

**DEVELOPMENT OF SINGLE PHASE TRANSFORMERLESS
INVERTER**

NUR SYAMIMI BINTI AHMAD FAUZI

**BACHELOR OF ELECTRICAL ENGINEERING
UNIVERSITI TEKNIKAL MALAYSIA MELAKA**

“I hereby declare that I have read through this report entitle “*Development of Single-Phase Transformerless Inverter*” and found that it has comply the partial fulfilment for awarding the degree of Bachelor of Electrical Engineering”

Signature :

Supervisor’s Name : DR. Maaspaliza Binti Azri

Date :

DEVELOPMENT OF SINGLE-PHASE TRANSFORMERLESS INVERTER

NUR SYAMIMI BINTI AHMAD FAUZI

**A report submitted in partial fulfilment of the requirements for the degree of
Bachelor of Electrical Engineering**

Faculty of Electrical Engineering

UNIVERSITI TEKNIKAL MALAYSIA MELAKA

JUNE 2018

I declare that this report entitles “*Single-Phase Transformerless Inverter*” is the result of my own research except as cited in the reference. The report has not been accepted for any degree and is not concurrently submitted in candidate of any other degree.

Signature :

Name : Nur Syamimi Binti Ahmad Fauzi

Date :

DEDICATION

This word is dedicated to my beloved parents and family for their supporting and for their helper no matter in what sense. Not forget to my beloved supervisor DR. Maaspaliza Binti Azri, which is the important person in helping and guide me to do this project with successful. Even though there are some problems that I faced in doing this project. Besides, thanks to all friends and lecturer that willing to give their hands to help me, without them I can't complete this project successful. Thank you everyone.

ACKNOWLEDGEMENT

First of all, I would like to thank God with all His kindness to letting me finish this final year project. I can't achieve anything without His permission. Every project whether it big or small is successful largely due to the effort of a number of wonderful people who have always given their valuable advice or lend a helping hand.

I would like to express my deepest appreciation to my parents and all my family that always supports me till the end of this final year project. This project requires me to gain so many strength, patience and support to finish my final year project. My family is my strength and they were my everything.

At this junction I feel deeply honored in expressing my sincere thanks to my final year project's supervisor, Dr. Maaspaliza Binti Azri, whose have invested his full effort in guiding me in achieving the goal. She teaches me, guide me and give much information to complete this project. With all her advice and tips I had been used for this project came with expected output result. Without her, I will not solve the project's entire problem hence completing this final year project due to the date.

Last but not least, I want to give a special gratitude to Universiti Teknikal Malaysia Melaka (UTeM), Faculty of Electrical Engineering (FKE) and to all my friends for their critical advice and guidance without them, this project would not have been possible.

ABSTRACT

The efficiency of the inverter can be improved when there is no transformer used in photovoltaic (PV) single-phase inverter system. One of the main problems in single-phase photovoltaic (PV) inverter is to control leakage current appearing between parasitic capacitor and ground. The main problem of ground leakage current is, it poses an electrical hazard to anyone touching the photovoltaic (PV) array's surface. As required in VDE-0126-1-1 German standard, the ground leakage current must be below $300\text{mA}_{\text{rms}}$ for safety issues. To reduce the ground leakage current, the single-phase transformerless inverter is analyzed, verified and compared in this report. There are four factors that affect the ground leakage current which are the switching technique, parasitic capacitance, filter design and topology used. The effective way to control the ground leakage current is by keeping the common-mode voltage constant. H-bridge inverter topology was used to investigate the suitable switching technique, which is bipolar SPWM and unipolar SPWM is used. In order to analyze the effect of filter design to the bipolar H-bridge transformerless inverter, the LC filter using one inductor and LC filter split inductor with same value is investigated. Filter design using LC filter split inductor with same value having a low leakage current. Therefore, the effect of filter impedance matching was analyzed. In addition, the effect of the parasitic capacitance on the bipolar H-bridge transformerless inverter is studied. After the three factors have been analyzed, a switching frequency of single-phase transformerless inverter using bipolar SPWM is analyzed in terms of ground leakage current. Appearing leakage current causes the safety problem and increased system losses.

