Combined Electricity and Mobile Network Situation Awareness System for Disturbance Management

Published in
2015 IEEE Innovative Smart Grid Technologies - Asia (ISGT Asia)

DOI
10.1109/ISGT-Asia.2015.7387099

Combined Electricity and Mobile Network Situation Awareness System for Disturbance Management

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***Abstract*—In this research, a demonstration of a situation awareness system is presented. A real case of the disturbance of the electricity network was illustrated with the demonstration. The state of the remote controlled switches was simulated based on the model of the mobile network coverage and compared with the real state information from the online remote field service provider. The case study confirmed that there are interdependencies between both networks. The main contribution of this research is a new method to improve the disturbance management of electricity and mobile networks and to improve the resilience of the society in disturbances by a combined situation awareness system.**

***Index Terms*—Disturbance, Situation awareness, Co-operation, Mobile network, Remote controlled switch.**

I. Introduction

There have been several problems in the information exchange between organizations in disturbances of electricity supply. Interdependencies between electricity and mobile networks have been noticed. The situation where both electricity and mobile network have an interruption at the same time is complex to manage.

Storms like Pyry and Janika in Finland in 2001, Gudrun 2005 and Per 2006 in Sweden, four storms in the summer of 2010, storms at Christmas of 2011and two storms in autumn of 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 of 2011 snow load on trees caused widespread disturbances in Finland. In addition to storms that affect the rural area, the hurricane Sandy caused widespread disturbances in Eastern parts of the USA in October of 2012 including some cities. There were e.g. floods that caused outages in Manhattan, New York. [1]-[7]

Many of the long lasting and wide spread disturbances, the so called major disturbances, are induced by storms and other severe weather conditions. However there have also been major disturbances that have not been especially long lasting but extremely wide spread, like the disturbances in the transmission systems in the USA and Canada in 2003 and in Central Europe in 2006. Both of these caused negative societal consequences. [1]-[7]

Typically, the disturbances caused problems in telecommunication, water supply, animals' conditions in farms and with the coldness in private houses. The coldness of the houses has even resulted in some evacuations. The problems with telecommunication also affected safety phones and safety buttons. [1]-[7]

Electricity distribution and mobile networks are interdependent. Mobile network base stations require electricity to operate. The base stations should have backup power batteries or other reserve power to maintain the transmission for at least three hours assigned by The Finnish Communications Regulatory Authority (FICORA). However, the electricity disturbance can last longer than the reserve backup power, e.g. because of storms. [8]-[10]

While the electricity network can operate without telecommunications for the operation of the distribution automation (DA) it is necessary. Traditionally most of the communication was done using proprietary communication methods and protocols. Nowadays the mobile network is utilized in multiple ways in distribution networks such as DA and communication with repair groups. [11], [12]

The electricity network is developing towards the Smart Grid, thus the amount of DA devices in the distribution network has increased in recent years. DA devices improve the outage recover times. Previously, a telecommunication link was only established to critical parts of the network such as substations. After a remote connection to substations, the utilization of remote controlled disconnecters started. Nowadays in addition to these devices a connection is also needed for automatic meter reading (AMR). The connection between control center and DA devices is often based on mobile network technologies. Powerline communication

The authors would like to thank the Finnish Funding Agency for Innovation (TEKES) for funding and supporting the research work

(PLC) is also used together with a mobile network (e.g. for AMR meters). These connections also depend on the mobile network as part of the communication link to the control center is implemented using a mobile network. [12], [13]

In addition to remotely controlled devices, Distribution System Operator (DSO) relies on mobile networks to contact and follow repair teams and subcontractors during disturbances. If both actors receive information about these disturbances, their recovery processes could be executed more efficiently.

