INTELLIGENT PWM TECHNIQUE FOR VOLTAGE CONTROL OF DC-AC INVERTER

By

MOHD HAZMAN BIN IDROS

FINAL PROJECT REPORT

Submitted to the Department of Electrical & Electronic Engineering
in Partial Fulfillment of the Requirements
for the Degree
Bachelor of Engineering (Hons)
(Electrical & Electronic Engineering)

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CERTIFICATION OF APPROVAL

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Approved:

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Project Supervisor

UNIVERSITI TEKNOLOGI PETRONAS

TRONOH, PERAK

May 2012

CERTIFICATION OF ORIGINALITY

This is to certify that I am responsible for the work submitted in this project, that the original work is my own except as specified in the references and acknowledgements, and that the original work contained herein have not been undertaken or done by unspecified sources or persons.

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MOHD HAZMAN BIN IDROS

ABSTRACT

The purpose of this project is to intelligently use various Pulse Width Modulation (PWM) techniques for voltage control of DC-AC inverter. In this project, various PWM techniques are analyzed to see the difference between each of the technique. Then, fuzzy logic controller is chosen as a control scheme to control the output voltage of the inverter. The scopes include the simulation of various PWM techniques using MATLAB/SIMULINK, modeling and simulation of the PWM inverter, modeling and simulation of fuzzy logic controller (FLC) feed into PWM inverter, and finally the detail analysis on the output waveforms based on the simulation. Different PWM techniques will result in different value of peak voltage and different level of harmonics. Therefore, the right choice of the PWM technique is crucial in designing the inverter. Instead of using a conventional controller, this project was about to introduce the ability and also the advantages of the FLC to intelligently control PWM’s pulses in inverters application. This project is a comprehensive research study about various PWM techniques to control. This project results in a number of ways to control the PWM inverter by using FLC that can suit with a lot of industrial applications. For future work, it is highly recommended to use Artificial-Neural Network (ANN) as a control scheme to control output voltage of an inverter, and compare the results between ANN and FLC.

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LIST OF ABBREVIATIONS

AC	- Alternating Current
ANN	- Artificial Neural Network
DC	- Direct Current
FLC	- Fuzzy Logic Controller
MATLAB	
PWM	- Pulse Width Modulation
SIMULINK	
THD	- Total Harmonic Distortion

CHAPTER 1
INTRODUCTION

1.1 Project Background

There are only two types of electrical transmissions exist which are direct current (DC) and alternating current (AC). Each of this has its own benefits instead of its disadvantages. DC current is said to be more efficient in power consume but has a limitation in transporting it over a long distance**.** For this reason, Nikola Tesla had invented alternating current so that long distance transmission is possible [1]. Apart from that, AC also can make use of the transformer to step up or step down the voltage for transmission and distribution purposes. As a result, electricity was generated at power stations in AC and transmits it over a long distance before distributes it to the end users. Even though the AC is important, but let's not forgets about DC. DC is very efficient in power consumes as it is constant in magnitude and direction. For this reason, electrical appliances like laptops, notebooks, televisions, and radios will use the DC source instead of AC source. It can be seen by the black box at the appliances where by it will convert the AC source form the supply into DC source before it goes into the circuitry. Therefore, both types of electrical transmissions whether DC or AC are important for people as they have advantages that people can make use of for different application and different purposes.

The process of changing DC to AC is called inverting by using an inverter. The function of an inverter is to change a dc input voltage to a symmetric ac output voltage of desired magnitude and frequency **[**1**]**. The output voltage could be fixed or variable at a fixed or variable frequency. Inverters are widely used in industrial applications drives, induction heating, standby power supplies and uninterruptible power supplies. This show how important is inverter to people in daily works. Inverters can be widely categorized into two types which are single-phase inverters and three-phase inverters depending on types of application used.

In the industrial applications, to control the output voltage of inverter is often necessary to cope with the variation of DC input voltage, to regulate voltage of an inverter and to satisfy the constant volts and frequency control requirement [2]. In order to control the gain and output voltage, PWM technique will be used. PWM technique is very useful to control the on and off of the switch so that various application can be implemented. There are a total of 11 modulation techniques are exist nowadays which are [2]:

1. Single pulse-width modulation
2. Multiple pulse-width modulation
3. Sinusoidal pulse-width modulation
4. Modified sinusoidal pulse-width modulation
5. Phase-displacement control
6. Trapezoidal modulation
7. Staircase modulation
8. Stepped modulation
9. Harmonic injection modulation
10. Delta modulation
11. Space vector modulation

Fuzzy Logic (FL) is a new control scheme that allows intermediate values to be defined between conventional evaluations like true or false, yes or no, high or low, small or big and others. The advantages is that we can use statement like rather fat, not really fast, pretty much slow, or very slow can now be formulated mathematically and processed by computers in order to apply more human-like way of thinking in the programming of computers [3]. With this ability and advantages, FL has become important and profitable tools to control and implement complex systems and applications.

1.2 Problem Statement

Problem Statement:

- Different PWM technique will result in different magnitude of peak voltage and different value of THD (%). Therefore, the right choice of PWM technique is crucial in order to suit with the applications
- Conventional controller like P, PI and PID controller has poor control scheme and slower response time that can contributes to a lot of harmonics' production. Therefore, an advance controller with better control scheme and faster response time is needed

Significance of Project:

- By using fuzzy logic controller, PWM pulses can be controlled intelligently and harmonics are expected to be reduced.

1.3 Objective and Scope of Study

Objective:

- To study on various PWM techniques in order to control an inverter.
- To determine which PWM technique is the best technique.
- To use FLC as a control scheme to control PWM pulses in order to control output voltage of an inverter.
- To do comparative analysis on the simulations results.

Scope of Study:

1. Modeling and simulation of PWM inverter using various types of PWM techniques.
2. Modeling and simulation of fuzzy logic controller.
3. Modeling and simulation of fuzzy logic controller to control PWM inverter.
4. Detail analysis on the load voltage and load current
5. Recommendation and improvement for future work

1.4 Relevancy of the project

Significance of project:

By employing the right PWM technique that controlled by fuzzy logic controller, magnitude of peak voltage is as desired while the harmonics are always at the least. Therefore, the performance and efficiency will be boosted up.

CHAPTER 2
LITERATURE REVIEW

2.1 Pulse-Width Modulation (PWM)

2.1.1 PWM Techniques

Pulse width modulation (PWM) is defined as a process of modifying the width of the pulses in a pulse train in direct proportion to a small control signal; the greater the control voltage, the wider the resulting pulses become [1]. In order to use PWM, comparator will be used to compare between the carrier signal and the reference signal. A comparator is a device that compares the input voltage to a reference signal and turns transistors on or off depending on the results of the test [2].

According to Muhammad H. Rashid in his book entitled Power Electronics: Circuit, Devices, and Applications, there are a total of 11 PWM techniques already been practiced [2].

Basic technique:

i. Single pulse-width modulation

In single pulse-width modulation control, there is only one pulse per half-cycle and the width of the pulse is varied to control the inverter output voltage [2]. The generation of gating signal is done by comparing magnitude of a rectangular reference signal with a triangular carrier wave. The frequency of the reference signal determines the frequency of output voltage [2].

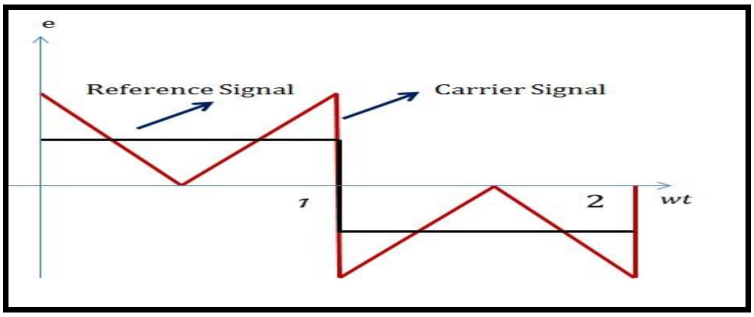

Figure 1: Single Pulse-Width Modulation

$$V_o = \left[\frac{2}{2\pi} \int_{\frac{\pi-\delta}{2}}^{\frac{\pi+\delta}{2}} Vs^2 \, d(wt)\right]^{½} = Vs\sqrt{\frac{\delta}{\pi}}$$

ii. Multiple pulse-width modulation

In multiple pulse width modulation control, there are multiple pulses per half cycle of output voltage [2]. By doing so, the harmonics can be reduced. This technique also is called uniform pulse-width modulation (UPWM) [1]. Similar to single pulse-width modulation, gating signal is generated by comparing the reference signal with a triangular carrier wave. The frequency of reference determines output voltage frequency while the frequency of carrier signal determines the number of pulses in each half-cycle [2].

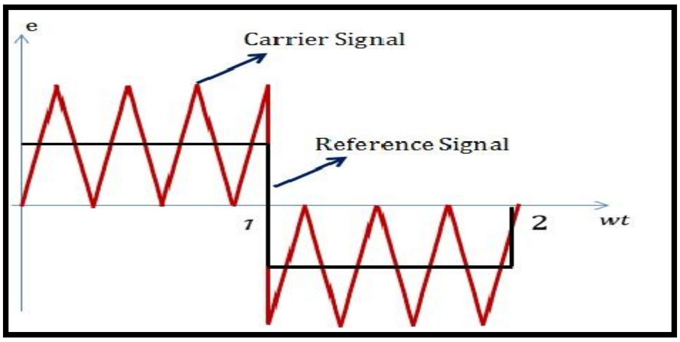

Figure 2: Multiple Pulse-Width Modulation

$$V_o = \left[\frac{2p}{2\pi} \int_{(\pi/p-\delta)/2}^{(\pi/p+\delta)/2} Vs^2 \, d(wt)\right]^{½} = Vs\sqrt{\frac{p\delta}{\pi}}$$

iii. <u>Sinusoidal pulse-width modulation (SPWM)</u>

In sinusoidal pulse-width modulation control, the width of each pulse is varied in proportion to the amplitude of a sine wave evaluated at the center of the same pulse [2]. Gating signal is generated by comparing a sine wave reference signal with a triangular wave as a carrier signal. Frequency of reference signal will be the output voltage frequency and its amplitude will determine the modulation index.

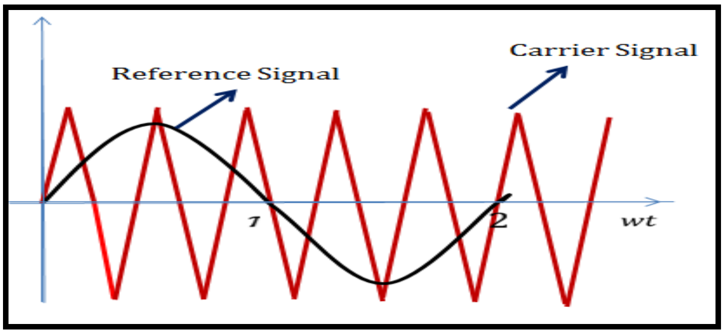

Figure 3: Sine Wave Pulse-Width Modulation

$$Vo = Vs \left(\sum_{m=1}^{2p} \frac{\delta m}{\pi}\right)^{1/2}$$

Advance technique:

iv. <u>Modified sine wave pulse-width modulation (MSPWM)</u>

In modified sine wave pulse-width modulation, it is very much similar to SPWM. The only different is that the carrier wave is only applied at the first and 60 degree per half cycle.

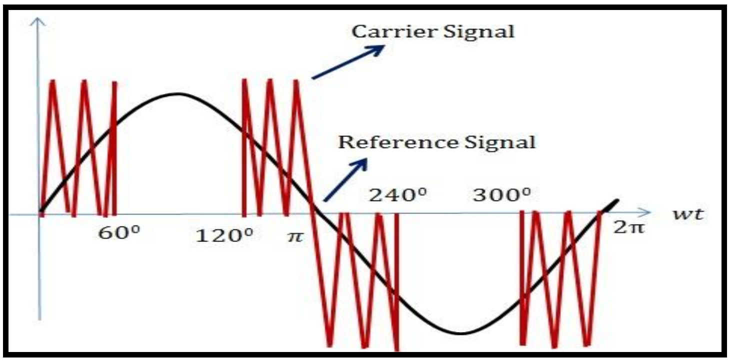

Figure 4: Modified Sine Wave Pulse-Width Modulation

$$Vo = Vs \left(\sum_{m=1}^{2p} \frac{\delta m}{\pi}\right)^{1/2}$$

v. Phase displacement control

Phase displacement control technique is very different when compare to other techniques mentioned earlier. For this technique, voltage controls is obtained by using multi-level inverters and do the summation of the output in each inverter [2]. As a result, 180 degree phase displacements give effect to the output voltage and delay angle.

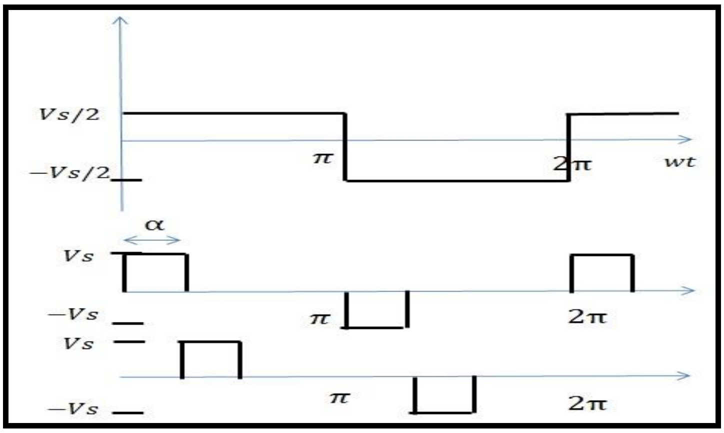

Figure 5: Phase Displacement Control

$$Vo = Vs\sqrt{\frac{\alpha}{\pi}}$$

vi. Trapezoidal modulation

In the case of trapezoidal modulation, it is very much similar to SPWM. The only different is that carrier wave which is the triangular wave will be compared by trapezoidal wave before it goes to gating signal [2].

