FAILURE CAUSES OF DISTRIBUTION NETWORK COMPONENTS

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ABSTRACT

Failures of network components could significantly affect the reliability of power systems. Component failures are caused by different factors. Analysis of the failure causes has a practical value since the knowledge of failure causes could help power utilities to take remedial actions and determine appropriate method for failure reduction. To understand the causes of component failures an extensive cause analysis was carried out in a project recently performed at the power company, Vattenfall Distribution in Sweden. The project studied a large amount of network component failures recorded by the company during the latest five-years' period. The project analyzed the fault characteristics and root causes for different component categories. The results of the analysis are presented and discussed in the paper.

INTRODUCTION

A distribution system consists of network components. Failures of the components can lead to a system failure. The component outages are the root cause of customer power interruptions. Power outages in distribution systems could significantly affect the reliability of the systems.

Analysis of reliability performance of distribution systems over the past years related to outages caused by different component failures is very useful for power utilities. To increase distribution reliability it is necessary to understand the causes of outages. Knowing the cause of an outage can help to reduce the number of outages. Significant rise from the trend in outages caused by a specific factor would help the utility to take remedial actions. For example, if lightning is a major cause of outages, then lightning arresters can be installed. Tracking outage causes allows power utilities to correct a known problem.

In order to understand the major causes and influencing factors behind the component failures, an extensive cause analysis was carried out at the power company, Vattenfall in Sweden. The project studied 10710 network component failures that caused customer outages longer than 6 hours at Vattenfall distribution systems in Sweden during the latest five-years' period.

The company records the outages together with the associated details. The outage database covers all system voltages. The data identify the major distribution equipment categories, including distribution lines and cables, transformers, fuse boxes, apparatus cabinets, and stations. The cause of component failures has been an important issue in the outage reporting. Component forced outages are classified by 6 primary causes in the data collection system of the company, which may be divided further into several sub-causes.

The primary causes include:

- Weather related;
- External influences;
- Material defect;
- Technique related;
- Dimensioning failure;
- Operation and people related.

The weather related outages include interruptions due directly to a weather phenomenon, and the weather related sub-causes include snow, tree falls, wind, ice, thunder and rain. The sub-causes for external influence related outages include environment related, animal, digging, sabotage, salt and traffic. Lack of maintenance, overloading, improper method, improper montage and faulted operation are sub-causes for operation and people related outages.

The causes of component failures were studied and analyzed for each component category at low voltage, medium voltage and high voltage levels. In the following sections the results of the analysis are presented.

FAILURE CAUSES OF LV EQUIPMENT

The cause analyses of low voltage distribution equipment rely on the failure records on the LV networks during the period from 2004 to 2008. In the analysis each component failure event recorded was taken into consideration and sorted according to causes of failures. The contributions of the primary causes and sub-causes to the failures of each component category are then calculated. The results of the calculations are presented in the following subsections.

Overhead lines

Overhead distribution lines constitute a large part of distribution grids. This type of equipment is directly exposed to weather, vegetation, and animals. It typically has failure rates that are higher than corresponding underground cables. Major failures on overhead distribution lines are normally due to environment and weather they are exposed to. Outage causes of overhead lines are studied for the line categories of bare conductor line, insulated line and aerial cables.

Tables 1, 2 and 3 summarize the results of the analysis and show the division of faults by causes on overhead lines. It is clear seen in the figures that the dominant causes of the customer interruptions resulting from overhead line failures are weather and environment related.

As indicated by Table 1, over 70% failures on bare conductor overhead lines were caused by tree falls due to wind. The cause analysis for insulated lines and overhead aerial cables confirm that the dominant failure causes are

also related to weather and environment, as shown in Tables 2 and 3.

Table 1 The causes of LV bare conductor line failures that caused long duration customer outages over 6 hours during 2004-2008.

Failure cause	Number of failures	Percentage (%)
Tree fall, wind	1436	72,4
Wind	205	10,3
Tree fall, snow	149	7,5
Thunderstrom	88	4,4
Snow, ice load	35	1,8
Material failure	22	1,1
Traffic	9	0,5
Animal	8	0,4
Tree felling	7	0,4
Fuse blow	3	0,2
Lack of maintenance	1	0,1
Dig in	5	0,3
Wrong montage	2	0,1
Sabotage	3	0,2
Unkown	6	0,3
Other	4	0,2
Total	1983	100,0

Table 2 The causes of LV insulated line failures that caused long duration customer outages over 6 hours during 2004-2008.

