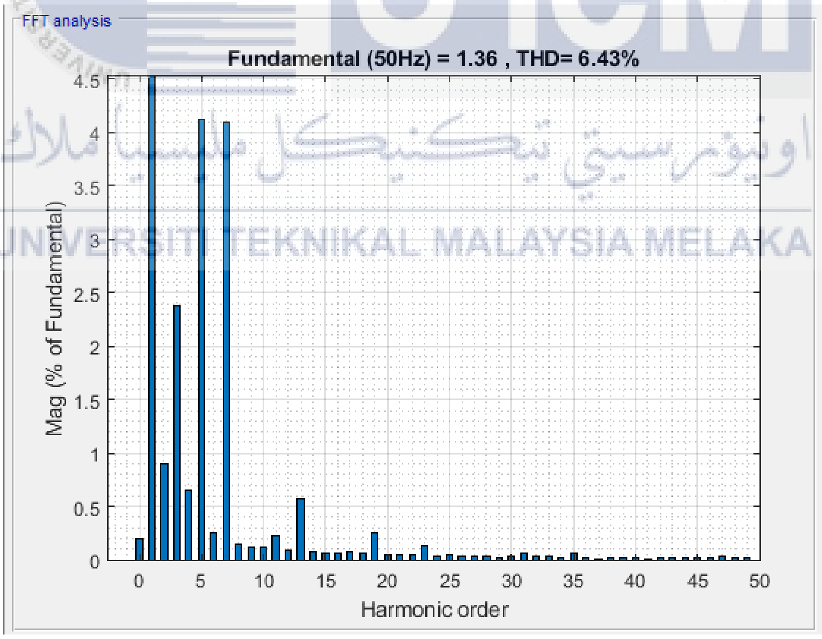

Figure 4.15: Harmonic spectrum for current at output 5-level CHB-MLI with MI = 0.55

4.2.4 Switching angle for 5-level modified CHB-MLI

In this case, the switching angles for the Modulation Index (MI) angle in the range of 0.55–0.949 have been discussed. Table 4.1 shows the values of switching angles for the Modulation Index (MI). Based on the calculation from the code as shown in Appendix A, the optimisation and non-optimisation of switching angles can be determined and the suitable MI obtained for both techniques is equal to 0.949.

Table 4.1: Switching angle of different MI

Modulation Index (MI)	θ_1	θ_2
0.949	13.4105	41.934
0.75	28.886	64.886
0.55	32.875	69.99

4.3 Result of the Hardware Implementation

In order to validate the performance of the proposed multilevel inverter, a prototype was designed and built for modified CHB-MLI of five level as shown in Figure 3.5. The purpose of the proposed modified CHB-MLI for single-phase functions as an interface with DSP TMS320F2812 is to obtain an output voltage and current waveform. The analysis for the THD is also carried out for the output voltage and current waveform with different value of MI. The switching signal has been generated by using DSP-TMS320F2812 target board as it is an important hardware in order to operate the CHB-MLI.

The source code programming based on the PSO techniques has been created and tested for the single-phase modified CHB-MLI. The proposed source codes for PSO techniques were stored into DSP TMS320F2812 to switch the scheme of the algorithm source for the CHB-MLI. Hence, a written algorithm source code based on the PSO techniques, had been integrated by using DSP TMS320F2812 to operate the five level CHB-MLI.

The DC supply was used and is applied for single-phase modified CHB-MLI. The generated switch pulses with MI values equal to 0.949 and 0.75 were stored in the DSP TMS320F2812. The MI and parameters used in order to obtain the simulation result, is similar to employed the experiment.

4.3.1 Experimental Result of 5-level CHB-MLI with MI= 0.949 based on PSO technique

The switching operation for the optimisation of modified five-level CHB-MLI with the value of MI equal to 0.949 is developed by using source code as shown in Appendix. The developed source code was then embedded in DSPTMS320F2812. The DSPTMS320F2812 card was then interfaced with the proposed prototype of a modified five-level CHB-MLI for single-phase schemes. Figure 4.16 has shown the switching waveform for the five-level CHB-MLI which comprises switches S1, S2, S3, S4 and S5.

