Contents

Synopsis iv

Acknowledgements xi

List of Figures xvii

List of Tables xxiii

1 Introduction 1

1.1 General 1

1.2 State-of-the Art 3

1.3 Motivation 12

1.4 Thesis Organization 15

2 Mathematical Modeling of Power System 17

2.1 General 17

2.2 Generator model 17

2.3 Excitation System 19

2.3.1 Initial Conditions 19

2.4 Linearization and Eigen Properties 20

2.4.1 Linearization 20

2.4.2 Sate Space Representation 22

2.4.3 Eigen Values 23

2.4.3.1 Eigen Vector 24

2.4.3.2 Participation Factor 25

2.4.3.3 Eigen value and Stability 26
2.5 Linear model of power system 27
2.5.1 Calculation of K_1 to K_{10} Constants 27
2.5.2 State Space Representation of System 29
2.6 Power System Stabilizer 31
2.6.1 Conventional Power system stabilizer 31
2.6.1.1 Model of Power System with CPSS 32
2.6.2 Proportional Integral Derivative Power System Stabilizer 33
2.6.2.1 Model of Power System with PID-PSS 33
2.7 Thyristor Control Series Capacitor 34
2.7.1 Model of Power system with Inclusion of TCSC 36
2.7.2 Model of Power System with Inclusion of TCSC and PSS 38
2.8 Conclusion 40

3 Design of PSS and TCSC Using Genetic Algorithm 42
3.1 Introduction 42
3.2 GA based Design of CPSS and PID-PSS 43
3.2.1 Genetic Algorithm 43
3.2.2 Problem Formulation and Optimization Function 44
3.2.3 Calculation of Initial Conditions 45
3.2.4 Eigen values and Participation Factor 47
3.2.5 Results 47
3.3 GA based Design of TCSC and PSS 53
3.3.1 Problem Formulation and Optimization Function 53
3.3.2 Calculation of $K_1$to K_{10} Constants 55
3.3.3 Eigen values and Participation factor 55
3.3.4 Results 56
3.4 Non-linear Simulation 60
3.4.1 Case I 61
3.4.2 Case II 65
3.4.3 Case III 67

3.4.4 Case IV 70
3.4.5 Case V 72
3.4.6 Case VI 74
3.5 Conclusion 76

4 Design of PSS and TCSC Using ANFIS and ANN 77
4.1 Introduction 77
4.2 Adaptive Neuro-Fuzzy Inference System (ANFIS) 78
4.2.1 ANFIS- Architecture 78
4.3 Steps for Designing of ANFIS based PSS and TCSC 81
4.3.1 ANFIS-Power System Stabilizer 81
4.3.2 ANFIS-Thyristor Control Series Capacitor 85
4.4 Levenberge-Marquardt Neural Network 88
4.4.1 Levenberg-Marquardt Algorithm 88
4.5 Steps for Designing of LMNN based PSS and TCSC 90
4.5.1 ANN-Power System Stabilizer 90
4.5.2 Design of LMNN-TCSC 92
4.6 Non Linear Simulation 93
4.6.1 Case I 94
4.6.2 case II 94
4.6.3 Case III 95
4.6.4 Case IV 96
4.6.5 Case V 97
4.7 Conclusion 97

5 Design of PSS Using NARMA-L2 and GA-ANN Controller with TCSC 99
5.1 Introduction 99
5.2 Nonlinear Auto regressive Moving average -L2 Controller 100
5.2.1 NARMA-L2 (Feedback Linearization) Control 100
5.2.1.1 Identification Stage 100
5.2.1.2 Controller Stage 102
5.3 NARMA-L2 Controller based Power System Stabilizer 102

5.3.1 Neural Network Identifier 103
5.3.2 Neural Network Controller 105
5.4 GA-ANN Hybrid-Power System Stabilizer 105
5.4.1 Genetic Algorithm 106
5.4.2 Neural Network 108
5.5 Non Linear Simulation 110
5.5.1 Case I 110
5.5.2 Case II 112
5.5.3 Case III 113
5.5.4 Case IV 114
5.5.5 Case V 115
5.5.6 Case VI 115
5.6 Simulation of System with Intelligent Techniques based PSS and ANFIS-TCSC 116
5.6.1 Case I 117
5.6.2 Case II 118
5.6.3 Case III 119
5.6.4 Case IV: 120
5.7 Conclusion 121

6 Design of Ancillary Controllers for Restructured Electric Market 123
6.1 Introduction 123
6.2 Restructured Power System 124
6.3 Design of TCSC Controller with First Order Power System Model 126
6.3.1 Power system model 127
6.3.2 Tie Line Power Flow Model With TCSC 127
6.3.3 Block Diagram and Model of Interconnected Two area System 129
6.3.4 GA- tie line TCSC Controller: Problem Formulation and Optimization Function 134
6.3.5 ANFIS- Tie Line TCSC Controller 135
6.3.6 Simulation and Results 136

6.3.7 Discussion 141
6.4 Design of PSS and TCSC Controller with Fourth order Power System Model 142
6.4.1 Power System Model 143
6.4.1.1 Model of Power System with multiple PSS 143
6.4.1.2 Model of Power System with PSSs and TCSC 143
6.4.2 Design of Ancillary controllers using GA 148
6.4.2.1 GA based Multiple PSS : Problem Formulation and Optimization Function 148
6.4.2.2 GA based PSSs and TCSC : Problem Formulation and Optimization Function 149
6.4.3 Design of Ancillary controllers using ANFIS 150
6.4.3.1 ANFIS based Multiple PSS 151
6.4.3.2 ANFIS based PSSs and TCSC 151
6.4.4 Analysis 151
6.4.5 Non Linear Simulation 153
6.5 Conclusion 161

7 Conclusions **164**
7.1 General 164
7.2 Summary of Important Findings 165
7.3 Scope of Future Research 170

Bibliography **172**

A Data of Single machine Infinite Bus system **183**

B Numerical Values of the Restructured Model **184**