Isolation and Restoration Procedures of Distribution System Based on Partial Restricted Substation Capacity

Muhammad Sofar Bin Yahya
Faculty of Electrical Engineering
Universiti Teknologi MARA Malaysia
40450 Shah Alam, Selangor, Malaysia
Email: eyzasof_94@yahoo.com

Abstract - **The management of electricity distribution has to cope with rapid changes in the business environment, due to the liberalization in the electrical energy market. This will cause difficult for modeling the power system during the restoration process following the major outage. The modeling power system has three stages: 1) Generation 2) Transmission 3) Distribution. This paper is discussed the impact of distribution system capacity on load point reliability and the cost of load point interruptions. They also talk about why we use the isolator compared the circuit breaker. The main goals is maximizes the amount of load that can be restored after a grid blackout, substation outage, and distribution feeder line section outages. The outage in the system can give impact to the cost of the maintenance. The case study in this paper discusses about the when the fault occurs in the system, some of the load is transferred to another substation.**

***Keyword** –distribution system, isolation and restoration, cost, interruptions cost.*

I. INTRODUCTION

In power system, if any fault occurs in the feeder section, the technician must analysis of the problem. To analysis the problem, a technician must isolate the section fault from other section. This is for the avoidance of defective parts affects the undamaged another part. Isolation is a separate the fault section from another load in the power system. Then the fault available must be restoring to the system to function normally. In the system must be has the procedures to analysis the problem, isolated and restoration the section fault.

The maintenance costs are very important in power system because it is very high and may be can reduce profits. Profitability is very important in business because the business can grow profits and avoid losses [3]. This paper is related to the maintenance cost in the power system when the load has not transfer and transfer to other substations. It also discussed about the outage load when another load feeder has the fault [4]-[7]. This means that if a fault occurs on the section feeder load 1 and whether load point 2 will be involved. If the load point 2 is involved, it must repair or switching activities only. The ability of a distribution system configuration to transfer loads during outage depends on the substation design and operational procedures [8]. Some of common distribution substation configuration used by utilizes are:

1. Single transmission source : single transformer
2. Single transmission source : dual transformer
3. Dual transmission sources : single transformer

Dual transmission sources: dual transformer

1. Dual transmission sources : dual transformer with tiebreakers
2. Dual transmission sources : dual transformer with three breakers
3. Dual transmission sources : single transformer with ring bus

This paper will present three case studies revealing the load point restoration transfer procedures defined in tables necessary to restore power from alternate supplies to selected load points on outage from their primary or normal supply. The case studies presented in this paper are intended to clearly reveal the significant changes in load point reliability indices caused by the following distribution system constraints and operating characteristics:

1. Capacity limited distribution substations

2. Capacity limited feeder circuit inter-ties;

3. The varying cost of grid blackouts to a distribution system due to restricted and unrestricted substation capacity;

4. The cost of substation outages and their ability or non-ability to transfer their loads to adjacent substations whose capacity may be restricted or unrestricted;

5. The unique impact of individual line section outages in creating unique islands within a distribution network.

II. DISTRIBUTION SYSTEM CHRACTERISTIC

The distribution system shown in figure 1 which has two substation distribution is A and B. The substation A supplying the energy to nine load point and the substation B supplying the energy to the six load point. The methodology presented in this paper can be applied to any number of distribution feeder circuits that are looped radial or strictly radial or combinations of both.

