

**Chapter 1 : Switched Voltage Regulators 1-1 to 1-62**

Syllabus : Review of basic dc-dc voltage regulator configurations- Buck, Boost, Buck-boost converters, Flyback and Forward converters, Other converter configurations like Half bridge, Full bridge configurations, Push pull converter, C'uk converter, Sepic converter, Design criteria for SMPS, Multi output switch mode regulators, Design of inductor and high frequency transformer.

1.1	Introduction	1-2	1.5.5	Disadvantages of Buck-Boost Regulator	1-19
1.1.1	Linear Power Supplies	1-2	1.5.6	Comparison of Switching Regulators	1-21
1.1.2	Switch Mode Power Supply (SMPS)	1-3	1.6	Cuk Regulators	1-21
1.1.3	Advantages of SMPS	1-4	1.6.1	Analysis of Cuk Regulator	1-23
1.1.4	Disadvantages of SMPS	1-4	1.6.2	Advantages Cuk Converter	1-26
1.1.5	Comparison of Linear and Switching Mode Regulators	1-4	1.6.3	Disadvantages Cuk Converter	1-26
1.2	Classification of SMPS	1-5	1.6.4	Features of Cuk Converter	1-26
1.3	Buck Converter	1-5	1.7	SMPS with Electrical Isolation	1-26
1.3.1	Analysis of Buck Converter	1-7	1.8	Flyback Converters	1-27
1.3.2	Advantages of Buck Regulator	1-9	1.8.1	Discontinuous Conduction Mode	1-27
1.3.3	Disadvantages	1-9	1.8.2	FB Regulator in Continuous Mode	1-30
1.4	Switching Boost Regulator	1-10	1.8.3	Continuous versus Discontinuous Mode	1-31
1.4.1	Discontinuous Conduction Mode	1-11	1.8.4	Why is Discontinuous Mode Preferred ?	1-32
1.4.2	Continuous Conduction Mode	1-11	1.8.5	Design Criterion for F.B. Converter	1-32
1.4.3	Analysis of Boost Converter	1-13	1.9	Forward Converter	1-34
1.4.4	Advantages of Boost Regulator	1-14	1.9.1	Single Ended Forward Converter	1-34
1.4.5	Disadvantages	1-15	1.9.2	F.C. with Tertiary Winding	1-35
1.5	Switching Buck-Boost Regulator	1-15	1.9.3	F.C. using Two Transistors	1-37
1.5.1	Discontinuous Conduction Mode	1-16	1.9.4	Flyback Versus Forward Converter	1-41
1.5.2	Continuous Conduction Mode	1-17	1.9.5	Comparison of F.B. and Forward Converters	1-41
1.5.3	Analysis of Buck-Boost Converter	1-18	1.10	Push-Pull Converter	1-42
1.5.4	Advantages of Buck-Boost Regulator	1-19	1.10.1	Important Points	1-43
			1.10.2	Advantages of P-P Converter	1-43
			1.10.3	Disadvantages of P-P Converter	1-43
			1.10.4	Applications of P-P Converter	1-44
			1.11	SEPIC	1-44
			1.11.1	Discontinuous Mode	1-46