Failure cause	Number of failures	Percentage (%)
Tree fall, wind	44	57,1
Wind	4	5,2
Tree fall, snow	6	7,8
Thunderstrom	2	2,6
Snow, ice load	1	1,3
Material failure	9	11,7
Traffic	0	0,0
Animal	1	1,3
Tree felling	2	2,6
Fuse blow	2	2,6
Lack of maintenance	2	2,6
Dig in	0	0,0
Wrong montage	0	0,0
Sabotage	1	1,3
Unkown	3	3,9
Other	0	0,0
Total	77	100,0

Table 3 The causes of LV overhead aerial cable failures that caused long duration customer outages over 6 hours during 2004-2008.

Failure cause	Number of failures	Percentage (%)
Tree fall, wind	1157	80,5
Wind	37	2,6
Tree fall, snow	71	4,9
Thunderstrom	8	0,6
Snow, ice load	0	0,0
Material failure	89	6,2
Traffic	29	2,0
Animal	2	0,1
Tree felling	11	0,8
Fuse blow	3	0,2
Lack of maintenance	3	0,2
Dig in	9	0,6
Wrong montage	3	0,2
Sabotage	2	0,1
Unkown	10	0,7
Other	3	0,2
Total	1437	100,0

Underground cables

Table 4 presents the results of cable failure analysis. It is noted that underground cables have much less weather related faults compared with overhead lines.

Table 4 The causes of LV underground cable failures that caused long duration customer outages over 6 hours during 2004-2008.

Failure cause	Number of failures	Percentage (%)
Tree fall, wind	145	12,4
Wind	11	0,9
Tree fall, snow	15	1,3
Thunderstrom	12	1,0
Snow, ice load	11	0,9
Material failure	654	55,8
Traffic	30	2,6
Animal	2	0,2
Tree felling	2	0,2
Fuse blow	11	0,9
Lack of maintenance	3	0,3
Dig in	180	15,4
Wrong montage	16	1,4
Sabotage	4	0,3
Unkown	57	4,9
Other	19	1,6
Total	1172	100,0

The analysis indicates that main causes of underground cable failures are due to deterioration from age and excavation. The five-year's average value shows that the aging-related faults are at much higher level than the faults caused by excavation. It is observed that relatively high percentage of LV underground cable failures were caused by tree fall in bad weather. This was due to the faults on cable parts above ground in conjunction with the overhead lines on underground and overhead mixed networks.

Fuse and apparatus boxes

Table 5 summarizes the results of failure event studies on fuse and apparatus boxes. It reveals that approximate 27% failures during the period were initiated by weather and about 25% faults were related to aging and material defects.

Table 5 The causes of LV fuse and apparatus box failures that caused long duration customer outages over 6 hours during 2004-2008.

Failure cause	Number of failures	Percentage (%)
Tree fall, wind	121	27,4
Wind	9	2,0
Tree fall, snow	21	4,8
Thunderstrom	19	4,3
Snow, ice load	13	2,9
Material failure	110	24,9
Traffic	2	0,5
Animal	1	0,2
Tree felling	2	0,5
Fuse blow	56	12,7
Lack of maintenance	8	1,8
Dig in	5	1,1
Wrong montage	13	2,9
Sabotage	0	0,0
Unkown	33	7,5
Other	28	6,3
Total	441	100,0

FAILURE CAUSES OF MV EQUIPMENT

Failure cause analyses for MV components were performed in the similar manner as for LV equipment. During 2004-2008 about 5400 long duration customer outages (over 6 hours) occurred due to failures on MV equipment. Based on the fault records the contributions of the dominant causes to the failures of major categories of distribution equipment were analysed. The following subsections present the results of failure distributions over different causes.

Overhead lines

Tables 6 and 7 present the results of failure cause analysis for MV overhead lines. The calculations confirm that the major causes of MV overhead equipment were weather and environment related. The most of faults were occurred during bad weather. A comparison of the cause distributions shown in these two tables reveals the similar major causes for both line categories, however tree fall due to wind was a more significant cause for insulated line failures than for bare conductor line failures.