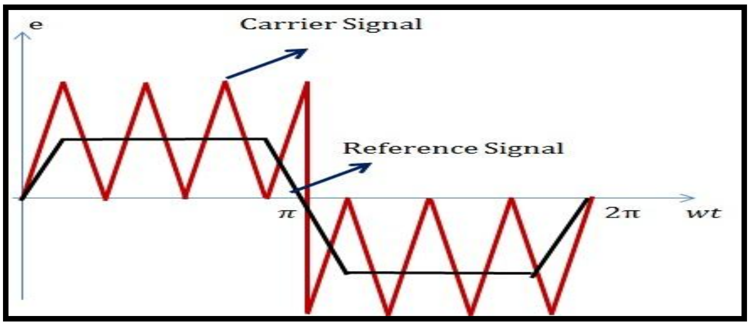

Figure 6: Trapezoidal Modulation

vii. Staircase modulation

The staircase modulation is use staircase wave as a modulating signal and will be compared with triangular wave. The staircase wave is not an approximation of a sine wave [2]. The designer purposely uses this kind of wave to compare with the carrier wave. It is said to be that this type of control can provides a high quality output voltage.

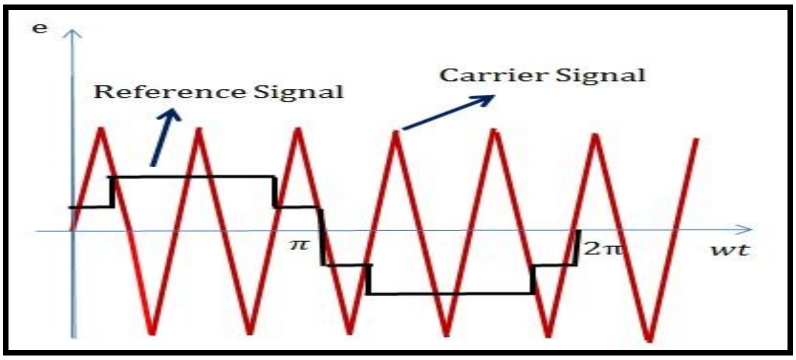

Figure 7: Staircase Modulation

viii. Stepped modulation

The stepped modulation is very much similar to staircase modulation. The only different is that it uses stepped wave that is divided to specified intervals [2]. This type of control can provides lower distortion and higher amplitude of output voltage [2].

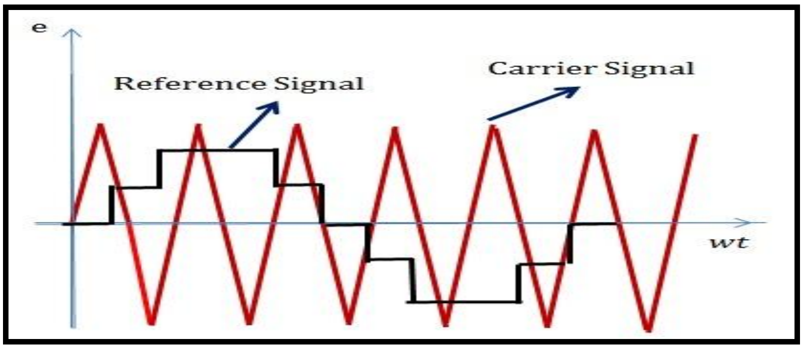

Figure 8: Stepped Modulation

ix. Harmonic injection modulation

This technique is implemented by generate the modulating signal by injecting selected harmonics to the sine wave before comparing it with triangular carrier wave [2]. By doing this, higher fundamental amplitude and low rate of distortion can be achieved.

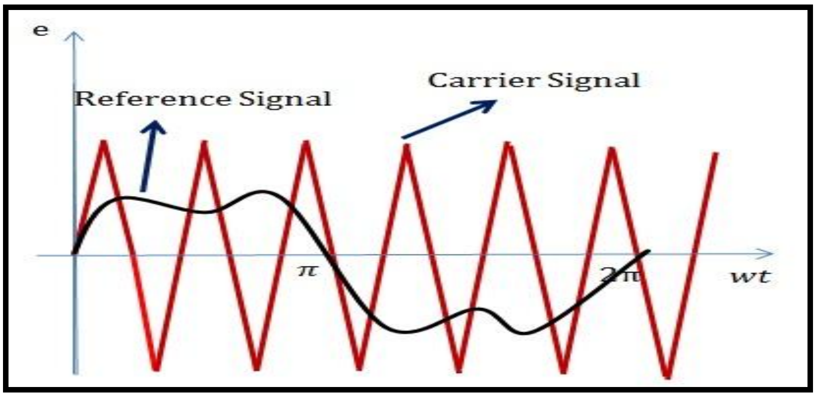

Figure 9: Harmonic Injection Modulation

x. Delta modulation

In delta modulation, a triangular wave is allowed to oscillate within a defined window above and below the reference sine wave. It is also involve hysteresis modulation. This technique can produce high output voltage. It also can make the control of voltage to frequency is possible [2].

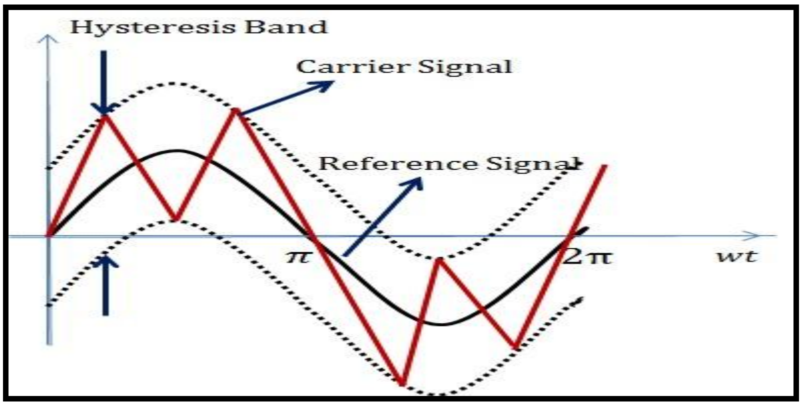

Figure 10: Delta Modulation

xi. Space vector modulation (SVM)

SVM is a digital modulating technique where the objective is to generate PWM load line voltages that are in average equal to a reference load line voltage [2]. For this technique, space vector (SV) will be used to select the states and the periods. A lot of mathematics involves in order implementing this technique.

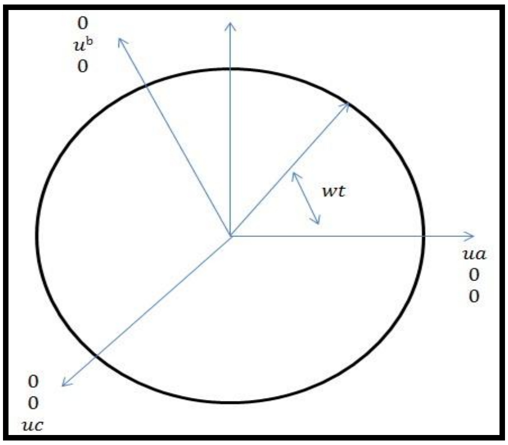

Figure 11: Space Vector Modulation

2.1.2 Advantages and Disadvantages of PWM Technique [5]

- Advantages
  - Easier to implement this technique
  - There is no temperature variation
  - Have lower power dissipation
- Disadvantages
  - Attenuation of fundamental component
  - Switching losses due to switching frequency
  - Harmonics component

2.1.3 Total Harmonic Distortion

Total harmonic distortion (THD) will occur in most power systems with certain loading condition. Electrical load that connected to the power supply will usually draw current [9]. Current drew will create a harmonic distortion and it is depends on whether the load is capacitive loads or inductive loads [9].

2.2 <u>Inverter</u>

2.2.1 Half Bridge and Full Bridge Inverter

Inverter is used to convert from DC to AC. There are two types of inverter which are half-bridge inverter and full bridge inverter. Half bridge and full bridge inverters are almost the same except they produce different level of output voltage. Half bridge inverter will produce half of the value of input voltage while full bridge inverter will produce full value of input voltage [2]. Apart from that, the numbers of switches also are different for both half bridge and full bridge inverter. As for the half bridge inverter, there are only two switches used while full bridge inverter will require 4 switches to operate. Because of this, the output value of the inverter is different. Below is the diagram of half bridge inverter and full bridge inverter:

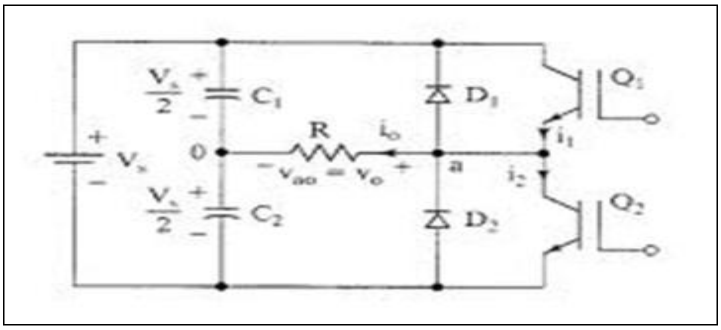

Figure 12: Half-Bridge Inverter

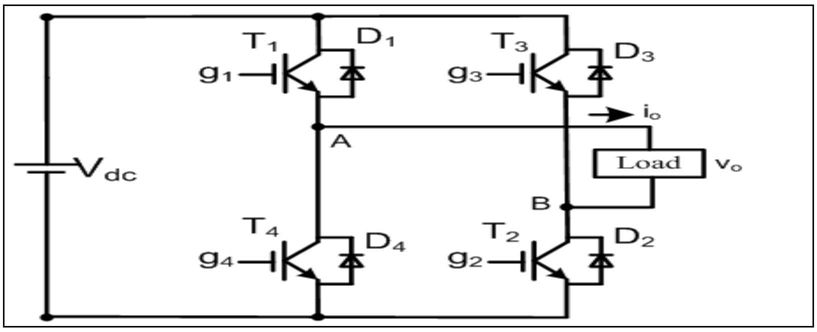

Figure 13: Full-Bridge Inverter

2.2.2 PWM Inverter

PWM inverter is an inverter which the output voltage is controlled by using PWM technique [3]. PWM inverter is said to be has an advantage compare to conventional inverter as the PWM waveform has a much lower low-order harmonic content than the other waveform [2]. For this reason, PWM inverter is widely used in industrial application. However, it is also has disadvantage from the switching losses occur. But, this problem can be overcome by choosing the right modulation technique and also the right switch. Below is the diagram for PWM inverter:

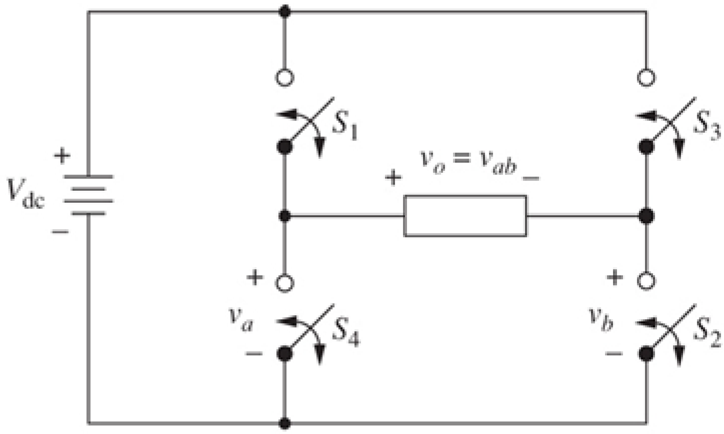

Figure 14: Full-Bridge PWM Inverter

2.2.3 PWM Inverter Switching Methodology

For the PWM inverter, the switching methodology is as below:

- S1 is paired with S2 while S3 is paired with S4.
- These pairs are turned on and off alternately for one half period of the ac output.
- Gating signals are given such that these pairs will turned on and off alternately
- The on and off periods are varied such that the on-periods are longest at the peak of wave
- Area of each pulse corresponds to the area under the sine wave between the adjacent midpoints of the off-periods.

2.2.4 Application in Industry [2][3]

- UPS (Un-interrupted Power Supply)
  - As a backup supply if anything happen to the main power supply
- VFP (Variable Frequency Drive)
  - AC rectify first to DC Then change back to AC in order to control power electronics devices and electrical machines
- STATCOMS (Static Synchronous Compensator)
  - Acts as a source on sinks of AC power

- UPFC (Unified Power Flow Controller)
    - Acts as an electrical device for providing fast transmission on high voltage electricity transmission

2.3 <u>Fuzzy Logic Controller</u>

2.3.1 Overview on Fuzzy Logic Controller

Fuzzy controllers are used to control products by using fuzzy logic expression. Fuzzy controllers are very famous and been used in various applications. Several control schemes had been used to control fuzzy controllers such as direct control and feed forward control. Fuzzy logic controller is actually an advance controller with fast response [4]. It is simpler to design and can be understood and implemented by non-specialist in control theory [6]. It provides higher probabilities to the sets thus make this controller more accurate.

Below is the structure of a fuzzy controller [6]:

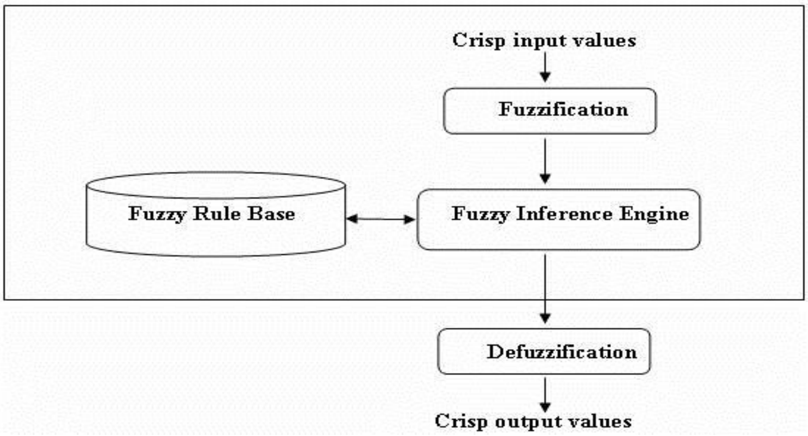

Figure 15 : Structure of a fuzzy controller

In implementing fuzzy logic controller, it consists of three major steps which are fuzzification, fuzzy inference engine, and finally defuzzification [7]. For fuzzification, basically it is a converter to convert the measured value into fuzzy sets variables [4]. For fuzzy inference engine, it is like a processor that contains some logic blocks to do the operation [4][5]. Finally, for the defuzzification, it will turns back the fuzzy variables into real signal [7].

