Praise Worthy Prize

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Influence of Major Disturbances in Electricity Supply on the Operating Environment of Distribution System Operators: a Case Study

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Abstract – *Several major disturbances in the supply of electricity have taken place in Finland during the last decades causing significant problems in different operations of the modern society. Consequently, many measures have been taken in order to improve the preparedness of the society against these kinds of events. Tightening of the economic regulation of distribution system operators (DSOs) and changes to electricity market legislation are changing the operating environment of DSOs. In order to be sufficiently prepared against prospective major disturbances, in addition to network investments, DSOs need to develop their communication and cooperation with other actors, inform their customers better and take societally critical customers into account in their plans. Thus, the whole process will be much more complicated and just optimizing the total costs will not be enough in the future.*

***Keywords**: Interruption, Major Disturbance, Outage, Preparedness, Power System Reliability, Societal Problem*

I. Introduction

The dependency of society on electricity as well as the consumers' expectations concerning the security of power supply have increased and are still increasing. At the same time, many weather-related major disturbances in the supply of electricity have taken place in distribution networks in Finland.

These wide and long-lasting interruptions have caused remarkable problems in the operations of the modern society [1]-[5]. Consequently, shortcomings have been found in the preparedness of both the responsible actors (e.g. distribution system operators (DSO), fire and rescue services, municipalities), and citizens.

These events have also received great attention in the media leading to wide public discussions on the subject and have initiated many measures to improve the situation, including legislative amendments [6], [7]; tightened economic regulation of DSOs [8]; actions among DSOs, and some other actions. Hence it really seems that DSOs' network planning and other operations will be more complicated than not only an optimization of total costs in the future. DSOs are not, however, the only responsible actors in the field whose operations in major disturbances should be developed. Also communication and cooperation between all these actors need more development [9]-[12]. The study presented in this paper has been made as part of two research projects – 'Development of the Risk Analysis and Management Methods in Major Disturbances in the Supply of Electric Power' and 'Smart Grids and Energy Markets (SGEM)' – both funded for the most part by the Finnish Funding Agency for Technology and Innovation (TEKES). The former was carried out by Tampere University of Technology and VTT Technical Research Centre of Finland in Tampere during 2009-2011 and the latter is a national research program carried out in Finland during 2009-2014 and coordinated by Cleen Ltd (Cluster for Energy and Environment). The main research method in this study has been literature research. The questionnaire study carried out in the former project and workshops of both projects have generated good input material for this research as well.

The main objective of this paper is to present what kind of measures major disturbances in the supply of electricity experienced since 2001 have initiated, and consequently how the operating environment of DSOs has changed and is still changing. The focus is on distribution networks and major disturbances caused by severe weather conditions.

Issues considered are mainly from a Finnish point of view but some supporting examples are presented also from Sweden. Firstly, the term 'major disturbance in the supply of electricity' is clarified and some definitions for it are presented. Section III contains some case examples of major disturbances and their societal consequences.

In Section IV, different measures taken in order to improve the preparedness against major disturbances are presented.

Section V shows what is at the moment under development in the field. Finally there is a discussion section with some conclusions.

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II. Definition of a Major Disturbance

The concept of a major disturbance in the supply of electricity is typically defined in a very technical and electric power system oriented way. For example in the IEEE Standard major disturbance (major event) is defined as follows:

"***Major Event:*** *Designates an event that exceeds reasonable design and or operational limits of the electric power system. A Major Event includes at least one Major Event Day.*"

"***Major Event Day (MED):*** *A day in which the daily System Average Interruption Duration Index (SAIDI) exceeds a Major Event Day threshold value. For the purposes of calculating daily system SAIDI, any interruption that spans multiple calendar days is accrued to the day on which the interruption began. Statistically, days having a daily system SAIDI greater than TMED are days on which the energy delivery system experienced stresses beyond that normally expected (such as during severe weather). Activities that occur on Major Event Days should be separately analyzed and reported.*" [13]

Finnish researchers have presented quite a technical definition as well:

"A major disturbance is a condition in which more than 20 % of the customers are without electricity, or the 110 kV line, the 110/20 kV primary substation or the primary transformer is out of operation for several hours because of a fault." [14]

The perspective of this study is to consider major disturbances not only as problems of DSOs but the whole society and from that point of view both previous definitions are poor. Major disturbances should not be excluded from the statistics and on the other hand the certain percentage of the network without electricity may have no correlation to the criticality of the situation. Thus in this study it is seen that the definition of major disturbance should be totally different:

A major disturbance is long lasting and/or a widespread interruption in the supply of electric power during which the fire and rescue services and one or more other public actor (municipality, police, etc.) need, in addition to the distribution system operator (DSO), to start implementing measures for reducing possible severe consequences to people and property.

