APPENDIX 1

DATA AND RESULTS OF 12-BUS DISTRIBUTION SYSTEM

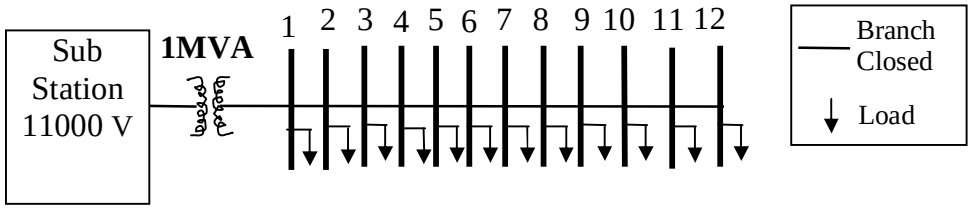

Figure A1.1 12-Bus Distribution System (under pre-fault condition)

DATA OF 12-BUS DISTRIBUTION SYSTEM

Base MVA = 100 Base KV = 33 Sub-station voltage = 33000V

Number of feeder = 1 Number of transformer = 1

Type of conductor employed for Feeder = Mink C.T Ratio = 525/1

Capacity of the feeders = 234A Plug setting = 1.0

Rating of transformer 1 = 1.0 MVA

Over load setting of the transformer breaker = 1.25

Table A1.1 Bus data of 12-Bus Distribution System

Bus No	Load		LPRO	Q_{sh} in KVAR	Bus No	Load		LPRO	Q_{sh} in KVAR
	KW	KVAR				KW	KVAR		
1	0.000	0.000	0	0.00	7	55.00	55.00	6	0.00
2	60.00	60.00	1	0.00	8	45.00	45.00	8	0.00
3	40.00	30.00	7	0.00	9	40.00	40.00	11	0.00
4	55.00	55.00	3	0.00	10	35.00	30.00	2	0.00
5	30.00	30.00	5	0.00	11	40.00	30.00	9	0.00
6	20.00	15.00	4	0.00	12	15.00	15.00	10	0.00

Table A1.2 Line data of 12-Bus Distribution System

Br No	Bus		R in Ω	X in Ω	Br No	Bus		R in Ω	X in Ω	Br No	Bus		R in Ω	X in Ω
	From	To				From	To				From	To		
1	1	2	1.0930	0.4550	5	5	6	1.0930	0.4550	9	9	10	2.9800	0.8180
2	2	3	1.1840	0.4840	6	6	7	1.0020	0.4170	10	10	11	1.5140	0.4880
3	3	4	2.0950	0.8730	7	7	8	4.4030	1.2150	11	11	12	1.2380	0.3510
4	4	5	3.1880	1.3290	8	8	9	5.6420	1.5970	12	--	--	--	--

RESULTS OF SERVICE RESTORATION ANALYSIS OF THE 12-BUS DISTRIBUTION SYSTEM

The 12-Bus distribution system is shown in Figure A1.1. The results of the 12-Bus distribution system under pre-fault condition is given in Table 3.1. In order to perform the service restoration analysis, here it is assumed that a single line to ground fault takes place at the Bus 6. The loads connected that the buses 6, 7, 8, 9, 10, 11 and 12 are in dark state. The power supply is restored to loads connected to the buses 6 to 12 only after clearing the fault because this distribution system does not have any tie lines. Hence,

the problem of search for the optimal configuration of PDN does not arise. The configuration of the PDN is shown in Figure A1.2.

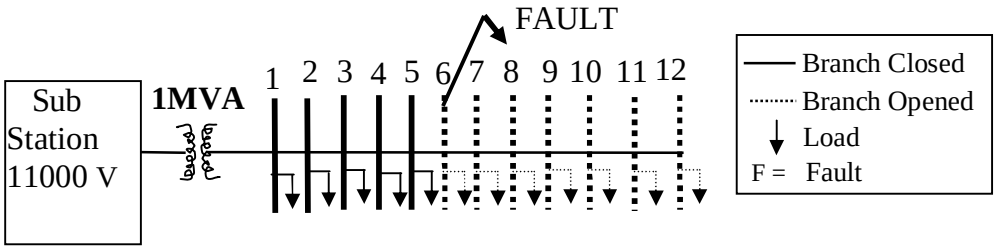

Figure A1.2 12-Bus Distribution System (under post-fault condition)

The voltages during fault of the 12-Bus distribution system and the Line Currents during single line to ground fault at the Bus 6 are given Table A1.3 and Table A1.4, respectively.

Table A1.3 Voltage during the fault of the 12-Bus Distribution System

Bus No	Voltage Magnitude			Bus No	Voltage Magnitude			Bus No	Voltage Magnitude		
	Phase a	Phase b	Phase c		Phase a	Phase b	Phase c		Phase a	Phase b	Phase c
1	0.9873	1.0000	1.0000	5	0.1356	0.9799	0.9799	9	0.0192	0.9645	0.9645
2	0.8809	0.9966	0.9966	6	**0.0169**	**0.9678**	**0.9678**	10	0.0207	0.9631	0.9631
3	0.7780	0.9898	0.9898	7	0.0123	0.9668	0.9668	11	0.0265	0.9675	0.9675
4	0.6982	0.9895	0.9895	8	0.0119	0.9589	0.9589	12	0.0278	0.9645	0.9645

Table A1.4 Line current during the fault for 12-Bus Distribution System

From Bus	To Bus	Line Current Magnitude			From Bus	To Bus	Line Current Magnitude		
		Phase a	Phase b	Phase c			Phase a	Phase b	Phase c
1	2	0.1345	0.0078	0.0078	**6**	**F**	**0.1224**	**0.0000**	**0.0000**
2	3	0.1654	0.0060	0.0060	7	8	0.0022	0.0022	0.0022
3	4	0.1278	0.0065	0.0065	8	9	0.0017	0.0017	0.0017
4	5	0.1282	0.0045	0.0045	9	10	0.0011	0.0011	0.0011
5	6	0.1298	0.0039	0.0039	10	11	0.0007	0.0007	0.0007
6	7	0.0068	0.0029	0.0029	11	12	0.0002	0.0002	0.0002

Total Fault Current I_f = 0.1230 per unit

Optimistic Time of operation of the relay = 1.6 s

Pessimistic Time of operation of the relay = 0.6857 s

Mostly Likely Time of operation of the relay = 1.8057s

Expected Time of operation of the relay = 1.5847s

$\therefore$ TRT_1 = 1.5847 s

The time taken to search for optimal switching configuration of the power distribution (TRT_2) has been found to be 0.3250 seconds.

Total Restoration Time (TRT) = TRT_1 +TRT_2 =1.9097 s.

The results of the power flow analysis of the post-fault PDN is given in Table A1.5. From the result it is observed that the transformer and feeder are not overloaded. A summary of results for GA and NSGA methods is given in Table A1.6.

Table A1.5 Bus voltage in the post-fault 12-Bus Distribution System

Bus No	|V| in p.u	Bus No	|V| in p.u	Bus No	|V| in p.u	Bus No	|V| in p.u
1	1.0000	4	0.9939	7	**0.0000**	10	**0.0000**
2	0.9977	5	0.9927	8	**0.0000**	11	**0.0000**
3	0.9960	6	**0.0000**	9	**0.0000**	12	**0.0000**

Table A1.6 Summary of results for GA and NSGA methods

Summary of results for GA and NSGA methods	Pre-fault condition 12-Bus		Post-fault condition 12-bus	
	GA	NSGA	GA	NSGA
Total real power demand (KW)	435.00	**435.00**	185.00	185.00
Total reactive power demand (KVAR)	405.00	**405.00**	175.00	175.00
Total real power loss (KW)	20.716	**19.862**	1.1785	**1.1220**
Total reactive power loss (KVAR)	8.0178	**7.9805**	0.4885	**0.4210**
Total real power supplied from the sub-station (KW)	455.716	**454.862**	186.18	**186.122**
Total reactive power supplied from the sub-station (KVAR)	413.0178	**412.9805**	175.489	**175.421**
Number of iterations taken	11	**6**	7	**5**
Percentage loading of transformer 1	0.6149	**0.60104**	0.2358	**0.2201**
Percentage loading of feeder 1	0.0800	**0.07650**	0.0322	**0.0122**
Computational time in seconds	0.066	**0.0451**	0.582	**0.325**
Total service restoration time in seconds	0.066	**0.0451**	2.1667	**1.9097**

APPENDIX 2

DATA AND RESULTS OF 16-BUS, THREE FEEDER DISTRIBUTION SYSTEM

DATA OF 16-BUS, THREE FEEDER DISTRIBUTION SYSTEM

Base MVA = 100 Base KV = 11 Sub-station voltage = 11000 V

Number of feeders = 3 Number of transformers = 3

Type of conductor employed for feeder = Mink CT ratio =525/1

Capacity of the feeders = 234A Plug setting = 1.0

Resistance R= 0.4565Ω/ Km Reactance X =0.4565Ω/ Km

Rating of transformer 1 = 10MVA

Rating of transformer 2 = 15MVA

Rating of transformer 3 = 10MVA

Over load setting of the transformer breaker = 1.25

Table A2.1 Bus data of 16-Bus, three feeder EPDS

Bus No	Load		LPRO	Q_{sh} in KVAR	Bus No	Load		LPRO	Q_{sh} in KVAR
	KW	KVAR				KW	KVAR		
1	0.00	0.00	0	0.00	9	1.30	0.78	13	1.20
2	0.00	0.00	0	0.00	10	1.65	0.78	2	0.00
3	0.00	0.00	0	0.00	11	0.94	0.56	8	0.60
4	2.10	0.92	3	0.00	12	3.45	2.00	11	3.70
5	1.75	0.87	1	1.10	13	1.42	0.68	5	0.00
6	1.25	0.65	4	1.20	14	1.45	0.67	6	1.80
7	1.50	0.80	7	0.00	15	1.98	0.79	10	0.00
8	1.28	0.76	9	0.00	16	1.08	0.45	12	1.80

Table A2.2 Line data of 16-Bus, three feeder Electrical Power Distribution System (EPDS)

Br No	Bus		Line Length in Km	Br No	Bus		Line Length in Km	Br No	Bus		Line Length in Km
	From	To			From	To			From	To	
1	1	4	1.25	7	8	10	0.79	13	13	14	1.50
2	4	5	2.50	8	5	11	1.18	14	14	13	0.98
3	4	6	0.75	9	9	11	2.10	15	15	16	0.89
4	6	7	2.16	10	9	12	0.98	16	7	16	1.58
5	2	8	1.05	11	11	3	1.50	--	--	--	--
6	8	9	1.00	12	10	14	1.25	--	--	--	--

RESULTS OF SERVICE RESTORATION ANALYSIS FOR THE OCCURRENCE OF A SINGLE LINE TO GROUND FAULT AT THE BUS 13 OF THE 16-BUS, THREE FEEDER DISTRIBUTION SYSTEM

The 16-bus, three feeder distribution system is shown in Figure 2.3 in Chapter 2. In order to perform the service restoration analysis, here it is assumed that a single line to ground fault takes place at the Bus 13 with a fault impedance of j0.1p.u. The selection of parameters of the NSGA is given Table 6.1. The node 3 of the feeder-3 (which is connected to the sub-station) gets isolated from the PDN. Hence the loads connected to the buses 13, 15 and 16 are in the dark state.

The detailed service restoration analysis is the same as which has already been presented in Section 7.6. The variation of the combined objective function and its function with respect to the generations of the NSGA is shown in Figure A2.1. The combined objective function has reached the global minimum at the 7^{th} generation of the NSGA. The Optimal Configuration of the post-fault PDN corresponding to the 7^{th} generation of the NSGA is shown in Figure A2.2.

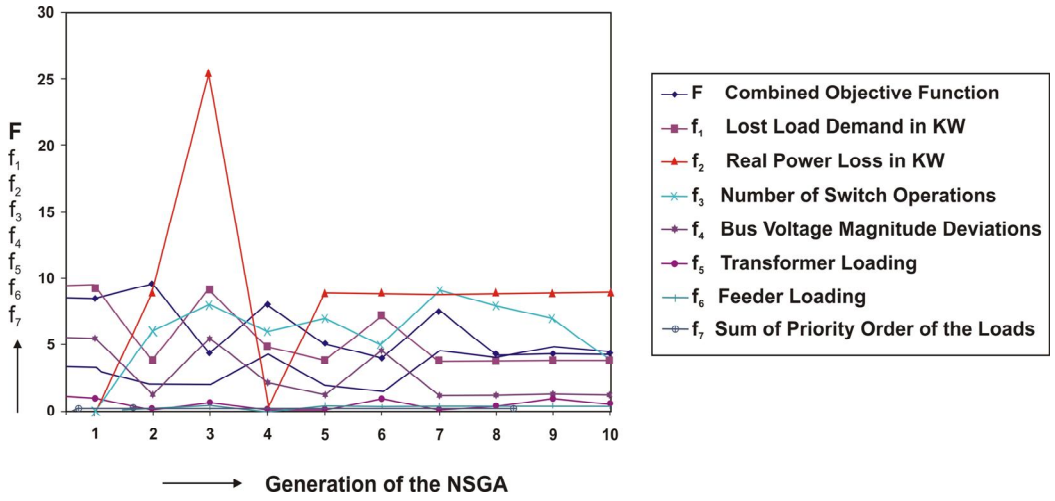

Figure A2.1 Variation of the combined objective function with respect to the generation of the NSGA for 16-Bus, three feeder Distribution System

From the post-fault PDN it has been observed that the loads connected to the buses 15 and 16 are transferred to the feeder 1. The Line Currents during the Single Line Ground fault is given in Table 5.2 (Chapter 5). Voltages during the pre-fault and post- fault condition, for the 16-Bus system are given in Table 5.3 (Chapter 5).

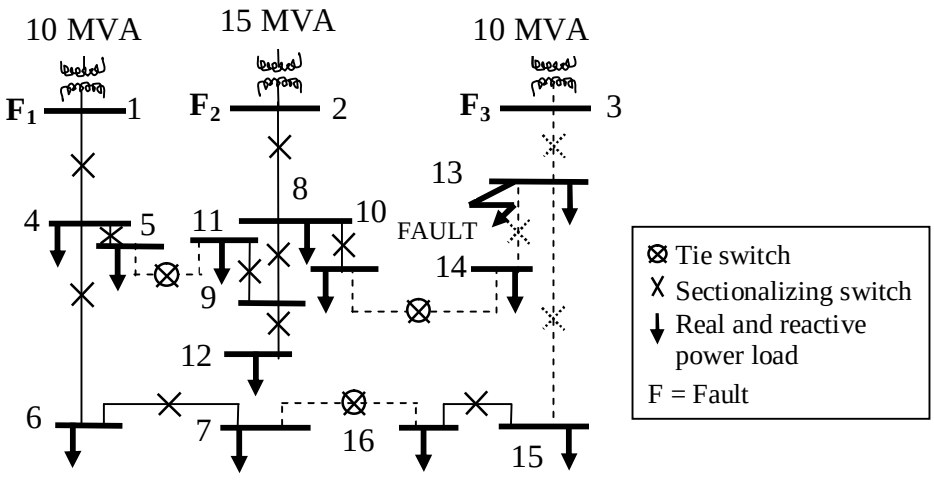

Figure A2.2 16-Bus, three feeder practical Distribution System (under post-fault condition)

From Table 5.3 it is observed that the post-fault voltages at the buses 7, 15 and 16 is less than minimum allowable limit and also the feeders 1 and 2 are overloaded. The preemptive method is used to minimize these voltage limit violations and low priority loads (which are connected to the buses 9 and 16) are set zero (these details are explained in Chapter 4). The result of the power flow analysis with the priority order consideration of loads is given in Table A2.3. From Table A2.3 it is observed that voltage limit violations are minimized and also the overloading of feeders and transformers are also minimized.

