



PROTECTIVE RELAYING THEORY AND APPLICATIONS

Second Edition, Revised and Expanded

WALTER A. ELMORE

TM77
E48
E-2

PROTECTIVE RELAYING THEORY AND APPLICATIONS

Second Edition, Revised and Expanded

WALTER A. ELMORE
*Consulting Engineer
Blue Ridge, Virginia*



E200404577



MARCEL DEKKER, INC.

NEW YORK • BASEL

Although great care has been taken to provide accurate and current information, neither the author(s) nor the publisher, nor anyone else associated with this publication, shall be liable for any loss, damage, or liability directly or indirectly caused or alleged to be caused by this book. The material contained herein is not intended to provide specific advice or recommendations for any specific situation.

Trademark notice: Product or corporate names may be trademarks or registered trademarks and are used only for identification and explanation without intent to infringe.

Library of Congress Cataloging-in-Publication Data

A catalog record for this book is available from the Library of Congress.

ISBN: 0-8247-0972-1

This book is printed on acid-free paper.

Headquarters

Marcel Dekker, Inc., 270 Madison Avenue, New York, NY 10016, U.S.A.
tel: 212-696-9000; fax: 212-685-4540

Distribution and Customer Service

Marcel Dekker, Inc., Cimarron Road, Monticello, New York 12701, U.S.A.
tel: 800-228-1160; fax: 845-796-1772

Eastern Hemisphere Distribution

Marcel Dekker AG, Hutgasse 4, Postfach 812, CH-4001 Basel, Switzerland
tel: 41-61-260-6300; fax: 41-61-260-6333

World Wide Web

<http://www.dekker.com>

The publisher offers discounts on this book when ordered in bulk quantities. For more information, write to Special Sales/ Professional Marketing at the headquarters address above.

Copyright © 2004 by ABB Power T&D Company Inc. All Rights Reserved.

Neither this book nor any part may be reproduced or transmitted in any form or by any means, electronic or mechanical, including photocopying, microfilming, and recording, or by any information storage and retrieval system, without permission in writing from the publisher.

Current printing (last digit):

10 9 8 7 6 5 4 3 2 1

PRINTED IN THE UNITED STATES OF AMERICA

PROTECTIVE RELAYING THEORY AND APPLICATIONS

Preface

Continuous change in protective relaying has been caused by two different influences. One is the fact that the requirements imposed by power systems are in a constant state of change, and our understanding of the basic concepts has sharpened considerably over the years. The other is that the means of implementing the fundamental concepts of fault location and removal and system restoration are constantly growing more sophisticated.

It is primarily because of these changing constraints that this text has been revised and expanded. It began with contributions from two giants of the industry, J. Lewis Blackburn and George D. Rockefeller. From the nucleus of their extensive analyses and writings, and the desire to cover each new contingency with new relaying concepts, this volume has evolved. New solutions to age-old problems have become apparent as greater experience has been gained. No problem is without benefit in the solution found.

This new edition weeds out those relaying concepts that have run their course and have been replaced by more perceptive methods of implementation using new solid-state or microprocessor-based devices.

No single technological breakthrough has been more influential in generating change than the microprocessor. Initially, the methods of translating a collection of instantaneous samples of sine waves into useful current, direction, and impedance measurements were not obvious. Diligent analysis and extensive testing allowed these useful functions to be obtained and to be applied to the desired protective functions. This text attempts to describe, in the simplest possible terms, the manner in which these digital measurements are accomplished in present-day devices.

In addition to those already mentioned, huge contributions were made in the development and refinement of the concepts described in this book by Hung Jen Li, Walter Hinman, Roger Ray, James Crockett, Herb Lensner, Al Regotti, Fernando Calero, Eric Udren, James Greene, Liancheng Wang, Elmo Price, Solveig Ward, John McGowan, and Cliff Downs. Some of these names may not be immediately recognizable, but all have made an impact with their thoughtful, accurate, well-reasoned writings, and they all deserve the gratitude of the industry for the wealth of knowledge they have contributed to this book. I am keenly aware of the high quality of the technical offerings of these people, and I am particularly grateful for the warmth and depth of their friendship.

