

List of Figures

1.1	Functional block diagram of power generation and control system	3
2.1	Turbine and Generator torque	15
2.2	Prime-mover model	16
2.3	Isochronous Governor	17
2.4	Governor with speed-droop feedback loop	18
2.5	Block diagram of governor with droop	18
2.6	Speed – Droop characteristics	18
2.7	Allocation of unit outputs with governor droop	19
2.8	Speed-changer settings	19
2.9	Block diagram of single area system	20
2.10	Block diagram representation of interconnected areas	21
3.1	Block diagram of PV-Wind Hybrid Power System.	32
3.2	Electrical equivalent circuit of single diode model.	35
3.3	P-V and I-V Characteristics of PV cell	36
3.4	Electrical equivalent circuit of single diode model.	37
3.5	Simulink implementation of model A.	38
3.6	Sub-system of the PV1 module in model A.	39
3.7	Sub-system implementation of the PV module	39
3.8	Block Parameters of PV1 model A	40
3.9	Simplified equivalent circuit of PV cell.	41
3.10	Implementation of Equation 3.9.	42
3.11	Implementation of Effect of Temperature and Solar Irradiation.	44
3.12	Implementation of PV cell.	44
3.13	Implementation of PV panel	45
3.14	Simulink implementation of PV module model B.	45
3.15	electrical equivalent of Two-diode model of PV cell.	46
3.16	Simulink implementation of PV cell model C.	46
3.17	Subsystem implementation of two-diode model C.	47
3.18	Solar Cell Block in Simscape/Simelectronics.	47
3.19	Block Parameters of Solar Cell in Simscape/Simelectronics.	48
3.20	Solar Cell Model in the Simulink.	48
3.21	I-V Characteristics from Data-sheet.	50
3.22	"P-V & I-V Characteristics of Model-A (Simulink)".	52
3.23	"P-V & I-V Characteristics of Model-B (Simulink)".	52
3.24	"P-V & I-V Characteristics of Model-C (Simulink)".	53
3.25	"P-V & I-V Characteristics of Model-D (Simscape)".	54

3.26 "P-V & I-V Characteristics of Model-E (Simscape)"	54
3.27 "P-V & I-V Characteristics of Model-F (Simscape)"	54
3.28 Block diagram of PV based generation	55
3.29 Flow chart for the iterative Algorithm to calculate Rs and Rp	58
3.30 characteristics of Sharp NU-E245 (J5) from data sheet	60
3.31 Simulink implementation of Two-diode model of PV panel.	61
3.32 Simscape implementation of Two-diode model of PV panel.	61
3.33 Characteristics of Two-diode model of PV panel implemented in simulink.	61
3.34 Characteristics of Two-diode model of PV panel implemented in simscape.	61
3.35 Schematic of boost converter	62
3.36 Waveform of the boost converter operating in CCM.	63
3.37 P-V & I-V characteristics of PV panel	66
3.38 Flow-chart of P & O algorithm	69
3.39 Graphical representation of MPP tracking of P & O algorithm	70
3.40 Simulink implementation of P & O MPP tracking algorithm	70
3.41 Model based modeling of PV based generation	71
3.42 Equation based modeling of PV based generation	71
3.43 Two numerical solutions	72
3.44 Voltage and current samples for MPPT algorithm of Model-based design of PV panel	72
3.45 Two numerical solutions	73
3.46 Voltage and current samples for MPPT algorithm of equation based implementation of PV panel	74
4.1 Block diagram of PV-Wind Hybrid Power System.	78
4.2 Growth of Wind Power Installation over years in India	79
4.3 Schematic of Wind power generation	80
4.4 Schematic of Wind power generation with Power Electronic Controller	81
4.5 Simulated Power Coefficient	88
4.6 Vertical Axis Wind Turbine [201]	89
4.7 Vertical Axis Wind Turbine [202]	90
4.8 Vertical Axis Wind Turbine on buildings [203]	90
4.9 Simulink implementation of the VAWT	93
4.10 Upwind and Down Wind turbines [204]	93
4.11 Horizontal Axis Wind Turbine [204]	94
4.12 Simulink implementation of the HAWT	95
4.13 Schematic diagram of wind power generation system	98
4.14 The equivalent circuit of d-axis	100
4.15 The equivalent circuit of q-axis	100
4.16 Equation based implementation of PMSG in Simulink	102
4.17 Boost converter in wind power generation system	103
4.18 Tip Speed Ratio control of Wind Power generation	104
4.19 Power Signal Feedback control of Wind Power generation	104
4.20 MPP tracking using HCS algorithm	105
4.21 Simulink implementation of HCS MPPT algorithm	106
4.22 Wind speed	107
4.23 Simulated Load Voltage, Current, and Power	108
4.24 Simulated Load Voltage, Current, and Power	109

