

List of Figures

2.1	Two Bus System	64
2.2	Series Compensation of Line	66
2.3	Point Estimation Method	72
2.4	Flow Diagram of Two Point Estimation	73
2.5	Problem with Random Sampling	79
2.6	Latin Hypercube Sampling	80
2.7	Comparison Between MCS and LHS	81
2.8	Relation of Variables with different correlation	94
2.9	Transformation of Variable using Correlation	95
2.10	Two Bus System with Wind Farm Supplying Load	99
2.11	Two Bus System with Wind Farm and Infinite Bus Supplying Load	103
2.12	IEEE 12-Bus Radial Network	106
2.13	Comparison of Voltage Magnitude at Bus-12 with Wind Power at Bus-12 using MCS, TPE, LHS MEADIAN and TPE+LHS MEADIAN	116
2.14	Comparison of Voltage Angle at Bus-12 with Wind Power at Bus-12 using MCS, TPE, LHS MEADIAN and TPE+LHS MEADIAN	117
2.15	Comparison of Voltage Magnitude at Bus-12 with Wind Power at Bus-06 using MCS, TPE, LHS MEADIAN and TPE+LHS MEADIAN	126
2.16	Comparison of Voltage Angle at Bus-12 with Wind Power at Bus-06 using MCS, TPE, LHS MEADIAN and TPE+LHS MEADIAN	127
2.17	Comparison of Voltage Magnitude at Bus-12 with Wind Power at Bus-02 using MCS, TPE, LHS MEADIAN and TPE+LHS MEADIAN	136
2.18	Comparison of Voltage Angle at Bus-12 with Wind Power at Bus-02 using MCS, TPE, LHS MEADIAN and TPE+LHS MEADIAN	137

2.19 Comparison of Voltage Magnitude Variation at Bus-12 with MCS and TPE+LHS MEADIAN	148
2.20 Comparison of Voltage Angle Variation at Bus-12 with MCS and TPE+LHS MEADIAN	149
2.21 IEE-39 Bus New England System	152
2.22 Comparision of Bus-4 Voltage PDF Estimation	155
2.23 Comparision of Bus-14 Voltage PDF Estimation	157
2.24 Comparision of Bus-31 Voltage PDF Estimation	159
3.1 Flowchart for Critical Frequency Determination	176
3.2 Cable Connected to System	176
3.3 Modal Impedance of Cable Connected to Line.	177
3.4 Circuit with "T" Equivalent Model of Cable	178
3.5 Modal Impedance of Cable represented as "T" Model.	179
3.6 Network Aggregation	180
3.7 Modal Impedance of Aggregated Network	181
3.8 Process of Simmulated Annealing	184
3.9 Exponential Monotonic Multiplicative Cooling	188
3.10 Logarithmical Monotonic Multiplicative Cooling	189
3.11 Linear Monotonic Multiplicative Cooling	189
3.12 Quadratic Monotonic Multiplicative Cooling	190
3.13 Linear Additive Monotonic Cooling	190
3.14 Quadratic Additive Monotonic Cooling	191
3.15 Exponential Additive Monotonic Cooling	191
3.16 Trigonometric Additive Monotonic Cooling	192
3.17 Non-Monotonic Cooling	192
3.18 Wind Farm Network	196
3.19 Detailed Wind Farm Network	196
3.20 Aggregated Wind Farm Network	197
3.21 Mode-3 of Wind Farm	198
3.22 First peak of Mode- at 9.4^{th} order	199
3.23 Second peak of Mode-3 at 47.9^{th} order	199
3.24 Part of Network Participating in Mode-3-1 at 9.4^{th} order	200

