# Customer-Based Reliability Monitoring Criteria for Finnish Distribution Companies

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***Abstract*— In Finland, new reliability criteria for electricity distribution companies have been analysed, and now, the implementation of the criteria is being discussed. The criteria cover the customer-based cumulative sum of durations of long interruptions and the cumulative number of short interruptions. The criteria are established by the Finnish Energy Industries (ET) together with electricity distribution companies and technical universities.**

***Index Terms*—Power quality, availability, electricity distribution business, investment strategies, long-term planning**

## I. Introduction

TODAY, the electricity distribution business is facing the challenge of reliability. Traditionally, the reliability of supply is measured at the system level, and it is described for instance by SAIDI, SAIFI and MAIFI. These factors indicate the average reliability and availability of supply, but they are not able to address the situation from the individual end-customer point of view. Similarly, incentives from the electricity distribution regulation (economic sanctions and rewards) consider reliability from the system-level perspective. Power quality (reliability) is monitored by including outage costs in the economic regulation. This has created a strong incentive to improve reliability at the system level; however, the model does not guarantee good quality from an individual customer point of view. The situation is similar in Finland and in most European countries.

One of the main questions is how the perspective of an individual customer and electricity end-user could be taken into account in a reasonable way in electricity distribution? An exception to common reliability practices is CDI (Customer Dissatisfaction Index), which considers harm and inconvenience caused by an interruption from the customer point of view [1].

In Finland, the Finnish Energy Industries (ET) together with the electricity distribution companies hase decided to reform the monitoring practices and criteria for the reliability of supply. One incentive has been the fact that the quality standards do not give detailed definitions for reliability; for instance, no numerical limits or qualitative conditions are given for interruptions. The target of this reform is to implement new planning criteria into the long-term network development. The criteria will cover the customer-based cumulative sum of durations of long interruptions and the cumulative number of short interruptions (< 3 min). The targets vary for different areas (city, urban and rural areas), and they are linked to areas, not to the present network structure.

Reliability and availability are central terms when the quality of supply is estimated. Power quality as a whole is presented in Fig. 1. The criteria introduced in this paper focus on reliability and availability. The issue of voltage quality is outside the scope of the criteria.

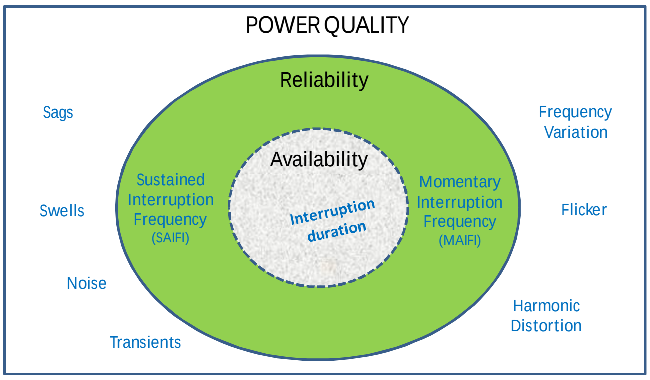


Fig. 1. Power quality and reliability [2].

The supply reliability criteria related to the subject of overall reliability have to be selected with care: setting too tight requirements for reliability indices may lead to network solutions that are too expensive for the national economy and that increase the transmission fees excessively. On the other hand, if reliability is not included as a boundary condition in the planning task, this may lead to decreased reliability when the distribution company is optimising the financial performance of its business.

## II. Reliability in Electricity Distribution Business

The role of reliability and the quality of supply is emphasised in the Nordic environment, which is characterised by a high forest rate and overhead lines that are vulnerable to adverse weather phenomena. In Finland, about half of the outages experienced by end-customers are caused by trees falling on the lines [3]. If the climate change increases windiness, the amount of storms and swift temperature variations around zero degrees Celsius and thereby problems related to reliability will definitely increase in forest areas. Simultaneously, as the challenges of reliability are aggravated by the climate change, also the issue of quality is emphasised among the electricity end-users. This poses a challenge to the asset management and long-term network development. In Fig. 2, the interruption statistics of a distribution company illustrate how the years differ from each other with respect to fault rate. To be able to develop the network reliability, the companies have to be well aware of the interruptions experienced by the customers, the costs caused by interruptions, and their effects on the economy of the company, both from the regulatory perspective and from the planning and operating point of view.

