MODELING THE INTERRUPTION CRITICALITY OF CUSTOMERS OF DISTRIBUTION NETWORKS

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ABSTRACT

The dependency on the supply of electricity varies very much between different customers of the distribution networks. Thus it would be reasonable to determine the most important customers and to take these also into consideration in repair actions and network investments. Present-day models used in the economic regulation of the Finnish distribution system operators (DSOs) and in the Finnish legislation are rather poor for modeling this criticality. By combining the best features of these present-day models and new models introduced in the literature, a new model of interruption criticality has been formed and is presented in this paper.

Determining and utilizing the criticality models is challenging. However, if this could be done in the cooperation of all the responsible stakeholders, not a DSO alone, all will also get benefits. In this paper a proposal for this kind of procedure is introduced, mainly from DSO's point of view.

INTRODUCTION

It is obvious that the electrical equipment and operations of different customer types of distribution networks vary much from each other. Thus the dependency on the supply of electricity could be rather various among different customers: while someone's operations may suffer a great deal from interruption even shorter than one second (e.g. industry and hospital), another may stand without electricity for several days (e.g. households). Consequently, it would be reasonable to take this interruption criticality of different types of customers into account when prioritizing restoration actions after disturbances and also in network planning.

In Finland, there is an ongoing research project, whose objective is to develop the management of major disturbances in the supply of electricity. The research partners in the project are Tampere University of Technology (TUT) and Technical Research Centre of Finland (VTT). As cooperation partners, there are the National Emergency Supply Agency (NESA), four distribution system operators, two departments of the fire and rescue services and a software house. One task of the project, is to study how the interruption criticality of the customers can be determined and modeled especially concerning the wide and long-lasting blackouts. The task is very complicated including many challenges such as modeling itself, legislative issues, issues related to responsibilities, privacy protection, determining the critical duration for interruption, et cetera.

There are different ways to model the interruption criticality of the customers, and several ways to utilize these models. In this paper, different methods for modeling the customer interruption criticality, applying them for different purposes and challenges of this whole process are analyzed. As the most important research results, new methods for both modeling the criticality and utilizing this information, especially in order to improve the preparedness for major disturbances in the distribution of electricity, are introduced.

MODELING THE INTERRUPTION CRITICALITY

Present-day modeling in Finnish regulation

From the beginning of the year 2008 the particular interruption cost parameters (the money value for the disutility caused to a customer by interruption or autoreclosing) are used in the economic regulation when calculating the acceptable profit of a distribution system operator (DSO) in Finland. Thus the DSOs as well use them to some extent in network planning and repair actions when optimizing costs. The total interruption costs are calculated multiplying these parameters by conventional reliability indices, like SAIDI, SAIFI and MAIFI weighted by annual energies. Only medium voltage (1-70 kV) interruptions are considered. Interruption cost parameters are combined, which means that the same values are used for all interruptions although the variability of customers' energy behavior has been taken into account when determining these parameters. Table 1 shows these parameters (in the money value of 2005). Combined parameters are used because the reliability indices gathered by the regulator do not include the information about the interruption statistics of different customer groups. [1]

Table 1 Interruption cost parameters used in the economic regulation of Finnish DSOs [1].

Unexpected interruption		**Planned interruption**		**High speed AR**	**Delayed AR**
€/kW	€/kWh	€/kW	€/kWh	€/kW	€/kW
1.1	11.0	0.5	6.8	0.55	1.1

Calculating the total interruption costs using parameters and indices of this kind creates a great incentive for DSO to target the network investments and restoration operations after disturbances in the areas of big consumption. In other words, the current regulation model states that the bigger consumer of energy a customer is, the more critical for interruptions it is. Consequently small even if very critical customers, like home care patients, are more or less ignored.

Present-day modeling in Finnish legislation

Current interruption cost modeling used in regulation is also valid only for interruptions lasting not more than a few hours. Longer interruptions are taken into account by standard compensation practice (also considered in regulation). This means that a customer is entitled according to law to standard compensation for continuous interruption if the interruption time exceeds certain duration (12, 24, 72 or 120 h). The compensation is certain percentage (10, 25, 50 or 100 %) of the annual system service fee of the end-user in question. In any event the maximum amount of annual compensation is 700 euro per user. Figure 1 illustrates the stepwise increasing function of standard compensation. [2]