2.3.2 Types of Fuzzy Logic Controller

Fuzzy logic controller has several control schemes which are direct control, feedforward control and adaptive parameter control. For direct control, the fuzzy controller is in forward path in a feedback control system [6]. The controller will take action if there is an error between the reference signal and also the feedback signal. For feedforward control, a measureable disturbance is being compensated. Below is the diagram for all the control scheme of FLC [6]:

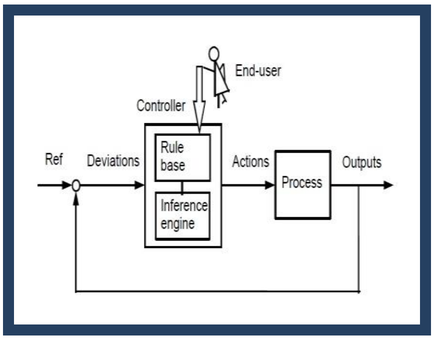

Figure 16: Direct Control FLC [6]

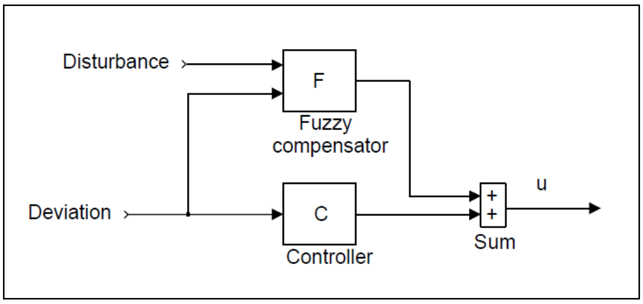

Figure 17: Feedforward FLC [6]

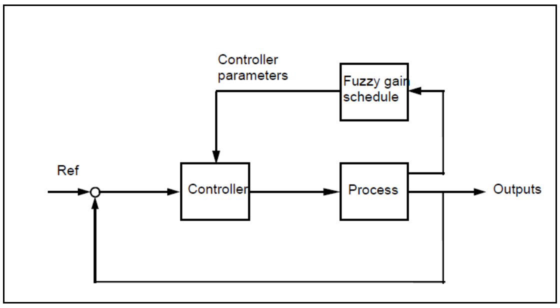

Figure 18: Adaptive Parameter FLC [6]

2.3.3 Comparison between FLC and Conventional Controller [10]

Table 1: Comparison between FLC and Conventional Controller

	Fuzzy Logic Controller	Conventional Controller
Rise Time	5 sec	8 sec
Settling Time	8 sec	14 sec
Overshoot	7.03%	4.95%

CHAPTER 3
METHODOLOGY

3.1 Project Activities

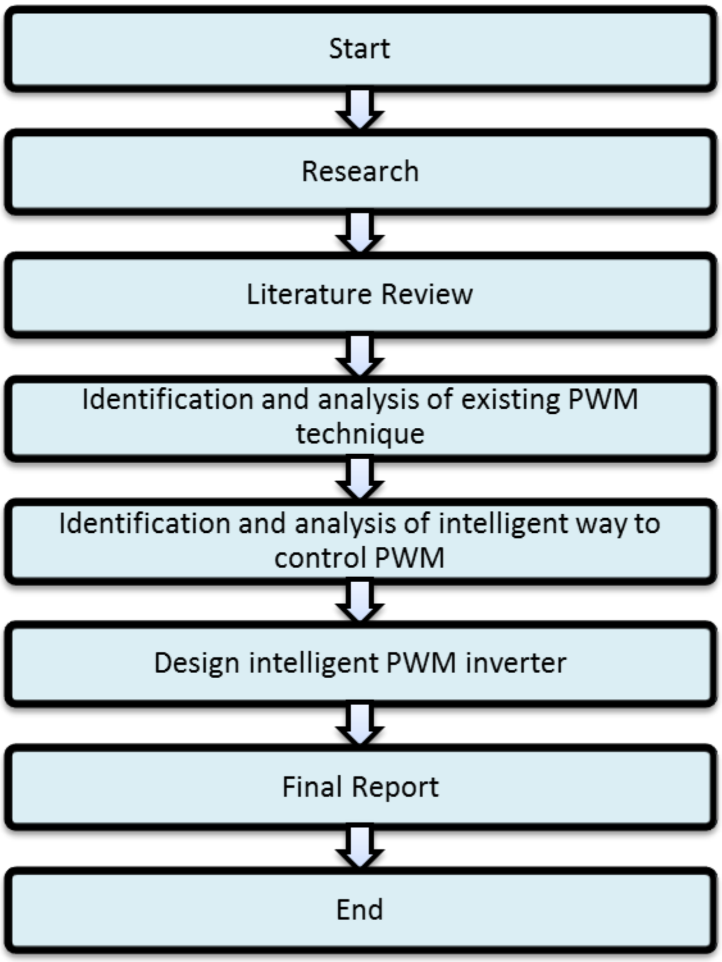

Figure 19: Project Activities Flow

This project is a study based project or research based project. To be specific, it is a study of various PWM techniques for voltage control of DC-AC inverter. The project was begun with the research on several issues which had been mentioned in the research methodology below. Research on the inverter, PWM technique, and fuzzy logic controller was done first.

With all the collective and informative information, the project proceeded with the literature review on the existing PWM technique, PWM inverter and also intelligent controller that already be implemented successfully. All the literature review materials will be downloaded directly from the IEEE store to maintain the source reliability. Materials review may be any journals or conference papers related to the field of this project.

After completing the literature review, the further studies on PWM technique and intelligent controller were done. During this period, analysis was took place and all the characteristics will be noted out. Simulations also were done so that the results can be analyzed for further improvement.

Then, it came to the hardest part which was designing the product. During this period, results from the analysis part will be compiled and reviewed. Based on that, calculations will be made and the model will be designed. Modeling will be done by using MATLAB/SIMULINK.

After that, result from the simulation will be analyzed in details. The analysis will be on the comparative study between the techniques which cover the output voltage characteristic of each technique, harmonics analysis of each technique, and the response of each technique with the control scheme applied.

Finally, all the studies, data gathering, results, discussion and conclusion will be compiled together in the final report.

3.2 Research Methodology

Research is a method taken in order to gain information regarding the major scope of the project. The sources of the research cover the textbook of power electronics, e-journal, e-thesis and several trusted link.

The steps of research:

1. Gain information on the existing PWM inverter.
2. Gain information of different technique in PWM.
3. Gain information on fuzzy logic controller.
4. Compile all the information.
5. Analyse all the information.
6. Make a conclusion and propose a way to intelligently control PWM inverter

Table 2: Gantt Chart and Key Milestone

No	Detail/Week	1	2	3	4	5	6		7	8	9	10	11	12	13	14	15
1	Project Work Continues							Mid-Semester Break									
2	Submission of Progress Report									▲							
3	Project Work Continues																
4	Pre - EDX												▲				
5	Submission of Draft Report														▲		
6	Submission of Final Report (Technical Paper)															▲	
7	VIVA																▲

3.3 Tools

a. MATLAB R2012a

MATLAB/SIMULINK

1. Software to run the simulation on PWM inverter and fuzzy logic controller based control scheme

2. Able to design both mathematical model and also electrical/electronic model

3. Able to perform for single phase, two phase and three phase, and multilevel inverter

4. Which include the models of:

    - The PWM inverter
    - The control scheme of PWM inverter using fuzzy logic controller

5. Able to analyses and do the comparison based on the result of the simulation

6. Able to do the Fourier transforms and analysis easily

CHAPTER 4
RESULTS AND DISCUSSIONS

4.1 Data Gathering and Analysis

4.1.1 Layout of PWM inverter

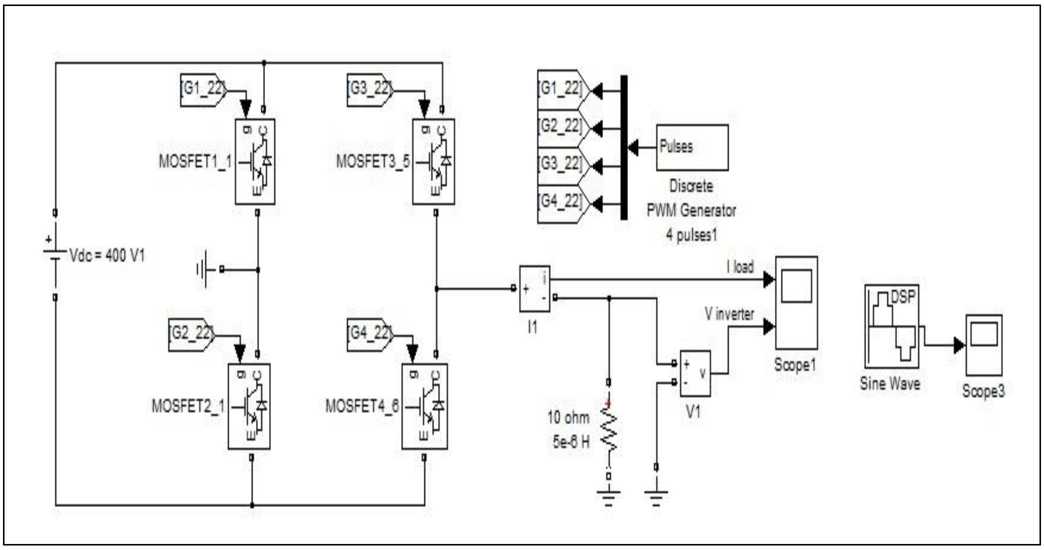

Figure 20 : Layout of PWM Inverter

For single-phase full bridge inverter, four switches will be used to alternately control the gating signal in order to produce AC voltage. In this case, MOSFET (Metal-Oxide Semiconductor Field Effect Transistor) switches will be used. MOSFET is chosen by considering its ability to switch at highest frequency with less distortion and noise. It is capable to do switching up to kHz range. MOSFET also is very beneficial where it can connect directly with other MOS (Metal-Oxide Semiconductor) devices or TTL (Transistor-Transistor Logic) devices.

4.1.2 Design Parameters

Table 3: Design Parameters

Parameters	**Value**
Vdc	**400 V**
R	**10 ohms**
L	**5e-6 H**
C	**10e-6 F**
Output Frequency	**50 Hz**
Switch	**MOSFET**
Modulating Frequency	**50 Hz**
Carrier Frequency	**20 kHz**
Modulation Index	**0.8**

Table 3 shows all the parameters used in this project. Output frequency is set to be 50 Hz so that it suit with Malaysia's national frequency. Carrier frequency is set to be 20 kHz with modulation index of 0.8. MOSFET is capable to handle high switching frequency. High switching frequency is good in order to get more accurate value. However, switching loss will occur and need to be considered. The higher the switching frequency, the higher the switching loss will it become. For this reason, L-C filter need to be used in order to filter the noise and unwanted signals in the output waveform.

4.1.3 Analysis of PWM technique

Based on the simulation done in FYP 1, Table 4 indicates the peak voltage of each PWM's techniques and percentage of total harmonic distortion (THD). Simulation was done by using PSpice Student Edition and also MATLAB/SIMULINK.

Table 4: PWM Technique Analysis

PWM Techniques	Output Voltage	Voltage THD (%)
Unipolar PWM	**0.9 * V_{input}**	**4**
Modified sine-wave PWM	**0.9 * V_{input}**	**4**
3rd harmonic PWM	**1.2 * V_{input}**	**5**
Sine Wave PWM	**1.1 * V_{input}**	**22**
Multiple-Pulse PWM	**1.2 * V_{input}**	**39**
Trapezoidal PWM	**1.0 * V_{input}**	**39**
Single-Pulse PWM	**1.3 * V_{input}**	**48**

Based on Table 4, in term of peak voltage, single-pulse PWM technique gives the highest value followed by multiple PWM and also 3^{rd} harmonic PWM. But, in term of THD, single PWM, multiple PWM and sine PWM give high value of THD. Therefore, it is not good for the inverter to have high value of THD as it will reduce the performance of the inverter.

Therefore, considering the peak voltage and value of THD, it can be concluded that the best PWM technique is modified sine wave PWM followed by unipolar PWM and finally 3^{rd} harmonic injection modulation.

4.1.4 Layout of Fuzzy Logic Controller Control Scheme

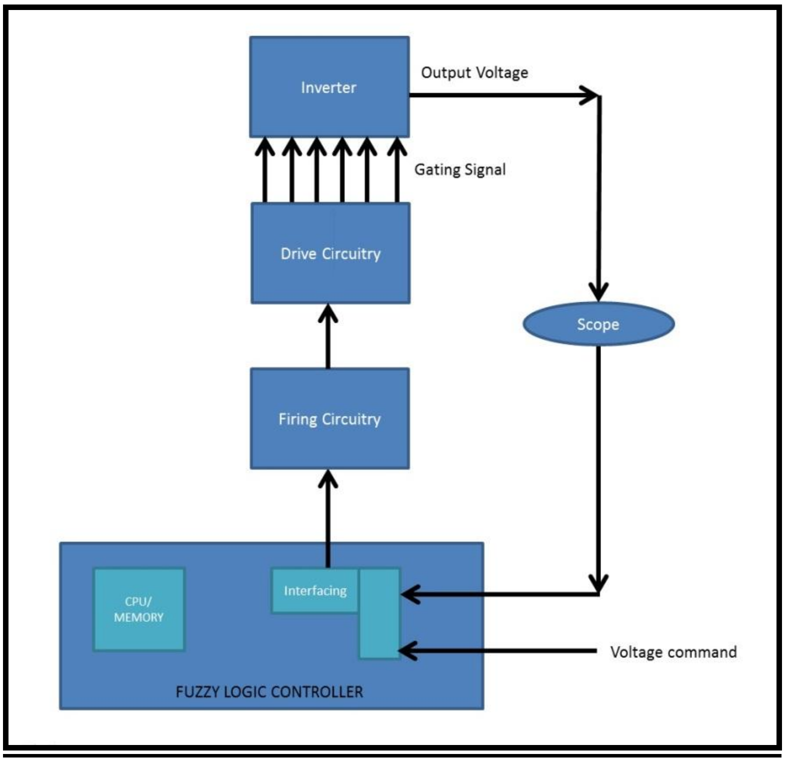

Figure 21: Layout of fuzzy logic controller control scheme

Figure 21 shows the layout of fuzzy logic controller (FLC) control scheme feed to the PWM inverter. The output voltage from the inverter wills then feedback into the fuzzy logic controller. At the interfacing part, it acts like a comparator where it compares the output voltage with the voltage command. It also calculates the rate of change of the error for the output voltage. Output from the FLC will go to the firing circuitry. Firing circuitry will determine how much the firing angle needed in order to get the desired output voltage. Lastly, the signals go the drive circuitry to produce the gating signal for the MOSFET switches.

