



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

**FINAL YEAR PROJECT REPORT
JUNE 2015**

**DEVELOPMENT AND ANALYSIS OF THREE PHASE NINE LEVEL
CASCADED H-BRIDGE MULTILEVEL INVERTER USING
BIPOLAR AND UNIPOLAR SWITCHING SCHEMES**

**NAME : AKMAL AFIQ BIN NAZMUDI
MATRIX NO : B011210199
SUPERVISOR : EN. MUSA BIN YUSUP LADA
COURSE : POWER ELECTRONIC & DRIVE**

DECLARATION

“I hereby declared that this report is a result of my own work except for the excerpts that have been cited clearly in the references”

Signature : _____

Name : AKMAL AFIQ BIN NAZMUDI

Date : ___/___/2015

DECLARATION

“I hereby declared that I have read through this report entitle „Development and Analysis
Three Phase Nine Level Cascaded H-Bridge Multilevel Inverter Using Bipolar and
Unipolar Switching Schemes””

Signature : _____

Name : MUSA BIN YUSUP LADA

Date : ___/___/2015

ACKNOWLEDGEMENT

First and foremost, thanks to Allah for giving me this grate opportunity to live in this world and also giving me this healthy body that enables to gain the knowledge, experience and able to finish this project.

Secondly, I would like to express my great appreciation to my supervisor, Mr. Musa Bin Yusup Lada for his patience guidance and enthusiastic encouragement throughout the duration of this project. The supervision and patient guidance that he gave truly help the progression and smoothness of my final year project. The support and hard work are much appreciated indeed. He is the one of the best lecturer that I ever met.

Next, I would like to extend my thanks to all my friends for their supports and time during my final year project. Last but not least, I would like to show my gratitude to my family for their encouraging and supporting in completion my final year project. Without their support, I am not able to complete my project successfully. Therefore, I feel very appreciated to their sincerely helps and support.

ABSTRACT

Multilevel inverter is one of the popular devices used in high power medium-voltage (MV) drives. The multilevel inverter has a particular advantage of operation at high direct current (DC). The most significant advantage of multilevel inverter can generate output voltage with very low harmonic distortion and synthesis a staircase voltage waveform by having multiple voltage level. The MLI can solve the problem of high harmonic distortion that produce by the square wave or the conventional inverter that have been used widely in the power DC to alternative current (AC) conversion. The total harmonic distortion (THD) can cause the additional losses, overheating and overloading to the system. There are various topologies of Multilevel Inverter are introduced; however, the most common multilevel inverter topologies are Neutral Point Clamped (NPC) inverter and the Cascaded H-Bridge (CHB) inverter. In this project, the cascaded multilevel inverter is selected because the cascade multilevel is easy to implement compared to other topologies. The cascaded inverter is more reliable because the cascaded H-bridge multilevel inverter (CHB-MLI) does not require any clamping diode and flying capacitor. The performance of cascaded H-bridge inverter was analyzed and discussed by using bipolar and unipolar switching schemes. The performance of the cascaded multilevel inverter was evaluated in term of the total harmonic distortion for current (THD_i) and voltage (THD_v) connected to the R, RL and RC load. The simulation of the CHB-MLI was tested with manipulating several parameters such as the various numbers of carrier wave, various values of amplitude modulation ratio and the various values of the frequency modulated ratio. The RL load produce the lowest of THD compared to another load that has been tested. The RL load produces the lowest THD_i which is 0.23% using unipolar switching scheme, with the 0.95 of amplitude modulation ratio (m_a) and 500 of frequency modulation ratio (m_f). The development of Hardware of Three Phase Nine- Level Cascade H-Bridge Multilevel Inverter (CHB-MLI) is conducted after the simulation result obtained. The hardware experiment is connected to only R and RL loads. The hardware experiment of the Three Phase Nine Level CHB-MLI is tested with manipulating several parameters such as various values of amplitude modulation ratio and the various values of the frequency modulated ratio. The lowest THD that produced in the hardware experiment is produced by the RL load with 1.09% of THD_i . MATLAB simulink is used to model the

CHB-MLI. Some of the result met the standard of IEEE 519 and for high value of harmonic, the additional of passive filter will reduce the THD.