Walter A. Elmore

About the Editor

WALTER A. ELMORE is Consulting Engineer, Blue Ridge, Virginia, and retired from the Relay Division of the ABB Power T & D Company, Inc., Coral Springs, Florida. The author or coauthor of more than 100 professional publications including *Pilot Protective Relaying* (Marcel Dekker, Inc.), Mr. Elmore is a Life Fellow of the Institute of Electrical and Electronics Engineers (IEEE) and a member of the National Academy of Engineering, and holds six patents. He is a recipient of the IEEE's Gold Medal for Engineering Excellence (1989) and the Power System Relaying Committee Award for Distinguished Service (1989). A registered Professional Engineer in Florida, Mr. Elmore received the B.S. degree (1949) in electrical engineering from the University of Tennessee, Knoxville

Contents

Preface

iii

1 Introduction and General Philosophies	1
<i>Revised by W. A. Elmore</i>	
1 Introduction	1
2 Classification of Relays	1
2.1 Analog/Digital/Numerical	2
3 Protective Relaying Systems and Their Design	2
3.1 Design Criteria	3
3.2 Factors Influencing Relay Performance	4
3.3 Zones of Protection	4
4 Applying Protective Relays	4
4.1 System Configuration	5
4.2 Existing System Protection and Procedures	5
4.3 Degree of Protection Required	5
4.4 Fault Study	5
4.5 Maximum Loads, Transformer Data, and Impedances	6
5 Relays and Application Data	6
5.1 Switchboard Relays	6
5.2 Rack-Mounted Relays	7
6 Circuit-Breaker Control	8
7 Comparison of Symbols	9
2 Technical Tools of the Relay Engineer: Phasors, Polarity, and Symmetrical Components	11
<i>Revised by W. A. Elmore</i>	
1 Introduction	11
2 Phasors	11
2.1 Circuit Diagram Notation for Current and Flux	11
2.2 Circuit Diagram Notation for Voltage	12

2.3	Phasor Notation	12
2.4	Phasor Diagram Notation	13
2.5	Phase Rotation vs. Phasor Rotation	15
3	Polarity in Relay Circuits	15
3.1	Polarity of Transformers	15
3.2	Polarity of Protective Relays	15
3.3	Characteristics of Directional Relays	16
3.4	Connections of Directional Units to Three-Phase Power Systems	17
4	Faults on Power Systems	18
4.1	Fault Types and Causes	18
4.2	Characteristics of Faults	20
5	Symmetrical Components	21
5.1	Basic Concepts	21
5.2	System Neutral	23
5.3	Sequences in a Three-Phase Power System	23
5.4	Sequence Impedances	24
5.5	Sequence Networks	26
5.6	Sequence Network Connections and Voltages	27
5.7	Network Connections for Fault and General Unbalances	28
5.8	Sequence Network Reduction	29
5.9	Example of Fault Calculation on a Loop-Type Power System	32
5.10	Phase Shifts Through Transformer Banks	37
5.11	Fault Evaluations	39
6	Symmetrical Components and Relaying	42
3	Basic Relay Units	43
	<i>Revised by W. A. Elmore</i>	
1	Introduction	43
2	Electromechanical Units	43
2.1	Magnetic Attraction Units	43
2.2	Magnetic Induction Units	45
2.3	D'Arsonval Units	47
2.4	Thermal Units	47
3	Sequence Networks	47
3.1	Zero Sequence Networks	47
3.2	Composite Sequence Current Networks	48
3.3	Sequence Voltage Networks	49
4	Solid-State Units	50
4.1	Semiconductor Components	50
4.2	Solid-State Logic Units	52
4.3	Principal Logic Units	52
5	Basic Logic Circuits	54
5.1	Fault-Sensing Data Processing Units	54
5.2	Amplification Units	59
5.3	Auxiliary Units	59
6	Integrated Circuits	63
6.1	Operational Amplifier	63
6.2	Basic Operational Amplifier Units	65
6.3	Relay Applications of Operational Amplifier	68
7	Microprocessor Architecture	70

