

**DESIGN AND IMPROVEMENT OF PHOTOVOLTAIC BASED  
INDUCTION MOTOR USING MULTILEVEL INVERTERS**

by

Ali Yahya Surajuddin Mohamed

I.D. 15667

Dissertation submitted in partial fulfilment of  
the requirements for the  
Bachelor of Engineering (Hons)  
(Electrical & Electronics)

SEPTEMBER 2015

Universiti Teknologi PETRONAS  
32610 Bandar Seri Iskandar  
Perak Darul Ridzuan

CERTIFICATION OF APPROVAL

**DESIGN AND IMPROVEMENT OF PHOTOVOLTAIC BASED  
INDUCTION MOTOR USING MULTILEVEL INVERTERS**

by

Ali Yahya Surajuddin Mohamed  
15667

A project dissertation submitted to the  
Electrical and Electronics Engineering Program  
Universiti Teknologi PETRONAS  
in partial fulfilment of the requirement for the  
BACHELOR OF ENGINEERING (Hons)  
(Electrical & Electronics)

Approved by,

---

(DR. RAMANI KANNAN)

UNIVERSITI TEKNOLOGI PETRONAS

BANDAR SERI ISKANDAR, PERAK

SEPTEMBER 2015

## 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.

---

ALI YAHYA SURAJUDDIN MOHAMED

## **ABSTRACT**

Multilevel Inverters are power devices that convert direct current (DC) to alternating current (AC). The focus of this work lies in the study, simulation and implementation of cascaded H-bridge multilevel inverters, since they operate on the basis of multiple inputs. Each DC input could be interchanged with a solar panel to achieve the photovoltaic setup of the system. Furthermore, tests on the solar irradiances around an area of interest were carried. Full analysis of two and three levels inverters are included as well. Matlab and Simulink software packages are used in the study and simulation. Resistive and Inductive loads are present in the design, illustrating the resistive-inductive property of the single-phase induction motor.

## **ACKNOWLEDGMENT**

First of all, I would like to channel my appreciation to my direct supervisor, Dr. Ramani Kannan, a Senior Lecturer in the Electrical and Electronics Engineering Department, Universiti Teknologi PETRONAS. His precious supervision, guidance, assistance and support throughout the project period was of utmost usefulness. His teaching was beneficial for improving the technical and linguistic aspects of the project. His golden advices for the betterment of my own to achieve high personal development were a key in achieving the objectives of this project. Furthermore, I would like to express my great thanks and appreciation to my co-supervisor, Dr. Fakhizan Mohd Romlie for his valuable assistance. Special thanks are also extended to everyone who had a direct or indirect involvement in making this project a reality. Finally, I wish to offer my special thanks to my mother for her faith, love, support and encouragement throughout my life.

## TABLE OF CONTENTS

<b>CERTIFICATION OF APPROVAL</b> .....	<b>II</b>
<b>CERTIFICATION OF ORIGINALITY</b> .....	<b>III</b>
<b>ABSTRACT</b> .....	<b>IV</b>
<b>ACKNOWLEDGMENT</b> .....	<b>V</b>
<b>LIST OF FIGURES</b> .....	<b>VII</b>
<b>LIST OF TABLES</b> .....	<b>VIII</b>
<b>ABBREVIATION AND NOMENCLATURES</b> .....	<b>IX</b>
<b>CHAPTER 1: INTRODUCTION</b> .....	<b>1</b>
1.1 Background .....	1
1.2 Problem Statements.....	2
1.3 Objectives.....	3
1.4 Scope Of The Project Work .....	3
<b>CHAPTER 2: LITERATURE REVIEW</b> .....	<b>5</b>
2.1 Overview Of Photovoltaics (Pv).....	5
2.2 Overview Of Multilevel Inverters (Mli) .....	7
2.2.1 Multilevel Inverters Topologies.....	8
2.2.1.1 Symmetrical Multilevel Inverters .....	8
2.2.1.2 Asymmetrical Multilevel Inverter.....	11
2.3 Single Phase Full Bridge Inverters.....	13
2.4 Related Work And Critical Analysis .....	14
<b>CHAPTER 3: METHODOLOGY</b> .....	<b>16</b>
3.1 Research Methodology .....	16
3.2 Project Management .....	18
<b>CHAPTER 4: RESULTS AND DISCUSSION</b> .....	<b>19</b>
4.1 Photovoltaic Solar Panel .....	19
4.1.1 Experiment On Solar Irradiances.....	19
4.1.2 Characteristics Of The Solar Panel .....	22
4.2 The Inverter Subsystem .....	25
4.2.1 Simulation Of Single Phase,Full Bridge Inverter .....	25
4.2.2 Multilevel Inverter Simulation.....	32

4.3 Asynchronous (Induction) Motor Drive.....	35
4.3.1 Simulation Of A Single-Phase, Induction Motor.....	35
<b>CHAPTER 5: CONCLUSION AND RECOMMENDATION .....</b>	<b>37</b>
5.1 Conclusion .....	37
5.2 Recommendation .....	37
<b>REFERENCES .....</b>	<b>38</b>
<b>APPENDICES .....</b>	<b>41</b>
APPENDIX A .....	42
APPENDIX B .....	43
APPENDIX C .....	44

## LIST OF FIGURES

Figure 1.1	Block diagram of the overall system.....	4
Figure 2.1	Equivalent Circuit of a PV cell.....	6
Figure 2.2	Circuit diagram of Diode Clamped inverter.....	9
Figure 2.3	Circuit diagram of a general cascaded H-Bridge inverter.....	11
Figure 2.4	Circuit diagram of a binary multilevel inverter.....	12
Figure 2.5	Single phase, full bridge inverter.....	13
Figure 3.1	Summary and breakdown of project Methodology.....	17
Figure 4.1	Setup for solar panel experiment (I-V & P-V characteristics).....	20
Figure 4.2	Readings from the panel through the USB Voltage Tester.....	20
Figure 4.3	Solar Irradiances on October 29th.....	21
Figure 4.4	Solar Irradiances on November 3rd.....	21
Figure 4.5	Current vs. Voltage of rated solar panel.....	23
Figure 4.6	Power vs. Voltage of rated solar panel.....	24
Figure 4.7	Simulink model of a full bridge inverter with R-L load.....	25
Figure 4.8	Transistor gates switching functions.....	26
Figure 4.9	Output voltage and current of the R-L INVERTER.....	26
Figure 4.10	DC input vs. AC Voltage output vs. Current output at R=0 $\Omega$ .....	27
Figure 4.11	DC input vs. AC Voltage output vs. Current output at R=10 $\Omega$ .....	28
Figure 4.12	DC input vs. AC Voltage output vs. Current output at R=100 $\Omega$ .....	28
Figure 4.13	DC input vs. AC Voltage output vs. Current output at R=1000 $\Omega$ .....	28
Figure 4.14	Output of full bridge multilevel inverter at V=0V, R=10 $\Omega$ .....	29
Figure 4.15	Output of full bridge multilevel inverter at V=0V, R=1000 $\Omega$ .....	29
Figure 4.16	Output of full bridge multilevel inverter at V=50V, R=10 $\Omega$ .....	30
Figure 4.17	Output of full bridge multilevel inverter at V=50V, R=1000 $\Omega$ .....	30
Figure 4.18	Output of full bridge multilevel inverter at V=100V, R=10 $\Omega$ .....	31
Figure 4.19	Output of full bridge multilevel inverter at V=100V, R=1000 $\Omega$ .....	31
Figure 4.20	Matlab Simulink model of single topology multilevel inverter.....	32
Figure 4.21	Output of single H-bridge inverter vs. 10V sinusoid input.....	32
Figure 4.22	Matlab Simulink model of dual topology multilevel inverter.....	33
Figure 4.23	Output of two H-bridge inverters vs. 10V sinusoid reference input.....	33
Figure 4.24	Matlab Simulink model of three topologies multilevel inverter.....	34
Figure 4.25	Output of triple H-bridges inverter vs. 10V sinusoid reference input.....	34
Figure 4.26	Matlab Simulink model of a single phase Induction motor drive.....	35
Figure 4.27	Rotor Speed and Torque of the designed Induction motor.....	36



## LIST OF TABLES

Table 2.1	Switching States For The Diode Clamped Inverter .....	9
Table 2.2	A List Of Recently Related Papers. ....	14
Table 3.1	Timeline For FYP I .....	18
Table 3.2	Timeline For FYP II.....	18

## ABBREVIATION AND NOMENCLATURES

AC	Alternating Current
API	Air Pollution Index
BMLI	Binary Multilevel Inverter
DC	Direct Current
DCMLI	Diode Clamped Multilevel Inverter
I	Current
IGBT	Insulated Gate Bipolar Transistor
$I_{ph}$	Photocurrent in a photovoltaic cell
$I_r$	Reverse saturation current of diode in a photovoltaic cell
k	Boltzmann constant.
MLI	Multi Level Inverter
MOSFET	Metal Oxide Semiconductor Field Effect Transistor
MPP	Maximum Power Point
MPPT	Maximum Power Point Tracking
P	Power
PV	Photovoltaic
PWM	Pulse Width Modulation
Q	Electron charge
R	Resistance
$R_s$	Photovoltaic cell resistance
SVPWM	Space Vector Pulse Width Modulation
THD	Total Harmonic Distortion
TMLI	Ternary Multilevel Inverter

$T_r$	Reference operating temperature of the cell
UTP	Universiti Teknologi Petronas
V	Voltage
$V_{PV}$	Solar Cell voltage.

# CHAPTER 1

## INTRODUCTION

### 1.1 Background Of Study

The energy harnessed from the sun is considered to be the most ideal source in terms of various aspects ranging from economic viability, efficiency, and most importantly the fact that solar energy is among the elites in the category of green energy [1]. This energy is often converted into its usable form through photovoltaic technology.

Such process is achieved by using Solar Cells. They are made of materials built around semiconductors mostly used in the artificial intelligence and computers industry. These materials possess the property of having their electrons to be knocked loose from their respective atoms when sunlight is assimilated, allowing a relatively unique degree of freedom for those electrons to flow freely through the substance thus producing electricity. Einstein's explained this principle in his photoelectric effect theory where he outlined the conversion process of light to electricity. [2]

In contrast, solar cells which are strongly related to Photovoltaic (PV) technology, is thus an application in the field of technology and research related to the conversion of sunlight into useful electricity. [1]

In laboratories, scientists have managed to develop solar panels with efficiency of up to 40 percent. While 40% is considered ideal on average, there is a marginal difference between the real world application and

development in confined laboratories where environmental factors are minimal. In addition, high efficiency does not necessarily mean better as it is mostly related to the physical size of the solar panel. [3]

The research and development in the renewable energy sector is an ever evolving process. New technologies that operate using non-conventional fuels are introduced. However optimizing the generated energy for efficient and reliable applications is considered as the main challenge. For instance, optimizing the direct current farmed from solar energy is imperative when applications such as powering inductive devices and machines are considered, since they require Alternating Current (AC) as the main operating drive. [2]

The conversion process that is required between the DC and its AC counterpart can be achieved through multiple types of power electronics devices and circuitry known as Inverters. Similar to the Transformers family; a power inverter does not produce any power, however it handles frequency, input and output voltages. Power inverters are either built entirely over electronic basis or operate electromechanically. [4]

## **1.2 Problem Statements**

Current energy resources are restricted. In the sense that their lifespans have reached an alarming level that has been statistically approximated and assumed, especially when they are placed next to the supply and demand estimates. Fuel resources such as gas, oil, and coal have been the norm for almost a century now, however the time to invest in renewable energy is here and most notably the solar sector.

In accordance to the competitiveness of solar energy with its neighboring renewable counterparts, superior utilization of its advantages mostly governed by its cleanliness, is crucial. An approach to achieve such feat will be through

the development of the economical and efficient systems.

For instance, powering an induction motor through a solar panel should not take significant space. Temperature and sun exposure on the other hand could both be considered as major factors that can affect the efficiency of solar panels, in other words solar irradiances.

Another challenge is the conversion or the inversion process required for the integration between the direct current generated from the solar panels with the alternating current driven induction motor. This is tackled through the introduction of power inverters.

### **1.3 Objectives**

The objectives of this project are summarized in the following:

- To simulate a photovoltaic based induction motor drive.
- Analyze the performance of induction motor with various environmental changes.
- Form a foundation for the implementation of the PV drive system.

### **1.4 Scope Of The Project**

As previously mentioned, a solar panel generates a single phase direct current which must be inverted to an alternating current to feed the induction motor. This is achieved through implementing inverters of pre-determined levels according to the design of the overall system.

Therefore the main scope of the project lies in the study, simulation and implementation of multilevel inverters.

The following is the proposed block diagram of the project operation:

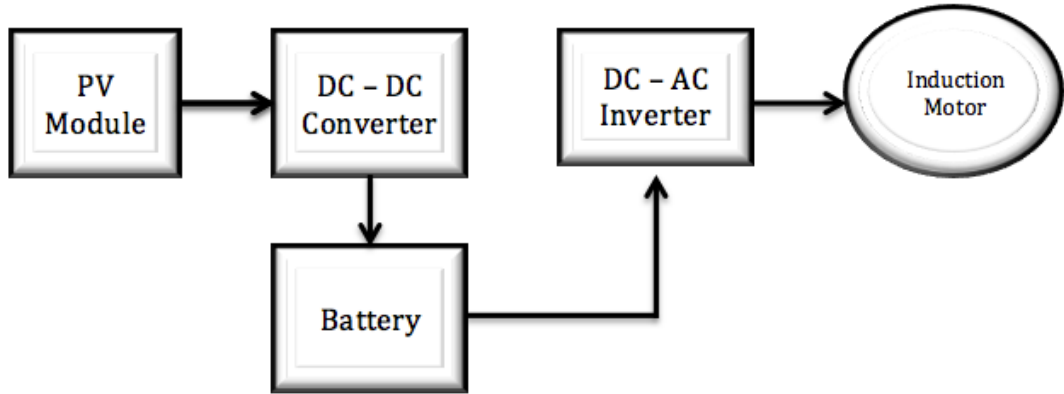


Figure 1.1 Block Diagram of the overall system

The variation in the output from the PV module depends on the temperature and intensity of the sunlight (radiation) [1]. Figure 1 is addressed as the basic blocks for a solar module, a DC-DC step-up converter, otherwise known as a Boost Converter is important in order to raise the potential of the generated solar energy to be stored in a power bank to be used for operating the motor. According to the demand, the DC energy is released to the inverter circuit to be converted to an alternating single phase current that matches the rated input of the induction motor.