Comparing this definition with the previous ones the difference of perspective can be easily seen – a major disturbance in the supply of electricity is not only a problem in the grid but also in many other operations of society. This kind of approach seems to be quite unusual in this field of engineering.

III. Causes and Consequences of Major Disturbances

The origins of major disturbances can be divided for example into two categories: interruptions caused by the weather (e.g. storms, snow loads, or lightning) and interruptions caused by other incidents (e.g. human error, wrong protection settings, or vandalism/terrorism).

Typically major disturbances in the distribution systems have been weather-related whereas major disturbances in the transmission systems have usually been caused by some other incidents.

As said, in this paper the main focus is in distribution networks in Finland, and thus some case examples of major disturbances caused by weather conditions in Finland are presented herein. As points of comparison, two case examples from Sweden are also presented.

III.1. Experienced Major Disturbances

The main characteristics of the most relevant major disturbances are shown in Table I. Based on this data, Gudrun storm (Sweden 2005) has evidently been the most devastating storm in this area, especially according to the costs and forest damages.

The longest interruptions caused by Gudrun were equal to durations in the 2010 storms in Finland, and thus it could be supposed that the level of destruction in the 2010 storms was quite similar to Gudrun but only in certain small areas. Even though the longest interruption durations and forest damages in the 2011 storms were under half of those as in 2001 or 2010, the expenses for the whole Finnish society were the most substantial ever.

TABLE I
MAJOR DISTURBANCES AS NUMBERS [1]-[4], [15]-[18]

Major disturbance	Amount of interrupted customers	Longest interruption experienced by a customer	Total costs of distribution system operators	Compensations paid by insurance companies	Forest damages
Finland 2001 (Pyry, Janika)	860,000	Over 5 days	Over 10 M€	n/a	Over 7 Mm^3
Finland 2010 (Asta, Veera, Lahja, Sylvi)	480,000	42 days	32 M€	81.5 M€	8.1 Mm^3
Finland 2011 (Tapani, Hannu)	570,000	Over 14 days	71 M€	102.5 M€	3.5 Mm^3
Sweden 2005 (Gudrun)	730,000	45 days	300 M€ (*	400 M€ (*	70 Mm^3
Sweden 2007 (Per)	440,000	10 days	140 M€ (*	55 M€ (*	16 Mm^3

*) *1 € = 10 SEK*

This is mainly because of location. The destruction area in 2011 was in southern Finland near the metropolitan area where the majority of the Finnish people live.

All these major disturbances have caused basically similar societal problems.

There have been interruptions in telecommunication networks (including the authority radio network VIRVE), problems in water supply and sewerage, and problems in farms with animals because many of them have had no reserve power. One of the big problems has been poor situation awareness of some main responsible actors (such as DSOs and fire and rescue services) mostly due to insufficient communication and cooperation.

The other problem has been in many cases insufficient information to citizens, for example no estimations about the duration of the outages have been given or they have been poor.

According to a consumer survey carried out after the 2011 storms the biggest problem for consumers seemed to be the unawareness of the expected duration of the interruption. [1]-[5], [17]-[19]

III.2. Major Disturbances in Interruption Statistics

The major disturbances can be seen in the interruption statistics as well. Fig. 1 shows the development of SAIDI in Finland during 1973-2012. Only permanent medium voltage faults are considered.

During 1973-2004, DSOs were categorized into two groups, rural and urban, depending on the rate of underground cabling of the network (less than 10 % and over or equal to 10 %, respectively) and the data was collected at the distribution transformer level. From 2005, the categorization is still based on the amount of underground cabling but at the feeder level (rural < 30 %, urban 30-75 % and city > 75 %). Also the data collected is more detailed because it contains actual interruptions experienced by the customers, not at the transformer level. [20]

The effect of storms mentioned above, as well as earlier storm years, can be easily seen as peak values in Fig. 1. According to statistics, 61 per cent of the interruption duration experienced by the customers was caused by weather conditions (83 % in 2011). Despite the changes in collecting the data, the direction of development in the past three years (particularly 2010 and 2011) seems to be very alarming especially in rural areas.