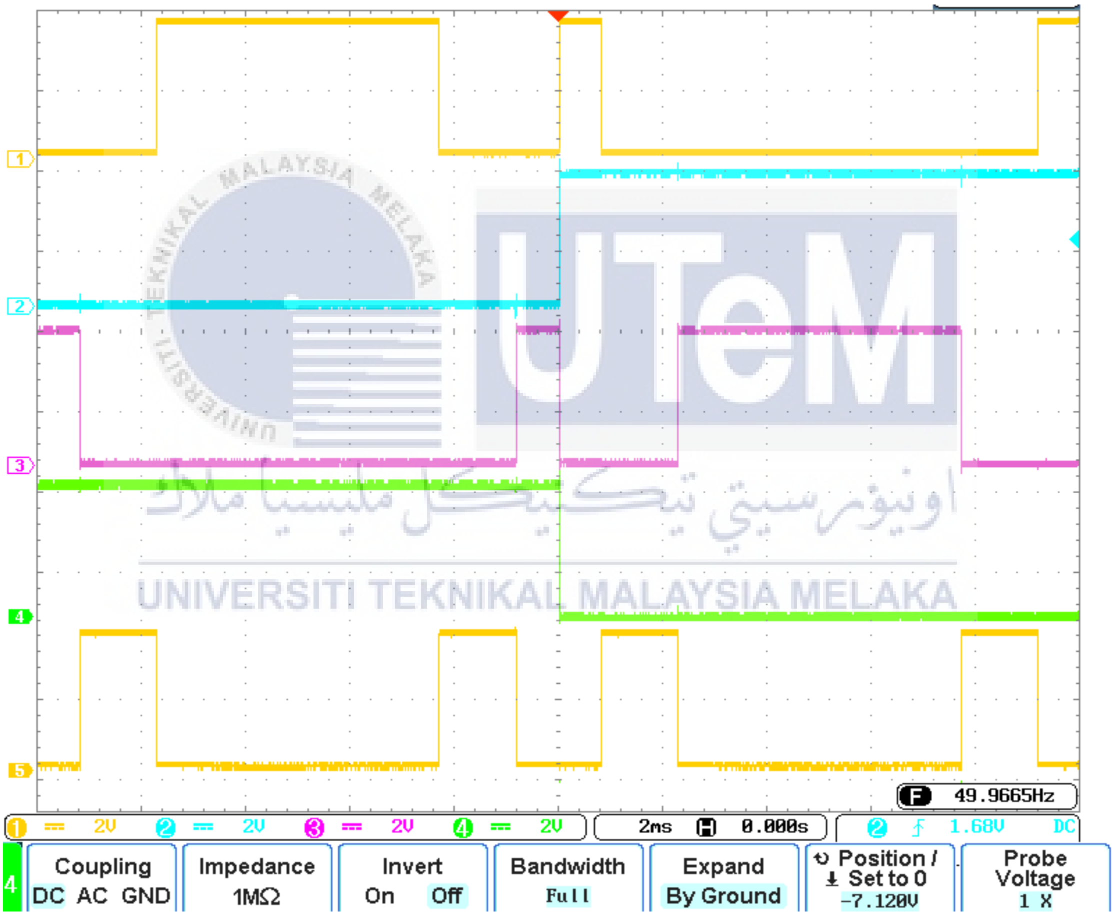

Figure 4.16: Timing diagram of a modified CHB-MLI using PSO technique with MI= 0.949

The output voltage waveform for five-level CHB-MLI with MI value of 0.949 is represented in Figure 4.17. The voltage waveform is smooth compared to other voltage waveform with different MI because optimised MI has been used for this output. The value of THD for the output voltage waveform can be obtained via harmonic spectrum as shown in Figure 4.18. The value of THD for output voltage is 15.5%.

