EMERGING RELIABILITY REQUIREMENTS FOR DISTRIBUTION SYSTEMS IN EXTREME WEATHER CONDITIONS

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ABSTRACT

Extreme weather conditions challenge electricity distribution from time to time. In the Nordic countries, strong wind and snow storms together with the high rate of overhead lines located in forests create demanding conditions for the distribution business. To meet the requirements of modern society, management of major blackouts plays a significant role in the economic regulation of the electricity distribution business. This paper presents the results of a survey commissioned by the Finnish Ministry of Employment and the Economy on supply interruptions and electricity supply security. The paper focuses on two main elements; the customer compensation payments and the maximum blackout duration limits. The study is based on actual large-scale blackouts experienced by several distribution companies.

INTRODUCTION

Major weather-related disturbances in electricity distribution, that is, blackouts covering large geographical areas, have raised public debate on the importance of continuous, uninterrupted electricity supply. In December 2011 and January 2012, as a result of heavy snowfall, several major disturbances occurred in the electricity distribution in Finland. At that time, there were 570 000 customers in total without electricity, and the disturbances caused over 60 M€ costs for the distribution utilities. The events of late 2011 and early 2012 once again aroused politicians' interest in electricity supply security, as the 12-day supply interruptions close to the capital area were considered intolerable to society. As a result, the Finnish Ministry of Employment and the Economy initiated a legislative reform concerning the requirements for the security of supply, sanctions and opportunities to develop the distribution system [1]. The main target of the reform is to set a limit for the maximum duration of an interruption for the customer. The limit values are 6 hours for urban area customers and 24 or 36 hours for rural area customers. The reform in its planned form will have significant effects on network development.

The paper introduces and discusses the results of a survey commissioned by the Ministry of Employment and the Economy on supply interruptions and electricity supply security. The assignment comprised the following research tasks: an analysis of statistical information about past blackouts, definition of distribution network structures required to meet the interruption duration limits, an analysis of the organisation for the clearance of disturbances, and finally, an analysis of the costs of the system development. In practice, the target of the research has been to find out how the optional reliability requirements can be met, and to determine the impacts of rural-area-specific 24- or 36-hour interruption limits on the distribution fees paid by the electricity end-customers (step 4 in Figure 1). In urban areas, the target value for the limit is 6 hours. In addition, the Ministry is considering expanding the present compensation scheme so that compensation payments would still increase after 120 hours of interruption (step 1 in Figure 1). The planned target of the Ministry is that 50 % of the electricity end-users are within the 24 or 36 h limit values before year 2020, 75 % in the end of 2023 and 100 % in the end of 2027 [1].

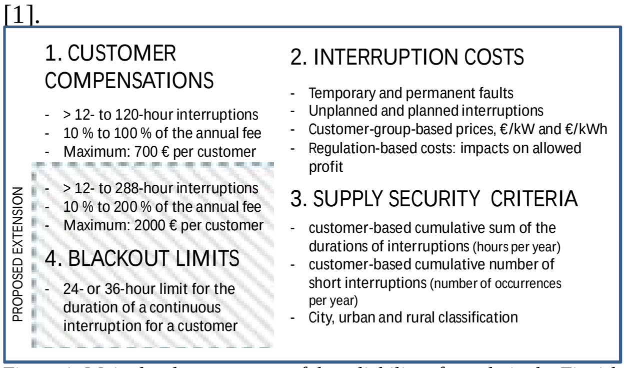

Figure 1. Main development steps of the reliability of supply in the Finnish electricity distribution.

In the Finnish regulation, since 2003, economic incentives for preparing against blackouts are implemented by a compensation system, according to which the electricity users are entitled to financial compensation if they experience interruptions that exceed 12 h. Now, a proposal is made to extend the compensation scheme to 288 hours (12 days). In that case, the compensation would be 200 % of the annual distribution fee paid by the customer. The maximum amount of compensation would be 2000 € per customer instead of the present limit of 700 € (Figure 2).