The vulnerability of the overhead distribution systems to weather conditions is evident. In addition, the percentage of overhead lines in the medium voltage networks in Finland is very high, 87 per cent. [20]

If the method of the above-presented IEEE standard, in which major event days are excluded from normal statistics, had been used, the trend curve of SAIDI would probably have been constantly decreasing from the seventies to present-day. This might lead a distorted image about the state of the reliability of supply in Finland.

IV. Measures to Improve Preparedness Against Major Disturbances

The severe consequences of the experienced major disturbances have initiated many actions in order to improve the preparedness of the society against these kinds of events. It is quite obvious that the legislator and regulator must have taken some measures but the DSOs themselves have also proactively carried out many actions to be more prepared for major disturbances.

IV.1. Legislative Amendments

The price reductions and compensations that were paid to customers according to the Finnish Electricity Market Act after the storms in 2001 were small and case-specific.

They were generally considered inadequate for covering the real losses experienced by customers [1].

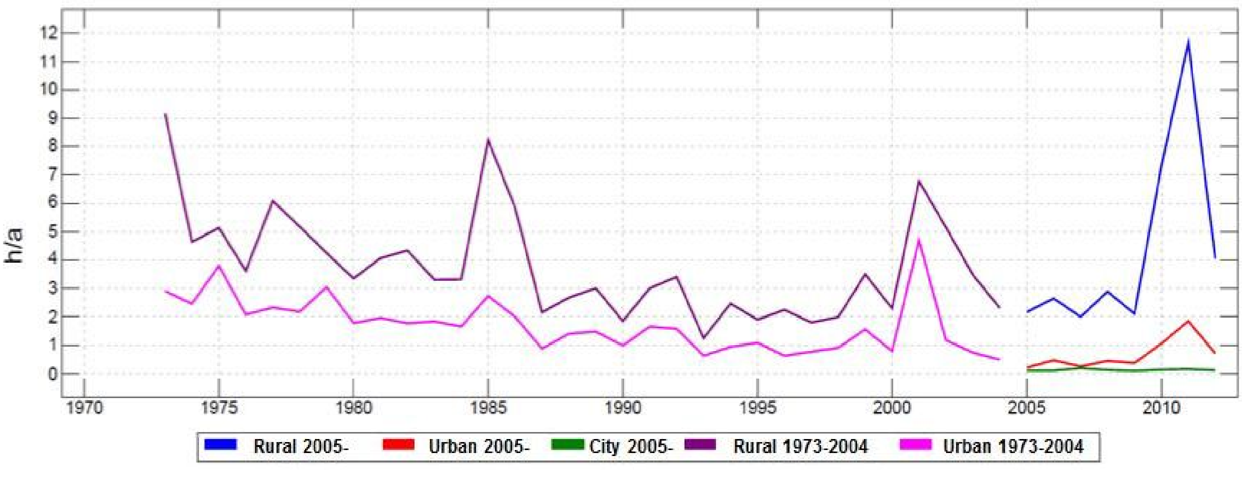

Fig. 1. Development of SAIDI (permanent faults) in Finland during 1973-2012 [20]

The status of a customer was improved by reforming the Act in 2003 with the so called standard compensation practice. According to this practice, a customer was entitled to a stepwise increasing compensation after an interruption lasting 12 hours or longer (10 - 100 % of the annual system service fee but 700 € at the maximum, see Fig. 2) [6]. A similar but stricter standard compensation practice was also added to the Swedish Electricity Act from the beginning of 2006.

At the same time, an obligation to prepare risk and vulnerability analysis and an action plan annually for improving the reliability as well as maximum duration of an interruption (24 hours from the beginning of the year 2011) were introduced in Sweden [21].

Due to the most recent storms and the consequent wide and long-lasting interruptions, the Ministry of Employment and the Economy proposed some amendments to the Finnish Electricity Market Act and to a few other related acts in March 2012. In August 2013, these proposals were, more or less unchanged, introduced to be part of the new Electricity Market Act.

