

Contents

Preface	...(vii)
Acknowledgement	...(ix)
Nomenclature	...(xv)
About the Author	...(xix)

Chapter 1: Introduction to Multilevel Inverters

1.1 Introduction	...1
1.2 Classification of Multilevel Inverters	...10
1.3 Harmonic Distortion	...11
1.4 Classification of Modulation Techniques	...12
1.5 Classification of Power Semiconductor Switching Devices	...13
1.6 Applications of Multilevel Inverters	...16
1.7 Summary	...16
Learning Outcomes	...16
Questions	...16
Multiple Choice Questions	...17
Answers to Multiple Choice Questions	...18

Chapter 2: Modulation Techniques for Multilevel Inverters

2.1 Introduction	...19
2.2 Pulse Width Modulation Technique	...20
2.2.1 Sinusoidal Pulse Width Modulation Technique	...21
2.2.2 Third Harmonic Injection Pulse Width Modulation Technique	...22
2.2.3 Selected Harmonic Elimination Pulse Width Modulation Technique	...25
2.3 Multicarrier Pulse Width Modulation Technique	...32
2.3.1 Phase-shifted Carrier Pulse Width Modulation Technique	...33
2.3.2 Level-shifted Carrier Pulse Width Modulation Technique	...35
2.4 Space Vector Pulse Width Modulation Technique	...40
2.4.1 Two-dimensional Algorithm for SVPWM	...41
2.4.2 Three-dimensional (3-D) Algorithm for SVPWM	...63

2.5	Carrier-based Space Vector Pulse Width Modulation	...75
2.6	Summary	...82
	Learning Outcomes	...82
	Questions	...83
	Multiple Choice Questions	...83
	Exercise Problems	...85
	Answers to Multiple Choice Questions	...87

Chapter 3: Diode-Clamped Multilevel Inverters

3.1	Construction of Single-phase Three-level Diode-clamped Inverter	...88
3.2	Three Level Diode-Clamped Inverter	...92
3.3	Five level and Seven Level Diode-Clamped Inverter	...100
3.4	m-Level Diode Clamped Inverter	...171
3.5	Case Studies	...173
	3.5.1 Case Study 1	...174
	3.5.2 Case Study 2	...180
	3.5.3 Case Study 3	...183
	3.5.4 Case Study 4	...186
3.6	Summary	...189
	Learning Outcomes	...190
	Questions	...190
	Multiple Choice Questions	...192
	Exercise Problems	...194
	Answers to Multiple Choice Questions	...198

Chapter 4: Flying-Capacitor Multilevel Inverters

4.1	Construction of Three-level Flying Capacitor Inverter	...199
4.2	Three level Flying Capacitor Inverter	...203
4.3	Five Level Flying Capacitor Inverter	...211
4.4	Seven Level Flying Capacitor Inverter	...236
4.5	m-level Flying Capacitor Inverter	...266
4.6	Case Studies for Flying-capacitor Multilevel Inverter	...267
	4.6.1 Case Study 1	...267
	4.6.2 Case Study 2	...271
4.7	Summary	...276
	Learning Outcomes	...276

Questions	...277
Multiple Choice Questions	...278
Exercise Problems	...280
Answers to Multiple Choice Questions	...283

Chapter 5: Cascaded H-Bridge Inverters

5.1 Introduction	...284
5.2 Symmetrical Cascaded H-Bridge Inverters	...285
5.2.1 Symmetrical Configuration for Three Level Cascaded H-bridge Inverter with Equal dc Voltage Sources	...285
5.2.2 Symmetrical Configuration for Five - Level Cascaded H-bridge Inverter with Equal dc Voltage Sources (with two cells)	...288
5.2.3 Symmetrical Configuration for Seven-Level Cascaded H-bridge Inverter with Equal dc Voltage Sources (with three cells)	...295
5.3 Asymmetrical Cascaded H-Bridge Inverters	...304
5.3.1 Asymmetrical Configuration for Seven-Level Cascaded H-bridge Inverter with Unequal dc Voltage Sources (with two-cells)	...304
5.3.2 Asymmetrical Configuration for Thirteen - Level Cascaded H-bridge Inverter with Unequal dc Voltage Sources (with three-cells)	...313
5.4 Symmetrical Transistor-clamped Cascaded H-Bridge Inverters	...331
5.4.1 Symmetrical Configuration of Five-level Transistor-Clamped H- bridge Inverter with Reduced Number of Switching Devices	...331
5.4.2 Symmetrical Configuration of Transistor-clamped Nine-level Cascaded H-bridge Inverter with Reduced Number of Switching Devices or H-bridges	...335
5.5 Asymmetrical configuration of Transistor-clamped Cascaded H-Bridge Inverters	...348
5.5.1 Asymmetrical Configuration of Seven - Level Transistor-clamped Single H-bridge Inverter with Reduced Number of Switching Devices or H-bridges	...349
5.5.2 Asymmetrical Configuration of Twenty-one - Level Transistor-clamped Cascaded two-H-bridge Inverter with Reduced Number of Switching Devices or H-bridges	...356
5.6 m-level Cascaded H-bridge Inverter	...382
5.7 Case Studies for Cascaded H-bridge Inverters	...384
5.7.1 Case Study 1	...385
5.7.2 Case Study 2	...391

