TAMPEREEN TEKNILLINEN YLIOPISTO
TAMPERE UNIVERSITY OF TECHNOLOGY

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VISUALIZATION REQUIREMENTS AND CONCEPTS FOR A COMBINED SCADA AND DISTRIBUTION MANAGEMENT SYSTEM

Master of Science Thesis

Examiner: Professor Pekka Verho
Examiner and topic approved by the Council of the Faculty of Computing and Electrical Engineering on 4th June 2014

ABSTRACT

TAMPERE UNIVERSITY OF TECHNOLOGY
Master's Degree Programme in Electrical Engineering
MANNINEN, JUKKA: Visualization requirements and concepts for a combined SCADA and Distribution Management System
Master of Science Thesis, 77 pages
November 2014
Major: Power systems and Electricity Market
Examiner: Professor Pekka Verho
Keywords: SCADA, Distribution Management System, Visualization, Control Center processes

The use of SCADA and DMS systems in the main control center of a distribution company overlaps. A new common user interface framework for SCADA and DMS systems in ABB MicroSCADA Pro is currently in development, and it was piloted in this thesis. To be able to make a successful user interface for a combined SCADA and DMS system, it must be known how the systems are used. In this thesis, three distribution companies were visited to identify most common tasks performed in the main control center.

Three most common tasks performed in the main control center of a distribution company are supervision, fault management, and maintenance outage management. The supervision task consisting of high voltage, medium voltage, and low voltage network supervision, power management and system supervision, is described in this thesis. The fault management and maintenance outage management tasks are described with as much details as possible and also the specialties caused by a major disturbance situation is covered.

In addition to the most common tasks, also visualization requirements for a combined SCADA and DMS system were gathered during the visits. The requirements were gathered by studying the problems in the existing systems as well as the ideas and solutions found in the distribution companies current systems. It was found out that for a combined SCADA and DMS system, there are visualization requirements concerning events and alarms, navigation and zooming, supervision and overviews, fault management and maintenance outage management.

In this thesis, four visualization prototypes to help fault management were created into the common user interface framework. The four visualizations form a basis for a new fault management dashboard. The fault management dashboard supports the new fault management model introduced in this thesis. Also visualization concepts to help operators in maintenance outage management and power management were created.

This thesis concludes, that many kinds of visualizations are required for a combined SCADA and DMS system. The faults and alarms in the system should be clearly visualized, especially in a major disturbance situation. In a combined SCADA and DMS system, the operator can work more effectively, because only one user interface is required. The common user interface framework was found to have a good potential to become a successful user interface for a combined SCADA and DMS system: No major problems were found and integrating data from both systems into one user interface was found easy and efficient.

Going forward, the visualizations in the fault management dashboard should be finalized and deployed into real environments. A few improvements should be implemented into the common user interface framework, and a lot of new visualizations are required to support all required features in a combined SCADA and DMS system.

TIIVISTELMÄ

TAMPEREEN TEKNILLINEN YLIOPISTO
Sähkötekniikan koulutusohjelma
MANNINEN, JUKKA: Visualisointivaatimukset ja konseptit yhdistetyssä SCADA- ja DMS -järjestelmässä.
Diplomityö, 77 sivua
Marraskuu 2014
Pääaine: Sähköverkot ja -markkinat
Tarkastaja: professori Pekka Verho
Avainsanat: SCADA, DMS, Visualisointi, Käyttökeskuksen prosessit

SCADA- ja DMS -järjestelmien käyttö sähköverkkoyhtiöiden käyttökeskuksissa on päällekkäistä. Uusi, yhteinen käyttöliittymäkehys SCADA- ja DMS -järjestelmille ABB:n MicroSCADA Pro -tuoteperheessä on tällä hetkellä kehitysvaiheessa, ja sitä pilotoitiin tässä diplomityössä. Jotta yhdistetylle SCADA- ja DMS -järjestelmälle osataan tehdä menestyksekäs käyttöliittymä, täytyy tietää, kuinka järjestelmiä käytetään. Tässä työssä vierailtiin kolmessa sähköverkkoyhtiössä tarkoituksena tunnistaa yleisimmät työtehtävät käyttökeskuksessa.