Table A2.3 Bus voltage in the post-fault 16-Bus, three feeder Distribution System (after use of Preemptive Method)

Bus No	|V| in p.u	Bus No	|V| in p.u	Bus No	|V| in p.u	Bus No	|V| in p.u
1	1.0000	5	0.9741	9	0.9711	13	0.0000
2	1.0000	6	0.9746	10	0.9770	14	0.9752
3	1.0000	7	**0.9768**	11	0.9787	15	**0.9765**
4	0.9721	8	0.9789	12	0.9749	16	**0.8999**

Total real power demand = 17350.00 KW

Total reactive power demand = 8800.00 KVAR

Total real power loss = 1317.27 KW

Total reactive power loss = 1056.13 KVAR

Total real power supplied from the sub-station = 18667.30 KW

Total reactive power supplied from the sub-station = 9856.13 KVAR

Number of iterations taken = 8

Percentage loading of transformer 1 = 1.03269

Percentage loading of transformer 2 = 0.84212

Percentage loading of transformer 3 = 0.00000

Percentage loading of feeder 1 = 1.4076

Percentage loading of feeder 2 = 1.1177

Summary of results for GA and NSGA methods is given in Table A2.4.

Table A2.4 Summary of results for GA and NSGA methods

Summary of results for GA and NSGA methods	Pre-fault condition 16-Bus		Post-fault condition 16-bus	
	GA	NSGA	GA	NSGA
Total real power demand (KW)	21150.00	21150.00	19730.00	**19730.00**
Total reactive power demand (KVAR)	10710.000	10710.000	10030.00000	**10030.00**
Total real power loss (KW)	1202.7415	**1202.4012**	1781.991520	**1781.6966**
Total reactive power loss (KVAR)	964.3009	**963.9988**	1428.716092	**1428.3025**
Total real power supplied from the sub-station (KW)	22352.700	**22352.4012**	21512	**21511.6966**
Total reactive power supplied from the sub-station (KVAR)	11674.300	**11673.898**	11458.7	**11458.3025**
Number of iterations taken	11	**6**	14	**8**
Percentage loading of transformer 1	0.8079	**0.80310**	1.17621	**1.1521**
Percentage loading of transformer 2	0.9600	**0.9100**	0.960029	**0.94218**
Percentage loading of transformer 3	0.4606	**0.4102**	0.0000	**0.0000**
Percentage loading of feeder 1	1.0923	**1.07368**	1.61869	**1.5682**
Percentage loading of feeder 2	1.2849	**1.2037**	1.28494	**1.1988**
Percentage loading of feeder 3	0.6127	**0.6028**	0.0000	**0.0000**
Computational time in seconds	0.084	**0.056**	0.72	**0.52**
Total service restoration time in seconds	0.084	**0.056**	1.235	**1.035**

APPENDIX 3

DATA OF 26-BUS PRACTICAL DISTRIBUTION SYSTEM

Base MVA = 100 Base KV=11 Sub-station voltage = 11000V

Number of feeder = 1 Number of transformer = 1

Type of conductor employed for feeder = Mink CT ratio = 525/1

Capacity of the feeders = 234A Plug setting = 1.0

Rating of transformer 1 = 5.0 MVA

Over load setting of the transformer breaker = 1.25

Summary of results for GA and NSGA methods are given in Table A3.3.

Table A3.1 Bus data of 26-Bus practical Distribution System

Bus No	Load		LPRO	Q_{sh} in KVAR	Bus No	Load		LPRO	Q_{sh} in KVAR
	KW	KVAR				KW	KVAR		
1	0.0000	0.0000	0	0.000	14	0.0000	0.0000	0	0.000
2	0.0000	0.0000	0	0.000	15	80.000	60.000	11	0.000
3	128.00	96.00	2	0.000	16	200.00	150.0	14	0.000
4	80.000	60.000	4	0.000	17	252.00	189.00	15	0.000
5	80.000	60.000	3	0.000	18	128.00	96.00	10	0.000
6	80.000	60.000	1	0.000	19	160.00	120.00	16	0.000
7	80.000	60.000	6	0.000	20	80.000	60.000	20	0.000
8	80.000	60.000	5	0.000	21	80.000	60.000	17	0.000
9	80.000	60.000	7	0.000	22	80.000	60.000	21	0.000
10	80.000	60.000	8	0.000	23	80.000	60.000	19	0.000
11	80.000	60.000	0	0.000	24	80.000	60.000	18	0.000
12	80.000	60.000	13	0.000	25	200.00	150.00	23	0.000
13	80.000	60.000	9	0.000	26	100.00	75.000	22	0.000

Table A3.2 Line data of 26-Bus practical Distribution System

Br No	Bus		R in Ω	X in Ω	Br No	Bus		R in Ω	X in Ω	Br No	Bus		R in Ω	X in Ω
	From	To				From	To				From	To		
1	1	2	0.6381	0.2695	10	10	11	0.1823	0.0770	19	2	19	0.0912	0.0385
2	2	3	0.1823	0.0770	11	11	12	0.3646	0.1540	20	19	20	0.0912	0.0385
3	3	4	0.1823	0.0770	12	12	13	0.2735	0.1155	21	11	21	0.0912	0.0385
4	4	5	0.2735	0.1155	13	1	14	3.3729	1.4134	22	21	22	0.0912	0.0385
5	5	6	0.4558	0.1925	14	13	14	0.2735	0.1155	23	11	23	0.3646	0.1540
6	6	7	0.0912	0.0385	15	14	15	0.0912	0.0385	24	23	24	0.2735	0.1155
7	7	8	0.0912	0.0385	16	15	16	0.1367	0.0578	25	14	25	0.0912	0.0385
8	8	9	0.1823	0.0770	17	16	17	0.1767	0.0578	26	25	26	0.0912	0.0385
9	9	10	0.1823	0.0770	18	17	18	0.3646	0.1540	--	--	--	--	--

Table A3.3 Summary of results for GA and NSGA methods

Summary of results for GA and NSGA methods	Pre-fault condition 26-Bus		Post-fault condition 26-bus	
	GA	NSGA	GA	NSGA
Total real power demand (KW)	2368.000	2368.000	2288.00	2288.00
Total reactive power demand (KVAR)	1776.000	1776.000	1761.00	1761.00
Total real power loss (KW)	83.3120	**83.010**	82.026462	**81.786**
Total reactive power loss (KVAR)	35.0434	**34.6766**	34.474578	**34.1201**
Total real power supplied from the sub-station (KW)	2451.310	**2451.010**	2370.03	**2369.786**
Total reactive power supplied from the sub-station (KVAR)	1811.040	**1810.676**	1795.47	**1795.1201**
Number of iterations taken	10	**8**	10	**6**
Percentage loading of transformer 1	0.3695	**0.31020**	0.329263	**0.319501**
Percentage loading of feeder 1	0.00002	**0.00002**	0.215171	**0.20164**
Computational time in seconds	0.1586	**0.1024**	15.91	**8.06891**
Total service restoration time in seconds	0.1586	**0.1024**	**17.5562**	**9.71311**

APPENDIX 4

DATA AND RESULTS OF 29-BUS PRACTICAL DISTRIBUTION SYSTEM

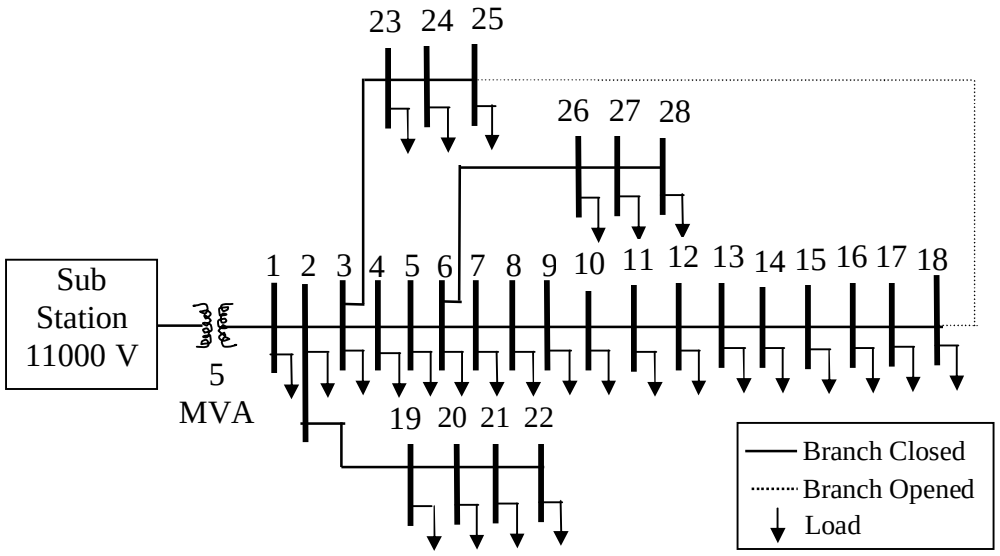

Figure A4.1 29-Bus practical Distribution System (under pre-fault condition)

DATA OF 29-BUS PRACTICAL DISTRIBUTION SYSTEM

Base MVA = 100 Base KV = 11 Sub-station voltage = 11000V

Number of feeder = 1 Number of transformer = 1

Type of conductor employed for feeder = Mink CT ratio = 525/1

Capacity of the feeders = 234A Plug setting = 1.0

Rating of transformer 1 = 5.0 MVA

Over load setting of the transformer breaker = 1.25

Table A4.1 Bus data of 29-Bus practical Distribution System

Bus No	Load		LPRO	Q_{sh} in KVAR	Bus No	Load		LPRO	Q_{sh} in KVAR
	KW	KVAR				KW	KVAR		
1	0.0000	0.0000	0	0.00	15	70.000	40.000	8	0.00
2	140.00	90.000	13	0.00	16	70.000	40.000	10	0.00
3	80.000	50.000	6	0.00	17	60.000	30.000	7	0.00
4	80.000	50.000	19	0.00	18	60.000	30.000	17	0.00
5	100.00	60.000	18	0.00	19	70.000	40.000	27	0.00
6	80.000	50.000	2	0.00	20	50.000	30.000	22	0.00
7	90.000	40.000	9	0.00	21	50.000	30.000	21	0.00
8	90.000	40.000	11	0.00	22	40.000	20.000	24	0.00
9	80.000	50.000	14	0.00	23	50.000	30.000	16	0.00
10	90.000	50.000	12	0.00	24	50.000	30.000	26	0.00
11	80.000	50.000	3	0.00	25	60.000	40.000	15	0.00
12	80.000	40.000	4	0.00	26	40.000	20.000	23	0.00
13	90.000	50.000	1	0.00	27	40.000	20.000	20	0.00
14	70.000	40.000	5	0.00	28	40.000	20.000	25	0.00

Table A4.2 Line data of 29-Bus practical Distribution System

Br No	Bus		R in Ω	X in Ω	Br No	Bus		R in Ω	X in Ω	Br No	Bus		R in Ω	X in Ω
	From	To				From	To				From	To		
1	1	2	1.8216	0.7580	11	10	11	2.7520	0.7780	21	20	21	2.7520	0.7780
2	2	3	2.2270	0.9475	12	11	12	1.3760	0.3890	22	21	22	4.9536	1.4004
3	3	4	1.3662	0.5682	13	12	13	4.1280	1.1670	23	3	23	3.5776	1.0114
4	4	5	0.9180	0.3790	14	13	14	4.1280	0.7780	24	23	24	3.0272	0.8558
5	1	6	2.7324	1.1370	15	14	15	3.0272	0.7780	25	24	25	5.5040	1.5560
6	5	6	3.6432	1.5160	16	15	16	2.7520	0.7780	26	6	26	2.7520	0.7780
7	6	7	2.7324	1.1370	17	16	17	4.1280	0.7780	27	26	27	1.3760	0.3890
8	7	8	1.4573	0.6064	18	17	18	2.7520	0.7780	28	27	28	1.3760	0.3890
9	8	9	2.7324	1.1370	19	2	19	3.4400	0.9725	29	18	25	3.4400	0.9725
10	9	10	3.6432	1.5160	20	19	20	1.3760	0.3890	--	--	--	--	--

RESULTS OF SERVICE RESTORATION ANALYSIS OF THE 29-BUS PRACTICAL DISTRIBUTION SYSTEM

The 29-Bus distribution system is shown in Figure A4.1. In order to perform the service restoration analysis, here it is assumed that a single line to ground fault takes place at the Bus 23. The occurrence of fault at the Bus 23 leads to disconnection of the power supply to the loads which are connected to the buses 23, 24 and 25.

The detailed service restoration analysis is the same as presented in Section 7.6 of the thesis. The selection of parameters of the NSGA is given Table 6.1. The variation of the combined objective function and with respect to the generations of the NSGA is shown in Figure A4.2. The combined objective function has reached the global minimum at the 8^{th} generation of the NSGA. The optimal configuration of the post-fault PDN corresponding to the 8^{th} generation of the NSGA is shown in Figure A4.3. The time taken to search for optimal switching configuration of the power distribution (TRT_2) has been found to be 14.685 seconds. The voltage during the fault and Line Currents during the Single Line Ground fault are given in Table A4.3 and Table A4.4, respectively.