ABSTRAK

Penyongsang bertingkat (PBT) adalah salah satu peranti yang popular digunakan dalam kuasa tinggi voltan sederhana (VS) pemacu. Penyongsang bertingkat mempunyai kelebihan tertentu apabila beroperasi di arus terus (AT) yang tinggi. Kelebihan yang paling ketara daripada penyongsang bertingkat boleh menjana voltan keluar dengan herotan harmonik yang rendah dan sintesis voltan gelombang tangga dengan mempunyai tahap voltan bertingkat. Penyongsang bertingkat (PBT) boleh menyelesaikan masalah herotan harmonik tinggi yang dihasilkan oleh penyongsang gelombang persegi atau penyongsang biasa yang telah digunakan secara meluas dalam penukar kuasa daripada AT kepada AU. Jumlah herotan harmonik (JHH) boleh menyebabkan kehilangan kuasa yang tinggi, panas yang berlebihan dan muatan yang berlebihan kepada sistem. Terdapat pelbagai topologi daripada PBT yang diperkenalkan; Walau bagaimanapun, topologi yang paling biasa bagi penyongsang bertingkat adalah diod terkapit-penyongsang dan penyongsang berganda. Dalam projek ini, penyongsang bertingkat berganda dipilih untuk menganalisis prestasi mereka kerana penyongsang bertingkat berganda adalah lebih mudah untuk dilaksanakan berbanding dengan topologi yang lain. Penyongsang berganda adalah lebih mudah kerana penyongsang jejambat-H bertingkat yang berganda (PBT-JHB) tidak memerlukan diod pengapit dan kapasitor. Prestasi PBT-JHB dianalisis dan dibincangkan dengan menggunakan bipolar dan skim pensuisan unipolar. Prestasi PBT-JHB dinilai dari segi jumlah herotan harmonik untuk arus (JHH_i) dan voltan (JHH_v) yang disambungkan kepada beban R, RL dan RC. Simulasi daripada PBT-JHB diuji dengan memanipulasi beberapa parameter seperti pelbagai bilangan gelombang pembawa, pelbagai nilai nisbah pemodulatan amplitud dan pelbagai nilai nisbah frekuensi termodulat. Beban RL menghasilkan JHH terendah berbanding beban yang lain yang telah diuji. Beban RL menghasilkan JHH_i yang paling rendah iaitu 0.23% menggunakan skim pensuisan unipolar, dengan 0.95 nisbah pemodulatan amplitud (m_a) dan 500 nisbah frekuensi modulasi (m_f). yang. Pembangunan Perkakasan Tiga Fasa sembilan Tahap PBT-JHB jalankan selepas hasil simulasi yang diperolehi. Eksperiment perkakasan hanya disambungkan kepada beban R dan RL sahaja. Simulasi daripada PBT-JHB akan diuji dengan memanipulasi beberapa parameter seperti pelbagai nilai nisbah pemodulatan

amplitud dan pelbagai nilai nisbah frekuensi termodulat. Nilai JHH yang terendah dalam eksperiment perkakasan dihasilkan oleh beban RL dengan 1.09% nilai JHH_i . MATLAB SIMULINK digunakan untuk memodelkan PBT-JHB. Sebahagian dari keputusan yang menepati piawaian bagi IEEE 519 dan untuk nilai harmonik yang tinggi, tambahan penapis pasif akan mengurangkan JHH.

TABLE OF CONTENTS

CHAPTER	TITLE	PAGE
	ABSTRACT	v
	ABSTRAK	vii
	TABLE OF CONTENTS	ix
	LIST OF FIGURES	xivv
	LIST OF TABLES	xxivv
	LIST OF ABBREVIATIONS	xxvi
	LIST OF APPENDICES	xxvii
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	6
	2.1 Introduction	6
	2.2 Type of Inverter	7
	2.2.1 Current-source Inverter (CSI)	7
	2.2.2 Voltage-Source Inverter (VSI)	7
	2.2.2.1 Single-phase Half-bridge Inverter	8
	2.2.2.2 Single-phase Full- bridge Inverter	9
	2.2.2.3 Square Wave Inverter	11
	2.2.2.4 Pulse width Modulated Invertr	11
	2.3 General Topologies of Multilevel Inverter	11
	2.3.1 Neutral Point Clamped Multilevel Inverter (NPC- MLI)	12
	2.3.2 Flying Capacitor Multilevel Inverter (FC-MLI)	12

2.3.3	Cascaded H-bridge Multilevel Inverter (CHB-MLI)	13
2.4	Multilevel Inverter Modulation Control Schemes	14
2.4.1	PWM with Bipolar Switching	15
2.4.2	SPWM with Unipolar Switching	16
2.4.3	PWM Consideration	18
2.4.3.1	Frequency Modulation Ratio, m_f	18
2.4.3.2	Amplitude Modulation Ratio, m_a	18
2.4.4	Sinusoidal PWM (SPWM)	19
2.4.4.1	Phase- Shifted PWM (PSPWM)	19
2.4.4.2	Level- Shifted PWM (LSPWM)	20
2.5	Power Quality	21
2.5.2	Harmonic Distortion Definition	22
3	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	Cascaded Multilevel Inverter	27
3.4	Control Switching Technique Used	28
3.5	Manipulated Parameter	28
3.5.1	Multi-carrier Parameters	29
3.5.1.1	One Triangle Wave Carrier.	29
3.5.1.2	Two Triangle Wave Carriers	31
3.5.1.3	Three Triangle Wave Carriers	33
3.5.1.4	Four Triangle Wave Carriers	36
3.5.2	Amplitude Modulation Ratio, m_a Parameter	40
3.5.2.1	Amplitude Modulation Ratio, $m_a=0.95$.	40
3.5.2.2	Amplitude Modulation Ratio, $m_a=0.7$	42
3.5.2.3	Amplitude Modulation Ratio, $m_a=0.4$	45
3.5.2.4	Amplitude Modulation Ratio, $m_a=0.2$	47
3.5.3	Frequency Modulation Ratio, m_f	49
3.5.3.1	Frequency Modulation Ratio, $m_f= 100$	49