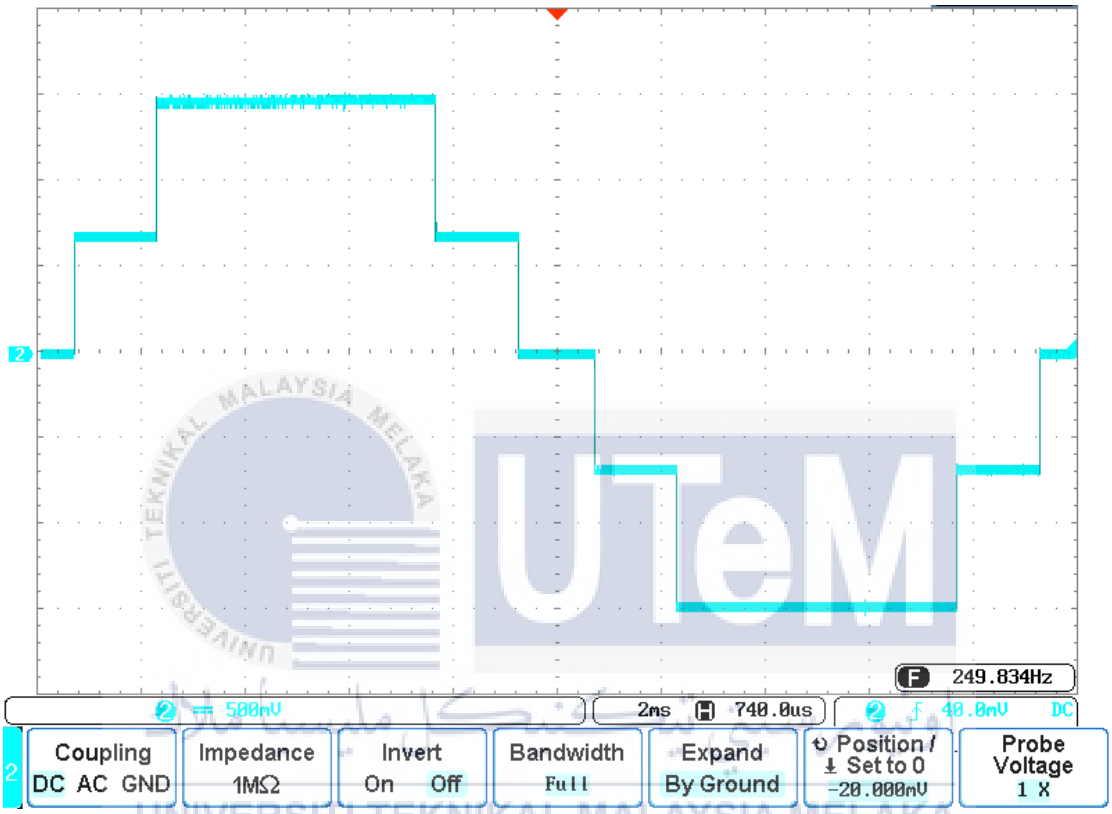

Figure 4.17: Output voltage waveform for optimisation five-level CHB-MLI with MI= 0.949

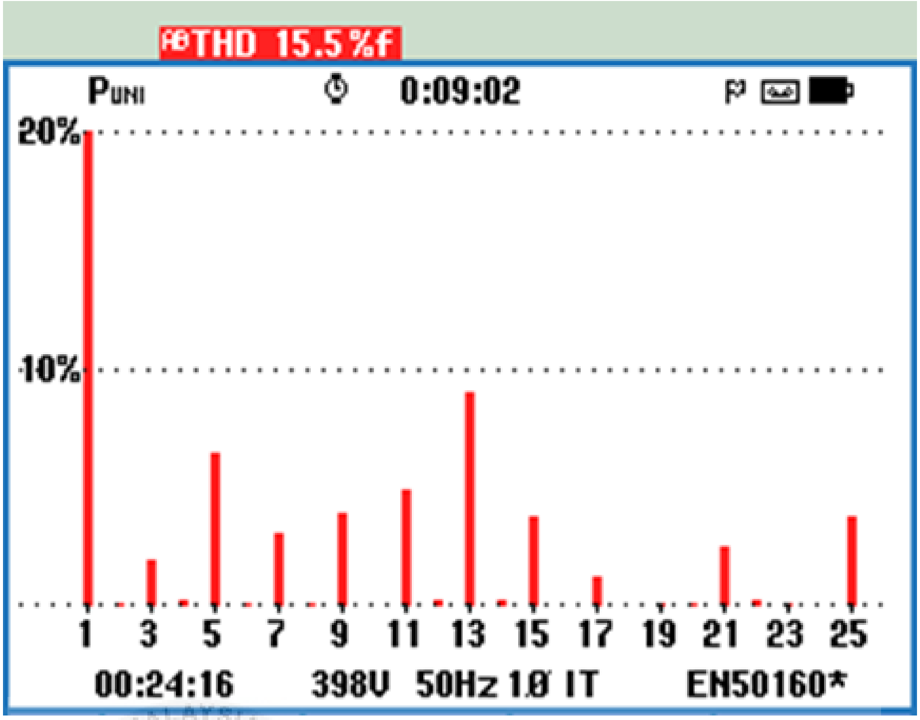

Figure 4.18: Harmonic spectrum of voltage output waveform using PSO technique with MI= 0.949

Based on the timing diagram in Figure 4.16, the current output waveform for five-level CHB-MLI is displayed in Figure 4.19 as the waveform is smooth and sinusoidal due to the use of optimal value of MI. The harmonic spectrum of the current output waveform for five-level CHB-MLI is shown in Figure 4.20. The value of THD for this MI is equal to 3.9% as being displayed in harmonic spectrum in Figure 4.20.