ABSTRAK

Kecekapan boleh ditingkatkan apabila tiada pengubah yang digunakan dalam sistem penyongsang fasa tunggal fotovoltaik (PV). Salah satu masalah utama dalam penyongsang photovoltaic (PV) fasa tunggal adalah untuk mengawal arus kebocoran ke bumi yang muncul di antara kapasitor parasit dan bumi. Masalah utama kebocoran arus bumi adalah, ia menimbulkan bahaya elektrik kepada sesiapa yang menyentuh permukaan array photovoltaic (PV). Seperti yang dikehendaki dalam standard Jerman VDE-0126-1-1, arus kebocoran tanah mestilah di bawah $300m_{rms}$ untuk isu keselamatan. Untuk mengurangkan arus kebocoran tanah, pengubah penyongsang fasa tunggal dianalisis, disahkan dan dibandingkan dalam laporan ini. Terdapat empat faktor yang mempengaruhi arus kebocoran ke bumi iaitu teknik pensuisan, kapasitans parasit, reka bentuk penapis dan topologi yang digunakan. Cara yang berkesan untuk mengawal arus kebocoran ke bumi adalah dengan mengekalkan pemalar voltan biasa mod. Topologi penyongsang H-bridge digunakan untuk menyiasat teknik penukaran yang sesuai, iaitu *bipolar SPWM* dan *unipolar SPWM* digunakan. Untuk menganalisis kesan reka bentuk penapis kepada penyongsang penukar *H-bridge bipolar*, penapis LC menggunakan satu penunjuk induktor dan LC penukar berpecah induktor dengan nilai yang sama disiasat. Reka bentuk penapis menggunakan LC penapis pemisah pecah dengan nilai yang sama mempunyai arus kebocoran yang rendah. Oleh itu, pepadanan impak penapis kesan telah dianalisis. Di samping itu, kesan kapasitans parasit pada penyongsang penukar *H-bipolar* dipelajari. Selepas tiga faktor telah dianalisis, satu penukar penyongsang fasa yang dicadangkan dan dianalisis dari segi kebocoran ke bumi. Kebocoran arus ke bumi menyebabkan masalah keselamatan dan peningkatan kehilangan sistem.

TABLE OF CONTENT

CHAPTER	TITLE	PAGE
	ACKNOWLEDGEMENT	ii
	ABSTRACT	iii
	ABSTRAK	iv
	TABLE OF CONTENT	v
	LIST OF FIGURE	ix
	LIST OF TABLE	xiv
	LIST OF APPENDICES	xv
1	INTRODUCTION	1
	1.1 Background	1
	1.2 Problem Statement	2
	1.3 Objective	3
	1.4 Scope	3
	1.5 Report Outline	4
2	LITERATURE REVIEW	5
	2.1 Introduction	5
	2.2 Renewable Power Source	5
	2.2.1 Solar Energy System	6
	2.2.2 Wind Energy System	6
	2.2.3 Fuel Cells System	6
	2.3 Inverter	7
	2.3.1 Current Source Inverter (CSI)	7
	2.3.2 Voltage Source Inverter (VSI)	7
	2.4 VSI Topologies	8
	2.4.1 Single-Phase Inverter Topology for PV Grid	8