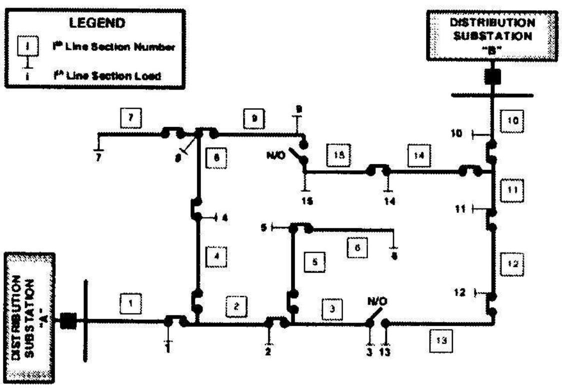

Figure 1.0:Distribution looped feeder : normal operating configuration

The distribution circuit can be divided into line sections that can be separated manually. Each line section has a switching device at the end of the line section closest to the normal supply. The switching devices associated with the line sections allows the isolated loads to be transferred to adjacent energized feeder circuits other than their normal supply subject to system constraints dependent upon the duration of the outage. The average load and peak for each part of the line shown in Table 1.0 and Table 2.0. The pysical length for each section line shown in Tables 3.0 and 4.0.

TABLE 1.0: LINE SECTION COMPOSITE LOADS (SUBSTATION A)

Load Point	Peak Load(kW)	Average Load (kW)
1	1000	800
2	500	400
3	1000	800
4	1500	1200
5	700	560
6	1300	1040
7	500	400
8	1000	800
9	1500	1200

TABLE 2.0: LINE SECTION COMPOSITE LOADS (SUBSTATION B)

Load Point	Peak Load(kW)	Average Load (kW)
10	1250	1000
11	250	200
12	500	400
13	750	600
14	1000	800
15	750	600

The peak load is a maximum power load on electrical power supply system compares the base load and the load average is an average system load over period time.

TABLE 3.0: DISTRIBUTION FEEDER LINE SECTION LENGTH (SUBSTATION A)

Line section	1	2	3	4	5	6	7	8	9
Physical length (km)	2	1	2	3	3	3	2	3	1

TABLE 4.0: DISTRIBUTION FEEDER LINE SECTION LENGTH (SUBSTATION B)

Line section	10	11	12	13	14	15
Physical length (km)	5	2	4	3	2	3

a) Distribution load transfer characteristic

The electricity in the distribution system operates using radials feeder. This feeder links between the load points to another load point. The feeders are tied through normally open tied switch. This will cause any line section outage can be manually isolated and the remaining line sections can be energized from the alternative feeder or from the nearest continuous feeder. The load transfer is depends to the reserve capacity can be accommodated.

b) Operates procedures :line section outage

When the fault occurs in any line section, the substation circuit breaker will trip to isolated the another line section. The faulty line section is first isolated and another load point for this paper depends to the Table 6.0 and Table 7.0 transfer or not. The load point transferred to the adjacent energized substation is dependent upon the following constrained operating conditions:

1) The load transfeered occurs when the sum of the peak Loads of the energized substation plus the sum of the isolated peak loads being transferred to the energized feeder(s) from the de-energized feeder(s)do not exceed the rated capacity of the energized substation

$$\sum_{i=1}^{n} L_{pei} + \sum_{i=1}^{n} L_{pisoj} \leq C_{sub} \qquad (1)$$

2) If the sum of the peak loads being transferred to the energized feeder plus the sum of the PEAK Loads of the energized substation exceeds the rated capacity of the substation, the normally opened tie switches will not be closed and no load will be transferred.

$$\sum_{i=1}^{n} L_{pei} + \sum_{i=1}^{n} L_{pisoj} \geq C_{sub} \qquad (2)$$

where

L_{pei} : ith energized feeder peak load

L_{pisoj} : the jth de-energized feeder peak load being transferred to substation i from substation j

C : The capacity of the energized substation

n : The number of energized loads

m : The number of de-energized loads being transferred to the energized substation

c) Feeder circuit reliability data

1. λ (feeder failure rate) = 2 failures per 100 km per year
2. Repair time = 4 hours per feeder section failure
3. Switching time = 1.0 hour (includes one or more switching operations)
4. Grid and substation outage = 1 every 10 years lasting for more than 4 hours

d) Cost load point interruptions

The interruption cost to any load point being supplied by the looped radial feeders is shown in Table 5.0. From the Table 5.0, the repair time requires 4 h with the cost is 25 dollar per kW. The switching time is 1 h with the cost 10 dollar per kW. The 6 h and 8 h for the grid blackout.