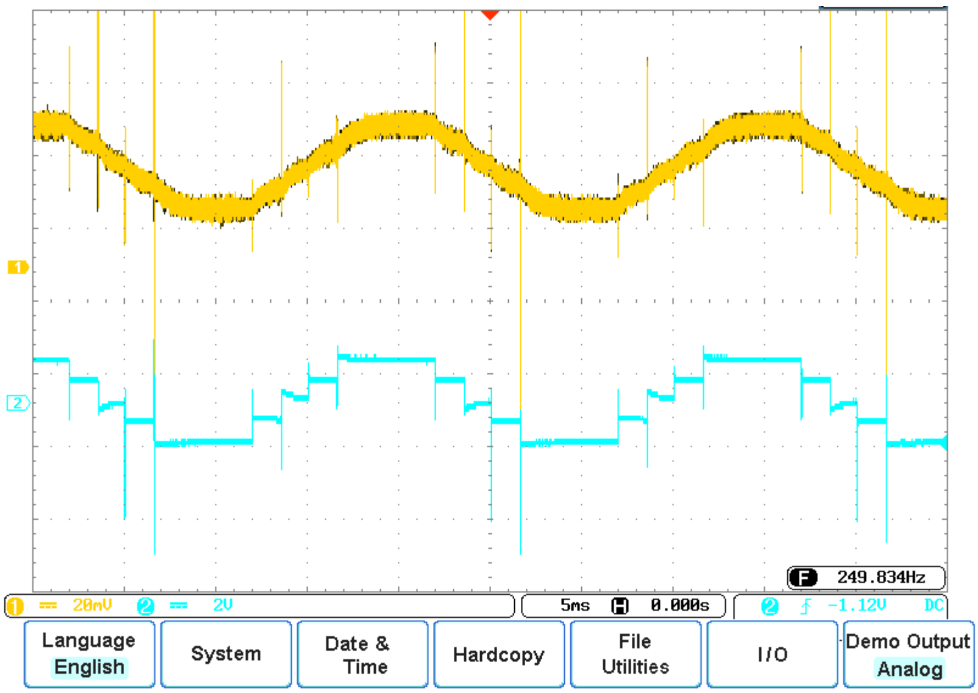

Figure 4.19: Output voltage waveform for optimisation five-level CHB-MLI with MI= 0.949

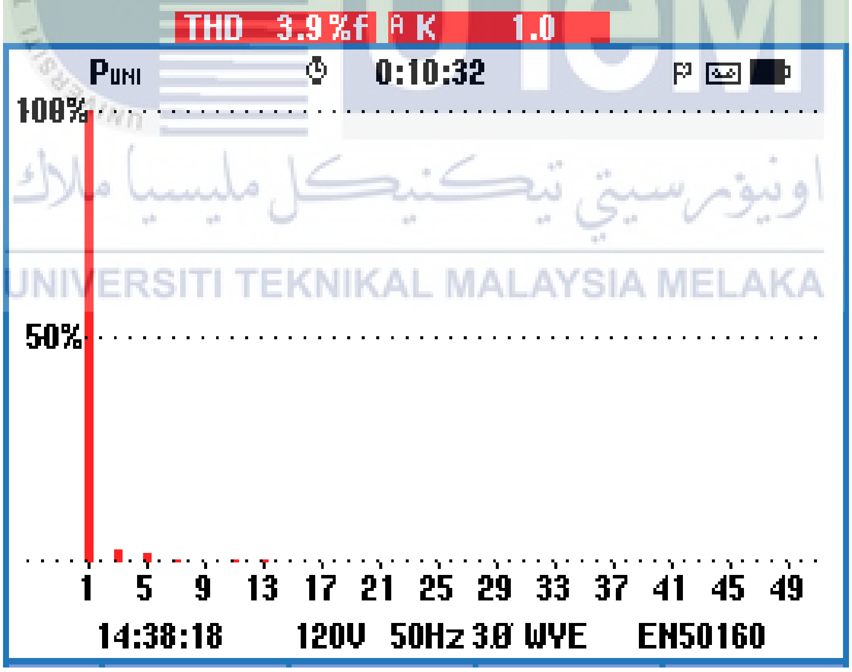

Figure 4.20: Harmonic spectrum of current output waveform using PSO technique with MI= 0.949

4.3.2 Experimental Result of 5-level CHB-MLI with MI= 0.75 based on PSO technique

The value of different MI which is 0.75 is used for the purpose of hardware implementation for five-level modified CHB-MLI. Figure 4.21 illustrates the switching waveform where there are five switches which comprises switches S1, S2, S3, S4 and bi-directional S5. Each switch produces different waveform in order to produce output voltage and current waveform as shown respectively in Figure 4.22 and Figure 4.24 using MI value of 0.75.