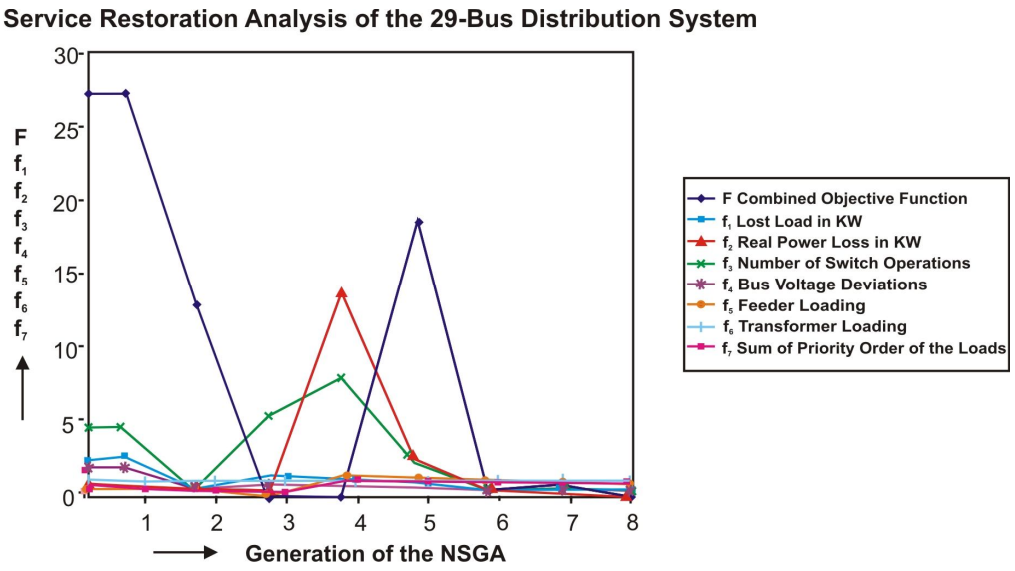

Figure A4.2 Variation of the combined objective function and with respect to the generation of NSGA for 29-Bus Distribution System

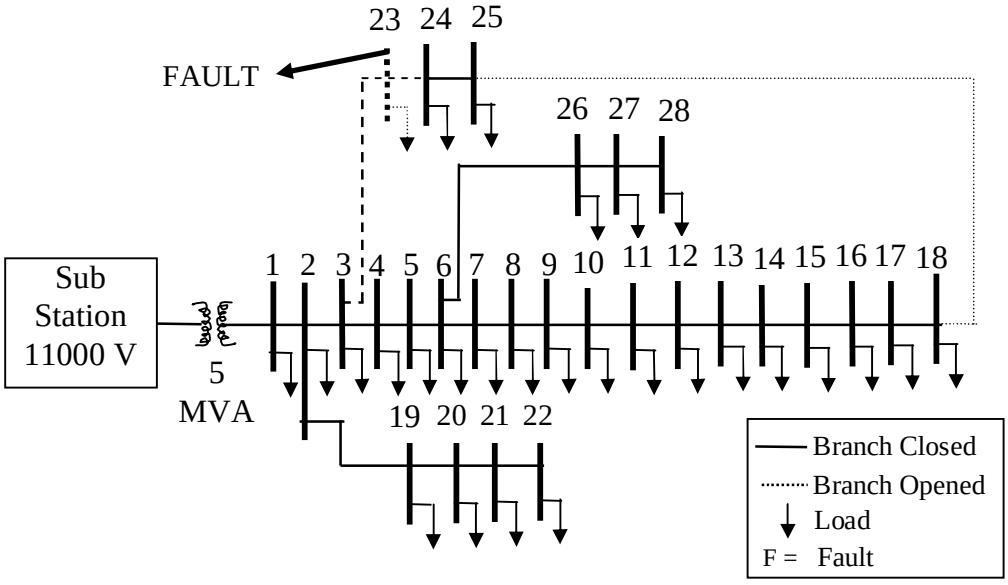

Figure A4.3 29-Bus Distribution System (under post-fault condition)

Table A4.3 Voltage during the fault of the 29-Bus practical Distribution System

Bus No	Voltage Magnitude			Bus No	Voltage Magnitude			Bus No	Voltage Magnitude		
	Phase a	Phase b	Phase c		Phase a	Phase b	Phase c		Phase a	Phase b	Phase c
1	0.9848	1.0000	1.0000	11	0.3876	0.8956	0.8956	21	0.7621	0.9645	0.9645
2	0.7823	0.9767	0.9767	12	0.3823	0.8867	0.8867	22	0.7356	0.9721	0.9721
3	0.7684	0.9796	0.9796	13	0.3621	0.8732	0.8732	23	0.0178	0.9564	0.9564
4	0.4984	0.9456	0.9456	14	0.3453	0.8685	0.8685	24	0.0187	0.9589	0.9589
5	0.4675	0.9678	0.9678	15	0.3245	0.8678	0.8678	25	0.0234	0.9753	0.9753
6	0.9699	0.9871	0.9871	16	0.3423	0.8456	0.8456	26	0.9745	0.9856	0.9856
7	0.9686	0.9846	0.9846	17	0.3357	0.8653	0.8653	27	0.9567	0.9868	0.9868
8	0.9570	0.9787	0.9787	18	0.3678	0.8676	0.8676	28	0.9871	0.9865	0.9865
9	0.9687	0.9758	0.9758	19	0.7678	0.9745	0.9745	--	---	--	--
10	0.3994	0.9257	0.9257	20	0.7345	0.9712	0.9712	--	--	--	--

Table A4.4 Line current during the fault for 29-Bus Distribution System

From Bus	To Bus	Line Current Magnitude			From Bus	To Bus	Line Current Magnitude		
		Phase a	Phase b	Phase c			Phase a	Phase b	Phase c
1	2	0.1523	0.0265	0.0265	12	13	0.0067	0.0067	0.0067
1	6	0.0070	0.0078	0.0078	13	14	0.0067	0.0067	0.0067
2	3	0.2123	0.0216	0.0216	14	15	0.0042	0.0042	0.0042
2	19	0.0067	0.0032	0.0032	15	16	0.0037	0.0037	0.0037
3	4	0.0057	0.0041	0.0041	16	17	0.0027	0.0027	0.0027
3	10	0.0086	0.0089	0.0089	17	18	0.0009	0.0009	0.0009
3	23	0.2561	0.0020	0.0020	19	20	0.0028	0.0028	0.0028
4	5	0.0034	0.0024	0.0024	20	21	0.0031	0.0031	0.0031
6	7	0.0067	0.0041	0.0041	21	22	0.0008	0.0008	0.0008
6	26	0.0065	0.0024	0.0024	23	24	0.0023	0.0023	0.0023
7	8	0.0032	0.0038	0.0038	**23**	**F**	**0.1369**	**0.0000**	**0.0000**
8	9	0.0026	0.0029	0.0029	24	25	0.0006	0.0006	0.0006
10	11	0.0085	0.0082	0.0082	26	27	0.0009	0.0009	0.0009
11	12	0.0072	0.0075	0.0075	27	28	0.0005	0.0005	0.0005

The time taken to isolate the faulty Bus 23 and restore the power supply to the remaining part of the PDN has been estimated using CPM as explained in Section 7.6 of the thesis.

Fault Current I_f = 0.1369 per unit

Optimistic Time of operation of the relay = 1.7420 s

Pessimistic Time of operation of the relay = 0.7457 s

Mostly Likely Time of operation of the relay = 1.9637 s

Expected Time of operation of the relay = 1.7234 s

$\therefore$ TRT_1 = 1.7234 s

Total Restoration Time (TRT) = $TRT_1 + TRT_2$ = 16.4084 s.

The results of the power flow analysis of the post-fault power distribution network is given in Table A4.5. From the result it is observed that the transformer and feeder are not overloaded. Summary of results for GA and NSGA methods is given in Table A4.6.

Table A4.5 Bus voltages in the post-fault 29-Bus practical Distribution System

Bus No	**|V| in p.u**	**Bus No**	**|V| in p.u**	**Bus No**	**|V| in p.u**	**Bus No**	**|V| in p.u**	**Bus No**	**|V| in p.u**
1	1.0000	7	0.9856	13	0.8643	19	0.9786	25	0.7856
2	0.9854	8	0.9825	14	0.8653	20	0.9821	26	0.9880
3	0.9657	9	0.9745	15	0.8547	21	0.9732	27	0.9867
4	0.9523	10	0.9645	16	0.8654	22	0.9710	28	0.9845
5	0.9562	11	0.8865	17	0.7965	23	**0.0000**	----	-----
6	0.9868	12	0.8834	18	0.7887	24	0.7831	----	----

Table A4.6 Summary of results for GA and NSGA methods

Summary of results for GA and NSGA methods	Pre-fault condition 29-Bus		Post-fault condition 29-bus	
	GA	NSGA	GA	NSGA
Total real power demand (KW)	1900.00	**1900.00**	1850.00	**1850.00**
Total reactive power demand (KVAR)	1070.00	**1070.00**	1040.00	**1040.00**
Total real power loss (KW)	179.4095	**179.2032**	227.59	**227.21**
Total reactive power loss (KVAR)	64.4618	**64.2315**	77.98	**77.31**
Total real power supplied from the sub-station (KW)	2079.41	**2079.2032**	2077.59	**2077.21**
Total reactive power supplied from the sub-station (KVAR)	1134.46	**1134.2315**	1117.99	**1117.31**
Number of iterations taken	19	**10**	21	**12**
Percentage loading of transformer 1	0.3699	**0.33211**	0.36807	**0.3231**
Percentage loading of feeder 1	0.2469	**0.22015**	0.24566	**0.2321**
Computational time in seconds	0.108	**0.103**	28.19	**14.685**
Total service restoration time in seconds	0.108	**0.103**	29.91	**16.4084**

APPENDIX 5

DATA OF 33-BUS DISTRIBUTION SYSTEM

Base MVA = 100 Base KV = 12.66 Sub-station voltage = 12600 V

Number of feeder = 1 Number of transformer = 1

Type of conductor employed for feeder = Mink CT ratio = 525/1

Capacity of the feeders = 234A Plug setting = 1.0

Rating of transformer 1 = 7.5 MVA

Over load setting of the transformer breaker = 1.25

Summary of results for GA and NSGA Methods is given in Table A5.3.

Table A5.1 Bus data of 33-Bus Distribution System

Bus No	Load		LPRO	Q_{sh} in KVAR	Bus No	Load		LPRO	Q_{sh} in KVAR
	KW	KVAR				KW	KVAR		
1	0.00	0.00	0	0.000	18	90.00	40.00	26	0.000
2	100.00	60.00	14	0.000	19	90.00	40.00	29	0.000
3	90.00	40.00	15	0.000	20	90.00	40.00	28	0.000
4	120.00	80.00	4	0.000	21	90.00	40.00	11	0.000
5	60.00	30.00	19	0.000	22	90.00	40.00	27	0.000
6	60.00	20.00	18	0.000	23	90.00	50.00	10	0.000
7	200.00	100.00	20	0.000	24	420.00	200.00	32	0.000
8	200.00	100.00	13	0.000	25	420.00	200.00	9	0.000
9	60.00	20.00	17	0.000	26	60.00	25.00	5	0.000
10	60.00	20.00	24	0.000	27	60.00	25.00	8	0.000
11	45.00	30.00	23	0.000	28	60.00	20.00	1	0.000
12	60.00	35.00	22	0.000	29	120.00	70.00	31	0.000
13	60.00	35.00	25	0.000	30	200.00	600.00	7	0.000
14	120.00	80.00	16	0.000	31	150.00	70.00	2	0.000
15	60.00	10.00	21	0.000	32	210.00	100.00	6	0.000
16	60.00	20.00	3	0.000	33	60.00	40.00	30	0.000
17	60.00	20.00	12	0.000	--	--	--	--	---

Table A5.2 Line data of 33-Bus Distribution System

Br No	Bus		R in Ω	X in Ω	Br No	Bus		R in Ω	X in Ω	Br No	Bus		R in Ω	X in Ω
	From	To				From	To				From	To		
1	1	2	0.0922	0.0477	14	14	15	0.5910	0.5260	27	24	25	0.8990	0.7091
2	2	3	0.4930	0.2511	15	9	15	0.0000	2.0000	28	6	26	0.2030	0.1034
3	3	4	0.3660	0.1864	16	15	16	0.7463	0.5740	29	26	27	0.2842	0.1447
4	4	5	0.3811	0.1941	17	16	17	1.2890	1.7210	30	27	28	1.0590	0.9377
5	5	6	0.1890	0.7070	18	17	18	0.7320	0.5740	31	28	29	0.8042	0.7006
6	6	7	0.1872	0.6118	19	2	19	0.1640	0.1565	32	25	29	0.000	0.5000
7	7	8	1.7114	1.2351	20	19	2`0	1.5042	1.3554	33	29	30	0.5075	0.2585
8	8	9	1.0300	0.7400	21	20	21	0.4095	0.4784	34	30	31	0.9744	0.9630
9	9	10	1.0400	0.7400	22	8	21	0.0000	2.0000	35	31	32	0.3105	0.3619
10	10	11	0.1966	0.0650	23	21	22	0.7089	0.9373	36	32	33	0.3410	0.5302
11	11	12	0.3744	0.1238	24	12	22	0.0000	2.0000	37	18	33	0.0000	0.5000
12	12	13	1.4680	1.1550	25	3	23	0.4512	0.3083	--	--	--	--	--
13	13	14	0.5416	0.7129	26	23	24	0.8980	0.7091	--	--	--	--	--

Table A5.3 Summary of results for GA and NSGA methods

Summary of results for GA and NSGA methods	Pre-fault condition 33-Bus		Post-fault condition 33-bus	
	GA	NSGA	GA	NSGA
Total real power demand (KW)	3715.000	**3715.000**	3625.00	**3625.00**
Total reactive power demand (KVAR)	2300.000	**2300.000**	2260.00	**2260.00**
Total real power loss (KW)	189.0791	**189.0430**	232.83478	**232.222**
Total reactive power loss (KVAR)	134.9114	**134.6001**	159.5393	**159.2121**
Total real power supplied from the sub-station (KW)	3904.08	**3904.043**	3857.83	**3857.222**
Total reactive power supplied from the sub-station (KVAR)	2434.91	**2434.6001**	2419.54	**2419.2112**
Number of iterations taken	15	**10**	10	**8**
Percentage loading of transformer 1	0.613445	**0.58861**	0.607128	**0.601211**
Percentage loading of feeder 1	0.000006	**0.000004**	0.513865	**0.51201**
Computational time in seconds	0.111	**0.101**	32.9670	**17.4903**
Total service restoration time in seconds	0.111	**0.101**	33.6207	**18.0104**

APPENDIX 6

DATA AND RESULTS OF 69-BUS PRACTICAL DISTRIBUTION SYSTEM

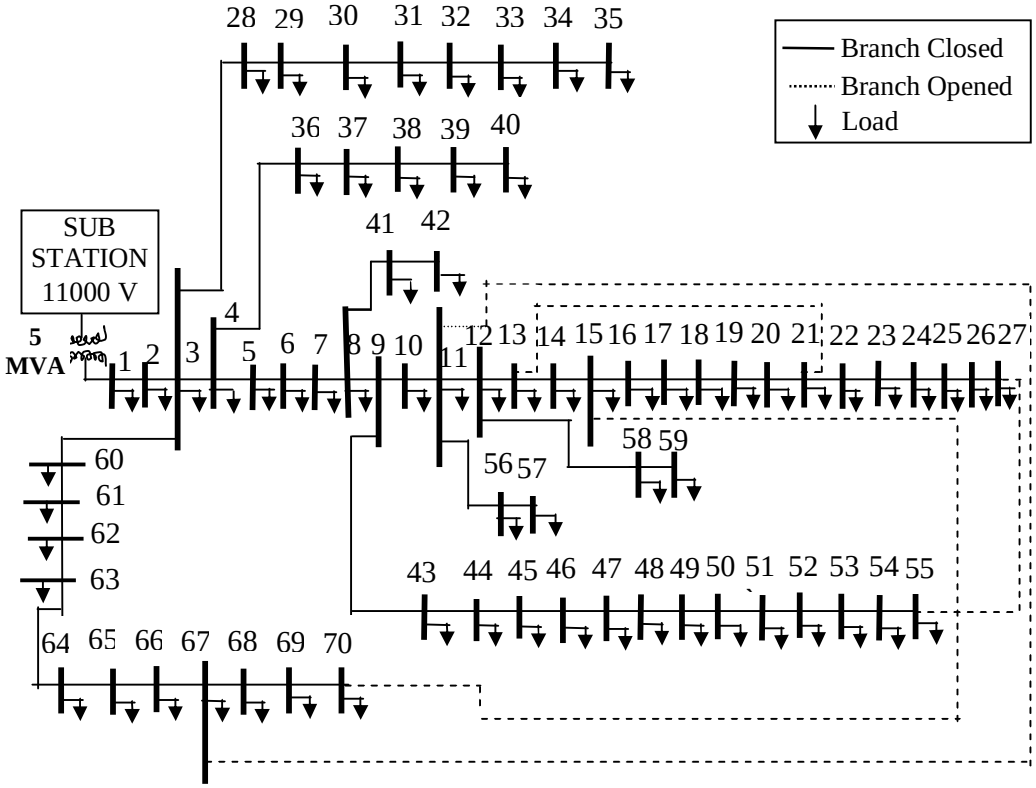

Figure A6.1 69-Bus practical Distribution System (under pre-fault condition)