3.5.3.2	Frequency Modulation Ratio, $m_f=200$	51
3.5.3.3	Frequency Modulation Ratio, $m_f=500$	53
3.5.3.4	Frequency Modulation Ratio, $m_f=1000$	56
3.6	Simulation	58
3.6.1	Simulink block	58
3.6.1.1	Unipolar Three-Phase Multilevel Inverter	59
3.6.1.2	Bipolar Three-Phase Multilevel Inverter	61
3.6.1.3	Nine-Level CHB-MLI	63
3.7	Hardware Design	64
3.7.1	H-Bridge Inverter Circui	65
3.7.2	Gate Drive Circuit	67
3.7.3	DC/DC Converter Circuit	68
3.7.4	Arduino Mega 2560 Microcontroller	69
3.7.5	Printed Circuit Board (PCB) Design	71
3.7.6	Hardware Experimental Setup	71
4	RESULT AND DISCUSSION	73
4.1	Introduction	73
4.2	Simulation Result	73
4.2.1	Simulation of Multicarrier	74
4.2.1.1	Simulation of One Triangle Wave Carrier.	74
4.2.1.2	Simulation of Two Triangle Wave Carriers.	77
4.2.1.3	Simulation of Three Triangle Wave Carriers.	80
4.2.1.4	Simulation of Four Triangle Wave Carriers.	83
4.2.1.5	Summary of the Multicarrier Simulation.	86
4.2.2	Simulation of Various Amplitude Modulation Ratio, m_a .	90
4.2.2.1	Amplitude Modulation Ratio, $m_a=0.95$.	91
4.2.2.2	Amplitude Modulation Ratio, $m_a=0.7$.	94
4.2.2.3	Amplitude Modulation Ratio, $m_a=0.4$.	97
4.2.2.4	Amplitude Modulation Ratio, $m_a=0.2$.	100
4.2.2.5	Summary of the Amplitude Modulation Ratio, m_a Simulation.	103
4.2.3	Simulation of Various Frequency Modulation Ratio,	

	m_f .	107
	4.2.3.1 Frequency Modulation Ratio, $m_f=100$	107
	4.2.3.2 Frequency Modulation Ratio, $m_f=200$	110
	4.2.3.3 Frequency Modulation Ratio, $m_f=500$	113
	4.2.3.4 Frequency Modulation Ratio, $m_f=1000$	116
	4.2.3.5 Summary of the Frequency Modulation Ratio, m_f Simulation.	119
	4.3 Hardware Result	124
	4.3.1 Result of Various Amplitude Modulation Ratio, m_a .	124
	4.3.1.1 Amplitude Modulation Ratio, $m_a=0.95$.	125
	4.3.1.2 Amplitude Modulation Ratio, $m_a=0.7$.	128
	4.3.1.3 Amplitude Modulation Ratio, $m_a=0.4$.	131
	4.3.1.4 Amplitude Modulation Ratio, $m_a=0.2$.	134
	4.3.1.5 Summary of the Amplitude Modulation Ratio, m_a Experimental.	137
	4.2.3 Simulation of Various Frequency Modulation Ratio, m_f .	140
	4.2.3.1 Frequency Modulation Ratio, $m_f=100$	140
	4.2.3.2 Frequency Modulation Ratio, $m_f=200$	143
	4.2.3.5 Summary of the Frequency Modulation Ratio, m_f Simulation.	146
	4.4 Comparison Summary	149
5	CONCLUSION	156
	5.1 Conclusion	156
	5.2 Recommendation	157
	REFERENCE	159
	APPENDIX A	161
	APPENDIX B	174
	APPENDIX C	187
	APPENDIX D	200
	APPENDIX E	208