1.11.2	Reliability and Efficiency	1-46	2.1.2	Disadvantages of Resonant Converters	2-2
1.11.3	Advantages of SEPIC	1-46	2.2	Classification of Resonant Converters	2-3
1.11.4	Disadvantages of SEPIC	1-47	2.2.1	Applications of Resonant Converters	2-4
1.11.5	Applications of SEPIC	1-47	2.3	Series Loaded Resonant (SLR) DC-DC Converters	2-4
1.12	Half Bridge Converter	1-47	2.3.1	Discontinuous Conduction Mode ($\omega_s < \omega_o / 2$)	2-5
1.12.1	Advantages of Half Bridge Converter	1-50	2.3.2	Continuous Conduction Mode with $\omega_o / 2 < \omega_s < \omega_o$	2-6
1.12.2	Disadvantages of H.B. Converter	1-50	2.3.3	Continuous Conduction Mode ($\omega_s > \omega_o$)	2-7
1.12.3	Forward versus H. B. Converter	1-50	2.3.4	Regulation of output voltage of SLR Converter	2-8
1.13	Full Bridge Converter	1-51	2.3.5	Advantages of SLR DC-DC Converter ..	2-9
1.13.1	Advantages of F.B. Converter	1-53	2.3.6	Disadvantages of SLR Converter	2-9
1.13.2	Disadvantages	1-53	2.4	Parallel Loaded Resonant (PLR) DC-DC Converters	2-9
1.13.3	Applications	1-53	2.4.1	Discontinuous Current Mode	2-10
1.13.4	Half Bridge Versus Full Bridge Converter	1-53	2.4.2	Continuous Conduction Mode ($\omega_s < \omega_o$)	2-12
1.13.5	General Applications of SMPS	1-53	2.4.3	Continuous Conduction Mode ($\omega_s > \omega_o$)	2-13
1.14	Design criteria for SMPS	1-53	2.4.4	Regulation of output voltage of PLR Converter	2-13
1.15	Multi Output SMPS	1-55	2.4.5	Advantages of PLR DC-DC Converter	2-13
1.16	Design of Inductor and Transformer	1-55	2.4.6	Disadvantages of PLR Converter	2-14
1.16.1	Transformer Design	1-56	2.4.7	Comparison of SLR and PLR Converters	2-14
1.16.2	Design of a DC Inductor	1-59	2.5	Class-E Resonant Converters	2-14
1.16.3	Magnetic Saturation.....	1-61	2.5.1	Optimum Mode of Operation	2-15
	• Review Questions	1-61			
Chapter 2 : Resonant Converters		2-1 to 2-34			
Syllabus : Introduction, Need of resonant converters, Classification of resonant converters, Load resonant converters, Resonant switch converters, Zero voltage switching dc-dc converter, Zero current switching dc-dc converter, Clamped voltage topologies.					
2.1	Need of Resonant Converters	2-2			
2.1.1	Advantages of Resonant Converters	2-2			



2.5.2	DC-to-DC Converter	2-16
2.5.3	Advantages of Class E Converter	2-16
2.5.4	Disadvantages of Class E Converter ...	2-16
2.5.5	Application	2-16
2.6	Resonant Switch Converters	2-16
2.6.1	Categories of Resonant Switch Converter	2-16
2.7	ZCS DC-DC Converter	2-17
2.7.1	L and M Types of ZCS Switch	2-17
2.7.2	Half-wave Types of ZCS Resonant Switches	2-17
2.7.3	Full-wave Types of ZCS Resonant Switch	2-18
2.7.4	M-Type ZCS DC-DC Converter	2-18
2.7.5	L-Type ZCS DC-DC Converter	2-21
2.7.6	L-Type ZCS Converter with Energy Feedback	2-22
2.7.7	Advantages of ZCS Converter	2-23
2.7.8	Disadvantages of ZCS Converter	2-23
2.8	Zero Voltage Switching (ZVS) DC-DC Converter	2-23
2.8.1	Features of ZVS Converter	2-26
2.8.2	Advantages of ZVS Converter	2-26
2.8.3	Disadvantages of ZVS Converter	2-27
2.8.4	Comparison of ZVS and ZCS Topologies	2-27
2.8.5	ZVS is Better Than ZCS	2-28
2.9	ZVS Clamped-Voltage Topologies	2-28
2.9.1	ZVS-CV DC-to-DC (Two Quadrant) Resonant Converter	2-28
2.9.2	ZVS-CV DC-to-AC Inverters	2-32

2.9.3	Switch-Mode Converter With Voltage Cancellation.....	2-32
• Review Questions.....		2-33

Chapter 3 : Multilevel Converters **3-1 to 3-30**

Syllabus : Need for multi-level inverters, Concept of multi-level, Topologies for multi-level: Diode Clamped, Flying capacitor and Cascaded H-bridge multilevel Converters configurations; Features and relative comparison of these configurations, Applications, Introduction to Carrier based PWM technique and SVPWM for Multilevel converters.