DATA OF 69-BUS PRACTICAL DISTRIBUTION SYSTEM

Base MVA = 100 Base KV = 12.66 Sub-station voltage = 12600 V

Number of feeder = 1 Number of transformer = 1

Type of conductor employed for feeder = Mink CT ratio = 525/1

Capacity of the feeders = 234A Plug setting = 1.0

Rating of transformer 1 = 5.0 MVA

Over load setting of the transformer breaker = 1.25

Table A6.1 Bus data of 69-Bus Distribution System

Bus No	Load		LPRO	Q_{sh} in KVAR	Bus No	Load		LPRO	Q_{sh} in KVAR
	KW	KVAR				KW	KVAR		
1	0.0000	0.000	0	0.00	36	0.0000	0.000	0	0.00
2	0.0000	0.000	0	0.00	37	79.000	56.40	37	0.00
3	0.0000	0.000	0	0.00	38	384.70	274.5	19	0.00
4	0.0000	0.000	0	0.00	39	384.70	274.5	38	0.00
5	0.0000	0.000	0	0.00	40	0.0000	0.000	0	0.00
6	2.6000	2.200	42	0.00	41	40.500	28.30	39	0.00
7	40.400	30.00	2	0.00	42	3.6000	2.700	18	0.00
8	75.000	54.00	31	0.00	43	4.3500	3.500	40	0.00
9	30.000	20.00	30	0.00	44	26.400	19.00	17	0.00
10	28.000	19.00	29	0.00	45	24.000	17.20	41	0.00
11	145.00	104.0	32	0.00	46	0.0000	0.000	0	0.00
12	145.00	104.0	1	0.00	47	0.0000	0.000	0	0.00
13	8.0000	5.500	3	0.00	48	0.0000	0.000	0	0.00
14	8.0000	5.500	28	0.00	49	100.00	72.00	16	0.00
15	0.0000	0.000	0	0.00	50	0.0000	0.000	0	0.00
16	45.500	30.00	4	0.00	51	1244.0	888.0	43	0.00
17	60.000	35.00	33	0.00	52	32.000	23.00	15	0.00
18	60.000	35.00	27	0.00	53	0.0000	0.000	0	0.00
19	0.0000	0.000	0	0.00	54	227.00	162.0	14	0.00
20	1.0000	0.600	26	0.00	55	59.000	42.00	48	0.00
21	114.00	81.00	34	0.00	56	18.000	13.00	13	0.00
22	5.3000	3.500	25	0.00	57	18.000	13.00	44	0.00
23	0.0000	0.000	0	0.00	58	28.000	20.00	12	0.00
24	28.000	20.00	24	0.00	59	28.000	20.00	45	0.00
25	0.0000	0.000	0	0.00	60	0.0000	0.000	0	0.00
26	14.000	10.00	5	0.00	61	26.000	18.55	46	0.00
27	14.00	10.00	23	0.00	62	26.000	18.55	11	0.00
28	26.000	18.60	35	0.00	63	0.0000	0.000	0	0.00
29	26.000	18.60	22	0.00	64	24.000	17.00	10	0.00
30	0.0000	0.000	0	0.00	65	24.000	17.00	9	0.00
31	0.0000	0.000	0	0.00	66	1.2000	1.000	47	0.00
32	0.0000	0.000	0	0.00	67	0.0000	0.000	0	0.00
33	14.000	10.00	21	0.00	68	6.0000	4.300	8	0.00
34	19.500	14.00	36	0.00	69	0.0100	0.008	6	0.00
35	6.0000	4.000	20	0.00	70	39.220	26.30	7	0.00

Table A6.2 Line data of 69-Bus Distribution System

Br No	Bus		R in Ω	X in Ω	Br No	Bus		R in Ω	X in Ω	Br No	Bus		R in Ω	X in Ω
	From	To				From	To				From	To		
1	1	2	0.0005	0.0012	24	24	25	0.7488	0.2745	47	47	48	0.7837	0.2630
2	2	3	0.0005	0.0012	25	25	26	0.3089	0.1021	48	48	49	0.3042	0.1006
3	3	4	0.0015	0.0036	26	26	27	0.1732	0.0572	49	49	50	0.3861	0.1172
4	4	5	0.0251	0.0294	27	3	28	0.0044	0.0108	50	50	51	0.5075	0.2585
5	5	6	0.3660	0.1864	28	28	29	0.0640	0.1565	51	51	52	0.0974	0.0496
6	6	7	0.3811	0.1941	29	29	30	0.3978	0.1315	52	52	53	0.1450	0.0738
7	7	8	0.0922	0.0470	30	30	31	0.0702	0.0232	53	53	54	0.7105	0.3619
8	8	9	0.0493	0.0251	31	31	32	0.3510	0.1160	54	54	55	1.0410	0.5302
9	9	10	0.8190	0.2707	32	32	33	0.8390	0.2816	55	11	56	0.2012	0.0611
10	10	11	0.1872	0.0691	33	33	34	1.7080	0.5646	56	56	57	0.0047	0.0014
11	11	12	0.7114	0.2351	34	34	35	1.4740	0.4673	57	12	58	0.7393	0.2444
12	12	13	0.0300	0.3400	35	4	36	0.0034	0.0084	58	58	59	0.0047	0.0016
13	13	14	1.0440	0.3450	36	36	37	0.0851	0.2083	59	3	60	0.0044	0.0108
14	14	15	1.0580	0.3496	37	37	38	0.2898	0.7091	60	60	61	0.0640	0.1565
15	15	16	0.1966	0.0650	38	38	39	0.0822	0.2011	61	61	62	0.1053	0.1230
16	16	17	0.3744	0.1238	39	39	40	0.0000	0.0000	62	62	63	0.0304	0.0355
17	17	18	0.0047	0.0016	40	8	41	0.0928	0.0473	63	63	64	0.0018	0.0021
18	18	19	0.3276	0.1083	41	41	42	0.3319	0.1114	64	64	65	0.7283	0.8509
19	19	20	0.2106	0.0696	42	9	43	0.1740	0.0886	65	65	66	0.3100	0.3623
20	20	21	0.4316	0.1129	43	43	44	0.2030	0.1034	66	66	67	0.0410	0.0478
21	21	22	0.0140	0.0046	44	44	45	0.2842	0.1447	67	67	68	0.0092	0.0116
22	22	23	0.1591	0.0526	45	45	46	0.2813	0.1433	68	68	69	0.1089	0.1373
23	23	24	0.4363	0.1145	46	46	47	1.5900	0.5337	69	69	70	0.0009	0.0012

RESULTS OF SERVICE RESTORATION ANALYSIS OF THE 69-BUS DISTRIBUTION SYSTEM

The 69-bus distribution system is shown in Figure A6.1. In order to perform the service restoration analysis, here it is assumed that a single line to ground fault takes place at the Bus 60. The occurrence of fault at the Bus 60 leads to disconnection of the power supply to the loads which are connected to the buses 60 to 70. The power supply has been restored to the buses 61 to

70 by using the optimal configuration of the PDN which is obtained from the service restoration analysis.

The detailed service restoration analysis is the same as presented in Section 7.6 of the thesis. The selection of parameters of the NSGA is given Table 6.1. The variation of the combined objective function with respect to the generations of the NSGA is shown in Figure A6.2. The combined objective function has reached the global minimum at the 5^{th} generation of the NSGA. The optimal configuration of the post-fault PDN corresponding to the 5^{th} generation of the NSGA is shown in Figure A6.3.

The time taken to search for optimal switching configuration of the power distribution (TRT_2) has been found to be 30.56 seconds. The voltage during the fault and line currents during the single line ground fault is given in Table A6.3 and Table A6.4, respectively.

The time taken to isolate the faulty Bus 60 and restore the power supply to the reaming part of the PDN has been estimated using CPM is explained in Section 7.6 of the thesis.

Fault Current I_f = 8.2479 per unit

Optimistic Time of operation of the relay = 0.2480 s

Pessimistic Time of operation of the relay = 0.1062 s

Mostly Likely Time of operation of the relay = 0.2798 s

Expected Time of operation of the relay = 0.2455 s

$\therefore$ TRT_1 = 0.2455 s

Total Restoration Time (TRT) = TRT_1 +TRT_2 = 30.8055s.

The results of the Power Flow analysis of the post-fault PDN is given in Table A6.5. From the result it is observed that the transformer and feeder are not overloaded. Summary of results for GA and NSGA methods is given in Table A6.6.

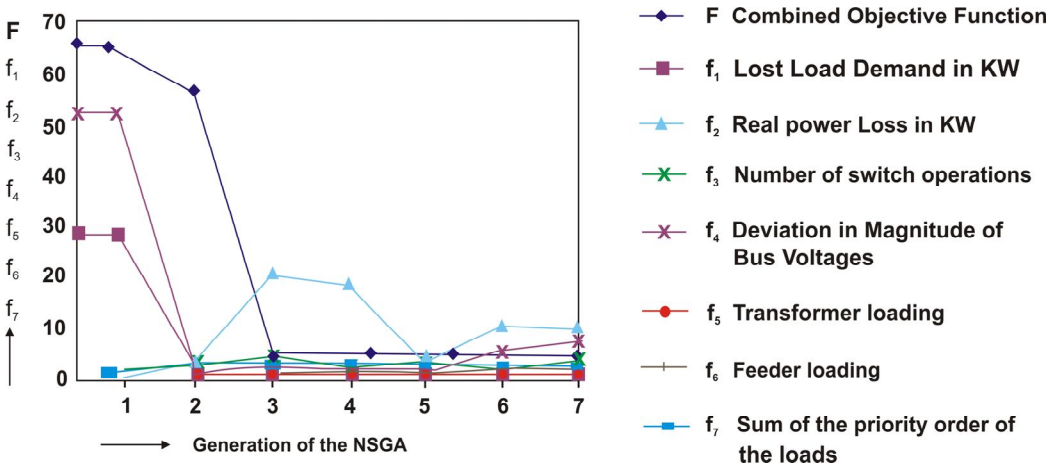

Figure A6.2 Variation of the combined objective function with respect to the generation of NSGA for 69-Bus Distribution System

Table A6.3 Voltages during the fault of the 69-Bus Distribution System

Bus No	Voltage Magnitude			Bus No	Voltage Magnitude			Bus No	Voltage Magnitude		
	Phase a	Phase b	Phase c		Phase a	Phase b	Phase c		Phase a	Phase b	Phase c
1	0.0854	1.0000	1.0000	25	0.0426	0.9789	0.9789	49	0.0667	0.9865	0.9865
2	0.0738	1.0000	1.0000	26	0.0426	0.9685	0.9685	50	0.0712	0.9796	0.9796
3	0.0756	0.9999	0.9999	27	0.0426	0.9675	0.9675	51	0.0640	0.9876	0.9876
4	0.0765	0.9998	0.9998	28	0.0426	0.9999	0.9999	52	0.0578	0.9745	0.9745
5	0.0721	0.9990	0.9990	29	0.0734	0.9997	0.9997	53	0.0590	0.9865	0.9865
6	0.0645	0.9900	0.9900	30	0.0705	0.9992	0.9992	54	0.0586	0.9896	0.9896
7	0.0547	0.9887	0.9887	31	0.0812	0.9991	0.9991	55	0.0621	0.9791	0.9791
8	0.0521	0.9865	0.9865	32	0.0824	0.9986	0.9986	56	0.0456	0.9787	0.9787
9	0.0536	0.9869	0.9869	33	0.0765	0.9975	0.9975	57	0.0465	0.9768	0.9768
10	0.0498	0.9786	0.9786	34	0.0859	0.9954	0.9954	58	0.0464	0.9853	0.9853
11	0.0478	0.9821	0.9821	35	0.0877	0.9938	0.9938	59	0.0458	0.9789	0.9789
12	0.0564	0.9891	0.9891	36	0.0752	0.9998	0.9998	60	0.0000	0.9999	0.9999
13	0.0467	0.9781	0.9781	37	0.0678	0.9984	0.9984	61	0.0008	0.9998	0.9998
14	0.0465	0.9870	0.9870	38	0.0589	0.9970	0.9970	62	0.0006	0.9996	0.9996
15	0.0521	0.9680	0.9680	39	0.0685	0.9984	0.9984	63	0.0005	0.9996	0.9996
16	0.0437	0.9672	0.9672	40	0.0894	0.9994	0.9994	64	0.0004	0.9996	0.9996
17	0.0437	0.9829	0.9829	41	0.0710	0.9880	0.9880	65	0.0006	0.9996	0.9996
18	0.0437	0.9819	0.9819	42	0.0734	0.9980	0.9980	66	0.0021	0.9998	0.9998
19	0.0437	0.9681	0.9681	43	0.0753	0.9880	0.9880	67	0.0018	0.9998	0.9998
20	0.0437	0.9756	0.9756	44	0.0687	0.9865	0.9865	68	0.0017	0.9998	0.9998
21	0.0521	0.9737	0.9737	45	0.0652	0.9872	0.9872	69	0.0020	0.9998	0.9998
22	0.0521	0.9687	0.9687	46	0.0521	0.9786	0.9786	70	0.0020	0.9998	0.9998
23	0.0521	0.9834	0.9834	47	0.0401	0.9780	0.9780	--	---	---	---
24	0.0521	0.9769	0.9769	48	0.9512	0.9867	0.9867	---	---	---	---

