FAULT AND EVENT DATA UTILIZATION IN DISTRIBUTION NETWORK OPERATION

Kari MÄKI
VTT – Finland
kari.maki@vtt.fi

Susanna KUNTTU
VTT – Finland
susanna.kunttu@vtt.fi

Heikki PAANANEN
Elenia – Finland
heikki.paananen@elenia.fi

Sirpa REPO
Elenia – Finland
Sirpa.repo@elenia.fi

Hanna-Mari PEKKALA
Elenia – Finland
hanna-mari.pekkala@elenia.fi

Hannu KOIVUNIEMI
Elenia – Finland
hannu.koivuniemi@elenia.fi

ABSTRACT

This paper addresses possibilities for utilizing fault and event related data to enhance distribution network operation and planning activities. Currently distribution automation systems gather significant amounts of data on all events occurring in the network. In addition to obvious fault-related data, significant amounts of data on pre-fault triggering and disturbances are gathered. While the fault data is utilized to high level of details, use of disturbance data has not been as developed so far.

INTRODUCTION

Modern distribution network automation systems provide high amounts of data for the operator. The data can come from protection relays, switching points, transformers, sensors and generally many other equipment monitoring systems.

Utilization of real time monitoring data in decision making can offer new possibilities for distribution network management in near future. [1] Especially intelligent control systems making decisions independently seem very potential as they are able to reduce the workload of operation personnel. Distribution network management increasingly applies systems with artificial intelligence characteristics, especially FLIR (fault location, isolation and restoration) functionalities which could be expanded towards continuous monitoring of network data and independent operation. [2]

A significant amount of data is already collected on pre-fault triggerings which do not lead to relay tripping and breaker operation. While these events do not exceed the actual tripping limit, it is anyhow relevant to assume that those are related to events which cause faults in the network. Such events can be observed due to tree touching overhead line or equipment, due to equipment condition or other technical problems. For instance, it could be possible to observe cable connection about to failure.

Use of pre-trigger data has not been widely applied so far and there are many open questions, especially on dependability of observations based on this data.

OBJECTIVES

The main research question in this study was to consider whether data available through network automation systems can be used to forecast network faults. This would enable precautionary actions such as adjusting network topology to minimize number of affected customers. Such precautionary actions would require some time to be taken, thus the timeframe considered has been starting from 2 minutes.

A further research question was to study the statistical effectiveness of auto-reclosings. In case auto-reclosings turn out ineffective on certain network area and/or certain fault types, they could be deactivated in order to reduce customer disturbances.

A longer perspective objective was to consider how the measurements and fault probabilities could be presented as a part of operations. For instance the idea of applying traffic light thinking on individual medium voltage feeder level has been proposed. Figure 1 presents an example where two feeders have different profiles and the traffic light colours are defined accordingly.

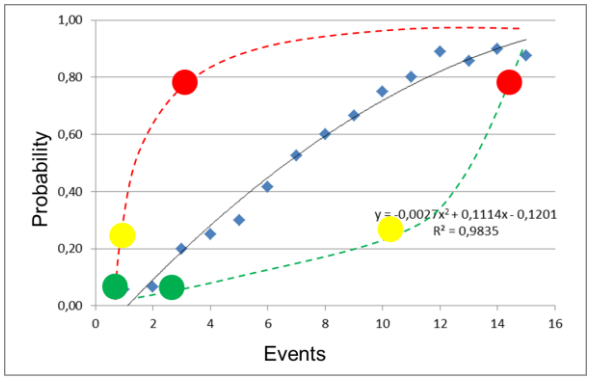


Figure 1. Example of two feeder fault probability profiles.

Here the red dotted line indicates a more event critical feeder whereas green dotted line is a more stable feeder. The limits for traffic lights can be located on profiles and updated in real time.

Summing these main research questions, a higher-level objective was to consider how data available from automation systems can be processed statistically and applied for network monitoring purposes.

METHODOLOGY

The study was performed by means of analysing real network data provided by Elenia Oy which is the second biggest electricity distribution company in Finland. The used data included recorded network events during time period 1.1.2014-11.7.2015 and covered 54 110/20 kV primary substations. The data was processed in different ways as described later in order to find the essential information. Certain storm periods were also removed from the material as they would otherwise strongly bias the data set.