	Connected System	
	2.4.1.1 Cascaded Multilevel Inverter Topology	8
	2.4.1.2 A Power Electronic Transformer (PET) with a Cycloconverter on The Grid Side Topology	9
	2.4.2 Transformer Inverter System	11
	2.4.3 Single-phase Inverter Transformerless Topology	11
	2.4.3.1 Split-capacitor H-bridge (SC-HB) Topology	11
	2.4.3.2 H6 single-phase Inverter Topology	12
	2.4.3.3 High Efficient and Reliable Inverter Concept (HERIC) Topology	13
	2.4.3.4 Single-phase Full-bridge Grid Connected PV Transformerless Inverter Topology	14
	2.5 Switching Techniques for Single-Phase Inverter Circuit	15
	2.5.1 Pulse-width-modulated Inverters	15
	2.5.2 Square-wave Inverters	16
	2.5.3 Single-phase Inverters with Voltage Cancellation	16
	2.6 Modulation Schemes	16
	2.6.1 SPWM with Bipolar Switching	17
	2.6.2 SPWM with Unipolar Switching	18
	2.6.3 PWM Consideration	19
	2.6.3.1 Frequency Modulation Ratio, m_f	19
	2.6.3.2 Amplitude Modulation Ration, m_a	20
	2.7 Harmonic Distortion Definition	20
	2.7.1 Relation Between Harmonic Voltage and Current	21
	2.7.2 Total Harmonic Distortion	21
	2.8 AC Filters	22
	2.9 Summary	22
3	DESIGN METHODOLOGY	24
	3.1 Introduction	24
	3.2 Research Methodology	24
	3.2.1 Flowchart	25

3.2.2	Milestone Research	26
3.2.3	Project Gantt Chart	27
3.3	Single-phase transformerless Inverter	28
3.3.1	Ground Leakage Current	28
3.3.2	Common-mode Voltage in Single-phase Transformerless Inverter	29
3.3.3	Parasitic Capacitance of PV Grid System	32
3.3.4	Hbridge inverter transformerless Control Switching Technique	33
3.3.5	Filter Design	38
3.4	Simulation of Single-Phase Transformerless Inverter	40
3.4.1	Simulink Parameter	41
3.5	Hardware Design	42
3.5.1	H-bridge transformerless Inverter Circuit	42
3.5.2	Gate Drive Circuit	43
3.5.3	XMC 4500 Microcontroller	44
3.6	Hardware Experimental Setup	46
3.7	Summary	47
4	RESULT AND DISCUSSION	48
4.1	Introduction	48
4.2	Simulation Result	48
4.2.1	Simulation of Single-phase Transformerless Inverter	48
4.2.2	Effect of Filter Design	58
4.2.3	Effect of Filter Impedance Matching	60
4.2.4	Effect of Parasitic Capacitance	65
4.2.5	Effect of Switching Frequency	67
4.3	Hardware Results	69
4.3.1	Pulse Width Modulation	69
4.3.2	Single Phase Transformerless Inverter	70
4.3.3	Effect of Filter Design	74
4.3.4	Effect of Filter Impedance Matching	75

4.3.5	Effect of Parasitic Capacitance	77
4.3.6	Effect of Switching Frequency	79
4.4	Comparison Result Between Simulation and Hardware	80
4.4.1	Analysis on LC Filter using One Inductance, LC Filter using Split Inductance, Parasitic Capacitance and Switching Frequency at Ground Leakage Current	82
4.5	Summary	84
5	CONCLUSION AND RECOMMENDATION	86
	REFFERENCES	87
	APPENDICES	90

LIST OF FIGURE

FIGURE	TITLE	PAGE
2.1	Circuit Structure of CSI Inverter	7
2.2	Circuit Configuration of VSI Inverter	8
2.3	Cascaded Multilevel Inverter Topology	9
2.4	Power Electronic Transformer Topology For Integrating Multiple Renewable Energy	10
2.5	SC-HB Inverter Topology	12
2.6	H6 Inverter Topology	13
2.7	HERIC Topology	13
2.8	Single-phase Grid Connected Transformerless PV Inverter	14
2.9	(a) Switching Pattern (b) Output Waveform	17
2.10	Full Bridge Converter	18
2.11	Waveform Of Unipolar Modulation Scheme	18
2.12	Current Distortion Caused By Nonlinear Resistance	20
2.13	Relation between Harmonic Voltage and Current	21
3.1	Flowchart of Research Methodology	25
3.2	Transformerless Single-Phase Inverter With Parasitic Capacitance	29
3.3	The Common-Mode Model For The PWM Voltage Source Inverter System	30
3.4	Simplified Equivalent Model Of Common-Mode Resonant Circuit	31
3.5	Equivalent Circuit For The Common-Mode Leakage Current Path	32
3.6	(a) Maximum and (b) Minimum PV Module Earth Capacitance	33
3.7	Transformerless H-Bridge Inverter	34

