CHAPTER 5

ESTIMATION OF SERVICE RESTORATION TIME IN POWER DISTRIBUTION SYSTEMS USING CRITICAL PATH METHOD

5.1 INTRODUCTION

The Electrical Power Distribution Systems are subjected to types of faults, causing power blackouts to occur. Minimizing the time of these power blackouts is the main responsibility of distribution engineers that can be achieved by the detailed study of pre-fault load condition of the distribution system, quick isolation of the faulty section and restoring the supply to healthy sections of the distribution system. Hence in Electrical Power Distribution Systems (EPDS) estimation of service restoration time is very important. A detailed knowledge of the operating time of the various relays in EPDS is required for the estimation of service restoration time. The quality and maintenance of the components of EPDS play an important role in distribution system operation. Hence the probability of exact time associated with distribution system is considered in this thesis work.

In this chapter new concepts of Optimistic Time (OT), Pessimistic Time (PT) and Mostly likely Time (MT) of the operation of the relay are introduced for various EPDS. This method is implemented on various distribution system Viz., 12-Bus, 16-bus, 26-Bus, 29-Bus, 33-Bus, 69-Bus, 79-Bus and 133-Bus systems and the analysis of Service Restoration Time is carried on for various types of faults in EPDS.

5.2 PROBABILITY DISTRIBUTIONS

The quality and maintenance of the protective devices decide the probability of their success and failure of operation. The various probability distributions are Binomial Distribution, Poisson Distribution, T-Distribution, Log-Normal Distribution, Beta Distribution and F-Distribution. For the probability based operational analysis of the protective devices, the Binomial and Beta Distribution are used.

Beta Distribution: It is a continuous distribution bounded between '0' and '1'. The beta distribution has two parameters, viz., first shape parameter (a) and second shape parameter (b). When a = b = 1, the beta distribution is identical to the uniform distribution on (0, 1). This distribution is used for modeling the probability of success for a binomial distribution

The range of probability for the successful and failure operation of relays/circuit breakers lies between 0 and 1. Moreover, these operations of the protective devices are not necessarily mutually exclusive events, which are based on manufacturing methods: quality and proper maintenance in addition to the switching transients in the power distribution network operating conditions. Hence the operation of these relays/breakers has been assumed to follow the beta distribution of probability.

5.3 SERVICE RESTORATION TIME ESTIMATION USING CRITICAL PATH METHOD (CPM) AND PROGRAM EVALUTION AND REVIEW TECHNIQUE (PERT)

Before the start of each restoration activity, based on certain conditions, the service restoration process involves several actions. In restoring the power supply to radial feeder the main process/activities can be classified into two types

i) Restoration under power failure

This process involves closure of switches and breakers at the distribution network.

ii) Restoration under faulty conditions

This process needs the isolation or disconnection of the faulty load and then reconnecting the feeders within the minimum time.

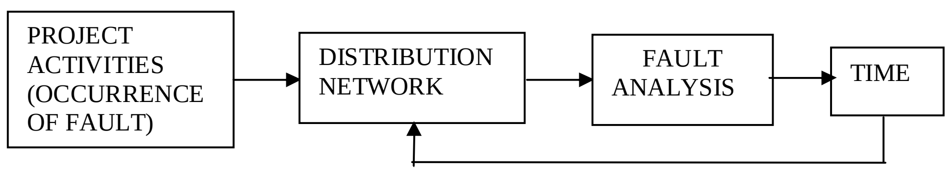

Figure 5.1 Phases for the Estimation of Service Restoration Time with CPM – PERT

At every stage of the above mentioned processes, the network based methods like the Critical Path Method and Program Evaluation and Review Technique (Verma 2002) help in exact estimation of restoration time and also are designed to assist in planning, scheduling and control of the projects. To provide analytic means for scheduling the activities is the main objective of these methods.

The steps of the CPM-PERT techniques are summarized in Figure 5.1. By the operation of the relay/breaker the occurrence of the fault in the Power Distribution Network (PDN) is sensed first. The operating time of relay/breaker is calculated based on the value of fault current obtained by the analysis of symmetrical/ unsymmetrical fault. A feedback loop is included to update the time schedule, between the time schedule and phase of PDN during the analysis of Service Restoration Time because the restoration schedule may not be realized as planned, causing some of the service restoration processes/ activities to be expedited or delayed.