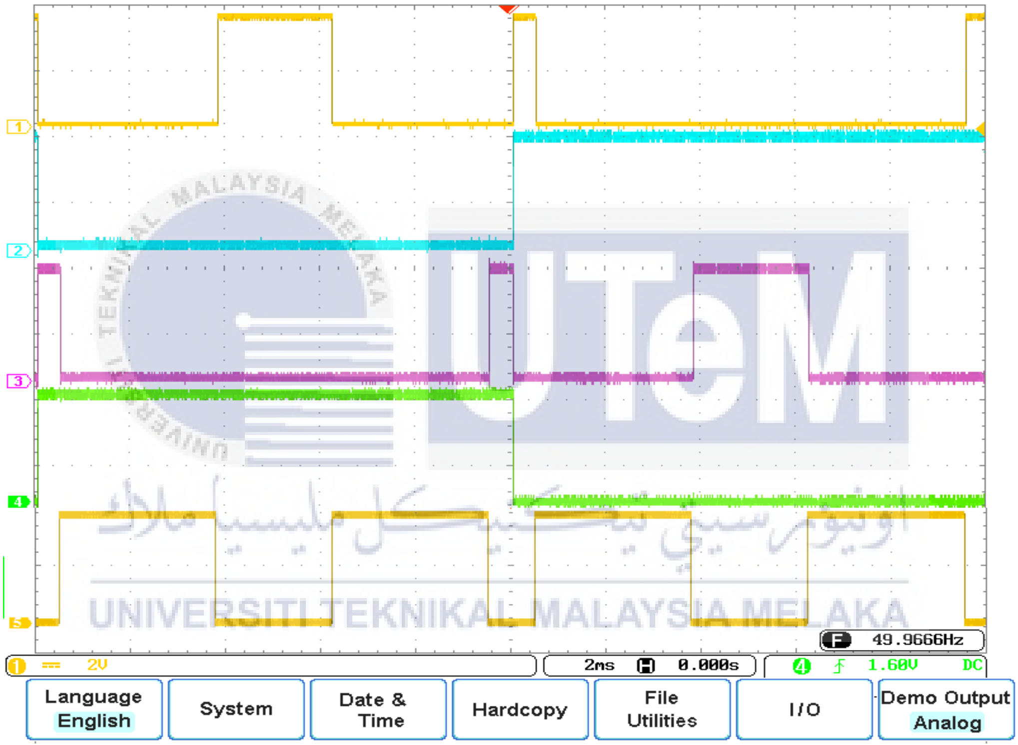

Figure 4.21: Timing diagram of a modified CHB-MLI using PSO technique with MI= 0.75

Based on the timing diagram as shown in Figure 4.21, the optimisation of output voltage and current waveform of a single-phase modified CHB-MLI of five levels using PSO with MI value equal to 0.75 can be illustrated in Figure 4.22 and Figure 4.24. The output voltage and current waveform is less smooth and less sinusoidal compared to previous result in Figure 4.19. Figure 4.23 and Figure 4.25 shows the non-optimisation harmonic spectrum of the output voltage and current waveform of a single-phase modified CHB-MLI with THD values equivalent to 30.4% and 6.87% respectively using the PSO technique.

