

Contents

Main Chapters		
Chapter No.	Title	Page No.
1	Marine High Voltage Regulations	1
2	High Voltage Hazards and Protective Equipment	21
3	High Voltage Safe Working Procedures	47
4	High Voltage Generation and Distribution	99
5	High Voltage Switchgear	139
6	High Voltage Protection Systems	171
7	Alternate Marine Power (Cold Ironing)	191
8	High Voltage Electrical Propulsion Systems	211
9	High Voltage Cables and Insulation Testing	253
10	Questions and Answers	275

Contents

Chapter 1 – Marine High Voltage Regulations		
Article No.	Article	Page No.
1.1	Introduction	1
1.2	Competency Requirements for Personnel working on High Voltage Systems	2
1.2.1	STCW Section B-III/2	3
1.3	Advantages and Disadvantages of High Voltage (HV) Onboard	4
1.3.1	Reduction in Current	4
1.3.2	Reduction in Short Circuit Level	5
1.3.3	Reduction in Losses	5
1.3.4	Disadvantages	5
1.4	A Typical High Voltage Installation	6
1.5	Marine / Offshore Statutory Requirements	7
1.5.1	International Organizations for High Voltage Electrical Standards	7
1.5.1.1	IEC - International Electrotechnical Commission	7
1.5.1.2	IEC 60092 Electrical Installations in Ships	7
1.5.1.3	IEEE 45 - Institute of Electrical and Electronics Engineers	7
1.5.1.4	NEMA - The National Electrical Manufacturers Association	7
1.5.1.5	NFPA - National Fire Protection Association	7
1.5.1.6	ANSI-American National Standards Institute (ANSI)	8
1.5.1.7	OSHA - Occupational Safety and Health Agency	8
1.5.1.8	CENELEC - European Committee for Electro Technical Standardization	8
1.5.1.9	BSI - British Standards Institute	8
1.5.1.10	Multilateral Environment, Global Adoption	9
1.6	International Association of Classification Societies Requirements for High Voltage	9
1.7	Differences Between High Voltage Supply and Low Voltage Supply Onboard Ships	20

Contents

Chapter 2 – High Voltage Hazards and Protective Equipment		
Article No.	Article	Page No.
2.1	The Risk of Electricity	21
2.2	Electrical Hazards Associated with High Voltage Systems	22
2.2.1	Electric Shock	23
2.2.2	Effects of Electrical Shock	24
2.2.3	Body Resistance with Increase in Voltage	25
2.2.4	Steps to Minimize the Risk of an Electrical Shock Onboard	26
2.2.5	First Aid in the Event of an Electric Shock	27
2.2.5.1	The Basic Procedure	28
2.2.5.2	Rescue of a Victim of Electric Shock	28
2.2.5.3	Mouth-to-Mouth Resuscitation	29
2.2.6	Arc Hazard	30
2.2.7	Electric Arc Resulting in an Electrical Arc Blast (Explosion)	31
2.2.7.1	Causes of an Arc Flash	32
2.2.7.2	Effect of an Arc Flash on the Human Body	33
2.2.8	Arc Flash Regulations and Standards	33
2.2.8.1	Warning Labels on Equipment	34
2.2.8.2	Arc Flash Prevention	35
2.2.8.3	Arc Flash Analysis Input	35
2.2.8.4	Arc Flash Analysis Output	35
2.2.9	Fault Current Calculation	35
2.2.10	Incident Energy	36
2.2.10.1	Incident Energy Calculation	37
2.2.10.2	Incident Energy and Damage Level	37
2.2.10.3	Hazard Risk Category	37
2.2.11	Approach / Protection Boundaries	38
2.2.11.1	Flash Protection Boundary (Outer Boundary)	38
2.2.11.2	Limited Approach	38
2.2.11.3	Restricted Approach	39
2.2.11.4	Prohibited Approach (Inner Boundary)	39