Three estimations of durations are considered, namely, optimistic time, pessimistic time and most likely time for each stage of the restoration process or activity. The duration of activities follows the beta distribution of probability. Then the Expected Time (ET) for an activity is approximately expressed as:

$$ET = \left(\frac{OT + 4 \times MT + PT}{6} \right) \tag{5.1}$$

If the breaker or relay is fast electronically controlled device and its operating time is in terms of milliseconds, then optimistic time, most likely time and pessimistic time is treated as almost equal. Hence, for these very fast operating switches the expected time of operation is given by

$$ET = \left(\frac{OT + 4 \times MT + PT}{6} \right) = OT = MT = PT \tag{5.2}$$

The Total Restoration Time is sum of the all the durations, that is length of each critical path is given by

$$TRT = \sum_{i=1}^{n} ET_i \tag{5.3}$$

where ‘n’ is the total number of activities

The longest critical path will draw more attention to the substation operator or to the distribution engineer, which will take more time to receive the power supply from the distribution substation, and hence it is considered as critical path. The software developed using CPM and PERT considers all these factors in each stage of restoration activity durations by averaging the power failure and faulty conditions of restoration plans of the distribution network.

5.4 SYMMETRICAL AND UNSYMMETRICAL FAULT ANALYSIS IN EPDS

EPDS disturbances are classified into short circuit fault (Phase to phase fault) and earth fault (phase to earth fault). These are further classified as either temporary or permanent faults. A class of fault which disappears itself and need no action of a circuit breaker is classified as ‘self extinguishing’. Many faults are cleared by High-Speed Auto Re-Closing (HSAR) or Delayed Auto Re-closing (DAR) breakers.

The delay of HSAR breaker is 0.5 seconds in the isolated neutral network and 0.6 seconds in the compensated network that is revealed by field experience. The division of faults in compensated network is explained as follows: snow burden 35%, fallen trees 27%, boughs on pole transformers 9%, diggers 6% in-case of under ground cables and lighting impulses 6%. Animals such as birds and squirrels caused the remaining 17% faults. However, one-third of these events occur during thunderstorms or windy weather

Under faulty conditions the analysis of restoration time needs the knowledge of fault current in the EPDS. Based on the type of fault in EPDS the analysis of symmetrical/unsymmetrical faults has been done. The details of fault analysis are taken from Nagarath and Kothari (1994). In the Power Distribution System for the various faults, the fault current at the faulted bus ‘k’ is as follows:

a) For symmetrical fault, the total fault current is given by

$$I_f = \left(\frac{V_f}{Z_{kk}+Z_f}\right) \tag{5.4}$$

b) For single line to ground fault, the total fault current in the phase 'A' is given by

$$I_{fA} = \left(\frac{V_f}{Z_{kk}^{(1)}+Z_{kk}^{(2)}+Z_{kk}^{(0)}+3Z_f}\right) \tag{5.5}$$

c) For single line to line fault (that is, fault between the lines B and C), the total fault current is given by

$$I_{fC} = -I_{fB} = a^2 I_{fA}^{(1)} + a I_{fA}^{(2)} \tag{5.6}$$

where

$$I_{fA}^{(1)} = -I_{fA}^{(2)} = \left(\frac{V_f}{Z_{kk}^{(1)}+Z_{kk}^{(2)}+Z_f}\right) \tag{5.7}$$

d) For the double line to ground fault (that is, fault between the lines B and C, to the ground), the total fault current is given by

$$I_f = \left(I_{fB} + I_{fC}\right) \tag{5.8}$$

where

$$I_{fB} = I_{fA}^{(0)} + a^2 I_{fA}^{(1)} + a I_{fA}^{(2)} \tag{5.9}$$

$$I_{fC} = I_{fA}^{(0)} + a I_{fA}^{(1)} + a^2 I_{fA}^{(2)} \tag{5.10}$$

where

Z_f = Impedance of the fault

= 0; for the bolted fault.