APPENDIX F	212
APPENDIX G	234

LIST OF FIGURES

FIGURE	TITLE	PAGE
2.1	Inverter	6
2.2	Circuit Configuration of CSI inverter	7
2.3	Circuit Configuration of VSI Inverter	8
2.4	Circuit configuration of a single-phase, half-bridge inverter	8
2.5	Signal for switch S1 and S2	9
2.6	Output voltage of single phase, half-bridge inverter	9
2.7	Circuit configuration of a single-phase, full-bridge inverter	10
2.8	Signal for switch S1, S2 , S3 and S4.	10
2.9	Output voltage for single phase, full-bridge inverter	11
2.10	Three –level Neutral Point Clamped Topology [4]	12
2.11	Three-level Flying Capacitor Topology [5]	13
2.12	Five-level Cascaded H-bridge Topology [5]	14
2.13	Multilevel converter modulation methods	14
2.14	(a) Switching pattern (b) Output waveform	15
2.15	Full bridge converter	16
2.16	(a) Switching pattern (b) Output Waveform	17
2.17	\Multi-carrier SPWM control techniques	19
2.18	Level-shifted multicarrier modulation: (a) PD, (b) POD, and (c) APOD.	20
3.1	Flowchart of research methodology ²⁵	25
3.2	Unipolar Switching Wave for One-Carrier	29
3.3	Bipolar Switching Wave for One-Carrier	30
3.4	Unipolar PWM Compensator Signal for One-Carrier	30
3.5	Bipolar PWM Compensator Signal for One-Carrier	31
3.6	Unipolar Switching Wave for Two-Carriers.	31
3.7	Bipolar Switching Wave for Two-Carriers.	32
3.8	Unipolar PWM compensator signal for two-carriers	32
3.9	Bipolar PWM compensator signal for two-carriers	33
3.10	Unipolar Switching Wave for Three-Carriers.	33
3.11	Bipolar Switching Wave for Three-Carriers.	34

3.12	Unipolar PWM compensator signal for three-carriers	35
3.13	Bipolar PWM compensator signal for three-carriers	36
3.14	Unipolar Switching Wave for Four-Carriers.	37
3.15	Bipolar Switching Wave for Four-Carriers.	37
3.16	Unipolar PWM compensator signal for four-carriers	38
3.17	Bipolar PWM compensator signal for four-carriers	39
3.18	Unipolar Switching Wave for $m_a=0.95$.	40
3.19	Bipolar Switching Wave for $m_a=0.95$.	41
3.20	Unipolar Switching Wave for $m_a=0.95$.	41
3.21	Bipolar PWM compensator signal for $m_a=0.95$	42
3.22	Unipolar Switching Wave for $m_a=0.7$.	43
3.23	Bipolar Switching Wave for $m_a=0.7$.	43
3.24	Unipolar Switching Wave for $m_a=0.7$.	44
3.25	Bipolar Switching Wave for $m_a=0.7$	44
3.26	Unipolar Switching Wave for $m_a=0.4$.	45
3.27	Bipolar Switching Wave for $m_a=0.4$.	45
3.28	Unipolar Switching Wave for $m_a=0.4$.	46
3.29	Bipolar Switching Wave for $m_a=0.4$.	46
3.30	Unipolar Switching Wave for $m_a=0.2$.	47
3.31	Bipolar Switching Wave for $m_a=0.2$.	47
3.32	Unipolar Switching Wave for $m_a=0.2$.	48
3.33	Bipolar Switching Wave for $m_a=0.2$.	48
3.34	Unipolar Switching Wave for $m_f= 100$.	49
3.35	Bipolar Switching Wave for $m_f= 100$.	50
3.36	Unipolar PWM compensator signal for $m_f= 100$	50
3.37	Bipolar PWM compensator signal for $m_f= 100$	51
3.38	Unipolar Switching Wave for $m_f= 200$.	51
3.39	Bipolar Switching Wave for $m_f= 200$.	52
3.40	Unipolar PWM compensator signal for $m_f= 200$	52
3.41	Bipolar PWM compensator signal for $m_f= 200$	53
3.42	Unipolar Switching Wave for $m_f= 500$.	54
3.43	Bipolar Switching Wave for $m_f= 500$.	54
3.44	Unipolar PWM compensator signal for $m_f= 500$	55