Contents

Chapter 2 – High Voltage Hazards and Protective Equipment (Continued)		
Article No.	Article	Page No.
2.2.12	Expected Proximity of Hands and Tools to Live LV Conductors	39
2.2.13	PPE for Arc Flash Hazards	39
2.2.13.1	Requirements of PPE	39
2.2.13.2	Voltage-Rated Gloves	41
2.2.13.3	Electrical Insulating Matting (IEC 61111-2009)	43
2.2.14	Arc Flash Detector	44
2.2.14.1	Wavelength and Illumination	46
2.2.15	The Best Way to Prevent the Hazards of High Voltage	46

Chapter 3 – High Voltage Safe Working Procedures		
Article No.	Article	Page No.
3.1	Identifying the need for Safe Working Procedures	47
3.2	The Inherent Dangers and Avoidance of Disastrous Consequences	48
3.2.1	Risk Assessment	49
3.2.2	Tool Box Meeting	52
3.2.2.1	Toolbox Meeting Agenda	52
3.2.3	High Voltage Electrical Risk Assessment Steps	53
3.2.4	Risk Assessment Forms	55
3.3	Important Terminology Associated with High Voltage Systems	60
3.3.1	Authorized Person (AP)	60
3.3.2	Responsibility and Authority of the Authorised Person	60
3.3.3	Competent Person	61
3.3.4	Permit to Work (PTW)	62
3.4	Permit to Work Procedure	62
3.4.1	Guidelines for the Permit Issuer (Authorised Person)	62
3.4.2	Guidelines for the Permit Receiver (Competent Person)	63
3.5	Sanction for Test (SFT)	64
3.5.1	Sanction for Test (SFT) – High Voltage Electrical Equipment	65
3.6	Limitation of Access Form (LOA)	66
3.7	Caution and Danger Notices	67

Contents

Chapter 3 – High Voltage Safe Working Procedures (Continued)		
Article No.	Article	Page No.
3.8	Earthing Down	68
3.8.1	Additional Earth (Portable Ground Earth Rod Set with Earthing Wire and Clamp)	69
3.8.1.1	Grounding Sticks	69
3.8.2	Bus Bar Earthing	71
3.8.3	Safety Lock	71
3.8.4	Key Safe	71
3.8.5	Dead	71
3.8.6	Locking Off	72
3.8.7	Live	72
3.8.8	Withdrawn Apparatus	72
3.9	Safety Rules Related to the Code of Safe Working Practices in High Voltage Systems	73
3.10	Working on De-Energized High Voltage Power Systems	74
3.11	Safe Working Procedures	74
3.11.1	Working on High Voltage Apparatus	74
3.11.2	Working on HV Systems	75
3.11.3	Check of Completed Temporary Earthing	77
3.11.4	Procedure for the Use of Earthing Leads	77
3.11.5	Checking for A Dead Condition and for Proving That a Circuit Is Dead	78
3.11.6	Entry to Enclosures Containing High Voltage Apparatus	78
3.11.7	Entry to Enclosures Containing High Voltage Equipment / Installations	79
3.11.8	Precautions Prior to Live Voltage and Phasing Checks (Only in an Emergency)	79
3.11.9	High Voltage Test Enclosures	80
3.11.10	Working on Transformers	80
3.11.11	Working on Ring Main Units	80
3.11.12	Working on Bus Bars and Directly Connected Bus Bar Equipment	81
3.11.13	Working on Bus Bar Spouts of Multi-Panel Switchboards	81
3.11.14	Working on High Voltage Cables	82
3.11.15	Re-energizing of a High Voltage Installation after Work	83
3.12	Trapped Key and Key Safe Systems	84