Z_{kk} = k^{th} row, kth column impedance element of Z_{BUS}

V_f = Pre-fault voltage at the bus 'k' in p.u.

The pre-fault voltage has been obtained from power flow analysis of pre-fault power distribution network. The sequence network interconnection has to be done based on the type of unsymmetrical faults in the EPDS. Based on the total equivalent sequence impedances, the positive, negative and zero sequence currents and hence the fault currents are calculated.

5.5 CALCULATION OF OT, PT AND MT OF OPERATION OF THE RELAY

To calculate the expected time of operation the relay/breaker under consideration, a knowledge of optimistic time, pessimistic time and most likely time of operations of the relay/breaker is essential. In power distribution network the relay senses the fault and actuate the Circuit Breaker to isolate faulty circuit from the healthier one. Manufacturing methods, maintenance, quality and the magnitude of switching surges of the distribution network operating conditions decide the probability of successful operation of relay. The probability of successful operation of the relay is assumed as 0.70 taken from Van (1969). The relay employed is taken as electromagnetic type and these relays have inverse definite minimum time characteristics in this research.

5.5.1 Calculation of the Optimistic Time of operation of the Relay

Abnormal conditions in electrical circuits are detected by the protective relays. These devices constantly measure the electrical quantities that differ under normal and faulty conditions. If a fault is detected, the relay operator has to complete the trip circuit which results in the opening of Circuit Breaker (CB). This isolates the faulty circuit from the healthy circuit of the EPDS. The optimistic time of operation of the relay has been taken as the operating time of the relay. The operating time of the relay depends on the magnitude of the fault current. The fault current flows through the primary winding of Current Transformer (CT) initially. The relay coils are connected to the secondary winding of the CT. Hence, the current flowing in secondary windings of the CT depends on the CT ratio. The operating time of the relay depends on the operating current.

Secondary current of CT,

$$I_s = \frac{I_f}{C.T.Ratio} \tag{5.11}$$

Plug Setting Multiplier

$$PSM = \left(\frac{I_s}{OLS \times PS} \right) \tag{5.12}$$

where OLS = Over load setting for operation of CB

PS = Plug setting of circuit breaker.

The time corresponding to the operating current or PSM has been found from the time-current characteristic of the relay as shown in Figure 5.2.

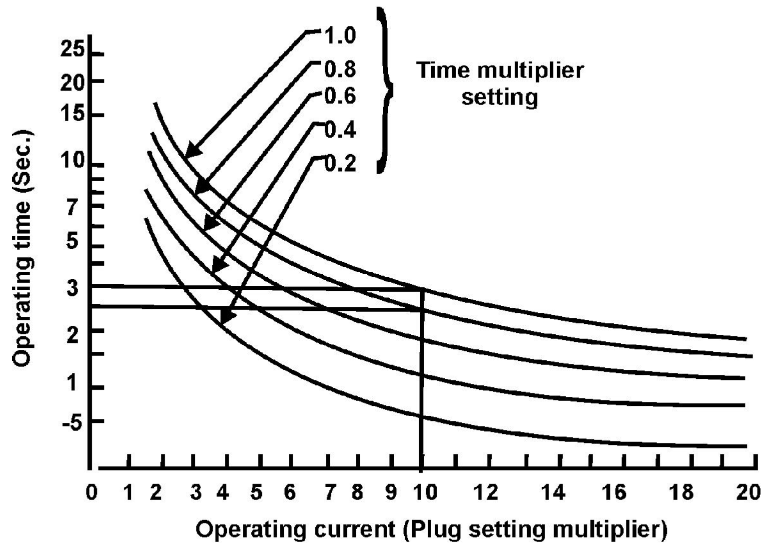

Figure 5.2 Time - Current Characteristics of the Relay

The Probability of optimistic time of operation of the relay has been assumed as

$$P(OT) = 0.70 \qquad (5.13)$$

The operating time of the relay has been taken as optimistic time of operation of the relay.

