Developing Situation Awareness in Major Disturbances of Electricity Supply

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***Abstract*—Many major disturbances in the electricity supply have taken place in the last decade causing significant problems in the functioning of the modern society. In major disturbances there are multiple organizational actors like fire and rescue services, emergency response centres, police and municipalities along with distribution system operators (DSOs) and network repairers involved in the management of disturbance situations. In previous studies, lack of inter-organizational situation awareness in disturbance situations has been noticed. After the storms in Finland in 2011 it was proposed that DSOs should be obligated to co-operate with public authorities and deliver information to them in major disturbances. The paper presents a demonstration of the inter-organizational situation awareness system developed in this research and compares it with other systems. The aim of the comparison is to find similarities and differences in the systems so that the situation awareness in major disturbances of the electricity supply could be improved.**

***Index Terms*-- Disturbance management, Information exchange, Power distribution faults, Situation awareness, Web services.**

I. INTRODUCTION

Several major disturbances occurred in the past view years. In these disturbances, lack of information exchange between the actors has been noticed. Usually in disturbances, municipalities and authorities receive information by DSOs' web pages, like transformer level maps or lists that show the outages and their duration and phone conversations. This is usually complicated, because there are several different DSOs working in the fire and rescue services operating area or in area of the municipality. [1]-[4]

The Storms like Pyry and Janika in Finland in 2001, Gudrun in Sweden in 2005, four storms in the summer of 2010, storms at Christmas 2011 and two storms in the autumn 2013 in Finland caused widespread and long lasting disturbances in the supply of electric power. In those storms, some individual customers were without electricity for a few weeks. In January 2011 snow load on trees caused widespread disturbances in Finland. In addition to storms that affect the rural area the hurricane Sandy caused widespread disturbance in Eastern parts of the USA in October 2012 including some cities. There were e.g. floods that caused outage to Manhattan in New York. Many of the major disturbances are induced by storms and other severe weather conditions. However, there have also been major disturbances caused by human mistake that have not been especially long lasting but extremely wide spread. Good examples of these are the disturbances in the transmission systems in the USA and Canada in 2003 and in Central Europe in 2006 which both of these caused negative societal consequences. Typically, the disturbances caused problems in telecommunication, water supply and animals' conditions in farms. Also the coldness of the houses has led to even some evacuations in Finland. [1]-[9]

After the storms in Finland in December 2011, the Finnish Electricity Market act was changed so that major disturbances could be prevented. One addition to legislation was that DSOs should participate in the formation of a situational awareness and supply any information relevant to this purpose to the responsible authorities. [10]

This paper presents results based on research done by Tampere University of Technology and Technical Research Centre of Finland. DSOs, fire and rescue services and one municipality participated in the cooperative workshops done in the research. In this research, a major disturbance in the supply of electricity was defined as *a long lasting or 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*. [1]

In this research, a concept of the inter-organizational situation awareness in disturbances has been created. The

concept extends the integration of Distribution Management System (DMS) in an unusual direction by taking the other actors into account. Based on the concept a demonstration of situation awareness system has been developed. The paper also compares this concept and demonstration with other concepts and systems which are under development process or are in use.

II. Inter-Organizational Situation Awareness in Major Disturbances

In Endsley's theory about situation awareness (SA), SA can be seen as the triad of "perception", "comprehension" and "projection". In the first level the status, attributes and dynamics of relevant elements in the environment are perceived. At the second level the comprehension of the current situation will be created based on the information of the level one. It is about understanding the meaning of the information. At the third level of SA the projection about what will happen in the future in the situation is formed. In major disturbances, there are always multiple actors who need to get SA from the disturbance in order to plan and carry out their actions effectively. Information, that they need vary depending on their duties. [11],[12]

Usually, the theories of the SA consider mainly organization's internal SA. The basic theory is based on individual's SA and it can be extended on SA of team or shared SA. In shared SA, every individual has their own view of the situation. Same time there is some overlap in awareness between some members or even between every member. The awareness that overlaps is always smaller than individual awareness. In the major disturbances of the electricity supply, each actor needs different information about the same situation. It is similar to the usual case of shared SA. However, in the case of major disturbances there are multiple organizations involved so shared SA has to be extended to inter-organizational SA. [11]-[13]

