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A Study on the Reliability of the Distribution Automation System for the Lightning Effect

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Abstract

In today's competitive power market, electric power utilities have strived to provide energy at an acceptable level of quality due to increased expectations from customers. For this reason, electric power utilities have invested in electric equipment and new techniques. That is the Distribution Automation System (DAS). A merit of DAS is the ability to reduce outage time because of fast service restoration. However, DAS is usually installed in outdoor environments. Therefore, their efficiency is affected by the external conditions. Lightning creates varying degrees of physical stress on DAS. This paper focuses on the reliability of DAS for lightning. Four application studies were performed to compare the reliability indices.

Key Words : Distribution Automation System (DAS), Lightning, Reliability Indices

1. Introduction

Nowadays electric power utilities have strived to provide a highly reliable power supply to customers at the lowest possible cost. Electric power utilities have invested in electric equipment and new techniques. The result is the Distribution Automation System (DAS). DAS is acknowledged as a method for using appreciated technology at reduced system outage time. Automated operation and service restoration can eliminate the need to switch operations manually and could have a significant effect on the system reliability [1]. As a general rule, DAS exists in outdoor environments. Therefore, performance is affected by the external conditions. External conditions such as lightning, snow, ice, high winds etc. can significantly increase the failure rates of components and system outage time. In this paper, lightning from various conditions is considered. Lightning creates a diversity of physical strain on DAS and is one of the major factors affecting the reliability of distribution systems.

DAS consists of the control center, communication unit, remote terminal unit and automated switches. Communication units configured by DAS are important to the efficiency of DAS. The units are between the control center and the remote control units and can deliver instructions from the control center. It is the communication unit that makes it possible to implement the

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desired control functions. However, it is easily damaged by lightning [2]. In case 3, the variation of the reliability indices that monitor the degree of damage of the communication unit due to lightning are identified.

The failure rate of components on the distribution system is affected by lightning [3-7]. From a reliability point of view, the failure rate of the components increases. In case 4, the degradation of the reliability indices are presented.

The purpose of the paper is to confirm the reliability of DAS with regard to lightning. Comparative studies are used to evaluate the reliability of DAS. In this paper, four application studies are presented.

2. Distribution System Reliability

Conventionally, a radial distribution system consists of a set of series components including a circuit breaker, section switch, transformer, overhead line, fuse and normally open switch. The duration and frequency of sustained interruption is used with a statical coefficient for reliability on the distribution system.

2.1 Basic parameters of Distribution System Indices [8, 9]

For the reliability evaluation of a distribution system, we should know three basic reliability parameters. They are as follows:

$$\lambda_s = \sum_j \lambda_j \qquad (1)$$

$$U_s = \sum_j \lambda_j r_j \qquad (2)$$

$$r_s = \frac{U_s}{\lambda_s} = \frac{\sum_j \lambda_j r_j}{\sum_j \lambda_j} \qquad (3)$$

where,

s : series system

j : load point

λ_s : average failure rate

U_s : average annual outage time

r_s : average outage time

Even through the three basic indices are fundamentally important, these indices are not deterministic values for system behavior and response.

2.2 Customer- and Energy-oriented indices [8, 9]

In order to reflect the significance of a system outage, additional reliability indices can be evaluated. The additional indices commonly used are classified below.

(1) System Average Interruption Frequency Index, SAIFI

$$SAIFI = \frac{\sum \lambda_j N_j}{\sum N_j} \qquad (4)$$

(2) System Average Interruption Duration Index, SAIDI

$$SAIDI = \frac{\sum U_j N_j}{\sum N_j} \qquad (5)$$

(3) Customer Average Interruption Duration Index, CAIDI

$$CAIDI = \frac{\sum U_j N_j}{\sum \lambda_j N_j} \qquad (6)$$

(4) Average Service Availability Index, ASAI

$$ASAI = \frac{\sum N_j \times 8760 - \sum U_j N_j}{\sum N_j \times 8760} \quad (7)$$