3.25 Part of Network Participating in Mode-3-2 at 47.9 th order	201
3.26 Mode-4 at 76 th order	202
3.27 Mode-5 at 32.5 th order	203
3.28 Mode-1 without Detuned reactor	207
3.29 Mode-1 with Detuned reactor	208
3.30 Mode-2 without Detuned reactor	208
3.31 Mode-2 with Detuned reactor	209
3.32 Mode-3 without Detuned reactor	209
3.33 Mode-3 with Detuned reactor	210
3.34 Mode-4 without Detuned reactor	210
3.35 Mode-4 with Detuned reactor	211
3.36 Mode-5 without Detuned reactor	211
3.37 Mode-5 with Detuned reactor	212
3.38 Mode-6 without Detuned reactor	212
3.39 Mode-6 with Detuned reactor	213
3.40 Mode-7 without Detuned reactor	213
3.41 Mode-7 with Detuned reactor	214
3.42 C - Type Filter	216
3.43 Mode-1 with Detuned Reactor and C Filter on Bus-5	217
3.44 Mode-2 with Detuned Reactor and C Filter on Bus-5	218
3.45 Mode-3 with Detuned Reactor and C Filter on Bus-5	218
3.46 Mode-4 with Detuned Reactor and C Filter on Bus-5	219
3.47 Mode-5 with Detuned Reactor and C Filter on Bus-5	219
3.48 Mode-6 with Detuned Reactor and C Filter on Bus-5	220
3.49 Mode-7 with Detuned Reactor and C Filter on Bus-5	220
3.50 High Frequency Filter	222
3.51 Mode-1 with Detuned Reactor and High Frequency Filter on Bus-5	223
3.52 Mode-2 with Detuned Reactor and High Frequency Filter on Bus-5	223
3.53 Mode-3 with Detuned Reactor and High Frequency Filter on Bus-5	224
3.54 Mode-4 with Detuned Reactor and High Frequency Filter on Bus-5	224
3.55 Mode-5 with Detuned Reactor and High Frequency Filter on Bus-5	225
3.56 Mode-6 with Detuned Reactor and High Frequency Filter on Bus-5	226
3.57 Mode-7 with Detuned Reactor and High Frequency Filter on Bus-5	226

3.58	Different Types of Filter	229
3.59	Mode-1 with Optimized First Order Filter on Bus-3	230
3.60	Mode-2 with Optimized First Order Filter on Bus-3	230
3.61	Mode-3 with Optimized First Order Filter on Bus-3	231
3.62	Mode-4 with Optimized First Order Filter on Bus-3	231
3.63	Mode-5 with Optimized First Order Filter on Bus-3	232
3.64	Mode-6 with Optimized First Order Filter on Bus-3	232
3.65	Mode-7 with Optimized First Order Filter on Bus-3	233
3.66	Capacitance of Optimized First Order Filter on Bus-3	233
3.67	Resistance of Optimized First Order Filter on Bus-3	234
3.68	Impedance of Optimized First Order Filter on Bus-3	234
3.69	Impedance at Bus-1 without Optimized First Order Filter	237
3.70	Impedance at Bus-1 with Optimized First Order Filter	237
3.71	Impedance at Bus-2 without Optimized First Order Filter	238
3.72	Impedance at Bus-2 with Optimized First Order Filter	238
3.73	Impedance at Bus-3 without Optimized First Order Filter	239
3.74	Impedance at Bus-3 with Optimized First Order Filter	239
3.75	Impedance at Bus-4 without Optimized First Order Filter	240
3.76	Impedance at Bus-4 with Optimized First Order Filter	240
3.77	Impedance at Bus-5 without Optimized First Order Filter	241
3.78	Impedance at Bus-5 with Optimized First Order Filter	241
3.79	Impedance at Bus-6 without Optimized First Order Filter	242
3.80	Impedance at Bus-6 with Optimized First Order Filter	242
3.81	Impedance at Bus-7 without Optimized First Order Filter	243
3.82	Impedance at Bus-7 with Optimized First Order Filter	243
3.83	Harmonic Current Spectrum of Wind Turbine of Type-I	244
3.84	Harmonic Current Spectrum of Wind Turbine of Type-II	245
3.85	Harmonic Voltage at Bus-1 with Wind Turbine of Type-I	245
3.86	Harmonic Voltage at Bus-1 with Wind Turbine of Type-II	246
3.87	Harmonic Voltage at Bus-5 with Wind Turbine of Type-I	246
3.88	Harmonic Voltage at Bus-5 with Wind Turbine of Type-II	247
4.1	Control Structure of Grid Connected Wind Converters	251

4.2	Thevenins Equivalent Circuit	252
4.3	Norton's Equivalent Circuit	253
4.4	Converter Output Circuit	254
4.5	Phase Lock Loop (<i>PLL</i>)	255
4.6	Block Diagram of Simple Phase Lock Loop	256
4.7	Block Diagram of Modified Phase Lock Loop	257
4.8	Frequency Response of Simple Phase Lock Loop	257
4.9	Grid Connected Inverter with R-L Filter	258
4.10	Frequency Response of Impedance with RL Filter without PI Controller	260
4.11	Frequency Response of Impedance with RL Filter with PI Controller	260
4.12	L-C Filter	261
4.13	Frequency Response of LC Filter without PI Controller	262
4.14	Frequency Response of LC Filter with <i>PI</i> Controller	262
4.15	L-C-L Filter	263
4.16	Frequency Response of L-C-L Filter with PI Controller	264
4.17	Type-I L-C-L Filter	266
4.18	Frequency Response of Type-I L-C-L Filter	268
4.19	Type-II L-C-L Filter	269
4.20	Frequency Response of Type-II L-C-L Filter	270
4.21	Type-III L-C-L Filter	270
4.22	Frequency Response of Type-III L-C-L Filter	271
4.23	Type-IV L-C-L Filter	272
4.24	Frequency Response of Type-IV L-C-L Filter	273
4.25	Type-V L-C-L Filter	274
4.26	Frequency Response of Type-V L-C-L Filter	275
4.27	Block Diagram of Active Damping of Filter	276
4.28	Control Diagram of Active Damping of Filter	276
5.1	System Network	282
5.2	Single Line Diagram of System Network	285
5.3	Simplified System Network	285
5.4	Impedance Plot for 33 kV WTG Bus	291
5.5	Voltage Plot for 33KV PCC	292