3.45	Bipolar PWM compensator signal for $m_f= 500$	55
3.46	Unipolar Switching Wave for $m_f= 1000$	56
3.47	Bipolar Switching Wave for $m_f= 1000$.	56
3.48	Unipolar PWM compensator signal for $m_f= 1000$	57
3.49	Bipolar PWM compensator signal for $m_f= 1000$	57
3.50	Block Diagram of Unipolar and Bipolar Three-Phase Cascaded Multilevel Inverter	58
3.51	MATLAB simulink model of one-carrier unipolar cascaded multilevel inverter	59
3.52	MATLAB simulink model of two-carriers unipolar cascaded multilevel inverter	60
3.53	MATLAB simulink model of three-carriers unipolar cascaded multilevel inverter.	60
3.54	MATLAB simulink model of four-carriers unipolar cascaded multilevel inverter	61
3.55	MATLAB simulink model of one-carrier bipolar cascaded multilevel inverter	61
3.56	MATLAB simulink model of two-carriers bipolar cascaded multilevel inverter	62
3.57	MATLAB simulink model of three-carriers bipolar cascaded multilevel inverter	62
3.58	MATLAB simulink model of four-carriers bipolar cascaded multilevel inverter	63
3.59	Single phase of nine-level CHB-MLI circuit	64
3.60	Three phase of nine-level CHB-MLI circuit	64
3.61	IGBT IHW15N120R3 [19]	65
3.62	H-Bridge Inverter Circuit	65
3.63	Gate drive HCPL3120-000E	67
3.64	Gate Drive Circuit	68
3.65	IQ0515SA DC/DC Converter	68
3.66	DC/DC Converter Circuit	69
3.67	Arduino Mega 2560	70
3.68	Hardware Configuration	71

3.69	Experimental Setup	72
4.1	(a) Unipolar Wave for Three Phase Voltage (RL-load) for One-Carrier, (b) Unipolar THD for Three Phase Voltage (RL-load) for One-Carrier.	75
4.2	Unipolar Wave for Three Phase Current (RL-load) for One-Carrier, (b) Unipolar THD for Three Phase Current (RL-load) for One-Carrier.	76
4.3	(a) Bipolar Wave for Three Phase Voltage (RL-load) for One-Carrier, (b) Bipolar THD for Three Phase Voltage (RL-load) for One-Carrier	76
4.4	(a) Bipolar Wave for Three Phase Current (RL-load) for One-Carrier, (b) Bipolar THD for Three Phase Current (RL-load) for One-Carrier.	77
4.5	(a) Unipolar Wave for Three Phase Voltage (RL-load) for Two-Carriers, (b) Unipolar THD for Three Phase Voltage (RL-load) for Two-Carriers.	78
4.6	(a) Unipolar Wave THD for Three Phase Current (RL-load) for Two-Carriers, (b) Unipolar THD for Three Phase Current (RL-load) for Two-Carriers.	79
4.7	(a) Bipolar Wave for Three Phase Voltage (RL-load) for Two-Carriers, (b) Bipolar THD for Three Phase Voltage (RL-load) for Two-Carriers.	79
4.8	(a) Bipolar Wave for Three Phase Current (RL-load) for Two-Carriers, (b) Bipolar THD for Three Phase Current (RL-load) for Two-Carriers.	80
4.9	(a) Unipolar Wave for Three Phase Voltage (RL-load) for Three-Carriers, (b) Unipolar THD for Three Phase Voltage (RL-load) for Three-Carriers.	81
4.10	(a) Unipolar Wave for Three Phase Current (RL-load) for Three-Carriers, (b) Unipolar THD for Three Phase Current (RL-load) for Three-Carriers	82
4.11	(a) Bipolar Wave for Three Phase Voltage (RL-load) for Three-Carriers, (b) Bipolar THD for Three Phase Voltage (RL-load) for Three-Carriers	82

4.12	(a) Bipolar Wave for Three Phase Current (RL-load) for Three-Carriers, (b) Bipolar THD for Three Phase Current (RL-load) for Three-Carriers.	83
4.13	(a) Unipolar Wave for Three Phase Voltage (RL-load) for Four-Carriers, (b) Unipolar THD for Three Phase Voltage (RL-load) for Four-Carriers.	84
4.14	(a) Unipolar Wave for Three Phase Current (RL-load) for Four-Carriers, (b) Unipolar THD for Three Phase Current (RL-load) for Four-Carriers.	85
4.15	(a) Bipolar Wave for Three Phase Voltage (RL-load) for Four-Carriers, (b) Bipolar THD for Three Phase Voltage (RL-load) for Four-Carriers.	85
4.16	(a) Bipolar Wave for Three Phase Current (RL-load) for Four-Carriers, (b) Bipolar THD for Three Phase Current (RL-load) for Four-Carriers.	86
4.17	The Current THD of R load with Multicarriers	88
4.18	The Current THD of RL load with Multicarriers	88
4.19	The Current THD of RC load with Multicarrier	89
4.20	The Voltage THD of R,RL and RC load with Multicarrier	89
4.21	(a) Unipolar Wave for Three Phase Voltage (RL-load) for $m_a=0.95$, (b) Unipolar THD for Three Phase Voltage (RL-load) for $m_a=0.95$.	91
4.22	(a) Unipolar Wave for Three Phase Current (RL-load) for $m_a=0.95$, (b) Unipolar THD for Three Phase Current (RL-load) for $m_a=0.95$.	92
4.23	(a) Bipolar Wave for Three Phase Voltage (RL-load) for $m_a=0.95$, (b) Bipolar THD for Three Phase Voltage (RL-load) for $m_a=0.95$.	93
4.24	(a) Bipolar Wave for Three Phase Current (RL-load) for $m_a=0.95$, (b) Bipolar THD for Three Phase Current (RL-load) for $m_a=0.95$.	93
4.25	(a) Unipolar Wave for Three Phase Voltage (RL-load) for $m_a=0.7$, (b) Unipolar THD for Three Phase Voltage (RL-load) for $m_a=0.7$.	94
4.26	(a) Unipolar Wave for Three Phase Current (RL-load) for $m_a=0.7$, (b) Unipolar THD for Three Phase Current (RL-load) for $m_a=0.7$.	95
4.27	(a) Bipolar Wave for Three Phase Voltage (RL-load) for $m_a=0.7$, (b) Bipolar THD for Three Phase Voltage (RL-load) for $m_a=0.7$.	96