TABLE 5.0: LOAD POINT INTERRUPTION COSTS

Duration of Outage (h)	$/Average kW of Load Interruption
1	10.00
4	25.00
6	75.00
8	90.00
10	105.00

III. CASE STUDY

The load of distribution system has two distribution substations A and B. The limiting capacity of substation A is 15MVA or 13.5 MW with the total peak load of 9000kW with 4500 kW capacity is reserve. The limiting capacity of substation B is 10 MVA or 9.0 MW with the total peak load of 4500kW and a 4500kW capacity in reserve for short-term outages. The reserve capacity not only provides the alternative energy supply for load points in the adjacent substation network feeder line section in the event of a substation outage. Restoration tables for the distribution load looped feeder are shown in Tables 6.0 and Table 7.0.

TABLE 6.0: RESTORATION TABLE – SUBSTATION A

LEGEND
i - Load Point "i" energized from normal supply
- Load interrupted
- Load transfered to alternate supply

Faulted Section	Sub A Loads Restored Following Isolation of Fault									Sub A Loads Transferred to Sub B									Total kW Transfered
	1	2	3	4	5	6	7	8	9	1	2	3	4	5	6	7	8	9	
1													4 1,500			7 500	8 1,000	9 1,500	4,500
2	1												4 1,500			7 500	8 1,000	9 1,500	4,500
3	1	2		4			7	8	9										0
4	1	2	3		5	6										7 500	8 1,000	9 1,500	3,000
5	1	2	3	4			7	8	9										0
6	1	2	3	4	5		7	8	9										0
7	1	2	3	4	5	6		8	9										0
8	1	2	3	4	5	6												9 1,500	1,500
9	1	2	3	4	5	6	7	8											0

The restoration table is references to the transferred load point to another substation or not. From the Table 6.0 and 7.0, the maximum transfer is 4500 kW because the capacity reserve for the substation A and B is 4500 kW.

TABLE 7.0: RESTORATION TABLE – SUBSTATION B

Faulted Section	Sub B Loads Restored Following Isolation of Fault						Sub B Loads Transferred to Sub A						Total kW Transfered
	10	11	12	13	14	15	10	11	12	13	14	15	
10								11 250	12 500	13 750	14 1,000	15 750	3,250
11	10								12 500	13 750	14 1,000	15 750	3,000
12	10	11			14	15				13 750			750
13	10	11	12		14	15							0
14	10	11	12	13								15 750	750
15	10	11	12	13	14								0

IV. METHODOLOGY

The figure 2.0 has shown the flowchart to calculate the total cost of the interruptions for the system in the figure 1.0 and the restoration table. The flowchart shows there are seven steps to calculate the total cost of the interruptions.

Step 1: Initialize system data.

The distribution system has two substation distributions A and B. The substation A includes loads points of 1 to 9 and substations B accommodate loads point from 10 to 15. The restoration table show the transfer load or no transfer load when the load point section has the fault. The table 7.0 shows the transfer load happen when the fault occurs at the section 1, 2, 4, and 8 and the Table 8.0 shows the transfer load happen when the fault occurs at the section 10, 11, 12, and 14.

Step 2: Calculate λ, the number of feeder outages per year for each section

To calculate the number of feeder outages per year for each section using the equation below:

λ (feeder failure rate) = 2 failures per 100 km/year (3)

The example calculation for detailed load point 1:

TABLE 8.0: DETAILED LOAD POINT 1

Section	Length (km)	λ (failures/year)
1	2	0.04
2	1	0.02
3	2	0.04

From the Table 8.0, the section 1 has the length 2 km. The example calculation failure per year for detailed load point 1 and section 1:

$$\frac{\lambda}{L} = \frac{2}{100}$$

$$\lambda = \frac{2L}{100} = \frac{2x2}{100} = \frac{4}{100} = 0.04 \text{ f/year} \qquad (4)$$