3.8	Half-positive Cycle State i for Unipolar H-bridge Circuit	35
3.9	Half-positive Cycle State ii for Unipolar H-bridge Circuit	35
3.10	Half-positive Cycle State iii for Unipolar H-bridge Circuit	36
3.11	Positive Cycle State i for Bipolar H-Bridge Circuit	37
3.12	Positive cycle state ii for Bipolar H-Bridge Circuit	38
3.13	LC Filter With One Inductor (L_f)	39
3.14	LC Filter With Split Inductor (L_f)	39
3.15	MATLAB Simulink Model Of Single-Phase Transformerless Inverter For Bipolar Switching Scheme	40
3.16	Operation Mode Of The CD-Boost Converter In Switch-On Mode	41
3.17	Flowchart Of Hardware	42
3.18	IGBT G4PC50UD-E	42
3.19	Gate Drive circuit	44
3.20	Microcontroller XMC 4500	44
3.21	CCU4 circuit	45
3.22	Block Parameter Sine Wave	45
3.23	Block Parameter CCU4	46
3.24	Hardware Setup	47
4.1	(A) Common-Mode Voltage (V_{cm}), (B) V_{ao} And (C) V_{bo} That Obtained Using Unipolar Switching Technique	49
4.2	Output Inverter Voltage 30 V (V_{ab})	50
4.3	Output Inverter Current 24.48 mA (I_o)	50
4.4	Output Inverter Voltage 24.48 V (V_o)	51
4.5	THD current for unipolar H-bridge inverter (0.75 %)	51
4.6	THD Voltage For Unipolar H-Bridge Inverter (0.75 %)	52
4.7	Ground Leakage Current Using Unipolar Switching Technique (155.2 mA)	52
4.8	THD Ground Leakage Current For Unipolar H-Bridge Inverter (26761.36 %)	53
4.9	(a) Common-mode Voltage (V_{cm}), (b) V_{ao} and (c) V_{bo} That Obtained Using Unipolar Switching Technique	54
4.10	Output Inverter Voltage 30 V (V_{ab})	54

4.11	Output Inverter Current 24.98 mA (I_o)	55
4.12	Output Inverter Voltage 24.98 V (V_o)	55
4.13	THD Current For Bipolar H-Bridge Inverter (3.21 %)	56
4.14	THD Voltage For Bipolar H-Bridge Inverter (3.21 %)	56
4.15	Ground Leakage Current Using Bipolar Switching Technique (1.556 mA)	57
4.16	THD Ground Leakage Current For Bipolar H-Bridge Inverter (189.13 %)	57
4.17	The Effect Of Filter With One Inductor On Ground Leakage Current (3 A)	59
4.18	The Ground Leakage Current Spectrum When Used Filter With One Inductor (142138.91 %)	59
4.19	The Effect Of Filter With Split Inductor With Same Value On Ground Leakage Current (1.556 mA)	60
4.20	The Ground Leakage Current Spectrum When Used Filter With Split Inductor Same Value (189.13 %)	60
4.21	Ground Leakage Current Of Filter Ratio 1 (1.556 mA)	61
4.22	Ground Leakage Spectrum Filter Ratio 1 (189.13 %)	61
4.23	Ground Leakage Current Of Filter Ratio 1.2 (51.99 mA)	62
4.24	Ground Leakage Spectrum Filter Ratio 1.2 (8171.57 %)	62
4.25	Ground Leakage Current Of Filter Ratio 1.4 (63.69 mA)	63
4.26	Ground Leakage Spectrum Filter Ratio 1.4 (11218.36 %)	63
4.27	Ground Leakage Current Of Filter Ratio 2 (158.7 mA)	64
4.28	Ground Leakage Spectrum Filter Ratio 2 (25782.03 %)	64
4.29	Ground Leakage Current Of Filter Ratio 5 (4460.8 mA)	65
4.30	Ground Leakage Spectrum Filter Ratio 5 (85271.87 %)	65
4.31	Ground Leakage Current ($1.556 \text{ mA}_{\text{peak}}$) Using Parasitic Capacitor = 10 nF	66
4.32	Ground Leakage Current ($3.21 \text{ mA}_{\text{peak}}$) Using Parasitic Capacitor = 30 nF	66
4.33	Ground Leakage Current ($3.772 \text{ mA}_{\text{peak}}$) Using Parasitic Capacitor = 40 nF	67
4.34	Ground Leakage Current ($3.928 \text{ mA}_{\text{peak}}$) Using Parasitic	67