## **CHAPTER 2**

### **LITERATURE REVIEW**

#### **2.1 Overview Of Photovoltaics (PV)**

The introduction of solar cells dates back to the previous century, more specifically in the late 50s where they were introduced as power drivers in space applications [3]. Today, they are abundantly available for the average consumer through products that range from calculators to watches. Furthermore, they are mounted on roofs of houses or assembled into large power stations where majority of solar modules are used for powering up the green houses worldwide. [5]

Since a single solar cell is typically rated for about 0.5 volts [5], a combination of these cells was necessary throughout the development of this non-conventional source of energy, known as a photovoltaic modules or solar panels which would later be linked together to form photovoltaic arrays.

Solar panels can take the two well known electrical connections, either in parallel or in series. Connecting the panels in series results in a constant current through the cell. In the contrary, parallel connected solar cells achieve constant voltages throughout the cells whilst current is being added up across them. [6]

The following diagram demonstrates an equivalent circuit of a photovoltaic array. It is important to note that there exists several notions and models of PV arrays that differ among themselves in terms of the number of state variables or parameters involved in the calculations.

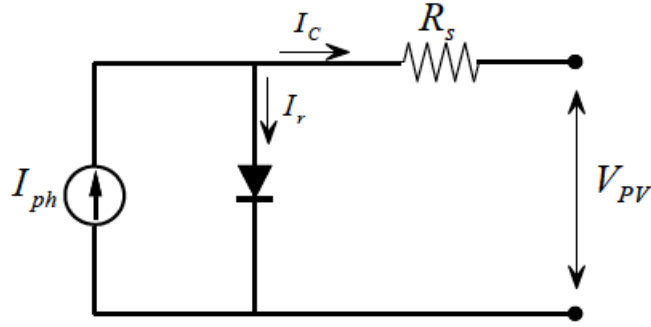


Figure 2.1 Equivalent Circuit of a PV cell.

PV arrays takes a non-linear output in the nature of its operation, since the output is governed by various conditions that range from the temperature to the level of solar insolation. According to [5] and [6], they supported the effects of the previously mentioned factors through relating the final mathematical representation of the PV array with parameters that complement these factors.

$$V_{PV} = \frac{AkT_c}{q} \ln \left( \frac{I_{ph} + I_r - I_c}{I_r} \right) - I_c R_s \quad (1)$$

Where:

- $V_{PV}$ : cell voltage in Volts (V).
- $I_c$ : output current in Amperes (A).
- $R_s$ : cell resistance in Ohms ( $\Omega$ ).
- $I_{ph}$ : photocurrent in Amperes (A).
- $I_r$ : reverse saturation current of diode (A).
- $Q$ : electron charge in Coulomb (C).
- $k$ : Boltzmann constant.
- $T_r$ : reference operating temperature of the cell in Kelvin (K).

As mentioned, solar energy has an enormous potential. Currently being promising, it may well become a significant source of electricity in the future. However, for this to happen, and while increasing the efficiency of the conversion process, costs of generation for solar power systems have to be reduced [5] [6].



## 2.2 Overview Of Multilevel Inverters (MLI)

Multi-level inverters, a sub category of power inverters, play a key role in today's micro grids with renewable energy sources. These power electronic devices are used for high level applications denoting power and voltage. Furthermore, and alongside the distinguishing additions of low switching stress and lower Total Harmonic Distortion (THD), they are capable of reducing the size and bulk of passive filters [7].

Multi Level Inverters (MLI) are power electronics systems that produce output voltages from multiple sources of input voltages possessing a DC nature. An alluring attribute of this technology can be categorized according to its applications that range from average to high voltages [8]. It presents a number of technical benefits when it is brought alongside the conventional two-level inverters. Multilevel inverters are utilized in power conversion systems due to their enhanced voltage and current waveforms [9]. Recently, and because of its advantages over the conventional inverter, it became prominent and apparent as a very important alternative in high power and medium voltage applications, as well as their capability in reducing undesirable harmonics, ultimately proving vital in the improvement of the performance and efficiency of any system [9].

The reduction of switching losses and the ability to obtain the output voltage with multiple steps to achieve the improved power quality and higher voltage capability summarizes the concept and structure performance of any multilevel inverter [8]. Multilevel inverters are mostly used in distributive generation, as well as high voltage direct transmission and AC motor drives

### **2.2.1 Multi-Level Inverters (MLI) Topologies**

The term ‘multilevel’ usually implies levels of two and above. Multilevel inverters (MLI) have broad applications in the power industry that is suffering till this day from unbalanced voltage issues [7]. Researchers have managed to categorize MLIs into the following three distinctive groups:

- Symmetrical multilevel inverters
- Asymmetrical multilevel inverters
- Hybrid multilevel inverters

Hybrid multilevel inverters are basically the result of combining symmetrical and asymmetrical inverters [10]. Therefore, extensive analysis for the hybrid topologies are not considered in this project work.

#### **2.2.1.1 Symmetrical Multilevel Inverters**

An inverter with an equal voltage sources amplitude for every single level. In other words, if a single level is designed for a capacity of 50V, this threshold is pre-set for the other switches accordingly. There are various constructions for this family type, with new designs being introduced regularly [11], however Diode Clamped and Cascaded H-Bridge multilevel inverters are considered to be the backbone of multilevel inverters design [12].

- Diode Clamped Multilevel Inverter

The overall design of this inverter is to lower the voltage at the power devices through the introduction of diodes. Some specifications are outlined by specific number of capacitors, diodes, and switches per each leg [8].

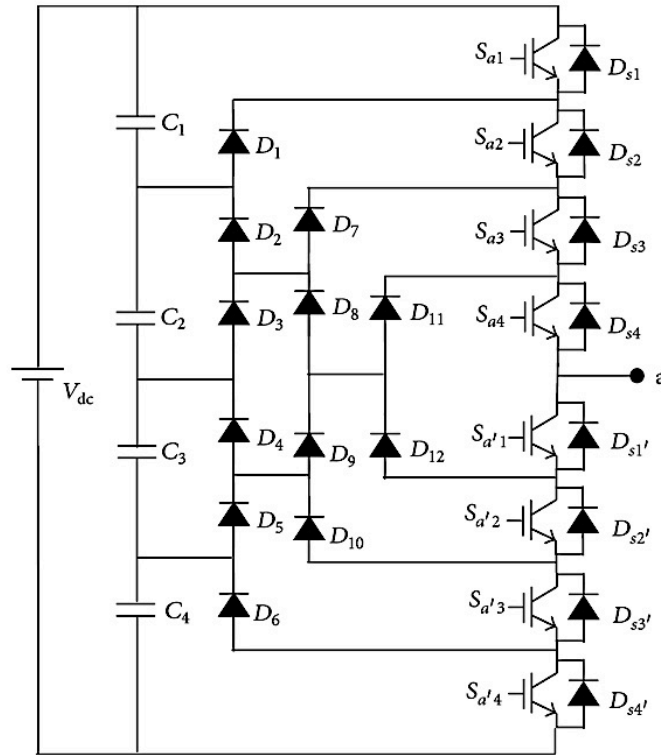


Figure 2.2 Circuit diagram of Diode Clamped Multilevel Inverter

Table 2.1 Switching States for the Diode Clamped Multilevel Inverter

<b>Switch State</b>								<b>Output</b>
$S_{a1}$	$S_{a2}$	$S_{a3}$	$S_{a4}$	$S_{a1}'$	$S_{a2}'$	$S_{a3}'$	$S_{a4}'$	$V_a$
1	1	1	1	0	0	0	0	$+V_{dc}/2$
0	1	1	1	1	0	0	0	$+V_{dc}/4$
0	0	1	1	1	1	0	0	0
0	0	0	1	1	1	1	0	$-V_{dc}/4$
0	0	0	0	1	1	1	1	$-V_{dc}/2$

The goal is to produce a staircase output voltage. For simplicity, consider a single leg out of the five proposed in Figure 2.2.

State condition 1 means the switch is on, and state 0 means the switch is off. It should be noticed that each switch is turned on only once per cycle and there are four complementary switch pairs in each phase. These pairs for one leg of the inverter are  $(S_{a1}, S_{a1}')$ ,  $(S_{a2}, S_{a2}')$ ,  $(S_{a3}, S_{a3}')$  and  $(S_{a4}, S_{a4}')$ . Thus, if one of the complementary switch pairs is turned on, the other of the same pair must

be off. Four switches are always on at the same time. The line voltage consists of the positive phase-leg voltage of terminal a and the negative phase-leg voltage of terminal b. Each phase-leg voltage tracks one-half of the sinusoidal wave [13]. The demonstration is continued by outlining the resulting line voltage being a five-level staircase wave. This implies that an m-level converter has an m-level output phase-leg voltage and a (2m-1) level output line voltage.

According to [8], below are the main advantages and disadvantages of the diode clamped multilevel inverters.

Advantages of Diode Clamped Multilevel Inverter:

1. Simple Control scheme.
2. Reactive power flow (Q) can be controlled.
3. High efficiency.

Disadvantages of Diode Clamped Multilevel Inverters:

1. Unbalanced voltages at the capacitors.
2. More number of diodes are required for higher levels.
3. Difficult to analyze Real Power (P) flow for a single converter.

- Cascaded H-Bridge Multilevel Inverter

In order to synthesize a multilevel waveform, the AC output of each of the different level H-bridge cells is connected in series. The synthesized voltage waveform is, therefore, the sum of the inverter outputs [14]. The number of output phase voltage levels in a cascaded- inverter is defined by:

$$m = 2s+1 \text{ ..... (2)}$$

Where:

m: output voltage levels

s: number of DC sources required

For example, a 7-level output phase can be obtained with three independent DC sources and three H-bridge circuits, respectively. Similarly, a nine-level output phase voltage waveform can be obtained with four-separated dc sources and four H-bridge cells connected, and so forth. [15]

Figure 2.3 depicts the generalized connection of a cascaded multilevel inverter.

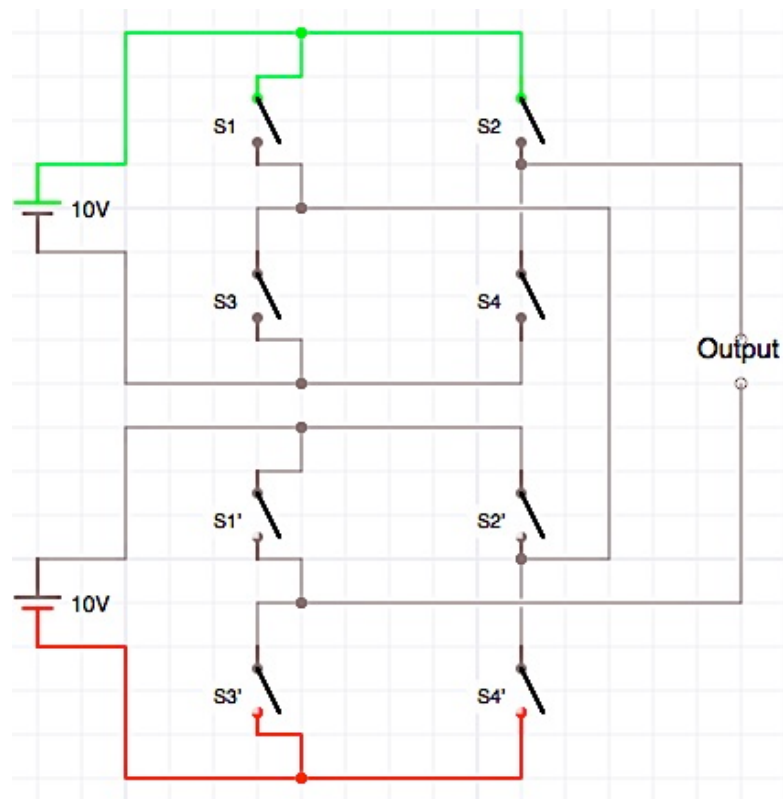


Figure 2.3 Circuit diagram of a general cascaded H-bridge multilevel inverter.

### 2.2.1.2 Asymmetrical Multilevel Inverters.

- Binary Multilevel Inverter

Shown in Figure 2.5 is a configuration for a cascaded H-bridge multilevel inverter. It employs a binary DC input source. There exists a level of similarity between it and the traditional cascaded H-bridge multilevel

inverter with a slight exception in the input dc sources. Using  $V_{dc}$  and  $2V_{dc}$ , incorporates the following five output levels;  $-2V_{dc}$ ,  $-V_{dc}$ ,  $0$ ,  $V_{dc}$ ,  $2V_{dc}$ . [16] The lower inverter generates a fundamental output voltage with two levels, and then the upper inverter adds or subtracts one level from the fundamental wave to synthesize stepped waves [15]. Finally, the summation of all voltages at each terminal produces the final output voltage which is given as:

$$V_{out} = V_{HB1} + V_{HB2} \quad (3)$$

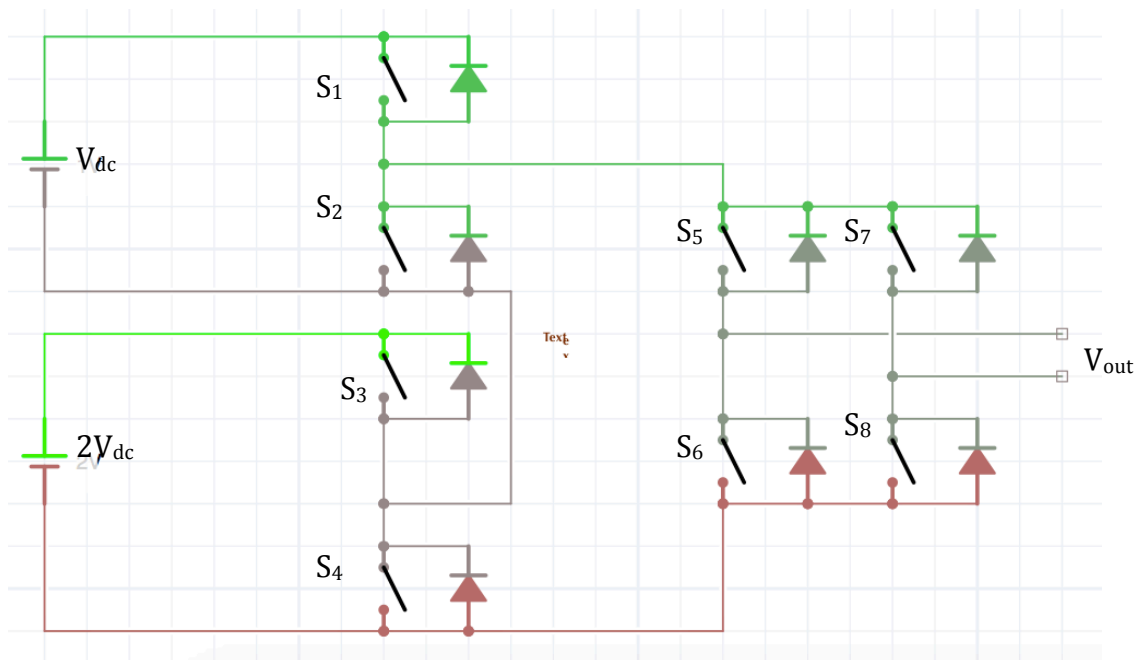


Figure 2.5 Circuit diagram of a binary multilevel inverter.