4.25 Real-Rime data of Wind speed	110
4.26 Simulated Load Voltage, Current, and Power	110
4.27 Simulated Load voltage, Current and Power	111
5.1 Block diagram of PV-Wind Hybrid Power System.	115
5.2 Block Diagram of PV-Wind hybrid Power system with DC load	119
5.3 Simulated load Voltage, Current and Power of Hybrid power system	120
5.4 Block diagram of boost converter for PV generation	120
5.5 Block diagram of boost converter for Wind generation	121
5.6 Basic elements of Fuzzy Logic Control	121
5.7 Simulated result of Load Voltage	125
5.8 Simulated result of Load Current	125
5.9 Simulated result of Load Power	125
5.10 Weather Monitoring Systems installed at BITS-Pilani, Hyderabad	127
5.11 Solar illumination measured over a day	127
5.12 Solar Illumination measured over a week	127
5.13 Solar illumination measured over a month	127
5.14 Solar illumination measured over a year	127
5.15 Wind Speed measured over a day	128
5.16 Wind Speed measured over a week	128
5.17 Wind Speed measured over a month	128
5.18 Wind Speed measured over a year	128
5.19 Hourly irradiation for a day	128
5.20 Hourly wind speed for a day	128
5.21 Simulated Load Voltage	129
5.22 Simulated Load Current	129
5.23 Simulated Load Power	129
5.24 Simulated Load Voltage	130
5.25 Simulated Load Current	130
5.26 Simulated Load Power	130
6.1 Block Diagram of Predictive model implementation procedure	135
6.2 Schematic of NN model developed	135
6.3 Performance of NN model for prediction	136
6.4 Long-term Prediction of Solar Illumination	139
6.5 A day ahead solar Illumination Prediction	139
6.6 Long-term Prediction of Solar Illumination	140
6.7 A day ahead solar Illumination Prediction	140
6.8 Long-term Prediction of Solar Illumination	141
6.9 A day ahead solar Illumination Prediction	141
6.10 Long-term wind speed prediction	142
6.11 A day ahead wind speed forecast	142
6.12 Long-term wind speed prediction	143
6.13 A day ahead wind speed forecast	143
6.14 Long-term wind speed prediction	144
6.15 A day ahead wind speed forecast	144
6.16 A day ahead PV power fore-cast by NN model	145