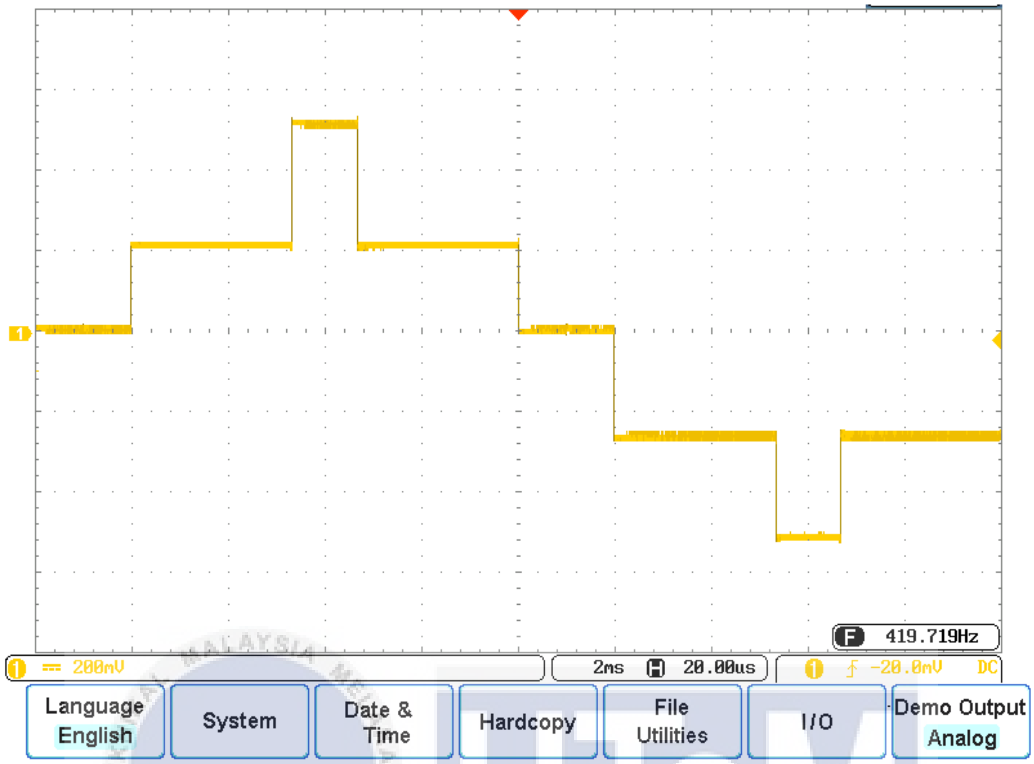

Figure 4.22: Output voltage waveform for optimisation five-level CHB-MLI with MI= 0.75

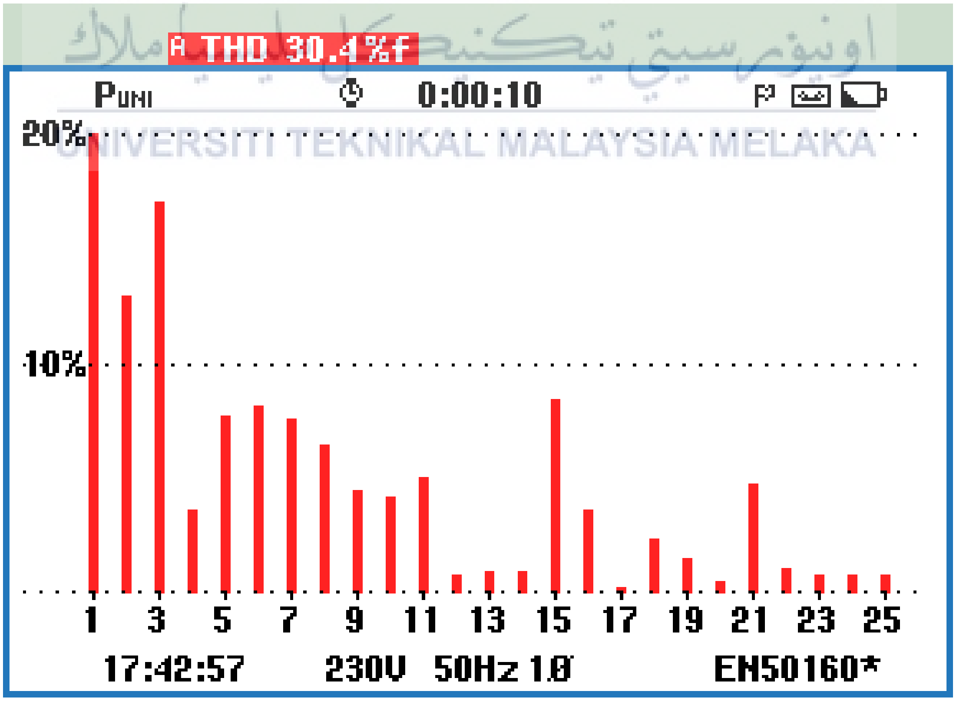

Figure 4.23: Harmonic spectrum of voltage output waveform using PSO technique with MI= 0.75