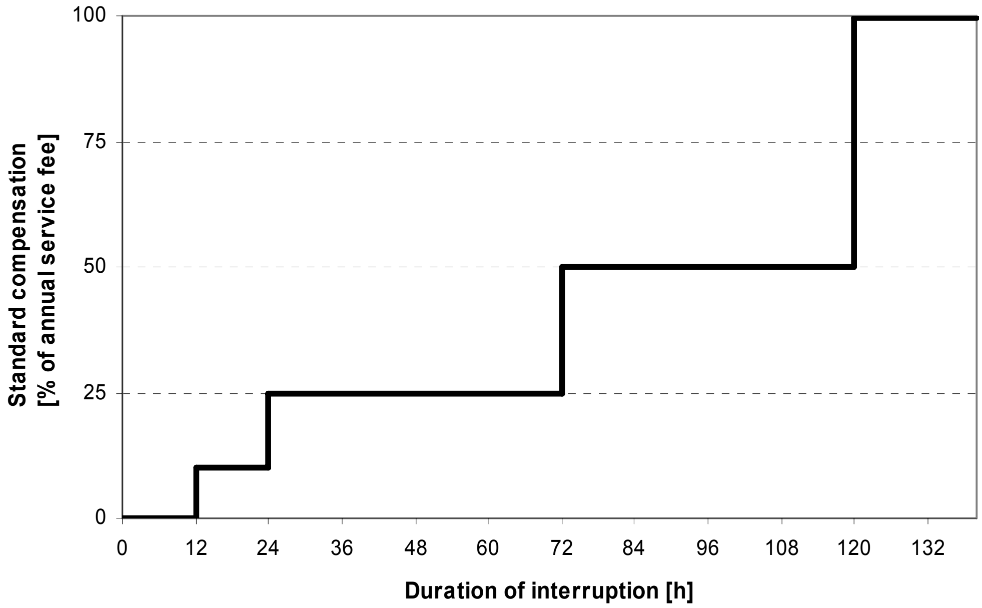

Figure 1 Function of standard compensations for interruption [2].

In a way, the standard compensation function models the interruption criticality of a customer rather logically: when certain time limit is exceeded the interruption turns more critical. A few weaknesses in this model can be found however. The first is that again the bigger consumer of energy a customer is, the more critical for interruption it is because criticality (compensation) is determined by the annual system service fee. The second one is that despite the customer the critical duration of interruption is the same. One more shortage in the standard compensation practice is the fact that the set time limits do not seem to be based on any research results but have just been decided to be the values they are nowadays.

New models

A new, more customer-oriented reliability index, customer dissatisfaction index (CDI) has been introduced in 2007 in [3]. CDI is defined as the probability that a customer is dissatisfied with the reliability of the electricity supply, and therefore describes better single customer's experiences than the other average indices. According to [3] there seems to be quite a sharp threshold value to customers' satisfaction. In [4] two different satisfaction criteria have been presented: one for domestic customers and one for important customers (industry, hospitals, nursing homes, supermarkets, et cetera). The reliability of electricity supply is considered insufficient for domestic customers if at least one interruption longer than eight hours or more than three interruptions have been experienced per year. For important customers, the limits are one hour and two interruptions, respectively. Short interruptions, three minutes or less, were excluded from the study. In figure 2, this is illustrated as areas of sufficient and insufficient reliability.