3.1	Multilevel Inverters	3-2
3.1.1	Need of Multilevel Inverters	3-2
3.1.2	Multilevel Concept	3-3
3.1.3	Output Phase Voltage	3-4
3.1.4	Realization of multilevel Inverters	3-4
3.1.5	Features/Advantages of MLI	3-4
3.1.6	Limitations of MLI	3-5
3.2	Types of Multilevel Inverter	3-5
3.3	Diode Clamped Multilevel Inverter	3-5
3.3.1	Features of Diode-Clamped Inverter	3-7
3.3.2	Advantages of Diode-Clamped Inverter	3-8
3.3.3	Disadvantages of Diode-Clamped Inverter	3-8
3.3.4	Diode-Clamp Inverter with Series Connected Diodes	3-8
3.3.5	Improved Diode-Clamp Inverter	3-9
3.4	Flying Capacitors Multi-level Inverter (FCMLI)	3-10
3.4.1	Features of Flying Capacitors Multi-level Inverter	3-11
3.4.2	Advantages of FCMLI	3-12



3.4.3	Disadvantages of FCMLI	3-12
3.5	Cascaded Multi-level Inverter	3-12
3.5.1	Generation of Quasi-square Waveform	3-14
3.5.2	Features of Cascaded Inverter	3-15
3.5.3	Advantages of Cascaded Inverter	3-15
3.5.4	Disadvantages of Cascaded Inverter ..	3-15
3.6	Comparison of Multi-level Converters	3-15
3.7	Comparison of Two-level and Multi-level Inverters	3-16
3.8	Applications of Multilevel Inverter	3-16
3.8.1	Reactive Power Compensation	3-17
3.8.2	Back-to-Back Intertie	3-18
3.8.3	Adjustable Speed Drives	3-18
3.9	DC Link Capacitor Voltage Balancing	3-19
3.10	PWM for Two Level Inverters	3-20
3.10.1	Sinusoidal Pulse Width Modulation (SPWM)	3-20
3.10.2	Three Phase Two Level PWM Inverter	3-22
3.10.3	Advantages of SPWM	3-24
3.10.4	Disadvantages of SPWM	3-24
3.11	Two Level Space Vector PWM Inverter	3-24
3.11.1	Implementing the SVPWM	3-26
3.11.2	Advantages of SVPWM	3-26
3.11.3	Applications of SVPWM	3-26
3.11.4	Comparison of PWM Techniques	3-26
3.12	Carrier based PWM technique for MLI	3-27
3.12.1	Three Level Three Phase Inverter	3-27
3.12.2	Generation of Gating Signals	3-27
3.12.3	SPWM in Three-Level Inverter	3-28
3.12.4	SVPWM in Three-Level Inverter	3-29
	• Review Questions	3-29

Chapter 4 : Multi-Pulse Converters 4-1 to 4-32

Syllabus : Concept of multi-pulse, Configurations for m-pulse ($m = 12, 18, 24 \dots$) converters, Different phase shifting transformer ($Y-\Delta 1, Y-\Delta 2, Y-Z1$ and $Y-Z2$) configurations for multi-pulse converters, Applications.

4.1	Introduction.....	4-2
4.1.1	Advantages of Multi-pulse Converters.....	4-2
4.1.2	Disadvantages of Multi-pulse Converters.....	4-2
4.1.3	A 3-Pulse Converter.....	4-3
4.2	Six-Pulse SCR Rectifier	4-3
4.2.1	Idealized 6-Pulse Converter.....	4-3
4.2.2	Expression for Average Output Voltage.....	4-6
4.2.3	Fourier Analysis of Source Current.....	4-7
4.3	Analysis of Six- Pulse Converter.....	4-9
4.3.1	Input Displacement Factor (DSF).....	4-9
4.3.2	Current Distortion Factor (CDF)	4-9
4.3.3	Input Power Factor (PF).....	4-9
4.3.4	Total Harmonic Distortion (THD)	4-10
4.4	Effect of Source Inductance	4-10
4.4.1	Operation Without Source Inductance	4-10
4.4.2	Operation with Source Inductance.....	4-10
4.4.3	Effect of Source Inductance in Three Pulse Converter.....	4-11
4.4.4	Effect of Source Inductance in 6-Pulse Converter.....	4-12
4.4.5	THD Profile of 6-Pulse Converter	4-14
4.4.6	Input PF Profile of 6-Pulse Converter.....	4-14
4.5	Multi-pulse SCR Rectifiers	4-16