Kolme yleisintä työtehtävää sähköverkkoyhtiön käyttökeskuksessa ovat valvonta, vikojen hallinta ja työkeskeytysten hallinta. Valvontatehtävää, sisältäen suurjänniteverkon, keskijänniteverkon ja pienjänniteverkon valvonnan, tehonhallinnan ja järjestelmien valvonnan, kuvaillaan tässä työssä. Vikojen hallintaa ja työkeskeytysten hallintaa kuvaillaan mahdollisimman tarkasti, ja myös suurhäiriötilanteen aiheuttamat erikoisuudet käsitellään.

Yleisimpien työtehtävien lisäksi vierailuilla kerättiin visualisointivaatimuksia yhdistetylle SCADA- ja DMS -järjestelmälle. Vaatimuksia kerättiin tutkimalla nykyisissä järjestelmissä esiintyviä ongelmia, sekä ideoita ja ratkaisuja, joita verkkoyhtiöillä oli omissa järjestelmissään. Työssä löydettiin yhdistetylle SCADA- ja DMS -järjestelmälle visualisointivaatimuksia koskien tapahtumia ja hälytyksiä, navigointia ja zoomausta, valvontaa ja yleiskuvia, vikojen hallintaa ja työkeskeytysten hallintaa.

Työssä tehtiin neljä visualisointiprototyyppiä yhdistettyyn käyttöliittymäkehykseen auttamaan vikojen hallinnassa. Nämä neljä visualisointia muodostavat pohjan uudelle vikojen hallintapaneelille. Hallintapaneeli tukee uutta vikojen hallintamallia, joka esitellään tässä työssä. Myös visualisointikonseptit, jotka auttavat operaattoria työkeskeytysten hallinnassa ja tehonhallinnassa, kehitettiin tässä työssä.

Työn päätelmänä voidaan todeta, että monenlaisia visualisointeja tarvitaan yhdistetyssä SCADA- ja DMS -järjestelmässä. Järjestelmässä olevat viat ja hälytykset pitää visualisoida selkeästi, erityisesti suurhäiriötilanteessa. Yhdistetyssä SCADA- ja DMS -järjestelmässä operaattori voi työskennellä tehokkaammin, koska vain yhtä käyttöliittymää tarvitsee käyttää. Yhteisellä käyttöliittymäkehyksellä todettiin olevan hyvä potentiaali olla menestyksekäs käyttöliittymä yhdistetylle SCADA- ja DMS -järjestelmälle: Isoja ongelmia ei löytynyt ja järjestelmien datan yhdistäminen yhteen käyttöliittymään todettiin olevan helppoa ja tehokasta.

Tulevaisuudessa, vikojen hallintapaneelin visualisoinnit täytyy viimeistellä ja ottaa käyttöön todellisissa ympäristöissä. Yhteiseen käyttöliittymäkehykseen tarvitsee tehdä muutama parannus, ja paljon uusia visualisointeja täytyy tehdä, jotta kaikkia yhdistetyn SCADA- ja DMS -järjestelmän vaadittuja ominaisuuksia tuetaan.

PREFACE

This Master of Science thesis was written for ABB Oy Power Systems, Network Management and Tampere University of Technology (TUT). I want to thank my superior Marko Viitala, product managers Matti Kärenlampi and Mikael Molander, and my supervisor Matti Ranta for providing me this practical, beneficial and very interesting topic to study on. I would like to thank Professor Pekka Verho for examining this thesis. I have enjoyed studying the topic and I feel privileged to have met so many great minds during the process.

Many thanks to Antti Kostiainen for helping with the customer visits and for sharing some of his knowledge with me. I want to thank Matti Karhinen from PKS Sähkönsiirto Oy, Timo Kiiski from SVV Oyj, and Jouni Vanhanarkaus from Tampereen Sähköverkko Oy for hosting the visits, giving superb comments, and sharing information about work flows and systems. I want to thank also Mikko Leinonen from PKS Sähkönsiirto Oy, Matti Pirskanen from SVV Oyj, Juha Järvensivu and Karoliina Laine from Tampereen Sähköverkko Oy and all the other operators and managers who gave comments and ideas during the visits.

While doing this thesis, I have received lots of feedback and support concerning technical issues, analytical issues and grammatical issues. I want to thank all co-workers in ABB, who have helped me finishing this thesis.