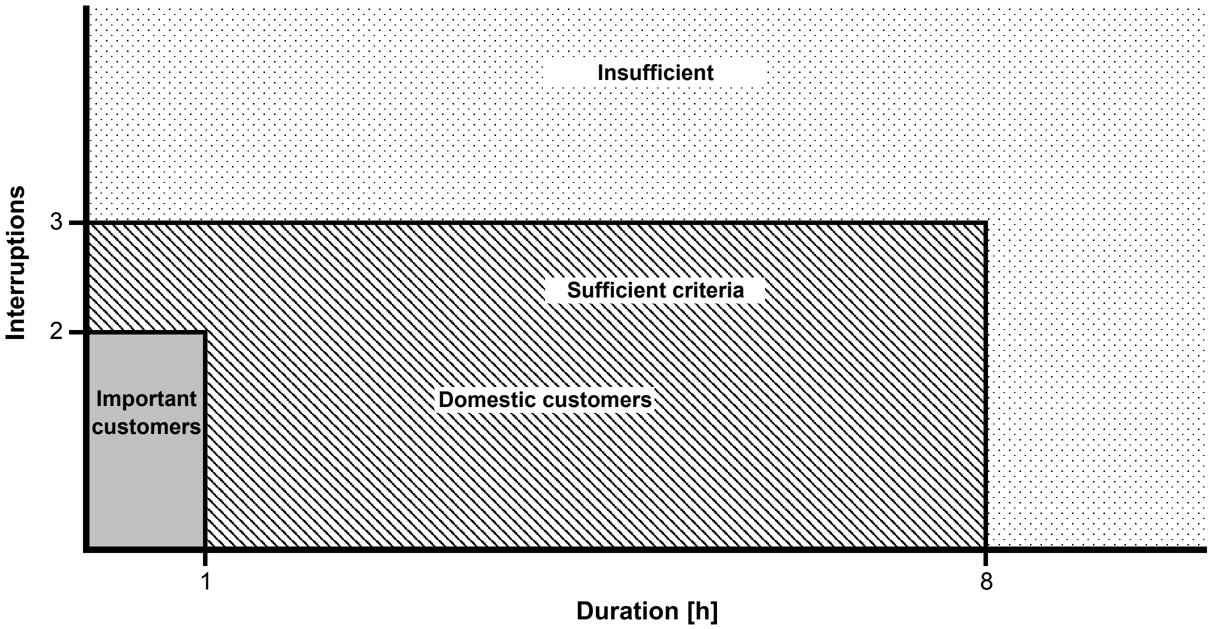

Figure 2 The dependency of customers' satisfaction on number of interruptions and duration of those [4].

Concerning long-lasting interruptions CDI models the criticality of a customer similarly as standard compensation practice does: after certain duration, the interruption turns more critical. However, the interruption criticality model of CDI is not consumption dependent – customers are purely classified as domestic customers and others (important ones). Thus, the variety in the interruption criticality of different customer groups has also been considered in CDI to some extent. Unlike standard compensations, the threshold values of CDI models are based on former research results.

In Finland, the Finnish Energy Industries association together with DSOs has decided to implement a new supply reliability criteria as planning criteria into long-term network development. The criteria cover cumulative sum of duration of long interruptions and number of short interruptions (less than three minutes) experienced by a customer per year. Thus, the concept is rather similar to criteria given with CDI. However, in the new criteria different customers are not classified according to their importance but according to their location. Customers will be divided into three groups: city, urban and rural area customers. This classification is based purely on community structure, not on present network structure as usual. In figure 3 targets of the new criteria are presented like the threshold values of CDI in figure 2. Given values are based loosely on the statistics of a few DSO and the comprehensive simulations of the research group. One exceeding to the criteria is allowed per one reference period (three years). The criteria model is presented in more detail in [5].