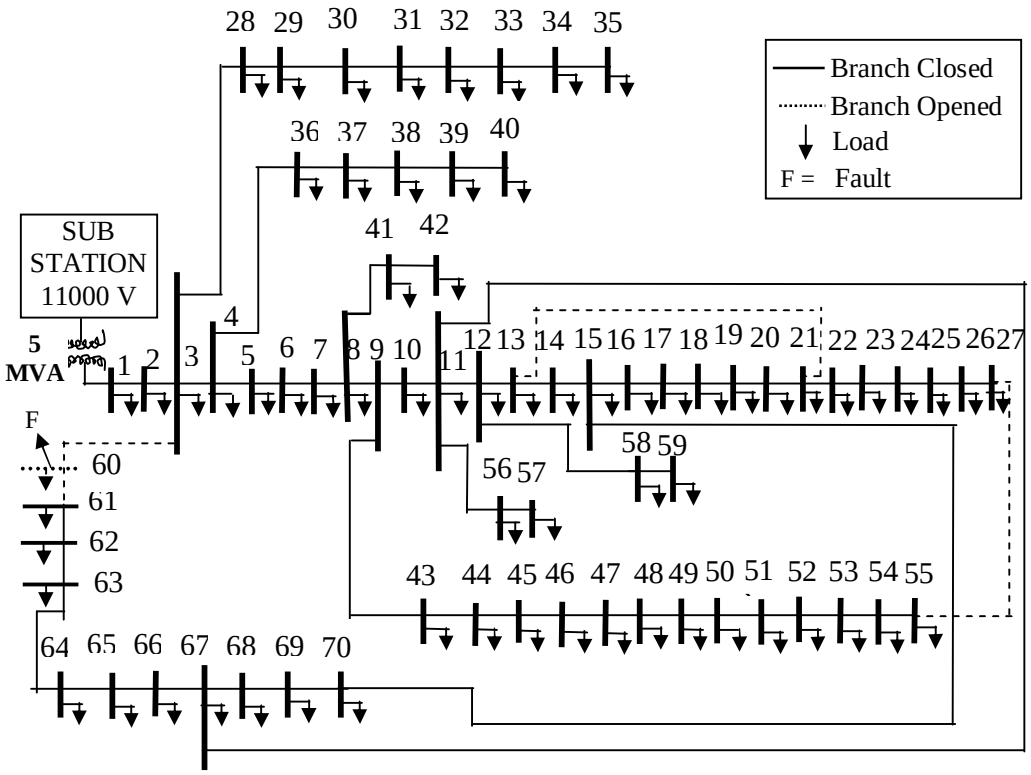

Figure A6.3 69-Bus Distribution System (under post-fault condition)

Table A6.4 Line current during the fault for 69-Bus Distribution System

From Bus	To Bus	Line Current Magnitude			From Bus	To Bus	Line Current Magnitude		
		Phase a	Phase b	Phase c			Phase a	Phase b	Phase c
1	2	8.573	0.0410	0.0410	30	31	0.0020	0.0020	0.0020
2	3	8.573	0.0410	0.0410	31	32	0.0020	0.0020	0.0020
3	4	0.0423	0.0385	0.0385	32	33	0.0020	0.0020	0.0020
3	28	0.0021	0.0021	0.0021	33	34	0.0019	0.0019	0.0019
3	60	8.4290	0.0015	0.0015	34	35	0.0016	0.0016	0.0016
4	5	0.0321	0.0341	0.0341	36	37	0.0099	0.0099	0.0099
4	36	0.0099	0.0099	0.0099	37	38	0.0091	0.0091	0.0091
5	6	0.0430	0.0350	0.0350	38	39	0.0051	0.0051	0.0051
6	7	0.0360	0.0350	0.0350	41	42	0.0016	0.0016	0.0016
7	8	0.0545	0.0345	0.0345	43	44	0.0228	0.0228	0.0228
8	9	0.0410	0.0330	0.0330	44	45	0.0225	0.0225	0.0225
8	41	0.0021	0.0021	0.0021	45	46	0.0222	0.0222	0.0222
9	10	0.023	0.0229	0.0229	46	47	0.0215	0.0215	0.0215
9	43	0.0107	0.0107	0.0107	47	48	0.0214	0.0214	0.0214
10	11	0.0085	0.0085	0.0085	48	49	0.0214	0.0214	0.0214
11	12	0.0004	0.0004	0.0004	49	50	0.0200	0.0200	0.0200
11	56	0.0060	0.0060	0.0060	50	51	0.0208	0.0208	0.0208
12	13	0.0007	0.0007	0.0007	51	52	0.0042	0.0042	0.0042
12	58	0.0059	0.0059	0.0059	52	53	0.0038	0.0038	0.0038
13	14	0.0058	0.0058	0.0058	53	54	0.0038	0.0038	0.0038
14	15	0.0058	0.0058	0.0058	54	55	0.0008	0.0008	0.0008
15	16	0.0053	0.0053	0.0053	56	57	0.0002	0.0002	0.0002
16	17	0.0046	0.0046	0.0046	58	59	0.0003	0.0003	0.0003
17	18	0.0038	0.0038	0.0038	60	61	0.0015	0.0015	0.0015
18	19	0.0038	0.0038	0.0038	**60**	**F**	**8.4279**	**0.0000**	**100000**
19	20	0.0038	0.0038	0.0038	61	62	0.0014	0.0014	0.0014
20	21	0.0024	0.0024	0.0024	62	63	0.0011	0.0011	0.0011
21	22	0.0023	0.0023	0.0023	63	64	0.0011	0.0011	0.0011
22	23	0.0020	0.0020	0.0020	64	65	0.0008	0.0008	0.0008
23	24	0.0018	0.0018	0.0018	65	66	0.0005	0.0005	0.0005
24	25	0.0018	0.0018	0.0018	66	67	0.0005	0.0005	0.0005
25	26	0.0020	0.0020	0.0020	67	68	0.0005	0.0005	0.0005
26	27	0.0020	0.0020	0.0020	68	69	0.0005	0.0005	0.0005
28	29	0.0020	0.0020	0.0020	69	70	0.0004	0.0004	0.0004
29	30	0.0020	0.0020	0.0020	--	---	---	---	---

Table A6.5 Bus voltages in the post-fault 69-Bus Distribution System

Bus No	|V| in p.u	Bus No	|V| in p.u	Bus No	|V| in p.u	Bus No	|V| in p.u	Bus No	|V| in p.u
1	1.0000	15	0.9795	29	0.9997	43	0.9864	57	0.9784
2	1.0000	16	0.9865	30	0.9992	44	0.9800	58	0.9761
3	0.9999	17	0.9879	31	0.9991	45	0.9886	59	0.9741
4	0.9998	18	0.9836	32	0.9986	46	0.9767	**60**	**0.0000**
5	0.9990	19	0.9748	33	0.9975	47	0.9764	61	0.9868
6	0.9895	20	0.9786	34	0.9984	48	0.9678	62	0.9768
7	0.9896	21	0.9867	35	0.9988	49	0.9785	63	0.9868
8	0.9878	22	0.9785	36	0.9998	50	0.9678	64	0.9868
9	0.9871	23	0.9743	37	0.9984	51	0.9758	65	0.9873
10	0.9865	24	0.9785	38	0.9960	52	0.9786	66	0.9774
11	0.9768	25	0.9875	39	0.9983	53	0.9829	67	0.9875
12	0.9846	26	0.9853	40	0.9973	54	0.9656	68	0.9799
13	0.9764	27	0.9865	41	0.8872	55	0.9674	69	0.9700
14	0.9746	28	0.9999	42	0.9898	56	0.9784	70	0.9700

Table A6.6 Summary of results for GA and NSGA methods

Summary of results for GA and NSGA methods	Pre-fault condition 69-Bus		Post-fault condition 69-bus	
	GA	NSGA	GA	NSGA
Total real power demand (KW)	3762.97	**3762.97**	3762.97	**3762.97**
Total reactive power demand (KVAR)	2668.30	**2668.30**	2668.30	**2668.30**
Total real power loss (KW)	236.0167	**235.5654**	249.31	**248.860**
Total reactive power loss (KVAR)	107.7378	**107.4256**	113.73	**113.520**
Total real power supplied from the sub-station (KW)	3998.99	**3998.5354**	4012.28	**4011.83**
Total reactive power supplied from the sub-station (KVAR)	2776.04	**2775.7256**	2782.03	**2781.82**
Number of iterations taken	15	**9**	16	**10**
Percentage loading of transformer 1	0.9736	**0.9568**	0.976486	**0.8789**
Percentage loading of feeder 1	0.000069	**0.000059**	0.549388	**0.46988**
Computational time in seconds	0.215	**0.1547**	89.010	**30.560**
Total service restoration time in seconds	0.215	**0.1547**	89.2555	**30.8055**

APPENDIX 7

DATA AND RESULTS OF 79-BUS PRACTICAL DISTRIBUTION SYSTEM

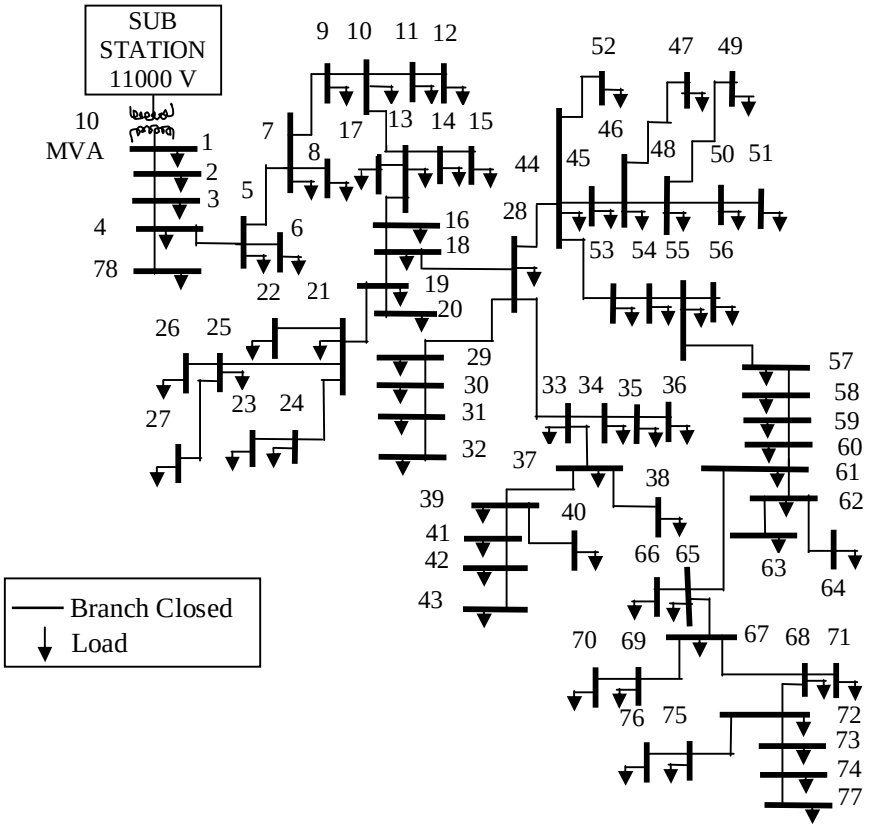

Figure A7.1 79-Bus practical Distribution System (under pre-fault condition)

DATA OF 79-BUS PRACTICAL DISTRIBUTION SYSTEM

Base MVA = 100 Base KV = 11 Sub-station voltage = 11000 V

Number of feeder = 1 Number of transformer = 1

Type of conductor employed for feeder = Mink CT ratio = 525/1

Capacity of the feeders = 234A Plug setting = 1.0

Rating of transformer 1 = 10 MVA

Over load setting of the transformer breaker = 1.25

Table A7.1 Bus data of 79-Bus practical Distribution System

Bus No	Load		LPRO	Q_{sh} in KVAR	Bus No	Load		LPRO	Q_{sh} in KVAR
	KW	KVAR				KW	KVAR		
1	0.000	0.000	0	0.00	40	0.200	0.150	21	0.00
2	0.080	0.080	44	0.00	41	0.086	0.060	36	0.00
3	0.080	0.080	9	0.00	42	0.200	0.150	6	0.00
4	0.000	0.000	0	0.00	43	0.080	0.060	22	0.00
5	0.000	0.000	0	0.00	44	0.000	0.000	0	0.00
6	0.080	0.060	43	0.00	45	0.080	0060	49	0.00
7	0.080	0.060	45	0.00	46	0.000	0.000	0	0.00
8	0.200	0.150	8	0.00	47	0.080	0060	35	0.00
9	0.200	0.150	10	0.00	48	0.000	0.000	0	0.00
10	0.000	0.000	0	0.00	49	0.200	0.150	5	0.00
11	0.200	0.150	11	0.00	50	0.080	0060	23	0.00
12	0.250	0.187	46	0.00	51	0.050	0.037	34	0.00
13	0.000	0.000	0	0.00	52	0.080	0060	50	0.00
14	0.200	0.150	12	0.00	53	0.200	0.150	24	0.00
15	0.080	0.060	42	0.00	54	0.080	0.0600	33	0.00
16	0.000	0.000	0	0.00	55	0.0000	0.0000	0	0.00
17	0.080	0.060	13	0.00	56	0.2000	0.1500	4	0.00
18	0.000	0.000	0	0.00	57	0.1300	0.0970	3	0.00
19	0.080	0.060	41	0.00	58	0.2000	0.1500	51	0.00
20	0.080	0.060	14	0.00	59	0.2000	0.1500	25	0.00
21	0.000	0.000	0	0.00	60	0.0500	0.0370	52	0.00
22	0.080	0.060	40	0.00	61	0.000	0.0000	0	0.00
23	0.080	0.060	47	0.00	62	0.0800	0.060	32	0.00
24	0.080	0.060	15	0.00	63	0.1600	0.1200	53	0.00
25	0.000	0.000	0	0.00	64	00800	0.0600	26	0.00
26	0.080	0.060	39	0.00	65	0.4000	0.3000	54	0.00
27	0.080	0.060	16	0.00	66	0.0800	0.060	2	0.00
28	0.000	0.000	0	0.00	67	0.000	0.000	0	0.00
29	0.080	0.060	17	0.00	68	0.2000	0.1500	31	0.00
30	0.080	0.060	38	0.00	69	0.0800	0.0600	55	0.00
31	0.080	0.060	7	0.00	70	0.2000	0.1500	1	0.00
32	0.080	0.060	18	0.00	71	0.0800	0.0600	30	0.00
33	0.000	0.000	0	0.00	72	0.000	0.000	0	0.00
34	0.080	0.060	19	0.00	73	0.2000	0.1500	29	0.00
35	0.080	0.060	37	0.00	74	0.0800	00600	27	0.00
36	0.000	0.000	0	0.00	75	0.2000	0.15000	28	0.00
37	0.080	0.060	20	0.00	76	0.2000	0.1500	56	0.00
38	0.0500	0.0377	48	0.00	77	0.000	0.000	0	0.00
39	0.000	0.000	0	0.00	78	0.000	0.000	0	0.00

