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**Electronics
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ELECTRICAL POWER ENGINEERING

Impact of Protection System on Distribution System Reliability

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Abstract - Modern society generally expects high reliability power supply. Electricity interruption may cause high damage to consumers. Most of load interruptions are due to breakdowns in distribution systems. Therefore, the improvement of reliability for a distribution system including its protection system is of interest in this paper. Equipment failure may occur electricity interruption. However with a proper protection system, the interruption will be confined in a particular area, resulting in better reliability performance. In this paper, impact of protective devices installation, e.g. disconnecting switch and fuse on distribution system reliability will be analyzed. In addition, impact of voltage dip on each interested load point will also be calculated and presented. The developed method has been tested with the Reliability Test System (RBTS) [2].

Keywords: impact of protection, distribution system reliability, voltage dip

1. INTRODUCTION

A key function of a power system is to supply customers with electrical energy as economically and reliably as possible. Electrical service interruption can have a profound economic impact on certain customers. Not only sustained interruption results in lost production, but momentary interruptions may also cause damages to the consumers.

In general, customers will be reluctant to increase their service reliability locally, exerting in higher pressure for utilities to improve their service reliability. Apart from replacing high failure rate components, i.e. replacing bare conductor by insulated conductor, it is widely known that the utility can improve its reliability by improving its protection system. Better coordination or more appropriate protective devices, e.g. recloser, fuse and disconnecting switch, put into the system can help improve its reliability.

The coordination of protective devices aims to maintain the selectivity among the devices involved in several fault possibilities, in order to assure the safe operation and the reliability of the system. In an efficient and coordinated protection system, faults are eliminated in the smallest possible time, isolating the smallest part of the system containing the cause of the fault.

The disconnected switches, reclosers or fuses can be properly placed on radial systems which result in better system reliability. This paper will analyse the impact of protective devices on distribution system reliability. The

analysis will focus on permanent outage events. Results of system and load point reliability indices will be presented.

When a fault occurs, the voltage level of each load point will be decreased. It is known as voltage dip or voltage sag. The voltage dips have to be compared with customer voltage envelope. If the customer cannot tolerate the dip or the dip violates the envelope, it will be cut off from the supply permanently. Therefore, this event will impact on reliability of the system. In addition the impact on voltage dip due to protective device operation and fault locations will also be analyzed. The bus 2 of Reliability Test System (RBTS) will be used in this analysis.

II. RADIAL DISTRIBUTION SYSTEM PROTECTION

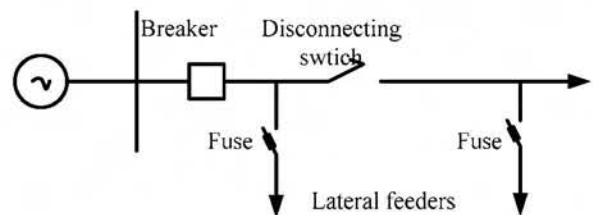


Fig. 1 Typical radial distribution feeder

The main aspect of the protection coordination is that the primary device, closer to the fault point, should act before the backup device [5]. Additional protection is frequently used in practical distribution systems. One possibility in the case of the system shown in Fig. 1 is that a short circuit on a lateral distributor causes its appropriate fuse to blow. The event causes disconnection of its load point until the failure is repaired. However, it does not affect or cause the disconnection of any other load points.

A second or alternative reinforcement or improvement scheme is the provision of disconnecting switches or isolators at judicious points along the main feeder. These are generally not fault-breaking switches and therefore any short circuit on a feeder still causes the main breaker to operate. After the fault has been detected, however, the relevant disconnect can be opened and the breaker reclosed. This procedure allows restoration of all load points between the supply point and the point of isolation before the repair process has been completed. Whether these devices are used on the system or not have great effect on the system. A

lateral fuse is responsible for the permanent fault that occurs in part of the lateral feeder.