The amendments are somewhat similar to those introduced in Sweden in 2006. Limit values for the duration of an interruption experienced by a customer were set. Maximum duration will be six hours in urban areas and 36 hours in rural areas from the beginning of 2029 (100 % of the customers). DSOs must prepare development plans to describe how these limits will be achieved. In order to facilitate the development of reliability, roadside cabling will be made easier and DSOs have the entitlement to preventatively clear forests near overhead lines. DSOs must also draw up preparedness plans for major disturbances and take part in emergency planning; cooperate with other actors, contribute local situation awareness and arrange an independent communication connection to other actors; inform customers about the reliability level of electricity supply in the customer's connection point, inform them how to be prepared for interruptions, and in case of a disturbance, tell customers how long the interruption will most likely last. Standard compensations will be increased by adding more steps and setting the maximum value gradually from 700 to 2000 euros by 2018. Fig. 2 illustrates the stepwise increasing function of standard compensations in Finland. In addition to these compensations, exceeding the limit value for the maximum duration of an interruption will lead to extra financial sanctions for the DSO. [7]

It is quite obvious that these kinds of changes arouse discussion and there are many opinions both for and against. This fact can be found in the comments on the proposals given by different authorities and some other actors requested by the Ministry of Employment and the Economy. In most of the comments, for example by the regulator, representatives of municipalities as well as telecommunications and consumers, the amendments were seen relevant and reasonable.

At the same time, the representatives of DSOs considered some of these changes too strict and unfair.

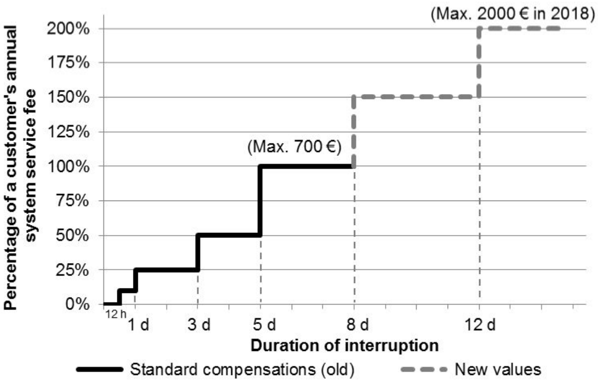

Fig. 2. Function of standard compensations [6], [7]

IV.2. Tightened Economic Regulation

Because DSOs operate as local monopolies, their operations are regulated. From the beginning of the second regulatory period (2008-2011) the regulation was tightened in Finland by also taking the interruptions (in the medium voltage networks) into account when calculating the acceptable profit of the DSOs. In addition to the power quality incentive, an efficiency incentive for each DSO was also added. Moreover, the standard compensations were included in the controllable operating costs, whereas they were earlier treated as pass-through components, and thus had no effect on the acceptable profit.

The value of interruptions is determined with the help of the energy weighted reliability indices of networks and interruption cost parameters defined in advance, and this is compared with the calculated reference values. Half of the interruption costs have an effect on the DSOs' acceptable profit via the power quality incentive and half of them affect via the efficiency incentive.

From the beginning of the third regulatory period (2012-2015), the maximum effect of interruption costs via power quality incentive was increased from 10 to 20 per cent of the reasonable return calculated for capital invested after taxes. In the second regulatory period, the efficiency incentive concerned only the controllable operational costs of the DSOs but nowadays also the interruption costs are included.

The new regulation model has some other changes as well, such as an investment incentive, a new model for efficiency incentive, and an innovation incentive that try to encourage DSOs towards a better reliability of supply (e.g. underground cabling) [8].

IV.3. Actions Among DSOs

Evidently, due to legislative amendments and tightened regulation, DSOs have had a need to develop their reliability of supply. However, along with their interest group, Finnish Energy Industries, the DSOs have also proactively taken many measures to improve the preparedness against major disturbances and to increase the reliability of the system.

The Finnish Electricity Association (nowadays Finnish Energy Industries) published the guidelines for a preparedness plan against major disturbances in 2002. Among other instructions the importance of cooperation with other actors and crisis communications are emphasized. According to the questionnaire study carried out in the project [12], about 80 per cent of the DSOs have prepared some kind preparedness plan and it was seen as useful but still to some extent also as inadequate in many cases.

Some projects have been executed in order to improve the cooperation with other actors. One example is the cooperation organized by the Finnish Forestry Centres against forest damages. In order to be prepared for storms, the Forestry Centres with the representatives of fire and rescue services, forest industry, and DSOs have created regional preparedness plans. However, many DSOs have found these plans not that effective from the fault repairing point of view. Instead they are more focused on minimizing the economic losses of forest damages.