	Capacitor = 50 nF	
4.35	Ground Leakage Current (1.556 mA _{peak}) using 8 kHz Switching Frequency	68
4.36	Ground Leakage Current (1.1 mA _{peak}) using 16 kHz Switching Frequency	68
4.37	Ground Leakage Current (529.4 μA _{peak}) using 24 kHz Switching Frequency	68
4.38	Bipolar Switching Scheme Using XMC 4500	69
4.39	Unipolar Switching Scheme Using XMC 4500	70
4.40	(a) V _{ao} Using Unipolar Switching Technique (b) V _{bo} Using Unipolar Switching Technique	70
4.41	Output Inverter Voltage Using Unipolar Switching Technique 30V _{peak} (10 V/div)	71
4.42	AC Waveform For Unipolar H-Bridge Inverter. Output Voltage 12 V _{peak} (Blue Trace 5 V/div) and Output Current 600 mA _{peak} , (Purple Trace 500 mA/div)	71
4.43	THD Voltage (0.5 %) For Unipolar H-Bridge Inverter Using Fluke 43B Power Quality Analyzer	71
4.44	Ground Leakage Current Using Bipolar Switching Technique 100 mA _{peak} (100 mA/div)	72
4.45	(a) V _{ao} Using Bipolar Switching Technique (b) V _{bo} Using Bipolar Switching Technique	73
4.46	Output Inverter Voltage Using Bipolar Switching Technique 30 V _{ab} (10 V/div)	73
4.47	AC Waveform For Bipolar H-Bridge Inverter. Output Voltage 24 V _{peak} (Blue Trace 10.0 V/div) and Output Current 1.2 A _{peak} (Purple Trace 1 A/div)	73
4.48	THD Voltage (1.7 %) For Bipolar H-Bridge Inverter Using Fluke 43B Power Quality Analyzer	74
4.49	Ground Leakage Current Using Bipolar Switching Technique (1.8 mA _{peak})	74
4.50	The Effect Of Filter With One Inductor On Ground Leakage Current 2 A _{peak} (1 A/div)	75

4.51	The Effect Of Filter With Split Inductor With Same Value On Ground Leakage Current $1.8 \text{ mA}_{\text{peak}}$ (2 mA/div)	75
4.52	Ground Leakage Current $40 \text{ mA}_{\text{peak}}$ Using Filter Ratio 1.2 (20 mA/div)	76
4.53	Ground Leakage Current $55 \text{ mA}_{\text{peak}}$ Using Filter Ratio 1.4 (50 mA/div)	76
4.54	Ground Leakage Current $160 \text{ mA}_{\text{peak}}$ Using Filter Ratio 2 (100 mA/div)	76
4.55	Ground Leakage Current $500 \text{ mA}_{\text{peak}}$ Using Filter Ratio 5 (250 mA/div)	77
4.56	Ground Leakage Current $1.8 \text{ mA}_{\text{peak}}$ With Parasitic Capacitor Value 10 nF (2 mA/div)	77
4.57	Ground Leakage Current $2 \text{ mA}_{\text{peak}}$ With Parasitic Capacitor Value 30 nF (2 mA/div)	78
4.58	Ground Leakage Current $3 \text{ mA}_{\text{peak}}$ With Parasitic Capacitor Value 40 nF (2 mA/div)	78
4.59	Ground Leakage Current $4.4 \text{ mA}_{\text{peak}}$ With Parasitic Capacitance Value 50nF (20 mA/div)	79
4.60	Ground Leakage Current $1.556 \text{ mA}_{\text{peak}}$ Using 8 kHz Switching Frequency (2 mA/div)	79
4.61	Ground Leakage Current $0.6 \text{ mA}_{\text{peak}}$ Using 16 kHz Switching Frequency (1 mA/div)	80
4.62	Ground Leakage Current $529.4 \mu \text{ A}_{\text{peak}}$ Using 24 kHz Switching Frequency (1 mA/div)	80
4.63	Ground Leakage Current Levels Against L_r (L_{f1}/L_{f2})	83
4.64	Parasitic Capacitance Vs. Ground Leakage Current	83
4.65	Comparison Effect Of Switching Frequency Between Simulation And Experiment Hardware	84