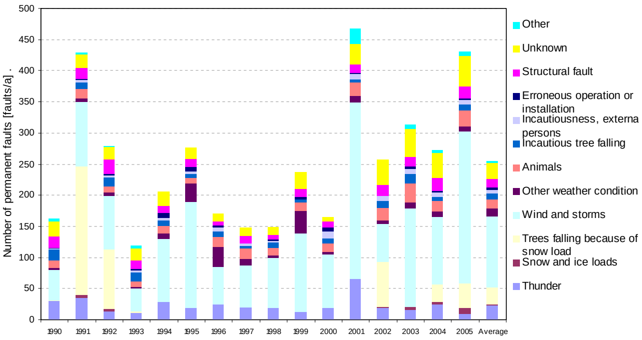

Fig. 2. Examples of the causes of interruptions.

From the regulatory perspective, annual variations in reliability are challenging; the regulatory model should react fast enough to the development actions carried out on the network, yet simultaneously, the model should be able to filter out the annual natural variations. Similar statistics on the causes of interruptions are compiled in most European countries [4]. This information is important for the regulators and is essential for the companies in order to improve the continuity of supply. From society's perspective, interruptions and the quality of supply have a significant economic impact. It has been estimated that for instance in Norway the annual economic harm caused by long supply outages has varied from 42 to 66 M€/a between 2001 and 2008 [5]. In Finland, this economic harm was estimated to be 116 M€/a [6] for all distribution companies in 2006.

From the perspective of distribution network development in Finland, the main factors related to the quality of supply in the present regulatory model are:

### A. *Quality incentive*

A quality incentive is created, when actual outages and outage costs are compared with the company's historic data on reliability, that is, with a reference level. An improvement in reliability increases the return of the company, while degrading reliability has an opposite effect on the return thereby constituting a strong economic incentive for the quality of supply and development efforts. Outage costs consist of short and long interruptions, both scheduled and unplanned (fault) interruptions. Outage costs are used as a reference level and in the efficiency benchmarking in the Finnish regulation model.

### B. *Efficiency benchmarking*

Distribution companies are compared with each other by employing Data Envelopment Analysis and Stochastic Frontier Analysis. The quality of supply is included in this efficiency benchmarking through outage costs. Reduction of outage costs has a positive effect on the efficiency score thereby increasing the allowed return of the company. In practice, the efficiency score increases if the total costs reduce in proportion to the efficient cost level.

### C. *Standard compensations*

The term 'exceptional events' (major storms) is widely used all over Europe, but the term is applied to classify very different kinds of situations in different countries. In Finland, from the beginning of September 2003, the companies have been obliged to pay standard compensations to their customers, if the customer has experienced an interruption of supply that has lasted at least 12 hours. The amounts of the standard compensations of the annual system service fee are presented in Table I.

TABLE I. STANDARD COMPENSATIONS

| Length of interruption | Standard compensation |
|---|---|
| > 12 but < 24 hours | 10 % |
| > 24 but < 72 hours | 25 % |
| > 72 but < 120 hours | 50 % |
| ≥ 120 hours | 100 % |

The maximum amount of the standard compensation because of an interruption is, however, 700 €/a per customer. Contrary to almost all other European countries, exceptional events are not excluded from compensation payment in Finland [4]. Standard compensations are included in the controlled OPEX, and thus, long supply interruptions have a direct effect on the company return and thereby on the efficiency target for the next period. Figure 3 illustrates the penalty structure of the Finnish distribution business regulation model by the variation of interruption duration. The case feeder has 300 customers and the distribution fee is 5 cent/kWh. Penalties for outages of excessive duration (>12 hours) are based on the limits presented above. It is assumed that the whole feeder is without electricity.