Contents

Chapter 3 – High Voltage Safe Working Procedures (Continued)		
Article No.	Article	Page No.
3.12.1	Key Exchange Systems	85
3.12.2	Use of Key Safes	86
3.12.3	Key Interlock for a Generator Cable Compartment	87
3.12.4	Key Interlock for a Motor Starter	88
3.12.5	Key Safe Arrangement for a Generator	90
3.12.6	Bus Bar Earthing Key Safe Interlocking Arrangement	91
3.12.7	VFD Safety Key Exchange System	92
3.13	Procedure for Isolation in High Voltage Switch Gear	93

Chapter 4 – High Voltage Generation and Distribution		
Article No.	Article	Page No.
4.1	Medium Voltage Alternator	99
4.1.1	Generation of Power Supply	100
4.1.2	Frequency of Induced E.M.F	101
4.1.3	The Main Rotating Field	101
4.2	The Brushless Alternator (Rotary Excitation System)	103
4.3	Salient Features of a Brushless Alternator's Major Components	104
4.3.1	The Exciter	104
4.3.1.1	The Exciter Field	105
4.3.1.2	The Exciter Armature	105
4.3.2	The Rotating Rectifier	105
4.4	The Alternator with a Self-excited System	105
4.4.1	The Static Excitation System	105
4.4.2	De-excitation of a Generator	107
4.5	The Alternator with a Separately Excited System	108
4.5.1	Advantages of PMG Excitation Systems	109
4.5.2	De-excitation Relay	110
4.5.3	Restoring Residual Magnetism (Flashing of the Field)	110
4.5.3.1	The Effects of Diode Failure	112
4.6	The Neutral Point of a Supply System	112

Contents

Chapter 4 – High Voltage Generation and Distribution (Continued)		
Article No.	Article	Page No.
4.6.1	IEC Regulations Related to Shipboard Neutral Systems	113
4.6.2	Importance of Neutral Grounding	115
4.6.3	Methods of Neutral Earthing	115
4.6.4	Ungrounded / Neutral Insulated Systems	116
4.6.4.1	Advantages	117
4.6.4.2	Disadvantages	117
4.7	Resistance Earthed Systems	117
4.7.1	Advantages	119
4.7.2	Disadvantages	119
4.7.3	Marine and Offshore NERs	120
4.7.4	Monitoring of the NER	120
4.7.5	NER Monitoring Relay	121
4.7.6	Isolation of the NER	122
4.8	Basic features of a Marine HV Power Supply and Distribution System	123
4.8.1	High Voltage System for a Liquefied Natural Gas Carrier	125
4.8.1.1	Salient Features	125
4.8.2	High Voltage Supply Generation and Distribution in Gas Tankers	126
4.8.3	Radial / Tree-type Electrical Power Distribution System	133
4.8.4	Ring Net Topology	134
4.8.4.1	Interlocking of a Circuit Breaker for the 6600 / 440 V transformer	135

Chapter 5 – High Voltage Switchgear		
Article No.	Article	Page No.
5.1	Basic Design of Marine High Voltage Switchgear and Control Gear	139
5.1.1	Safety Features of Metal-enclosed Switchgear	141
5.2	HV Switchgear Panel	142
5.2.1	The Bus Bar Compartment	144
5.2.2	The Circuit Breaker Compartment	144
5.2.3	The Cable Compartment	146
5.2.4	Core Balance Current Transformer (CBCT) / ZCT	146