LIST OF TABLE

TABLE	TITLE	PAGE
2.1	Switching Control	19
3.1	Gantt Chart of Research Methodology	27
3.2	Half-positive cycle operation mode of transformerless H-Bridge inverter	34
3.3	Operation mode of transformerless H-Bridge inverter	37
3.4	Simulation Parameter of single-phase transformerless inverter	41
3.5	Parameter of IGBT IHW15N120R3	43
3.6	The parameter of XMC 4500	45
4.1	Simulations result for unipolar SPWM and bipolar SPWM	58
4.2	Unipolar switching technique comparison result between simulation and hardware	81
4.3	Bipolar switching technique comparison result between simulation and hardware	81
4.4	The comparison between simulation and hardware by using LC filter with one inductance and split inductance with same value	83
4.5	Calculation of inductance value	84

LIST OF APPENDICES

APPENDIX	TITLE	PAGE
A	INFINEON-UTeM FYP Competition Poster	91

CHAPTER 1

INTRODUCTION

1.1 Background

Inverter is the power electronic circuit that converts direct current (DC) to alternating current (AC). In specifically, inverters convert power from a DC source to an AC source. The inverters are commonly used to supply AC fed from DC source such as grid-connected PV systems, grid connected fuel cell system and batteries. The grid-connected inverters play a crucial role in providing the electric power supply in an eco-friendly manner. Grid connected system required a galvanic isolation to prevent from ground leakage current. Nowadays, the technology of transformerless for grid-connected PV systems are introduced due to offer the high efficiency power conversion, less weight and low cost.

In the transformerless grid-connected PV systems, the path for the ground leakage current to flow, which is the parasitic capacitor is appear between positive and negative terminal of PV grid with the ground. Ground leakage current can produce serious electromagnetic interference either through directed or radiated emission that cause safety issues. In view of the VDE-0126-1-1 standard, the level of ground leakage current must be lower than $300 \text{ mA}_{\text{rms}}$, the level that can cause ventricular fibrillation and involuntary muscle contractions. Therefore, the topologies, switching algorithm, AC filter design have been proposed by previous researchers.

In the AC signal, the quality of signal is important parameter to consider. In electrical power distribution system, there are many non-linear loads drawing non-sinusoidal current is exists. It cause serious problem to power quality of the power

distribution system. The harmonic of the voltage and current will affect the power system components. Moreover, the harmonic can cause extra losses, overheating and over-loading to the system.

1.2 Problem Statement

Mostly, the commercial grid connected photovoltaic inverter will use line-frequency transformer, which is provide galvanic isolation and safety. However, the line-frequency transformers are big and weighty that causes the system bulky and makes the system become complex. Besides using line-frequency transformer, high-frequency isolation transformers also can be used which is cheaper, small size and weight. But, the inverters with high-frequency transformers have a several power stages that make the system complexity and decrease the system efficiency. Therefore, to make the system become more efficiency, the transformerless grid is used due to small loss. The advantages of the system are smaller size, lower cost, weight and high power density.