Another good example is also the project mentioned above [12] where the management of major disturbances has been developed. The management includes cooperation and communication between different actors participating in the recovery operations during major disturbances. According to the questionnaire carried out in the project, DSOs seemed to have made contracts with other actors. A major part of respondents has contracts with neighboring DSOs, network contractors, excavator contractors, and local forest workers. A minor part also has contracts with local electricians, transport companies, forest harvester contractors, farmers, and forestry societies. A helicopter company was also mentioned by one respondent. Over a half of the respondents have carried out training, and about half of them mentioned that they have also had training together with other actors, above all with fire and rescue services. [12]

Deficiencies in providing information for customers were seen as big problems during the 2001 storms. After the storms, many DSOs have developed their customer communications considerably by utilizing real time map-based web services about interruptions (see Fig. 3) as well as SMS and email services.

The questionnaire carried out in the project mentioned above showed that 78 per cent of the DSOs used a conventional phone service, 72 per cent used the internet, 72 per cent (local) radio channels, 56 per cent a telephone answering machine, and 8 per cent SMS or email services as communication channels during major disturbances [12]. Three levels could be found in the DSOs' customer communications: some delivered information in real time (e.g. map-based web service), some gave daily bulletins, and some published information at longer intervals. Many DSOs' websites also have good instructions for households about how to be prepared for outages.

Fig. 3 gives an example of the interruption information system used by many DSOs in Finland.

The system is map-based and shows the customers without electricity at distribution transformer level. By moving the cursor on the red/black circle (transformer), the viewer is able to see information about the outage, such as information about the fault (blank in the Fig. 3), the amount of customers affected, starting time, and estimated ending time. All interruptions are shown, both interruptions due to faults and due to planned maintenance activities.

In some systems there is also a table that shows the total amount of customers affected in different parts (municipalities) of the network and a diagram that illustrates the number of customers interrupted as the function of time. Unfortunately, there have been many problems in these systems during major disturbances. For example, the capacity of the systems has been underestimated and the systems have been overloaded and finally collapsed at the most critical moment.

Therefore some DSOs have implemented lighter versions of their web pages for these kinds of events. Of course, the most significant issue is how the customers can use the system during interruptions in power supply and telecommunications.

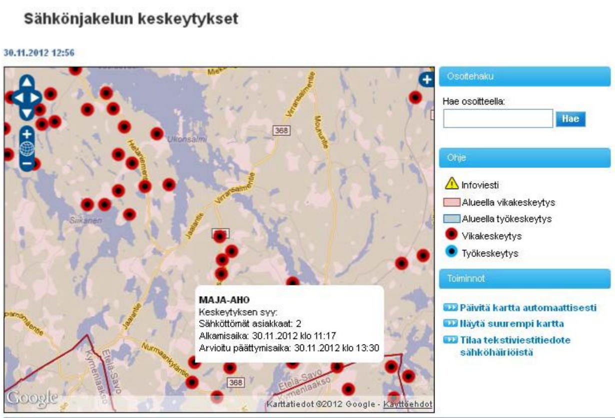

Fig. 3. Screenshot from the real time map-based web service of Järvi-Suomen Energia Ltd in 2012 [22]

One measure for improving the reliability of electricity supply and for improving preparedness against major disturbances is obviously network investments. DSOs have recently invested in underground cabling and in network automation among other things, but quite often these investments aim at better reliability only at the system level.

This may often be an optimal solution from the interruption costs perspective, but easily leads to a situation where some customers may still experience inadequate reliability of supply. In Finland, the Finnish Energy Industries together with DSOs published in 2010 (before the summer storms) new reliability criteria for the supply of electricity to be used as planning guidelines for long-term network development. The criteria define the maximum sum of duration of long interruptions and number of short interruptions (< 3 min) experienced by a customer per year. This way the status of an individual customer can be improved.

Customers are 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. It is allowed to exceed these target values once in a three year period. The objective is to fulfill the criteria in 2030 at the latest. The criteria are illustrated in Table II and presented in detail in [23].

TABLE II
CRITERIA FOR RELIABILITY OF ELECTRICITY SUPPLY [23]

Criteria	City	Urban	Rural
Maximum cumulative duration of long interruptions, [h/year]	1	3	6
Maximum number of short interruptions (< 3 min), [1/year]	-	10	60

Meanwhile in Sweden, the DSOs have carried out for example the following measures after Gudrun: a tree securing program for the regional networks has been carried out, DSOs have invested more in underground cabling due to new tightening in the Electricity Act, and personnel have been trained to use the computerized support system (SUSIE) for cooperation between DSOs.