Lastly, but not least, I want to thank my beautiful and intelligent wife, Hanna, for the support she has given throughout the process.

Tampere, 12th November 2014

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SYMBOLS AND ABBREVIATIONS

SYMBOLS

h_E	Customer outage unit costs in the value of year 2005 [€/kWh]
KAH	Customer outage costs of a fault [€/h]
KHI_{2013}	Consumer price index of year 2013
KHI_{2005}	Consumer price index of year 2005
P	Total unsupplied power caused by the fault [kW]

ABBREVIATIONS

ABB	Asea Brown Boveri
AMR	Automated Meter Reading
API	Application Programming Interface
CAD	Computer Aided Design
CIS	Customer Information System
CPM	Collaborative Production Management
CSS	Cascading Style Sheet
D3	Data-Driven Document
DMS	Distribution Management System
DMS600	ABB MicroSCADA Pro DMS600
DMS600 WS	ABB MicroSCADA Pro DMS600 Workstation
DMSC	DMS Connector
DNS	Domain Name System
ET	Energiateollisuus ry, Finnish Energy Industries
FDIR	Fault Detection, Isolation and Restoration
FP	Feature Pack
HF	Hotfix
HISC	SYS600 Historian Connector
HMI	Human Machine Interface
HTML	Hypertext Markup Language
HV	High Voltage
IEC	International Electrotechnical Commission
IEEE	Institute of Electrical and Electronics Engineers
KAH	Keskeytyksestä Aiheutunut Haitta, Customer Outage Costs
LV	Low Voltage
MV	Medium Voltage
NIS	Network Information System
NPM	Node Package Manager

OPC	open connectivity via open standards
OS	Operating System
PKS	Pohjois-Karjalan Sähkö
RTU	Remote Terminal Unit
SA	ABB MicroSCADA Pro DMS600 Server Application
SCADA	Supervisory Control and Data Acquisition
SMS	Short Message Service
SLD	Single Line Diagram
SQL	Structured Query Language
SVG	Scalable Vector Graphics
SVV	Savon Voima Verkko
SYS600	ABB MicroSCADA Pro SYS600 Control System
SYS600C	ABB MicroSCADA Pro SYS600C Compact System
SYSC	SYS600 Connector
TUT	Tampere University of Technology
UI	User Interface
UX	User Experience
W3C	World Wide Web Consortium
WebUI	ABB MicroSCADA Pro WebUI
XML	Extensible Markup Language

1. INTRODUCTION

The amount of measurements, statuses and different alarms gathered from the distribution network is continuously increasing. As the amount of data increases, more processing of the data is needed, but also as a result, there is continuously increasing amount of information to be shown in the user interface. *Visualization* means displaying the information clearly and efficiently. According to [1], a good visualization is a well-built presentation of “interesting” data, which aims to clearly, precisely and efficiently present and communicate complex ideas. It should not distort or create false interpretations of the data, it should not be overloaded with elements, and the complex details should be easily accessible. Generally, a good visualization fully satisfies the requirements of those whom it was intended and created. [1, p.12-14] The visualization of the data is important, as nowadays the biggest competition in software business is in the ease of use and visualization, and a majority of the problems are due to human errors or problems one is not capable to handle, because the user interface is not clear, intuitive and error-preventive.

Monitoring and controlling the process in the main control center of an electricity distribution company relies mostly on two software systems, SCADA (Supervisory Control and Data Acquisition) and DMS (Distribution Management System). However, as currently SCADA and DMS are separate systems, two user interfaces have to be used to perform the required tasks. For a long time, there have been discussions that the use of the SCADA and DMS systems overlaps, and some previous studies state that in the future, the SCADA system may be left in the background and only the DMS user interface would be used [2, p.22; 3, p.43]. In ABB MicroSCADA Pro product family, the idea is to first combine the systems under one common user interface (UI) and later into a one combined system.

The common user interface framework for the SCADA and DMS systems in ABB MicroSCADA Pro product family is called MicroSCADA Pro WebUI in this thesis. It is a project name used to describe the common user interface framework in this thesis. The WebUI is developed to fulfill requirements such as integrating the systems, enabling use with different (mobile) devices and platforms, seamlessly switch-over in case of server failure, and modernizing the user interface [4, p.4]. The WebUI is still being developed, and it is piloted in this thesis: One of the targets for this thesis is to provide feedback, problems and ideas about the WebUI framework. Also, while the WebUI was already integrated well with the SCADA system before this thesis, one of the targets is to further integrate the WebUI with the DMS system.