III. EVALUATION METHODS

3.1. Reliability Indices

A distribution system is one of the main three parts of a power system, responsible for transferring electrical energy to the end users compared with generation and transmission parts. However, analysis of the customer failure statistics of most utilities indicates that the distribution system makes the greatest individual contribution to the unavailability of supply to a customer [3].

In order to reflect the severity or significance of system outages, customer indices are evaluated [1]. In this paper, system average interruption frequency index (SAIFI), system average interruption duration index (SAIDI), customer average interruption duration index (CAIDI), energy not supplied index (ENS) will be considered to analyze the impact of protection system on reliability indices. The equations of additional indices which are used in this paper are as follows [1]:

$$\begin{aligned} \text{SAIFI} &= \frac{\text{total number of customer interruptions}}{\text{total number of customer served}} \\ &= \frac{\sum \lambda_i N_i}{\sum N_i} \text{ f/customer/yr} \end{aligned} \quad (1)$$

$$\begin{aligned} \text{SAIDI} &= \frac{\text{sum of customer interruption duration}}{\text{total number of customer}} \\ &= \frac{\sum U_i N_i}{\sum N_i} \text{ hr/customer/ye} \end{aligned} \quad (2)$$

$$\begin{aligned} \text{CAIDI} &= \frac{\text{sum of customer interruption duration}}{\text{total number of customer interruptions}} \\ &= \frac{\sum U_i N_i}{\lambda_i N_i} \text{ hr/customer/year} \end{aligned} \quad (3)$$

$$\text{ENS} = \sum L_{a(i)} U_i \text{ MWh/yr} \quad (4)$$

$$\text{AENS} = \sum \frac{L_{a(i)} U_i}{N_i} \text{ MWh/yr} \quad (5)$$

Where $L_{a(i)}$ is average load demand at load point i and U_i is outage time at load point i . Reliability indices are useful for determining what a customer can expect in terms of interruption frequencies and durations [4]. Reliability indices are typically computed by utilities at the end of each year by using historical outage data recorded in distribution outage reports. This is important so that utilities know how their systems are performing, but is less useful when the specific impact of various design improvement options wish

to be quantified and compared. To make such comparisons, a model must be developed which is capable of predicting reliability measures based on system topology, component reliability data, and operational data [4].

3.2. Fault Calculation

A three-phase fault is only considered in this paper. Other type of fault can also be calculated based on prospered methodology. The fault currents and voltages are calculated using bus impedance matrix Z_{bus} , which is based on the principle of superposition. The detail calculation and the equation can be seen in [5].

$$V_i(F) = V_i(0) - \frac{Z_{ik}}{Z_{kk} + Z_f} V_k(0) \quad (6)$$

Where $V_i(F)$ is bus voltage at bus i during fault, $V_i(0)$ is pre-fault bus voltage, $V_k(0)$ is bus voltage at fault bus k and Z is impedance from Z_{bus} . With the knowledge of bus voltage during the fault, the fault current in all the lines can also be calculated.

IV. TEST SYSTEM

The test system used in this paper is the Bus 2 of the RBTS as described in [2]. This system consists of four 11-kV feeders (F1-F4) fed from a distribution substation and serves 22 load points (LP1-22). The peak load levels is 20 MW FI and F2 are operated in a looped configuration as are feeders F3 and F4.