The positive effects of these measures could be seen during the storm Per. [17], [18]

IV.4. Some Other Actions

The Government Resolution on the Strategy for Securing the Functions Vital to Society determines the measures for upholding national sovereignty, the security of society, and the livelihood of the population in Finland. The resolution defines vital functions, their threat scenarios, strategic tasks assigned to competent ministries, and the focus areas and schedules.

The importance of reliable electricity supply has been considered since the second version of the strategy (2006): disturbances in the electrical infrastructure (information systems, telecommunications networks, power grid etc.) are mentioned first in the list of threat scenarios and it is decided that the security of energy supply is one of the focus areas of the strategy.

In December 2010 the new update of the strategy was published. Former ‘disturbances in the electrical infrastructure’ is now divided into smaller parts and serious disturbances in the power supply are on the top of the threat scenario list while serious disturbances in the information systems and telecommunications (cyber threats) are mentioned second on the list [24], [25].

The National Emergency Supply Agency (NESA) is responsible for planning and operational activities concerning maintaining and developing the national security of supply, including the supply of electricity, in Finland. To support preparedness and continuity planning of the most critical companies from the national security of supply perspective, a portal named HUOVI coordinated by NESA was introduced in Finland recently. Through the HUOVI portal, critical companies can carry out maturity analyses, peer comparisons, and consequently get information about their own state and instructions on how to develop their continuity management. The pools representing different fields of business may give some proposals for actions to companies based on the results of maturity analyses. On the basis of analyses and proposals, NESA annually creates an up-to-date image about the state of national security of supply [26].

In order to improve the preparedness of certain electricity users, some measures have been taken by different authorities: for instance farmers have had a possibility to get financial support for a reserve power supply system and the Finnish Communications Regulatory Authority has set new regulations (the latest in 2012) that defines the priority rating of the components of the communications networks and the securing of their power supply [27]. Due to repetitive problems in authority radio network VIRVE during major disturbances, NESA has decided on a 2.8 million euro funding to increase the security of the power supply of VIRVE’s base stations in Finland [5]. The Ministry of Defence of Finland has published a guide about preparation for citizens in 2008. A more comprehensive guide has also been introduced mainly for the use of the authorities and similar other actors.

The Accident Investigation Board of Finland thoroughly investigated the 2010 summer storms and issued 14 recommendations to improve preparedness for natural disasters. Among some other recommendations an obligation was proposed that requires the DSOs to draw up a preparedness plan for major disturbances, development of economic regulation to consider better reliability of supply and preparedness for major disturbances, development of preparedness of teleoperators, development of operations of the most relevant responsible actors (emergency response center, fire and rescue services and municipalities) in disturbances, development of the clearance process of overhead power and communication lines, and development of nationwide situation awareness including state of the electric power system. It is worthwhile to notice that these recommendations concern most of the relevant actors in the field, whereas in the amendments of the legislation has been seen that it is the DSOs’ responsibility to take almost all the measures by themselves [3].

V. What Is Still Under Development?

Even though many corrective measures have been taken and the situation has developed during the last decade, the latest cases again showed many deficiencies in the preparedness against these kinds of events.

Therefore further development is still needed.

V.1. Situation Awareness and Cooperation

Typically, the lack of information about the situation has been seen as one of the biggest problems for managing one’s operations during a disturbance.

As mentioned, both responsible actors and citizens have confronted this problem. This issue has now been noticed also by the legislator, and as mentioned above, some amendments have been added to the Electricity Market Act [7].

One of the main results of the project, reported in [11] and [12], was a concept of shared situation awareness for major disturbance management. The concept has been further developed in the SGEM project. The idea of this concept is to extend the DSOs' existing web services so that graphical information is served for authorities such as fire and rescue services and municipalities. The information contains not only the interruption data but also information about interruption critical sites such as hospitals, pump stations of water supply, and base stations of telecommunications in the affected area (e.g. the location and the level of criticality). With the help of this information, the DSOs as well as authorities are able to prioritize consumers and allocate their actions on most critical sites. The need for the prioritization of customers is also mentioned in the new Electrcity Market Act to be part of both development and preparedness plans. Especially the importance of securing the power supply for critical base stations of telecommunication networks has been emphasized. This is also a necessity in order to make the information system for major disturbance management operate correctly.