- Ternary Multilevel Inverter

Similarly to the binary multilevel inverter, the  $2V_{dc}$  is replaced by a source with a magnitude of  $3V_{dc}$ . It can generate five output levels  $-3V_{dc}$ ,  $-V_{dc}$ ,  $0$ ,  $V_{dc}$ ,  $3V_{dc}$  through using  $V_{dc}$  and  $3V_{dc}$ . The lower inverter generates a fundamental output voltage with three levels, and then the upper inverter adds or subtracts one level from the fundamental wave to synthesize stepped waves [17].

“In the proposed circuit topology, if n number of H-bridge module has independent DC sources in sequence of the power of 3, an expected output voltage level is given as  $V_n = 3n$ ,  $n = 1,2,3..$ ” [16].

### 2.3 Single Phase, Full Bridge Inverters.

Figure 2.6 shows the full bridge circuit configuration for a voltage–source inverter. Depending on the sequence of switching of the four switches; output voltage may be controlled through varying the input voltage [18].

When the first two switches are connected, a positive cycle of  $V_d$  appears across the output, while a negative output is observed when S3 and S4 are conducting.

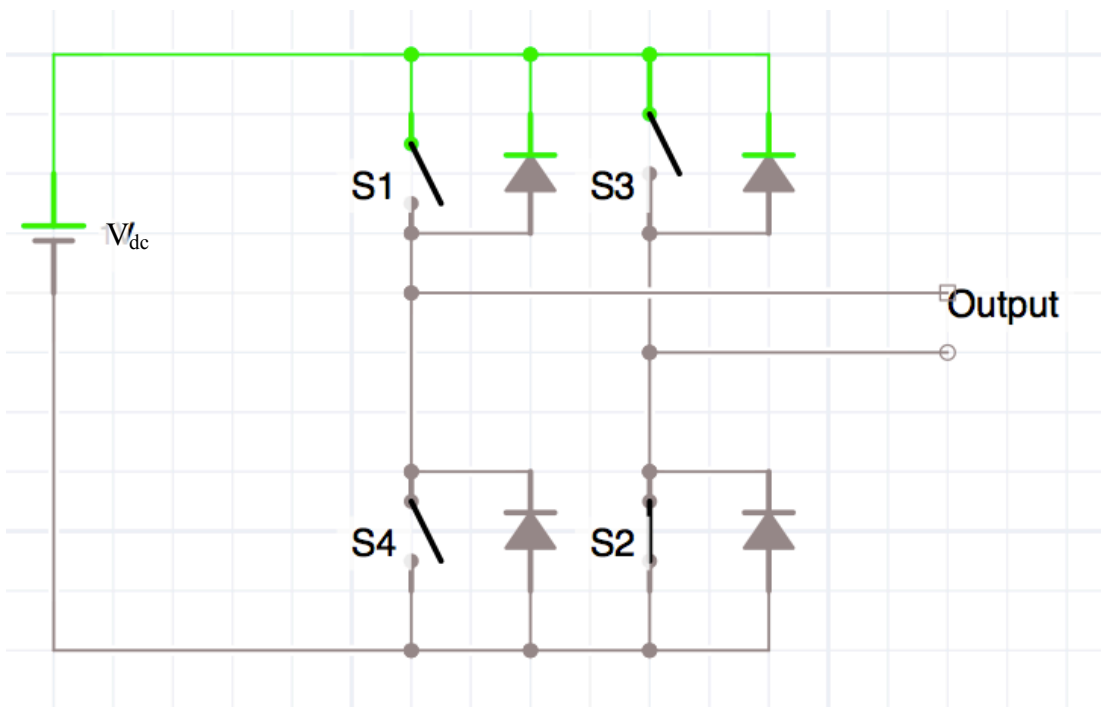


Figure 2.3 Single phase, full bridge inverter.

## 2.4 Related Work And Critical Analysis

The PV characteristics and the issue of maximum power point tracking (MPPT) applied to the induction motor control have been addressed in different ways in the literatures of Abarnaa and Santhosh et al. The space vector pulse width modulation (SVPWM) method and direct torque control techniques for variable frequency drive applications have been discussed in details in the literature of Bhavnesh et al. Gudimetla and co. outlined in their paper the reliability and importance of utilizing dc converters and maximum power point tracking technique in order to farm as much solar energy as possible.

The project research focused on comparing the different types of multi-level inverters and modulation techniques. Thus, Table 3 summarizes the methods and analysis of different approaches with some common and shared techniques.

Table 2.2: A list of recently related papers.

Author	Title	Year	Method/Keywords
P.Abarnaa and Mrs.S.P.G. Bhavani	“A Solar Powered PV Based Induction Motor Drive in Water Pumping System”	2014	<ul style="list-style-type: none"> <li>- Two Inductor Boost Converter (TIBC)</li> <li>- Energy storage to overcome lack of solar energy.</li> </ul>
K. Lakshmi Ganesh, U. Chandra Rao	“Performance of Symmetrical and Asymmetrical Multilevel Inverters”	2012	<ul style="list-style-type: none"> <li>- Symmetrical Multilevel Inverters.</li> <li>- Asymmetrical Multilevel Inverters.</li> </ul>
Gudimetla Ramesh, Kari Vasavi, and S.Lakshmi Sirisha	“Photovoltaic Cell Fed 3-Phase Induction Motor Using MPPT Technique”	2014	<ul style="list-style-type: none"> <li>- DC-DC Converter</li> <li>- Dspic4011</li> <li>- Maximum Power Point Tracker</li> </ul>



B. Santhosh Kumar, S. Arul Daniel, and H. Habeebullah Sait	“Analog controller for Photovoltaic array fed inverter driven Single-phase induction motor”	N/A	<ul style="list-style-type: none"> <li>- Sinusoidal Pulse Width Modulation (SPWM)</li> <li>- Solar Irradiations</li> <li>- Amplitude Controller</li> </ul>
--	---	-----	--

## **CHAPTER 3**

### **METHODOLOGY AND PROJECT ACTIVITIES**

#### **3.1 Research Methodology**

This section of the report will discuss about the methods and software used to complete the project. As shown in Figure 7, the project methodology is broken down into six steps in order to achieve the ultimate goal. First of all, step 1 will be the literature review of past research regarding the different constituents of the project. This step is aimed to collect all the necessary research papers, understand the current integrity assessment methods for solar panels, inverters and single phase induction motors. All of that to figure out the capability along with advantages and disadvantages any respective technique.

Next, step 2 is about optimizing the solar panel which will be the main supplier of power to the induction motor. From the literature review that has been done, a critical analysis is carried out to compare and choose the most suitable approach for this project. After reviewing the complex process involved in the designing of a solar panel and the delicate chemical procedures, it was decided that the budget given by the department will be used to purchase a solar panel that meets the requirements of the rated multilevel inverter and the induction motor.

Step 3 is a relatively simple process, and since this work is leaning more towards the application and implementation of power inverters, the whole designing, from the-ground-up process will be dedicated to the latter. Therefore storage of generated solar energy shall be achieved through utilizing after market batteries in the form of power banks.

Storage of generated energy is complimentary to the fourth step, involving the boosting or in other words, stepping up of the stored voltage in order to meet the requirements of the load ensuring optimum performance. This will be achieved

through applying Boost DC-DC converters. An initial idea of designing the converters alongside the inverter is present, however it is prone to be adjourned or discarded according to the requirements and circumstances of the project at a later stage.

As stated earlier, step 5 actually outlines the backbone of this work. With an initial design of a single phase, full-bridge inverter circuit, with an inductive and resistive load being simulated, the project work will continue through implementing this simple designed inverter with a DC battery source of any kind to further understand the principle. Later, towards the end of the project, an actual multilevel inverter of more than 2 levels shall be designed, ensuring smooth AC output with minimum ripples and irradiances. Subsequently, such ripples and distortions shall be treated through applying modulation techniques, for instance pulse width modulation technique (PWM).

Finally, the project will be concluded after more than 25 weeks with submission of the documents.

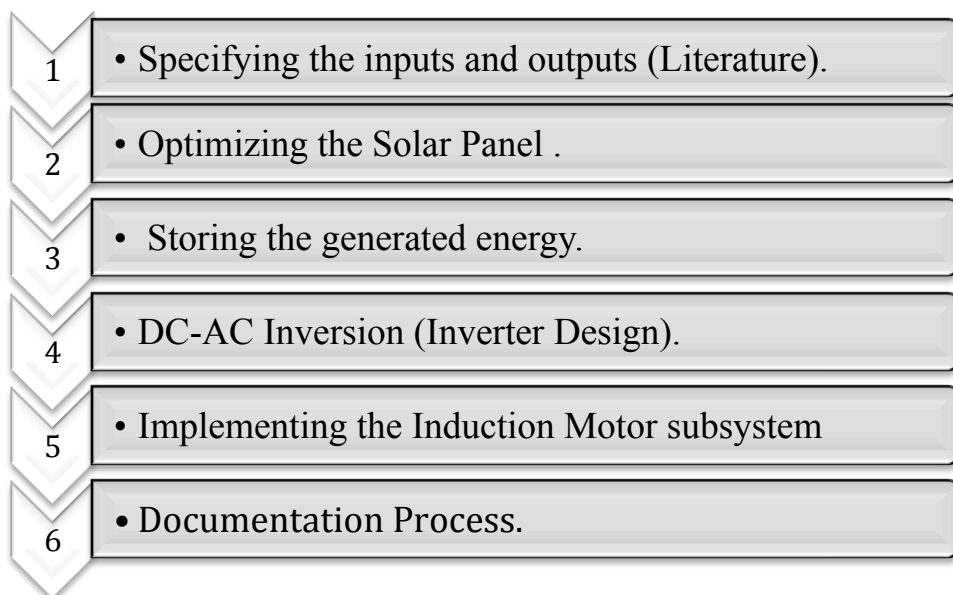


Figure 3.1 Summary and breakdown of project Methodology

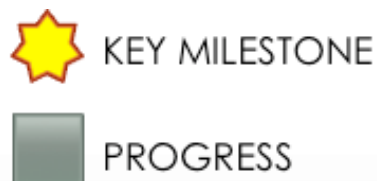
### 3.2 Project Management

Table 3.1: Timeline for FYP1

Task/Objective	01	02	03	04	05	06	07	08	09	10	11	12	13	14
Selection of Project Topic	■	■	★											
Preliminary Research Work		■	■											
Literature review and Research				■	■	■								
Design of MLI							■	■						
Research on algorithms								■						
Preparation for the Proposal Defense								■	■	★				
Simulation, Testing and recording results											■	■	■	■

Table 3.2: Timeline for FYP2

Task/Objective	01	02	03	04	05	06	07	08	09	10	11	12	13	14
Simulation, Testing subsystems (1)	■	■	■	■	■	■								
Documentation Processes (1)							■	■	■					
Progress Report Submission								■	★					
Testing and Recording Results (2)							■	■	■	■				
Pre-SEDEX										■	■	★		
Testing and recording results(3)											■	■		
Submission of Final Report and Technical Paper (2)												■	■	★
VIVA													■	★
Dissertation Report														■



## **CHAPTER 4**

### **RESULTS AND DISCUSSION**

This section includes the results obtained after carrying different tests and simulations on the three sub systems of the project. Experiments were carried in the order of the functioning of the system, however in an independent manner.

The design is initiated by performing constructive analysis on a chosen photovoltaic solar panel. Simulations on multilevel inverters were carried using Simulink and Multisim packages prior to testing an asynchronous (induction) motor through the former package.

#### **4.1 Photovoltaic Solar Panel**

##### **4.1.1 Experiment On Solar Irradiances**

Two experiments on two different days have been conducted in order to observe solar irradiances behavior of the obtained solar panel for several days in UTP. The open field area in V4 was used as an ideal place to get readings. Due to the haze problem that struck the state in the previous weeks, data were collected on random days from a usb voltage tester that provided readings for four parameters, namely voltage, current, total power and the average current drawn.