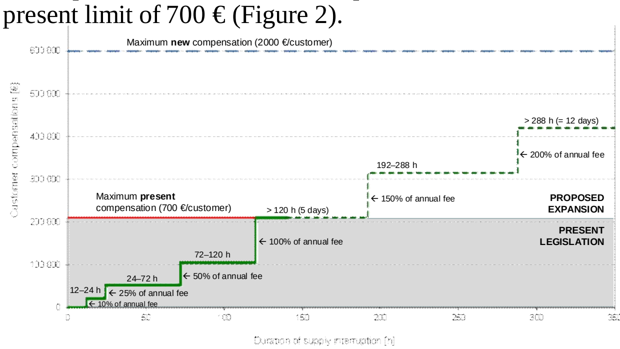

Figure 2. Customer compensation payments in the present and proposed model in the example case.

BACKGROUND OF THE ANALYSES

The research has been carried out in cooperation with several Finnish electricity distribution utilities that have experienced large-scale blackouts as a result of major storms in their electricity networks over the past few years [2]. Background information is presented in Table 1. It can be seen that the case companies participating in the study represent a significant proportion of all Finnish distribution companies, especially with respect to compensations paid (the bottom row in the table). Over 90 % of the compensation payments in Finland in 2010 and 2011 were made by these companies. Hence, from the perspective of the electricity distribution business, the compensation payments can play a significant role for an individual company (the right-hand column in the table).

Table 1. Background information of the case companies.

		Network (km)			Energy	Revenue	**Storm compensations (M€)**		
	Utility	MV	LV	Customers	(GWh)	(M€)	Summer	Winter	Of rev.
1	Elenia Verkko Oy	22 459	38 626	394 705	5 789	210	3.0	5.2	2 %
2	Fortum Sähkönsiirto Oy	23 094	45 272	441 456	7 135	242	-	29.0	12 %
3	Järvi-Suomen Energia Oy	8 620	17 730	99 311	1 164	49.2	1.6	2.5	5 %
4	Parikkalan Valo	926	1 719	10 119	145	3.3	0.9	0.1	28 %
5	PKS Sähkönsiirto Oy	9 759	11 241	86 814	1 107	43.6	0.6	1.4	3 %
6	Savon Voima Verkko Oy	11 149	13 544	110 642	1 739	59.9	3.0	3.4	6 %
7	Vatajankosken Sähkö Oy	1 431	2 393	17 596	280	8.2	-	1.8	22 %
		77 438	**130 525**	**1 160 643**	**17 358**	**616**	**9.1**	**43.5**	**7.1 %**
	Percentage of all distribution companies	56 %	55 %	35 %	35 %	31 %	90 %	93 %	2.3 %

Main objectives and research questions

There are two main objectives in the paper. The first one is to determine the distribution network structures required to meet the interruption duration limits. This means, in practice, determining the required underground cabling rates in medium-voltage (MV) and low-voltage (LV) networks (Figure 3). The second objective is to determine the costs of the system development, in other words, the impacts of the 24- or 36-hour interruption limits on the distribution fee paid by the electricity end-customer.

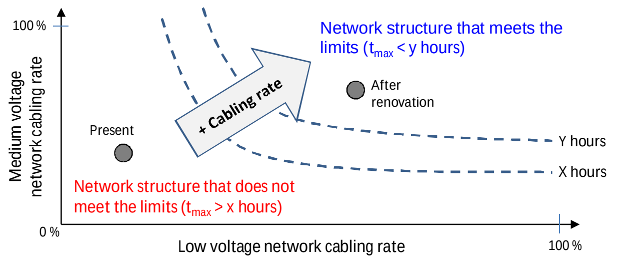

Figure 3. Network cabling renovations required to meet the interruption duration limits.

Storm modelling

To be able to define the development requirements in the present network, different kinds of major storms were analysed. Figure 4 illustrates the curve form typical of blackouts: first, the numbers of faults and end-customers without supply increase rapidly; then, after peaking, the number of end-customers without supply first reduces rapidly in proportion to the faults cleared, and after that, at a decreasing rate.

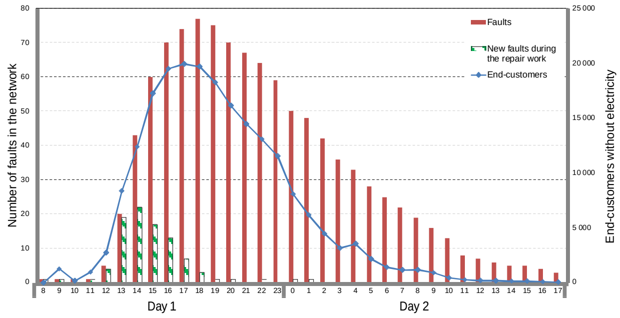

Figure 4. Development of the number of customers left without electricity supply during a blackout (Lohjala, 2009).