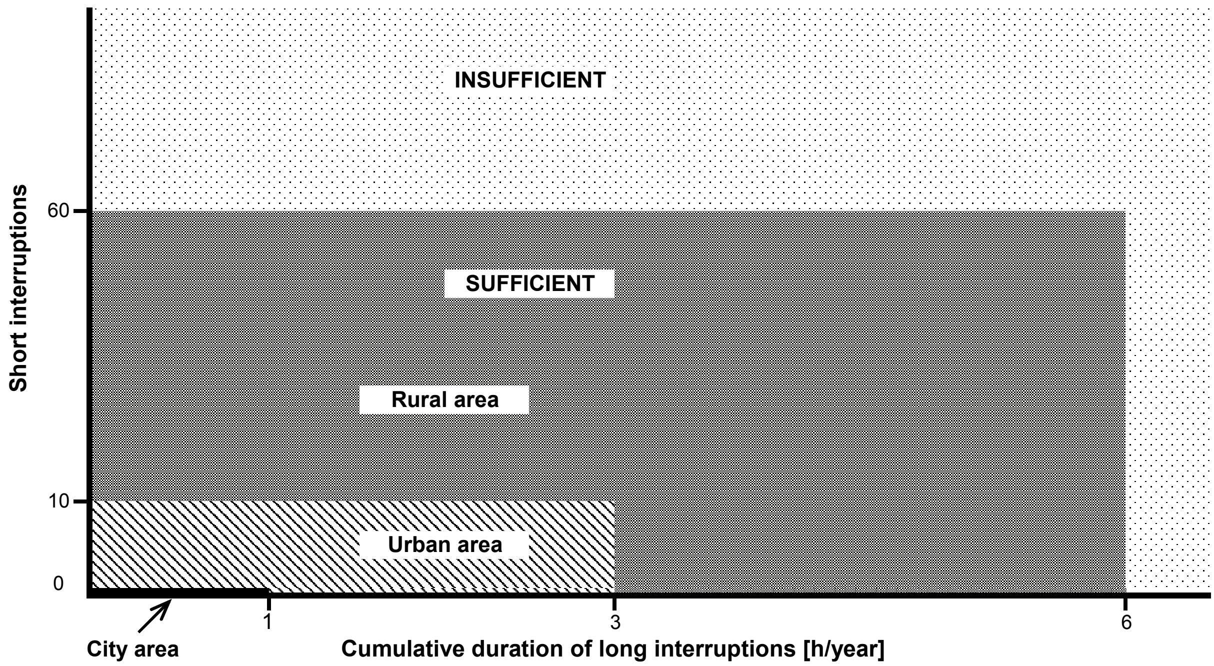

Figure 3 The dependency of sufficient reliability on number of short interruptions and cumulative duration of long interruptions [5].

From the interruption criticality modeling point of view, the model given by the new criteria is poor. Target values only depend on location of a customer although the consequences of long interruption in rural area for an individual customer could be much more severe than in urban or city area in some cases. Furthermore, the cumulative duration of interruptions experienced per year is not as good target value for modeling criticality as the duration of a single interruption like used in CDI. However, classification of this kind is reasonable for improving the reliability of supply in general. Unequal target values for different areas may herein be justified by the already existent variance of reliability between different areas. Thus, the present state will not turn worse. Other public services, like water supply and sewerage, and fire and rescue services, have this variance between different areas as well.

Future modeling?

The models for the interruption criticality of a customer presented above, have all some pros and cons. The model used in the economic regulation of the DSOs is reasonable for interruptions lasting a few hours, as mentioned, and it also considers the disutility for the customer immediately from the beginning of an interruption. However, it models the criticality as an increasing linear function, which means that no critical duration of the interruption for a customer has been defined. Other models mentioned do not contain the feature that the criticality can get a value immediately after interruption has started but the critical duration of the interruption for a customer is included in the models. In the model of new reliability criteria, also the conditions of a customer are considered in a way.

The proposal for improving the criticality model is to combine the best parts of each model. In fact, this kind of combination method has already been used in analyses in [4], where CDI has been used alongside conventional reliability indices (SAIFI, CAIDI, etc.) in calculations. In figure 4 a new, combined model (broken line) for modeling the interruption criticality of a customer in long-lasting interruptions is illustrated graphically. Also the linear model used in present regulation is presented in the figure (solid line). One should notice that real values are not under consideration herein, but only the shapes of these diagrams.

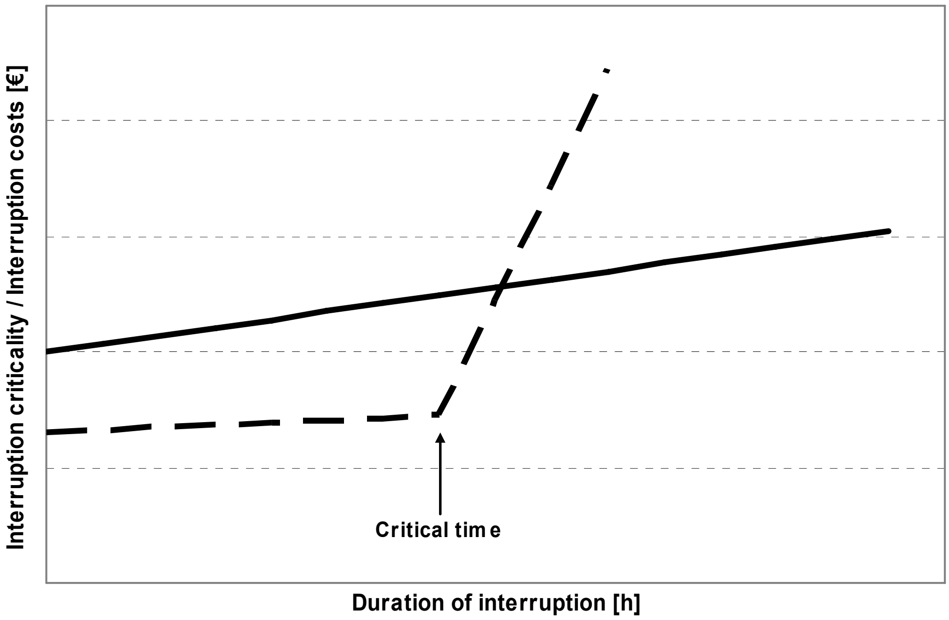

Figure 4 Proposal for new interruption criticality model illustrated in parallel with model used in present regulation.