4 Protection Against Transients and Surges	71
<i>W. A. Elmore</i>	
1 Introduction	71
1.1 Electrostatic Induction	71
1.2 Electromagnetic Induction	72
1.3 Differential- and Common-Mode Classifications	72
2 Transients Originating in the High-Voltage System	73
2.1 Capacitor Switching	73
2.2 Bus Deenergization	73
2.3 Transmission Line Switching	74
2.4 Coupling Capacitor Voltage Transformer (CCVT) Switching	74
2.5 Other Transient Sources	74
3 Transients Originating in the Low-Voltage System	74
3.1 Direct Current Coil Interruption	74
3.2 Direct Current Circuit Energization	75
3.3 Current Transformer Saturation	75
3.4 Grounding of Battery Circuit	75
4 Protective Measures	75
4.1 Separation	75
4.2 Suppression at the Source	77
4.3 Suppression by Shielding	77
4.4 Suppression by Twisting	77
4.5 Radial Routing of Control Cables	78
4.6 Buffers	78
4.7 Optical Isolators	78
4.8 Increased Energy Requirement	79
5 Instrument Transformers for Relaying	81
<i>W. A. Elmore</i>	
1 Introduction	81
2 Current Transformers	81
2.1 Saturation	81
2.2 Effect of dc Component	82
3 Equivalent Circuit	82
4 Estimation of Current Transformer Performance	82
4.1 Formula Method	83
4.2 Excitation Curve Method	83
4.3 ANSI Standard: Current Transformer Accuracy Classes	85
5 European Practice	87
5.1 TPX	88
5.2 TPY	88
5.3 TPZ	88
6 Direct Current Saturation	88
7 Residual Flux	89
8 MOCT	91
9 Voltage Transformers and Coupling Capacitance Voltage Transformers	91
9.1 Equivalent Circuit of a Voltage Transformer	91
9.2 Coupling Capacitor Voltage Transformers	92
9.3 MOVTE/EOVT	93
10 Neutral Inversion	93

6 Microprocessor Relaying Fundamentals	95
<i>W. A. Elmore</i>	
1 Introduction	95
2 Sampling Problems	97
3 Aliasing	97
4 How to Overcome Aliasing	98
4.1 Antialiasing Filters	98
4.2 Nonsynchronous Sampling	98
5 Choice of Measurement Principle	99
5.1 rms Calculation	100
5.2 Digital Filters	100
5.3 Fourier-Notch Filter	100
5.4 Another Digital Filter	101
5.5 dc Offset Compensation	101
5.6 Symmetrical Component Filter	102
5.7 Leading-Phase Identification	102
5.8 Fault Detectors	102
6 Self-Testing	103
6.1 Dead-Man Timer	103
6.2 Analog Test	103
6.3 Check-Sum	103
6.4 RAM Test	103
6.5 Nonvolatile Memory Test	103
7 Conclusions	104
7 System Grounding and Protective Relaying	105
<i>Revised by W. A. Elmore</i>	
1 Introduction	105
2 Ungrounded Systems	105
2.1 Ground Faults on Ungrounded Systems	105
2.2 Ground Fault Detection on Ungrounded Systems	107
3 Reactance Grounding	108
3.1 High-Reactance Grounding	108
3.2 Resonant Grounding (Ground Fault Neutralizer)	109
3.3 Low-Reactance Grounding	109
4 Resistance Grounding	110
4.1 Low-Resistance Grounding	110
4.2 High-Resistance Grounding	111
5 Sensitive Ground Relaying	112
5.1 Ground Overcurrent Relay with Conventional Current Transformers	112
5.2 Ground Product Relay with Conventional Current Transformers	113
5.3 Ground Overcurrent Relay with Zero Sequence Current Transformers	114
6 Ground Fault Protection for Three-Phase, Four-Wire Systems	114
6.1 Ungrounded Four-Wire Systems	114
6.2 Multigrounded Four-Wire Systems	115
8 Generator Protection	117
<i>Revised by C. L. Downs</i>	
1 Introduction	117
2 Choice of Technology	117

3	Phase Fault Detection	117
3.1	Percentage Differential Relays (Device 87)	118
3.2	High Impedance Differential Relays (Device 87)	119
3.3	Machine Connections	119
3.4	Split-Phase	119
4	Stator Ground Fault Protection	120
4.1	Unit-Connected Schemes	120
4.2	95% Ground Relays	120
4.3	Neutral-to-Ground Fault Detection (Device 87N3)	121
4.4	100% Winding Protection	122
5	Backup Protection	123
5.1	Unbalanced Faults	123
5.2	Balanced Faults	124
6	Overload Protection	126
6.1	RTD Schemes (Device 49)	126
6.2	Thermal Replicas (Device 49)	126
7	Volts per Hertz Protection	126
8	Overspeed Protection	126
9	Loss-of-Excitation Protection	127
9.1	Causes of Machine Loss of Field	127
9.2	Hazard	127
9.3	Loss-of-Field Relays	128
9.4	KLF and KLF-1 Curves	129
9.5	Two-Zone KLF Scheme	129
10	Protection Against Generator Motoring	130
10.1	Steam Turbines	131
10.2	Diesel Engines	131
10.3	Gas Turbines	131
10.4	Hydraulic Turbines	131
11	Inadvertent Energization	132
12	Field Ground Detection	134
12.1	Brush-Type Machine	135
12.2	Brushless Machines	136
12.3	Injection Scheme for Field Ground Detection	136
13	Alternating-Current Overvoltage Protection for Hydroelectric Generators	136
14	Generator Protection at Reduced Frequencies	136
15	Off-Frequency Operation	138
16	Recommended Protection	139
17	Out-of-Step Protection	139
18	Bus Transfer Systems for Station Auxiliaries	139
18.1	Fast Transfer	139
18.2	Choice of Fast Transfer Scheme	140
18.3	Slow Transfer	142
19	Microprocessor-Based Generator Protection	143
9	Motor Protection	145
	<i>Revised by C. L. Downs</i>	
1	Introduction	145
1.1	General Requirements	145
1.2	Induction Motor Equivalent Circuit	146
1.3	Motor Thermal Capability Curves	146