The case storm illustrated in Figure 4 shows that during the first six hours (12–18 hours), the effects were at their largest; in this time period, almost 20 000 end-customers were left without electricity in the storm in the case company. Over the following six hours (18–24 hours), the influence of faults could be limited to 8 000 customers by focusing on faults on the medium-voltage network; this result was largely due to calming down of the storm and the efficient operation of the repair organisation. About a day after the storm, only a few hundred customers remained without supply. The small number of customers without supply is explained by the fact that the faults in the medium-voltage network had already been repaired and the repair activities were focused on the low-voltage networks. Depending on the scope and strength of a storm, this ”tail” owing to the repair operations in the low-voltage networks can become very long. The tail (duration of repair work) can be cut by the choice of low-voltage network components, such as underground cabling. Figure 5 presents the main factors affecting the shape of the major storm curve.

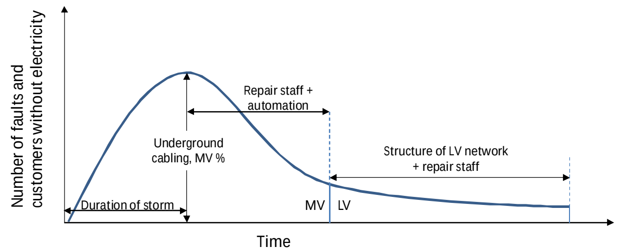

Figure 5. Major storm curve and affecting factors.

Cost and cabling demands analyses

The demands for cabling are defined based on historical data on major storms experienced in different distribution companies. Thus, the study provides an answer to the question of how high the cabling rate should be to survive from the storm with the present fault repair resources without exceeding the interruption limits (24 and 36 h) of any end-customer. A simplified illustration of data processing is given in Figure 6. At the top of the figure, the background information is grouped into main types of data required. The main results, the required cabling rates and cost effects are presented in the lower part of the figure.

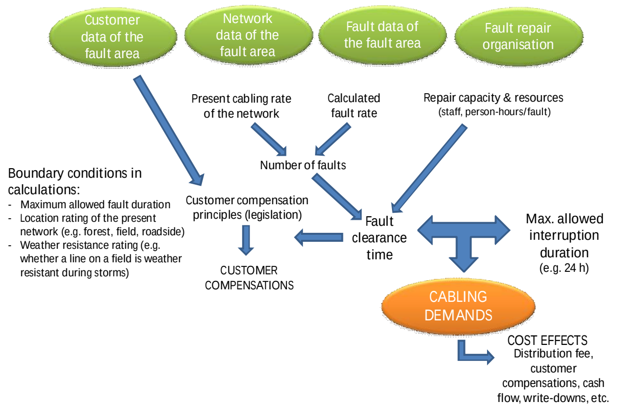

Figure 6. Background information of the major storms and boundary conditions applied in the study on cabling demand.

A detailed cost analysis of the system development, in other words, determination of the impacts of 24- or 36-hour interruption limits for instance on the distribution fee paid by the electricity end-customer, is performed for four distribution companies. The analysis is based on detailed information of the network asset. The specific calculation principles are presented in [2], and they are based on the economic regulation guidelines of the current regulation period [3].

RESULTS

Effects on the network development

In Figure 7, the required cabling rates for MV and LV networks are presented in a situation where the maximum duration of interruption is a) 36 h and b) 24 h. The curves represent the limits for the easiest case in the companies. Because of the significant differences in the nature of storms, the curves are defined separately for different seasons. The points in the lower left corner indicate the present cabling rates of the case companies.