<p>4.6 The 12-Pulse SCR Rectifier..... 4-16</p> <p>4.6.1 Idealized 12-Pulse Rectifier..... 4-17</p> <p>4.6.2 Current waveforms..... 4-17</p> <p>4.6.3 RMS Value of Transformer Primary Line Current..... 4-18</p> <p>4.6.4 Elimination of Harmonics..... 4-18</p> <p>4.6.5 Effect of Line and Leakage Inductances..... 4-20</p> <p>4.6.6 THD and PF of 12-Pulse Converter:..... 4-20</p> <p>4.6.7 Merits of 12-Pulse Converter 4-20</p> <p>4.6.8 Application of a 12-Pulse Converter..... 4-21</p> <p>4.7 18-pulse SCR Rectifier 4-21</p> <p>4.7.1 Voltage and Current Waveforms 4-22</p> <p>4.7.2 Harmonic Contents 4-23</p> <p>4.7.3 The Line Current THD and Input PF..... 4-23</p> <p>4.7.4 Merits of 18-Pulse Converter 4-24</p> <p>4.7.5 Comparison of 12-Pulse and 18-Pulse Converters..... 4-24</p> <p>4.8 24-pulse SCR Rectifier 4-24</p> <p>4.8.1 Harmonic Contents 4-25</p> <p>4.9 Phase Shifting Transformers 4-25</p> <p>4.10 Y/Z Phase Shifting Transformers 4-26</p> <p>4.10.1 Y/Z-1 Transformers..... 4-26</p> <p>4.10.2 Y/Z-2 Transformers..... 4-27</p> <p>4.11 The Δ / Z Transformers..... 4-28</p> <p>4.11.1 The Δ / Z-1 Transformer..... 4-28</p> <p>4.11.2 The Δ / Z-2 Transformer..... 4-29</p> <p>4.11.3 Transformers for Multi-pulse Converters..... 4-30</p> <p>4.12 Harmonic Current Cancellation:..... 4-30</p>	<p>4.12.1 Phase Displacement of Harmonic Currents 4-30</p> <p>• Review Questions..... 4-31</p> <hr/> <p>Chapter 5 : HVDC Transmission 5-1 to 5-28</p> <div style="border: 1px solid black; padding: 5px; margin: 5px 0;"> <p>Syllabus : Introduction, Operation of 12-pulse converter as receiving and sending terminals of HVDC system, Equipment required for HVDC System and their significance, Comparison of AC and DC transmission, Control of HVDC transmission.</p> </div> <p>5.1 Introduction..... 5-2</p> <p>5.2 HVAC Transmission System 5-2</p> <p>5.2.1 Primary Transmission 5-2</p> <p>5.2.2 Secondary Transmission 5-3</p> <p>5.2.3 Primary Distribution 5-3</p> <p>5.2.4 Secondary Distribution 5-3</p> <p>5.3 Drawbacks of HVAC Transmission 5-3</p> <p>5.4 HVDC System 5-4</p> <p>5.5 Equipment for HVDC System 5-5</p> <p>5.5.1 Converter Station 5-5</p> <p>5.5.2 Converter Unit 5-6</p> <p>5.5.3 Thyristor Valves 5-8</p> <p>5.5.4 Converter Transformers 5-9</p> <p>5.5.5 Filters in the Converter Station 5-9</p> <p>5.5.6 DC Switchgear 5-10</p> <p>5.5.7 DC Cables 5-11</p> <p>5.6 Comparison of AC and DC Transmission 5-11</p> <p>5.6.1 Evaluation of Transmission Costs 5-11</p> <p>5.6.2 Evaluation of Technical Considerations 5-12</p> <p>5.6.3 Evaluation of Reliability and Availability 5-13</p>
---	---