Data processing

In the Table 1 are shown reasons and numbers of removed rows. Some of the rows were categorised to more than one group of removed rows, thus the sum of rows during storms or inspections and other irrelevant rows is more than total number of irrelevant rows. From the whole data about 25 % of the rows were relevant for this study. Later it is described with more details how this data (159 815 rows) was treated for analysis of triggering and tripping and analysis of reclosings.

Table 1. Content of used data

	Number of rows
Number of rows in total	693 750
Rows recorded during storms	85 575
Rows recorded during scheduled inspections/maintenance activities	171 574
Other irrelevant rows	411 481
Rows removed in total	533 935
Rows left for analysis	159 815

Definition of cases

The main objective of the study was to find out whether number of triggerings and trippings can predict occurrence of final tripping e.g. permanent fault. This objective can be transformed to two questions: 'How many times there is a final tripping after x number of triggerings and trippings?' and 'How many times there is no final tripping after x number of triggerings and trippings?'. Answers to these questions can be found when we can recognize from the data triggerings, trippings and final trippings belonging to the same event which is here called a case.

Cases were defined so that one case includes triggerings, trippings and final trippings which are occurred in one feeder during a time period maximum length 24 hours. A case begins from the first triggering or tripping and ends either to the final tripping or reaching the maximum case length.

Statistical methods

Data analysis has been mainly done by descriptive methods like frequencies, crosstabs and visualizations. Aim of these descriptive methods is in first place to have clear impression of content and quality of data. The other aim is to have preliminary understanding of relationships between variables in interest.

In addition to descriptive analysis it was applied logistic regression analysis which is a method to predict the value of a dichotomous variable (e.g. [2]) and thus an applicable method to find out whether occurrence of a permanent fault can be predicted with available data. In this study descriptive methods revealed essential conclusions and answers for the research questions. Thus the Result chapter presents results of descriptive analysis.

RESULTS OF EVENT DATA ANALYSIS

Description of cases

Little over ten thousand cases were created from the data according the process described above. Duration of most of the cases is less than two minutes. It should be noticed that duration of a case is 0 minutes if the case contains only one triggering or tripping. There were altogether 3255 cases containing only one triggering or tripping.

Table 2. Cases according to their duration.

Case duration	*Frequency*	*Percent*
0-2 min	6300	61 %
2-5 min	291	3 %
5-15 min	255	2 %
15-30 min	167	2 %
30-60 min	243	2 %
1-4 h	794	8 %
4-7 h	401	4 %
7-10 h	252	2 %
10-13 h	243	2 %
13-16 h	224	2 %
16-19 h	291	3 %
19-22 h	396	4 %
over 22 h	472	5 %
Total	10 329	100 %

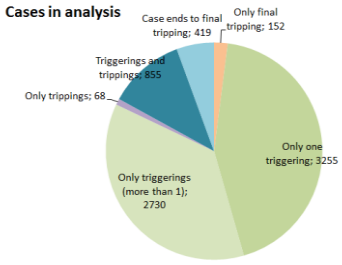


Figure 2. Cases type categorization in analysis data.

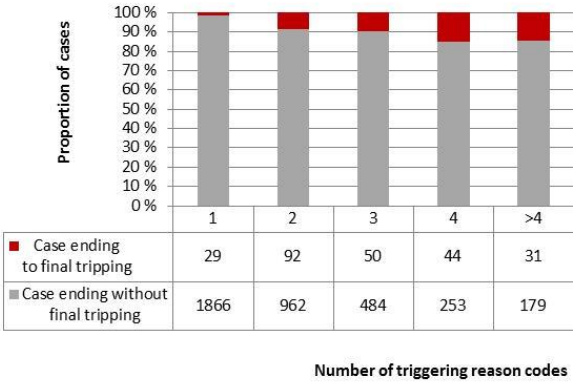
Statistical analysis on tripping probability

The main question in this study was can a number of triggerings and trippings predict probability of the final tripping. Based on data used in this study number of triggerings or trippings cannot in general predict occurrence of final tripping. From Figure 3 it can be seen that number of triggerings does not predict occurrence of a final tripping. In any cases despite number of triggerings probability of a final tripping is not higher than about 20% although probability slightly increases when number of triggerings increases.

Number of trippings predicts final tripping little bit better than number of triggerings. Number of trippings cannot be considered as valuable indicator as number of triggerings because trippings already cause disturbances to customers unlike triggerings.