2	Phase-Fault Protection	147
3	Ground-Fault Protection	147
4	Locked-Rotor Protection	149
5	Overload Protection	153
6	Thermal Relays	153
6.1	RTD-Input-Type Relays	154
6.2	Thermal Replica Relays	154
7	Low-Voltage Protection	155
8	Phase-Rotation Protection	155
9	Negative Sequence Voltage Protection	155
10	Phase-Unbalance Protection	156
11	Negative Sequence Current Relays	157
12	Jam Protection	157
13	Load Loss Protection	157
14	Out-of-Step Protection	158
15	Loss of Excitation	158
16	Typical Application Combinations	159
10	Transformer and Reactor Protection	163
	<i>Revised by J. J. McGowan</i>	
1	Introduction	163
2	Magnetizing Inrush	163
2.1	Initial Inrush	163
2.2	Recovery Inrush	165
2.3	Sympathetic Inrush	165
3	Differential Relaying for Transformer Protection	166
3.1	Differential Relays for Transformer Protection	166
3.2	General Guidelines for Transformer Differential Relaying Application	171
4	Sample Checks for Applying Transformer Differential Relays	173
4.1	Checks for Two-Winding Banks	173
4.2	Checks for Multiwinding Banks	178
4.3	Modern Microprocessor Relay	180
5	Typical Application of Transformer Protection	180
5.1	Differential Scheme with Harmonic Restraint Relay Supervision	180
5.2	Ground Source on Delta Side	182
5.3	Three-Phase Banks of Single-Phase Units	183
5.4	Differential Protection of a Generator-Transformer Unit	183
5.5	Overexcitation Protection of a Generator-Transformer Unit	184
5.6	Sudden-Pressure Relay (SPR)	185
5.7	Overcurrent and Backup Protection	185
5.8	Distance Relaying for Backup Protection	192
5.9	Overcurrent Relay with HRU Supplement	192
6	Typical Protective Schemes for Industrial and Commercial Power Transformers	193
7	Remote Tripping of Transformer Bank	197
8	Protection of Phase-Angle Regulators and Voltage Regulators	197
9	Zig-Zag Transformer Protection	202
10	Protection of Shunt Reactors	203
10.1	Shunt Reactor Applications	203
10.2	Rate-of-Rise-of-Pressure Protection	205
10.3	Overcurrent Protection	205
10.4	Differential Protection	206