In the new model, an initial value for criticality at the beginning of interruption is defined similarly as in the regulation. However, this value could be somewhat lower than in the linear model. This can be explained that the consequences of interruptions are of minor inportance during a certain period in most cases. After this period without electricity, the interruption turns more critical. To pick a few examples: running out the backup batteries or fuel of the reverse generator in a base station of the telecommunication network, running out the backup batteries of the respirator of a home care patient, overflow in the sewerage system, melting of the frozen food, et cetera. This critical duration is pointed out in the diagram. After that duration, the slope of the curve suddenly increases substantially, which illustrates the increase in disutility for a customer.

All different types of customers should have an own specific model that would contain initial criticality value, critical duration, and slopes before and after the critical time. In order to make the models even more accurate, the effects of different circumstances and point of time should be included in these models because in some cases the critical duration varies very much depending on for example temperature outside and which day it is that time. Obviously creating this kind of model for all types of customers is not too easy a task to carry out at all (see the chapter beginning from page 8).

DETERMINING AND USING CRITICALITY INFORMATION IN DISTRIBUTION COMPANIES – PRESENT STATE

All the Finnish DSOs have classified their customers at least to some extent. A rough plan at area or feeder level is obligatory to be done for serious power shortage situations in Finland. In case of a serious power shortage the Finnish transmission system operator (TSO) Fingrid contacts DSOs to take actions to restrict loads according to these plans [6]. A DSO participating in this project has done this prioritization by giving firstly points to all different customers. Then points are calculated at distribution transformer level and after that at feeder level. All the functions vital to society and DSO’s own operations have been excluded from these restrictions. Since the prioritization has been done for power shortage situations, which means interruptions lasting not more than a few hours, its suitability for long-lasting interruptions may be poor.

It is very common that operating personnel of DSOs know the most important customers of the network from the DSO’s point of view. These are often big consumers, like industry. More experienced employees may also know some small but still critical customers, at least in small distribution companies. It is possible that this information may disappear when these employees retire or leave the company for some other reason. Therefore information about the important customer would be reasonable to store also into databases.

One research method in this project, in addition to the literature review and workshops, has been questionnaire study for 86 Finnish DSOs. In total, 51 replies were received including one representing two DSOs within the same energy corporation. Response rate was thus 52 out of 86 that means about 60 per cent. According to answers, critical customers are known by the personnel to some extent in 62 per cent and comprehensively in 30 per cent of the DSOs. The information has been stored into the databases to some extent in 40 per cent and comprehensively in 12 per cent of the DSOs. Multiple answers were herein possible, which means that it was also allowed to answer both known by personnel and stored into the database. Almost every DSO (94 %) prioritizes its repair actions with the help of this criticality information. Major part uses it when allocating investments (70 %) and in power shortage situation (64 %). Minor part uses it also when prioritizing reserve power resources (34 %), when allocating resources for informing customers (10 %) and in the practices (2 %). Surprisingly many companies also take the information about customer’s reserve power into consideration when determining the criticality of the customers (comprehensively 8 %, to the extent that existence of reserve power is known 49 %).

The per cents about storing the criticality data in databases tell nothing about how usable this information is. For example in a small distribution company in Finland only the location data of the important customers is defined, and there is no linkage between it and the network information system. Thus, it is impossible to get any automatic alert about the interruptions of these customers.

As an example of storing the criticality information comprehensively into the database, a big Finnish DSO could be mentioned. It has classified its whole clientele excluding domestic customers. Customers are classified by two different parameters. First of these is classification by the field of activity of a customer (health service, industry, agriculture, etc.). The second one is defined basically by the power consumption of the customer. From this point of view the classification model is similar as used in economic regulation of the DSOs. This classification is not yet implemented.

Figure 5 illustrates the present state of utilizing the criticality information in DSOs. Herein only criticality determined by DSOs themselves is considered, and thus the effects of the regulation, standard compensations and use of them in reliability analysis are excluded from the flow chart. First, one or a few representatives of a DSO classify the customers and this information is uploaded to the database. This subjectively determined information is then used in load shedding plans for the power shortage situations, repair action prioritization and network investment allocation.