Table A7.2 Line data of 79-Bus practical Distribution System

Br No	Bus		R in Ω	X in Ω	Br No	Bus		R in Ω	X in Ω	Br No	Bus		R in Ω	X in Ω
	From	To				From	To				From	To		
1	1	2	0.32453	0.19832	27	18	28	0.13017	0.07933	53	53	54	0.0263	0.01587
2	2	3	0.22530	0.13730	28	28	29	0.12572	0.04804	54	54	55	0.10404	0.06346
3	3	4	0.11015	0.06712	29	29	30	0.35201	0.13452	55	55	56	0.18524	0.11289
4	4	5	0.14018	0.08543	30	30	31	0.13242	0.05061	56	55	57	0.05007	0.03501
5	5	6	0.13518	0.08238	31	31	32	0.13242	0.05061	57	55	58	0.05207	0.03173
6	5	7	0.11015	0.06712	32	28	33	0.14751	0.05637	58	58	59	0.07810	0.04760
7	7	8	0.10614	0.06468	33	33	34	0.09387	0.03587	59	59	60	0.10414	0.06346
8	7	9	0.10614	0.06468	34	34	35	0.4080	0.05381	60	60	61	0.02503	0.01526
9	9	10	0.15270	0.09306	35	35	36	0.4080	0.05381	61	61	62	0.22530	0.13730
10	10	11	0.04656	0.02837	36	33	37	0.11063	0.04228	62	62	63	0.05507	0.03356
11	11	12	0.13868	0.08451	37	37	38	0.05867	0.02242	63	62	64	0.27239	0.10409
12	10	13	0.16922	0.10312	38	37	39	0.07375	0.02819	64	61	65	0.03004	0.01831
13	13	14	0.06008	0.03661	39	39	40	0.35201	0.13452	65	65	66	0.01502	0.00915
14	14	15	0.21028	0.12814	40	39	41	0.09502	0.03459	66	65	67	0.06008	0.03661
15	13	16	0.08311	0.05065	41	41	42	0.09502	0.03459	67	67	68	0.03004	0.01831
16	16	17	0.06008	0.03661	42	42	43	0.13475	0.05253	68	67	69	0.10644	0.04068
17	16	18	0.08311	0.05065	43	28	44	0.24382	0.14859	69	69	70	0.03004	0.01831
18	18	19	0.30801	0.11771	44	44	45	0.27658	0.10569	70	68	71	0.18439	0.07046
19	19	20	0.14248	0.05445	45	45	46	0.27658	0.10569	71	68	72	0.08411	0.05126
20	19	21	0.04442	0.01698	46	46	47	0.05867	0.02242	72	72	73	0.02804	0.01709
21	21	22	0.01676	0.00641	47	46	48	0.02953	0.08007	73	73	74	0.02804	0.01709
22	21	23	0.08549	0.03267	48	48	49	0.06956	0.02658	74	72	75	0.07794	0.02979
23	23	24	0.12572	0.04804	49	48	50	0.05867	0.02242	75	75	76	0.02598	0.00993
24	21	25	0.12823	0.04900	50	50	51	0.04191	0.01601	76	74	77	0.11215	0.06834
25	25	26	0.01676	0.00641	51	44	52	0.01502	0.00915	77	4	48	0.17523	0.10679
26	25	27	0.17098	0.06534	52	44	53	0.07960	0.04851	--	---	---	---	---

RESULTS OF SERVICE RESTORATION ANALYSIS OF THE 69-BUS DISTRIBUTION SYSTEM

The 79-bus distribution system is shown in Figure A7.1. In order to perform the service restoration analysis, here it is assumed that a single line to ground fault takes place at the bus 29. The occurrence of fault at the bus 29 leads to disconnection of the power supply to the loads which are connected to the buses 29 to 32. The power supply has been restored to the buses 63 to

74 only after the fault at the Bus 29, because this system does not have tie lines. Hence, the problem of search for the optimal configuration of the power distribution network does not arise. The voltages during the fault and line currents during fault are given in Table A7.3 and Table A7.4, respectively.

Table A7.3 Voltage during the fault of the 79-Bus practical Distribution System

Bus No	Voltage Magnitude			Bus No	Voltage Magnitude			Bus No	Voltage Magnitude		
	Phase a	Phase b	Phase c		Phase a	Phase b	Phase c		Phase a	Phase b	Phase c
1	0.9746	1.0000	1.0000	27	0.1450	0.9709	0.9709	53	0.0478	0.9701	0.9701
2	0.8561	0.9967	0.9967	28	0.0702	0.9771	0.9771	54	0.0485	0.9721	0.9721
3	0.6781	0.9899	0.9899	**29**	**0.0000**	**0.9765**	**0.9765**	55	0.0468	0.9671	0.9671
4	0.6534	0.9886	0.9886	30	0.0014	0.9754	0.9754	56	0.0451	0.9689	0.9689
5	0.5423	0.9887	0.9887	31	0.0017	0.9735	0.9735	57	0.0466	0.9652	0.9652
6	0.5312	0.9874	0.9874	32	0.0016	0.9642	0.9642	58	0.0463	0.9702	0.9702
7	0.4656	0.9862	0.9862	33	0.0655	0.9612	0.9612	59	0.0402	0.9670	0.9670
8	0.4679	0.9898	0.9898	34	0.0646	0.9735	0.9735	60	0.0402	0.9609	0.9609
9	0.4215	0.9886	0.9886	35	0.0646	0.9765	0.9765	61	0.0401	0.9502	0.9502
10	0.3267	0.9840	0.9840	36	0.0646	0.9610	0.9610	62	0.0406	0.9531	0.9531
11	0.3264	0.9846	0.9846	37	0.0604	0.9713	0.9713	63	0.0406	0.9532	0.9532
12	0.3264	0.9810	0.9810	38	0.0604	0.9760	0.9760	64	0.0408	0.9578	0.9578
13	0.2374	0.9811	0.9811	39	0.0710	0.9601	0.9601	65	0.0386	0.9709	0.9709
14	0.2465	0.9808	0.9808	40	0.0686	0.9604	0.9604	66	0.0365	0.9709	0.9709
15	0.2421	0.9804	0.9804	41	0.0686	0.9608	0.9608	67	0.0391	0.9709	0.9709
16	0.1295	0.9793	0.9793	42	0.0683	0.9703	0.9703	68	0.0339	0.9604	0.9604
17	0.1964	0.9782	0.9782	43	0.0592	0.9749	0.9749	69	0.0339	0.9601	0.9601
18	0.1521	0.9772	0.9772	44	0.0546	0.9726	0.9726	70	0.0339	0.9589	0.9589
19	0.1416	0.9768	0.9768	45	0.0495	0.9708	0.9708	71	0.0341	0.9698	0.9698
20	0.1437	0.9801	0.9801	46	0.0467	0.9720	0.9720	72	0.0337	0.9734	0.9734
21	0.1518	0.9784	0.9784	47	0.0467	0.9761	0.9761	73	0.0367	0.9664	0.9664
22	0.1518	0.9745	0.9745	48	0.0467	0.9723	0.9723	74	0.0309	0.9646	0.9646
23	0.1481	0.9810	0.9810	49	0.0485	0.9723	0.9723	75	0.0330	0.9704	0.9704
24	0.1410	0.9786	0.9786	50	0.0485	0.9753	0.9753	76	0.0341	0.9731	0.9731
25	0.1420	0.9821	0.9821	51	0.0485	0.9631	0.9631	77	0.0338	0.9637	0.9637
26	0.1298	0.9771	0.9771	52	0.0561	0.9639	0.9639	78	0.5962	0.9891	0.9891

Table 7.4 Line current during the fault for 79-Bus practical Distribution System

From Bus	To Bus	Line Current Magnitude			From Bus	To Bus	Line Current Magnitude		
		Phase a	Phase b	Phase c			Phase a	Phase b	Phase c
1	2	0.4742	0.0192	0.0192	39	40	0.0036	0.0036	0.0036
2	3	0.4701	0.0185	0.0185	39	41	0.0050	0.0050	0.0050
3	4	0.4701	0.0189	0.0189	41	42	0.0041	0.0041	0.0041
4	5	0.4712	0.0191	0.0191	42	43	0.0030	0.0030	0.0030
5	6	0.0020	0.0020	0.0020	44	45	0.0067	0.0067	0.0067
5	7	0.4676	0.0199	0.0199	44	52	0.0019	0.0019	0.0019
7	8	0.0041	0.0061	0.0061	44	53	0.0277	0.0277	0.0277
7	9	0.4624	0.0120	0.0120	45	46	0.0059	0.0059	0.0059
9	10	0.4732	0.0191	0.0191	46	47	0.0090	0.0090	0.0090
10	11	0.0071	0.0066	0.0066	46	48	0.0082	0.0082	0.0082
10	13	0.465	0.0199	0.0199	48	49	0.0065	0.0065	0.0065
11	12	0.0040	0.0040	0.0040	48	50	0.0047	0.0047	0.0047
13	14	0.0048	0.0048	0.0048	50	51	0.0006	0.0006	0.0006
13	16	0.4753	0.0292	0.0292	53	54	0.0235	0.0235	0.0235
14	15	0.0025	0.0021	0.0021	54	55	0.0340	0.0340	0.0340
16	17	0.0020	0.0029	0.0029	55	56	0.0056	0.0056	0.0056
16	18	0.4862	0.0456	0.0456	55	57	0.0017	0.0017	0.0017
18	19	0.0078	0.0070	0.0070	55	58	0.0267	0.0267	0.0267
18	28	0.4889	0.0471	0.0471	58	59	0.0241	0.0241	0.0241
19	20	0.0018	0.0015	0.0015	59	60	0.0225	0.0225	0.0225
19	21	0.0056	0.0058	0.0058	60	61	0.0222	0.0222	0.0222
21	22	0.0017	0.0012	0.0012	61	62	0.0053	0.0053	0.0053
21	23	0.0031	0.0020	0.0020	61	65	0.0280	0.0280	0.0280
21	25	0.0050	0.0020	0.0020	62	63	0.0041	0.0041	0.0041
23	24	0.0061	0.0015	0.0015	62	64	0.0010	0.0010	0.0010
25	26	0.0016	0.0015	0.0015	65	66	0.0010	0.0010	0.0010
25	27	0.0016	0.0015	0.0015	65	67	0.0176	0.0176	0.0176
28	29	0.4570	0.0040	0.0040	67	68	0.0148	0.0148	0.0148
28	33	0.0110	0.0121	0.0121	67	69	0.0039	0.0039	0.0039
28	44	0.0351	0.0351	0.0351	68	71	0.0010	0.0010	0.0010
29	30	0.0070	0.0050	0.0050	68	72	0.0020	0.0020	0.0020
29	**F**	**0.4429**	**0.0000**	**0.0000**	69	70	0.0021	0.0021	0.0021
30	31	0.0020	0.0080	0.0080	72	73	0.0040	0.0040	0.0040
31	32	0.0010	0.0040	0.0040	72	75	0.0061	0.0061	0.0061
33	34	0.0020	0.0050	0.0050	73	74	0.0011	0.0011	0.0011
33	37	0.0087	0.0090	0.0090	75	76	0.0034	0.0034	0.0034
34	35	0.0010	0.0010	0.0010	---	---	---	----	----
37	38	0.0006	0.0004	0.0004	---	---	---	---	---
37	39	0.0071	0.0080	0.0080	---	--	--	--	--

The time taken to isolate the faulty Bus-29 is estimated using CPM as explained in Section 7.6 of the thesis.

Fault Current I_f	=	0.4439 per unit
Optimistic Time of operation of the relay	=	0.80 s
Pessimistic Time of operation of the relay	=	0.3429 s
Mostly Likely Time of operation of the relay	=	0.9029 s
Expected Time of operation of the relay	=	0.7924 s
$\therefore$ TRT_1	=	0.7924 s

The time taken to search for optimal switching configuration of the power distribution (TRT_2) has been found to be 6.986 seconds.

Total Restoration Time (TRT) = TRT_1 +TRT_2 =7.7784 s.

The Results of the power flow analysis of the post-fault PDN is given in Table A7.5. From the result it is observed that the transformer and feeder are not overloaded. Summary of results for GA and NSGA methods are given in Table A7.6.

Table A7.5 Bus voltages in the post-fault 79-Bus practical Distribution System

Bus No	|V| in p.u	Bus No	|V| in p.u	Bus No	|V| in p.u	Bus No	|V| in p.u	Bus No	|V| in p.u
1	1.0000	17	0.9793	33	0.9697	49	0.9561	65	0.9571
2	0.9936	18	0.9719	34	0.9688	50	0.9562	66	0.9501
3	0.9931	19	0.9750	35	0.9704	51	0.9591	67	0.9510
4	0.9952	20	0.9730	36	0.9694	52	0.9609	68	0.9575
5	0.9883	21	0.9710	37	0.9699	53	0.9591	69	0.9546
6	0.9875	22	0.9693	38	0.9677	54	0.9563	70	0.9505
7	0.9881	23	0.9702	39	0.9682	55	0.9574	71	0.9560
8	0.9890	24	0.9698	40	0.9672	56	0.9599	72	0.9546
9	0.9873	25	0.9703	41	0.9697	57	0.9583	73	0.9505
10	0.9837	26	0.9707	42	0.9684	58	0.9568	74	0.9525
11	0.9810	27	0.9699	43	0.9662	59	0.9595	75	0.9502
12	0.9870	28	0.9701	44	0.9608	60	0.9507	76	0.9541
13	0.9819	**29**	**0.0000**	45	0.9591	61	0.9509	77	0.9505
14	0.9811	30	0.0000	46	0.9579	62	0.9508	78	0.9888
15	0.9836	31	0.0000	47	0.9584	63	0.9507	--	--
16	0.9805	32	0.0000	48	0.9553	64	0.9560	--	--

Table 7.6 Summary of results for GA and NSGA methods

Summary of results for GA and NSGA methods	Pre-fault condition 79-Bus		Post-fault condition 79-bus	
	GA	NSGA	GA	NSGA
Total real power demand (KW)	6930.00	6930.00	6610.00	**6610.00**
Total reactive power demand (KVAR)	5195.00	5195.00	4955.00	**4955.00**
Total real power loss (KW)	175.8263	**175.6141**	150.85	**150.51**
Total reactive power loss (KVAR)	104.992	**104.761**	101.24	**100.86**
Total real power supplied from the sub-station(KW)	7105.83	**7105.6141**	6760.85	**6760.51**
Total reactive power supplied from the sub-station (KVAR)	5299.99	**5299.761**	5056.24	**5055.86**
Number of iterations taken	12	**8**	12	**7**
Percentage loading of transformer 1	0.0193	**0.0112**	0.0190991	**0.0123**
Percentage loading of feeder 1	0.1178	**0.1116**	0.116597	**0.1132**
Computational time in seconds	0.280	**0.185**	10.786	**6.986**
Total service restoration time in seconds	0.280	**0.185**	11.5784	**7.7784**

APPENDIX 8

DATA AND RESULTS OF 133-BUS PRACTICAL DISTRIBUTION SYSTEM

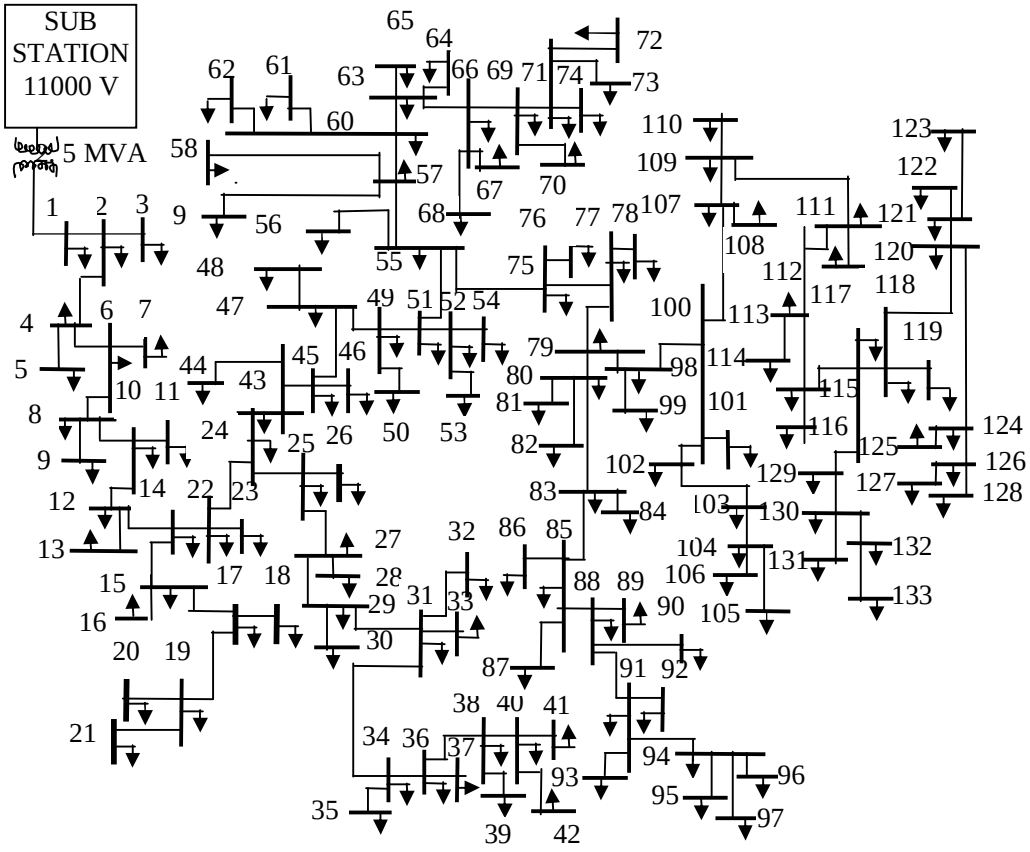

Figure A8.1 133-Bus Practical Distribution System (under pre-fault condition)