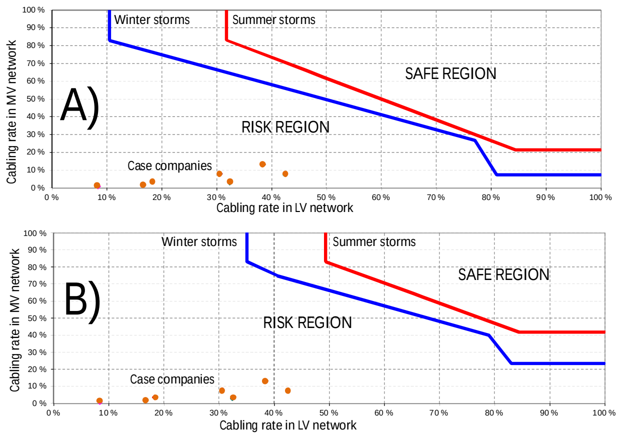

Figure 7. Required cabling rates (in the easiest case) for MV and LV networks when the maximum duration of interruption is a) 36 h and b) 24 h.

In practice, the 24 h limit in rural areas requires a 60–80 % MV cabling rate and a 50–90 % LV cabling rate. Again, the 36 h limit requires a 40–75 % MV cabling rate and a 40–90 % LV cabling rate. The differences between 24 and 36 h values in the case companies are from 5 to 20 % units. Figure 7 shows that there is a large gap between the present cabling rates and the storm-safe region both in the 24 h and 36 h cases. It can be also seen, that there will be a significant number of customers that are not within the weatherproof network after the renovation, and may still experience effects of major storms. However, the maximum interruption for these customers will be 24 or 36 h.

Figure 8 illustrates the customers on the weatherproof network vs. the required underground cabling rate in the case distribution companies. Because the customer density is at highest in urban areas (close to the primary substations), a relatively small amount of underground cabling is needed to cover a significant number of electricity end-users. It can be seen from Figure 8 that if the cabling rate were 50 % in the MV network, 70–80 % of the customers would be within the weatherproof electricity supply system. The six-hour requirement for urban area customers leads to a 100 % cabling rate in urban area MV and LV networks.

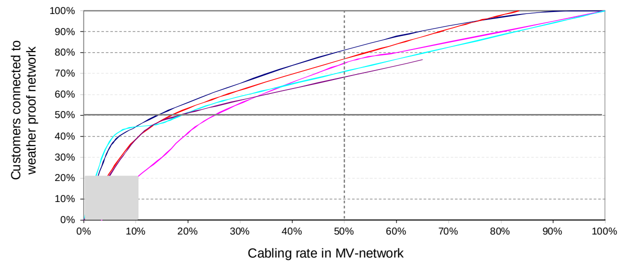

Figure 8. Customers on the weatherproof network vs. the required cabling rate in some companies. The starting point of the curves has been removed.

Distribution fee and customer compensations

As discussed in the previous section, the required cabling rate differs from 5 to 20 % unit depending on the maximum allowed duration of interruption. In LV networks, a 5–20 % units difference in the cabling rate has a slight effect on the distribution fee. In the maximum case, the additional payment would be 0.35 cent/kWh if the limit were 24 h instead of 36 h. In MV networks, the cost effect is significant. An additional 20 % unit increase in the cabling rate would increase the fee by 1.2 cent/kWh at maximum.

From the perspective of renovation scheduling, the proposed targets of the Ministry for the network renovation are tight. Moreover, accelerated renovation leads to a situation where overhead network components having lifetime left are replaced with underground cables. For the case companies, accelerated renovation leads to a situation where write-downs worth of 100–240 M€ have to be made to reach the renovation targets. Table 2 provides the results for four case distribution companies.

Table 2. Summary of cost effects for four case companies.

Cabling rate in MV- and LV-networks	**25 %**	**50 %**	**75 %**
Additional distribution fee, cent/kWh	0.30–1.2	0.80–2.5	1.3–3.9
Write-downs, M€	100	160	240

The effects of the cabling requirements on the distribution fees vary significantly depending on the network area. The length of the cable network built and the amount of energy delivered are the main factors affecting the fees. The more energy is used in the network area, the less there is need for a raise in distribution fees per kilowatt-hour.

Figure 9 demonstrates the results of a simplified cost analysis for all Finnish electricity distribution companies. The figure shows a need to raise the distribution fee when the present MV and LV overhead line networks are replaced by underground cable networks in 15 years so that the cabling rate is (at least) 50 % in the last year (2027). The effect on the distribution fee varies from 0.5 to 0.6 cent/kWh on average in Finland.