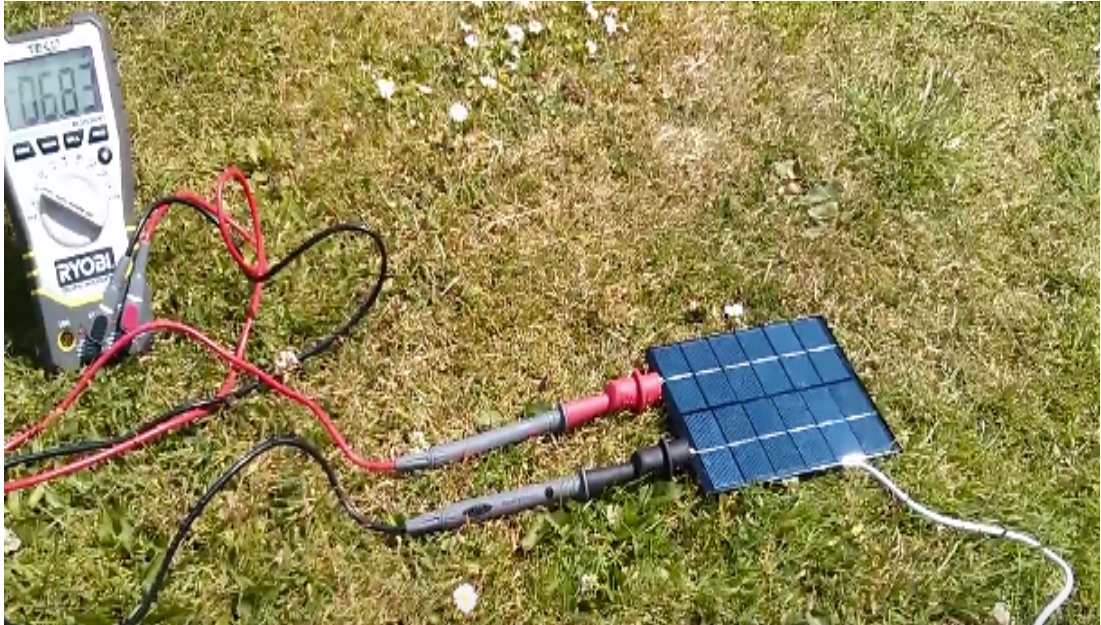


Figure 4.1 Setup for solar panel experiment (I-V & P-V characteristics)

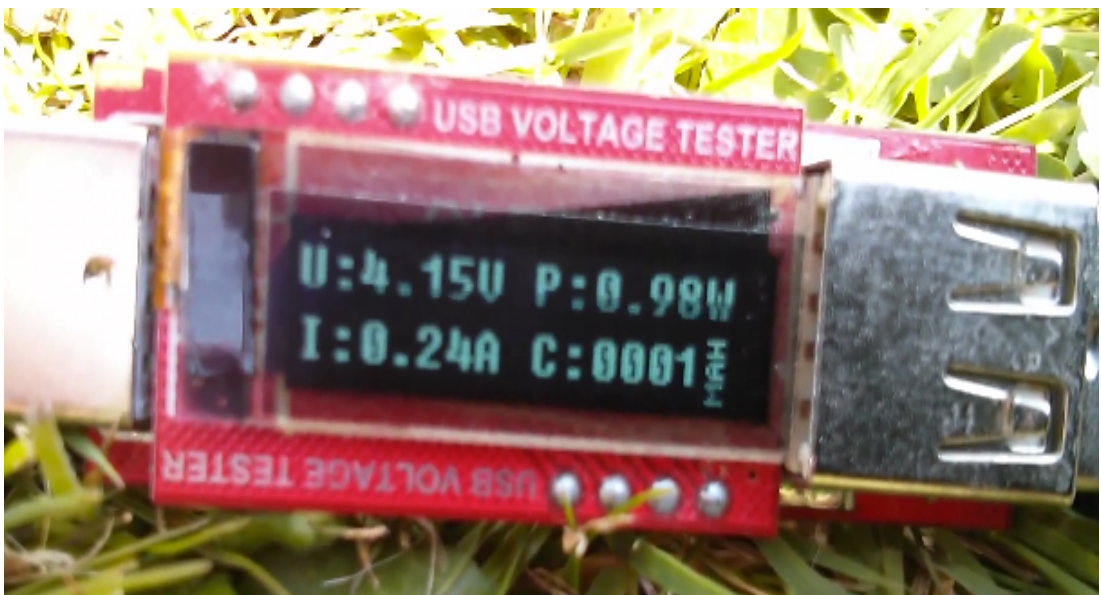


Figure 4.2 Readings from the panel through the USB Voltage Tester.

Below are the graphs for the obtained solar irradiances readings:

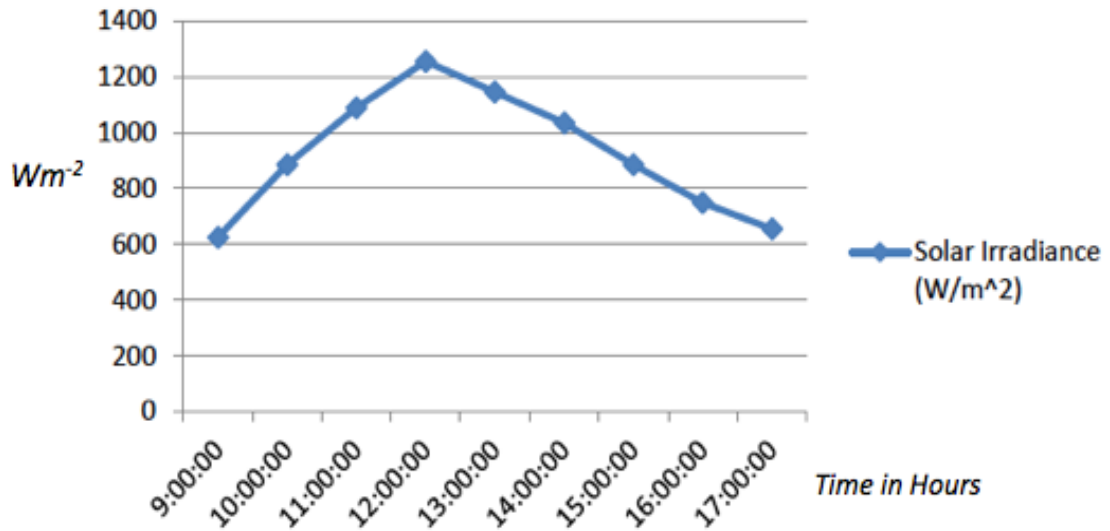


Figure 4.3 Solar Irradiances on October 29th.

Figure 4.3 illustrates the solar irradiance in watts per meter square on the 29<sup>th</sup> of October 2015 from 9:00 to 17:00 in Universiti Teknologi Petronas in Perak, Malaysia. It shows the steady increase of the solar irradiances between 9:00 and 12:00, from 621 Wm<sup>-2</sup> to 1247 Wm<sup>-2</sup> and starts falling in a linear matter from 12:00 (1247 Wm<sup>-2</sup>) to 17:00 (654 Wm<sup>-2</sup>).

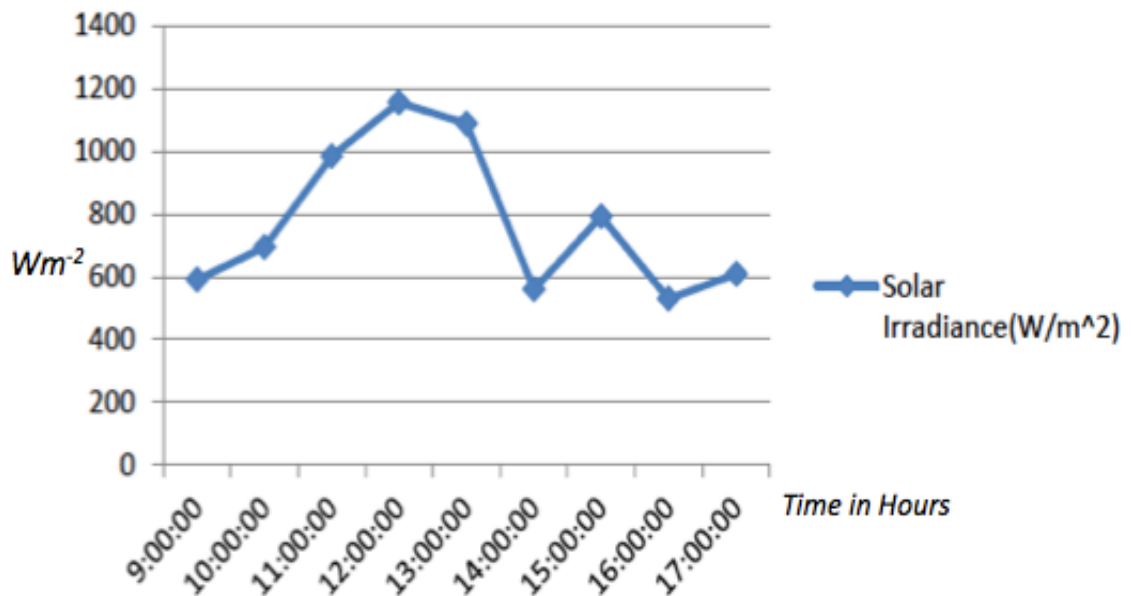


Figure 4.4 Solar Irradiances on November 3rd.

Similarly, Fig. 4.4 summarizes the readings through the same timeline but on a

different day, 5 days later. The weather forecast on that day reported an increase in the haze's air pollution index (API) index which must have affected the solar irradiance, as it is obvious from the sudden drop in the output, recording a value that is marginally less than  $600 \text{ Wm}^{-2}$  between 14:00 and 15:00.

According to the statistics and data collected, it is safe to assume that solar irradiances would achieve their peak at mid day whereby the sun rays are perpendicular to the earth's surface thus delivering maximum power per squared meter area of the panel. Moreover, solar irradiances have an inverse relative proportionality with respect to the weather. Due to such relation, it is not practical to directly use solar panels as sources for energy without auxiliary systems connected in parallel with them due to the mentioned drawback.

#### **4.1.2 Characteristics Of The Solar Panel**

In order to get a grasp on the specifications of the solar panel, a cellphone torch light was used to test the solar panel's characteristics between the three main parameters: voltage, current and power. The figure below shows the setup to test the characteristics of solar panel between voltage, current and power by manually varying the light irradiance values. Adjusting the distance between the cellphone and the solar panel is a way to vary the irradiances.  $200 \text{ Wm}^{-2}$  and  $300 \text{ Wm}^{-2}$  were selected to observe mentioned characteristics of the solar panel.



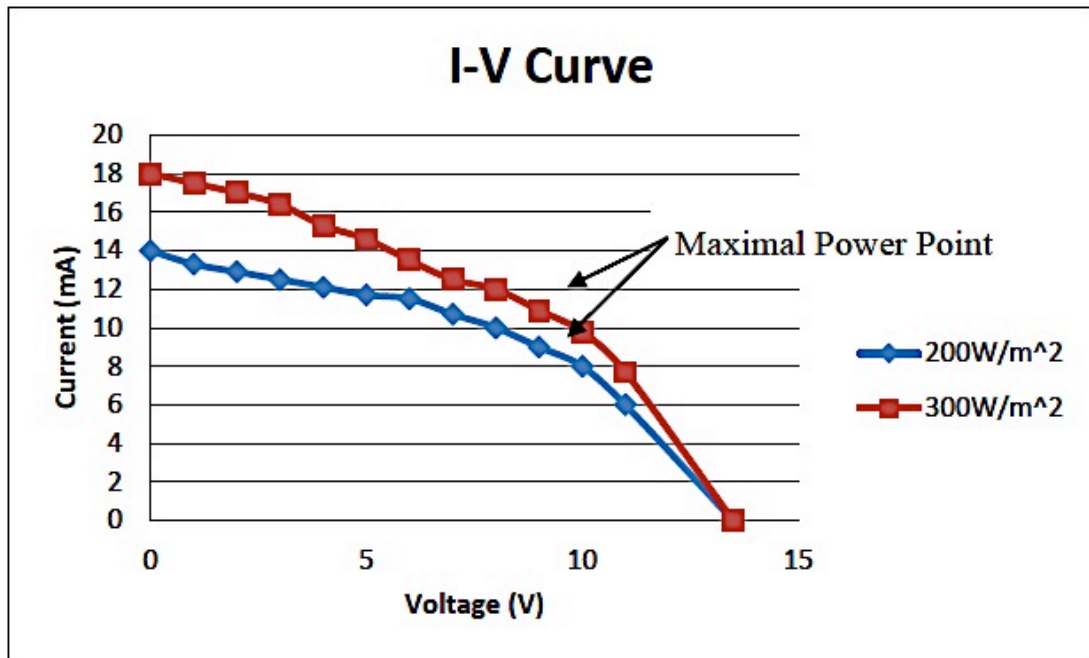


Figure 4.5 Current vs. Voltage of rated solar panel.

Figure 4.5 demonstrates the voltage and current relationship of the solar panel with solar irradiances of  $200\text{Wm}^{-2}$  and  $300\text{Wm}^{-2}$ . Current registered the highest value when short circuiting the output terminals of the solar panel i.e.  $V=0\text{V}$ . On the other hand, opening the terminals results in readings of zero amperes and maximum voltage. Furthermore, current decreases in opposite effect to rising voltages regardless of light irradiance. The maximum power point for both irradiances is around 9V.

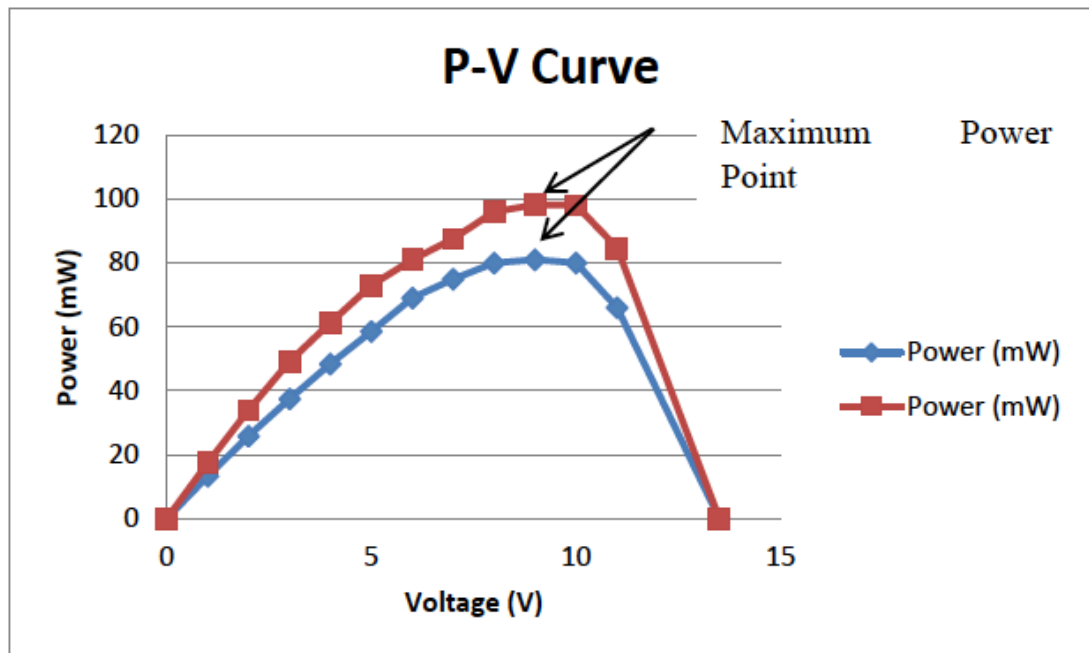


Figure 4.6 Power vs. Voltage of rated solar panel.