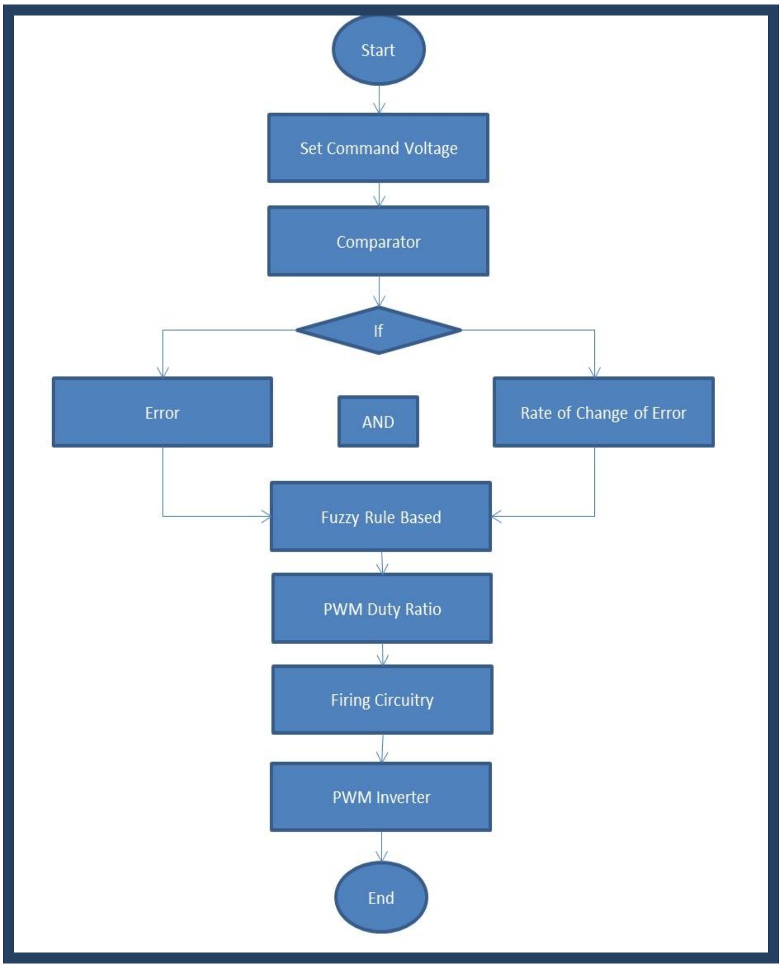

Figure 22: Layout of FLC

Figure 22 shows the operating principle for the fuzzy logic controller. At first, desired voltage is set by the user. Then, the desired voltage will be compared with the actual voltage feedback from the inverter. From that, the error and rate of change of error will be calculated. Based on these two parameters, it will look up at the fuzzy rule based and determine the output result. Fuzzy rule based will determine how much PWM duty ratio is needed in order to get the desired value. Finally, output from fuzzy rule based will go to the firing circuitry before being feed into the inverter.

4.1.5 Rule based

In this project, 9 rule based of fuzzy logic controller had been used. As far as concerned, 9 rule based already meet the requirement to control the output voltage of PWM inverter.

The strategy is as below:

Table 5: Rule Based

Error	Rate of change in error	Output
Negative	Negative	NB
Negative	Zero	NM
Zero	Negative	NM
Positive	Positive	PB
Zero	Positive	PM
Positive	Zero	PM
Negative	Positive	Zero
Zero	Zero	Zero
Positive	Negative	Zero

NB = Negative Big **NM = Negative Medium** **PB = Positive Big**

PM = Positive Medium

In order to see it clearly, table can be made so that any missing point will be noted out.

Table 6: Simplified Version of Rule Based

		Rate of change of error		
		Negative	Zero	Positive
Error	Negative	NB	NM	ZERO
	Zero	NM	ZERO	PM
	Positive	ZERO	PM	PB

4.1.6 Direct Control FLC [6]

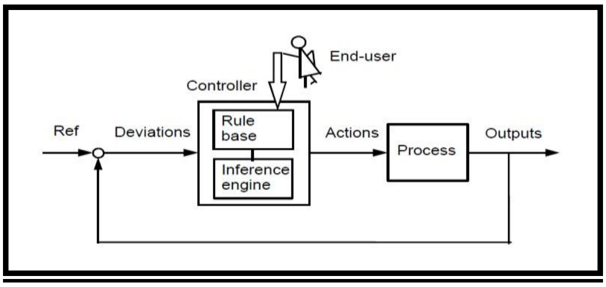

Figure 23 : Direct Control FLC

In this project, direct control FLC had been chosen as the control scheme. Direct control FLC is chosen because it suits with the requirement and specifications needed. Apart from that, it is also much simpler to design compare to other control scheme. For direct control FLC, the fuzzy controller is in the forward path in a feedback control system [6]. The output voltage is compared with the voltage command and if there is an error or difference, the controller will reacts according to the control strategy.

4.2 Modelling Fuzzy Logic Controller

4.2.1 Fuzzy Inference Engine

Fuzzy inference engine is like a heart to the fuzzy logic controller. It contains the entire rule and control scheme designed. In this project, Mandani inference engine had been chosen compare to Sugeno. This is because, Mandani has simpler structure compare to Sugeno structure. The structures are as below:

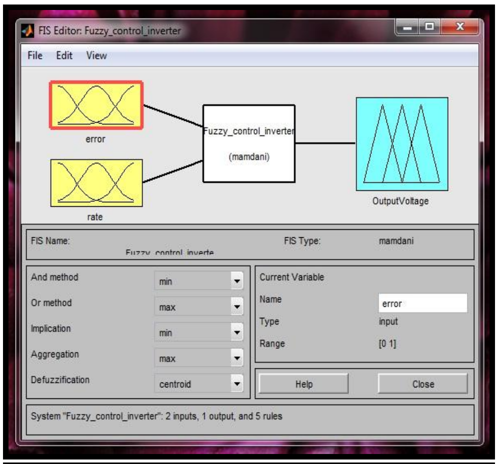

Figure 24: Overall FLC

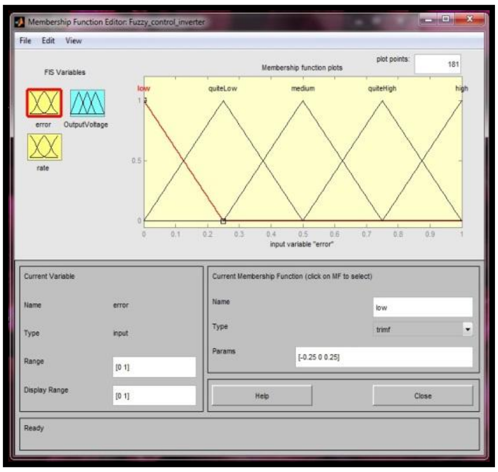

Figure 18: Input_Error

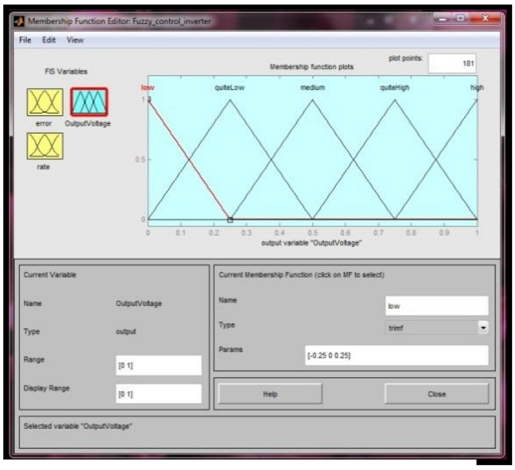

Figure 21: Output

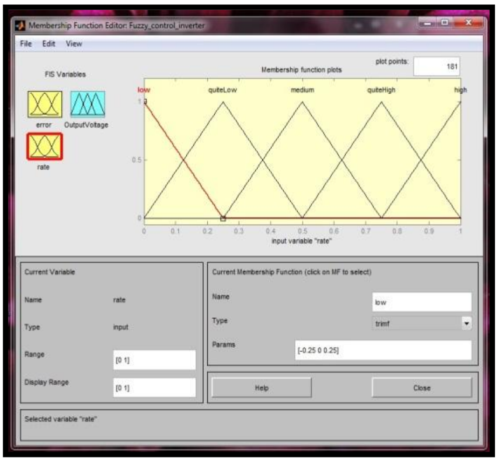

Figure 20: Input_ChangeError

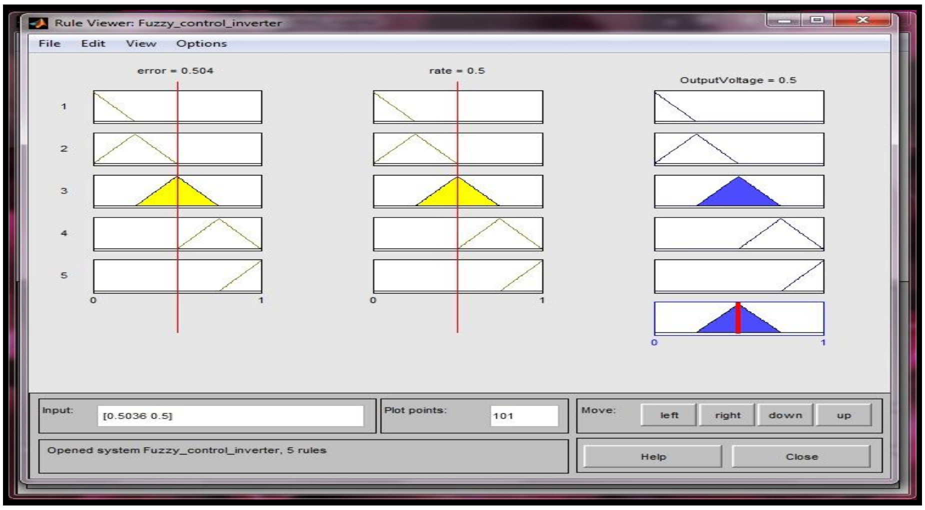

Figure 22 : Rule Viewer of FLC

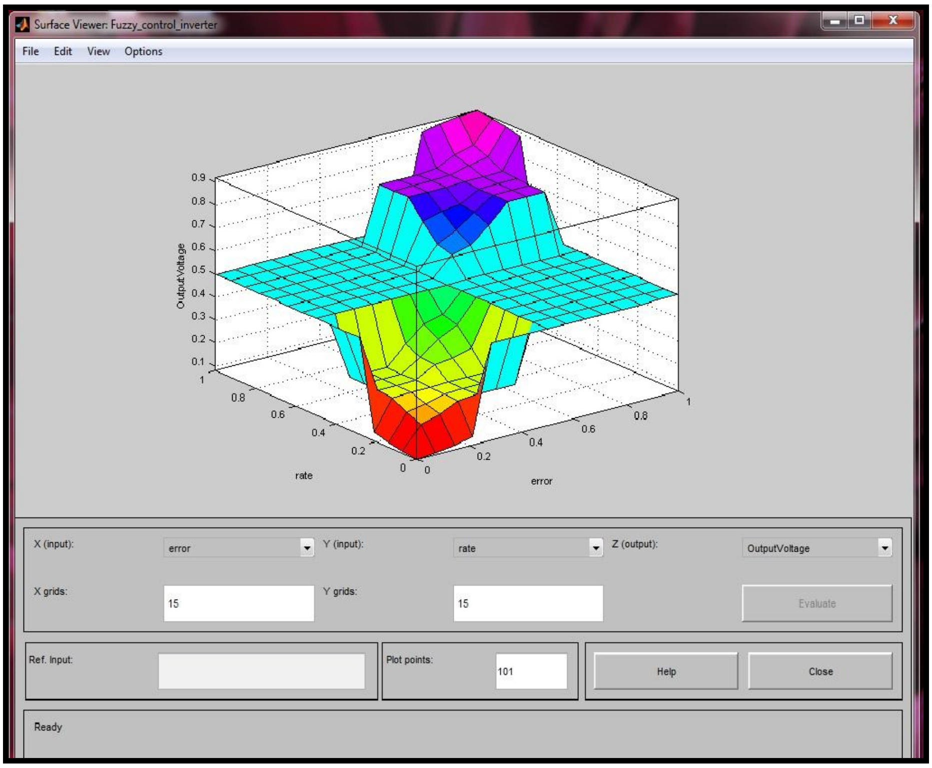

Figure 23: Surface Viewer of FLC

4.3 Modelling whole system

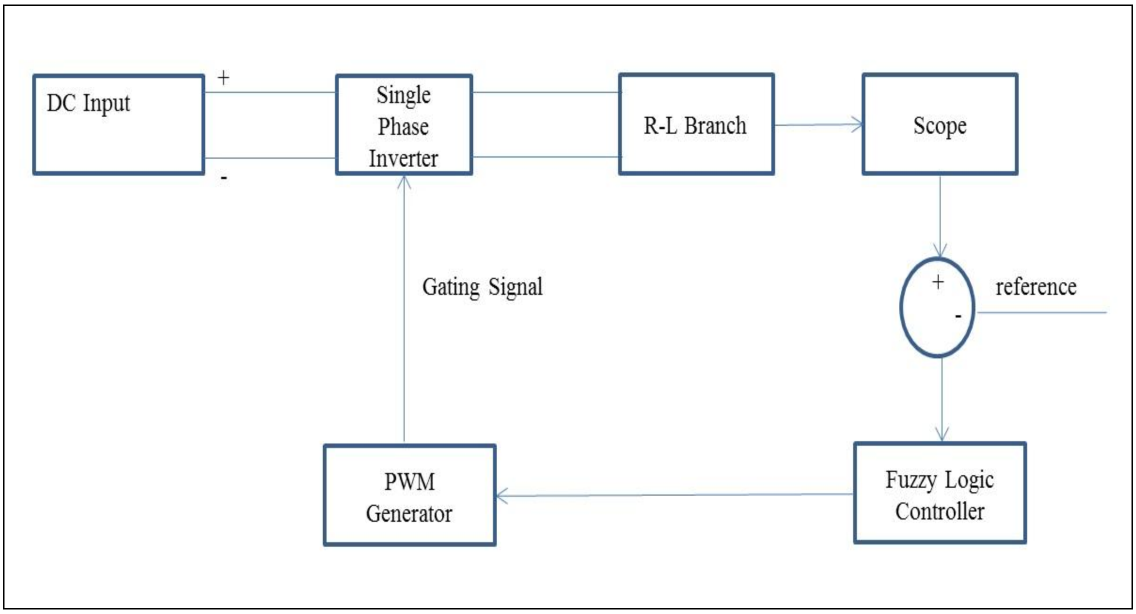

Figure 25: Overall System of Fuzzy Logic and PWM Inverter

4.4 Simulation Results and Discussions

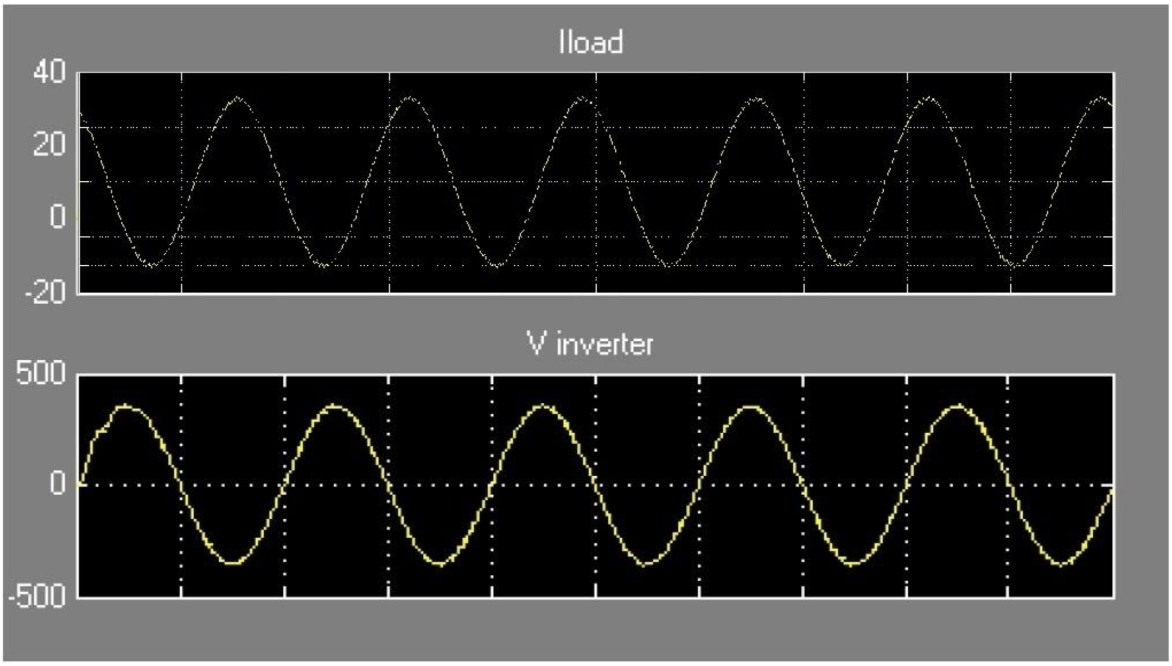

Figure 26: Modified Sine Wave PWM Inverter (Firing angle = 75°)

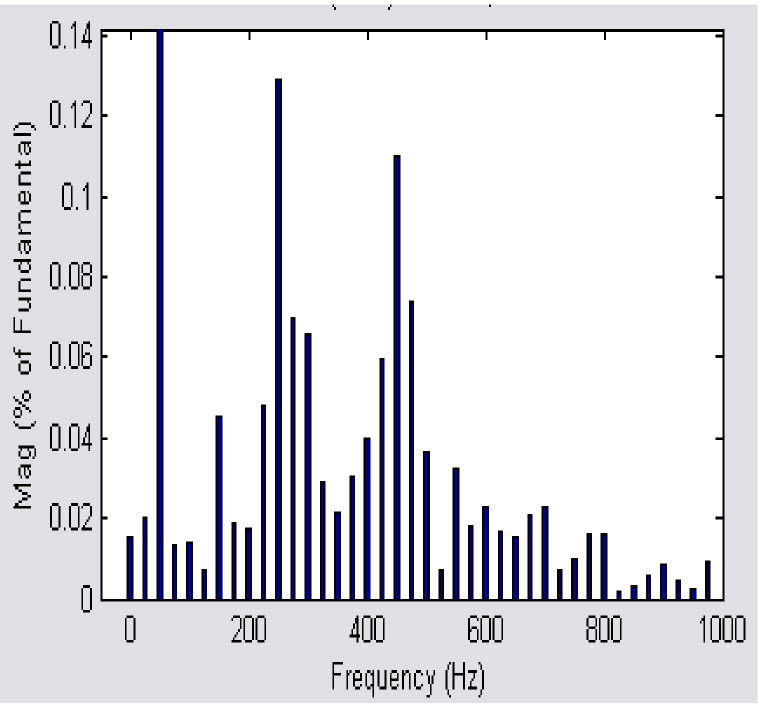

Figure 27: FFT Analysis for Voltage (Modified Sine Wave)

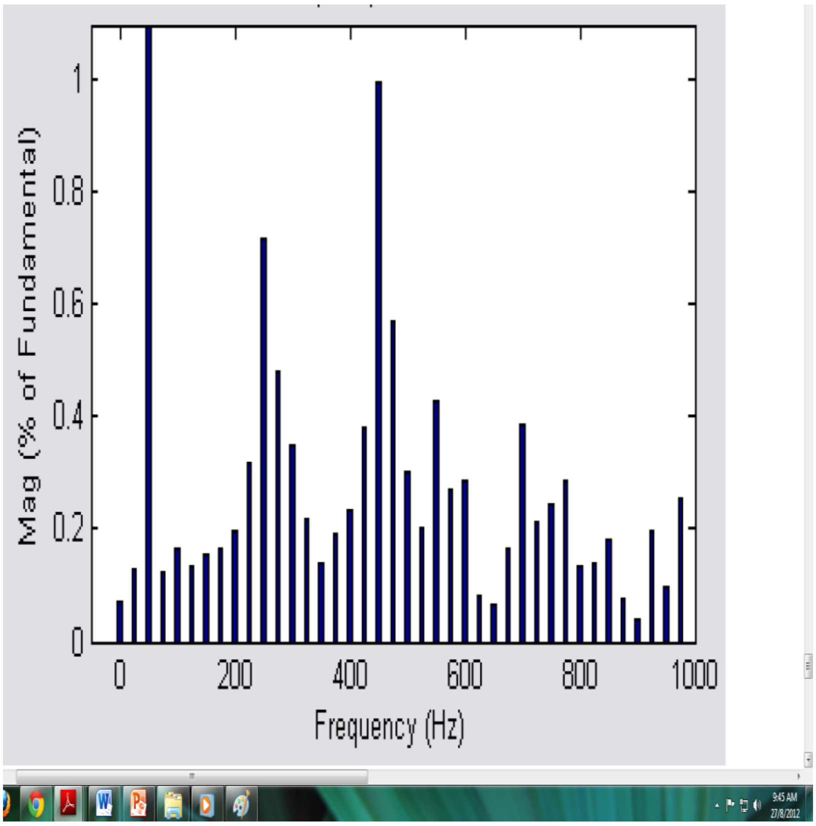

Figure 28: FFT Analysis for Current (Modified Sine Wave)

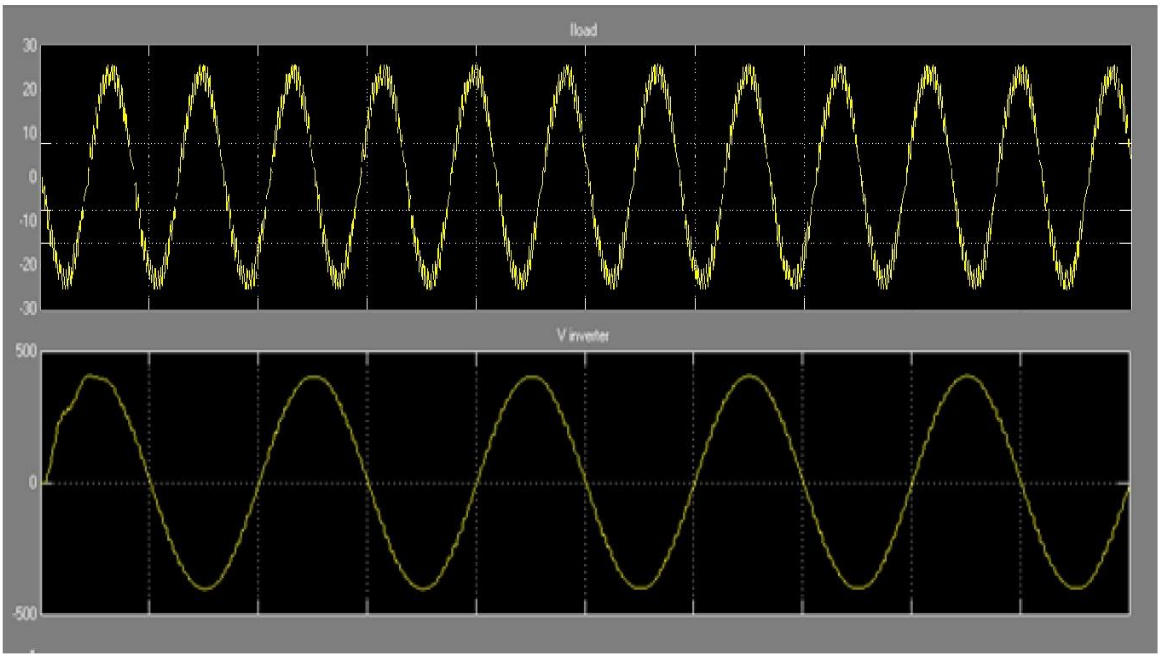

Figure 29: 3rd Harmonic Injection PWM Inverter (Firing angle = 68^o)

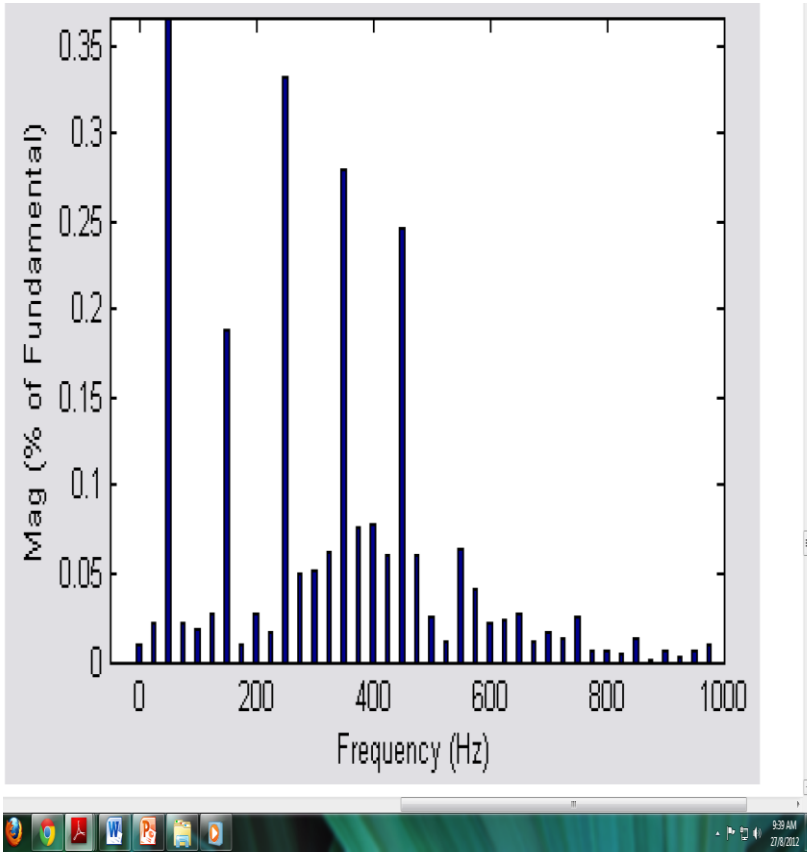

Figure 30: FFT Analysis for Voltage (3rd Harmonic Injection)

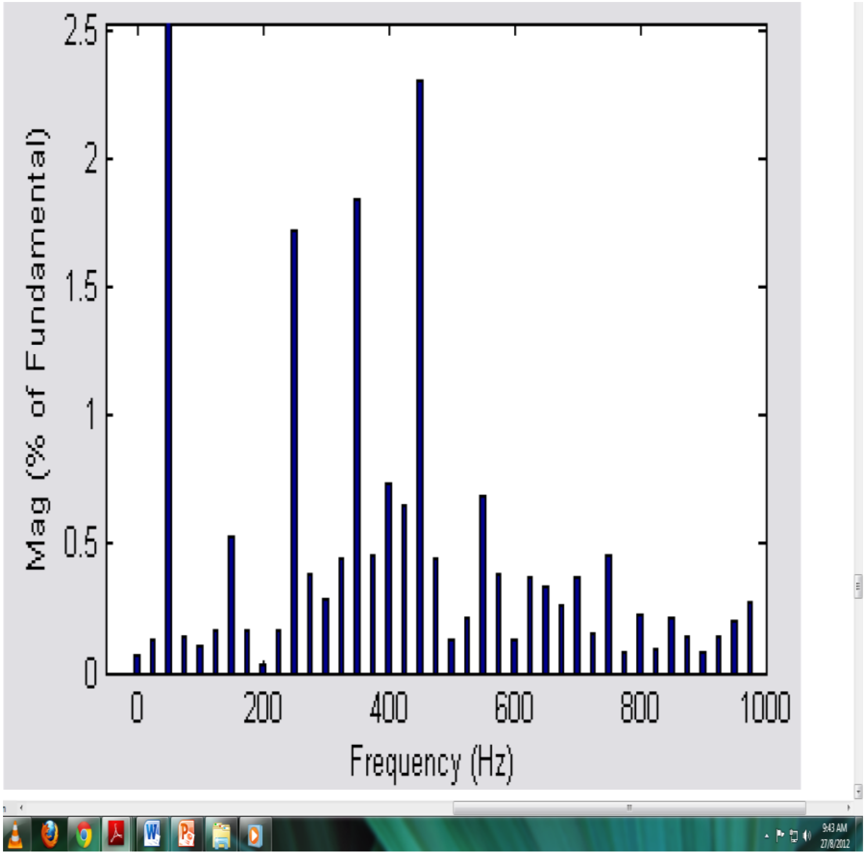

Figure 31: FFT Analysis for Current (3rd Harmonic Injection)

Figures 26 and 29 show the load current and also load voltage for modified sine wave PWM inverter and also 3rd harmonic injection PWM inverter. An inductive load was connected to the inverters. The load voltage was purposely designed to be having same value so that we can see how is actually THD can affect the load current. In order to get value for load voltage equal to 400 V, modified sine wave PWM inverter was fired at 75^{o} of firing angle while 3rd harmonic injection PWM inverter was fired at 68^{o}. The load voltages for both inverters are pretty much the same. However, big difference exists in characteristics of load currents. Load current for modified sine wave PWM inverter is smoother compare to load current for 3rd harmonic injection PWM inverter. This is due to the characteristic of 3rd harmonic injection techniques that produce more THD compare to modified sine wave PWM technique. 3rd harmonic injection techniques produced 5% of voltage THD compare to modified sine wave that produced only 4% of voltage THD. It is proven that the right choice of PWM techniques in inverter application is technically important. Even though the THD for both techniques only differ by 1%, but the final result shows big difference in load current characteristics. Therefore, choose correctly the PWM techniques before apply to any application.