10.5	Reactors on Delta System	207
10.6	Turn-to-Turn Faults	209
11	Station-Bus Protection	213
	<i>Revised by Solveig Ward</i>	
1	Introduction	213
1.1	Current Transformer Saturation Problem and Its Solutions on Bus Protection	213
1.2	Information Required for the Preparation of a Bus Protective Scheme	215
1.3	Normal Practices on Bus Protection	215
2	Bus Differential Relaying with Overcurrent Relays	216
2.1	Overcurrent Differential Protection	216
2.2	Improved Overcurrent Differential Protection	216
3	Multirestraint Differential System	217
4	High Impedance Differential System	219
4.1	Factors that Relate to the Relay Setting	221
4.2	Factors that Relate to the High-Voltage Problem	221
4.3	Setting Example for the KAB Bus Protection	222
5	Differential Comparator Relays	222
6	Protecting a Bus that Includes a Transformer Bank	223
7	Protecting a Double-Bus Single-Breaker with Bus Tie Arrangement	224
8	Other Bus Protective Schemes	226
8.1	Partial Differential Relaying	226
8.2	Directional Comparison Relaying	227
8.3	Fault Bus (Ground-Fault Protection Only)	227
12	Line and Circuit Protection	229
	<i>Revised by Elmo Price</i>	
1	Introduction	229
1.1	Classification of Electric Power Lines	229
1.2	Techniques for Line Protection	229
1.3	Selecting a Protective System	229
1.4	Relays for Phase- and Ground-Fault Protection	230
1.5	Multiterminal and Tapped Lines and Weak Feed	230
2	Overcurrent Phase- and Ground-Fault Protection	231
2.1	Fault Detection	231
2.2	Time Overcurrent Protection	232
2.3	Instantaneous Overcurrent Protection	237
2.4	Overcurrent Ground-Fault Protection	238
3	Directional Overcurrent Phase- and Ground-Fault Protection	239
3.1	Criteria for Phase Directional Overcurrent Relay Applications	239
3.2	Criteria for Ground Directional Overcurrent Relay Applications	239
3.3	Directional Ground-Relay Polarization	239
3.4	Mutual Induction and Ground-Relay Directional Sensing	243
3.5	Applications of Negative Sequence Directional Units for Ground Relays	244
3.6	Selection of Directional Overcurrent Phase and Ground Relays	244
4	Distance Phase and Ground Protection	247
4.1	Fundamentals of Distance Relaying	247
4.2	Phase-Distance Relays	250
4.3	Ground-Distance Relays	254
4.4	Effect of Line Length	257
4.5	The Infeed Effect on Distance-Relay Application	260

4.6	The Outfeed Effect on Distance-Relay Applications	261
4.7	Effect of Tapped Transformer Bank on Relay Application	261
4.8	Distance Relays with Transformer Banks at the Terminal	262
4.9	Fault Resistance and Ground-Distance Relays	265
4.10	Zero Sequence Mutual Impedance and Ground-Distance Relays	265
5	Loop-System Protection	267
5.1	Single-Source Loop-Circuit Protection	267
5.2	Multiple-Source Loop Protection	269
6	Short-Line Protection	270
6.1	Definition of Short Line	270
6.2	Problem Associated with Short-Line Protection	270
6.3	Current-Only Scheme for Short-Line Protection	270
6.4	Distance Relay for Short-Line Protection	270
7	Series-Capacitor Compensated-Line Protection	273
7.1	A Series-Capacitor Compensated Line	273
7.2	Relaying Quantities Under Fault Conditions	273
7.3	Distance Protection Behavior	275
7.4	Practical Considerations	276
8	Distribution Feeder Protection	276
8.1	Relay Coordination with Reclosers and Sectionalizers on a Feeder	277
8.2	Coordinating with Low-Voltage Breaker and Fuse	277
	Appendix A: Equation (12-2)	281
	Appendix B: Impedance Unit Characteristics	281
	B.1 Introduction	281
	B.2 Basic Application Example of a Phase Comparator	284
	B.3 Basic Application Example of a Magnitude Comparator	285
	B.4 Practical Comparator Applications in Distance Relaying	285
	B.5 Reverse Characteristics of an Impedance Unit	294
	B.6 Response of Distance Units to Different Types of Faults	298
	B.7 The Influence of Current Distribution Factors and Load Flow	302
	B.8 Derived Characteristics	305
	B.9 Apparent Impedance	305
	B.10 Summary	306
	Appendix C: Infeed Effect on Ground-Distance Relays	306
	C.1 Infeed Effect on Type KDXG, LDAR, and MDAR Ground-Distance Relays	306
	C.2 Infeed Effect on Type SDG and LDG Ground-Distance Relays	307
	Appendix D: Coordination in Multiple-Loop Systems	308
	D.1 System Information	308
	D.2 Relay Type Selection	308
	D.3 Relay Setting and Coordination	309
13	Backup Protection	323
	<i>Revised by E. D. Price</i>	
1	Introduction	323
2	Remote vs. Local Backup	323
2.1	Remote Backup	323
2.2	Local Backup and Breaker Failure	324
2.3	Applications Requiring Remote Backup with Breaker-Failure Protection	326
3	Breaker-Failure Relaying Applications	327
3.1	Single-Line/Single-Breaker Buses	327
3.2	Breaker-and-a-Half and Ring Buses	328