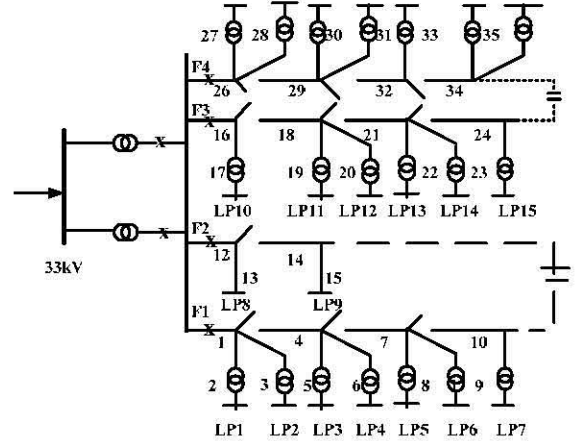


Fig. 2 Distribution system for RBTS bus 2

The test system topology is shown in Fig. 2 [6]. The data for feeder length and customer types, number and load data are taken from [2]. The single 11 KV supply point for the bus 2 distribution network is justified by the 20 MW load on this network. The feeders are operated as radial feeders although they are connected as a mesh through normally open sectionalizing points. There are 36 feeder sections in the test system. For calculation of indices, the failure of breaker can be neglected because its value is so small.

In this analysis, the fuse gear and disconnecting switches in the feeder are assumed to be 100% reliable. Component

reliability data for RBTS distribution system are taken from [2] and [6]. Due to limitation of the space, this analysis only considered the 11kV feeders, and ignores any failure in the 33kV system, the 33/11kV substation and the 11kV breakers. It is also assumed the 11kV source breaker operates successfully when required, disconnects are open whenever possible to isolate a fault.

Note: Lines and Cables failure rates are in f/yr-km. Where LT is lateral transformer, λ_m is momentary failure rate (f/yr), λ_a is active failure rate (f/yr), r is repair time(hr), r_p is replacement time of transformer and s is switching time (hr). For fault calculation, the impedance of lines are assumed.

V. TEST RESULTS

5.1. Impact on Reliability Indices

The tests are conducted for three cases, i.e. case A, B and C as in Table. Figure.3 shows the comparison of energy not supply for case case. According to Table 1, the values of SAIFI, SAIDI, CAIDI and ENS can be compared to decide which case are the best and the worst or which case is better one than another. SAIDI is the main factor to decide reliability of the system. The amount of energy not supply is depended on SAIDI.

The impact of disconnecting switches and fuses on reliability of the system can be seen for each case.

It can also be found that case C with full option of protective devices provides the best. Case A is that if the system has no protective devices, it will result in the worst reliability, as we may consider from highest energy not supply and other indices. The amount of energy not supply in case C is 41.1905 MWhr per yr and the amount of energy not supply in case A is 231.2879 MWhr per year. It can be seen clearly that the impacted amount of energy not supply using protective devices is 193. 5104 MWhr per year. Fig. 4 shows the comparison of energy not supply for three cases.