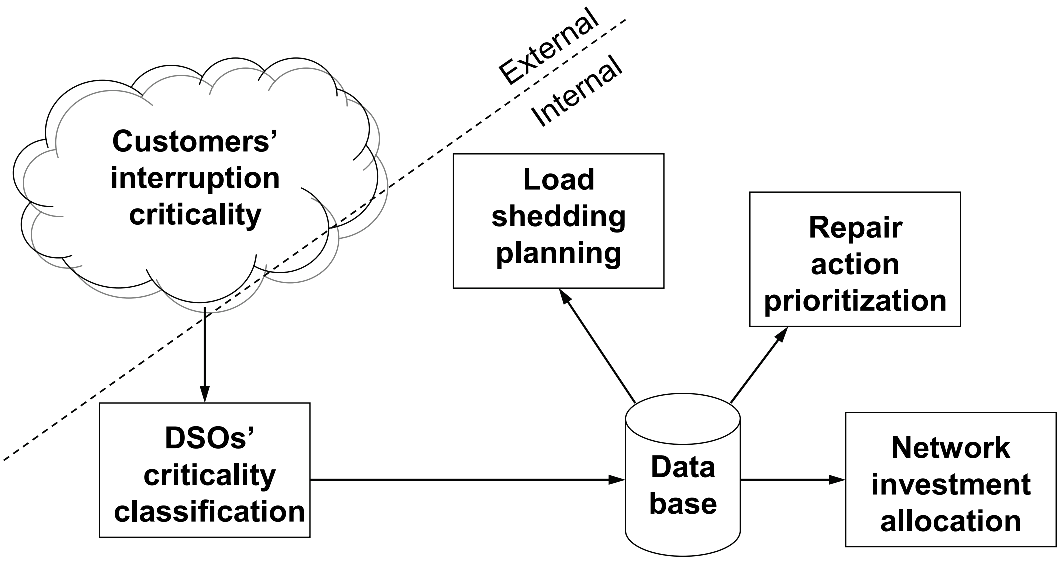

Figure 5 Flow of information about the interruption criticality nowadays.

The cloud in the flow chart represents the "vagueness" of the criticality information. It really depends on the perspective from which the criticality is considered. Nowadays DSOs basically do this by themselves inside the companies. Information about this prioritization may not be delivered to customers or other stakeholders.

CHALLENGES OF DETERMINING AND USING CRITICALITY INFORMATION

Legislation

The Finnish Electricity Market Act [2] states that DSO should secure the supply of sufficiently high-standard electricity to its customer by its own operations. On the other hand, in the Act and in its preambles, it has been emphasized the impartial and non-discriminatory treatment of customers when considering connection conditions and technical requirement, sale prices and the terms of system services. This may be easily understood that the reliability of the power supply should be equal for every single customer of the network. However, the customers can not be treated totally equally because the quality of supply varies depending on the network structure. Thus operating in accordance with the Act may be somewhat problematic and maybe should be clarified for these parts.

Another challenge may be the issues related to the confidentiality: to what sort of information for example DSOs are allowed to have access? This issue is one reason (with other legislative limitations) why the information about the critical customers concerning the security of supply in general defined by NESA is not yet available to DSOs [7].

Responsibility issue

One problem of determining and using interruption criticality information is the responsibility issue: Who is responsible for determining the interruption criticality of customers, and who will maintain and update this information?

In the workshops of this project (see introduction) it has been discovered that this task should not be neither customers' nor DSOs' responsibility. It is probable that many customers might see their own operations very critical and might estimate their own preparedness for interruptions very low on purpose. Vice versa, there could be also a risk that a customer does not understand one's own vulnerability and thus feels beeing prepared enough for interruptions. For DSOs this kind of task and maintaining this criticality information have been seen to be too big workload to carry out.

Thus the municipalities and/or authorities responsible for certain field should execute this determination process. Method of this kind has already introduced and tested in Sweden in a project called Styrel, organized by the Swedish Energy Agency. In that project, solutions for the prioritizing customers in the case of power shortage have been researched. In the proposed operations model, municipalities in cooperation with DSOs classify the network at feeder level. After this, a report about the prioritization process is prepared and given to county government where the final decision will be made. [8]

Determination itself

Determining the interruption criticality of customers is a very complicated process: What is the real critical interruption time for customer's operation? How the consequences of interruptions should be valued, i.e. why someone is more critical than another? Should the reserve power and other preparedness of a customer taken into account when prioritizing customers?

Determining the critical duration of interruption accurately is impossible in most cases. And as mentioned weather conditions and point of time may have an effect on critical duration. Also prioritizing customers correctly from all perspectives is more or less impossible because the consequences caused by lack of electricity may differ completely from each other: in some cases some one's life may be jeopardized, whereas some one else may encounter massive financial losses.