5.6.4	Comparison of HVAC and HVDC Systems	5-13
5.7	Advantages of HVDC System	5-15
5.8	Disadvantages of HVDC System	5-16
5.8.1	Advances in HVDC Technology	5-16
5.9	Applications of DC Transmission	5-16
5.10	Types of HVDC Systems	5-17
5.10.1	Monopolar Link	5-17
5.10.2	Bipolar Link	5-18
5.10.3	Homopolar Link	5-18
5.11	Multi-terminal DC Systems(MTDC)	5-19
5.11.1	Application areas of MTDC	5-19
5.11.2	Types of MTDC Systems	5-20
5.12	Controls of HVDC Transmission	5-20
5.12.1	Desired Features of DC Control	5-21
5.12.2	Steady state and dynamic requirements	5-21
5.12.3	Basics of Control for a Two-Terminal dc Link	5-21
5.12.4	Control modes at Rectifier	5-22
5.12.5	Control Modes at Inverter	5-23
5.12.6	Other Modifications	5-23
5.13	Control Implementation	5-23
5.13.1	Firing Angle Control	5-24
5.14	Control Loops	5-25
5.14.1	Current Control Loops	5-25
5.14.2	Gamma Control Loop	5-26
5.14.3	Hierarchy of dc Controls	5-27
5.14.4	Monitoring of Signals.....	5-28
	• Review Questions	5-28

Chapter 6 : FACTS Devices**6-1 to 6-24**

Syllabus : Importance of reactive power compensation, Flow of power in AC system and conventional control mechanisms, Definition of Flexible ac Transmission Systems (FACTS) and brief description, possible benefits from FACTS, Thyristor- Controlled Reactor (TCR), Fixed Capacitor-Thyristor-Controlled Reactor (FC-TCR), Thyristor-Switched capacitor and Reactor, Thyristor-Switched capacitor-Thyristor-Controlled Reactor (TSCTCR), STATCOM configuration and operating principle, Static characteristics of SVC and STATCOM Comparison of SVC and STATCOM, Principle of series compensation, Introduction to Static Synchronous Series Compensator, Advantages and limitation of SSSC, Introduction to UPFC and operating principle.

6.1	Reactive Power (VAR) Compensation.....	6-2
6.2	Introduction to FACTs	6-2
6.2.1	FACTS Devices	6-3
6.2.2	Advantages of FACTS Devices	6-3
6.2.3	FACTS Controllers	6-4
6.3	Flow of Power in AC System	6-4
6.3.1	Expressions for Active and Reactive Powers	6-4
6.3.2	Controllable Variables	6-6
6.4	Classification of FACTS Controllers	6-6
6.5	Shunt Compensators	6-7
6.5.1	Principle of Shunt Compensation	6-7
6.6	Classification of Shunt Compensators	6-8
6.6.1	Fixed Capacitor Thyristor-Controlled Reactor (FC-TCR)	6-9
6.6.2	Thyristor Switched Capacitor (TSC)	6-10
6.6.3	Summary of Shunt Compensators	6-12
6.7	Static VAR Compensator (SVC)	6-12
6.7.1	Static Characteristic of SVC	6-13
6.7.2	Advantages of SVC	6-14



6.7.3	Disadvantages of SVC	6-14	6.10	Static Synchronous Series Compensator (SSSC)	6-19
6.8	Static Compensator (STATCOM)	6-14	6.10.1	Advantages of SSSC	6-20
6.8.1	Static Characteristic of STATCOM	6-15	6.10.2	Disadvantages of SSSC	6-20
6.8.2	Features of STATCOM	6-15	6.10.3	Applications of SSSC	6-20
6.8.3	Difference between SVC and STATCOM	6-15	6.10.4	Summary of Series Compensators	6-21
6.8.4	Advantages of STATCOM over SVC	6-15	6.11	Phase Angle Compensation	6-21
6.8.5	Comparison of SVC and STATCOM	6-16	6.12	Unified Power Flow Controller (UPFC)	6-22
6.9	Series Compensation	6-16	6.12.1	Advantages of UPFC	6-23
6.9.1	Series Capacitor Compensation	6-17	6.12.2	Disadvantages of UPFC	6-23
6.9.2	Series Compensators	6-18		• Review Questions.....	6-23
6.9.3	Series Static VAR Compensator (SSVC)	6-18		• Appendix-A : Tables for Transformer Design	A-1 to A-4

□□□