Another perspective was to consider the fault or disturbance code related to the triggering and its relation to tripping probabilities. First the relationship between number of triggering reason codes in a case and probability of a final tripping was studied. In the previous chapter it was already stated that one triggering leads very rarely to final tripping. Cases with one triggering could have disturbed conclusions concerning this question because all these cases would have been categorized obviously to one reason code category. Thus in this analysis only cases with more than one triggering are in the data.

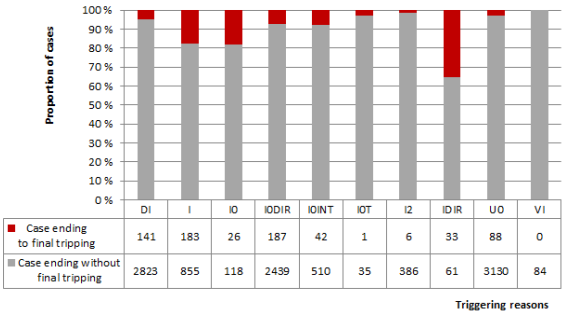
The relationship between number of triggering reason codes and probability of a final tripping is not strong but it should be noticed that if a case includes only one reason code the probability of a final tripping is very low, zero in practice. This conclusion holds even if number of trippings increases.



	1	2	3	4	>4
Case ending to final tripping	29	92	50	44	31
Case ending without final tripping	1866	962	484	253	179

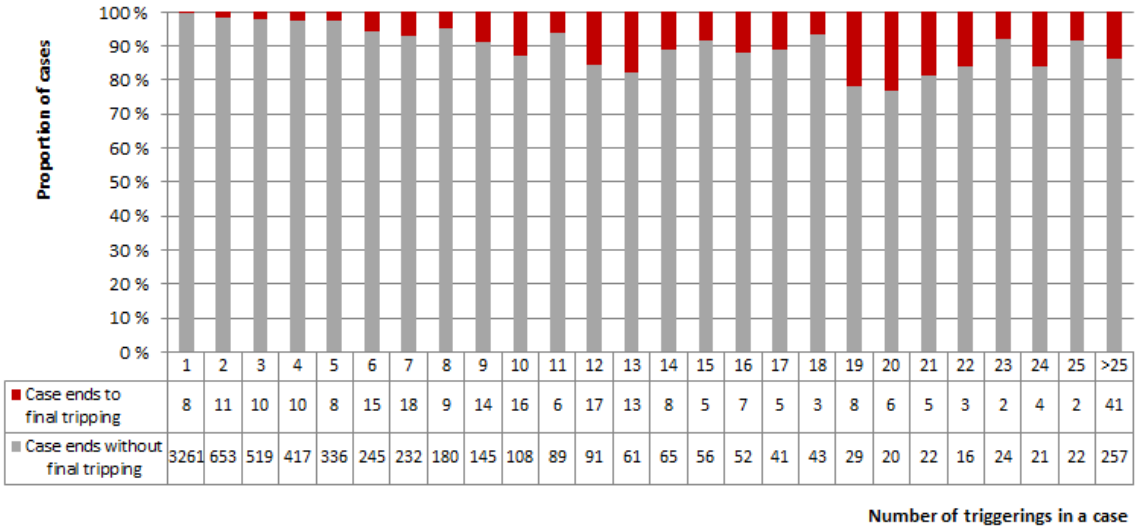
Figure 4. Impact of number of reason codes.

Another approach was to consider different reason codes and their impact on tripping probability. Figure 5 presents how existence of a certain triggering code in a case affects the probability of final tripping. There is some evidence that with certain reason codes in a case the probability of a final tripping is higher, about 30%. However the number of cases is too small for major conclusions.



	DI	I	IO	IODIR	IOINT	IOT	I2	IDIR	UO	VI
Case ending to final tripping	141	183	26	187	42	1	6	33	88	0
Case ending without final tripping	2823	855	118	2439	510	35	386	61	3130	84

Figure 5. Probability of final tripping according to reason codes.



	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	>25
Case ends to final tripping	8	11	10	10	8	15	18	9	14	16	6	17	13	8	5	7	5	3	8	6	5	3	2	4	2	41
Case ends without final tripping	3261	653	519	417	336	245	232	180	145	108	89	91	61	65	56	52	41	43	29	20	22	16	24	21	22	257

Figure 3. Final trippings as a function of triggerings.