Taking the preparedness of a customer into account in the prioritization process is rather conflicting. On one hand reserve power plants and other preparation should be considered when determining the critical duration of interruption and thus also the priority class of a customer. On the other hand this kind of procedure would punish in a way the customer about preparation because the determined critical duration of interruption would be longer and thereby the priority class might be lowered. In above mentioned Styrel project reserve power has no effect on prioritization. According to [8], one more disadvantage could be negative effect on the future reserve power plant purchases if it will be punished that way.

UTILIZING THE CRITICALITY INFORMATION IN FUTURE

As said, DSOs seem to be very critical against the fact that they should on their own determine interruption critical customers, model the customers' criticality, classify them into criticality classes and maintain this information. Thus it should be the responsibility of some other stakeholder. If supposed that the information about the criticality of the customers was available somehow, the utilizing process from the DSO's point of view could be the following:

1) DSO gets access to the needed information (e.g. criticality class, critical duration, possible reserve power and location) about interruption critical customers of its network area. This information could be available for instance in a portal.
2) DSO uploads this data into their own database.
3) With the help of statistics and reliability analysis probable interruption frequency and durations of these customers could be evaluated.
4) Benefits achieved from previous mentioned actions would be:
    a. Customers whose critical duration might be exceeded can be informed and advise to be prepared for interruption durations estimated in calculations. Also other possible stakeholders (e.g. fire and rescue services) should be informed about these customers for example via portal.
    b. In a case of major disturbance, if the critical duration of the customer is exceeding or is about to exceed, an automatic alert from DMS (distribution management system) would be seen by all responsible stakeholders via portal.

Figure 6 illustrates the procedure.

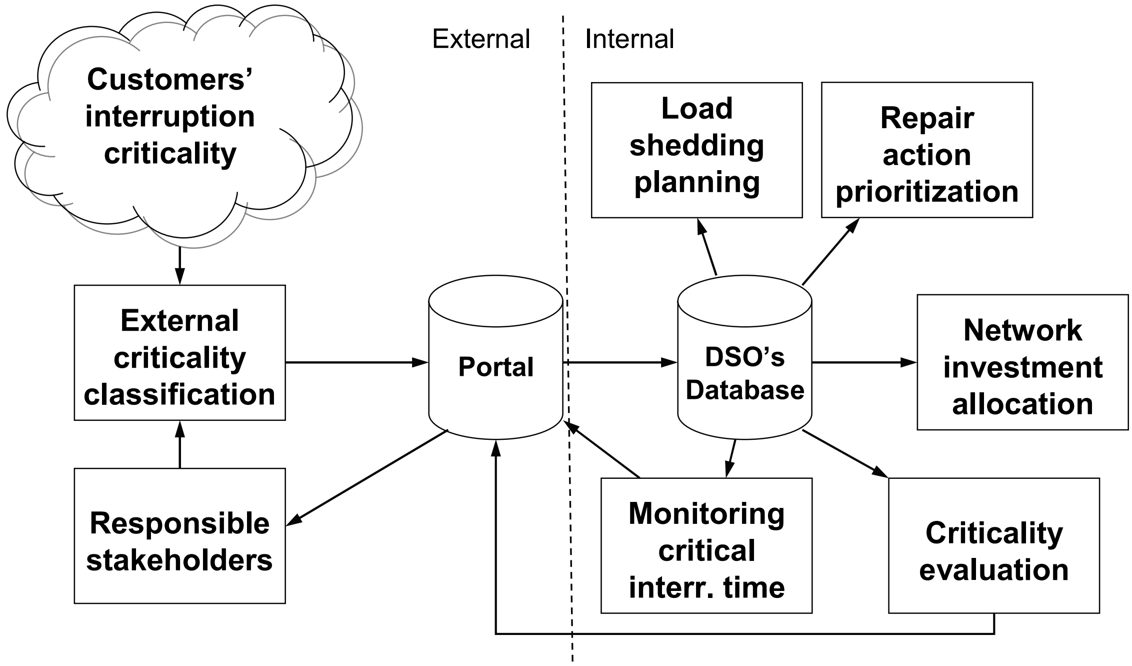

Figure 6 Flow of information about the interruption criticality in the future.

Delivering criticality information to all responsible stakeholders both beforehand and during the disturbances was seen rather important by DSOs in the questionnaire study carried out in this project. For example, providing DSOs proactively with the information about the critical duration of the interruption for the components of the telecommunication network (battery endurance and reserve power) was rated on average as 4.25 when the scale was from one to five (1 = not important at all, 5 = very important). Informing the authorities of special health care responsible for home care patients about the duration of interruptions was rated as 3.88.