Figure 4.6 shows the power versus voltage curve of the solar panel with light irradiance at  $200\text{Wm}^{-2}$  and  $300\text{Wm}^{-2}$ . Both light irradiances had increasing output power relative to the increasing voltage until the highest power point prior to decreasing. The maximum power point (MPP) for both irradiances lies around the 9V mark. From Figures 4.5 and 4.6, it can be concluded that the MPP is at the knee of the curve. At this point, the output power is at the maximum for this solar panel. Finally, the results show that the solar panel acts as voltage limiting current source.

## 4.2 The Inverter Subsystem

### 4.2.1 Simulation Of Single Phase, Full Bridge Inverter

It is important to note the differences between ideal and practical inverters, especially the nature of the load's power factor as it is observed to be unity for a purely resistive load, a rarely encountered scenario in practical applications. Furthermore, as this project's scope is leaning towards an inductive based load, it is safe to conclude that a practical representation of an inverter in the form of resistive-inductive load is imperative.

Below is the simulation model of a single phase, full bridge inductive and resistive load, performed using MatLab's SimuLink. Note the 24V peak to peak in the results, denoting the initially designed system comprising a 24V rated solar panel.

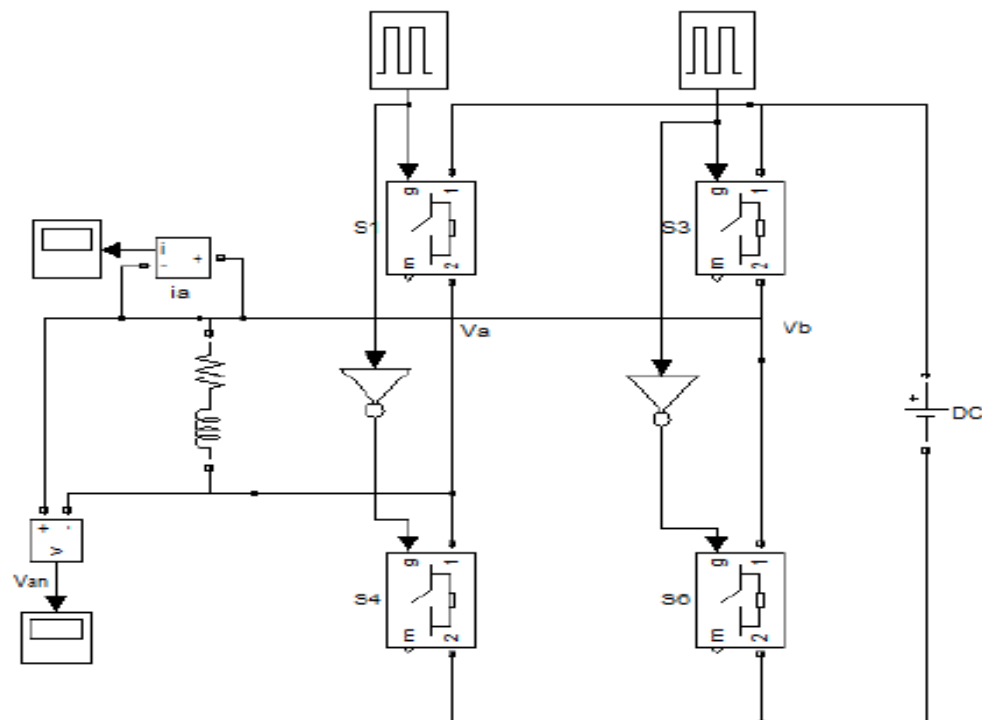


Figure 4.7 Simulink model of a full bridge inverter with resistive-inductive load.

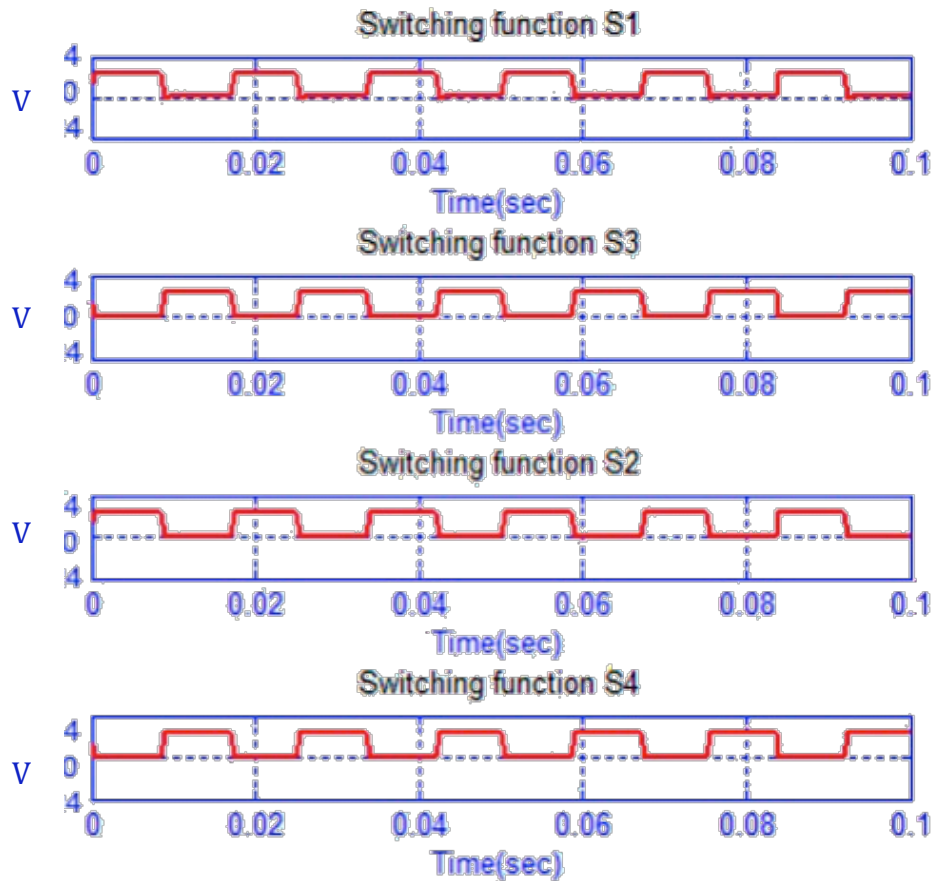


Figure 4.8 Transistor gates switching functions.

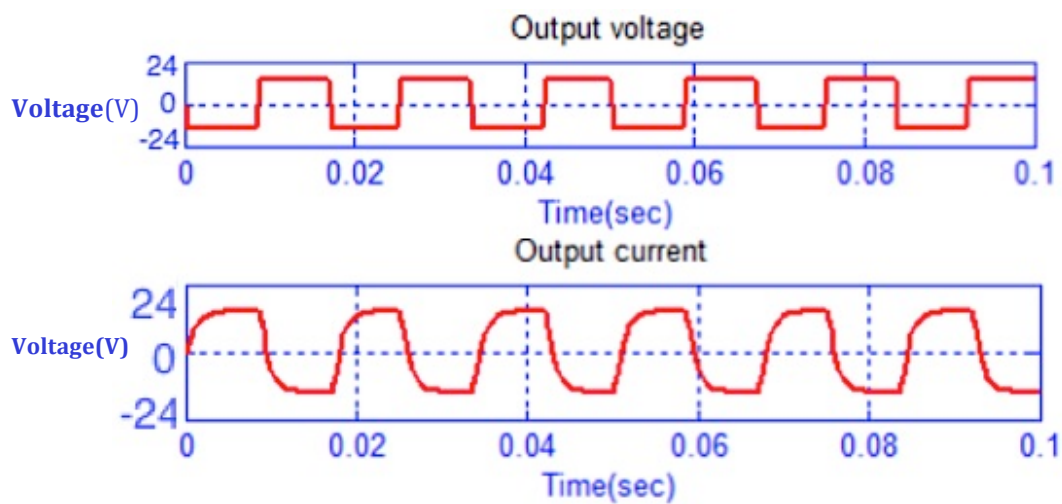


Figure 4.9 Output Voltage and Current of the inductive-resistive load full bridge inverter.

Observing the obtained results, it is obvious that the output is of a square wave and alternating current nature. The variations in the waveform of the output current outlines the effects of an inductive load to the current, whereby an

inductor takes a moment of time to actually charge and discharge instantaneously.

Moreover, another simulation for a full bridge inverter was performed using Multisim. The main goal of it was to observe the variations of voltage and current in the output of the inverter when variables in the form of load capacity, input voltage and the transistor gates' firing signals are present.

To have a clear mosaic, and while this project focuses in an inductive and resistive load in the form of an induction motor; only the latter was considered at this stage by varying the input voltage from zero to hundred in increments of ten. Similarly, values of the series resistances are adjusted between zero and one thousand by multiples of ten.

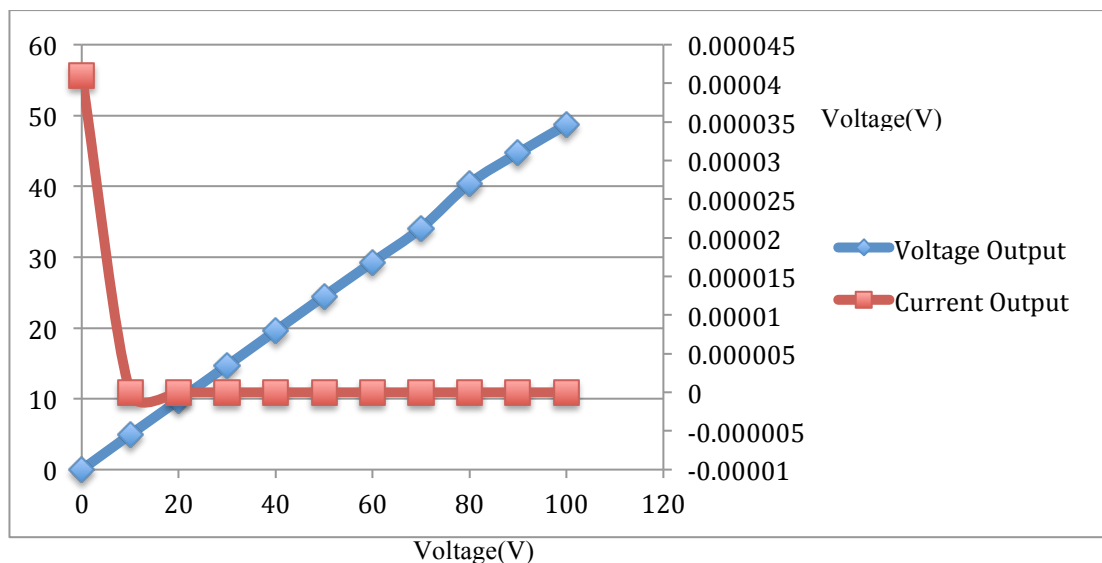


Figure 4.10 DC input vs. AC Voltage output vs. Current output at  $R=0 \Omega$

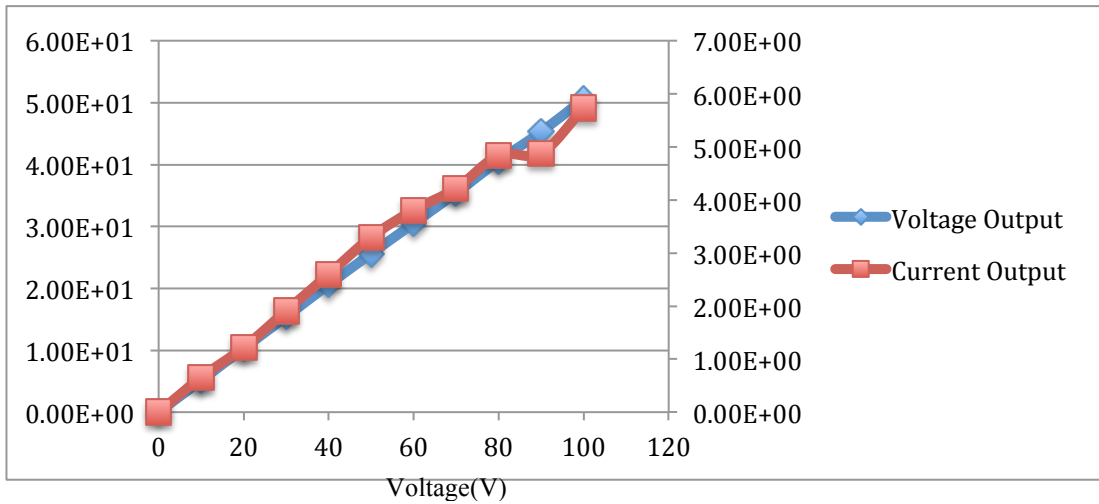


Figure 4.11 DC input vs. AC Voltage output vs. Current output at R=10 Ω

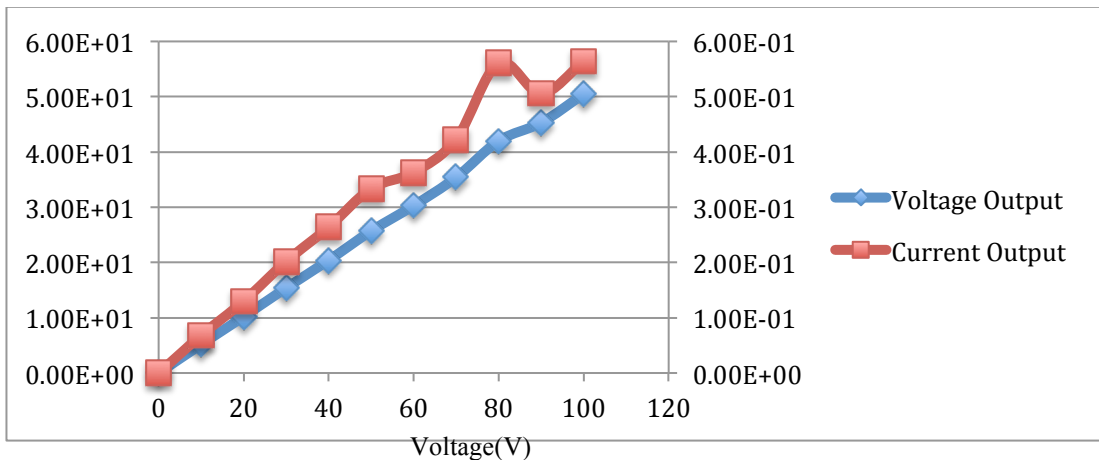


Figure 4.12 DC input vs. AC Voltage output vs. Current output at R=100 Ω

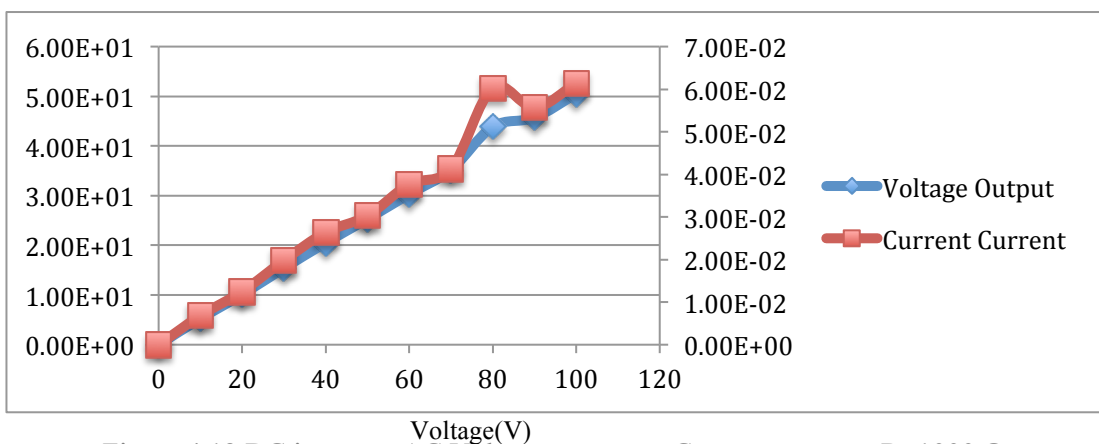


Figure 4.13 DC input vs. AC Voltage output vs. Current output at R=1000 Ω

The direct proportionality between the input DC voltage and output AC potential is observed, with different load values governing their oscillations.