Contents

Chapter 5 – High Voltage Switchgear (Continued)		
Article No.	Article	Page No.
5.2.5	Surge Arrestor	147
5.2.6	Metal Oxide Surge Arrestor	148
5.2.7	The Low Voltage Compartment	149
5.3	Ship's High Voltage Switch Board	149
5.3.1	Access and Lighting	149
5.4	Medium Voltage Circuit Breakers	150
5.4.1	The Vacuum Interrupter	151
5.4.1.1	Advantages of a Vacuum Circuit Breaker	152
5.4.1.2	Construction of a Vacuum Interrupter	153
5.4.1.2.1	Breaker Contacts	153
5.4.1.2.2	Vapour Condensing Shield or Metallic Shield or Spotter Shield	153
5.4.1.2.3	Metallic Bellows	153
5.4.1.2.4	End Flanges	153
5.4.1.2.5	Enclosure or Outer Envelope	153
5.4.1.3	Operation of a Vacuum Interrupter	154
5.4.1.3.1	Interruption Process in a Spiral Contact	155
5.4.1.4	Vacuum Contactor	156
5.4.1.4.1	Features of a Vacuum Contactor	156
5.4.2	Sulphur-hexafluoride (SF ₆) Circuit Breakers	159
5.4.2.1	SF ₆ Gas Breaker Properties	159
5.4.2.2	Advantages	162
5.4.2.3	Disadvantages	163
5.4.2.4	The Circuit Breaker Operating Mechanism	163
5.5	Routine Tests of Vacuum Circuit Breakers	166
5.6	Failure of a Vacuum interrupter	166
5.6.1	Dielectric Test	167
5.6.2	Vacuum Integrity Check	168
5.6.3	Contact Erosion Test	169

Contents

Chapter 6 – High Voltage Protection Systems		
Article No.	Article	Page No.
6.1	Basic Requirements of Protection Systems	171
6.2	Types of Faults and their Effects	172
6.2.1	Active Faults	172
6.2.2	Solid Faults	173
6.2.3	Incipient Faults	173
6.2.4	Passive Faults	173
6.2.5	Transient Faults	173
6.2.6	Symmetrical Faults	174
6.2.7	Unsymmetrical Faults	174
6.3	Protection Relays	175
6.3.1	Working Principle of a Protection Relay	175
6.3.2	Main Features of a Protection Relay	176
6.3.3	Static Relays	176
6.3.4	Digital / Numerical Type Protection Relays	177
6.3.4.1	Operation of a Digital / Numerical Type Protection Relay	179
6.4	ANSI Standard Device Numbers for Protection Devices	181
6.4.1	Over Current Protection (50 / 51)	183
6.4.2	Unbalanced Current Protection (46)	183
6.4.3	Loss of Excitation Protection (40)	184
6.4.4	Reverse Power Protection (32)	184
6.4.5	Under / Over Voltage Protection (27 / 59)	184
6.4.6	Under / Over Frequency Protection (81)	184
6.4.7	Differential Protection (87)	184
6.4.8	Balanced Earth Fault Protection	186
6.4.9	Faulty Bus Protection	186
6.4.10	Bus Bar Support Insulation Breakdown Protection	187
6.4.11	Transformer Protection	187

Contents

Chapter 7 – Alternate Marine Power (Cold Ironing)		
Article No.	Article	Page No.
7.1	Shore Supply or Alternate Marine Power	191
7.1.1	Retrofitting Existing Vessels	193
7.2	Container-Mounted Type AMP	193
7.2.1	Components in the AMP Container	194
7.2.2	Cables Connection to the Shore Side	196
7.3	Connection of Shore Supply	196
7.4	Disconnection of Shore Supply	197
7.5	The Circuit Breaker	198
7.6	The Cable Management System and Cables	198
7.7	Shore Connection Switchboard	199
7.7.1	Onboard Receiving Switchboard	199
7.8	Equipotential Bonding and Grounding Compatibility	200
7.9	Circuit Protection Systems	201
7.10	Characteristics of the AMP system	206
7.11	HVSC Emergency Shutdown	208

Chapter 8 – High Voltage Electrical Propulsion Systems		
Article No.	Article	Page No.
8.1	Electrical Propulsion	211
8.2	Advantages of Electrical Propulsion	213
8.2.1	Space Management in the Engine Room	213
8.2.2	Noise and Vibration	214
8.2.3	Lower Fuel Consumption and Emissions	214
8.2.4	Improved Manoeuvrability and Station-keeping Ability	214
8.2.5	Operating Convenience	214
8.2.6	Better Hydrodynamic Efficiency of the Propeller	215
8.3	Disadvantages of Electrical Propulsion	215
8.4	AC Induction Motor Drive with a Controllable Pitch Propeller	215
8.4.1	Frequency Control for the Speed of an AC Motor	217
8.4.1.1	AC Motor Speed	217
8.4.1.2	Voltage and Frequency Relationship	217