It was mentioned above that the information could be delivered via portal. A prototype of a portal of this kind will be the main output of this project. The objective of the portal is to help the responsible stakeholders in creating a common operational picture and thus to help they to communicate more effectively in the major disturbances in the supply of electricity. This system is introduced in detail in [9].

Obviously the procedure presented in the figure 6 is a very valuable in delivering more information about the interruption criticality of the customers both for preparation beforehand and restoration actions in the real situation. However the criticality models determined by for example local authorities are maybe too subjective and thus may not be utilized in the regulation. Modeling for regulation should be done at a national level and should be straightforward. At least considering the reserve power should be ignored.

Concerning the power shortage situations the prioritization of restrictions (i.e. load shedding) can be done more specifically by the means of advanced metering infrastructure (AMI). Restrictions will be possible to be made selectively, which means that for example one customer group, like only domestic customers, can be within restrictions.

CONCLUSIONS

Determining and modeling the interruption criticality of the customers of distribution networks is a very complicated task all in all. Present models in the Finnish economic regulation and legislation are rather poor from this point of view. Only average values are used (regulation), time limits are based on no research results (standard compensation) and the criticality depends strongly on the power consumption of the customers (both). Thus new innovations, like CDI, are very welcome improvements on this sector. However, CDI alone is not a comprehensive model. Hence some combination of these models should be formed. In this paper, a draft about the new model of interruption criticality combining the best parts of each present model has been introduced. To make this model more accurate, further study is needed.

Determining and utilizing the interruption criticality of a customer needs more cooperation between responsible stakeholders. A procedure tested in project Styrel in Sweden might be a good base for a pilot project where the procedure proposed above could be tested to some extent.

In order to get the best penetration of using criticality information it should be included in the economic regulation of the DSOs. Obviously many challenges will be confronted. Statistics should be more accurate and interruptions also in the low voltage network should be considered, which could be executed with the help of AMI. Of course, the biggest problem will be the differentiation of reliability: Why some customer is privileged to receive better quality of the supply than another although the service fees are basically the same?

REFERENCES

[1] Finnish Energy Market Authority, Sähkön jakeluverkkotoiminnan hinnoittelun kohtuullisuuden arvioinnin suuntaviivat vuosille 2008-2011 [Guidelines for Assessing the Reasonableness of the Pricing of Electricity Distribution Network Services in 2008-2011; in Finnish], Helsinki, Finland, 2007.

[2] The Finnish Electricity Market Act 368/1995.

[3] M. Bollen, A. Holm, Y. He, P. Owe, A Customer-Oriented Approach towards Reliability Indices, The 19th International Conference on Electricity Distribution (CIRED 2007), Paper No 0134, May 21-24, 2007, Vienna, Austria.

[4] A. Holm, J. Pylvänäinen, P. Owe, H. Paananen, M. Bollen, Customer Dissatisfaction Index (CDI): Pilot Use in Network Planning, The 20th International Conference on Electricity Distribution (CIRED 2009), Paper No 0367, June 8-11, 2009, Prague, Czech Republic.

[5] J. Lassila, T. Kaipia, J. Haakana, J. Partanen, P. Verho, P. Järventausta, J. Strandén, A. Mäkinen, New Finnish Supply Availability Criteria, 9th Nordic Electricity Distribution and Asset Management Conference (NORDAC 2010), September 6-7, 2010, Aalborg, Denmark, accepted.

[6] Fingrid, Web pages in English [Online]. Available: http://www.fingrid.fi/portal/in_english/

[7] J. Strandén, V.-P- Nurmi, P. Verho, M. Marttila, State of Preparedness of Finnish Society for Major Disturbances in Distribution of Electricity, International Review of Electrical Engineering (I.R.E.E.), Vol. 4, N. 2, April 2009, pp. 211-219.

[8] Swedish Energy Agency, Prioritering av elanvändare vid elbrist – Slutrapport från Energimydigshetens Styrel-projekt åren 2004-2007 [Prioritizing electricity customer in power shortage situation – Final report from Swedish Energy Agency's Styrel project in 2004-2007; in Swedish], ER 2007:38, Eskilstuna, Sweden, 2007.

[9] H. Krohns, J. Strandén, P. Verho, J. Sarsama, Developing Communication between Actors in Major Disturbances of Electric Power Supply, 9th Nordic Electricity Distribution and Asset Management Conference (NORDAC 2010), September 6-7, 2010, Aalborg, Denmark, accepted.