After the storms in Finland in December 2011 the Finnish Electricity Market act was changed to improve the reliability of the electricity networks. The new addition to the legislation requires DSO to prepare a contingency plan for disturbances. Further, it was added to the legislation that the maximum duration to outage will be six hours in urban areas and 36 hours in rural areas concerning all of the customers from the beginning of 2029. DSOs must prepare development plans to describe how these limits will be achieved and how the electricity supply for the sites that are important to the resilience of the society are ensured. Further, the new legislation requires that the DSOs should participate in the formation of a situational awareness and supply any information relevant to this purpose to the responsible authorities. [14]

This paper presents the demonstration of a situation awareness system that combines information about interruptions of electricity and mobile networks. This system can be utilized to improve the resilience of both networks. Further, a case in which an interruption occurred in both networks has been studied.

II. METHODS

A demonstration of inter-organizational situation awareness system to disturbances of electricity supply has been developed in this research. The developing process has been iterative. The present situation has been studied by literature review and in several cooperative workshops of this research. These results are presented in [1]-[3]. Methods of the usability and user-centered design have been utilized in the design process to improve the demonstration e.g. semi-structured interviews for user needs [14], [15].

In this paper, the main focus is in instrumental case study approach [16]. The case has been simulated with the developed demonstration and compared with the real life case. The results of the comparison were analyzed for studying the capability to utilize the demonstration to improve the restoration process of the electricity networks and mobile networks.

III. THE SOURCES OF THE SITUATION AWARENESS IN DISTURBANCES

Endsley's theory of the three levelled situation awareness is utilized in design process of the system. The theory defines the situation awareness (SA) as the triad of "perception", "comprehension" and "projection". The first level consists of perception of the status, attributes and dynamics relevant elements in the environment of the situation. At the second, level the comprehension of the situation is formed based on the information received at the first level. At the third level, the perception and comprehension are utilized to form a projection of the future happenings in the situation. [15], [17], [18]

DSO's situation awareness can be divided into two categories; internal and external (Fig 1). At present, the studies of DSO's SA are focused internal SA. Thus, the information systems that DSO utilizes are focused to support mainly on that. These systems are SCADA, Distribution Management System (DMS), work management system (WMS) and customer information system (CIS). All of these are designed to support the everyday actions of DSO. [19]-[21]

SCADA collects the status and measurement data from the network. This information is used to control the network. DMS connects data from SCADA and customer information system to map-based user interface. With DMS the overall picture about the network can be seen. It can be used to plan and remake the connections in the network. At disturbance situation DMS is important tool to locate the outages and to get an overall awareness of the situation. In addition, the WMS is an important tool in disturbances, thus it is utilized to locate the repairer teams and to communicate with them. It can be utilized to share tasks and send teams to right places to fix faults. [21]

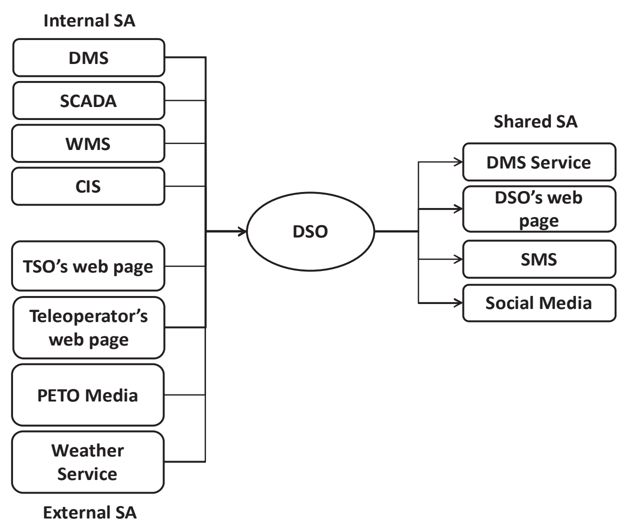

Figure 1. The DSO's situation awareness.