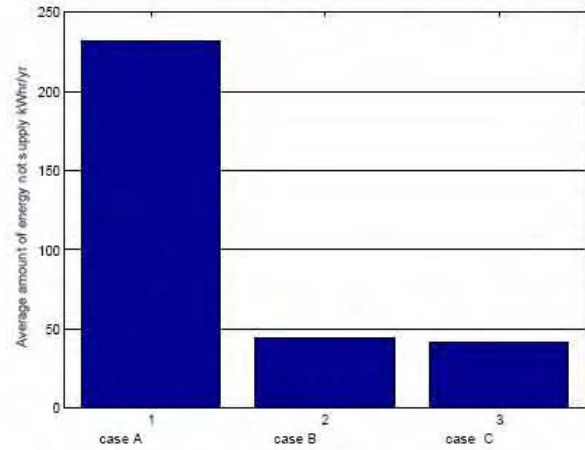


Fig.3. Comparison of energy not supply

TABLE I
COMPARISON OF CUSTOMER INDICES AND ENERGY-ORIENTED INDICES

	SAIFI	SAIDI	CAIDI	ENS	AENS
Feeder No.	Case (A) :no protective device				
1	0.6260	23.6020	37.7029	86.0293	0.1319
2	0.1917	0.96070	5.0104	2.0656	1.0328
3	0.5590	20.3420	36.3900	63.1823	0.1000
4	0.6260	23.6020	37.7029	80.0108	0.1286
System Total	0.6034	22.4984	37.2891	231.2879	0.1212
Feeder No.	Case (B) : with fuses				
1	0.2481	4.1654	16.7973	15.1827	0.0233
2	0.1397	0.6987	5.0000	1.5023	0.7512
3	0.2501	4.1754	16.7019	12.9688	0.0205
4	0.2509	4.1236	16.4448	13.9789	0.0225
System Total	0.2495	4.1514	16.6368	43.6328	0.0229
Feeder	Case (C) : fuse-recloser coordination				
1	0.1979	3.9146	20.5878	14.2689	0.0219
2	0.1203	0.6013	5.0000	1.2927	0.6463
3	0.2062	3.9560	21.0108	12.2875	0.0194
4	0.2133	3.9355	19.1610	13.3415	0.0214
Total	0.2056	3.9317	19.1245	41.1905	0.0216

5.2. Impact of Fuse's operation on Voltage Dip

When a fault occurs, the voltage dip will be back to 1 pu using fuses and recloser after total clearing time. But if the customer cannot tolerant the amount of voltage dip and duration, it will be cut off from the system. The voltage dip of each load points can be compared with voltage envelope curve. If the dip violates the envelope curve, the customer will be cut off from the system. Test system is shown in Fig 4.

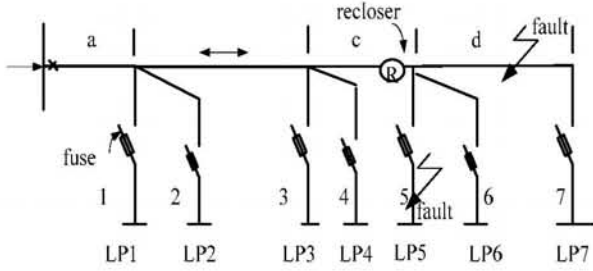


Fig. 4 Test system for voltage dips study

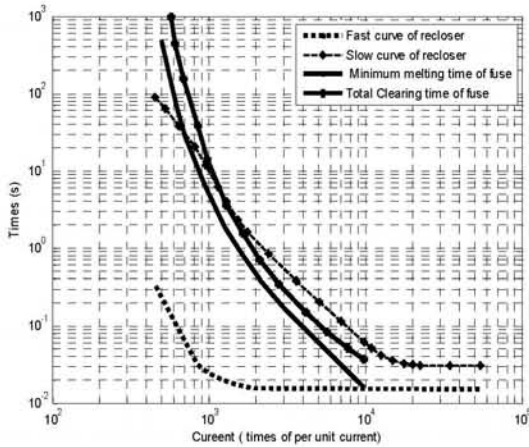


Fig. 5 Time-current characteristic of the system

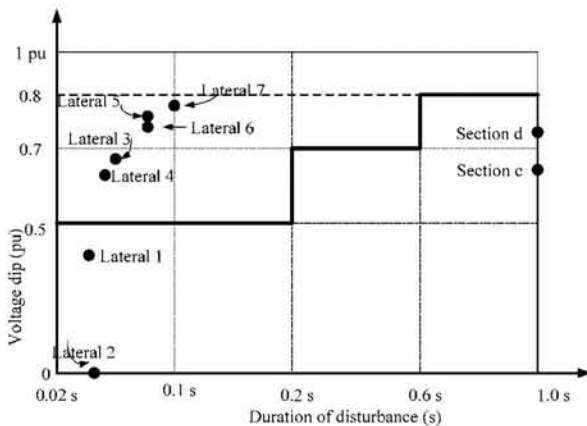


Fig. 6. Plot of voltage dip on the envelop curve

Using fault calculation method, the voltage and current during faults can be calculated. The fault current have to be compared with Time-current characteristic curve of the system of Fig. 5. And then, according to the fault clearing time, the dip or sag duration can be calculated. After that, the magnitude and duration of voltage dip have to be plotted on the enveloped curve. Fig. 6 shows the voltage dip characteristic of voltage dip at load point 2 for different fault location.