(5) Energy not Supplied Index, ENS

$$ENS = \sum L_{a(j)} U_j \quad (8)$$

where,

N_j : the number of customers of load point j

$L_{a(j)}$: the average load connected to load point j

3. Reliability Assessment of Distribution Automation System for Lightning

Fig. 1 is shown the overall reliability evaluation in this paper. First of all, the reliability assessment is divided into whether DAS is installed or not. Case 1 has been calculated for instances in which DAS is not installed. Case 2 assumes that DAS is installed but lightning does not affect it. Secondly, whether or not lightning will have an effect or not is considered. If DAS is installed and lightning will affect it, we considered two viewpoints. Case 3 was performed considering system outage time. Case 4 studies the failure rate of components. To compare the reliability of DAS for lightning, basic studies (Case 1 and Case 2) have been conducted. The test system is the distribution system to bus 2 of the RBTS [10]. It is four feeders and consists of 22 load points. However, in this paper, feeder 1 and 2 are the only ones considered. The required reliability data are given [10]. Additional reliability data are acquired [3-7]. These studies consider only the 11[kV] feeders and ignore any failure in the 33[kV] system and the 33/11[kV] substation. But these studies also reflect the failure rate of the breaker, section switch and transformer in 11[kV] by contrast to Ref. 10.

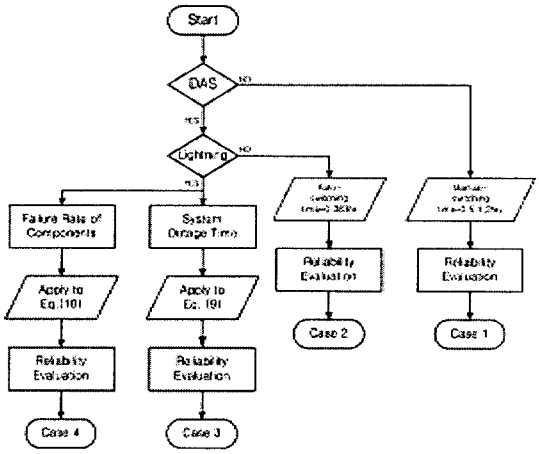

Fig. 1. Flowchart of Reliability Evaluation

4. Case Study

In this chapter, I performed the case study. Table 1 is a brief description of the four case studies.

Table 1. Description of case study

Case	Description
1	Reliability evaluation of non-DAS
2	Reliability evaluation of DAS
3	Compare performance of communication unit on DAS for lightning
4	Compare failure rate of each component on DAS for lightning

4.1 Basic Study

4.1.1 Reliability evaluation of distribution system without DAS

Fig. 2 shows a general power distribution system without automation. The reliability calculations have been performed for the non DAS. In the non DAS, a crew should be sent out after the fault occurs so that switching operations

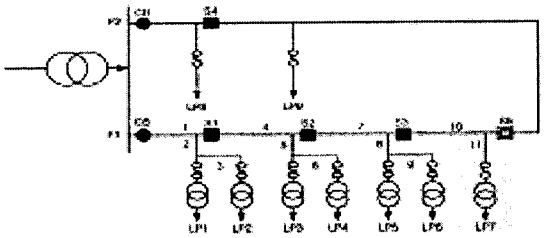

Fig. 2. Non-Distribution Automation System can occur. This is assumed to take (a) 0.5 hour, (b) 1 hour and (c) 2 hours. The results of the reliability assessment for non DAS are shown in Tables 2, 3, and 4

Table 2. Load point and system reliability indices for case 1-(a) 0.5 hour

Load Point	(f/yr)	r(h)	U(h/yr)
1	0.341	1.46	0.50
2	0.354	1.44	0.51
3	0.354	1.44	0.51
4	0.341	1.46	0.50
5	0.354	1.44	0.51
6	0.351	1.45	0.51
7	0.354	1.43	0.50
8	0.178	1.35	0.24
9	0.178	1.32	0.23