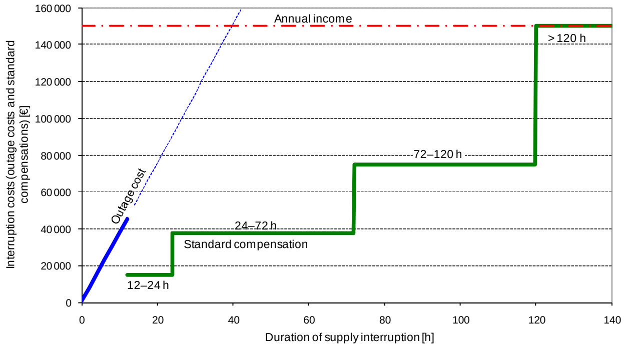


Fig. 3. Penalty structure in the Finnish distribution business regulation model. The figure is based on the example feeder (300 customers, 10 MWh/customer and 5 cent/kWh) [7].

The economic effect of the outage cost component depends on how close to the limit set for allowed return the company is operating. At present, the effect of customer outage cost may be at maximum 10 % of the allowed return calculated for the company. If the accumulated previous customer outage costs exceed the maximum limits for the year in question ("customer outage cost cutter"), the customer outage cost does not have a direct economic effect. On the other hand, if the accumulated outage costs remain clearly below the maximum level, the customer outage cost has an effect as illustrated by the outage cost curve in Fig. 3. After 12 hours from the occurrence of the outage, in addition to customer outage costs, standard compensations start to accumulate for the company.

## III. Proposal for the Criteria

### A. *Target levels of the criteria*

The criteria for the reliability of electricity supply concerns interruptions caused by faults in electricity distribution networks. In this context, an electricity distribution network refers to an entity comprising primary substations, medium-voltage networks and low-voltage networks. At primary substations, the balance limit is the primary voltage connection point of the main transformer.

The criteria for the reliability of supply are based on a division into areas. The areas are a city, an urban area and a rural area. Each customer belongs to one of these areas. The criteria for the reliability of electricity supply refer to design criteria for an electricity distribution network, in other words, the target level of service reliability applied in network design. The target levels determined in the criteria for the reliability of electricity supply in city, urban and rural areas are presented in Table II.

Table II. Target level for the reliability of supply in different areas.

| Criteria | City | Urban area | Rural area |
|---|---|---|---|
| Total interruption time | 1 hour in a year at max. | 2–3 hours in a year at max. | 4–6 hours in a year at max. |
| Number of short interruptions (< 3 min) | No short interruptions | ≤ 10 interruptions in a year | ≤ 60 interruptions in a year |

As a distribution network design criterion, the target levels indicate a principle according to which the target value may be exceeded only once within a period of three years at maximum. The basis for the design criteria is that an interruption caused by a very severe single fault or a large-scale blackout can be allowed, whereas from the perspective of an individual customer, events within normal operating conditions may not lead to exceeding of the target values. For instance, a damage in a 20/0.4 kV distribution transformer almost without exception leads to an interruption of longer than three hours for the end-users supplied by the transformer; however, a single customer seldom encounters situations of this kind. The length of the monitoring period involves some challenging aspects. A long monitoring period is advantageous from the perspective of the planning criteria and long-term development of distribution networks. From the customer point of view, a short period is more acceptable. One alternative for the period when most of the renovation work is performed is that for instance in a city area, customers could get compensations already in the same year when the criteria are exceeded without a long delay. From the risk management point of view, the highest risks are in rural area networks.

The effect mechanism of the reliability criteria is twofold. As to a design criterion, the effect of target levels is immediate in distribution companies. Nevertheless, changes will take place slowly. At the second level, because of public statistics, there will be comparison and even competition between electricity distribution companies. Listings of customers, the target values of which have been repeatedly exceeded, together with other key parameters associated with the electricity distribution business, may function as a tool when reassessing the obligations to develop the distribution networks as stipulated in the Electricity Market Act.