Table 7: Comparative Analysis on Both Techniques

	Fundamental Frequency (Hz)	THD (%) Output Voltage	THD (%) Output Current
Modified Sine Wave PWM	50 Hz	0.20%	1.55%
3rd Harmonic Injection PWM	50 Hz	0.55%	3.70%

Table 7 shows a comparative analysis of the voltage THD (%) and current THD (%). Modified sine wave PWM produces 0.20% of voltage THD and 1.55% of current THD. Meanwhile, 3rd harmonic injection PWM produces 0.55% of voltage THD and 3.70% of current THD. Therefore, it is clearly shows that modified sine wave PWM is much better in performance compare to 3rd harmonic injection PWM with the least production of both voltage and current harmonics.

CHAPTER 5
CONCLUSION

As a conclusion, this project is a comprehensive research study about intelligent PWM technique to control output voltage of an inverter. This project results in which PWM technique is the best in performance. It also results with an intelligent way to control the PWM inverter by using fuzzy logic controller that can suit with a lot of industrial applications. Modified sine-wave PWM inverter has a better output voltage with less voltage and current harmonic distortion compare to 3^{rd} harmonic injection inverter. Therefore, the right choice of PWM technique is crucial in order to maximize the efficiency of the inverter. Fuzzy logic controller has better control scheme compare to the conventional controller. With proper research, proper calculations, and proper control scheme, the fuzzy logic controller can results in good control of output voltage with very few production of voltage and current THD (%).

CHAPTER 6
RECOMMENDATION

To use Artificial-Neural Network (ANN) as a control scheme to control output voltage of an inverter, and compare the results between ANN and FLC. ANN is also an intelligent control similar to FLC. Starting a few years back, there is a gradual interest in ANN. ANN has several advantages that FLC does not have. In order to prove this, a comprehensive research study on ANN control scheme on an inverter need to be made.

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[4] L.A. Zadeh, "Making computers think like people," IEEE. Spectrum, 8/1984, pp. 26-32.

[5] Mahesh A Patel, Ankit R Patel, Dhaval R Vyas, Ketul M Patel,"Use of PWM Technique for Power Quality Improvement" International Journal of Recent Trends in Engineering, Vol 1, No 4, May 2009.

[6] Jan Jantzen," Design of Fuzzy Controllers" Report Paper, 1998.

[7] James Vernon, "Fuzzy Logic Systems", Visiting Consultant Scientist, control-systems-principles.co.uk.

[8] Robin M. Hilloowala and Adel M. Sharaf, "A Rule-Based Fuzzy Logic Controller for a PWM Inverter in a Stand Alone Wind Energy Conversion Scheme", IEEE Transaction on Industry Application, Vol 32, 1996.

[9] Halpin S.M., "Harmonics in Power Systems", in The Electric Power Engineering Handbook, L.L. Grigsby, Ed. Boca Baton, CRC Press, 2001.

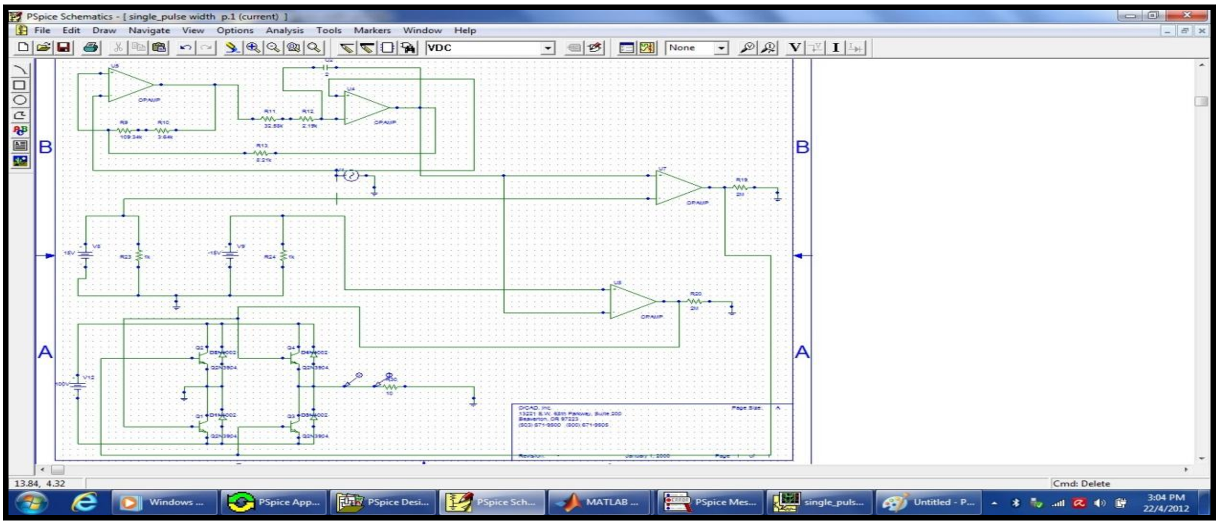
[10] Essam Natsheh, Khalid A. Buragga,"Comparison between Conventional and Fuzzy Logic PID Controllers for Controlling DC Motors" International Journal of Comp Science, Vol 7, Issue 5, Sept 2010

APPENDICES

1. PSpice Simulation

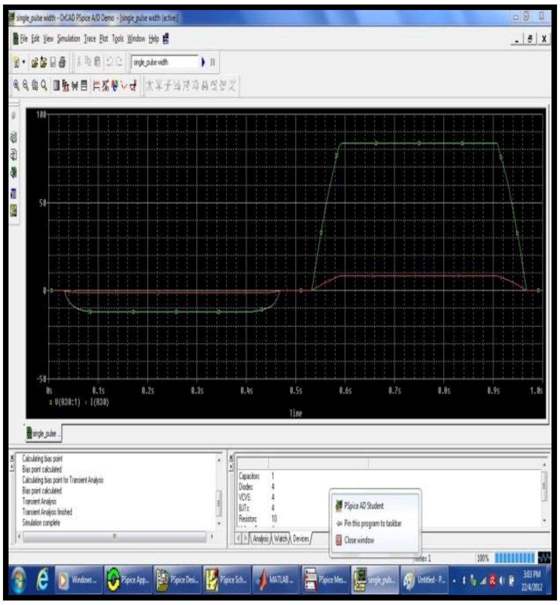
Single Pulse-Width Modulation

Schematic:

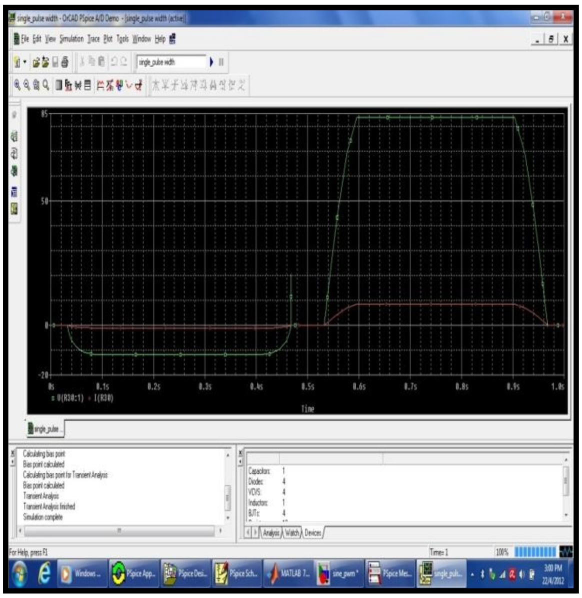


Result:

R Load

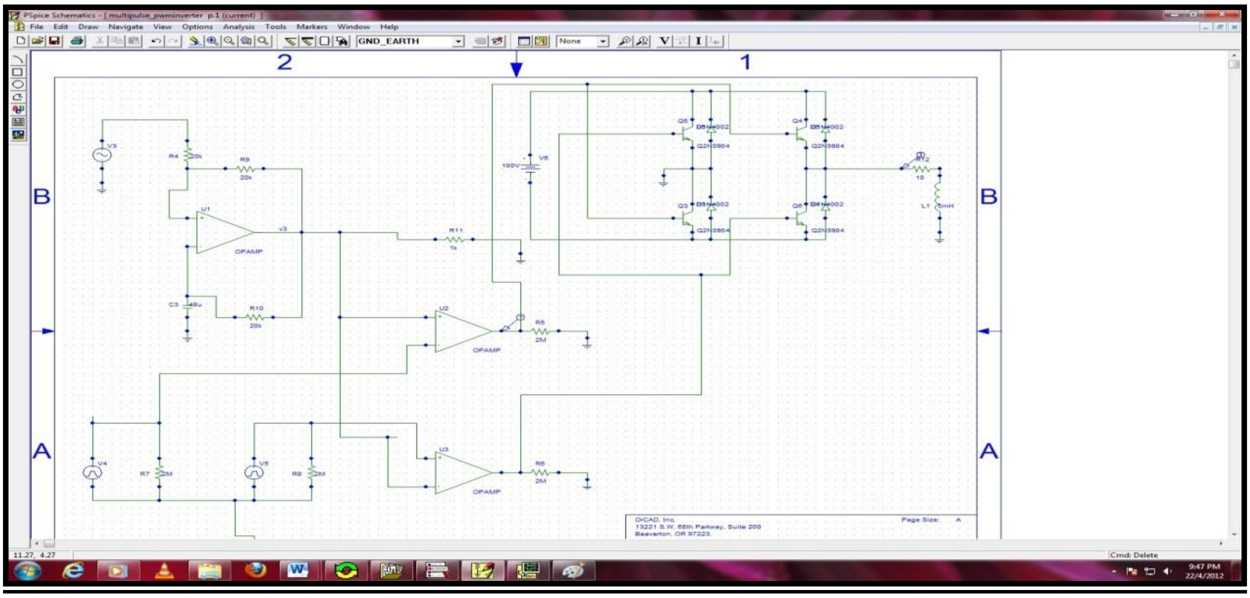


R-L Load



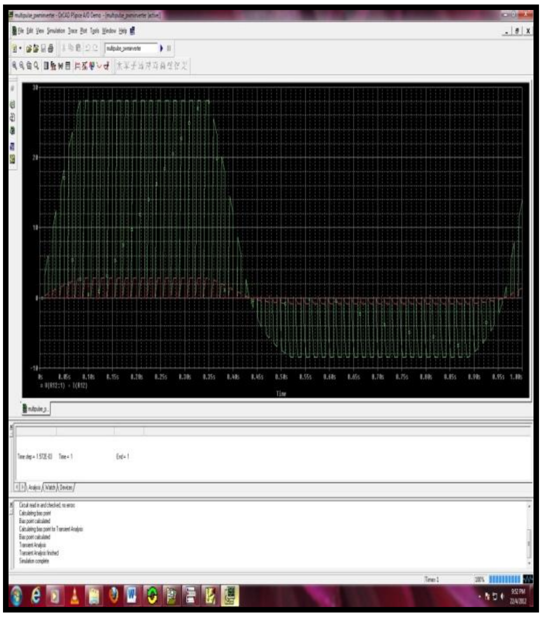
Multiple Pulse-Width Modulation

Schematic:

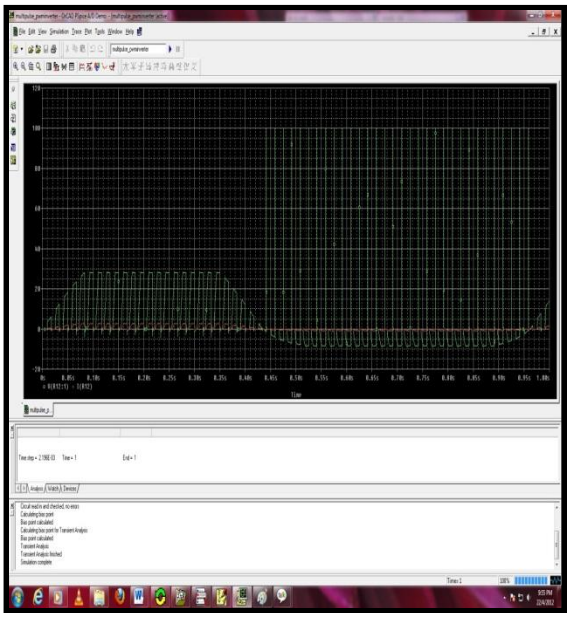


Result:

R Load

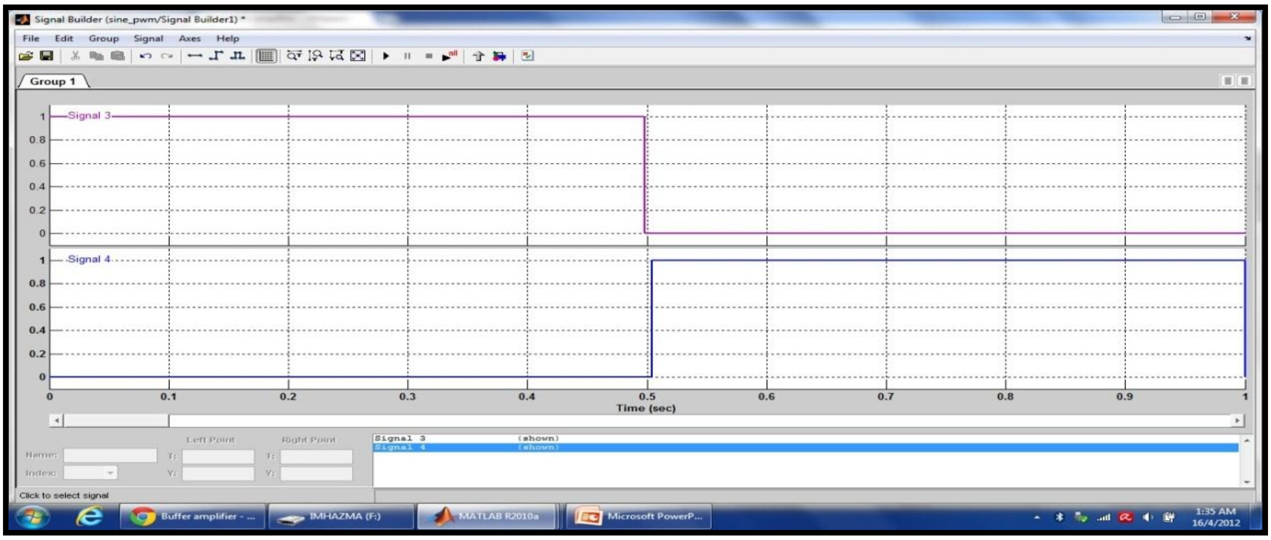


R-L Load



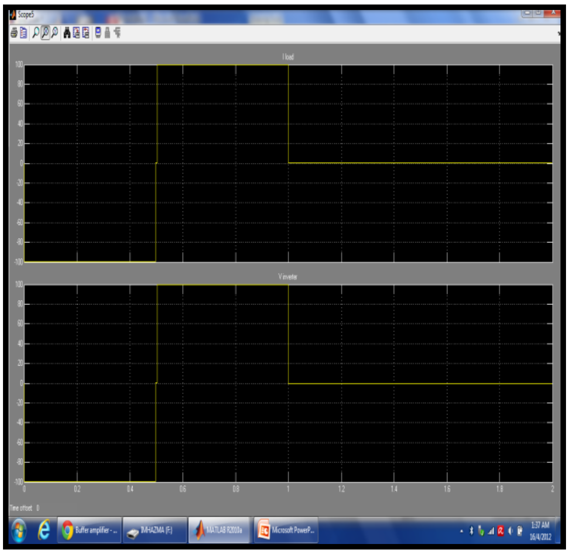
<u>**Phase Displacement Modulation**</u>

Schematic:

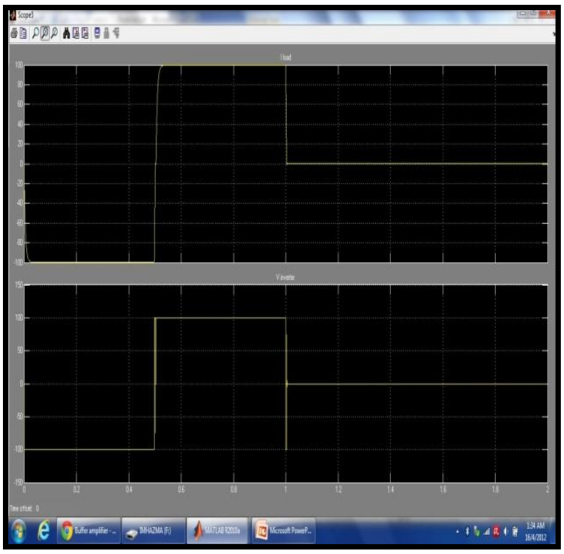


Result:

R Load



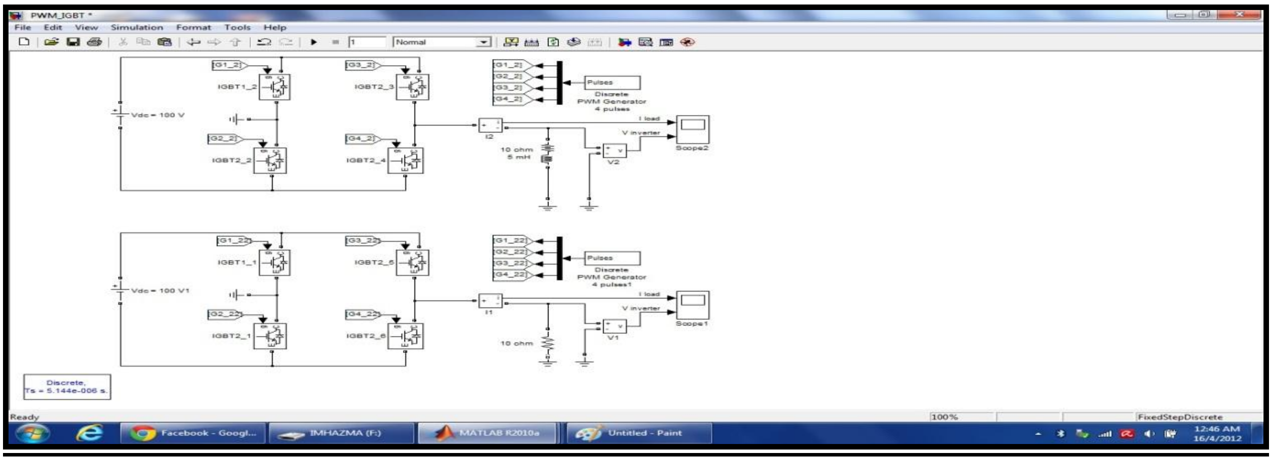
R-L Load



2. MATLAB/SIMULINK Simulation

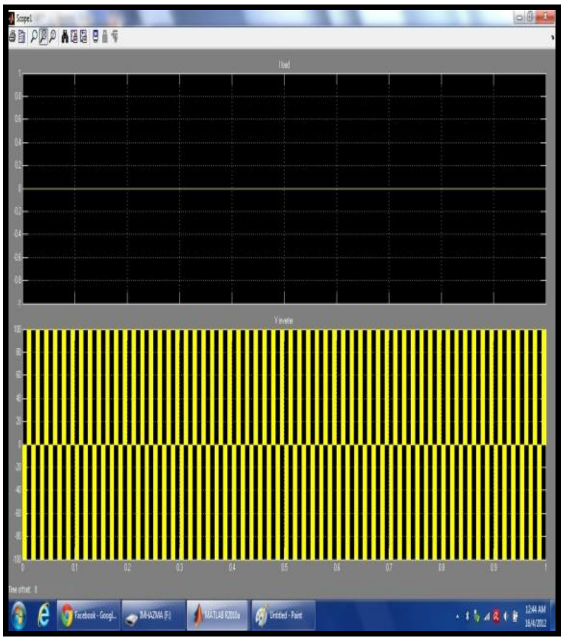
Sine PWM

Schematic:

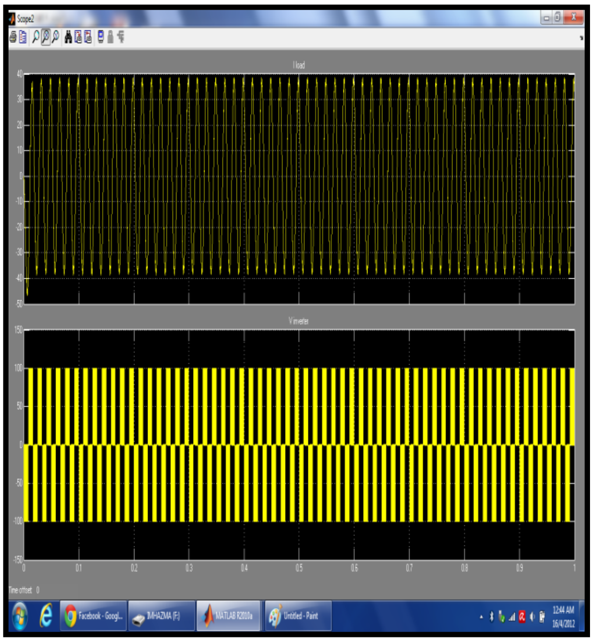


Result:

R Load

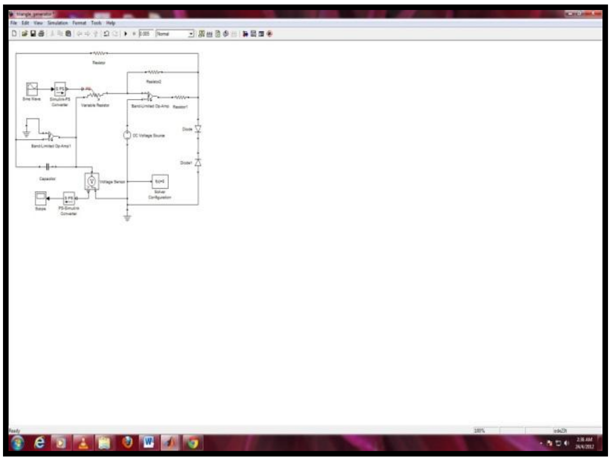


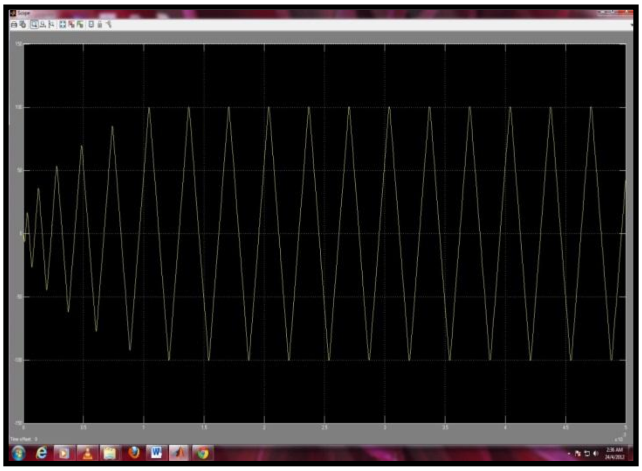
R-L Load



Triangle Wave Generator

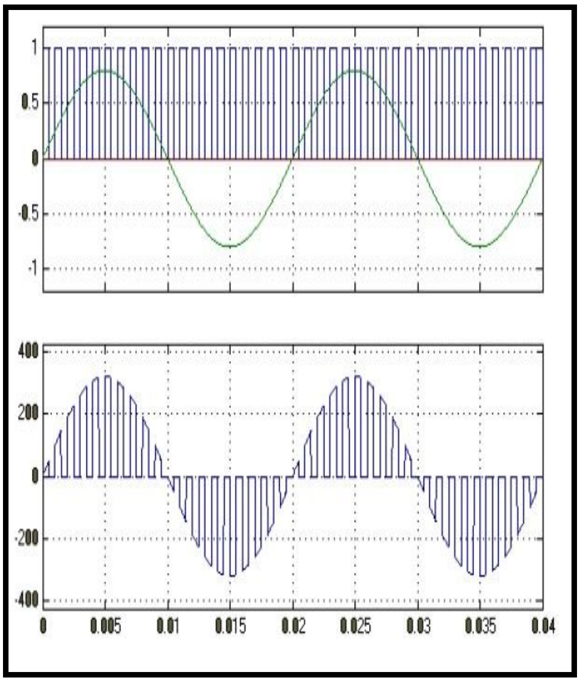
Schematic: Result :

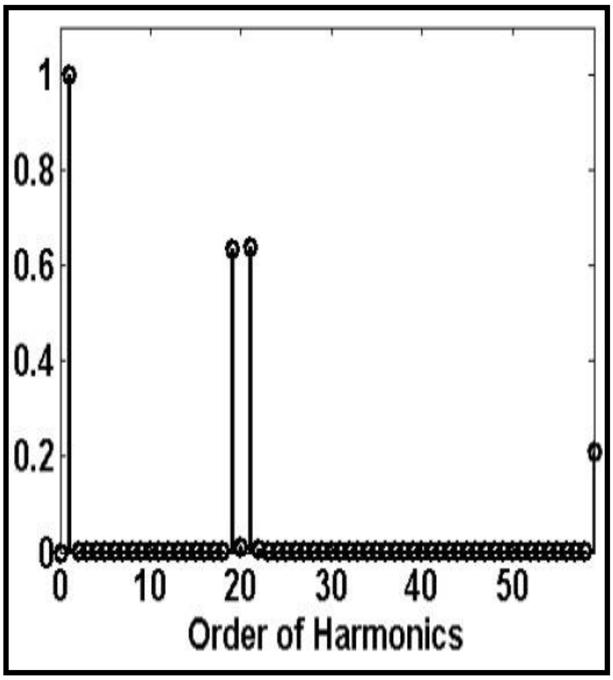




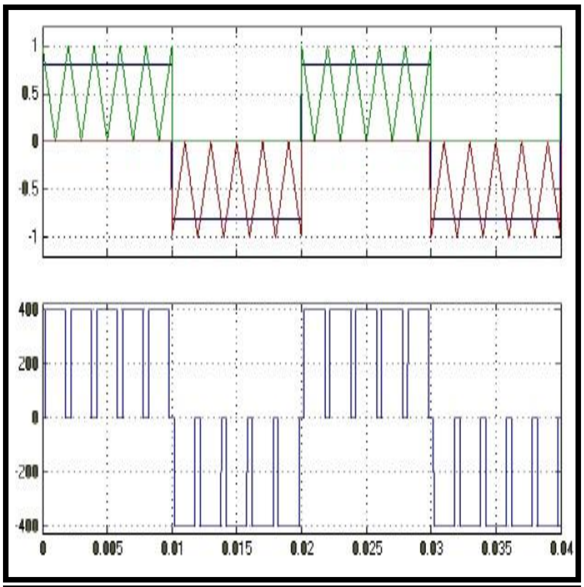
3. MATLAB/SIMULINK Mathematical Model (Output)

