

List of Figures

1.1	Annual change in global primary energy demand, 2011–2018	2
1.2	Global primary energy demand met by various sources in percentage,2018 .	3
1.3	Total installed capacity in the India	4
1.4	Renewable Energy Capacity Investment over the Decade, 2010-2019, \$BN .	5
1.5	Renewable Energy Capacity Investment from 2010 To 1h 2019, Top 20 Countries, \$BN]	6
2.1	Schematic of smart distribution system	25
2.2	(a) Grey wolves in the search space, (b) Four stages of GWO algorithm .	28
2.3	Flow chart to achieve radial topology using BNIM technique	32
2.4	Volt/VAR droop characteristics	36
2.5	Typical load and PV generation in per unit	37
2.6	modified 33 bus distribution system (TS-1)	37
2.7	modified 118 bus distribution system (TS-2)	38
2.8	Voltage profile of TS-1 at (a)valley and (b)peak loading hour	43
2.9	Voltage profile of TS-2 at (a) valley and (b) peak loading hour	43
2.10	Convergence curve of different algorithms of (a)TS-1 and (b)TS-2 under scenario 4, at peak hour (19:00)	45
2.11	modified unbalanced 33 bus distribution system	47
2.12	Stochastic analysis: forecasted errors for unbalanced 33 bus system	49
2.13	Percentage energy reduction in ELM and ZIP load models of TS-1 under four scenarios compared with TVVC	50
2.14	Percentage energy reduction in ELM and ZIP load models of TS-2 under four scenarios compared with TVVC	50
2.15	Voltage profile of TS-1 and TS-2 under different cases	52

3.1	A typical SOP connected to adjacent feeder	59
3.2	Modified 69 bus system	64
3.3	Typical Load, grid price and photovoltaic generation output	65
3.4	Modified 69 bus system with SOP	70
3.5	Active and reactive power scheduling of SOP-27 and SOP-65 under case 5	70
3.6	Active and reactive power scheduling of SOP-27 and SOP-65 under case 6	71
3.7	Active and reactive power scheduling of SOP-27 and SOP-65 under case 7	74
3.8	voltage profile of 69 bus system under different cases	75
3.9	active power losses over a typical day under different cases	75
3.10	energy demand of 69 bus system under different cases	76
3.11	Percentage reduction in energy consumption and losses under different cases w.r.t case 1	77
3.12	carbon emissions of the system under different cases	77
3.13	Total operating cost of 69 bus system under different cases	78
3.14	Convergence pattern of MBGWO under different cases	79
3.15	Convergence pattern of CGWO and MBGWO under case 7	79
3.16	minimum and maximum voltage of the system at each hour under two scenarios	83
3.17	Stochastic analysis comparison of total operating cost with/without optimal control & with/without forecasted errors	84
4.1	Schematic of proposed hierarchical coordinated VVO methodology	89
4.2	Implementation of proposed hierarchical coordinated VVO methodology	94
4.3	Volt VAr droop characteristics of smart inverter	97
4.4	Modified 33 bus distribution system	98
4.5	Typical load, grid price and PV generation output	100
4.6	Pareto front solution for case 2 and case 3	103
4.7	Pareto front solution for case 4 and case 5	103
4.8	SOC profile of BES under case 4	104
4.9	SOC profile of BES under case 5	105
4.10	Active power loss of the system for different cases	107
4.11	Reactive power loss of the system for different cases	107
4.12	Voltage profile of the system at 19th hour	108

4.13	OLTC tap variation over a day for different cases	109
4.14	status of capacitor banks under case 2 and case 4	109
4.15	status of capacitor banks under case 3	110
4.16	status of capacitor banks under case 5	110
4.17	Reactive power dispatch of smart inverter under case 3 negative value represents the absorption	111
4.18	reactive power dispatch of smart inverter under case 5 negative value represents the absorption	111
4.19	Power demand and CVR savings without BES	112
4.20	Power demand and CVR savings with BES	112
4.21	Energy demand variation under different cases	113
4.22	Total operating cost and savings under different cases	114
4.23	Lowest voltage and compensated reactive power from SI during 13:00 to 13:45 hour	116
4.24	Network active power loss during 13:00 to 13:45 hour	116
4.25	Active power consumption during 13:00 to 13:45 hour	117
4.26	Stochastic analysis comparison of total operating cost with/without optimal control & with/without forecasted errors	118
4.27	Stochastic analysis All node voltage deviation with/without optimal control & with/without forecasted errors	119
5.1	Implementation of proposed approach	122
5.2	Implementation of proposed approach	125
5.3	Droop characteristics of PV/SOP	127
5.4	Modified 33 distribution system	128
5.5	load and PV generation multiplier	128
5.6	Active power transmission of SOP	130
5.7	Reactive power compensation from SOP	131
5.8	voltage behaviour at hour 13 under different scenarios	132
5.9	voltage behaviour at hour 19 different scenarios	132
5.10	Structure of Real Time Co-simulation Platform	134
5.11	PV active power output and voltage behaviour in case 1 under cloud transient condition	136

5.12 PV active power output, voltage behaviour and reactive power output of PV, SOP smart inverter in case 2 under cloud transient condition	137
6.1 Framework of Proposed two layer model	140
6.2 Stochastic Variable Module (SVM) for uncertainties	142
6.3 Candidate solution of upper layer D1	147
6.4 Candidate solution of lower layer D2	147
6.5 schematic of the proposed hybrid optimization solver	148
6.6 modified 119 bus distribution system	149
6.7 Typical PV, wind, load and its price profile	150
6.8 average voltage of each node in the system for different cases	155
6.9 Cumulative probability distribution of nodal voltages in the system for different cases	156
6.10 Energy losses of system in each year for different cases	157
6.11 Energy consumption of system in each year for different cases	157
6.12 carbon emission from system in each year for different cases	158
6.13 Energy not served of system in each year for different cases	158
6.14 Convergence curve of different algorithms for case E	159