To conclude this section, some of the graphs obtained from the Multisim simulation (at  $V_{dc}=0,50,100V$  |  $R=10,1000$ ) are illustrated below. Notice the noise ripples in the output waves since smoothing inductors were neglected.

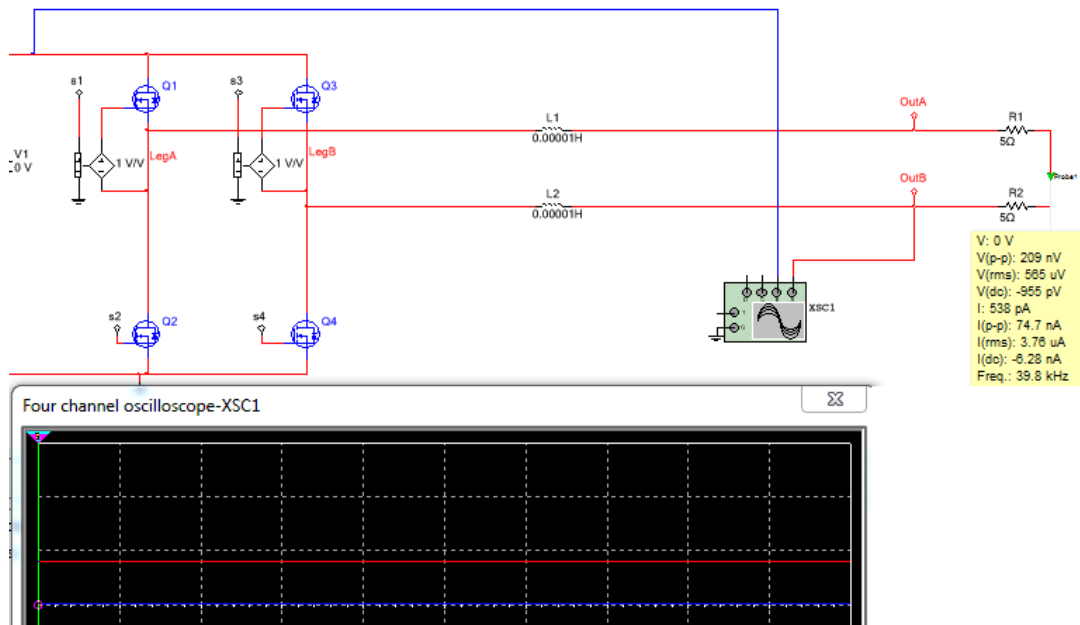


Figure 4.14 Output of full bridge multilevel inverter at  $V=0V$ ,  $R=10\ \Omega$

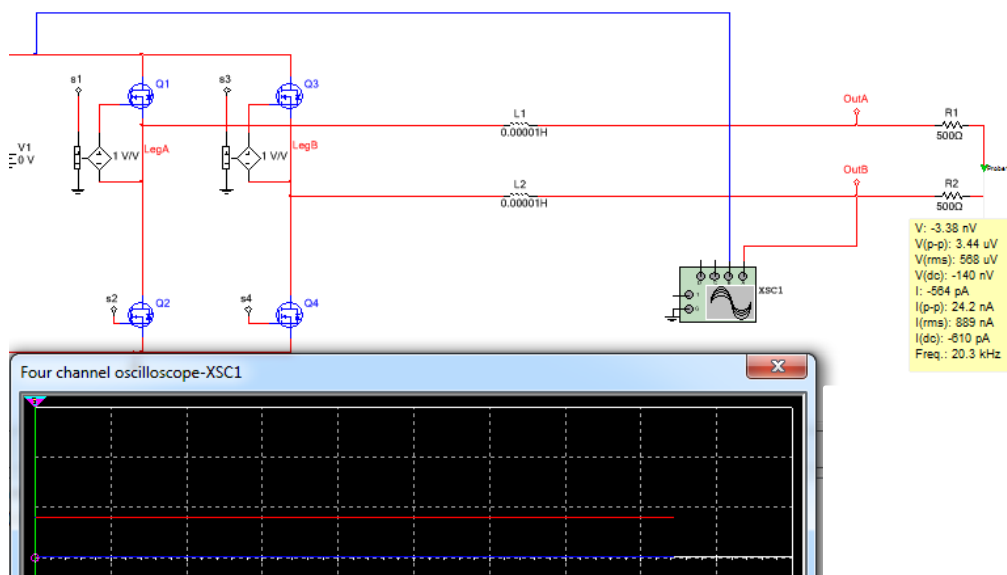


Figure 4.15 Output of full bridge multilevel inverter at  $V=0V$ ,  $R=1000\ \Omega$

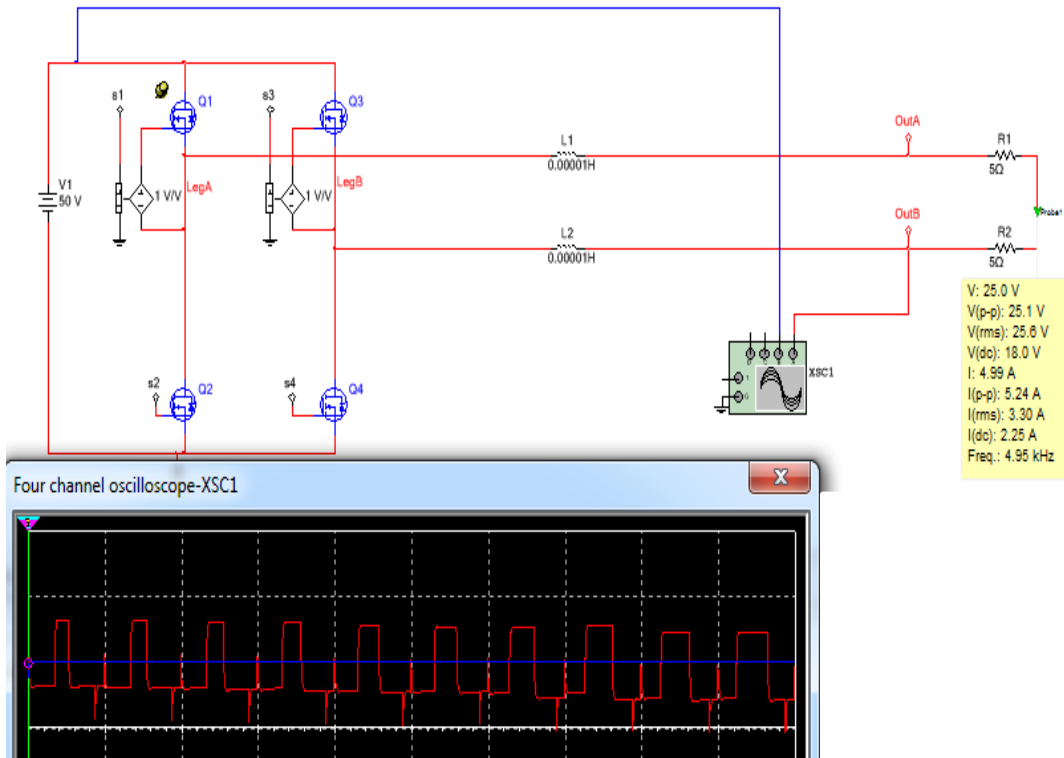


Figure 4.16 Output of full bridge multilevel inverter at  $V=50V$ ,  $R=10\ \Omega$

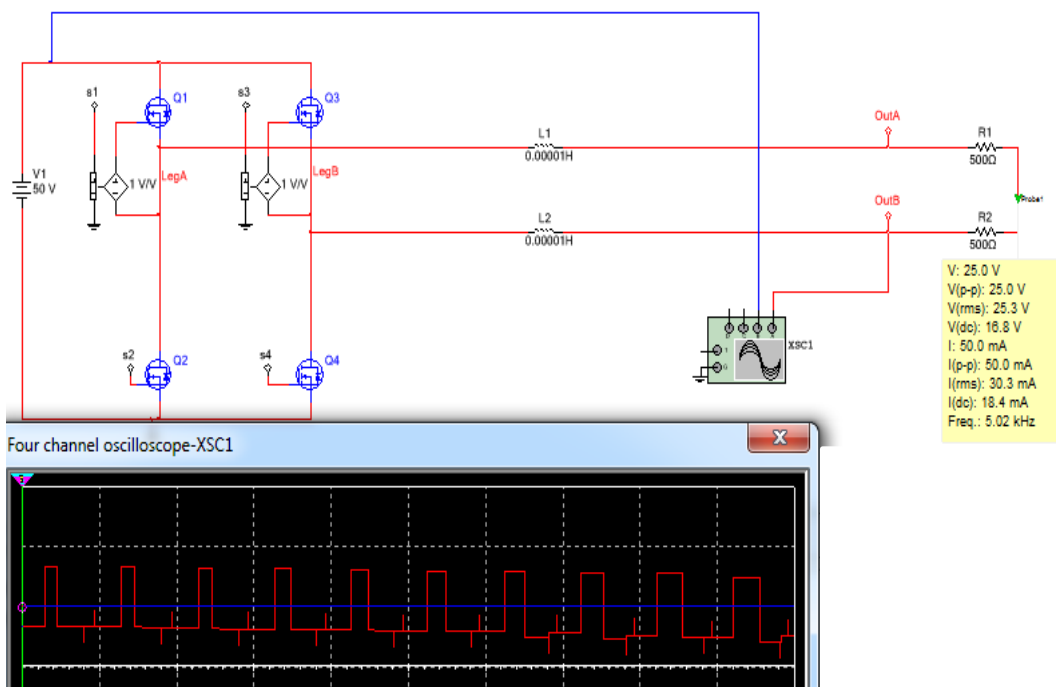


Figure 4.17 Output of full bridge multilevel inverter at  $V=50V$ ,  $R=500\ \Omega$



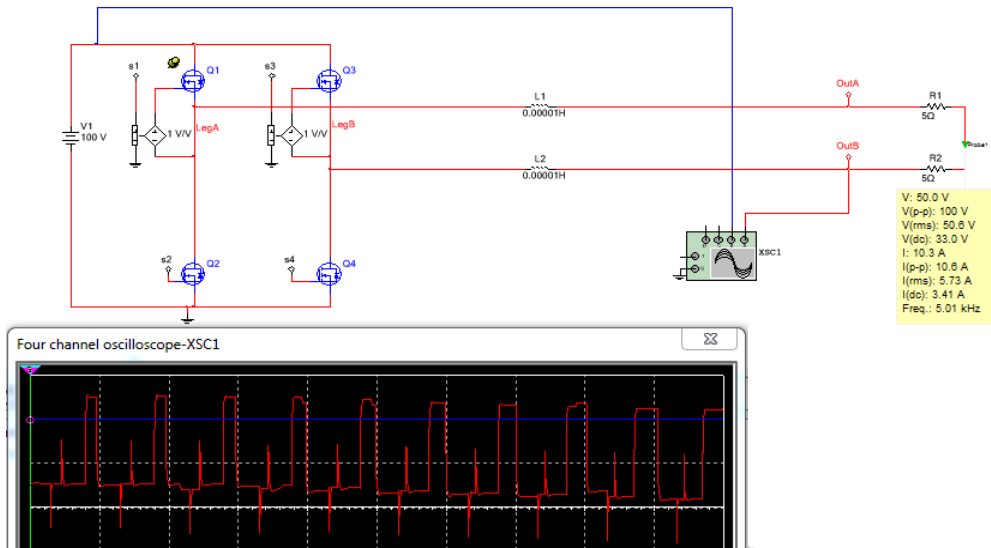


Figure 4.18 Output of full bridge multilevel inverter at  $V=100V$ ,  $R=10\ \Omega$

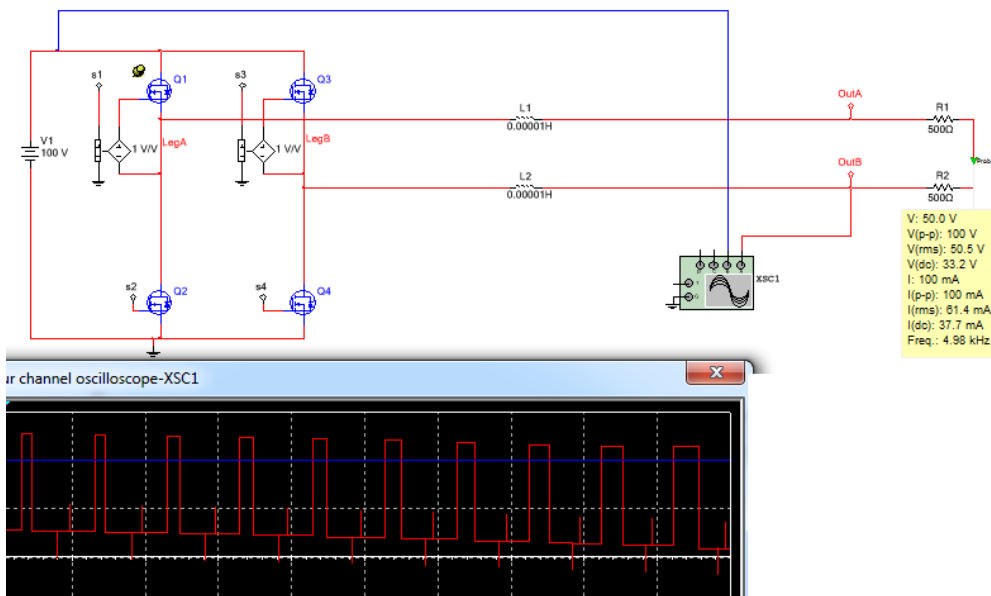


Figure 4.19 Output of full bridge multilevel inverter at  $V=100V$ ,  $R=1000\ \Omega$

## 4.2.2 Multilevel Inverter Simulation

Here, the model of the previous section which outlines a single topology is connected to two more of the same structure, in other words cascading them, ultimately forming three stage, symmetrical multilevel inverter.