6.17 A day ahead wind power forecast by NN model	145
6.18 Long-term solar illumination prediction for year 2016 by NN model	147
6.19 A day ahead solar illumination forecast by NN model	147
6.20 Long-term wind speed prediction for year 2016 by NN model	148
6.21 A day ahead wind speed forecast by NN model	148
6.22 Long-term solar illumination prediction for year 2017 by NN model	149
6.23 Long-term wind speed prediction for year 2017 by NN model	149
 7.1 Block diagram of PV-Wind Hybrid Power System.	152
7.2 Block Diagram of PV-Wind hybrid Power system with DC load	155
7.3 Voltage Regulated inverter	155
7.4 Block diagram of voltage regulated inverter	156
7.5 Block diagram of Discrete PLL	156
7.6 Solar illumination profile measured for a day	158
7.7 Wind speed profile measured for a day	158
7.8 a) DC Bus-Bar Voltage, b) DC Bus-Bar Current, c) DC Bus-Bar power	159
7.9 a) Load Voltage, b) Load Current, c) Inverter output voltage, d) Modulation index	160
7.10 Frequency of the system under constant load condition	160
7.11 Varying resistive load pattern	161
7.12 a) DC Bus-Bar Voltage, b) DC Bus-Bar Current, c) DC Bus-Bar power	162
7.13 a) Load Voltage, b) Load Current, c) Inverter output voltage, d) Modulation index	162
7.14 Frequency of the system under variable load condition	162
7.15 a) DC Bus-Bar Voltage, b) DC Bus-Bar Current, c) DC Bus-Bar power	164
7.16 Simulated Load Voltage	164
7.17 Simulated Load Current	164
7.18 Simulated Frequency of the system under increasing load pattern	165
7.19 Simulated Frequency of the system under increasing load pattern	166
7.20 Simulated Load Voltage	166
7.21 Simulated Load Current	166
7.22 Simulated Frequency of the system under increasing load pattern	166
7.23 Simulated Load Voltage	168
7.24 Simulated Load current	168
7.25 Simulated Frequency	169
7.26 Mechanical Torque	169
7.27 Graphical representation of Power system generation characteristics	171
7.28 Block diagram of droop based LFC control technique	172
7.29 Load Voltage, Current for the PLL based control	174
7.30 Load Voltage, Current for the Droop based control	175
7.31 Frequency of the system under constant load	175
7.32 Load Voltage, Current for the PLL based control	176
7.33 Load Voltage, Current for the Droop based control	176
7.34 Frequency of the system under decreasing load pattern	176
7.35 Load Voltage, Current for the PLL based control	177
7.36 Load Voltage, Current for the Droop based control	178
7.37 Frequency of the system under increasing load pattern	178
7.38 DC Bus-Bar Voltage, Cur- rent, Power Measurement for Discrete PLL LFC	179
7.39 DC Bus-Bar Voltage, Cur- rent, Power Measurement for Droop based LFC	179

7.40 Inverter output voltage for Discrete PLL LFC	179
7.41 Inverter output voltage for Droop based LFC	179
7.42 Inverter output voltage for Discrete PLL LFC	180
7.43 Inverter output voltage for Droop based LFC	180
7.44 Three phase load voltage for Discrete PLL LFC	180
7.45 Three phase load voltage for Droop based LFC	180
7.46 Three phase load current for Discrete PLL LFC	181
7.47 Three phase load current for Droop based LFC	181
7.48 A Comparative plot of frequency of the system	181
 8.1 Block diagram of grid connected PV-Wind hybrid power system	186
8.2 Circuit level implementation of Grid Connected PV-Wind hybrid power system	187
8.3 I-V and P-V Characteristics of PV generation	188
8.4 Simulated Power characteristics of Wind turbine	188
8.5 Block diagram of MPPT based inverter control technique	189
8.6 Measurement and conversion technique	189
8.7 Current regulator with Active and Reactive power flow control	191
8.8 Block diagram illustration of Vdc regulator	191
8.9 Block diagram illustration of voltage reference computation	192
8.10 PV generation with real time data of solar illumination	193
8.11 Wind generation with real time data of wind speed	193
8.12 DC bus-bar voltage	193
8.13 I_d current for inverter control	193
8.14 I_q current for inverter control	193
8.15 Simulated Inverter Output Voltage	193
8.16 Simulated Load Voltage	194
8.17 Simulated Load Current	194
8.18 ω_t measured and computed	194
8.19 Total Power Injected into the grid	194
8.20 Two-area system	197
8.21 Electrical equivalent of Two-area system	197
8.22 Element wise representation of hybrid power system	198
8.23 Droop Characteristics	199
8.24 Droop Characteristics	199
8.25 Simulink Implementation of two-area system	201
8.26 Inverter output voltage	201
8.27 Simulated Voltage of area 1	202
8.28 Simulated Current of area 1	202
8.29 Power generated in area 1	202
8.30 Simulated Voltage and current of area 2	202
8.31 power generated in area 2	202
8.32 Simulated Voltage and current of tie-line	203
8.33 Tie-line Power interchange	203
8.34 Frequency of the system	203