

Contents

List of Acronyms	xiii
1 Introduction	1
1.1 Background and Motivation	1
1.2 Interconnected Power Systems	4
1.3 Recent Blackouts	4
1.3.1 USA and Canada 2003	5
1.3.2 Sweden and Denmark in 2003	6
1.3.3 Italy in 2003	6
1.3.4 European System Disturbance in 2006	6
1.3.5 India 2012	7
1.4 Security, Reliability and Risk	7
1.5 Simulation Methods	7
1.5.1 DC Power Flow Approximation	7
1.5.2 Probabilistic Power Flow	8
1.5.3 Distributed Slack Bus	8
1.6 Contributions	9
1.7 Outline of Dissertation	10
1.8 List of Publications	11
2 Data Exchange and Coordination	13
2.1 Introduction	13
2.1.1 On European Practices	13

2.1.2	Literature Review	15
2.1.3	Contribution of Author	15
2.2	Response of Neighboring Control Areas	16
2.3	Fluctuating In-Feed in Interconnected Power Systems	17
2.3.1	Uni-, Bi- and Multilateral Compensation	18
2.4	Results	18
2.4.1	Results on Response of Neighboring Control Areas	18
2.4.2	Results on Compensation	21
2.5	Conclusions	26
3	Security Assessment	31
3.1	Introduction	31
3.1.1	Background	31
3.1.2	Literature Review	32
3.1.3	Contribution of Author	33
3.2	Execution of Security Assessment	34
3.2.1	Contingency List	34
3.2.2	Coordination in Interconnected Power Systems	35
3.2.3	Computational Complexity of Security Assessment	36
3.2.4	System Security State Classification	40
3.3	Risk-Based Security Assessment	41
3.3.1	Introduction	41
3.3.2	Risk	42
3.3.3	Probability of Contingency	42
3.3.4	Severity of Contingency	45
3.4	Model of Cascading Failure	47
3.4.1	Introduction	47
3.4.2	Data and Parameters	47
3.4.3	Wind Power Modeling	49
3.4.4	Power Flow and Tripping of Lines	50
3.4.5	Generation Adjustment and Load Shedding	50

3.4.6	Load Shedding	51
3.5	Results	52
3.5.1	Results on Computational Complexity	52
3.5.2	Security Assessment	53
3.5.3	Risk-Based Security Assessment	58
3.5.4	Post-Contingency Indicators	62
3.6	Conclusions	66
4	Security Assessment with Fluctuating In-Feed	69
4.1	Introduction	69
4.1.1	Literature Review	70
4.1.2	Contribution of Author	70
4.2	Probabilistic System Security State Classification	71
4.2.1	Background	71
4.2.2	Methods	71
4.2.3	Probabilistic Interpretation	73
4.3	Risk-Based Security Assessment	73
4.4	Results	74
4.4.1	Results on System Security State Classification	74
4.4.2	Effect of Forecast Horizon and Accuracy on Results	77
4.4.3	Summary	79
4.4.4	Results on Risk-Based Security Assessment	80
4.4.5	Number of Simulations	82
4.4.6	Size of Forecast Error	83
4.5	Conclusions	85
5	Remedial Actions	87
5.1	Introduction	87
5.1.1	Background	87
5.1.2	Literature Review	88
5.1.3	Contribution of Author	89
5.2	Coordination of Remedial Actions	89

5.3	Robust Re-Dispatch of Generators	90
5.3.1	Introduction	90
5.3.2	Problem	91
5.3.3	Linear Program Formulation	92
5.3.4	Security Margins	92
5.3.5	Prices	93
5.4	Security and Reliability	94
5.5	Optimal Reliability Level	95
5.6	Results	96
5.6.1	Robust Re-Dispatch of Generators	96
5.6.2	Optimal Reliability Level	97
5.7	Conclusions	100
6	Conclusions	105
7	Future Research	107
A	Test Systems	109
A.1	6 -Bus Test System	109
A.2	IEEE RTS-96 Test System	111
A.2.1	Three Area System without Wind	111
A.2.2	Three Area System with Wind	111
A.2.3	Single Area System	111
A.2.4	Two Area System	111
	Bibliography	116
	Curriculum Vitae	125