4	Traditional Breaker-Failure Scheme	329
4.1	Timing Characteristics of the Traditional Breaker-Failure Scheme	329
4.2	Traditional Breaker-Failure Relay Characteristics	330
4.3	Microprocessor Relays	331
5	An Improved Breaker-Failure Scheme	332
5.1	Problems in the Traditional Breaker-Failure Scheme	332
5.2	The Improved Breaker-Failure Scheme	333
5.3	Type SBF-1 Relay	334
6	Open Conductor and Breaker Pole Disagreement Protection	336
7	Special Breaker-Failure Scheme for Single-Pole Trip-System Application	337
14	System Stability and Out-of-Step Relaying	339
	<i>W. A. Elmore</i>	
1	Introduction	339
2	Steady-State Stability	339
3	Transient Stability	340
4	Relay Quantities During Swings	341
5	Effect of Out-of-Step Conditions	343
5.1	Distance Relays	343
5.2	Directional Comparison Systems	344
5.3	Phase-Comparison or Pilot-Wire Systems	344
5.4	Underreaching Transfer-Trip Schemes	344
5.5	Circuit Breakers	344
5.6	Overcurrent Relays	344
5.7	Reclosing	344
6	Out-of-Step Relaying	345
6.1	Generator Out-of-Step Relaying	345
6.2	Transmission-Line Out-of-Step Relaying	346
7	Philosophies of Out-of-Step Relaying	346
7.1	Utility Practice	347
8	Types of Out-of-Step Schemes	347
8.1	Concentric Circle Scheme	347
8.2	Blinder Scheme	348
9	Relays for Out-of-Step Systems	348
9.1	Electromechanical Types	348
9.2	Solid-State Types	349
10	Selection of an Out-of-Step Relay System	351
15	Voltage Stability	353
	<i>L. Wang</i>	
1	Introduction	353
1.1	Small-Disturbance Instability	353
1.2	Large-Disturbance Instability	355
1.3	Voltage Instability Incidents	356
2	Voltage Instability Indices	357
2.1	Indices Based on Current Operating Condition	357
2.2	Indices Based on Stressed System Conditions	360
2.3	Summary	362
3	Voltage Instability Protection	362
3.1	Reactive Power Control	362
3.2	Load Tap Changer Blocking Schemes	362
3.3	Load Shedding	362

16	Reclosing and Synchronizing	365
	<i>Revised by S. Ward</i>	
1	Introduction	365
2	Reclosing Precautions	365
3	Reclosing System Considerations	366
3.1	One-Shot vs. Multiple-Shot Reclosing Relays	366
3.2	Selective Reclosing	366
3.3	Deionizing Times for Three-Pole Reclosing	366
3.4	Synchronism Check	366
3.5	Live-Line/Dead-Bus, Live-Bus/Dead-Line Control	367
3.6	Instantaneous-Trip Lockout	367
3.7	Intermediate Lockout	367
3.8	Compatibility with Supervisory Control	367
3.9	Inhibit Control	368
3.10	Breaker Supervision Functions	368
3.11	Factors Governing Application of Reclosing	368
4	Considerations for Applications of Instantaneous Reclosing	368
4.1	Feeders with No-Fault-Power Back-Feed and Minimum Motor Load	369
4.2	Single Ties to Industrial Plants with Local Generation	369
4.3	Lines with Sources at Both Ends	369
5	Reclosing Relays and Their Operation	369
5.1	Review of Breaker Operation	369
5.2	Single-Shot Reclosing Relays	369
5.3	Multishot Reclosing Relays	371
6	Synchronism Check	377
6.1	Phasing Voltage Synchronism Check Characteristic	377
6.2	Angular Synchronism Check Characteristic	378
7	Dead-Line or Dead-Bus Reclosing	379
8	Automatic Synchronizing	379
17	Load-Shedding and Frequency Relaying	381
	<i>Revised by W. A. Elmore</i>	
1	Introduction	381
2	Rate of Frequency Decline	381
3	Load-Shedding	383
4	Frequency Relays	384
4.1	KF Induction-Cylinder Underfrequency Relay	384
4.2	Digital Frequency Relays	385
4.3	Microprocessor-Based Frequency Relay	385
5	Formulating a Load-Shedding Scheme	385
5.1	Maximum Anticipated Overload	385
5.2	Number of Load-Shedding Steps	386
5.3	Size of the Load Shed at Each Step	386
5.4	Frequency Settings	387
5.5	Time Delay	388
5.6	Location of the Frequency Relays	388
6	Special Considerations for Industrial Systems	389

Contents	xv
7 Restoring Service	390
8 Other Frequency Relay Applications	391
Bibliography	395
<i>Index</i>	399