The aim for this thesis is to discover visualization requirements for a combined SCADA and DMS system by studying the use and user interfaces of the current SCADA and DMS systems: It must be first understood how the current systems are used to be able to create a successful user interface for a combined SCADA and DMS system. In this thesis, three distribution companies are visited to get information, feedback and problems about the usage of the current systems. In addition, ideas and requirements for a combined SCADA and DMS system are gathered.

In this thesis, few visualization prototypes based on the requirements are created. The prototypes are implemented as views on MicroSCADA Pro WebUI framework using HTML5 web technologies. While creating the views, feedback, problems and ideas concerning the WebUI development platform are gathered and shared with other WebUI developers.

Chapter 2 presents how the SCADA and DMS systems act in the big picture of distribution automation system. In the chapter, also the SCADA and DMS systems in MicroSCADA Pro product family and the idea of a combined SCADA and DMS system are introduced.

Chapter 3 focuses on the web technologies needed to understand the visualizations created in this thesis. The technologies are introduced with a general approach, concentrating on the most important visualization technologies. Also, in the chapter it is explained why the certain technologies were chosen to be included into the WebUI.

Chapter 4 describes the visits to the distribution companies and the study methodology used. In the chapter, the most common tasks performed in the main control center are described with as much specifics as possible.

Chapter 5 discusses the visualization requirements for a combined SCADA and DMS system gathered from the customer visits. General visualization requirements along with fault management, maintenance outage management and other visualization requirements are discussed.

Chapter 6 describes the visualization concepts created within this thesis. First, a technical description of the visualizations is given. Then, the iterative development of the visualizations is described and finally the visualization prototypes created in this thesis are introduced and analyzed.

Finally, chapter 7 presents the conclusions and the required future development work.

2. DISTRIBUTION AUTOMATION SYSTEM

Any automation system, including electricity distribution automation system, can be divided into primary process and secondary process. The primary process contains the actuators in the system, which in electricity distribution can be devices like transformers, overhead lines, cables, switching devices, fuses, reactors and capacitors. The secondary process consists of systems, which are used to monitor and control the primary process. The processes in electricity distribution automation system are visualized in Figure 2.1. [2, p.13]