SAIFI	SAIDI	CAIDI	ASAI	Total ENS
0.350	0.505	1.446	0.99994	2350.42

Units: SAIFI-interruptions/customer.yr,
SAIDI-h/customer.yr
CAIDI-h/customer interruption
ENS-kWh/yr

Table 3. Load point and system reliability indices for case 1-(b) 1 hour

Load Point	(f/yr)	r(h)	U(h/yr)
1	0.341	1.66	0.57
2	0.354	1.63	0.58
3	0.354	1.63	0.58
4	0.341	1.66	0.57
5	0.354	1.63	0.58
6	0.351	1.64	0.57
7	0.354	1.63	0.58
8	0.178	1.46	0.26
9	0.178	1.46	0.26

SAIFI	SAIDI	CAIDI	ASAI	Total ENS
0.350	0.505	1.446	0.99994	2648.94

Units: SAIFI-interruptions/customer.yr,
SAIDI-h/customer.yr
CAIDI-h/customer interruption
ENS-kWh/yr

Table 4. Load point and system reliability indices for case 1-(c) 2 hours

Load Point	(f/yr)	r(h)	U(h/yr)
1	0.341	2.06	0.70
2	0.354	2.02	0.71
3	0.354	2.02	0.71
4	0.341	2.06	0.70
5	0.354	2.02	0.71
6	0.351	2.03	0.71
7	0.354	2.05	0.72
8	0.178	1.68	0.30
9	0.178	1.73	0.31

SAIFI	SAIDI	CAIDI	ASAI	Total ENS
0.350	0.505	1.446	0.99994	3245.97

Units: SAIFI-interruptions/customer.yr,
SAIDI-h/customer.yr
CAIDI-h/customer interruption
ENS-kWh/yr

Fig. 3 shows the SAIDI index of Case 1. From the comparative analysis, it can be observed that reliability deteriorates if repair time is increased.

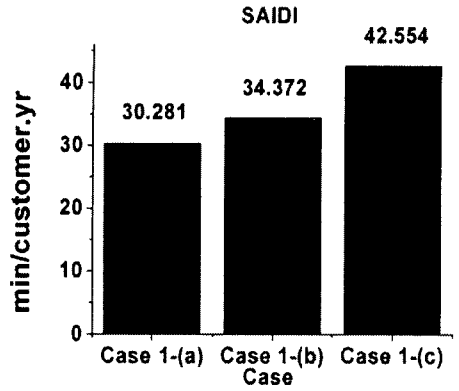

Fig. 3. Comparative analysis of case 1-(a), (b) and (c)

4.1.2 Reliability evaluation of distribution system with DAS

The reliability calculations have been performed for DAS. Fig. 4 shows the small DAS. The required reliability data are given [6, 10]. This assumes that the system could be re-configured within 5 minutes after the fault occurs.

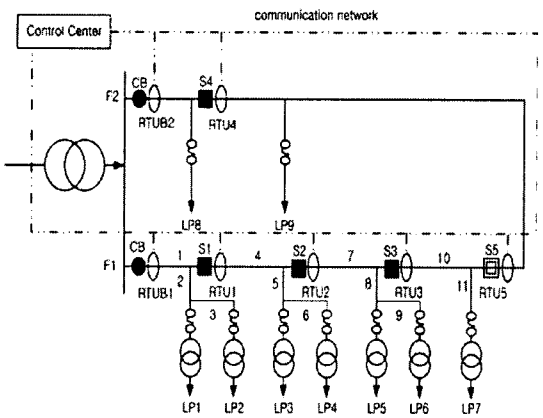

Fig. 4. Small Distribution Automation System

Table 5 shows the reliability indices of DAS. From the basic studies, it can be observed that reliability is improved. The system outage time is decreased by DAS. The results indicate that the system outage duration of SAIDI increases 19[%].