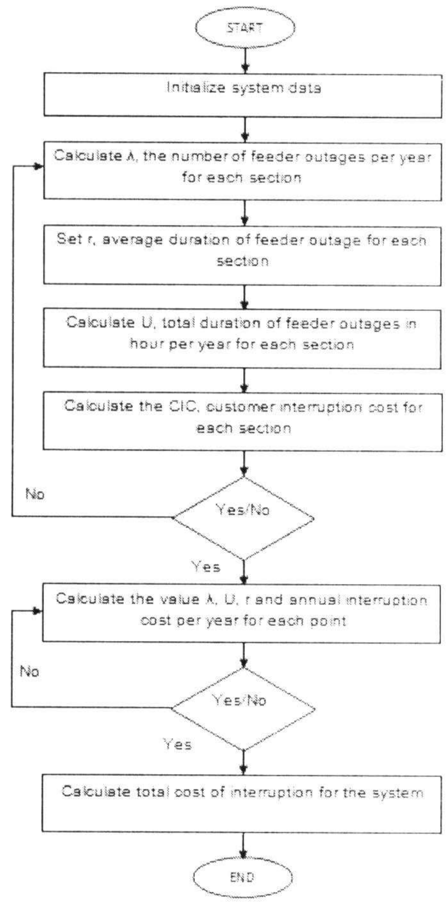

Figure 2.0: The flowchart to calculate the total cost of interruptions for the system

Step 3: Set the average duration of feeder outages, r.

In this case study, the duration outages is 1 h for the switching time and 4 h for the repair time. The duration outages must be depending on the restoration Table 6.0 and 7.0. In the restoration table, there are two case of load transfer and no load transfer. The detailed load point 1 to the value of r is shown in Table 9.0. When the fault happen at the feeder section 1, it is requires 4 h for the repair time and when the fault happen at the feeder section 2, it can manually isolated in 1 h and the feeder reenergized to provide power to the load point 1.

TABLE 9.0: THE VALUE "r" FOR THE LOAD POINT 1

Section	Length (km)	λ (failures/year)	r(h)
1	2	0.04	4.00
2	1	0.02	1.00
3	2	0.04	1.00

Step 4: Calculate value U, the total duration of feeder outages in hour per year for each section

To calculate the total duration is using the equation 5 below:

$$U_p = \sum_{i=1}^{N} \lambda_i \times r_i \quad (5)$$

where
λ : the frequency of load point interruptions per year
r : The average interruption duration expressed in hours per interruptions
U : The total annual interruption duration
N :The number of outage events effecting load point "p".

Step 5: Calculate the interruption cost for the each section.

$$CIC = \lambda_j \times L_p \times C\,(rj.p) \quad (6)$$

where
λ_j : the failure rate of feeder section j.
L_p : the average connected load at load point "p" refer to the table 1.0 and 2.0.
C (rj,p) : the cost of interruption in dollar per kilowatt for an outage duration of rj associated with feeder section j.

Step 6: Calculate the all value for the λ, r, U and the interruption cost for the all section. Repeat the step 2 until step 5 for section 1 until section 15.

Step 7: Calculate the total cost for all load point interruptions.

$$\text{Equation} = \sum_{i=1}^{n} \text{COLPI}_i \quad (7)$$

where
i : The i^{th} load point
n : The number of load points being serviced by the distribution feeder
COLPIi : the individual load point interruptions cost.

V. RESULT AND DISCUSSION

Table 10.0 and Table 11.0 show the result for the detailed load point 1 and the cost of interruptions for the load point 1. The total cost interruptions for the load point is 3680 dollar per kW. The load point 1 received energized from the substation A but when the fault happens at the section feeder 1, it is depending on the restoration Table 6.0. The cost of interruptions for this section is different because the load point interruption,λ and outages per year,r is different. The load point interruptions point is depend to the repair time or switching time.