In general, when a fault occurs a lateral 1, the fuse on this lateral will be trip out it from the system and there will be no impact on load point 2. But, if the impact of voltage dip is considered, the load point 2 cannot tolerate the voltage dip due to fault at lateral 1. Therefore, even though some protective devices are used, the voltage dip due to fault at any location can still impact on other location and load points. As the difference cases, impact of voltage dip for different fault location. Table II shows the final results for comparison of system and energy-oriented indices of the test system. The detail consideration for load point 2 is shown in table 3. The impedance of transformers is enough large. Therefore, even though the faults occur at transformers, it cannot impact to other load points and locations.

TABLE II
COMPARISON OF SYSTEM AND ENERGY-ORIENTED INDICES

Indices	No protective device	Using fuse recloser coordination	Using fuse-recloser with consideration of voltage dip impact
SAIFI	0.6260	0.1605	0.3736
(SAIDI	23.6020	4.2911	4.7930
CAIDI ENS	37.7029	26.738	12.83
AENS	86.0293	15.64	17.47
	131.9	24	26.8

VI. CONCLUSION

This paper describes the impact of protective devices on reliability indices of the distribution system. We can also focus clearly the difference amount of energy not supply to the system impacted from using protective devices. Moreover, the impact of fuses on voltage dip is also presented for each load points. The test results show that it is important to take into account of using protective devices in the distribution system. MatLab is used as a tool to solve the problems in this paper.

VII. ACKNOWLEDGEMENT

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Ohn Zin Lin is now currently pursuing the Master degree at Chulalongkorn University of Bangkok, Thailand. His interested research topic is " Power system reliability".



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TABLE III
IMPACT OF VOLTAGE ON LOAD POINT 2 (FUSE-RECLOSER COORDINATION)

Faulted location	Without consideration of voltage dip impact			With consideration of voltage dip impact							
	λ (failure/yr)	r (hr/yr)	μ (hr/failure)	Voltage Level (pu)	Total Fault Current (pu)	Total Fault Crt (A)	Dip Time (s)	Vtg dip	λ (failure/yr)	r (hr/yr)	μ (hr/failure)
section a	0.0488	5	0.244	0.0000	10.8046	24556	-	-	0.0488	5	0.2440
section b	0.0488	5	0.244	0.5000	5.4023	12278	-	-	0.0488	5	0.2440
section c	0	0	0	0.6667	3.6015	8185.2	1	yes	0.0488	5	0.2440
section d	0	0	0	0.7368	2.8433	6462	1	yes	0.0390	5	0.1950
lateral 1	0	0	0	0.4444	6.0025	13642	0.03	Yes	0.0390	5	0.1950
LT	0	0	0	0.9875	0.2141	486.59	-	No	0	-	-
lateral 2	0.0520	5	0.260	0.0000	5.2280	11882	0.035	-	0.0520	5	0.2600
LT	0.0150	200	3	0.0000	0.2134	485	-	-	0.0150	200	3
lateral 3	0	0	0	0.6739	3.5232	8007.3	0.05	No	0	-	-
LT	0	0	0	0.9874	0.2107	478.86	-	No	0	-	-
lateral 4	0	0	0	0.6429	3.8588	8770	0.04	No	0	-	-
LT	0	0	0	0.9875	0.2114	480.45	0	No	0	-	-
lateral 5	0	0	0	0.7541	2.6569	6038.4	0.08	No	0	-	-
LT	0	0	0	0.9874	0.2081	472.95	0	No	0	-	-
lateral 6	0	0	0	0.7500	2.7011	6138.9	0.075	No	0	-	-
LT	0	0	0	0.9874	0.2083	473.41	0	No	0	-	-
lateral 7	0	0	0	0.7945	2.2201	5045.7	0.1	No	0	-	-
LT	0	0	0	0.9873	0.2060	468.18	0	No	0	-	-
Total	0.165	22.72	3.75						0.2914	15.038	4.382