To understand the difference and results of adding topologies one after another, consider the following schematics with their outputs which are simulated in Simulink using SimPower libraries.

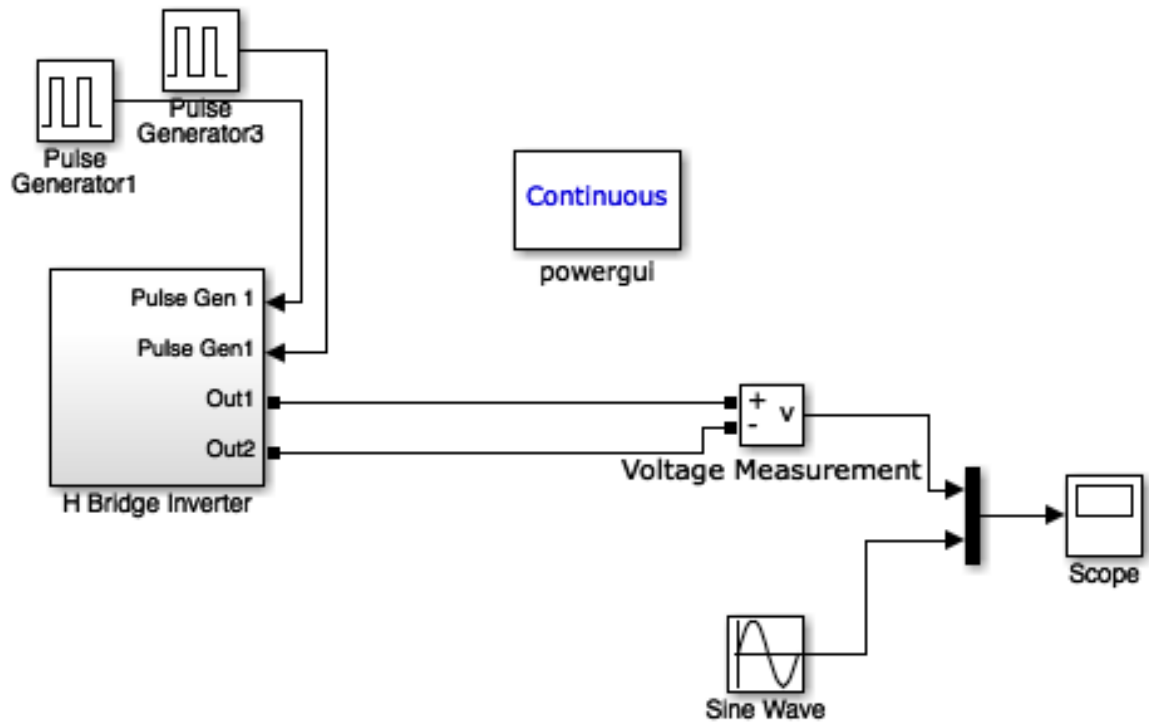


Figure 4.20 Matlab Simulink model of single topology multilevel inverter.

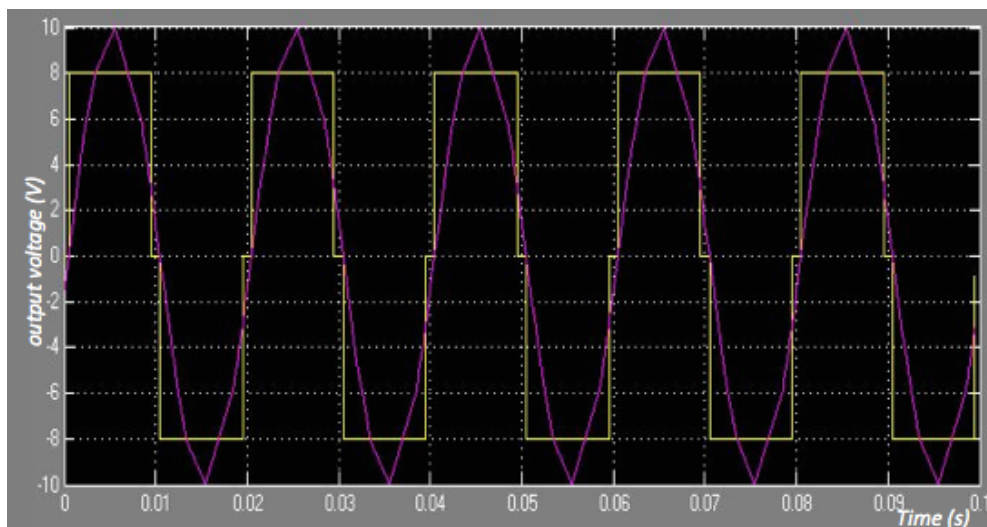


Figure 4.21 Output of single H-bridge inverter vs. 10V sinusoid reference input..

The graph shows the inverted output of an amplitude of 10V input, clearly highlighting the two level square wave structures whilst comparing the latter to an input sinusoid of the same amplitude to show the similarities in the alignment of the result.

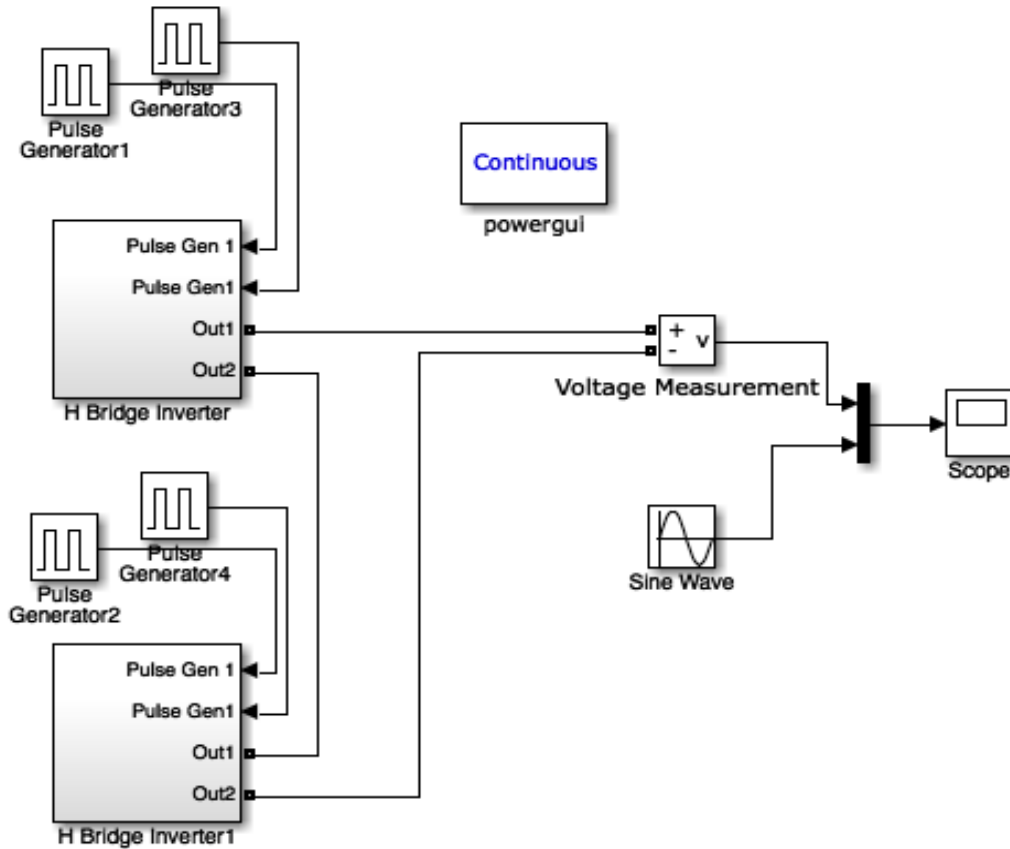


Figure 4.22 Matlab Simulink model of dual topology multilevel inverter.

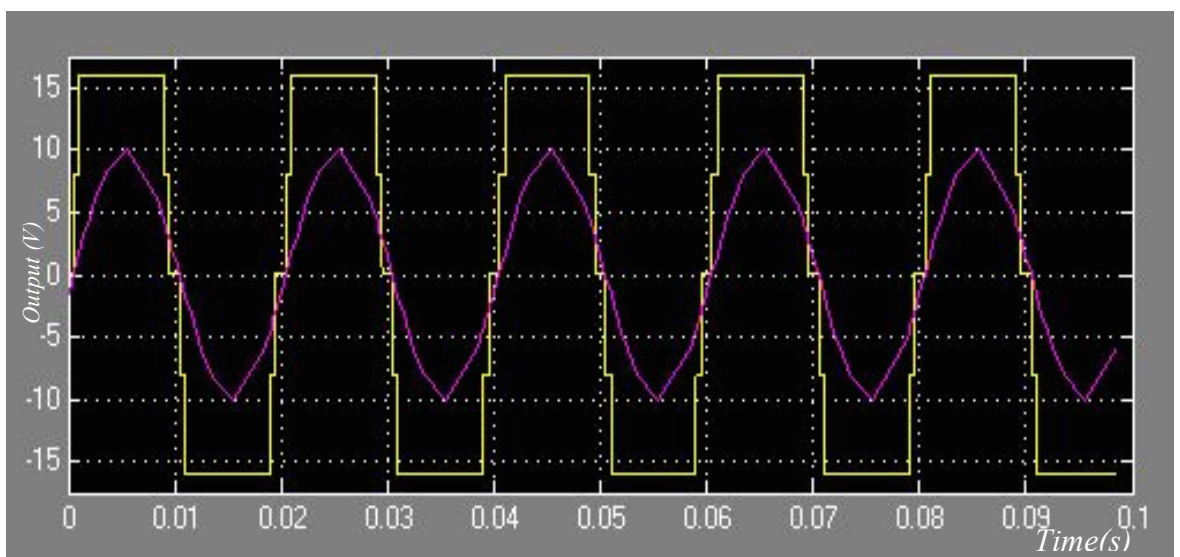


Figure 4.23 Output of two H-bridge inverters vs. 10V sinusoid reference input.

At this stage, it is proven by the obtained results that for symmetrical multilevel inverters, that is of same inputs, the output stage is doubled when put in contrast with the constant sine wave input. This is further supported by adding a third and final topology to this design in the following figures

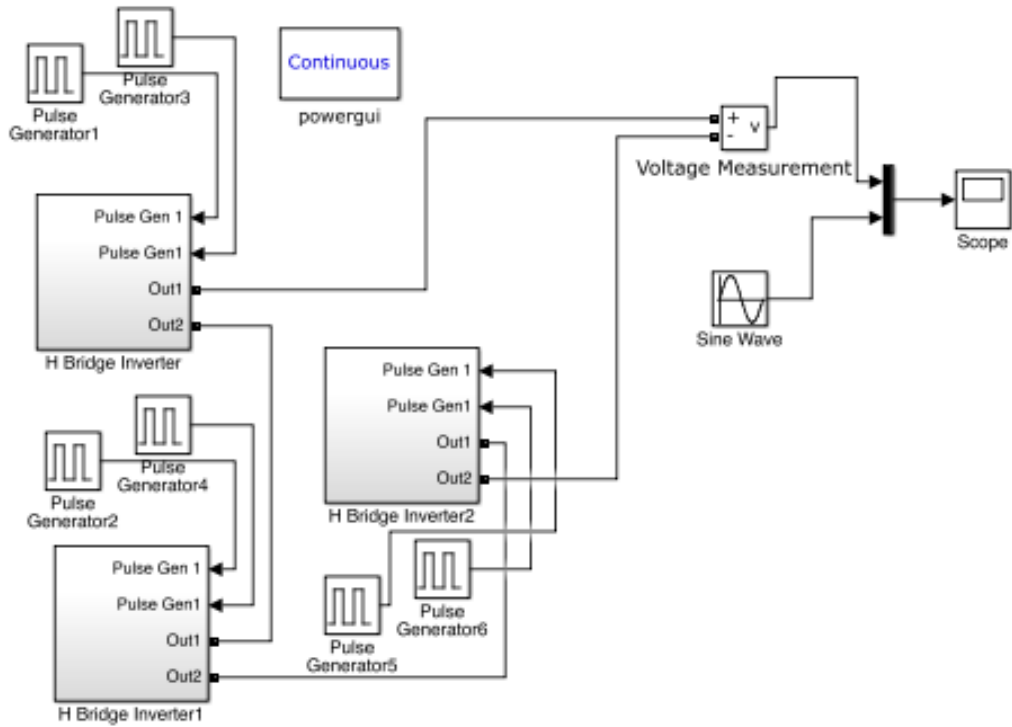


Figure 4.24 Matlab Simulink model of three topologies multilevel inverter.