4.28	(a) Bipolar Wave for Three Phase Current (RL-load) for $m_a= 0.7$, (b) Bipolar THD for Three Phase Current (RL-load) for $m_a= 0.7$.	96
4.29	(a) Unipolar Wave for Three Phase Voltage (RL-load) for $m_a= 0.4$, (b) Unipolar THD for Three Phase Voltage (RL-load) for $m_a= 0.4$.	97
4.30	(a) Unipolar Wave for Three Phase Current (RL-load) for $m_a= 0.4$, (b) Unipolar THD for Three Phase Current (RL-load) for $m_a= 0.4$.	98
4.31	(a) Bipolar Wave for Three Phase Voltage (RL-load) for $m_a= 0.4$, (b) Bipolar THD for Three Phase Voltage (RL-load) for $m_a= 0.4$.	99
4.32	(a) Bipolar Wave for Three Phase Current (RL-load) for $m_a= 0.4$, (b) Bipolar THD for Three Phase Current (RL-load) for $m_a= 0.4$.	99
4.33	(a) Unipolar Wave for Three Phase Voltage (RL-load) for $m_a= 0.2$, (b) Unipolar THD for Three Phase Voltage (RL-load) for $m_a= 0.2$.	100
4.34	(a) Unipolar Wave for Three Phase Current (RL-load) for $m_a= 0.2$, (b) Unipolar THD for Three Phase Current (RL-load) for $m_a= 0.2$.	101
4.35	(a) Bipolar Wave for Three Phase Voltage (RL-load) for $m_a= 0.2$, (b) Bipolar THD for Three Phase Voltage (RL-load) for $m_a= 0.2$.	102
4.36	(a) Bipolar Wave for Three Phase Current (RL-load) for $m_a= 0.2$, (b) Bipolar THD for Three Phase Current (RL-load) for $m_a= 0.2$.	102
4.37	The Current THD of R load with Various Value of Amplitude Modulation Ratio.	104
4.38	The Current THD of RL load with Various Value of Amplitude Modulation Ratio.	105
4.39	The Current THD of RC load with Various Value of Amplitude Modulation Ratio.	105
4.40	The Voltage THD of R,RL and RC load with Various Value of Amplitude Modulation Ratio.	106
4.41	(a) Unipolar Wave for Three Phase Voltage (RL-load) for $m_f= 100$, (b) Unipolar THD for Three Phase Voltage (RL-load) for $m_f= 100$.	108
4.42	(a) Unipolar Wave for Three Phase Current (RL-load) for $m_f= 100$, (b) Unipolar THD for Three Phase Current (RL-load) for $m_f= 100$.	109
4.43	(a) Bipolar Wave for Three Phase Voltage (RL-load) for $m_f= 100$, (b) Bipolar THD for Three Phase Voltage (RL-load) for $m_f= 100$.	109
4.44	(a) Bipolar Wave for Three Phase Current (RL-load) for $m_f= 100$, (b)	