The external situation awareness of DSO can be divided to the information that DSO delivers to other actors and customers and to the information that DSO receives from others. The main information that DSO needs is the situation of transmission network, because the issues in transmission network can affect the distribution network. Some of the DSOs want to follow the outages of their neighbour DSOs' networks. By following that information, DSO can predict if storm is coming to their operating area. However, public web pages are the only way to follow the other DSOs. In addition to their systems DSO gets weather forecast and warnings from local meteorological institute. Other information that DSO receives can be e.g. tasks of fire and rescue services. [1]

Some DSOs are co-operating with their local mobile network operators and they may have information about the locations of the important mobile network base stations. In addition, they may follow the coverage information of the mobile network from operator's public web page. In Finland, the mobile network operators are offering information about their interruptions on a digital map. There are no restrictions about how accurate level the information has to be illustrated, thus some operators are offering information in municipality level while others are offering it in more detailed level. For the purpose of the DSO this information is often too inaccurate.

Some DSOs are maintaining a database about customers that are highly dependent on electricity. However, this information is usually outdated because there are no established practices. [1], [2]

At present, the information that DSO shares to others is focused mainly on their web pages. Most of the DSOs in Finland have an outage map on their web page. Users can utilize the outage map to see which areas the outage affects (in transformer level accuracy), when it has started, when it is estimated to end and how many customers it affects. This information comes from DSO's DMS. Some DSOs utilizes DMS also to share more detailed information to repairers, subcontractors and fire and rescue services. This so called DMS service was originally designed to share information to subcontractors and it is a direct view to DMS. Technical language is used in the interface and can be difficult to use by the fire and rescue service. In addition, some DSOs have SMS services that send the outage start time, estimated duration and the estimated end time information to the customer. [22], [23]

In Finland, there are three main mobile network operators who have their own infrastructure. Their operating areas are wider than DSO's, i.e. nationwide. There are multiple DSOs in area of one mobile network operator. The mobile network operators are not offered any additional services i.e. DMS service by DSOs, thus they are relaying on public web pages of DSOs. Consequence of this is that the information that mobile network operators achieve from the disturbances of the electricity network is shattered to multiple systems.

There are some Situation Awareness (SA) systems available for the disturbances of electricity supply. Some of them are designed especially for disturbances of electricity supply and some for common emergency situations. Common for those systems are that they are focused on level 1 and 2 SA and do not process different information to give the projection to future. [20]-[26]

IV. The Demonstration of Situation Awareness System

The problem with present sources of the situation awareness is that the interdependency between electricity and mobile network has not been taken into consideration. None of the systems combines information of the both networks. Furthermore, the devices that are dependent on both networks are not included in present systems. [1], [2]

In this study, the demonstration of a situation awareness system to disturbances of electricity supply has been developed. This demonstration consists of two parts; 1) first part illustrates the mobile network coverage and base stations, 2) the second part illustrates the information from different actors related in disturbance e.g. fire and rescue services tasks. The demonstration combines information from multiple DSOs and mobile network operators to web based user interface. In addition, information about remote controlled devices can be added to the system. The system structure is presented in Fig. 2.

The main users are distribution system operators and mobile operators. In addition, municipalities, authorities and fire and rescue services can benefit on it. The demonstration can be personalized by organizations.

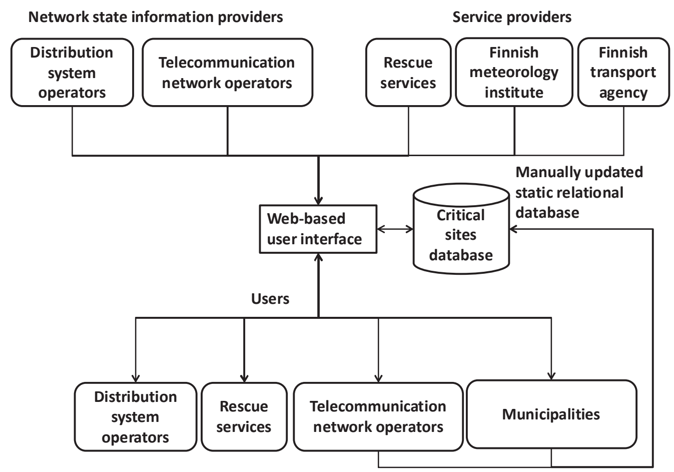

Figure 2. The diagram of the demonstration.