5.5.2 Calculation of the Pessimistic Time of operation of the Relay

The breakers/relays may fail to clear a fault for several reasons:

i) The trip circuit can be open (broken wire, blown fuse and open trip coil).

ii) The interrupting mechanism can stick, leaving a single phase of three phase connected.

iii) The interrupter can flash over due to loss of dielectric strength through contamination or damage.

iv) The operating mechanism can fail to operate

Along with the above causes of failure in relay/breaker operation, the ageing and loading effects of the relay also have a major impact on pessimistic time of operation of the relay. Hence the probability of pessimistic time of operation of the relay has been taken as [1- P(OT)], that is,

$$P(PT) = 0.30 \tag{5.14}$$

With knowledge of P(OT), corresponding to the OT of operation of the relay, the time corresponding to the probability of pessimistic time P(PT) has been calculated as below:

$$PT = OT \times \left(\frac{P(PT)}{P(OT)} \right) \tag{5.15}$$

From the equations (5.13) and (5.14), it can be observed that

$$P(PT) = 1 - P(OT)$$

The actual values of individual probabilities of pessimistic time of operation of the relay depends on conditions (i) and (iv), etc.,

5.5.3 Calculation of the Most likely Time of operation of the Relay

The breakers/relays may fail to clear the fault due to the following reasons:

i) The ageing and manufacturing defects influence the relays in late tripping of the faulty circuit.

ii) The stiffness of the spring/fault in the operating mechanism or the delay in decoders/encoders (that is, if the relay is electronically controlled) also causes late tripping of the faulty circuit.

iii) The increased delay time and switching time of electronic devices in case of static relays.

It can be concluded that the optimistic time and pessimistic time of operation of the relay are necessarily not mutually exclusive events from the above operational time analysis of the relay. Then from the addition rule for arbitrary events (Balagurusamy 1994), the union of these two events is given by

$$P(OT \cup PT) = P(OT) + P(PT) - P(OT \cap PT)$$

where $$P(OT \cap PT) = P(OT) \times P(PT) \tag{5.16}$$

The probability of the most likely event depends on both the probabilities of optimistic time and pessimistic time.

$$P(MT) = P(OT \cup PT)$$

$$P(MT) = P(OT) + P(PT) - P(OT) \times P(PT) \tag{5.17}$$

The most likely time of operation of the relay has been calculated as below:

$$MT = OT \times \left(\frac{P(MT)}{P(OT)} \right) \tag{5.18}$$

5.6 ALGORITHM FOR THE ESTIMATION OF SERVICE RESTORATION TIME IN EPDS

Step 1: Read the bus data, line data, substation voltages, shunt capacitor ratings, convergence tolerance, CT ratio, PSM of the relay and circuit breaker settings.

Step 2: Perform the power flow analysis for the pre-fault using forward substitution method.

Step 3: Compute the line flow for all the sections of feeders and lines in the distribution network.

Step 4: Check whether any power failure or fault (i.e., symmetrical or unsymmetrical, fault) has occurred or not,

If there is any failure of supply from grid, go to step 9 or

If there is any faulty condition, go to next step.

Step 5: If the fault is symmetrical, form bus impedance matrix, and if the fault is unsymmetrical, form the positive, negative, and zero sequence impedance matrices of the network.

Step 6: Compute the positive, negative, and zero sequences impedances based on the type of fault in the EPDS.

Step 7: Compute the positive, negative, and zero sequence currents and then calculate total fault current.

Step 8: Compute the operating time of the relays of the various sections of the feeders and go to step 10.

Step 9: Isolate the faulty section of the feeder by opening the related circuit breakers and go to next step.

Step 10: Compute the Total Restoration Time of the power supply as below:

TRT = Operating time in Step 8 + computational time performing the power flow analysis and time required to search the optimal switching configuration of the power distribution network (5.19)

Step 11: Stop the estimation of Service Restoration Time.