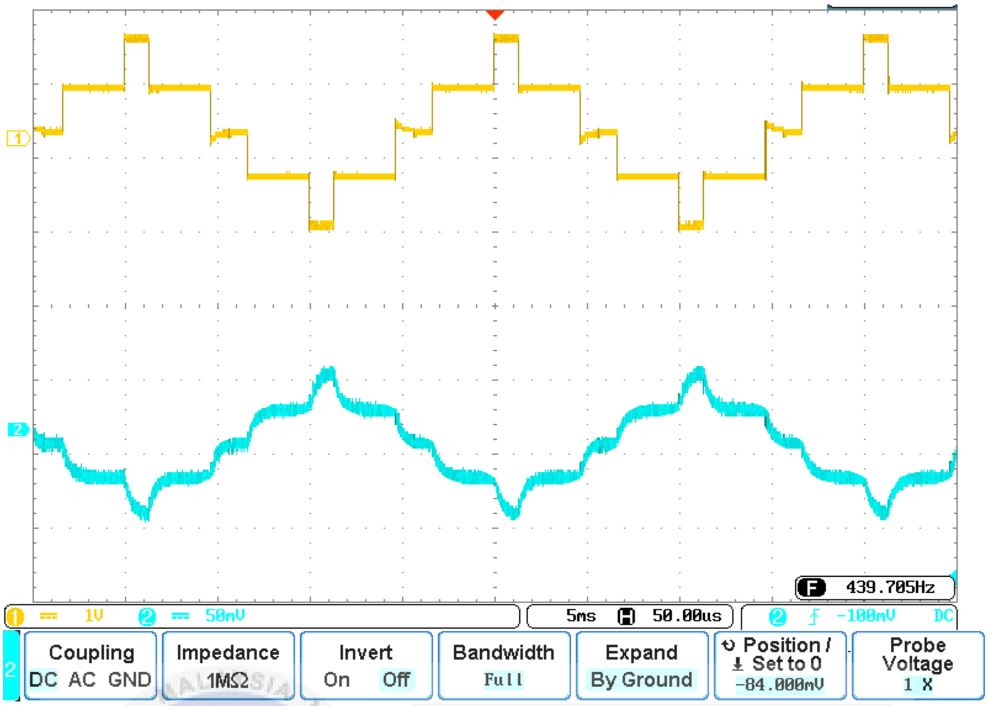

Figure 4.24: Output current waveform for optimisation five-level CHB-MLI with MI= 0.75

Figure 4.25: Harmonic spectrum of current output waveform using PSO technique with MI= 0.75

4.4 Performance comparison for experimental and simulation result of single-phase five-level CHB-MLI with different value of MI

Table 4.1 represent the performance comparison between simulation and experimental result based on different value of MI. Based on the analysis done for the experimental and simulation result, the THDv and THDi for the simulation and experimental is almost the same for every MI. Therefore, the value of THD which been obtained from the simulation and experimental result can be used to compare the performance of the five-level CHB-MLI. According to the result shown in Table 4.2, the best performance for the proposed CHB-MLI was the optimisation of CHB-MLI with MI of 0.949.

Table 4.2: Performance comparison between simulation and experimental result

RESULT	SIMULATION		EXPERIMENTAL	
MODULATION INDEX	THDv	THDi	THDv	THDi
0.949	15.34	0.9	15.5	3.9
0.75	28.93	3.83	30.4	6.87
0.55	32.87	6.43	-	-

4.5 Summary of the Result

The analysis for the simulation and experimental has been done without any problem for this chapter. The analysis starts with the study of the simulation design of modified five-level CHB-MLI using MATLAB/SIMULINK software in order to obtain the result for the simulation. The concept of PSO technique is used to calculate the switching angle which used to produce the output waveform.

Then, the parameter of the simulation design is implemented for the hardware purpose to design a prototype of five-level CHB-MLI. The coding based on PSO algorithm is embedded into DSP TMS320f2812 in order to operate the five-level CHB-MLI to produce the result. The performance for the five-level CHB-ML has been certified based on output voltage and current and also the value of THD.

The simulation results for the optimisation of single-phase modified CHB-MLI of five levels are in good agreement with the experimental results, which further exhibit the effectiveness of the proposed developed prototype and the effectiveness of the proposed techniques in reducing harmonics. The success of the experimental results also shows that these types of single–phase modified CHB-MLI using PSO techniques are suitable to be implemented.

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CHAPTER 5

CONCLUSION AND RECOMMENDATIONS

5.1 Conclusion

It can be concluded that the main objective for this project is to minimise the harmonic distortion of the multilevel inverter based on simulation and hardware result has been achieved. The five-level CHB-MLI is successfully designed for the simulation and hardware implementation. The value of MI that has been used in order to obtain the result is 0.949, 0.75 and 0.55 while 0.949 has been proven that is it the optimised value for the MI. PSO technique is implemented in the simulation and experimental to calculate the switching angle.