At present, DSOs' SA is focused on DMS, Supervisory Control and Data Acquisition system (SCADA) and sometimes on Work Management System (WMS). The main information comes only from DSOs' own network. Usually, DSOs decide the fixing order based on where the customers with high consumption are located and where the faults that cause most trouble with electricity supply occur. In these cases there can be critical infrastructure and customers, whose life is dependent on electricity, in the disturbance area and DSOs do not know that. In addition, the other actors achieve information about disturbances mainly from DSOs' public web pages, like transformer level maps or lists that show the outages and their duration or from phone conversations. Some DSOs' offers Short Message Service (SMS) service, which sends messages about outage's beginning time, estimate duration and ending to the customer. [1]-[4]

III. Concept and Demonstration of SA System

The research project to develop the concept of the inter-organizational SA system began in 2008. At that time, there was no similar concept of inter-organizational SA systems for the disturbances of electricity supply. However, some DSOs offered information about outages on their websites. The development process of the concept and demonstration has been iterative and the concept has been extended and developed further after creating the demonstration. This research has also affected other development projects in Finland regarding the SA. Information from the results of these projects has been used to develop the presented concept further.

A. *Concept*

Based on the cooperative workshops of the research, the concept of the SA system (CIOSAS) in disturbance situations has been created to improve inter-organizational SA. The concept is divided into disturbance management that creates the SA and into risk management that covers the network and preparedness development (Fig. 1). The concept has been developed so that it can be used also in case of other critical infrastructures than electricity supply e.g. water supply. It will carry out the demands on new legislation in Finland.

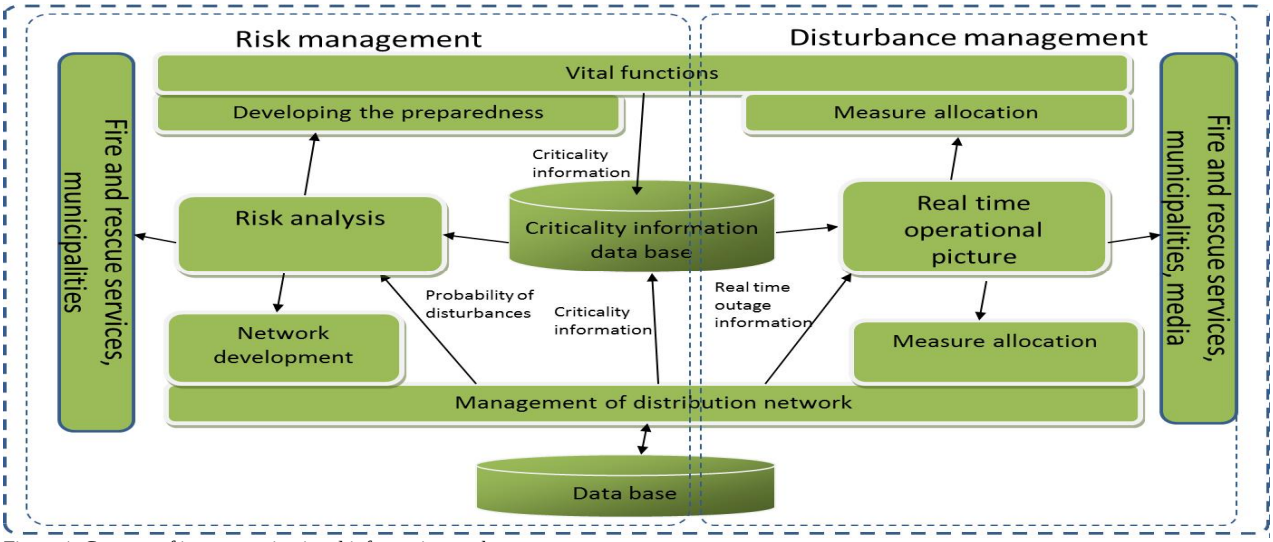

Figure 1. Concept of inter-organizational information exchange

In addition to the present ways of information exchange in disturbances, this concept has a criticality information database, which contains the information of customers who are highly dependent on electricity. The criticality information can be used for planning the order of restoring the network during disturbances and also for network development. Authorities can use criticality information in order to carry out their own actions. Maintaining the criticality information belongs to the customers themselves or to the authority responsible for the customer.