Table 5. Load point and system reliability indices for Case 2

Load Point	(f/yr)	r(h)	U(h/yr)
1	0.341	1.22	0.42
2	0.354	1.21	0.43
3	0.354	1.21	0.43
4	0.341	1.22	0.42
5	0.354	1.21	0.43
6	0.351	1.22	0.43
7	0.354	1.19	0.42
8	0.178	0.6	0.11
9	0.178	0.55	0.10

SAIFI	SAIDI	CAIDI	ASAI	Total ENS
0.350	0.505	1.446	0.99994	1765.39

Units: SAIFI-interruptions/customer.yr,
SAIDI-h/customer.yr
CAIDI-h/customer interruption
ENS-kWh/yr

4.2 Reliability indices of Distribution Automation System affected by lightning

The reliability of DAS for lightning is evaluated from two viewpoints. The first is system outage time, and the second consideration is the failure rate of components. In the same manner as basic studies, the reliability indices are evaluated using bus 2 of the RBTS [10]. Also, the assumption remains the same as that of the previous section.

4.2.1 Compare to the performance of communication unit on DAS for lightning

The communication unit on DAS is subject to possible failures due to lightning [2]. When the communication unit fails, the control center can't communicate with the RTUs. The service restoration should be implemented manually, and

this will increase the system outage time.

In this paper, the conditional probability approach can be used to evaluate the lightning failure event. If the communication unit fails due to lightning, the interrupted load points can be reconnected until the faulted section has been isolated manually. This means that the outage time "r" associated with a lightning failure event is the same as the manual switching time. When the communication unit is successful during a lightning event, the load points in the faulted section are interrupted for the proper automatic switching time. The conditional probability of outage time is:

$$\begin{aligned} r &= \{\{auto\text{-}switching\ time | communication\ success\ in\ lightning\}\} \\ &\quad \times P(communication\ success\ in\ lightning) \\ &\quad + \{\{manual\text{-}switching\ time | communication\ success\ in\ lightning\}\} \\ &\quad \times P(communication\ failure\ in\ lightning) \\ &= t_a(1-F_{CU}) + t_m F_{CU} \qquad (9) \end{aligned}$$

where, t_a : *auto-switching time*

t_m : *manual-switching time*

F_{CU} : *failure probability of communication due to lightning*

Reliability evaluations have been performed that consider eleven steps on ten percentages (0-100[%]) on the performance of the communication unit due to lightning. These assume that auto-switching time is 0.083hr and manual-switching time is 0.5 hr. The result of 0[%] is the same as in Case 2. The results of the reliability evaluation are shown in Table 6. It can be observed that the reliability indices are degraded when the failure probability of the communication unit for lightning increases. Figures 5 and 6 also present the reduction of reliability indices.

Table 6. Load point and system reliability indices for Case 3

Fcu([%])	SAIDI	CAIDI	ASUI
0	0.424	1.215	0.000048
10	0.430	1.232	0.000049
20	0.436	1.249	0.000050
30	0.442	1.266	0.000050
40	0.448	1.283	0.000051
50	0.454	1.30	0.000052
60	0.460	1.317	0.000052
70	0.466	1.334	0.000053
80	0.472	1.351	0.000054
90	0.477	1.368	0.000055
100	0.483	1.385	0.000056
Units: SAIDI-h/customer.yr CAIDI-h/customer interruption			

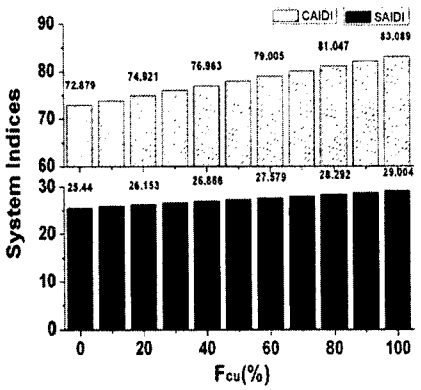

Fig. 5. SAIDI and CAIDI indices of Case 3 (SAIDI-min/customer.yr, CAIDI-min/customer interruption)