	Bipolar THD for Three Phase Current (RL-load) for $m_f=100$.	110
4.45	(a) Unipolar Wave for Three Phase Voltage (RL-load) for $m_f=200$, (b) Unipolar THD for Three Phase Voltage (RL-load) for $m_f=200$.	111
4.46	(a) Unipolar Wave for Three Phase Current (RL-load) for $m_f=200$, (b) Unipolar THD for Three Phase Current (RL-load) for $m_f=200$.	112
4.47	(a) Bipolar Wave for Three Phase Voltage (RL-load) for $m_f=200$, (b) Bipolar THD for Three Phase Voltage (RL-load) for $m_f=200$.	112
4.48	(a) Bipolar Wave for Three Phase Current (RL-load) for $m_f=200$, (b) Bipolar THD for Three Phase Current (RL-load) for $m_f=200$.	113
4.49	(a) Unipolar Wave for Three Phase Voltage (RL-load) for $m_f=500$, (b) Unipolar THD for Three Phase Voltage (RL-load) for $m_f=500$.	114
4.50	(a) Unipolar Wave for Three Phase Current (RL-load) for $m_f=500$, (b) Unipolar THD for Three Phase Current (RL-load) for $m_f=500$.	115
4.51	(a) Bipolar Wave for Three Phase Voltage (RL-load) for $m_f=500$, (b) Bipolar THD for Three Phase Voltage (RL-load) for $m_f=500$.	115
4.52	(a) Bipolar Wave for Three Phase Current (RL-load) for $m_f=500$, (b) Bipolar THD for Three Phase Current (RL-load) for $m_f=500$.	116
4.53	(a) Unipolar Wave for Three Phase Voltage (RL-load) for $m_f=1000$, (b) Unipolar THD for Three Phase Voltage (RL-load) for $m_f=1000$.	117
4.54	(a) Unipolar Wave for Three Phase Current (RL-load) for $m_f=1000$, (b) Unipolar THD for Three Phase Current (RL-load) for $m_f=1000$	118
4.55	(a) Bipolar Wave for Three Phase Voltage (RL-load) for $m_f=1000$, (b) Bipolar THD for Three Phase Voltage (RL-load) for $m_f=1000$.	118
4.56	(a) Bipolar Wave for Three Phase Current (RL-load) for $m_f=1000$, (b) Bipolar THD for Three Phase Current (RL-load) for $m_f=1000$.	119
4.57	The Current THD of R load with Various Value of Frequency Modulation Ratio.	121
4.58	The Current THD of RL load with Various Value of Frequency Modulation Ratio.	122
4.59	The Current THD of RC load with Various Value of Frequency Modulation Ratio.	122
4.60	The Voltage THD of R, RL and RC load with Various Value of	

	Frequency Modulation Ratio.	123
4.61	(a) Unipolar Wave for Three Phase Voltage (RL-load) for $m_a=0.95$, (b) Unipolar THD for Three Phase Voltage (RL-load) for $m_a=0.95$.	125
4.62	(a) Unipolar Wave for Three Phase Current (RL-load) for $m_a=0.95$, (b) Unipolar THD for Three Phase Current (RL-load) for $m_a=0.95$.	126
4.63	(a) Bipolar Wave for Three Phase Voltage (RL-load) for $m_a=0.95$, (b) Bipolar THD for Three Phase Voltage (RL-load) for $m_a=0.95$.	127
4.64	(a) Bipolar Wave for Three Phase Current (RL-load) for $m_a=0.95$, (b) Bipolar THD for Three Phase Current (RL-load) for $m_a=0.95$.	127
4.65	(a) Unipolar Wave for Three Phase Voltage (RL-load) for $m_a=0.7$, (b) Unipolar THD for Three Phase Voltage (RL-load) for $m_a=0.7$	128
4.66	(a) Unipolar Wave for Three Phase Current (RL-load) for $m_a=0.7$, (b) Unipolar THD for Three Phase Current (RL-load) for $m_a=0.7$.	129
4.67	(a) Bipolar Wave for Three Phase Voltage (RL-load) for $m_a=0.7$, (b) Bipolar THD for Three Phase Voltage (RL-load) for $m_a=0.7$.	130
4.68	(a) Bipolar Wave for Three Phase Current (RL-load) for $m_a=0.7$, (b) Bipolar THD for Three Phase Current (RL-load) for $m_a=0.7$.	130
4.69	(a) Unipolar Wave for Three Phase Voltage (RL-load) for $m_a=0.4$, (b) Unipolar THD for Three Phase Voltage (RL-load) for $m_a=0.4$.	131
4.70	(a) Unipolar Wave for Three Phase Current (RL-load) for $m_a=0.4$, (b) Unipolar THD for Three Phase Current (RL-load) for $m_a=0.4$.	132
4.71	(a) Bipolar Wave for Three Phase Voltage (RL-load) for $m_a=0.4$, (b) Bipolar THD for Three Phase Voltage (RL-load) for $m_a=0.4$.	133
4.72	(a) Bipolar Wave for Three Phase Current (RL-load) for $m_a=0.4$, (b) Bipolar THD for Three Phase Current (RL-load) for $m_a=0.4$.	133
4.73	(a) Unipolar Wave for Three Phase Voltage (RL-load) for $m_a=0.2$, (b) Unipolar THD for Three Phase Voltage (RL-load) for $m_a=0.2$.	134
4.74	(a) Unipolar Wave for Three Phase Current (RL-load) for $m_a=0.2$, (b) Unipolar THD for Three Phase Current (RL-load) for $m_a=0.2$.	135
4.75	(a) Bipolar Wave for Three Phase Voltage (RL-load) for $m_a=0.2$, (b) Bipolar THD for Three Phase Voltage (RL-load) for $m_a=0.2$.	136
4.76	(a) Bipolar Wave for Three Phase Current (RL-load) for $m_a=0.2$, (b) Bipolar THD for Three Phase Current (RL-load) for $m_a=0.2$.	136