5.7 ANALYSIS OF THE ESTIMATION OF SERVICE RESTORATION TIME FOR VARIOUS EPDS

The magnitude of the fault current varies with the type of disturbance/ fault in the EPDS. Calculation of the expected time of operation of the relay and hence, the estimation of total restoration time of power supply for the various EPDS is detailed below:

5.7.1 Estimation of Service Restoration Time for 12-bus Practical EPDS

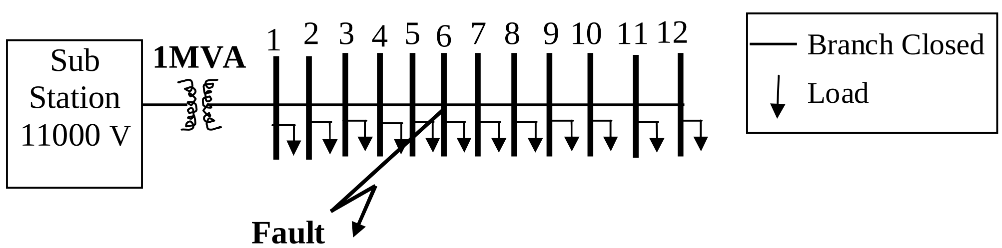

Figure 5.3 12-Bus Electrical Power Distribution Systems

The bus data and line data of the 12-Bus practical distribution system are given in Table A1.1 and Table A1.2, respectively. Here, it is assumed that **three phase fault** takes place at Bus No.6. The short circuit study has been performed to know post fault state of the EPDS. After the occurrence of the fault at the Bus No.6, the relay at the Bus No.6 will operate and isolate the faulty bus 6 from the distribution network.

The pre-fault and post fault voltages for the bolted fault at the Bus 6 are given below in Table 5.1.

Table 5.1 Bus Voltages in pre-fault, during the fault and Post-fault state of 12-Bus Distribution System

Bus No	Pre-Fault Voltage in p.u	Voltage During the fault in p.u	Voltage After the Restoration of supply	Bus No	Pre-Fault Voltage in p.u	Voltage During the fault in p.u	Voltage After the Restoration of supply
1	1.0000	0.9818	1.0000	7	0.9637	**0.0000**	0.9630
2	0.9943	0.8529	0.9998	8	0.9553	**0.0000**	0.9560
3	0.9890	0.7158	0.9818	9	0.9473	**0.0000**	0.9460
4	0.9806	0.4765	0.9880	10	0.9446	**0.0000**	0.9440
5	0.9698	0.1203	0.9883	11	0.9435	**0.0000**	0.9430
6	**0.9665**	**0.0000**	0.9690	12	0.9443	**0.0000**	0.9420

5.7.1.1 Estimation of Service Restoration Time for isolating the fault circuit

The fault current due to occurrence of the three phase fault without any fault impedance (that is, bolted fault) at the bus 6 has been calculated by building the bus impendence matrix and then performing the short circuit studies, that is using equation (5.4)

Fault current (I_f) = 1120.246 A

CT ratio = 525/1

From the equation (5.11), the Secondary Current of the CT is given by

I_s = 1120.246/(525/1) = 2.1338 A

Over Load Setting (OLS) of the breaker, which is located at the transformer at the bus 1, is taken as 12%, that is, OLS = 1.25

Plug Setting PS = 1.

The plug setting multiplier or the operating current is calculated using equation (5.12)

$$PSM = 2.1338/(1.25 \times 1) = 1.7070$$

Operating time = TMS x time from the time-current characteristics of the relay = 0.3 × 10 = 3 s

The estimation of restoration time for operation of the relays is done as follows:

The Optimistic Time (OT) of operation of the relay has been taken as Operating time of the relay with probability of 0.7.

that is, OT = 3 s; P(OT) = 0.70

Probability of pessimistic time of operation of the relay

P(PT) = 0.30;

Pessimistic time of operation of the relay from the Equation (5.15) is given by

$$PT = OT \times [P(PT)/P(OT)] = 1.2857 \text{ s}$$

Probability of most likely time of operation of the relay from equation (5.17) is given by