Realisation of the criteria for the reliability of electricity supply will be monitored by means of statistics. First, each electricity end-user receives a reliability report, which presents the above-described key parameters for the end-user in question. In the cases of exceeding of the target values, explanations are provided in the report. Second, each distribution company compiles statistics with information about the distribution of the total duration of fault interruptions experienced by the customers and the number of short interruptions. Third, the electricity distribution company compiles statistics on the number of customers, the target values of which have been exceeded 0, 1, 2 and 3 times during the reference period of three years. These data are public information. The data are gathered in connection with compilation of the reliability statistics by the Finnish Energy Industries (ET).

### *B. Rationale for determination of target values*

#### *1) City*

*City* represents the core areas of cities with a high load density and construction intensity. The distribution network is built 100 % underground and the primary substation density is high. The medium-voltage (MV) feeder lengths are typically a few kilometres. Supply interruptions are rare at an individual end-user. Automatic reclosings are not used in underground cable networks.

The target level for the reliability of electricity supply is determined based on the principle according to which a fault in the MV network shall not interrupt the electricity supply at the end-user for the duration of fault repair, but electricity supply will continue after the time required for fault isolation. In most cases, fault isolation can be carried out in 0.5–1 hours. The time of isolation depends on traffic conditions, substation automation and other similar factors.

The total MV feeder lengths in city areas are mainly 5–10 km, and thus, the average fault frequency per feeder,a remains low (0.05–0.2 faults/a) and the probability of multiple faults in a year is also low. The long interruption times related to faults in distribution substations and low-voltage networks do not pose a problem. From the viewpoint of an individual end-user, the probability of such events is low, and they fit within the allowed one event of exceeding the limit value in a three-year period.

#### *2) Urban area*

In an *urban area*, in addition to densely populated residential areas, there are services for people and communities, such as shops, banks, schools, kindergartens, old people's homes, nursing homes and the like. Disturbances or interruptions in these services cause serious problems and inconvenience for individual people and the community. As municipal engineering services are typically provided up to the boundary of the building lot, it is justifiable in urban areas to set tighter criteria for electricity distribution to domestic customers than in rural areas.

The target level for the reliability of electricity supply is based on a principle according to which a fault in the MV network shall not interrupt the electricity supply at the end-user for the duration of fault repair, but electricity supply will continue after the time required for fault isolation. In the case of faults in distribution substations and low-voltage networks, a longer interruption is allowed. From the viewpoint of an individual end-user, the probability of such events is low, and they fit within the allowed one event of exceeding the limit value in the reference period.

In practice, the target level suggested for urban distribution networks leads to a MV network structure in which the probability of multiple simultaneous faults and/or multiple faults in a year has to be kept low. A practical solution to this is a distribution network built underground, or a network that is otherwise "weatherproof" (e.g. a covered overhead line by the roadside, protected against damages caused by trees). The limit value for the total interruption time is determined by a) the probable number of faults/a and b) the time required for fault isolation. The electricity supply to distribution substations within the faulted section (disconnector zone) will be provided for by backup supplies (generators) during fault repair.

Considering blackouts, the criteria will significantly improve the electricity distribution in urban areas. The customers subject to the reliability criteria will not experience power failures caused by storms. Urban areas far away from the central facilities of the distribution company pose a special challenge for reaching the target values set for urban areas, as the time required for accessing the faulted area constitutes a significant part of the time needed for fault isolation. However, this time can be affected by organisational arrangements.

#### *3) Rural areas*

In rural distribution networks, the MV feeder lengths are typically 10–100 km/feeder. There are backup connections on the feeders, usually equipped with remote control. The line length of individual sections isolated by disconnectors is usually a few kilometres. The maximum lengths of radial branches are usually < 15 km. The total fault interruption time experienced by the end-users in the most challenging places on the network (radial branch line) depends on a) the total number of faults on the feeder and the time required for their isolation + time required for connection of the backup supplies and b) the number of faults and repair time on the branch line supplying the customer. The limit value presented here is typically exceeded in situations where two or more faults occur on a disconnector section or a branch line within the same year, and the fault repair takes more than three hours. The total interruption time will be long also if there are plenty of faults on the feeder and the time required for their isolation is long.