B. *Demonstration*

The demonstration of the inter-organizational SA system has been developed (Fig. 2) in this project. The demonstration bases on the presented concept. The demonstration consists of an internet service which combines information about outages from DMSs, information from other actors e.g. tasks of fire and rescue services and criticality information of customers.

In the demonstration, all information is gathered to one place and then shared to users. The users have been divided in different user groups depending on what information they need and based on the privacy issues. The user groups are DSOs, critical electricity users, who have sites that are critically dependent of electricity, authorities, who will observe critical sites and other users, who are the regular customers of DSOs. There is a MySQL database that stores information about customers, their sites and dependence on electricity. The information about outages comes to the system as an Extensible Markup Language form (XML) straight from the several DMSs. The demonstration uses Google Maps API, which is a programming interface, that enables creating own applications for Google's map service. The information about outages or any other situation can be brought to the map with XML, KML or RSS format.

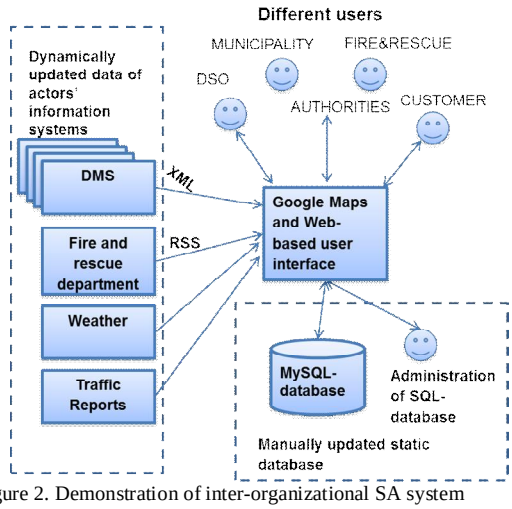

Figure 2. Demonstration of inter-organizational SA system

IV. Present Inter-Organizational Situation Awareness Systems

In the past view years, several concepts and systems have been developed to improve inter-organizational SA in emergencies and in the major disturbances of electricity supply. Few of these have been presented in this paper. These concepts have been divided based on the countries that they are from, because there are differences in emergency organization structures in every country.

A. *Canada*

The Canadian Multi-Agency Situational Awareness System (MASAS) has been developed for exchanging emergency management incident relevant information amongst multiple agencies and jurisdictions. MASAS is used as the national SA system for emergency management of Canada. It is not designed specifically for the disturbances of the electricity supply. However, it can be used for sharing information about outages too. The system bases on open source architecture and implementations. The usual way to information exchange in emergencies is a peer-to-peer approach where there are multiple information sources that are connected to each other. However, this method needs multiple changing interfaces. That is why MASAS bases on hub based architecture where the hub helps to decrease the amount of interfaces. The core of MASAS architecture is managed by the Canadian government to ensure that it maintains its focus on interoperability and addresses the needs of the emergency managers it serves nationally. Users of MASAS can be representatives of e.g. municipal, provincial, territorial, federal, emergency management, police, fire and rescue services and infrastructures. [14], [15]

B. *Germany*

In Germany, there have been two research projects about developing inter-organizational situation awareness in the disturbances of electricity supply. In both projects, the lack of inter-organizational SA in disturbances has been noticed. [16]-[18]

In the Infostrom project, they have been studying inter-organizational information exchange in disturbances of electricity supply in area of two counties. Their aim has been creating "Sicherheitsarena" (SiRena) (security arena in English) which would help different actors to share information. Several problems concerning the inter-organizational information exchange have been found. There are problems with distributed information, missing awareness about available information, policy issues of information, handling the uncertainties of information, terminology issues and perceiving interdependencies between information. They have noticed that main actors in the disturbances of electricity supply are infrastructure suppliers (e.g. power suppliers), public strategic administration (e.g. county administration), public operative administration (e.g. police, fire and rescue services) and citizens. [16], [17]

In Infostrom project, a concept of the inter-organizational SA software has been developed to face these challenges. It is based on a digital map and a resource repository and it allows adding different types of internal and external information e.g. place marks and weather information. Users have opportunity to show and hide information resources from the map and to add additional and new information resources to the map. It has been designed as a web-based solution which is independent of location and platform so in addition to using

the system in office, the actors are able to use it from various places via mobile phones and home computers. For the actor to be aware of available and suitable resources there is information repository where services can be registered, described and rated by users. [17]