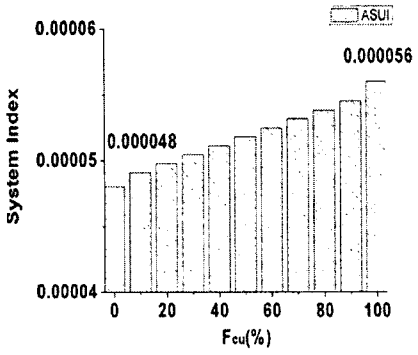

Fig. 6 ASUI index of Case 3

4.2.2 Compare failure rate of each component on DAS due to lightning

In failure of the components of the distribution system, lightning is one part [6]. Lightning affects both the failure rate of the components on DAS as well as the system outage time. Table 7 shows the probability of failure caused by lightning [3-7].

Table 7. Probability of failure caused by lightning

Components	Percentage ([%])
Breaker	44
Switch	3
Transformer	4.4
Line	39.8

The failure rate of components on the distribution system increases due to lightning. In this paper, the method to evaluate lightning's impact on the failure rate of DAS components is to compare the original reliability of DAS with the reliability of DAS for lightning. The expectation value of the failure rate of components is affected by lightning as follows:

Using equation 10, reliable evaluations of DAS for lightning have been performed. This assumes that the auto-switching time is 0.083hr.

The results are shown in Table 8. It can be observed from Table 5 and 8 that the reliability indices are degraded. The SAIFI, SAIDI and AENS increase 33.5[%], 12.4[%] and 15.6[%], respectively. The CAIDI decreases 15.8[%]. Fig. 7 shows that reliability degradation of DAS is affected by lightning.

Table 8. Load point and system reliability indices for Case 4

Load Point	(f/yr)	r(h)	U(h/yr)
1	0.454	1.02	0.47
2	0.473	1.02	0.48
3	0.473	1.02	0.48
4	0.454	1.02	0.47
5	0.473	1.02	0.48
6	0.468	1.02	0.48
7	0.473	0.99	0.47
8	0.243	0.61	0.15
9	0.243	0.56	0.14

SAIFI	SAIDI	CAIDI	ASAI	Total ENS
0.350	0.505	1.446	0.99994	2042.05

Units: SAIFI-interruptions/customer.yr,
SAIDI-h/customer.yr
CAIDI-h/customer interruption
ENS-kWh/yr

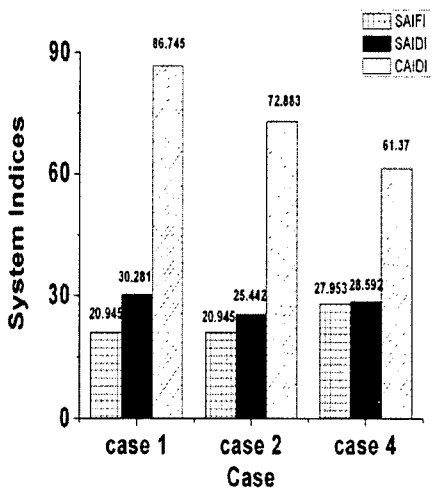

Fig. 7. Comparative studies of Case 1, Case 2 and Case 4

$$\lambda_l = \lambda_o + \lambda_m \qquad (10)$$

where, λ_l *: the failure rate of component is affected by lightning*

λ_o *: origined failure rate of component*

λ_m *: the failure rate associated with failure mode due to lightning*

5. Conclusion

In this paper, we have evaluated the reliability of the distribution system with automation for lightning. Previous studies have not performed reliability of distribution system with automation for lightning.

To compare the reliability, basic studies (Cases 1 and 2) were conducted. The reliability indices for a general power distribution system without automation and with automation are identified in Cases 1 and 2. This paper has evaluated the reliability of DAS for the impact of lightning. The reliability of DAS for lightning is evaluated from two viewpoints which are system outage time (Case 3) and the failure rate of components (Case 4). It can be observed that the reliability of DAS is affected by lightning via the case studies. The results easily show that the reliability degradation of DAS is affected by lightning. We have performed the reliability evaluation for the modified RBTS model. In the next study, we will be able to assess the reliability of a practical distribution system and DAS model.

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