The fault isolation and backup supply connection times can be influenced by automation (disconnectors, fault location) and response times of the organisation. The number of faults on branch lines and the repair times can also be affected by the placement and pruning of line paths, new backup connections and generators, and by tuning the operations of the organisation.

Determination of the limit value for fault interruption times is based on analysing the probability of exceeding the limit value twice or more during the reference period (three years). In most parts of the networks, the above target values can be reached by economically efficient solutions. For instance, the total fault interruption times can be kept below 6 hours in most parts of the networks already.

Based on practical experiences, it can be stated that the number of autoreclosings can be several dozens in rural areas. The number of autoreclosings can be influenced by network topology (parallel switches), line structures, overvoltage protection and earth fault compensation.

### *C. Discussion*

One main aspect and guiding principle in the development of the criteria has been the fact that the criteria are based on areas, not on the present distribution network. This will definitely lead to modification in the present network structure. For instance in an urban area, overhead lines will be removed, or they will at least be renovated into weatherproof structures. Moreover, the question of the efficiency of operative activities will be discussed. The length of interruption observed from the customer perspective is not only affected by network structures but also by fault location, isolation and fault repair activities.

## IV. Categorisation of Area Units

In the project on developing criteria for the reliability of electricity supply, a categorisation of three area units was suggested: city, urban area and rural area. A categorisation of this kind is clear and rational, and moreover, corresponds to the categorisation used previously as a basis in fault statistics. A significant difference is, however, that the previous categorisation was made based on the cabling rate, whereas in the project on developing criteria for the reliability of supply the target was to develop a categorisation that is independent of the electric power network.

First of all, the categorisation of area units should be as unambiguous as possible, and it should be easily implementable to the information systems. Special emphasis has been placed on the distinction between an urban area and a rural area, as there are significant differences between these areas in the target criteria for the reliability of supply, and network development in an individual area essentially depends on the category to which this area belongs.

In the implementation of the categorissation of area units, it is recommendable to utilise the information provided by the CORINE Land Cover (CLC) project[1], as this information is already available. The present CLC database illustrates the situation prevailing in 2000, and the database to be completed in 2010 will demonstrate the situation in 2006. The database illustrates the land cover in 25m x 25m squares, that is, in raster format, where each colour code represents the land cover in the square. The CORINE land cover nomenclature is extensive and it can be applied in various alternative ways; however, from the perspective of the supply reliability criteria, essential are the CLC unit areas ‘continuous urban fabric’, ‘discontinuous urban fabric’ and ‘industrial or commercial units’ [8].

A benefit of the CLC database is that it is freely available an easy to combine with existing information systems. A further benefit is that the Finnish Energy Market Authority suggests the use of the CLC database when determining the excavation conditions in underground cabling. However, information in the database is fragmentary, and this problem should be solved by establishing general rules for the minimum surface areas. In the EU, the minimum unit mapping size has been set at 25 hectares. Obviously, these units will be suitable for distinguishing urban areas from rural areas, even though the borders of these units will not necessarily coincide with the borders of the areas covered by town plans. However, the CORINE land cover nomenclature is not suitable for the category of city in the suggested categorisation, as there are no 25 ha areas in Finland that would belong to the category of continuous urban fabric. A further weakness of the CLC data is that unlike a provincial master plan, they do not illustrate the current situation but conditions several years ago.