Another project in Germany has been executed by the DSO MITNETZ STROM. It has been noticed that there is a lack of communication with local governments, police stations, fire and rescue services and rescue coordination centres e.g. in the past they received information about planned outages only from a daily newspaper. These actors wanted information about the outage and the ongoing restoration process earlier and more precise. That is why a new concept of inter-organizational communication has been developed. Their aim was to develop transparent, target group specific and contemporary communication process. Rescue coordination centres and municipalities where chosen for main target groups. [18]

Based on the concept the system called "PRONET SIS" has been developed. The system filters the needed information about planned and unplanned outages from the grid control system. Then the system sends relevant information to rescue coordination centres by email. The information from the email can be integrated straight to their system. It contains information about the outage, location, and geographical data of the substation, internal information about the affected power stations, the number of interrupted customers and a link to Google maps. A new email is sent every time when there are some changes to the event. [18]

The municipalities wanted more specific and personalized information. Thus, they will receive SMS that contains a phone number to contact the DSO and get more precise information as soon as a certain number of interrupted customers are reached. The municipalities can decide the threshold number of affected customers and the duration of interruption. [18]

At present the customers can get individual information about the outage by entering his zip code on the DSO's website. In future, different customer groups like telecommunication companies and big industrial grid customers could be added. The system will be further developed so that the social networks could be used to gain information about the outages and to distribute the information. [18]

C. Finland

In Finland, some improvements have been done to solve the observed problems with inter-organizational SA in the major disturbances of electricity supply. The most of the Finnish DSOs inform about their outages in their website. Some of them are map based systems and some are in text format. In this chapter two highly developed systems are presented.

DSO Elenia (former Vattenfall) offers different SA services to their customers and fire and rescue services in Finland. For customers, Elenia offers SMS service and map service in their website. These services have been developed because customers have been requesting some improvement to informing them about the outages. The outage information offered by the services is produced in DMS. DMS takes information from a Supervisory Control and Data Acquisition system (SCADA) or Automatic Meter Reading (AMR). The outage information is linked to information from the customer information system. This helps to solve which customers are affected on outage. All services are produced by a multichannel communication system (MCS). SMS or email service can be subscribed to in DSO's website. The service is provided on two levels: basic and extended. At both levels, the message includes information about sustained faults and planned interruptions. Information about outage's beginning time, status information and ending is delivered on both services. The extended service includes also messages about momentary interruptions. DSO has offered the outage map in their website since 2007, and the SMS service since 2008. After developing these, Elenia has begun to offer a service to their customers where customer can send information and photos about outage situation with mobile phone app. [19],[20]

In the cooperative workshop of this research it has been occurred that after 2011 storms, Elenia started to offer DMS service to fire and rescue departments whose responsible working area is in Elenia's network area. This development process bases partly on this research. The DMS service brought to fire and rescue departments bases on the same system that is earlier developed to give information to network repairers, presented in [21]. Real time operational and switching state of the whole network can be seen with this service. It is offered to improve fire and rescue departments' SA of the disturbances of electricity supply. In addition to this service, a representative from fire and rescue services has been following the disturbances in DSO's operation room as a connect person in some disturbances.

Another system used in Finland is Gridwise. It is a SA system offered to DSOs. In Finland, DSO Savon Voima is using this service. The system offers information to DSO themselves and to their customers. The Gridwise merges information from DSO's own systems, weather forecast and fire and rescue services tasks. Gridwise has been developed for fulfilling the demands that new Electricity market act in Finland sets concerning DSO's participating in the formation of a situational awareness and supply information relevant to this purpose to the responsible authorities. The system can be used via webpage. The Gridwise service can be built from different modules based on the customer needs. There are different functions for DSOs, customers and authorities. [22]

V. COMPARISON OF THE SA SYSTEMS

Based on the published information a comparison of above systems has been created. The comparison is focused on the main motivations, technical execution and details and users of the system. When the concept of inter-organizational SA began to be developed in this research, there were no other inter-organizational SA systems available. The meaning of the comparison is to find if there are similarities and differences with the systems. The results of the comparison are presented in table I.