5.6	Voltage Harmonic Spectrum	292
5.7	Network with LC Tuned Filter	294
5.8	C-Type Topology	296
5.9	Network with C - Type Filter	300
5.10	Shift in Resonance Frequency with Tuned LC Filter	303
5.11	Frequency Spectrum with Tuned LC Filter	303
5.12	Voltage Waveform with C-Type Filter	304
6.1	Generator - Motor Convention	308
6.2	Convention of Positive Direction of Current, Voltage and Flux	309
6.3	Position of $d - q$ frame with respect to abc frame	312
6.4	DFIG Model For Stability Study	314
6.5	DFIG Converter Model	320
6.6	Coefficient (C_p) Versus Lambda (λ)	321
6.7	Turbine Output Versus Rotor Speed	321
6.8	AC-DC Relationship of PWM-VSC	323
6.9	AC-DC Relationship of PWM-VSC	323
6.10	Orientation of DFIG Machine $d - q$ Frame and Slack Bus $D - Q$ Frame . .	325
6.11	Power Flow of Grid Connected DFIG	330
7.1	Grid Code Requirement	341
7.2	Primary Frequency Control	344
7.3	Voltage Control	344
7.4	PI Controller for d and q axis	345
7.5	MPPT Power Control of Wind Turbine	346
7.6	Pitch Control Loop	346
7.7	DFIG Scheme	347
7.8	Decoupled Control Structure	348
7.9	Grid Voltage Deviation Control	348
7.10	Measurement Block	350
7.11	Reactive Power Reference for Voltage Control	350
7.12	Reactive Power Reference for PF Control	350
7.13	Selection of Reactive Power Referencel	351
7.14	Selection of Reactive Power Referencel	351

7.15 Selection of Reactive Power Referencel	351
7.16 PI controller for v_{dRef}	352
7.17 PI controller for v_{qRef}	352
7.18 PI controller for DC Link Voltage Regulation	353
7.19 PI controller for dV_{dRef}	353
7.20 PI controlerl for dV_{qRef}	353
7.21 PWM reference for Unbalance Voltage Condition	353
7.22 $dq0$ to $\alpha\beta$ Conversion	354
7.23 $\alpha\beta$ to ABC Conversion	354
7.24 4-Bus EPRI Test System	355
7.25 Positve, Negative and Zero Sequence Current Under Unbalance Condition	357
7.26 Positve, Negative and Zero Sequence Voltage Under Unbalance Condition	358
7.27 Grid Side Converter - Outer Loop Currents	359
7.28 Grid Side Converter - Inner Loop Currents	360
7.29 Active and Reactive Power of RSC during Fault	361
7.30 Frequency Deviation During Fault	362
7.31 DC Link Voltage Deviation due to Fault	362
7.32 Pitch Angle Variation due to Fault	363
7.33 Fault Ride Through Activation	363
7.34 Wind Generator and Wind Turbine Speed Deviation during Fault	364
7.35 Grid Active Power, Reactive Power and Voltage during Fault	365
7.36 Wind Turbine Voltage during Fault	366
7.37 Positve, Negative and Zero Sequence Current Under Unbalance Condition	368
7.38 Positve, Negative and Zero Sequence Voltage Under Unbalance Condition	369
7.39 Grid Side Converter - Outer Loop Currents	370
7.40 Grid Side Converter - Inner Loop Currents	371
7.41 Active and Reactive Power of RSC during Fault	372
7.42 Frequency Deviation During Fault	373
7.43 DC Link Voltage Deviation due to Fault	373
7.44 Pitch Angle Variation due to Fault	374
7.45 Fault Ride Through Activation	374
7.46 Wind Generator and Wind Turbine Speed Deviation during Fault	375
7.47 Grid Active Power, Reactive Power and Voltage during Fault	376

7.48 Wind Turbine Voltage during Fault	377
--	-----