Table 6 The causes of MV bare conductor line failures that caused customer outages over 6 hours during 2004-2008.

Failure cause	Number of failures	Percentage (%)
Tree fall, wind	2205	59,8
Wind	322	8,7
Tree fall, snow	476	12,9
Thunderstrom	321	8,7
Snow, ice load	100	2,7
Material failure	175	4,7
Traffic	10	0,3
Animal	27	0,7
Tree felling	7	0,2
Fuse blow	1	0,0
Lack of maintenance	9	0,2
Dig in	2	0,1
Wrong montage	3	0,1
Unkown	18	0,5
Other	11	0,3
Total	3687	100,0

Table 7 The causes of MV insulated line failures that caused customer outages over 6 hours during 2004-2008.

Failure cause	Number of failures	Percentage (%)
Tree fall, wind	192	83,1
Wind	4	1,7
Tree fall, snow	21	9,1
Thunderstrom	4	1,7
Snow, ice load	0	0,0
Material failure	6	2,6
Traffic	1	0,4
Animal	1	0,4
Tree felling	1	0,4
Fuse blow	0	0,0
Lack of maintenance	1	0,4
Other	0	0,0
Total	231	100,0

Underground cables

Table 8 presents the results of cause analysis on underground cables. It is noted that MV underground cables have much less percentage of weather related faults compared with MV overhead lines. The factors that cause

the cable failures are mainly material defects and digging.

Table 8 The causes of MV underground cable failures that caused customer outages over 6 hours during 2004-2008.

Failure cause	Number of failures	Percentage (%)
Tree fall, wind	37	7,3
Wind	2	0,4
Tree fall, snow	10	2,0
Thunderstrom	14	2,8
Snow, ice load	2	0,4
Material failure	321	63,1
Traffic	10	2,0
Animal	1	0,2
Tree felling	2	0,4
Fuse blow	0	0,0
Lack of maintenance	2	0,4
Dig in	83	16,3
Wrong montage	2	0,4
Sabotage	2	0,4
Unkown	11	2,2
Other	10	2,0
Total	509	100,0

Primary substation

Table 9 summarizes the causes that contribute to primary substation failures. It is shown that tree fall, thunderstorm and material defects were responsible for the majority of failures.

Table 9 The causes of primary substation failures that caused customer outages over 6 hours during 2004-2008.

Failure cause	Number of failures	Percentage (%)
Tree fall, wind	46	13,6
Wind	8	2,4
Tree fall, snow	6	1,8
Thunderstrom	101	29,9
Snow, ice load	3	0,9
Material failure	141	41,7
Traffic	0	0,0
Animal	7	2,1
Tree felling	0	0,0
Fuse blow	3	0,9
Lack of maintenance	5	1,5
Dig in	2	0,6
Unkown	10	3,0
Other	6	1,8
Total	338	100,0

Secondary substation

Table 10 presents an overview of causal distribution of secondary substation failures. It is revealed that a large percentage of substation failures were due to material failures and bad weather. The causal distribution concerns the fault occurrences on all types of secondary substations including pole-installed stations, concrete and metal-plate stations.

Table 10 The causes of secondary substation failures.

Failure cause	Number of failures	Percentage (%)
Tree fall, wind	23	16,4
Thunderstrom	31	22,1
Material failure	74	52,9
Animal	2	1,4
Lack of maintenance	3	2,1
Unkown	3	2,1
Other	4	3,0
Total	140	100,0

It should be pointed out that the geographical location of distribution equipment is another influencing factor. The variations of failure events on distribution equipment by geographical location were observed in the study. There were more fault events on overhead lines in the west region of Sweden. The fault occurrences on underground cables were also influenced by geography. However, the geographical variation effect on the failures of underground cables was lower than that for overhead lines.

CONCLUSION

The knowledge of failure causes could help power utilities to take remedial actions and reduce customer outages. The paper presents the results of a project performed at the power company, Vattenfall in Sweden, that analysed failure causes based on a large amount of component failure records. The analyses show that weather has much influence on component failures. The dominant causes for faults on overhead network components are weather and environment related, while faults on underground distribution equipment are mainly material defect and digging related.

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