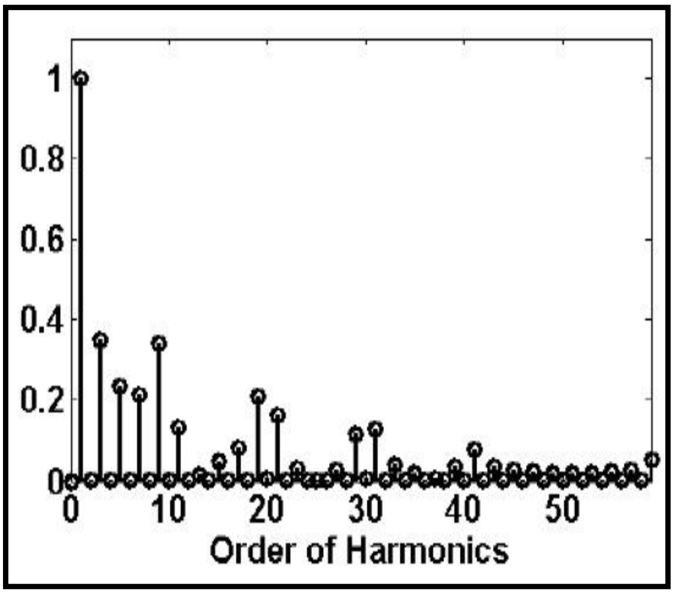
Sine PWM



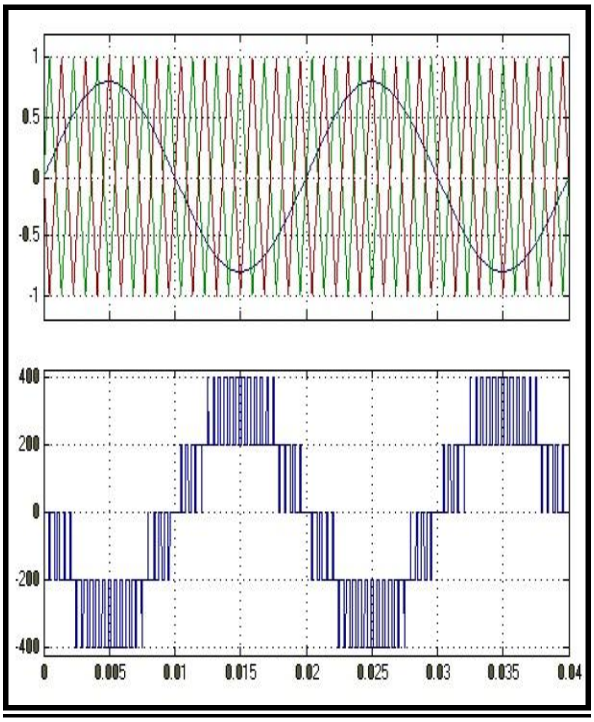


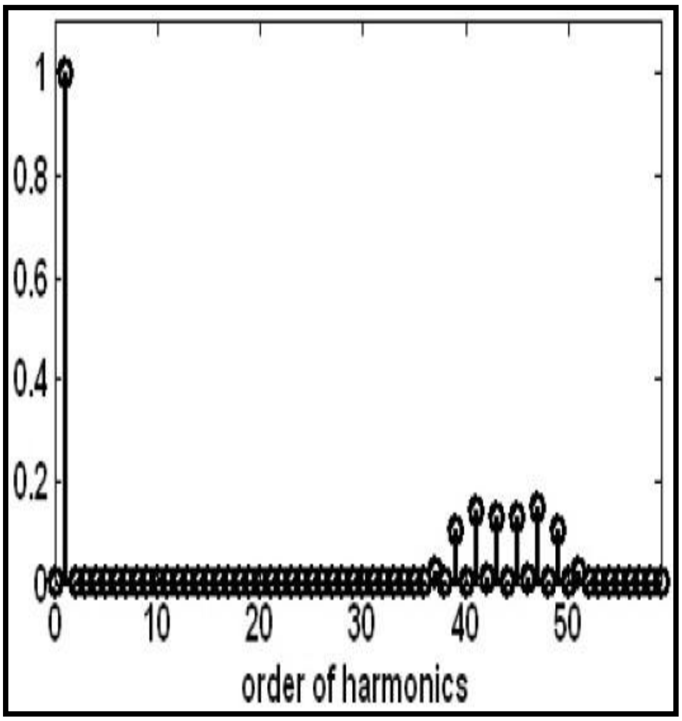
Multi-Pulse PWM



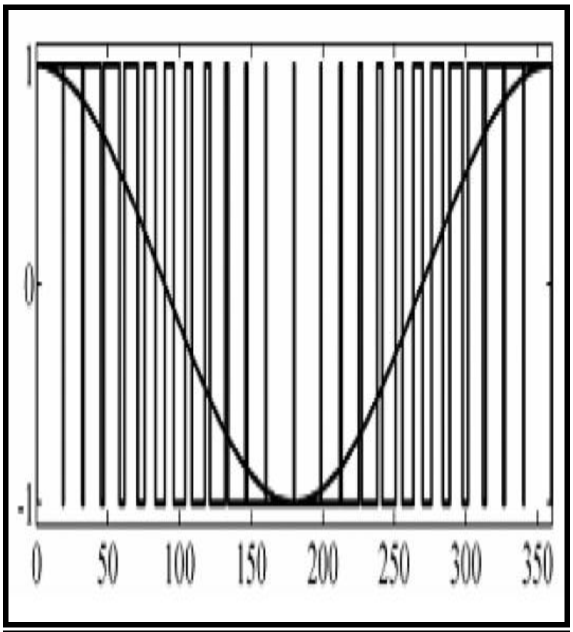


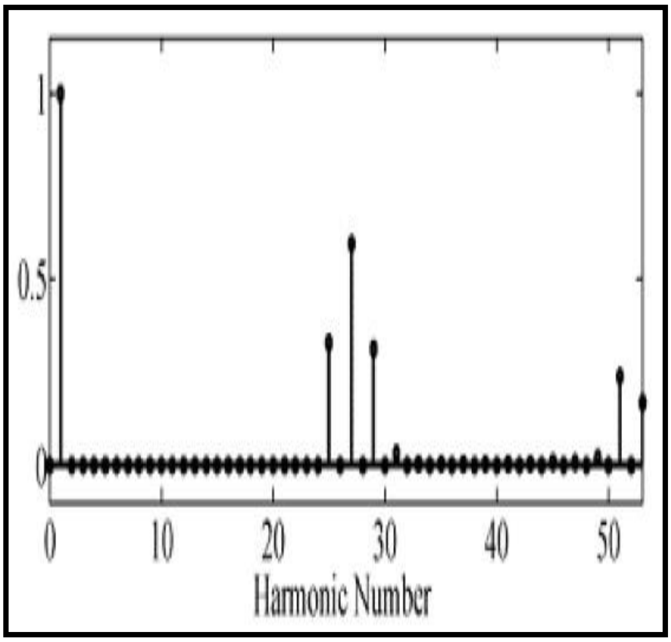
Modified Sine Wave PWM



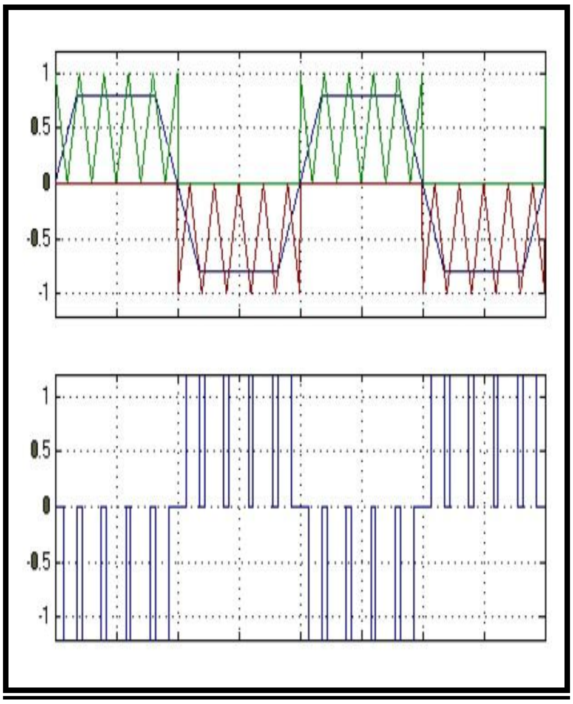


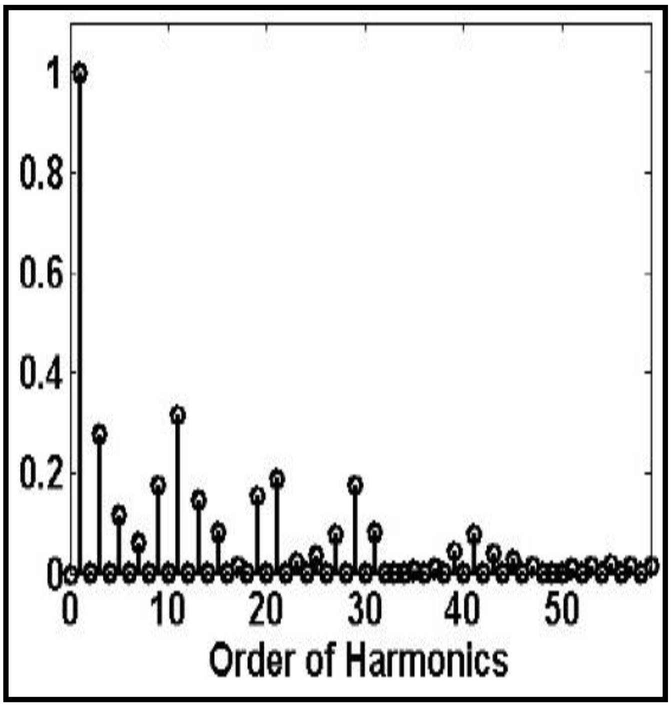
Third Harmonics Injection



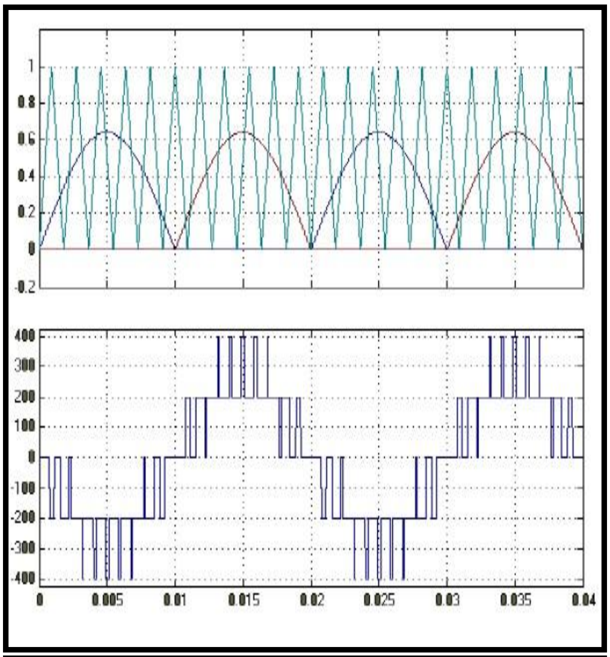


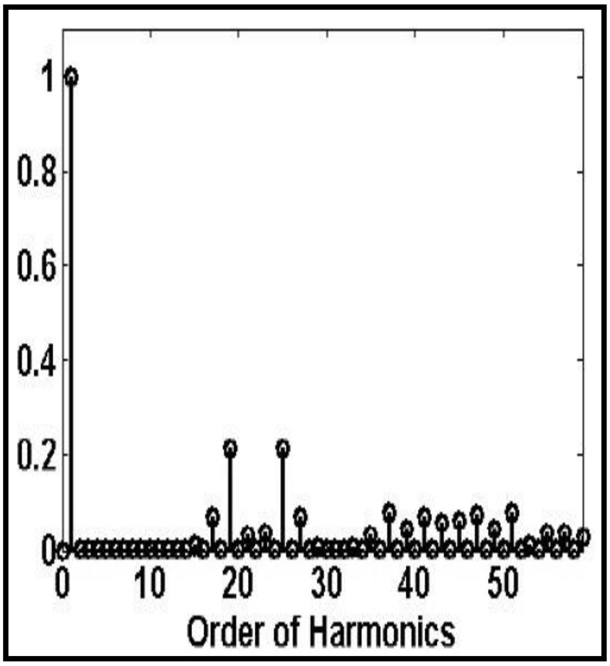
Trapezoidal Modulation





Unipolar Modulation





MATLAB/SIMULINK Code

Fuzzy Code

```
[System]
Name='Fuzzy_control_inverter'
Type='mamdani'
Version=2.0
NumInputs=2
NumOutputs=1
NumRules=5
AndMethod='min'
OrMethod='max'
ImpMethod='min'
AggMethod='max'
DefuzzMethod='centroid'

[Input1]
Name='error'
Range=[0 1]
NumMFs=5
MF1='low':'trimf',[-0.25 0 0.25]
MF2='quiteLow':'trimf',[0 0.25 0.5]
MF3='medium':'trimf',[0.25 0.5 0.75]
MF4='quiteHigh':'trimf',[0.5 0.75 1]
MF5='high':'trimf',[0.75 1 1.25]

[Input2]
Name='rate'
Range=[0 1]
NumMFs=5
MF1='low':'trimf',[-0.25 0 0.25]
MF2='quiteLow':'trimf',[0 0.25 0.5]
MF3='medium':'trimf',[0.25 0.5 0.75]
MF4='quiteHigh':'trimf',[0.5 0.75 1]
MF5='high':'trimf',[0.75 1 1.25]

[Output1]
Name='OutputVoltage'
Range=[0 1]
NumMFs=5
MF1='low':'trimf',[-0.25 0 0.25]
MF2='quiteLow':'trimf',[0 0.25 0.5]
MF3='medium':'trimf',[0.25 0.5 0.75]
MF4='quiteHigh':'trimf',[0.5 0.75 1]
MF5='high':'trimf',[0.75 1 1.25]

[Rules]
1 1, 1 (1) : 1
2 2, 2 (1) : 1
3 3, 3 (1) : 1
5  4, 4 (1) : 1
5 5, 5 (1) : 1
```

4. Fuzzy 9 Rule Based

Error	Rate of change in error	Corrective Output
Low (0 – 0.25)	Low (0 – 0.25)	Low
Quite Low (0 – 0.5)	Quite Low (0 – 0.5	Quite Low
Medium (0.25 – 0.75)	Medium (0.25 – 0.75)	Medium
Quite High (0.5 – 1)	Quite High (0.5 – 1)	Quite High
High (0.75 – 1)	High (0.75 – 1)	High

5. Schematic Whole System