This demonstration presents combined information from both networks (Fig. 3). The gray symbol indicates the transformer station which has an outage and the red polygon indicates the lack of mobile network coverage. In addition, mobile network base stations have their own symbol. The color of the base station symbol informs if the base station does not have electricity or if it runs on batteries. It is marked with a blue symbol when the situation is normal. If a base station has to rely on batteries, the color of the symbol is yellow, and if it does not have any electricity supply the color of the symbol is red.

In addition, there is a symbol for the repair team and remote controlled switches. The location information of the repair team can be combined with coverage information to achieve information if the repair team is approaching an area without coverage. Remote controlled switches are presented with a white symbol if they do not have mobile network coverage. Otherwise they have light blue symbols.

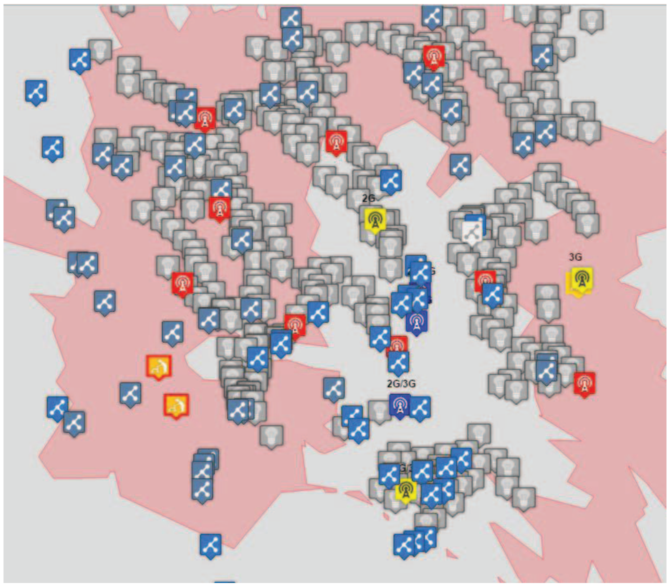

Figure 3. A view of the system.

The public authorities can add information about their own critical sites such as people with safety phones to the system. These sites are presented with their own symbols (orange symbol in Fig. 3). The symbol of such critical site will show if there is no electricity or mobile network coverage.

V. The Case Study - The Remote Controlled Switches

An outage case that occurred in Finland was studied in this research. Information about the case was received from multiple organizations. The DSO provided transformer status information about the area. The mobile network operator provided configuration and status information about the mobile network base stations. An online remote field service provider provided information about the communication link statuses of the switches in the electricity network.

The provided base station configuration data was used to simulate the coverage areas of each base station. The coverage areas have been accurately simulated with a mobile network simulation taking into account all necessary configuration parameters. These parameters include base station locations, antenna heights, antenna directions, antenna tilting, antenna models and their gains, transmission powers and any additional losses as well as the used frequencies for Global System for Mobile Communications (GSM) and Universal Mobile Telecommunications System (UMTS) systems. In addition, Okumura-Hata path loss model was used to calculate the overall signal power loss of the propagated signal from a transmitter to receiver, also taking into account the effect of the elevation differences in the area. The simulation results were exported separately for each base station site as images to visualize the coverage areas.

The base station data has been visualized on the map with the coverage areas and the status information. The mobile network operator provided the information whether the base station was active or not. No information was provided on whether the station is supplied by the network or by the backup battery. A simple model is used: whenever the nearest transformer is affected by the outage, the base station is being supplied by the backup battery.

In addition third party remote controlled switch statuses were displayed on the map. The status of a switch is either on or off. The switch mainly used the network of the mobile network operator that provided the mobile network data. If the switch is on, the packet loss is 0 %. If the switch is off, the packet loss is 100 %. The modelled coverage areas are used to calculate a modelled status for each switch based on their location in the coverage area. Both the modelled and the actual status are then displayed on the view.