TABLE I. COMPARISON OF THE SA SYSTEMS

		CIOSAS	MASAS	SiRena	PRONET SIS	Elenia services	GridWise
Basic use of the system	Disturbances of electricity network	x		x	x	x	x
	Emergency situations	x*	x				
Motivation	Legislation or Government		x				x
	Customers' wish					x	
	Other actors' wish	x		x	x		
Completeness	In use				x	x	x
	Pilot (in use)		x	x			
	Demonstration or project	x					
Technical execution	Peer-to-peer				x	x	x
	Hub based	x	x	x			
Communication method	Map	x	x	x	x	x	x
	Chart	x	x	x	x	x	x
	Phone call				x		
	Sms	x		x	x	x	x
	Email				x	x	
	Video		x				
	Possibility to input picture/photo		x	x		x	x
	Chat			x			
	Text	x	x	x			x
Specific database for SA use	Criticality information	x					
	Resources			x			
Administration	Commercial/DSO				x	x	x
	Government		x				
	University	x		x			
User groups	Authorities (e.g. fire and rescue, police)	x	x	x	x	x	x
	Electricity distribution system operators	x	x	x	x	x	x
	Emergency management		x		x		
	Rescue/emergency response centre	x	x		x		
	Government		x	x			
	Municipalities	x	x		x		
	Voluntary services	x	x				
	Citizens	x	x	x		x	x
	Companies		x		x	x	x
	Media	x	x			x	x

*The concept of CIOSAS offers a possibility to extend it to concern disturbances of the other critical infrastructures

Most of the systems have been developed straight to the cases of disturbances of electricity supply. Only MASAS is meant for all emergency situations. However, the concept of CIOSAS is developed so that it can be extended to the use of the disturbances of other infrastructures.

The motivation for developing the systems varies. In Finland there is a new legislation which demands inter-organizational SA in major disturbances and that has been a driver for the GridWise project. This change in legislation has also affected the CIOSAS development process. The situation of MASAS reminds the situation in Finland, because in Canada the government has been the driver for the development project. Other system's drivers have been mainly wishes from the customers or from the other actors.

The technical execution of the systems can be divided on two different main categories: peer-to-peer approach and hub based architecture. An interesting detail is that those systems that are already in use are all peer-to-peer systems. Two of the hub based systems are in pilot use and our system is still at demonstration level. However, like in CIOSAS, hub based method enables the possibility to get information from multiple DSOs to the same system. This improves of getting the SA of widespread disturbance situation at once. This feature is not in use in any of the present used systems.

The methods, that systems use to present the information varies some. However, common to all of them is to use maps and charts. CIOSAS has quite few presentation methods compared whit others. It is common for every Finnish system.

The main difference that CIOSAS has to the others is the criticality database. The database is meant to gather information about targets that needs electricity to maintain people lives, and about their ability to maintain their actions without electricity. Only other system that has specific

database in use for SA is SiRena, which has a database for available resources.

The administration of the systems seems to be related to the completeness of the systems. Those systems that are already in use are maintained by DSOs. Those which are still in pilot or demonstration state are maintained by either university or government.

The most variation between the systems is in user groups of the system. MASAS is meant for every actor and citizens affected the emergency situation. The other systems all have DSOs and authorities in part of their user groups. Most of the systems offer something also to the citizens. Some of this variation can be because of there is different kind of emergency organization structure in every country e.g. in Finland, there is no special emergency management actor.

VI. CONCLUSION

Lack of information exchange in the major disturbances of electricity supply has been noticed in many researches. Present methods are inadequate. Some inter-organizational SA systems have been developed in recently to the emergency and the disturbance of electricity supply situations. The concept presented in this research resembles the other systems that have been developed.

The main commonality between the studied systems is the variety of the presentation methods. The other common thing was that the DSOs and authorities are always part of the user groups.

From the comparison it can be seen that those systems that have been administered by DSOs have been taken in use already. This could mean that taking a commercial approach could be the most effective way to execute the inter-organizational SA system. However, in that case there is possibility that some important elements will be missing, because of the rush. Most of the commercial ones had less user groups than other systems.

The CIOSAS system developed in this research resembles mostly the other systems developed in Finland. Comparing with other Finnish systems, CIOSAS is only one using the hub based architecture, which enables bringing information about disturbance from several DSOs to the same system. The main difference to all of the other systems is that, CIOSAS brings criticality information to DSO and other actors. CIOSAS can also be extended to cover other emergency situations unlike systems designed only for the disturbances of electricity supply. The weakness in CIOSAS is that it is a demonstration for now and not in use yet.

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