$P(MT) = P(OT) + P(PT) – P(OT) \times P(PT) = 0.79$

Most likely time of operation of the relay from the equation (5.18) is given by

$MT = OT \times [P(MT)/P(OT)] = 3.3857$ s

Expected time of operation of the relay

$ET = [OT+4MT+PT]/6 = 2.9714$ s

Total restoration time for isolating the faulty circuit is given by

$$TRT_1 = 2.9714 \text{ s} \quad (5.20)$$

The power flow has been performed using the improved load power flow analysis which is presented in Chapter 3 of the thesis. The results obtained are as follows:

Total real power demand	=	435.0000 KW
Total reactive power demand	=	405.00000 KVAR
Total real power loss	=	20.5231 KW
Total reactive power loss	=	8.0145 KVAR
Total real power supplied from the sub-station	=	455.5231 KW
Total reactive power supplied from the sub-station	=	413.0145 KVAR
Computational time for performing the switching analysis:TRT_2	=	0.53s

Hence the total restoration time from equation (5.19)

$TRT = TRT_1 + TRT_2 = + 2.9714 + 0.53 = 3.5014$ s

5.7.2 Estimation of Service Restoration Time for 16-bus, Three Feeder EPDS

The 16-Bus, three-feeder distribution system is shown in Figure 2.3 in Chapter 2. The bus data and line data are given in Appendix 2 of the thesis. The pre-fault voltages, power demands and power supplied from the substation are given below in Table 5.2. Here it is assumed that a **line to ground fault** takes place at Bus No. 13. The unsymmetrical fault analysis has been carried out and results obtained are given below in Table 5.3. After the occurrence of the fault at Bus No.13, the relay at Bus No.13 will operate and isolate the faulty bus 13 from the distribution network. The voltage magnitudes during the fault and post fault state of EPDS are given below in Table 5.4. Here it can be noted that voltage at the faulty Bus 13 is zero in the post fault PDN in Table 5.4.

Table 5.2 Voltage during the Pre-fault condition for 16-Bus, Three Feeder 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	5	0.9547	9	0.9750	13	0.9831
2	1.0000	6	0.9690	10	0.9787	14	0.9860
3	1.0000	7	0.9402	11	0.9573	15	0.9761
4	0.9678	8	0.9775	12	0.9669	16	0.9656

Total real power demand = 21150.0000 KW

Total reactive power demand = 10710.0353 KVAR

Total real power loss	= 1202.4012 KW
Total reactive power loss	= 963.9988 KVAR
Total real power supplied from the sub-station	= 22352.4012 KW
Total reactive power supplied from the sub-station	= 11674.0341 KVAR
Number of iteration taken	= 6
Percentage loading of transformer 1	= 0.80310
Percentage loading of transformer 2	= 0.9100
Percentage loading of transformer 3	= 0.4102
Percentage loading of feeder 1	= 1.07368
Percentage loading of feeder 2	= 1.2037
Percentage loading of feeder 3	= 0.6028
Computational time	= 0.056 s.

Table 5.3 Line Currents due to the fault at Bus No.13 for the 16-Bus System

From Bus	To Bus	Line Current in p.u			From Bus	To Bus	Line Current in p.u		
		Phase a	Phase b	Phase c			Phase a	Phase b	Phase c
1	4	0.0696	0.0696	0.0696	8	9	0.0255	0.0255	0.0255
2	8	0.0639	0.0639	0.0639	8	10	0.0230	0.0230	0.0230
3	13	1.2649	0.0370	0.0370	9	12	0.0175	0.0175	0.0175
4	5	0.0217	0.0217	0.0217	10	14	0.0046	0.0046	0.0046
4	6	0.0247	0.0247	0.0247	13	15	0.0213	0.0213	0.0213
5	11	0.0077	0.0077	0.0077	**13**	**F**	**1.2281**	**0.0000**	**0.0000**
6	7	0.0180	0.0180	0.0180	15	16	0.0001	0.0001	0.0001

Table 5.4 Voltages during the fault and post-fault condition for the 16-Bus System