TABLE 10.0: DETAILED LOAD POINT 1 RELIABILITY INDICES AND COSTS OF INTERRUPTION

Section	Length (km)	Λ (failure/year)	r(h)
1	2	0.04	4.00
2	1	0.02	1.00
3	2	0.04	1.00
4	3	0.06	1.00
5	3	0.06	1.00
6	3	0.06	1.00
7	2	0.04	1.00
8	3	0.06	1.00
9	1	0.02	1.00
Total		0.40	r= 0.52/0.4 =1.3

TABLE 11.0: DETAILED LOAD POINT 1 COSTS OF INTERRUPTION

Section	*U*(h/year)	Load Point Interruption	$/Load Point Annual Cost
1	0.16	25	800.00
2	0.02	10	160.00
3	0.04	10	320.00
4	0.06	10	480.00
5	0.06	10	480.00
6	0.06	10	480.00
7	0.04	10	320.00
8	0.06	10	480.00
9	0.02	10	160.00
Total	0.52		3680.00

The value outages in the Table 10.0 are different and only have 4 h for the repair time. Another section is switching time is 1 h. If fault occurs in the feeder section 1, the load point 1 is not received energy from the substation A or B. The load point 1 requires 4 h for the repair time. If fault occurs on the feeder section 2, it can be manually isolated in 1 h and the feeder re-energized to provide power to load point 1 from substation A. So, the value for the duration of outages for the load point 1 on the section 1 and 2 is 4 h and 1h.

TABLE 12.0: SUMMARY OF LOAD POINT RELIABILITY INDICES

Load point	Λ (outages/year)	R (h/year)	U (h/outage)
1	0.40	1.30	0.52
2	0.40	1.45	0.58
3	0.40	1.75	0.70
4	0.40	1.45	0.58
5	0.40	2.20	0.88
6	0.40	2.65	1.06
7	0.40	1.75	0.70
8	0.40	1.45	0.58
9	0.40	1.15	0.46
10	0.38	1.79	0.68
11	0.38	1.32	0.50
12	0.38	1.63	0.62
13	0.38	1.47	0.56
14	0.38	1.32	0.50
15	0.38	1.47	0.56

TABLE 13.0: SUMMARY OF THE COST OF INTERRUPTIONS

Load Point	Interruption Cost ($/year)
1	$3680.00
2	$1960.00
3	$4400.00
4	$5880.00
5	$3584.00
6	$7592.00
7	$2200.00
8	$3920.00
9	$5160.00
10	$5300.00
11	$880.00
12	$2000.00
13	$2820.00
14	$3520.00
15	$2820.00
Total	**$55,716.00**

The Table 12.0 and 13.0 show the summary of load point reliability indices and the cost interruptions for the system. The total cost for the system when the fault occurs and load transfer or not is **$55,716.00.**For a grid blackout of the distribution system for 4 hours the capacity of both substations is able to pick up the entire feeder loads following the blackout. Therefore, it is not necessary to shed load. The average annual cost of the interruptions to load points being serviced by both substation A and B is **$21,600**. If the grid blackout is 8 hours then the average annual cost of interruptions to loads points being serviced by substation A and B would be **$100,800**.The calculation for the grid blackout 4 h and 8h are using the equation below:

Total cost = Power energized x load factor x average cost load of interruptions x grid system outage. (8)

Substation A- 4 h

Total cost = 9000 x 0.8 x 0.1 x$ 25 = $18,000

Substation B – 4h

Total cost = 4500 x 0.8 x 0.1 x $ 10 = $ 3,600

Substation A- 8 h

Total cost = 13500 x 0.8 x 0.1 x $90 = $ 97,200

Substation B – 8h

Total cost = 4500 x 0.8 x 0.1 x $ 10 = $ 3,600

The total cost grid blackout for 4 h = 18000 + 3600 =$21600

The total cost grid blackout for 8 h = 97,200 + 3600=$100,800

The total cost for the grid outage at the 4 h and 8 h substation B is same. It is because; the substation B has 9000kW capacity reserve to supply another load. When the grid blackout happens, it is only switching time to operate normally.