5.8 Summary	...397
Learning Outcomes	...399
Questions	...399
Multiple Choice Questions	...401
Exercise Problems	...406
Answers to Multiple Choice Questions	...408

Chapter 6: Introduction to Hybrid Multilevel Inverters

6.1 Introduction	...409
6.2 Hybrid Multilevel Inverters based on Combination of any Two Types of Multilevel Inverter	...410
6.2.1 Hybrid Multilevel Inverter with Half-bridge Modules	...410
6.2.2 New Symmetrical Hybrid Multilevel Inverter	...415
6.2.3 Hybrid-Clamped Five-level Inverter	...417
6.2.4 New Hybrid Asymmetrical Multilevel H-Bridge Inverter	...427
6.2.5 Hybrid H-bridge Type Diode Clamped Multilevel Inverter (H-bridge based NPC)	...428
6.2.6 Hybrid Flying Capacitor and Active NPC Inverter	...432
6.3 Hybrid Inverter with Reduced Power Semiconductor Switches	...435
6.3.1 Various Configurations of Hybrid Inverters	...435
6.3.2 49-Level Inverter from Two-Cascaded Seven-Level Inverters	...448
6.4 Advanced Hybrid Multilevel Inverter Classification	...450
6.5 Chapter Summary	...451
6.6 Overall Summary	...452
Learning Outcomes	...457
Questions	...458
Multiple Choice Questions	...459
Exercises	...463
Answers to Multiple Choice Questions	...464
References	...465
Index	...471

Nomenclature

MLI	Multi-Level Inverter
DCMLI	Diode-Clamped Multi-Level Inverter
FCMLI	Flying-Capacitor Multi-Level Inverter
NPC-MLI	Neutral Point Clamped Multi-Level Inverter
CHB-MLI	Cascaded H-Bridge Multi-Level Inverter
HMI	Hybrid Multi-level Inverter
PWM	Pulse Width Modulation
SPWM	Sinusoidal Pulse Width Modulation
THI-PWM	Third Harmonic Injected – Pulse Width Modulation
SHE-PWM	Selective Harmonic Elimination-Pulse Width Modulation
SVPWM	Space Vector Pulse Width Modulation
2-D SVM	Two-Dimensional Space Vector Modulation
3-D SVM	Three-Dimensional Space Vector Modulation
PS-PWM	Phase Shifted-Pulse Width Modulation
LS-PWM	Level Shifted-Pulse Width Modulation
CBPWM	Carrier Based Pulse Width Modulation
CBSVPWM	Carrier Based Space Vector Pulse Width Modulation
PD-CB-PWM	Phase Disposition-Carrier Based-Pulse Width Modulation
POD-CB-PWM	Phase Opposition Disposition-Carrier Based-Pulse Width Modulation
APOD-CB-PWM	Alternate Phase Opposite Disposition-Carrier Based-Pulse Width Modulation
CMLI	Cascaded Multi Level Inverter
CM	Common Mode
VSI	Voltage Source Inverter
VSC	Voltage Source Converter
SV	Small Vector
MV	Medium Vector
SSV	Switching State Vector
P	Prism
T	Tetrahedron
NZSV	Non-Zero State Vector

xvi | Nomenclature

ZSV	Zero State Vector
THD	Total Harmonic Distortion
STATCOM	Static VAR Compensation
FACTS	Flexible AC Transmission System
SSSC	Static Synchronous Series Compensation
DVR	Dynamic Voltage Restorer
D-STATCOM	Distributed Static VAR Compensation
PQ	Power Quality
EMI	Electro-Magnetic Interference
EMC	Electro-Magnetic Compatibility
RFI	Radio Frequency Interference
NPC	Neutral Point Converter
SMC	Stacked Multi Cell
ANPC	Active Neutral Point Converter
MMI	Modular Multilevel Inverter
HB-NPC	H-Bridge-Neutral Point Converter
HMC	Hybrid Multilevel Converter
HEV	Hybrid Electric Vehicles
EV	Electric Vehicles
HVDC	High Voltage Direct Current
HV	High Voltage
AC	Alternating Current
BJT	Bipolar Junction Transistor
MOSFET	Metal Oxide Semiconductor Field Effect Transistor
IGBT	Insulated Gate Bipolar Transistor
GTO	Gate Turn-off Thyristor
IGCT	Insulated Gate Commutated Transistor
ETO	Emitter Turn-Off Transistor
MTO	MOS Turn-Off Transistor
MCT	MOS Controlled Transistor
SITH	Static Induction Thyristor
V	Voltage
V_{dc}	DC Voltage
V_{aN}, V_{bN}, V_{cN}	Pole Voltages
V_{an}, V_{bn}, V_{cn}	Phase Voltages
V_{ab}, V_{bc}, V_{ca}	Line Voltages