RESULTS ON RECLOSING ANALYSIS

Aim of reclosing analysis was to study are fast and delayed reclosings effective tool to prevent permanent faults in distribution network. To answer this question effectiveness of reclosings was studied in general, according to tripping reason and according to tripping threshold level.

On all feeder reclosing events fast or delayed reclosing was able to handle **85.0 %** of faults, which is typical proportion according literature. Fast reclosings handled **63.4%** of faults and delayed reclosing additional **21.6 %**. Figure 6 presents the overall statistics.

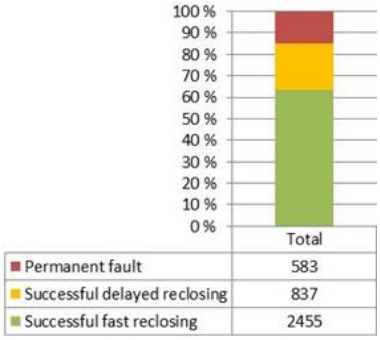


Figure 6. Overall statistics of reclosing performance.

The performance of reclosings was further studied according to attributes of reason code and tripping threshold level (fast/delayed).

Effectiveness of reclosing in two different threshold levels is in general on same level as can be seen from the two leftmost columns in Figure 7.

When threshold levels are studied further by reason code is can be seen that if the tripping reason is 'I0DIR' (directional residual overcurrent protection) with a threshold level '>' (delayed) then fast reclosing can handle only about 25 % of further consequences. Unfortunately the number of reclosing events in this category is rather small so more data would be needed for reliable conclusions. Anyhow the results clearly indicate that reclosings for I0DIR slower threshold may be not beneficial.

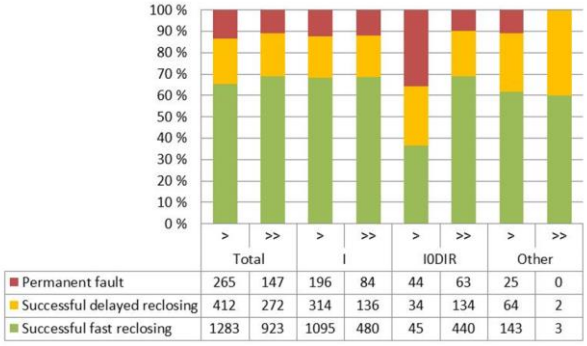


Figure 7. Success rate of reclosings according tripping threshold level and reason of tripping

CONCLUSIONS

The main aim of this study was to find out can number of triggerings or trippings predict probability of final tripping. Based on data available in this study clear relationship between number of triggerings or trippings and probability of final tripping could not be found. In the level of whole data probability of final tripping increases slightly when number of triggerings increases but the probability of final tripping is even at highest level only about 20 %.

In detailed analysis when probability of final tripping was considered in different kind of feeders and according triggering reasons was found some interesting preliminary results but reliable conclusions would need repetition of this study with bigger data. For example number of triggering code 'I' (simple overcurrent) seems to predict final tripping better that other triggering reasons but available data so small that so far this observation can be explained by chance.

In addition to descriptive analysis it was used logistic regression method to define a statistical model which could be used to estimate probability of final tripping. The result from this analysis was that with available variables it was not possible to predict occurrence of final tripping with reasonable certainty.

The reclosing analysis revealed that in general level fast and delayed reclosings work well and prevent permanent fault in almost 90 % of reclosing events in feeders. The detailed analysis showed slight differences in success of reclosing according tripping reason, if the tripping reason is 'I' the reclosings seems to work at best level. The most interesting result about reclosings is related to threshold level. The data provided rather strong evidence that when threshold level is '>' in tripping code 'I0INT' the fast reclosing succeeded only in 25 % of reclosing events and fast and delayed reclosings together can prevent permanent fault only in 60 % of reclosing events.

The results still indicate it would be useful to perform more analysis with larger data sets in order to look further on the potentially interesting results.

REFERENCES

[1] A. Ukil & R. Zivanovic, Automated Analysis of Power Systems Disturbance Records: Smart Grid Big Data Perspective. *2014 IEEE Innovative Smart Grid Technologies - Asia (ISGT ASIA).*

[2] SGEM Project: Proof of concepts Masala Field test, February 2013

[3] S. Chatterjee & J.S. Simonoff, 2013, *Wiley Handbooks in Applied Statistics : Handbook of Regression Analysis*. John Wiley & Sons, New Jersey, USA, 149-176