In the presented concept of the situation awareness information system, the input of the criticality values of the critical end users is realized with a web service. Actors responsible for critical end user sites maintain criticality information by themselves through this user interface.

The system could also be used as a planning tool by comparing the criticalities of critical sites (given by the respective end users) to the realized interruption statistics, to calculated probabilities or to the limit values for the maximum duration of interruption. From the point of view of a critical customer who is responsible for a few critical sites, this makes it possible to focus the preparations on the most critical sites. The DSO could take the criticalities given by the respective end users as initial data for network development. The information system could also be used as a simulator in major disturbance exercises.

A small scale demonstration made in the project verified the viability of the system, and the development of the system will continue in the national SGEM project (Smart Grids and Energy Markets) in Finland.

The concept and demonstration are presented in more detail in [28].

The preliminary stages of this kind of shared situation awareness concept can, however, be found in practical applications already. For example, a few DSOs have provided local fire and rescue departments with a computer enabling them to see an online view of the distribution management system (DMS) of DSOs. Thus, the fire and rescue services are all the time aware of the outage areas of the distribution network.

V.2. Changes in Network Planning

Incentives related to network planning seem to be changing. Traditionally, the main aim has been optimizing (i.e. minimizing) the total costs including regulatory interruption costs, which is quite a simple optimization task based on money. Interruption cost calculations are based on conventional reliability indices (SAIDI, SAIFI, and MAIFI) weighted by annual energies, and cost parameters are the same to all customer groups [8], thus there is a great incentive to prioritize the sites that consume the most over smaller ones. The effect of legislative standard compensations is similar. Therefore reliability can be good at the system level but inadequate to some customers.

To respond to the new reliability requirements, quite often changing the overhead lines to underground cables is seen as the only solution. For example, a study [29] presents that to achieve the legislative limit values, 100 per cent underground cabling is needed in urban areas (six hours limit) meanwhile 40-75 per cent of medium voltage (approx. 12 % at present) and 40-90 per cent of low voltage lines voltage (approx. 38 % at present) should be cabled in rural areas (36 hours limit). This would mean that 70-85 per cent of the customers are connected to the weather-proof network, which means that many of them have a higher reliability of supply than is required. Naturally, this is seen as a considerable increase in consumer prices.

The reliability criteria together with the maximum values in the Electricity Market Act try to improve the reliability of supply more from the point of view of the whole society. Most of the functions vital to the operations of society are in urban (or city) areas and therefore it is reasonable to have better reliability in general in these areas. The 2011 storms showed the vulnerability of the electricity supply in some urban areas when they were left without electricity for hours. Thus, some DSOs have already begun projects in order to prevent weather-related interruptions in urban areas, which basically mean underground cabling in those areas. However, all the investments are not necessarily economically reasonable based on the traditional optimization, but some focused extra network investments by the DSOs are needed. Financial sanctions due to exceeding the limit values should encourage the DSOs more to make these kinds of investments.

As mentioned, serious disturbances in the power supply are on the top of the threat scenario list in the Government Resolution, and in the new Electricity Market Act, prioritization of societally critical customers is part of the development and preparedness plan. This makes the optimization of future investments even a more complicated process – it is not only a mathematical task and a DSO cannot carry out the whole process alone, but needs information about these end users classified as critical. Thus, the DSO's traditional planning process seems to be changing to be a part of continuity management of the whole society, which means more cooperation with other actors.

VI. Discussion

This paper presents many consequences and followed measures of the recent major disturbances in the supply of electricity in Finland. The most relevant disturbances and measures taken to improve the situation are placed in the timeline in Fig. 4. The measures taken by authorities are shown above the timeline whereas the measures taken by DSOs are below it.

Fig. 4 illustrates very clearly how proactively the DSOs and their interest group have developed their operations. Of course, this does not concern all DSOs but just some of them. In addition to these, one DSO has also decided in a way to tighten the standard compensation practice and has begun to pay compensations voluntarily already after six hour interruptions. All these measures are now presented somehow in the Finnish Electricity Market Act (dashed line in Fig. 4).

Another similar example of this proactivity was the deployment of the advanced metering infrastructure (AMI) – some DSOs started to develop this kind of system in the early 2000s and in 2009 the percentage of automatic meter reading (AMR) meters was set to be at least 80 per cent of all meters at the end of 2013 [30].