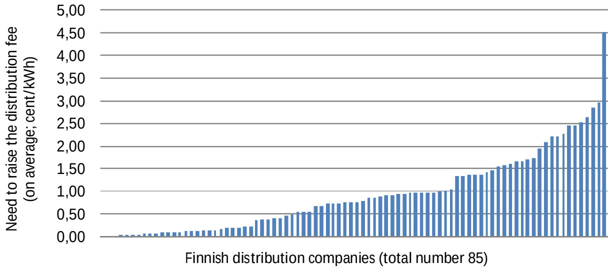

Figure 9. Need to raise the distribution fees in Finnish electricity distribution companies if the present overhead line networks are renovated so that in 2027 the cabling rate is 50% in both MV and LV networks.

Nationwide effects of the 24 and 36 h limits on the network investments and distribution fees are presented in Table 3. In the right-hand column, the effects on the distribution fee and paid by the customer are presented.

Table 3. Nationwide effects on the investments and distribution fees (average).

Maximum duration of interruption, share of customers in weatherproof network	Investments, M€			Effect
	MV network	LV network	Total	Distribution fee, cent/kWh
24 h 80–90%	4 000	1 100	5 100	+ 1.7 cent/kWh
36 h 70–85%	2 700	800	3 500	+ 1.2 cent/kWh

The effects of planned extensions on the customer compensation payment practices (Figure 1 and 2) are presented in Table 4. The table demonstrates how much customer compensation payments would have been as a result of the 2010 and 2011 storms if the planned extensions had been in force at that time.

Table 4. Effects of the planned extensions on the customer compensation payments after the 2010 and 2011 storms in the case companies.

	Storm compensations (M€)					
Utility	Summer	NEW	**Change**	Winter	NEW	**Change**
Elenia Verkko Oy	3.0	3.0	**101 %**	5.2	5.2	**100 %**
Fortum Sähkönsiirto Oy	-	-	-	29.0	40	**138 %**
Järvi-Suomen Energia Oy	1.6	2.1	**133 %**	2.5	2.5	**103 %**
Parikkalan Valo	0.9	1.3	**141 %**	0.1	0.1	**100 %**
PKS Sähkönsiirto Oy	0.6	-	-	1.4	-	-
Savon Voima Verkko Oy	3.0	4.1	**136 %**	3.4	3.6	**104 %**
Vatajankosken Sähkö Oy	-	-	-	1.8	2.1	**114 %**

CONCLUSIONS

The main results of the study can be concluded as follows:

- The urban area limit (6 h) leads to a 100 % cabling rate in the MV and LV networks in urban areas.
- The rural area limit (24 h or 36 h) requires a significant amount of cabling in the present MV and LV networks.
- The most efficient way to reach the year 2019 targets (50 % of customers within the limit values) is cabling of the MV network by the rolling method starting from the substations and continuing to the feeder ends, and isolating the overhead line network from the underground network with pole-mounted switchgear.
- Renovation should be started from urban areas.
- By following the previous recommendations, 70–85 % of customers can be connected to the weatherproof network with a cabling rate of 40–50 %. In practice, this would mean that 70–85 % of electricity end-users are within the 6 h limit, and for the rest, the maximum duration of interruption would be 36 h.
- By increasing the MV cabling rate by 5–20 % units, the 24 h limit can be reached. In this case, 80–90 % of electricity end-users are within the 6 h limit.
- Hence, we may conclude that from the perspective of the national economy, the 36 h limit for interruptions in rural networks is a more economically feasible and sustainable alternative than the 24 h limit.
- The pressure to raise prices as a result of the cabling of networks varies significantly between DSOs. At highest, the need for a price raise is several cents/kWh, while in some cases the need is virtually zero. In the distribution company, the need for price raises depends primarily on the ratio of the amount of overhead lines to the volume of energy consumed by the end-customers. The present network development trends further increase the differences in distribution fees, which are due to different operating conditions of the DSOs.
- In distribution companies, reaching the supply reliability targets calls for significantly higher investment volumes in an accelerated schedule.
- The proposed reforms to the customer compensation scheme increase the financial risk of DSOs, especially in small companies. The risk will reduce essentially with the increasing cabling rate.

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