The example of the system's view is shown in figure 3. The blue symbols present mobile network base stations that are being supplied by the network. The yellow symbols present mobile network base stations that are possibly being supplied by a backup battery. The red symbols present mobile network base stations that are down. The bright blue symbols present remote controlled switch that have a working telecommunication link. Similar white symbols present remote controlled switch without a working telecommunication link. Similar grey symbols present remote switch that are modelled to not have a working telecommunication link but actually have one. The differences in the model and the real state are discussed in the next chapter.

VI. The Results of the Case Study

In the studied case, the storm caused interruption to electricity network. Because of the storm, the interruption in electricity network expanded gradually. The base stations of the mobile network have backup power, thus the interruption did not effect on mobile network and switches immediately. Based on the modelled situation of the mobile network, the first switches (grey symbol in Fig. 4) became unreachable 2 hours earlier than in the real case

When the worst situation occurred in the mobile network, the worst situation from the switch point of view began. There were 103 switches in the studied interruption area. In the worst case 12 switches were unreachable (Fig. 4). This happened approximately 4 hours after the first failure in the electricity network. After this the situation was improving when the base station in south-west of the observed area was restored. However, 9 hours after the beginning of the interruption, more switches started to become unreachable even though the mobile network was already operating in the area. In this case, the dropped switches were located to the edge of the studied area. Approximately 12 hours after the beginning of the interruption all switches were fully functioning.

In the model, the amount of the switches that did not function was bigger than in real case. 63 switches were unreachable in the worst case in the model. In addition, the timing of the worst situation did not match to real case. In the last drop of the switches, the modelled values resembled the real data.

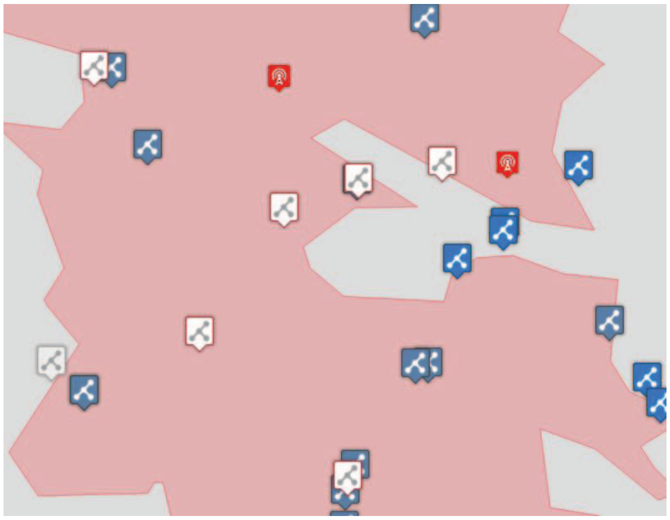

Figure 4. The worst situation in the observed case.

VII. DISCUSSION

The data about remote controlled devices illustrated in the system, was analyzed to utilize the demonstration to improve the restoration process of the both network was studied. Information about the modelled status of the switches and the real status of the switches were compared. There are some differences in the statuses especially in the edges of the observed area.

There were some issues with the information as the observed areas were slightly different. Some of the differences between modelled and real status can be caused by the 10 minute status polling time of switches.

If the data is observed only from the mobile network coverage point of view, it can be said that the modelled and measured statuses do not match. There can be several reasons for that. First, the coverage area has only been generated from a specific area and does not include the coverages of the surrounding base stations. The coverages usually overlap and can improve the service in the edges of the current observed area. Second, the switches could utilize two operators' mobile networks. However, in this case all the switches were using the same mobile network. If the comparison is made in the middle of the modelled area, the model and the real data resemble each other. The most probable reason for this is that that modelled mobile network area is too small. A larger area should have been modelled.