When comparing the effect of this proactive attitude to the operations models in the field of telecommunications, a clear difference may be found – DSOs seem to be well prepared against major disturbances whereas the preparedness of the teleoperators has not been that comprehensive even though they are obligated to have reserve power in their sites. Usually, the capacity of these systems is limited for outages lasting a few hours.

The main reason for this is the attitude that the DSOs should secure the supply of the telecommunication networks, which in many cases is not the most economical solution. The issue needs further studies in order to find out which is the optimal way to act from the society's point of view.

Typically, all the most severe major disturbances have been investigated thoroughly to clarify the causes and consequences.

However, the latest events at the end of 2011 initiated many amendments quite quickly, in two and a half months, at the authority level. This could be seen the way it should be, but on the other hand, some decisions might turn out hastily made. Evidently, the severe consequences of the major disturbances during quite a short period speed up decision making, but so does the fact that the area of influence in the latest case was around the metropolitan area.

The amendments also include quite a clear statement – particularly DSOs are seen as being responsible for the consequences of major disturbances and they should develop their operations. This kind of thinking differs fundamentally from the ideas presented in the investigation of the Accident Investigation Board of Finland where the most of the relevant actors in the field are seen as being responsible for developing their preparedness as well as the cooperation with each other. Even though DSOs are responsible for a reliable power supply, there always will be some interruptions and therefore customers should also somehow be prepared for them. It is evident that major disturbances have had a great effect on the operating environment of the Finnish DSOs.

The awareness and preparedness against these difficult events have increased but still many shortages could be found. The amendments to the Finnish Electricity Market Act will considerably increase the pressure of DSOs to improve their preparedness somehow. At the moment, the incentives in the economic regulation encourage only to network investments, whereas extra person-hours for better preparedness are considered as controllable operating costs which have a negative effect on the acceptable profit. Instead of investing in the networks, planning and practicing the operations for major disturbances would be economically reasonable from the whole society's point of view. In this respect, the regulation model should be revised.

Underground cabling seems to be the most relevant solution to meet the requirements. However, it may not be the most cost-effective way to solve the problem in all cases and thus there is a need for a study of securing the supply locally. This would mean utilizing a reserve power either at the transformer level or directly at the customer level and it would be managed by the DSO or the subcontractor. Small-scale wind turbines, solar panels, fuel cells, and batteries should be taken into consideration as well. In the case of customers behind the long medium voltage lines, this kind of solution could be quite profitable.

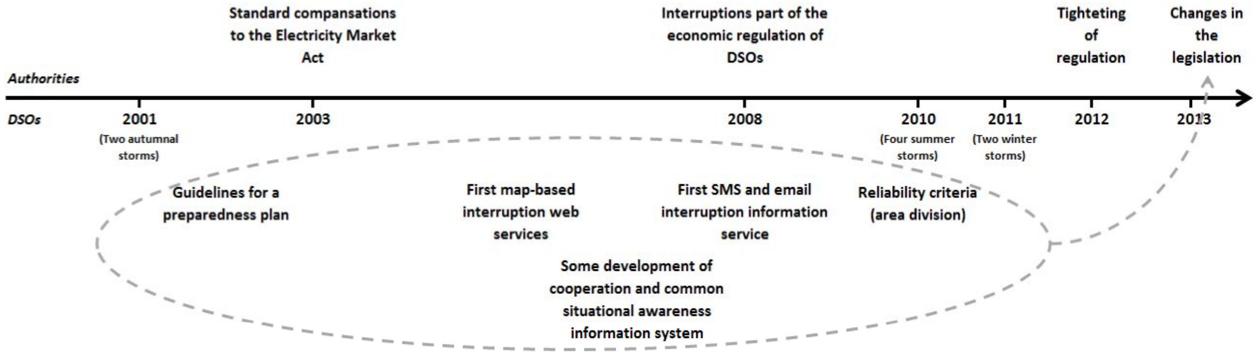

Fig. 4. Major disturbances and measures taken against the consequences of them presented in the timeline (in Finland)

In addition, local generation secures the supply even when there are problems in the primary electricity production or in the transmission grid.

Naturally the maintenance, electrical safety, and network protection issues need to be taken into consideration carefully. These issues concerning alternatives to underground cabling will be considered in further studies.

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