Bus No	Voltages magnitude During the fault in p.u			Post-fault voltages p.u	Bus No	Voltages magnitude During the fault in p.u			Post-fault voltages p.u
	Phase a	Phase b	Phase c			Phase a	Phase b	Phase c	
1	1.0000	1.0000	1.0000	1.0000	9	0.9552	0.9552	0.9552	0.9474
2	1.0000	1.0000	1.0000	1.0000	10	0.9587	0.9587	0.9587	0.9547
3	0.9910	0.9991	1.0000	1.0000	11	0.9273	0.9273	0.9273	0.9397
4	0.9579	0.9579	0.9579	0.9455	12	0.9469	0.9469	0.9469	0.9390
5	0.9317	0.9317	0.9317	0.9217	**13**	**0.1228**	**0.9732**	**0.9732**	**0.0000**
6	0.9490	0.9490	0.9490	0.9267	14	0.9560	0.9560	0.9560	0.9519
7	0.9302	0.9302	0.9302	0.8807	15	0.1160	0.1160	0.1160	0.8518
8	0.9675	0.9675	0.9675	0.9636	16	0.1160	0.1160	0.1160	0.8622

5.7.2.1 Estimation of Service Restoration Time for isolating the fault circuit

The occurrence of fault at the Bus 13 actuates the relay located at the Bus 13 and hence the breaker trips the circuit to isolate the faulty Bus 13. The time taken for isolating faulty circuit has been estimated as follows:

Fault current (I_f) = 1.2281 A

Base current I_{BASE} = $MVA_{BASE} \times 1000/ \sqrt{3} \times KV_{BASE}$

= $100 \times 1000/ \sqrt{3} \times 11 = 5248.64$ A

$\therefore \quad I_f = 5248.64 \times 1.2281 = 6445.85$A

CT ratio = 1000/5

I_s = Secondary current of CT = I_f / (CT ratio) = 32.23 A

PS = Plug setting of the relay = 1.0

OLS = Over load setting of the transformer breaker = 1.25

PSM = Plug setting multiplier or operating current of the relay

$= I_s /(OLS \times PS) = 25.78$ A

Operating time = TMS × time from the time-current characteristics of the relay = 0.40 ×1.3 = 0.52 s

$\therefore$ OT = 0.52 s (with a Probability of 0.7, i.e. P(OT))

PT = OT × [P(PT)/P(OT)] = 0.52 × (0.3/0.7) = 0.2228s

PT = 0.2228 s (with a Probability of 0.3, i.e. P(PT))

P(MT) = Probability of most likely time

$= P(OT) \cup P(PT) = P(OT) + P(PT) - P(OT) \times P(PT)$

$= 0.7 + 0.3 - 0.7 \times 0.3 = 0.79$

MT = OT × [P(MT)/P(OT)] = 0.52×(0.79/0.70) = 0.5868s

MT = Time corresponding to the P(MT) = 0.5868 s

ET = Expected time of operation of the relay

ET = [OT+4MT+PT]/6 = 0.5150 s

Total Restoration Time for isolating the faulty circuit is given by = TRT_1 = 0.5150 s

The fault at Bus 13 must be cleared in order to restore the supply to Bus 13.

The detailed explanation of searching the optimum configuration of PDN using a newly developed algorithm is presented in Chapter 7 of the thesis. The computational time for performing the power flow analysis and time required to search optimal configuration of post fault switching PDN has been found to be 0.52 s.

$TRT_2 = 0.52$ s

Total Restoration Time = TRT

$= TRT_1 + TRT_2 = 0.5150 + 0.52 = 1.035$ s.

5.8 SUMMARY

For the estimation of service restoration time in EPDS, an improved method is presented in this chapter. The additional consideration of the optimistic time, pessimistic time and most likely time of operation of the protective devices based on the probability, manufacturing defects and operators experience helps in improving accuracy of the estimation of service restoration time in EPDS. For illustration 12-Bus and 16-Bus distribution system results are presented in this Chapter and the remaining system results, including 12-Bus, 29-Bus, 69-Bus, 79-Bus and 133-Bus systems are presented in Appendices (1, 4, 6, 7 and 8). The knowledge of this exact service restoration time analysis helps the distribution power engineers to minimize the period of these power blackouts in the EPDS. Hence for restoring the power supply to the consumers in minimum time, this improved method could easily be incorporated in service restoration algorithms of distribution automation systems.