4.77	The Current THD of R load with Various Value of Amplitude Modulation Ratio.	138
4.78	The Current THD of RL load with Various Value of Amplitude Modulation Ratio.	139
4.79	The Voltage THD of R,RL and RC load with Various Value of Amplitude Modulation Ratio.	139
4.80	(a) Unipolar Wave for Three Phase Voltage (RL-load) for $m_f=100$, (b) Unipolar THD for Three Phase Voltage (RL-load) for $m_f=100$.	141
4.81	(a) Unipolar Wave for Three Phase Current (RL-load) for $m_f=100$, (b) Unipolar THD for Three Phase Current (RL-load) for $m_f=100$.	142
4.82	(a) Bipolar Wave for Three Phase Voltage (RL-load) for $m_f=100$, (b) Bipolar THD for Three Phase Voltage (RL-load) for $m_f=100$.	142
4.83	(a) Bipolar Wave for Three Phase Current (RL-load) for $m_f=100$, (b) Bipolar THD for Three Phase Current (RL-load) for $m_f=100$.	143
4.84	(a) Unipolar Wave for Three Phase Voltage (RL-load) for $m_f=200$, (b) Unipolar THD for Three Phase Voltage (RL-load) for $m_f=200$.	144
4.85	(a) Unipolar Wave for Three Phase Current (RL-load) for $m_f=200$, (b) Unipolar THD for Three Phase Current (RL-load) for $m_f=$	145
4.86	200.145 (a) Bipolar Wave for Three Phase Voltage (RL-load) for $m_f=200$, (b)	145
4.87	Bipolar THD for Three Phase Voltage (RL-load) for $m_f=200$. (a) Bipolar Wave for Three Phase Current (RL-load) for $m_f=200$, (b)	146
4.88	Bipolar THD for Three Phase Current (RL-load) for $m_f=200$. The Current THD of R load with Various Value of Frequency	147
4.89	Modulation Ratio.147 The Current THD of RL load with Various Value of Frequency	148
4.90	Modulation Ratio. The Voltage THD of R and RL load with Various Value of	148
4.91	Frequency Modulation Ratio.	151
4.92	The Voltage THD of R and RL loads with Various Value m_a	151
4.93	The Current THD of R load with Various Value m_a	152
4.94	The Current THD of RL load with Various Value m_a	153
4.95	The Voltage THD of R and RL loads with Various Value m_f	154

4.96	The Current THD of R load with Various Value m_f	154
5.1	The Current THD of RL load with Various Value m_f	158
	RCD snubber clamped circuit	

LIST OF TABLES

TABLE	TITLE	PAGE
2.1	Switching Contol	20
3.1	Gantt Chart of Research Methodology	32
3.2	Number of Components for Three phase of the Nine level MLI	33
3.3	Simulation Parameter of Unipolar and Bipolar Three Phase Inverter	66
3.7	Parameter of IGBT IHW15N120R3.	81
3.5	Switching Characteristic of IGBT IHW15N120R3.	81
3.6	IQ0515SA DC/DC Converter Parameter	84
3.7	Arduino Mega 2560 Parameter	85
4.1	Fixed Parameter for Multi-carrier Simulation	90
4.2	Simulation Result for One-Carrier	102
4.3	Simulation Result for Two-Carriers	103
4.4	Simulation Result for Three-Carriers	103
4.5	Simulation Result for Four-Carriers	103
4.6	Fixed Parameter for Various value of m_a Simulation	107
4.7	The THD of MLI for $m_a= 0.95$	120
4.8	The THD of MLI for $m_a= 0.7$	120
4.9	The THD of MLI for $m_a= 0.4$	120
4.10	The THD of MLI for $m_a= 0.2$	121
4.11	Number of level achived by MLI	124
4.12	Fixed Parameter for Various value of m_f Simulation	125
4.13	The THD of MLI for $m_f=100$	138
4.14	Table 4. 14: The THD of MLI for $m_f=200$	138
4.15	The THD of MLI for $m_f=500$	138
4.16	The THD of MLI for $m_f=1000$	139
4.17	Fixed Parameter for Various value of m_a Hardware Experiment	143
4.18	The THD of MLI for $m_a= 0.95$	156
4.19	The THD of MLI for $m_a= 0.7$	156
4.20	The THD of MLI for $m_a= 0.4$	156
4.21	The THD of MLI for $m_a= 0.2$	157
4.22	Fixed Parameter for Various value of m_f Hardware Experiment	160