DATA OF 133-BUS PRACTICAL DISTRIBUTION SYSTEM

Base MVA = 100 Base KV = 11 Sub-station Voltage = 11000 V

Number of feeder = 1 Number of transformer = 1

Type of conductor employed for feeder = Mink CT ratio = 525/1

Capacity of the feeders = 234A Plug setting = 1.0

Resistance R = 0.9116 Ω/ Km Reactance X = 0.3820 Ω/ Km

Rating of transformer 1 = 10 MVA

Over load setting of the transformer breaker = 1.25

Table A8.1 Bus data of 133-Bus practical Distribution System

Bus No	Load		LPRO	Q_{sh} in KVAR	Bus No	Load		LPRO	Q_{sh} in KVAR
	KW	KVAR				KW	KVAR		
1	0.000	0.000	0	0.000	68	8.500	5.268	61	0.000
2	0.000	0.000	0	0.000	69	0.000	0.000	0	0.000
3	8.500	5.268	34	0.000	70	8.500	5.268	24	0.000
4	0.000	0.000	0	0.000	71	0.000	0.000	0	0.000
5	8.500	5.268	33	0.000	72	8.500	5.268	60	0.000
6	0.000	0.000	0	0.000	73	17.000	10.536	59	0.000
7	8.500	5.268	78	0.000	74	8.500	5.268	23	0.000
8	0.000	0.000	0	0.000	75	0.000	0.000	0	0.000
9	8.500	5.268	32	0.000	76	8.500	5.268	43	0.000
10	0.000	0.000	0	0.000	77	0.000	0.000	0	0.000
11	8.500	5.268	35	0.000	78	34.000	21.071	22	0.000
12	0.000	0.000	0	0.000	79	0.000	0.000	0	0.000
13	8.500	5.268	77	0.000	80	0.000	0.000	0	0.000
14	0.000	0.000	0	0.000	81	8.500	5.268	44	0.000
15	0.000	0.000	0	0.000	82	17.000	10.536	21	0.000
16	21.420	13.275	31	0.000	83	0.000	0.000	0	0.000
17	0.000	0.000	0	0.000	84	8.500	5.268	58	0.000
18	8.500	5.268	76	0.000	85	0.000	0.000	0	0.000
19	0.000	0.000	0	0.000	86	8.500	5.268	1	0.000
20	21.420	13.275	75	0.000	87	17.000	10.536	45	0.000
21	8.500	5.268	74	0.000	88	0.000	0.000	0	0.000
22	0.000	0.000	0	0.000	89	8.500	5.268	2	0.000
23	21.420	13.275	36	0.000	90	17.000	10.536	57	0.000
24	0.000	0.000	0	0.000	91	0.000	0.000	0	0.000
25	0.000	0.000	0	0.000	92	8.500	5.268	20	0.000
26	8.500	5.268	73	0.000	93	17.000	10.536	3	0.000
27	0.000	0.000	0	0.000	94	0.000	0.000	0	0.000
28	8.500	5.268	72	0.000	95	17.000	10.536	46	0.000

Table A8.1 (Continued)

Bus No	Load		LPRO	Q_{sh} in KVAR	Bus No.	Load		LPRO	Q_{sh} in KVAR
	KW	KVAR				KW	KVAR		
29	0.000	0.000	0	0.000	96	17.000	10.536	19	0.000
30	8.500	5.268	37	0.000	97	8.500	5.268	4	0.000
31	0.000	0.000	0	0.000	98	0.000	0.000	0	0.000
32	8.500	5.268	30	0.000	99	8.500	5.268	18	0.000
33	8.500	5.268	71	0.000	100	0.000	0.000	0	0.000
34	0.000	0.000	0	0.000	101	21.420	13.275	5	0.000
35	8.500	5.268	70	0.000	102	0.000	0.000	0	0.000
36	0.000	0.000	0	0.000	103	8.500	5.268	56	0.000
37	8.500	5.268	69	0.000	104	0.000	0.000	0	0.000
38	0.000	0.000	0	0.000	105	21.420	13.275	6	0.000
39	8.500	5.268	38	0.000	106	8.500	5.268	16	0.000
40	0.000	0.000	0	0.000	107	0.000	0.000	0	0.000
41	8.500	5.268	29	0.000	108	8.500	5.268	7	0.000
42	8.500	5.268	68	0.000	109	0.000	0.000	0	0.000
43	0.000	0.000	0	0.000	110	8.500	5.268	55	0.000
44	8.500	5.268	67	0.000	111	0.000	0.000	0	0.000
45	0.000	0.000	0	0.000	112	21.420	13.275	8	0.000
46	8.500	5.268	28	0.000	113	0.000	0.000	0	0.000
47	0.000	0.000	0	0.000	114	8.500	5.268	15	0.000
48	21.420	13.275	39	0.000	115	0.000	0.000	0	0.000
49	0.000	0.000	0	0.000	116	8.500	5.268	54	0.000
50	8.500	5.268	66	0.000	117	0.000	0.000	0	0.000
51	0.000	0.000	0	0.000	118	0.000	0.000	0	0.000
52	0.000	0.000	0	0.000	119	8.500	5.268	10	0.000
53	8.500	5.268	27	0.000	120	0.000	0.000	0	0.000
54	8.500	5.268	65	0.000	121	0.000	0.000	0	0.000
55	0.000	0.000	0	0.000	122	8.500	5.268	49	0.000
56	85.000	52.678	40	0.000	123	17.000	10.536	14	0.000
57	0.000	0.000	0	0.000	124	0.000	0.000	0	0.000
58	8.500	5.268	26	0.000	125	8.500	5.268	50	0.000
59	17.000	10.536	64	0.000	126	0.000	0.000	0	0.000
60	0.000	0.000	0	0.000	127	21.420	13.275	51	0.000
61	17.000	10.536	63	0.000	128	21.420	13.275	11	0.000
62	8.500	5.268	41	0.000	129	21.420	13.275	13	0.000
63	0.000	0.000	0	0.000	130	0.000	0.000	0	0.000
64	17.000	10.536	62	0.000	131	8.500	5.268	52	0.000
65	8.500	5.268	25	0.000	132	8.500	5.268	53	0.000
66	0.000	0.000	0	0.000	133	8.500	5.268	12	0.000
67	17.000	10.536	42	0.000	---	---	----	---	---

Table A8.2 Line data of 133-Bus practical Distribution System

Br No	Bus		Line Length in Km	Br No	Bus		Line Length in Km	Br No	Bus		Line Length in Km	Br No	Bus		Line Length in Km
	From	To			From	To			From	To			From	To	
1	1	2	2.000	34	34	35	0.200	67	66	68	1.500	101	100	102	1.200
2	2	3	0.500	35	34	36	1.500	68	66	69	1.500	102	102	103	0.400
3	2	4	1.500	36	36	37	0.500	69	69	70	1.000	103	102	104	1.800
4	4	5	0.500	37	36	38	2.000	70	69	71	1.500	104	104	105	0.500
5	4	6	0.200	38	38	39	0.400	72	71	72	0.500	105	104	106	2.000
6	6	7	0.100	39	38	40	1.000	73	71	73	2.000	106	100	107	0.700
7	6	8	0.500	40	40	41	1.000	74	55	75	2.300	107	107	108	0.400
8	8	9	0.100	41	40	42	2.200	75	75	76	0.300	108	107	109	2.00
9	8	10	0.200	42	24	43	3.00	76	75	77	1.300	109	109	110	0.100
10	10	11	1.500	43	43	44	0.100	77	77	78	0.100	110	109	111	2.200
11	10	12	1.500	44	43	45	1.000	78	77	79	0.300	111	111	112	0.200
12	12	13	0.100	45	45	46	0.800	79	79	80	1.500	112	111	113	2.000
13	12	14	1.000	46	45	47	0.700	80	80	81	0.500	113	113	114	0.200
14	14	15	2.500	47	47	48	0.700	81	80	82	0.500	114	113	115	0.500
15	15	16	0.100	48	47	49	0.600	82	80	83	1.500	115	115	116	0.700
16	15	17	1.000	49	49	50	0.200	83	83	84	0.500	116	115	117	2.500
17	17	18	0.200	50	49	51	0.800	84	83	85	1.500	117	117	118	1.500
18	17	19	0.400	51	51	52	3.500	85	85	86	0.500	118	118	119	0.600
19	19	20	0.400	52	52	53	0.100	86	85	87	0.500	119	118	120	2.000
20	19	21	3.000	53	52	54	2.000	87	85	88	1.500	120	120	121	1.000
21	14	22	1.500	54	51	55	2.100	88	88	89	0.500	121	121	122	0.600
22	22	23	0.100	55	55	56	0.200	89	88	90	0.500	122	121	123	1.000
23	22	24	1.000	56	55	57	1.200	90	88	91	1.500	123	120	124	2.100
24	24	25	1.500	57	57	58	0.500	91	91	92	0.500	124	124	125	0.100
25	25	26	0.400	58	57	59	0.500	92	91	93	0.500	125	124	126	1.000
26	25	27	1.400	59	57	60	1.500	93	91	94	1.500	126	126	127	2.400
27	27	28	0.400	60	60	61	0.500	94	94	95	0.500	127	126	128	2.500
28	27	29	0.600	61	60	62	0.500	95	94	96	0.500	128	117	129	3.000
29	29	30	0.700	62	60	63	2.000	96	94	97	2.000	129	129	130	0.500
30	29	31	1.800	63	63	64	1.000	97	79	98	0.300	130	130	131	1.000
31	31	32	0.400	64	63	65	2.000	98	98	99	0.600	131	130	132	0.200
32	31	33	0.200	65	63	66	0.500	99	98	100	1.500	132	132	133	4.000
33	31	34	1.500	66	66	67	0.500	100	100	101	0.200	133	---	---	---

RESULTS OF SERVICE RESTORATION ANALYSIS OF THE 133-BUS DISTRIBUTION SYSTEM

The 133-Bus distribution system is shown in the Figure A8.1. The results of the power flow analysis for pre-fault condition of this distribution system are given in Table 3.2. In order to perform the service restoration analysis, here it is assumed that a single line to ground fault takes place at the Bus 63. The occurrence of fault at the Bus 63 leads to disconnection of the power supply to the loads which are connected to the buses 63 to 74. The Power Supply has been restored to the buses 63 to 74 only after the fault at the Bus 63, because this system does not have tie lines. Hence, the problem of search for the optimal configuration of the PDN does not arise.

The voltages during the fault and the line currents during fault are given in Table A8.3 and Table A8.4, respectively. The time taken to isolate the faulty Bus-63 is estimated using CPM as explained in Section 7.6 of the thesis.

Fault Current I_f	=	2.804 per unit
Optimistic Time of operation of the relay	=	5.95 s
Pessimistic Time of operation of the relay	=	2.54 s
Mostly Likely Time of operation of the relay	=	6.68 s
Expected Time of operation of the relay	=	5.86 s
$\therefore$ TRT_1	=	5.86 s

The time taken to search for optimal switching configuration of the power distribution (TRT_2) has been found to be 10.68 seconds.

Total Restoration Time (TRT) = TRT_1 +TRT_2 =16.54 s.

The results of the analysis of the post-fault PDN are given in Table A8.5. From the result it is observed that the transformer and feeder are not overloaded. Summary of results for GA and NSGA methods is given in Table A8.6.

Table A8.3 Voltage during the fault of the 133-Bus practical Distribution System

Bus No	Voltage Magnitude			Bus No	Voltage Magnitude			Bus No	Voltage Magnitude		
	Phase a	Phase b	Phase c		Phase a	Phase b	Phase c		Phase a	Phase b	Phase c
1	0.6871	1.0000	1.0000	46	0.2921	0.8810	0.8810	91	0.0845	0.8651	0.8651
2	0.6624	0.9879	0.9879	47	0.2946	0.8798	0.8798	92	0.0851	0.8650	0.8650
3	0.6585	0.9879	0.9879	48	0.2871	0.8793	0.8793	93	0.0848	0.8650	0.8650
4	0.5830	0.9744	0.9744	49	0.2589	0.8688	0.8688	94	0.0838	0.7996	0.7996
5	0.5770	0.9706	0.9706	50	0.2497	0.8787	0.8787	95	0.0830	0.7997	0.7997
6	0.5801	0.9792	0.9792	51	0.1999	0.8682	0.8682	96	0.0860	0.7997	0.7997
7	0.5710	0.9891	0.9891	52	0.1889	0.8761	0.8761	97	0.0835	0.7999	0.7999
8	0.5604	0.9838	0.9838	53	0.1988	0.8661	0.8661	98	0.0921	0.8797	0.8797
9	0.5603	0.9837	0.9837	54	0.1868	0.8581	0.8581	99	0.0941	0.8696	0.8696
10	0.5577	0.9877	0.9877	55	0.1850	0.8584	0.8584	100	0.0899	0.8753	0.8753
11	0.5654	0.9894	0.9894	56	0.1847	0.8591	0.8591	101	0.0898	0.8652	0.8652
12	0.4984	0.9857	0.9857	57	0.0879	0.8591	0.8591	102	0.0893	0.8747	0.8747
13	0.4902	0.9756	0.9756	58	0.0879	0.8689	0.8689	103	0.0892	0.8746	0.8746
14	0.4939	0.9652	0.9652	59	0.0879	0.8589	0.8589	104	0.0886	0.8739	0.8739
15	0.4995	0.9807	0.9807	60	0.0620	0.8667	0.8667	105	0.0884	0.8638	0.8638
16	0.4991	0.9605	0.9605	61	0.0603	0.8765	0.8765	106	0.0882	0.8736	0.8736
17	0.4968	0.9591	0.9591	62	0.0604	0.8685	0.8685	107	0.0883	0.8637	0.8637
18	0.4906	0.9788	0.9788	63	**0.0000**	**0.8241**	**0.8241**	108	0.0883	0.8736	0.8736
19	0.4922	0.9780	0.9780	64	0.0006	0.8536	0.8536	109	0.0860	0.7964	0.7964
20	0.4967	0.9779	0.9779	65	0.0006	0.8603	0.8603	110	0.0860	0.7973	0.7973
21	0.4934	0.9647	0.9647	66	0.0007	0.8586	0.8586	111	0.0794	0.7988	0.7988
22	0.4587	0.9603	0.9603	67	0.0007	0.8533	0.8533	112	0.0794	0.7988	0.7988
23	0.466	0.9602	0.9602	68	0.0012	0.8681	0.8681	113	0.0788	0.7962	0.7962
24	0.3901	0.9707	0.9707	69	0.0018	0.8515	0.8515	114	0.0778	0.7972	0.7972
25	0.3794	0.8999	0.8999	70	0.0020	0.8601	0.8601	115	0.0760	0.7963	0.7963
26	0.3890	0.8995	0.8995	71	0.0031	0.8525	0.8525	116	0.0759	0.7973	0.7973
27	0.3980	0.8975	0.8975	72	0.0038	0.8414	0.8414	117	0.0730	0.7883	0.7883
28	0.3865	0.8961	0.8961	73	0.0039	0.8593	0.8593	118	0.0696	0.7868	0.7868