Due to the capacitance between the Photovoltaic grid- connected system and earth, potential differences enforced by switching actions of the inverter introduce a ground leakage current. The leakage current is appearing because there is no galvanic isolation when using transformerless. Factor effected ground leakage current is based on the topology used, switching strategy, parasitic capacitor and filter design. Appearing leakage current is causes the safety problem and increased system losses.

Low-power PV applications have limited input voltage range. Therefore, an expansive number of PV modules are joined in series to get high dc input voltage. Even though this setup is meets the target input voltage anyhow, it influence the power output level of the PV modules [12]. Thus, the single-phase transformerless inverter is used to extract power from the PV modules.

1.3 Objective

The objectives of this project are:

1. To model and analyze the single-phase transformerless inverter using Matlab/Simulink.
2. To design and develop hardware of single-phase transformerless inverter.
3. To verify the performance of single phase transformerless inverter between the simulation and hardware result.

1.4 Scope

The aim of this project is to focus the performance of single-phase transformerless inverter on reducing ground leakage current less than 300mA_{rms} based on VDE0126-1-1 German Standard but at the same time maintain the THD below 5% based on IEEE Standard 519. The Matlab Simulink is used to model and analyze the performance of ground leakage current by using simulation approach that are switching technique, parasitic capacitor, filter design and topology used. The single-phase transformerless inverter is tested using R loads. The single-phase transformerless inverter is simulated to determine the factor that effected ground leakage current.

The performance of the single-phase transformerless are analyze by using bipolar switching schemes. The purpose of this simulation is to compare the performance of the single-phase transformerless inverter in terms of ground leakage current and total harmonic distortion (THD).

The experiment single-phase transformerless inverter will be developed after the simulation result is obtained. The equipment contain of gate drive to turn ON and OFF IGBT. The H-Bridge involves of Insulated Gate Bipolar Transistor (IGBT) type G4PC50UD-E and connected with LC filter. For the control plan of the power switches, the PWM algorithm will be transferred to the microcontroller XMC 4500 as the fundamental controller. At long last, the information and result from the equipment will be studied and compare with the simulation result from the MATLAB Simulink.

1.5 Report Outline

This report consist five chapters that is start with the introduction of the project and the following five chapters of this report are arranged as follows:

Chapter 1 covers a little explanation of the background project, problem statement, objectives and scope of the project.

Chapter 2 covers the theoretical background of this project including the detail about the general renewable energy, basic type of single-phase inverter, the general topologies of single-phase transformerless inverter, PWM consideration, common mode leakage current definition and total harmonic distortion definition.

Chapter 3 covers about the project methodology. This chapter consists of the flowchart of the project, milestone, Gantt chart, factor that affects the ground leakage current, simulation model, hardware design and the switching method used in this project.

Chapter 4 discusses the simulation result by using PWM switching technique, filter design, parasitic capacitor analysis, ground leakage current analysis and the harmonic analysis to evaluate the performance of the inverter.

Chapter 5 is the summary of this project and the recommendation for the further research.

CHAPTER 2

LITERATURE REVIEW

2.1 Introduction

Inverter is a circuit that converts a direct current (DC) power to an alternating current (AC) power at a desired output voltage and frequency. The output powers are fully come from DC source. DC source that used is coming from local energy source such as fuel cell, photovoltaic cell (PV), small turbines and small hydroelectric plants. Single-phase inverters are mostly used in numerous applications involving variable voltage and variable frequency AC supply. The examples of several main applications are adjustable-speed AC motor drives, DC motor drive, induction heating, standby power supply, uninterruptible power supplies (UPS) and high voltage DC transmission systems. The inverter can be designed using transformer or transformerless.

2.2 Renewable Power Source

Renewable energy is energy that is produced from natural processes that are nonstop replenished. Such as sunlight, geothermal heat, wind, tides, and water. Renewable energy sources have been taken the place of the traditional sources and especially rapidly developments of photovoltaic (PV) technology and Fuel cell (FC) technology have been put forward these renewable energy sources in all others renewable energy source. The common renewable power source used is solar energy system, wind energy system and fuel cell system.