9 hours after the beginning of the disturbances 10 switches became unreachable while there was mobile network coverage in the area. There is a small chance that the devices do not have electricity and their backup power was lost. However, the chance is quite small, because the backup batteries are designed to last at least 24 hours. The other option is that the mobile network coverage simulations are incorrect on that location. However, the switches are located in the area where everything else is working.

The studied remote controlled switches utilize the network of one mobile operator. Their resilience could be improved by utilizing networks of multiple operators. However, in Finland mobile operators are using common masts often, thus if the interruption in electricity network is affecting one mobile network it is most likely affecting the others too.

Based on the analysis of the case, the situation awareness system can be utilized to find the interdependencies between electricity network and mobile network. Further, this information can be utilized in the restoration planning of both networks. With the system the DSO and the mobile network operator can locate the most important base stations in the electricity network. The DSO can utilize the information to restore the electricity first to those base stations, thus achieving communication to their own remote controlled devices. The mobile network operator can utilize the information to locate the transferable backup generation to the base stations that are most important for DSO's communication. In addition, if the interruption information is combined with the information of how long the base station has backup power it can be utilized to project the future events of both networks.

The DSO can utilize the information about the coverage area of the mobile network to inform their repair teams about the problems in communication, e.g. the repair team can be warned if they are approaching an area with no coverage.

Further, the system can be utilized when developing both networks. The DSO can ensure the supply to the most important base stations e.g. by cabling. Likewise, the mobile network operator can improve the backup of the important base stations.

The public authorities can utilize the system to follow their own sites that are critically dependent on electricity or mobile network e.g. safety phone customers. With this information they can focus their actions better. In addition, the simulation part of the system can be utilized for training purpose.

For further development the methods utilized in the demonstration will be applied into a live demonstration. The demonstration presented above is an offline demonstration of a previous disturbance. In the live demonstration the mobile and electricity network data is gathered in real time, the data is combined and the current situation is shown on the web based user interface. Users such as the mobile network operator, the DSO and municipalities can use the system during the live demonstration to gain information about the current situation in the electricity and mobile networks. Different situation awareness rating and testing methods can be utilized to study the suitability of the demonstrated system to disturbance management when the live demonstration is own use.

CONCLUSION

Major interdependencies exist between electricity networks and mobile networks. The sources of the situation awareness of the DSO consist of internal and external sources. Present methods are focused mainly on DSO's internal situation awareness. There are some situation awareness systems to information exchange in disturbances and some of the DSOs are co-operating with their local mobile network operator to locate the most important base stations. However, any processed information about the interdependencies of the both networks is not supported. Further, the authorities are using multiple web pages and DMS services to achieve the information about both networks.

In this research, a demonstration of a situation awareness system was developed. This system illustrates the interruptions of electricity and mobile networks on a map. Information about the sites and devices that are dependent on either of these networks e.g. remote controlled switches or elderly residents can be added to map. This information can be utilized to improve the restoration process of the electricity networks or mobile network and to improve the resilience of the society in disturbances.

It was noticed from the analysis of the disturbance case, that the remote controlled switches are highly dependent on the mobile network. In the studied case, some contradiction between the modelled state of the switches and the real state appeared, because the effect on base stations outside the observed area could not be taken into account while modelling the mobile network coverage. Otherwise, the modelled area resembled the real case.

Based on the case it is not possible to make a conclusion how the unreachable switches effected on the restoration process of the electricity network. To make these conclusions, the information of the manually controlled switches would be needed in addition to information how long the manual opening process took.

The demonstrated situation awareness system could help the authorities to plan their actions better, e.g. to evacuate only the residents whose life is dependent on one or both of the networks. In addition, the resilience of the society can be improved by using the demonstration to plan the placement of the backup power.

The DSO and the mobile network operator can utilize the system to improve their restoration process after the situation, e.g. the mobile network operator can improve the backup of the base station which is important to the electricity network. Likewise, the DSO can plan the cabling to ensure the electricity supply to important base stations.

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