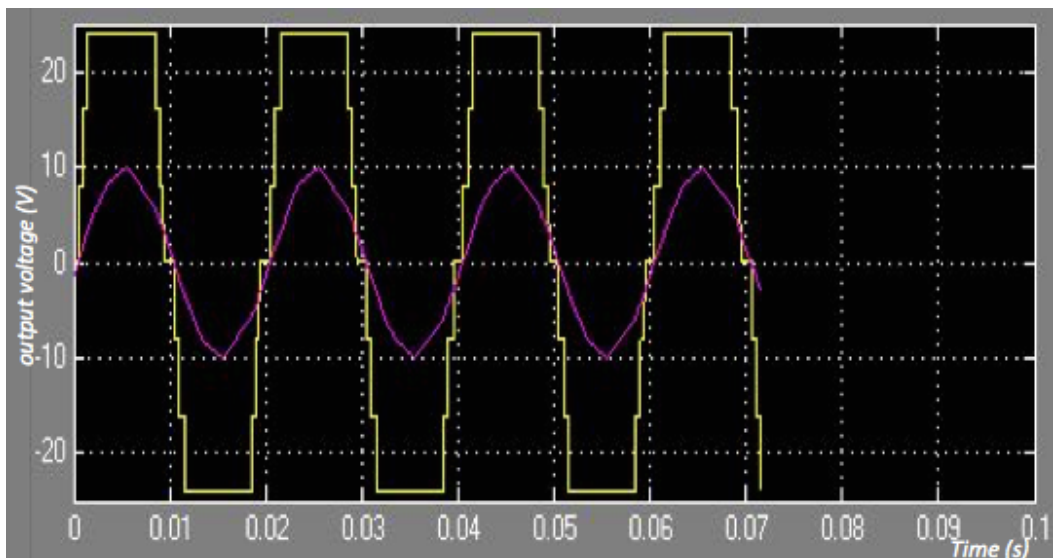


Figure 4.25 Output of triple H-bridges inverter vs. 10V sinusoid reference input

In contrast, cascaded multilevel inverter topology is deemed perfect when cost of implementation is concerned. Using this topology, it is possible to obtain ‘n’ levels using (n-1) H-bridges, with each bridge consisting of 4 switches in the form of insulated gate bipolar transistors (IGBT) or other similar switching devices.

### 4.3 Asynchronous (Induction) Motor Drive

#### 4.3.1 Simulation Of A Single-Phase, Asynchronous Motor Drive

A single phase asynchronous machine is simulated by connecting a 110V, 50Hz to the input terminal of the machine. Furthermore, it is fed by a current-controlled pulse width modulated inverter which is built using a universal Bridge block. Motor speed and mechanical torque were preset for 1500rpm and 1 N.m, respectively. This approach was chosen in order to monitor the performance of the drive and have a better understanding of the working principle. It was observed that the speed of the motor (shown in figure: ) remains constant regardless of the load capacity. Current and Voltage Measurement blocks provide signals for visualization purpose.

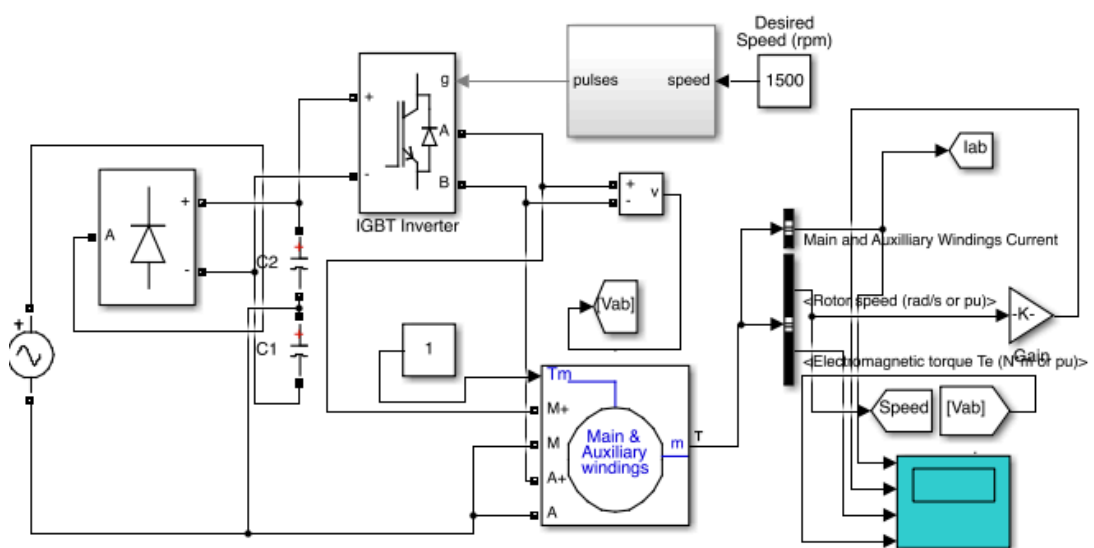


Figure 4.26 Matlab Simulink model of a single phase Induction motor drive.

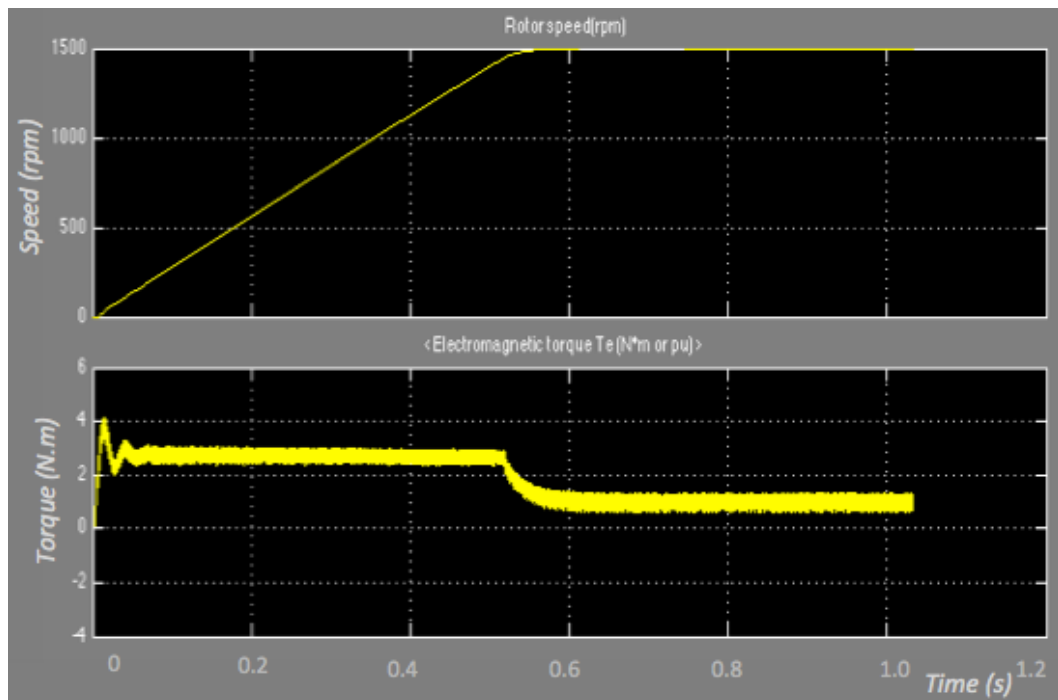


Figure 4.27 Rotor Speed and Torque of the designed Induction motor.

From the figures above, the torque of the induction motor is zero when the motor is being run at a speed below the synchronous speed. The maximum torque can also be obtained at around 1500rpm before slowly dropping down to a minimum state.

## **CHAPTER 5**

### **CONCLUSION AND RECOMMENDATION**

#### **5.1 Conclusion**

A cascaded full bridge multilevel inverter of three levels was designed using MatLab environment as well as MultiSim. Results were compared with each other using different values of resistive loads.

Solar irradiances over two different days were observed. Few issues arose when comparing calculated values with the experimental ones. This is perhaps due to the weather conditions in this part of the world. Weather conditions directly interrupt the performance of the solar panels, posing a challenge in getting around that.

While a prototype was not developed due to various constraints, strong foundation of the basics of integrating AC loads with a DC source has been formed, incorporating the requirements for future implementations.

#### **5.2 Recommendation**

Minimizing the number of switches used in the multilevel inverters in future designs is imperative to ensure limited power losses and switching time resulting in an overall efficient system with high power output.

## REFERENCES

- [1] P.S.Priambodo, N.R. Poespawati, D. Hartanto, "Chapter book: Solar Cell Technology", INTECH Open Access Publisher, ISBN 978-953-307-3163, Retrieved from [www.intechweb.org](http://www.intechweb.org) on June 16<sup>th</sup>, 2015.
- [2] AI Bratcu, I Munteanu, S Bacha, D Picault, B Raison. "Cascaded DC–DC converter photovoltaic systems: Power optimization issues". IEEE Trans. Ind. Electron., 2011; 58(2): 403–411.
- [3] McDonald, N.C.; Pearce, J.M., "Producer Responsibility and Recycling Solar Photovoltaic Modules," Energy Policy 38 (11) pp. 7041–7047.
- [4] Arun, V.; Shanthi, B.; Natarajan, S.P., "Investigation of Digital Control Strategy for Ternary DC Source Cascaded Multilevel Inverter," in International Journal of Emerging Trend in Engineering and Development, vol.1, Issue 3, January 2013, pp. 382-390
- [5] Branker, K.; Pathak, M.J.M.; Pearce, J.M. (2011). "A Review of Solar Photovoltaic Levelized Cost of Electricity". Renewable and Sustainable Energy Reviews 15 (9): 4470–4482.
- [6] Bullis, Kevin (23 June 2006). Large-Scale, Cheap Solar Electricity. Technologyreview.com. Retrieved on June 3<sup>rd</sup> 2015.
- [7] Nashiren F. Mailah, Neutral-Point-Clamped Multilevel Inverter Using Space Vector Modulation, European Journal of Scientific Research, ISSN 1450-216X Vol.28 No.1 (2009), pp.82-91.



- [8] Balamurugan C.R.; Natarajan S.P.; Revathy R., "Analysis of Control Strategies for Diode Clamped Multilevel Inverter," in International Journal of Innovation and Applied Studies, vol. 3, Issue 1,(May 2013), pp. 19-34.
- [9] Ho-Dong Sun ,Honnyong Cha, Heung-Geun Kim, Tae-Won Chun,Eui-Cheol Nho,. "Multi-level Inverter Capable of Power Factor Control with DC Link Switches", IEEE conf Rec. 978-1-4577-1216-6,2012, pp.1639-1643.
- [10] K. Lakshmi Ganesh, U. Chandra Rao, "Performance of Symmetrical and Asymmetrical Multilevel Inverters", International Journal of Modern Engineering Research, ISSN: 2249-6645, vol.2, no.4, 2012, pp-2293-2302.
- [11] Juan Dixon, Javier Pereda, Carlos Castillo, Sebastian Bosch, "Asymmetrical Multilevel Inverter for Traction Drives Using Only One DC Supply", IEEE Transactions On Vehicular Technology, vol. 59, no. 8, 2010, pp. 3736-3743.
- [12] Jih-Sheng Lai; Fang Zheng Peng, "Multilevel converters-a new breed of power converters," Industry Applications Conference, 1995. Thirtieth IAS Annual Meeting, IAS '95., Conference Record of the 1995 IEEE , vol.3, no., pp.2348,2356 vol.3, 8-12 Oct 1995.
- [13] Yusof, N.A.; Sapari, N.M.; Mokhlis, H.; Selvaraj, J., "A comparative study of 5-level and 7-level multilevel inverter connected to the grid," Power and Energy (PECon), 2012 IEEE International Conference on (2-5 Dec. 2012) , vol., no., pp.542-547.
- [14] Bharath, R.; Arun,V., "9-Level Ternary DC Source Inverter Using Embedded Controller," in IOSR Journal of Engineering (IOSRJEN), vol. 2, Issue 10 (October 2012), pp. 90-95.
- [15] Srikanth, G. R.; Charan, K. A.; Mowmin, A.; Baji, SK.; Latha, V. G.; Hussain, Md. M., "A Grid Connected Hybrid Asymmetrical Nine level Inverter Topology Using Boost Converter," in IOSR Journal of Engineering (IOSRJEN), vol. 2, Issue 4 (April 2012), pp.: 900-907.

- [16] Pravin, S.E.; Starbell, R.N., "Induction motor drive using seven level multilevel inverter for energy saving in variable torque load application," Computer, Communication and Electrical Technology (ICCCET), 2011 International Conference on , vol., no., pp.352,357, 18-19 March 2011
- [17] Kumar, B.; Chauhan,K.Y.; Shrivastava, V., "A Comparative Study of Maximum Power Tracking Methods for a Photovoltaic-based Water Pumping System," in International Journal of Sustainable Energy, vol. 33 No. 4, pp. 797-810. 2014
- [18] Batarseh, I.; "DC-AC Inverters" in Power Electronic Circuits, 1<sup>st</sup> ed, Florida, Wiley, 2004, pg. 423-440

## APPENDICES

## APPENDIX A

### SOLAR IRRADIANCES RESULTS ON 29<sup>TH</sup> OCTOBER 2015

Time	Solar Irradiance (W/m <sup>2</sup> )
9:00:00	624
10:00:00	884
11:00:00	1088
12:00:00	1254
13:00:00	1145
14:00:00	1034
15:00:00	884
16:00:00	748
17:00:00	654

## APPENDIX B

### SOLAR PANEL MAXIMUM POWER POINT (200Wm<sup>-2</sup>)

Irradiance (W/m <sup>2</sup> )	Voltage (V)	Current (mA)	Power (mW)
200	0	14	0
200	1	13.3	13.3
200	2	12.9	25.8
200	3	12.5	37.5
200	4	12.1	48.4
200	5	11.7	58.5
200	6	11.5	69
200	7	10.7	74.9
200	8	10	80
200	9	9	81
200	10	8	80
200	11	6	66
200	13.5	0	0

## APPENDIX C

### SOLAR PANEL MAXIMUM POWER POINT (300Wm<sup>-2</sup>)

Irradiance (W/m <sup>2</sup> )	Voltage (V)	Current (mA)	Power (mW)
300	0	18	0
300	1	17.5	17.5
300	2	17	34
300	3	16.4	49.2
300	4	15.3	61.2
300	5	14.6	73
300	6	13.5	81
300	7	12.5	87.5
300	8	12	96
300	9	10.9	98.1
300	10	9.8	98
300	11	7.7	84.7