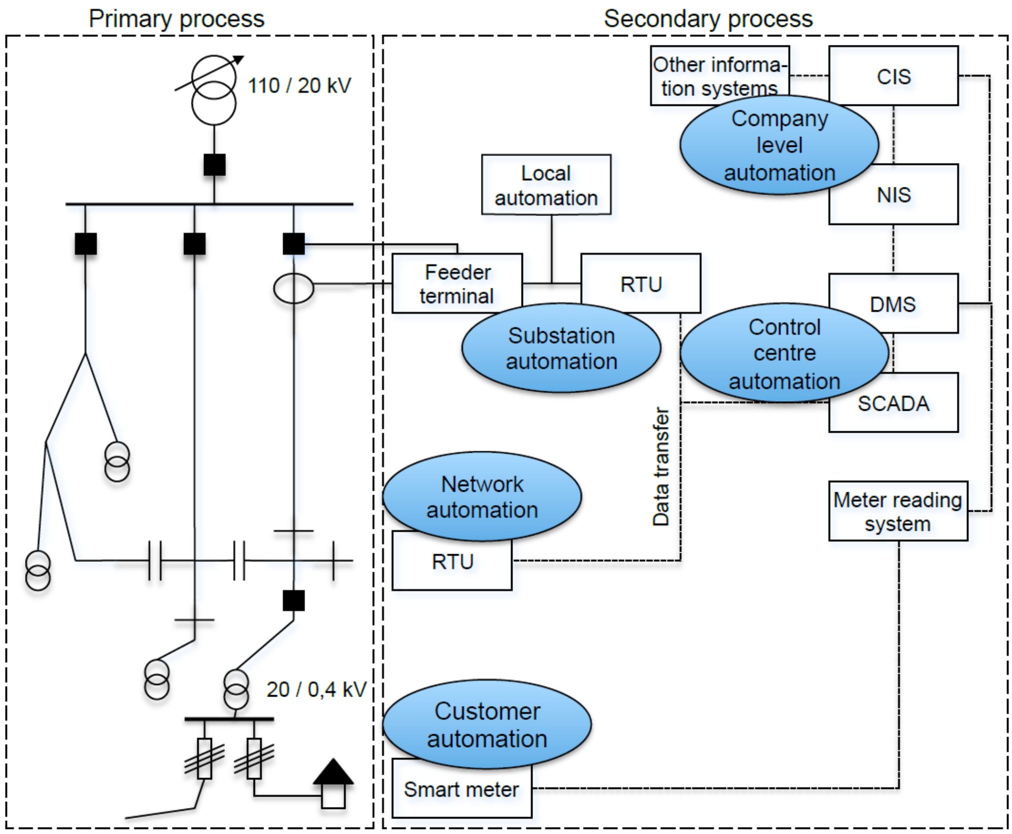

Figure 2.1 *Primary and secondary processes in electricity distribution automation [2, p.14].*

The secondary process of electricity distribution automation can be further divided into five levels: Company level automation, control center automation, substation automation, network automation and customer automation. This thesis studies a combined SCADA and DMS system, and therefore the control center automation level is mainly discussed. However, it is important to understand how the combined SCADA and DMS system appears in the big picture of electricity distribution automation: The substation automation and network automation are utilized by the SCADA system, and the customer automation is utilized by the DMS system. Also, the control center automation is utilized in company level automation.

In control center automation, two software systems, SCADA and DMS, are used. The SCADA is a process information system, which is used to receive and store real-time measurement and status data from the network. The SCADA system can be used independently without DMS system, and it offers a HMI (Human Machine Interface) to monitor and control the process. The SCADA system also provides the real-time process data and controlling functionality to the DMS system.

DMS system combines the SCADA process data, the data of Network Information System (NIS), and nowadays also Automated Meter Reading (AMR) data into a single system. It represents the network on top of a geographical map and offers a number of functionalities, such as fault management, workgroup/field crew management, maintenance outage management and reporting features, to help the operator accomplish the required tasks in the main control center. In addition to online-components, which statuses are updated real-time via SCADA system, the DMS system contains also the offline-components along the network such as manually operated disconnectors: The statuses of these components have to be updated manually into the DMS system by the operator to keep the switching status and topology up to date.

Although ABB has separate products for SCADA and DMS systems, they are tightly integrated within MicroSCADA Pro product family. The MicroSCADA Pro product family will be discussed in chapter 2.1.

In the electricity distribution field, the similar usage of SCADA and DMS systems has been noticed: Ideas of combining the systems can be found from previous studies, and some vendors have already combined the systems under one user interface. The combined SCADA and DMS system in general, as well as the common user interface framework in MicroSCADA Pro product family will be discussed in chapter 2.2.

2.1 MicroSCADA Pro

MicroSCADA Pro product family consists of 3 products, SYS600, SYS600C and DMS600. SYS600C is an industrial solid state computer which has SYS600 preinstalled to it [6]. SYS600 is a SCADA system, which is mainly used by electricity distribution companies but it can also be used in other various industry environments such as in water management [7]. SYS600 will be discussed with details in chapter 2.1.1.

DMS600 is a DMS system, which is used in the main control centers of electricity distribution companies to handle functionalities such as fault management, maintenance outage management, field crew management, power flow analysis, fault current calculations, operational simulations, load estimation, and map printing. Chapter 2.1.2 describes DMS600 with details.

2.1.1 SYS600

MicroSCADA Pro SYS600 is a SCADA system, which gathers real-time measurement and status data from the network. The data is collected in a process database and it can be shown in the SYS600 HMI. In addition to monitoring the process, it is possible to control the process from the SYS600 HMI, for example change the switching status of a switch. The process data as well as the controlling functionality are usually also offered for the DMS system to use.

The user interface of SYS600 is configurable. It can be created by an engineer in the distribution company or it can be at least partly created as a part of the deployment project of the SYS600. The most used features in SYS600 are events and alarms, measurement trends, and single line diagrams (SLD), which can represent for example the feeders, measurements and bays inside one primary substation. An example of SYS600 trends display, alarm display and a single line diagram is represented in Figure 2.2.