## V. Analyses

The reliability analysis performed by means of reliability calculation is a part of continuous network design process. In these studies, analyses are based on actual network and fault statistic information of the Finnish distribution companies. The main target of the analyses has been on the definition of reasonable limits applied in the criteria for the duration of supply interruptions experienced by customers. The analysis has been done also to estimate the effects of different network developing technologies on supply reliability. For the definition of the design parameters, it is important to determine the values for the failure rates of the network components as accurately as possible; for instance the differences in the failure rates are a reason for applying plastic-covered PAS overhead lines instead of bare overhead lines. Also the determination of times required for fault isolation, switching of backup supplies and fault repair is a part of the preparations for the reliability calculation.

In the analyses, the starting point has been the present network structure. In Fig. 4, a medium-voltage feeder of the case network and the estimated cumulative interruption times for customers (within the distribution

[1] CORINE (Coordination of information on the environment) programme of the European Commission is ‘an experimental project for gathering, coordinating and ensuring the consistency of information on the state of the environment and natural resources in the Community’ (Official Journal L 176, 6.7.1985)

substation) are presented. The background data consist of the distribution of actual faults (over 5000 fault cases in 8 years, the repair time being 3 hours on average). The locations of faults are simulated based on data of the present network structure (an overhead line in forest or by the roadside, a covered conductor etc.). One challenge in the analyses is the uncertainty in reliability; the number and locations of faults vary greatly from year to year. Therefore, long-term fault statistics play a significant role in the analyses. The simulation methodology is discussed in more detail in [9].

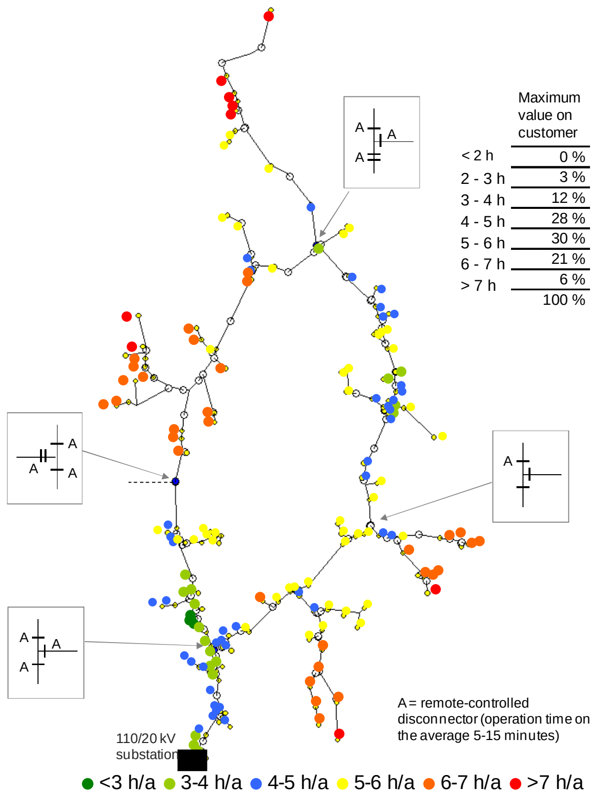


Fig. 4. One medium-voltage feeder of the case network and estimated cumulative interruption times for customers (in distribution substation).

## VI. Summary and Conclusions

In Finland, the Finnish Energy Industries (ET) together with electricity distribution companies has decided to reform the monitoring practices and criteria for the reliability of supply. The criteria cover the customer-based cumulative sum of durations of long interruptions and the cumulative number of short interruptions. The targets vary for different areas (city, urban and rural areas), and they are linked to areas, not to the present network structure. The customer–specific area classification is based on CLC data (Corine Land Cover). In the proposed criteria, the reference period is three years, and during that period, one exceeding of the criteria is allowed.

The criteria will pose new challenges to the distribution companies in the near future. At first, customer–specific monitoring and reporting in particular will certainly be a demanding (yet not unsolvable) task. The period of implementation of the proposed criteria has to be long enough so that companies are able to adopt the required changes to the network structures and information systems. From an electricity end-user point of view, commitment to comprehensive reporting will improve customer service. Wide-scale implementation of AMR meters will provide data that can be adopted to reliability statistics and analyses.

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