VI. CONCLUSION

This paper discussed about the analyzing the frequency and duration of load point interruptions. It also discussed about the annual cost of load point interruptions subject to substation capacity constraints including grid outages. This paper explains about differentiation between the annual cost for the transferred load and no transferred load to another substation. The relationship between the outage in the system and the cost maintenance to repair the fault happen. Furthermore, this paper discussed about step to calculate the cost in the system. The result show the total interruptions cost for the transfer load is low compared the no transfer load. The distribution line section outages had the highest average manual cost of interruptions compared to substation and grid outages.

RECOMMENDATION

In this paper stand out with two design of substation that has own advantage and disadvantage. To improve their substation configuration, rearrange and make some correction on the design in order to get the more reliable and fed utility power supply to the load point without interruptions.

ACKNOWLEDGMENT

In the name of almighty God, I would like to say great thanks to my supervisor, Dr Muhammad Murtadha bin Othman for giving me full guidance, opinion , information and idea throughout completion this paper. Thank you also to my friend have contributed immeasurably by giving response to inquiries, presentations and the draft report of the thesis work and also for their effort and helpful comment. Last but not least, special appreciation to my family for their support and also give me strength in order to complete this project successfully.

REFERENCES

[1] D.O.Koval, FIEEE, and A. A. Chowdhury, SMIEEE,*Reliability Aanlysis of the Isolation and Restoration Procedures of Distribution Feeders*

[2] Koval, D.O., Zone-Branch Reliability Methodology for Analyzing Industrial Power Systems", IEEE Transactions on Industry Application, Vol. 36, No. 5, pp. 1212-1219, Sept./Oct., 2000.

[3] GABRIEL NICOLAE POPA SORIN DEACONU CORINA MARIA DINIŞ ANGELA IAGĂR Department of Electro technical Engineering and Industrial Informatics Politechnica University Timişoara Str. RevoluŃiei, no.5, Hunedoara ROMANIA

[4] IEEE Std 493-1997, IEEE Recommended Practice for Design of Reliable Industrial and Commercial Power Systems(IEEE Gold Book), ISBN 1-55937-969-3, The Institute of Electrical and Electronics Engineers, Inc., 345 East 47th Street, New York, NY 10017-2394, USA.

[5] Koval, D.O, Zhang, X., Propst, J, Coyle, T, Arno, R., Hale, Jr., R.S., "Reliability Methodologies Applied to the IEEE Gold Book Standard Network", IEEE Industry Applications Magazine, January/February 2003, Vol. 9 No. 1 ISSN 1077-2618, pp. 32 – 41.

[6] Propst, J.E., Doan, D.R., "Improvements in Modeling and Evaluation of Electrical Power System Reliability, IEEE Transactions on Industry Applications, VOL. 37, NO. 5 Sept. / Oct., 2001, pp. 1413 – 1422.

[7] Peyton S. Hale, Jr., Robert G. Arno, Don O. Koval, "Analysis Techniques for Electrical and Mechanical Power Systems", 2001 IEEE Industry and Commercial Power Systems Technical Conference Record 01CH37226, pp. 61-65. 2001.

[8] D. O. Koval and Chowdhury .A .Ali , Power Distribution System Reliability, Practical Methods and Applications. *IEEE Press.445 Hoes Lane. Piscataway, NJ08854*

[9] A.A. Chowdhury, *Senior Member, IEEE.*Distribution Feeder Reliability Assesment

[10 Prof. Chi K. Tse Department of Electronic & Information Engineering Hong Kong Polytechnic University, Circuit Theory and Design of Power Factor Correction Power Supplies, *IEEE Distinguished Lecture 2005, Circuits and Systems.*