Table A8.3 (Continued)

Bus No	Voltage Magnitude			Bus No	Voltage Magnitude			Bus No	Voltage Magnitude		
	Phase a	Phase b	Phase c		Phase a	Phase b	Phase c		Phase a	Phase b	Phase c
29	0.3840	0.8945	0.8945	74	0.0034	0.8619	0.8619	119	0.0688	0.7867	0.7867
30	0.3853	0.8996	0.8996	75	0.1038	0.8500	0.8500	120	0.0675	0.7859	0.7859
31	0.3932	0.8997	0.8997	76	0.1030	0.8609	0.8609	121	0.0682	0.7886	0.7886
32	0.3868	0.8983	0.8983	77	0.0968	0.8571	0.8571	122	0.0679	0.7885	0.7885
33	0.3860	0.8985	0.8985	78	0.0986	0.8531	0.8531	123	0.0670	0.7874	0.7874
34	0.3821	0.8996	0.8996	79	0.0950	0.8527	0.8527	124	0.0675	0.7876	0.7876
35	0.3709	0.8992	0.8992	80	0.0920	0.8608	0.8608	125	0.0668	0.7866	0.7866
36	0.3992	0.8978	0.8978	81	0.0921	0.8507	0.8507	126	0.0674	0.7871	0.7871
37	0.3887	0.8970	0.8970	82	0.0924	0.8607	0.8607	127	0.0686	0.7854	0.7854
38	0.3948	0.8933	0.8933	83	0.0899	0.8504	0.8504	128	0.0657	0.7844	0.7844
39	0.3854	0.8969	0.8969	84	0.0892	0.8504	0.8504	129	0.0687	0.7856	0.7856
40	0.3847	0.8870	0.8870	85	0.0878	0.8492	0.8492	130	0.0689	0.7885	0.7885
41	0.3787	0.8868	0.8868	86	0.0888	0.8491	0.8491	131	0.0685	0.7884	0.7884
42	0.3955	0.8860	0.8860	87	0.0877	0.8501	0.8501	132	0.0685	0.7884	0.7884
43	0.2982	0.8894	0.8894	88	0.0871	0.8404	0.8404	133	0.0678	0.7860	0.7860
44	0.2891	0.8983	0.8983	89	0.0860	0.8303	0.8303	---	---	----	---
45	0.2756	0.8798	0.8798	90	0.0869	0.8193	0.8193	---	---	---	---

Table A8.4 Line current during the fault for 133-Bus Distribution System

Bus No	To Bus	Line Current Magnitude			Bus No	To Bus	Line Current Magnitude		
		Phase a	Phase b	Phase c			Phase a	Phase b	Phase c
1	2	4.1992	1.3847	1.3847	77	79	0.5990	0.5990	0.5990
2	3	0.2414	0.2514	0.2514	79	80	0.2388	0.2388	0.2388
2	4	4.1684	1.3839	1.3839	79	98	0.3802	0.3802	0.3802
4	5	0.2205	0.2515	0.2515	80	81	0.0506	0.0506	0.0506
4	6	4.1277	1.3633	1.3633	80	82	0.0388	0.0388	0.0388
6	**7**	0.1997	0.1997	0.1997	80	83	0.1999	0.1999	0.1999
6	8	4.1373	1.3828	1.3828	83	84	0.0267	0.0267	0.0267
8	9	0.1942	0.1962	0.1962	83	85	0.1881	0.1881	0.1881
8	10	4.1568	1.3424	1.3424	85	86	0.0289	0.0289	0.0289
10	11	0.1995	0.1995	0.1995	85	87	0.0387	0.0387	0.0387
10	12	4.1257	1.3313	1.3313	85	88	0.1478	0.1478	0.1478
12	13	0.1897	0.1897	0.1897	88	89	0.0287	0.0287	0.0287
12	14	4.0958	1.2953	1.2953	88	90	0.0386	0.0386	0.0386
14	15	0.2411	0.2411	0.2411	88	91	0.1089	0.1089	0.1089

Table A8.4 (Continued)

Bus No	To Bus	Line Current Magnitude			Bus No	To Bus	Line Current Magnitude		
		Phase a	Phase b	Phase c			Phase a	Phase b	Phase c
14	22	4.0570	1.2425	1.2425	66	67	0.0577	0.0577	0.0577
15	16	0.1826	0.1786	0.1786	66	68	0.0466	0.0466	0.0466
15	17	0.1960	0.1960	0.1960	66	69	0.0887	0.0887	0.0887
17	18	0.1862	0.1592	0.1592	69	70	0.0409	0.0409	0.0409
17	19	0.1882	0.1862	0.1862	69	71	0.0788	0.0788	0.0788
19	20	0.1795	0.1775	0.1775	71	72	0.0457	0.0457	0.0457
19	21	0.1580	0.1580	0.1580	71	73	0.0588	0.0588	0.0588
22	23	0.1591	0.1581	0.1581	71	74	0.0478	0.0478	0.0478
22	24	3.9798	1.1858	1.1858	75	76	0.0367	0.0367	0.0367
24	25	0.2407	0.2637	0.2637	75	77	0.6477	0.6477	0.6477
24	43	3.8780	1.0785	1.0785	77	78	0.0686	0.0686	0.0686
25	26	0.1687	0.1267	0.1267	77	79	0.5988	0.5988	0.5988
25	27	0.1477	0.1289	0.1289	79	80	0.2366	0.2366	0.2366
27	28	0.1284	0.1264	0.1264	79	98	0.3783	0.3783	0.3783
27	29	0.2206	0.2326	0.2326	80	81	0.0249	0.0249	0.0249
29	30	0.1283	0.1273	0.1273	80	82	0.0359	0.0359	0.0359
29	31	0.1944	0.1924	0.1924	80	83	0.1984	0.1984	0.1984
31	32	0.1260	0.1250	0.1250	83	84	0.0287	0.0287	0.0287
31	33	0.1279	0.1269	0.1269	83	85	0.1871	0.1871	0.1871
31	34	0.1692	0.1882	0.1882	85	86	0.0283	0.0283	0.0283
34	35	0.1278	0.1288	0.1288	85	87	0.0365	0.0365	0.0365
34	36	0.1591	0.1591	0.1591	85	88	0.1462	0.1462	0.1462
36	37	0.1287	0.1287	0.1287	88	89	0.0250	0.0250	0.0250
36	38	0.1499	0.1489	0.1489	91	92	0.0288	0.0288	0.0288
38	39	0.1286	0.1266	0.1266	91	93	0.0381	0.0381	0.0381
38	40	0.1397	0.1377	0.1377	91	94	0.0782	0.0782	0.0782
40	41	0.1285	0.1265	0.1265	94	95	0.0361	0.0361	0.0361
40	42	0.1294	0.1274	0.1274	94	96	0.0371	0.0371	0.0371
43	44	0.0986	0.0966	0.0966	94	97	0.0207	0.0207	0.0207
43	45	3.8642	1.0588	1.0588	98	99	0.0217	0.0217	0.0217
45	46	0.0857	0.0887	0.0887	98	100	0.3873	0.3873	0.3873
45	47	3.8586	1.0491	1.0491	100	101	0.0399	0.0399	0.0399
47	48	0.0953	0.0983	0.0983	100	102	0.0688	0.0688	0.0688
47	49	3.8274	1.0189	1.0189	100	107	0.2786	0.2786	0.2786
49	50	0.0698	0.0699	0.0699	102	103	0.0187	0.0187	0.0187
49	51	3.8189	1.0066	1.0066	102	104	0.0499	0.0499	0.0499
51	52	0.0798	0.0778	0.0778	104	105	0.0399	0.0399	0.0399
51	55	3.7899	0.9893	0.9893	104	106	0.0198	0.0198	0.0198
52	53	0.0686	0.0676	0.0676	107	108	0.0197	0.0197	0.0197
52	54	0.0686	0.0676	0.0676	107	109	0.2686	0.2686	0.2686
55	56	0.1592	0.1499	0.1499	109	110	0.0191	0.0191	0.0191

Table A8.4 (Continued)

Bus No	To Bus	Line Current Magnitude			Bus No	To Bus	Line Current Magnitude		
		Phase a	Phase b	Phase c			Phase a	Phase b	Phase c
55	57	3.0380	0.2388	0.2388	109	111	0.2584	0.2584	0.2584
55	75	0.6790	0.6599	0.6599	111	112	0.0349	0.0349	0.0349
57	58	0.0467	0.0487	0.0487	111	113	0.2266	0.2266	0.2266
57	59	0.0586	0.0589	0.0589	113	114	0.0164	0.0164	0.0164
57	60	3.0019	0.1997	0.1997	113	115	0.2089	0.2089	0.2089
60	61	0.0562	0.0578	0.0578	115	116	0.0166	0.0166	0.0166
60	62	0.0442	0.0487	0.0487	115	117	0.1987	0.1987	0.1987
60	63	2.9674	0.1668	0.1668	117	118	0.1298	0.1298	0.1298
63	64	0.0568	0.0588	0.0588	117	129	0.0699	0.0699	0.0699
63	65	0.0438	0.0488	0.0488	118	119	0.0155	0.0155	0.0155
63	66	0.1266	0.1276	0.1276	118	120	0.1176	0.1176	0.1176
63	**F**	**2.8048**	**0.0000**	**0.0000**	120	121	0.0398	0.0398	0.0398
66	67	0.0567	0.0577	0.0577	120	124	0.0788	0.0788	0.0788
66	68	0.0437	0.0487	0.0487	121	122	0.0176	0.0176	0.0176
66	69	0.0896	0.0889	0.0889	121	123	0.0266	0.0266	0.0266
69	70	0.0476	0.0489	0.0489	124	125	0.0155	0.0155	0.0155
69	71	0.0776	0.0788	0.0788	124	126	0.0660	0.0660	0.0660
71	72	0.0465	0.0409	0.0409	126	127	0.0374	0.0374	0.0374
71	73	0.0585	0.0577	0.0577	126	128	0.0351	0.0351	0.0351
71	74	0.0485	0.0455	0.0455	129	130	0.0388	0.0388	0.0388
75	76	0.0384	0.0323	0.0323	130	131	0.0196	0.0196	0.0196
75	77	0.6497	0.6477	0.6477	130	132	0.0282	0.0282	0.0282
75	78	0.0695	0.0655	0.0655	132	133	0.0196	0.0196	0.0196

Table A8.5 Bus voltages in the post-fault 133-Bus practical Distribution System

Bus No	|V| in p.u	Bus No	|V| in p.u	Bus No	|V| in p.u	Bus No	|V| in p.u	Bus No	|V| in p.u
1	1.0000	28	0.9559	55	0.8792	82	0.8770	109	0.8490
2	0.9877	29	0.9544	56	0.8691	83	0.8749	110	0.8590
3	0.9886	30	0.9640	57	0.8786	84	0.8749	111	0.8647
4	0.9771	31	0.9595	58	0.8685	85	0.8629	112	0.8647
5	0.9866	32	0.9693	59	0.8885	86	0.8529	113	0.8613
6	0.9852	33	0.9694	60	0.8681	87	0.8628	114	0.8612
7	0.9851	34	0.9381	61	0.8780	88	0.8613	115	0.8604
8	0.9806	35	0.9480	62	0.8781	89	0.8513	116	0.8604
9	0.9806	36	0.9369	63	**0.0000**	90	0.8712	117	0.8566
10	0.9788	37	0.9267	64	**0.0000**	91	0.8601	118	0.8551
11	0.9674	38	0.9155	65	**0.0000**	92	0.8701	119	0.8651
12	0.9773	39	0.9253	66	**0.0000**	93	0.8801	120	0.8433
13	0.9672	40	0.9349	67	**0.0000**	94	0.8994	121	0.8530
14	0.9774	41	0.9544	68	**0.0000**	95	0.8893	122	0.8630
15	0.9663	42	0.9637	69	**0.0000**	96	0.8693	123	0.8828
16	0.9662	43	0.8983	70	**0.0000**	97	0.8792	124	0.8621
17	0.9763	44	0.8962	71	**0.0000**	98	0.8889	125	0.8521
18	0.9651	45	0.8892	72	**0.0000**	99	0.8688	126	0.8416
19	0.9569	46	0.8859	73	**0.0000**	100	0.8746	127	0.8610
20	0.9625	47	0.8873	74	**0.0000**	101	0.8946	128	0.8509
21	0.9637	48	0.8860	75	0.8686	102	0.8841	129	0.8550
22	0.9749	49	0.8792	76	0.8686	103	0.8735	130	0.8648
23	0.9708	50	0.8882	77	0.8741	104	0.8834	131	0.8647
24	0.9688	51	0.8859	78	0.8781	105	0.8633	132	0.8548
25	0.9708	52	0.8889	79	0.8687	106	0.8631	133	0.8544
26	0.9686	53	0.8788	80	0.8681	107	0.8731	---	---
27	0.9671	54	0.8795	81	0.8891	108	0.8631	----	---

Table A8.6 Summary of results for GA and NSGA methods

Summary of results for GA and NSGA methods	Pre-fault condition 133-Bus		Post-fault condition 133-bus	
	GA	**NSGA**	**GA**	**NSGA**
Total real power demand (KW)	962.20	962.20	868.70	868.70
Total reactive power demand (KVAR)	596.33	596.33	538.38	538.38
Total real power loss (KW)	218.6628	**218.2416**	154.22	**154.11**
Total reactive power loss (KVAR)	91.6292	**91.4161**	64.62	**64.41**
Total real power supplied from the sub-station (KW)	1180.86	**1180.4416**	1022.92	**1022.81**
Total reactive power supplied from the sub-station (KVAR)	687.96	**687.7461**	603.00	**602.79**
Number of iterations taken	24	**12**	11	**8**
Percentage loading of transformer 1	0.5466	**0.51220**	0.466762	**0.43482**
Percentage loading of feeder 1	0.1809	**0.15461**	0.1540	**0.13468**
Computational time in seconds	0.78	**0.5621**	16.18	**10.68**
Total service restoration time in seconds	0.78	**0.5621**	22.04	**16.54**