Contents

Chapter 8 – High Voltage Electrical Propulsion Systems (Continued)		
Article No.	Article	Page No.
8.5	Cycloconverter Method of Speed Control	218
8.5.1	The Single-phase Cycloconverter	218
8.5.2	Three-phase Cycloconverters	219
8.5.3	SIMAR Drive with the Cycloconverter	221
8.6	Variable Frequency Drive Electrical Propulsion Speed Control	224
8.6.1	A 6.6 kV Electrical Propulsion System	224
8.6.2	Variable Frequency Drive Components	226
8.6.2.1	Supply Transformer	227
8.6.2.2	Converter - The Input Rectifier Bridges	227
8.6.2.3	Thyristor Crowbar Circuit	228
8.6.2.4	Snubber Circuit	228
8.6.2.5	di / dt Choke	228
8.6.2.6	Charging Unit	228
8.6.2.7	Smoothing Capacitor	229
8.6.2.8	Grounding Switch	229
8.6.2.9	IGBT (Insulated Gate Bipolar Transistor)	230
8.6.2.10	Inverter	231
8.6.2.11	<i>Method to Change Frequency</i>	231
8.6.2.12	<i>Method to Change Voltage</i>	232
8.6.2.13	<i>Three-phase AC by a Two-level Inverter</i>	235
8.7	Harmonic Distortion	237
8.7.1	Effects of Harmonic Distortion	237
8.8	Harmonic Filters	239
8.8.1	Passive Filters	239
8.8.2	Operating Principle	239
8.9	Fixed-Speed Alternators with Variable-Speed Synchronous Motors	239
8.10	Dual Fuel Diesel Electric Propulsion for LNG Carriers	241
8.11	SIMAR Drive PWM - The Drive with Insulated Gate Bipolar Transistors	243
8.11.1	Understanding the Azipod System	248
8.11.2	The Steering Gear	250
8.11.3	Advantages of the Azipod System	251
8.11.4	Disadvantages of the Azipod System	252

Contents

Chapter 9 – High Voltage Cables and Insulation Testing		
Article No.	Article	Page No.
9.1	Medium / High Voltage Power Cables	253
9.1.1	Parts of an MV Cable	254
9.1.2	Functions of a Strand Shield and Semiconductor Layer	254
9.1.3	Functions of a Metallic Shield	255
9.1.4	Jacket	256
9.1.5	Cable Termination	256
9.1.5.1	Various Parts and Functions of a Modern Medium Voltage Cable Termination	257
9.2	Reasons for Faults in Cable Insulation	258
9.2.1	Partial Discharge	258
9.2.2	Water Tree Degradation in Insulation	260
9.3	Faults in Cables	261
9.3.1	Open-circuit Fault	261
9.3.2	Short-circuit Fault	262
9.3.3	Ground or Earth Fault	262
9.3.4	Flashing Fault	263
9.3.4	Ingress of Moisture	263
9.4	High Voltage Equipment Testing	263
9.4.1	IR Value for Electrical Cable and Wiring	264
9.4.2	Megger Testing of an MV Cable	265
9.5	Safety Precautions while Carrying out IR Tests for HV Equipment	265
9.6	Dielectric Tests of Transformers	267
9.6.1	Induced Voltage Test of a Transformer	268
9.7	Insulation Resistance Test and Polarization Index Test	268
9.7.1	The Significance of the Polarization Index Test	270
9.7.2	Interpretation of Polarisation Index Results	272
9.7.3	Hipot Test	273
Chapter 10 – Questions and Answers		
Article No.	Article No.	Page No.
10.1	Objective Type Questions	275
10.2	Fill in the Blanks	280
10.3	Short Answer Questions	285