Based on the result achieved in chapter 4, it can be proven that result from both simulation and experimental is quite the same. It can be concluded that a higher value of MI will create a better and smooth output waveform with lower harmonic content. The harmonic content will be determined by the value of THD.

5.2 Recommendation

This study can be used as a benchmark towards designing a complex multilevel inverter in the development of harmonics minimisation in the future work with a better objective to minimise the harmonic content of the inverter output waveform. Other PWM technique could be implemented on the single phase CHB-MLI which may produce a better result. In this project, five-level CHB-MLI has been proposed to produce low value of THD. For the future work, maybe a higher level of CHB-MLI can be proposed for a new topology.

REFERENCES

[1] M Rasheed, R Omar, M Sulaiman. Review of multilevel inverters using particle swarm optimization (PSO). 2018; 1; 1-7.

[2] S Garg, AK Sharma,P Yadav.Performance Analysis of Cascaded Multilevel Inverter Using Particle Swarm Optimization Algorithm, 2016; 3(8); 580–586.

[3] W. Abd Halim, S. Ganeson, M. Azri, T.N.A. Tengku Azam. Review of Multilevel Inverter Topologies and Its Applications, 8(7); 51-55.

[4] L. M. Adesina1, O. A. Fakolujo. DETERMINATION OF TOTAL HARMONIC DISTORTION (THD) ON A 33KV DISTRIBUTION NETWORK: A CASE STUDY OF ISLAND BUSINESS DISTRICT, 2015; 34(4); 773-780.

[5] Owen, E.L. "A History of Harmonics in Power Systems", IEEE Industry Applications Magazines, Vol. 4, no. 1, 1998, pp. 6-12.

[6] Buso, S., Malesani, L., Mattavelli, P. and Veronese, R., "Design and Fully Digital Control of Parallel Active Power Filters for Thyristor Rectifiers to Comply with IEC-1000-3-2 Standards, IEEE Transactions on Industry Applications, vol. 34, 1998, pp. 508-517.

[7] G. Mahesh, Manivanna Kumar and S. Ram Reddy2011.Simulationand Experimental Results of 7-Level Inverter System. Research Journal of Applied Sciences, Engineering and Technology. 3(2): 88-95,ISSN: 2040-7467.

[8] M. Suresh Kumar, K. Ramani. Comparative Review of Modulation Techniques for Harmonic Minimization in Multilevel Inverter, 2014; 8(12); 1931-1937.

[9] A. Salami, B. Bayat.Total Harmonic Distortion Minimization of Multilevel Converters Using Genetic Algorithms, 2013; 1023-1027.

[10] Mudasir Ahmad Memon, Shahzad Memon, Shariq Khan. THD Minimization from H-Bridge Cascaded Multilevel Inverter Using Particle Swarm Optimization Technique, 2015; 33-38.

APPENDICES

APPENDIX A

Five-level CHB-MLI using PSO

```
clc;
clear;

num=input('How many times you want to run this script (5 Level): ')

for i=1:num

    [G_pos,gbest,objfunc] = Level_five_1();
   Result.Best_Angles(i,:)=G_pos;
   Result.Iterations(i,:)=objfunc;
   Result.Best_Harmonics(i,:)=gbest;
end

% Result=struct('Best_Theta',G_pos);
% Result.Modelation_Index= MI_Val;
% Result.THD=gbest;
% Result.Iterations = objfunc
% all=[Result.best result.angles]

All =[Result.Best_Angles Result.Best_Harmonics Result.Iterations];
bb=sortrows(All,3);

RE=sprintf('The best angles for 5-level inverter are: %.3f  %.3f, and the
best harmonic is: %.3f', bb(1,[1:2]),bb(1,3))

iter= bb(1,[4:end]);
figure;
plot(iter)
title('Five Level Multlevel Inverter')
xlabel('Iterations')
ylabel('THD (%)')
legend('Total Harmonic Distortion')
  Ang= bb(1,[1:2]);
len_Res= Result.Best_Angles;
for i =1:size(len_Res,1)
 y(i,:)=bb(i,[1:2]);
end
% bar(y);
figure
 bar(y,'hist');
 %bar(y,'stacked');
%  set(gca,'XTickLabel',{'CH1','CH2','CH3','CH4','CH5'});
%  %  D = ['CH1', 'CH2', 'CH3'];
 legend('First Angle','Second Angle')
```

```
figure;
plot(Ang)
ylim([0 90])
title('Five Level Multlevel Inverter')
xlabel('Numbers')
ylabel('Angels')
legend('Theta1','Theta2')
```