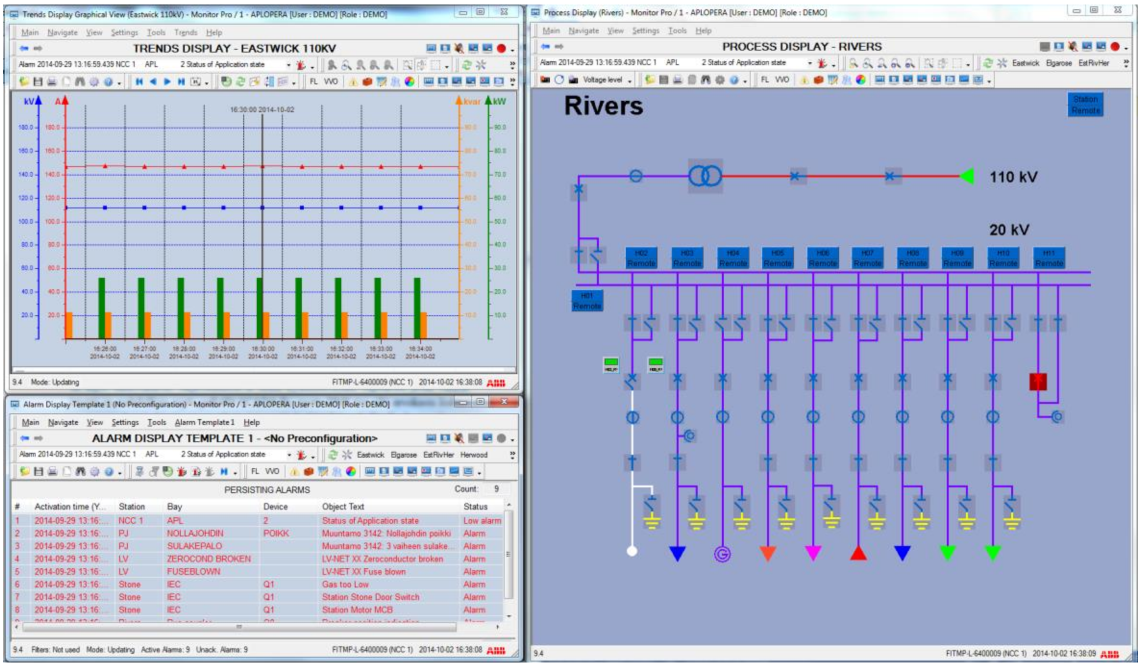

Figure 2.2 *Trends display, Alarm display and a single line diagram in MicroSCADA Pro SYS600.*

The trends display visualizes the history of certain measurements in the network and the alarm display shows the unacknowledged alarms in the system. The single line diagram can be used to check the current statuses in the primary substation. In a single line diagram, topological coloring is an important feature: For example in Figure 2.2, it can be easily seen that the leftmost feeder in the Rivers-substation is unsupplied and the circuit breaker has tripped. The circuit breaker could be closed from the control dialog, which is opened by pressing the icon.

The user interface of the SYS600 has not changed much in the latest decades. Because the SCADA system is considered critical and the customer basis is rather conservative, major changes are not preferred to occur very often. However, as nowadays the visualization technologies have advanced and the requirements for modern user experience have increased, it may be the time to utilize the newest technologies.

2.1.2 DMS600

MicroSCADA Pro DMS600 is a DMS system, which integrates SCADA process data, data from network information system, and nowadays also data from AMR system. It helps to perceive the network geographically as it presents the real-time status of the network on top of a geographical or aerial map. Alternatively, the network can be monitored from a schematic view. DMS600 offers a lot of different functionalities to help the operator in the distribution management, for example in the areas of fault management and maintenance outage management. It is said, that the DMS system is nowadays practically indispensable tool in the main control center along with SCADA [8, p.27].

The user interface of DMS600 usually consists of a few overviews of the network and an overview of the system’s status. The network is operated by zooming in and clicking on a network component. Faults are managed by using a fault management dialog and maintenance outages are managed by using maintenance outage management dialog. An example of a DMS600 user interface, when there is one fault in the network, is shown in Figure 2.3.

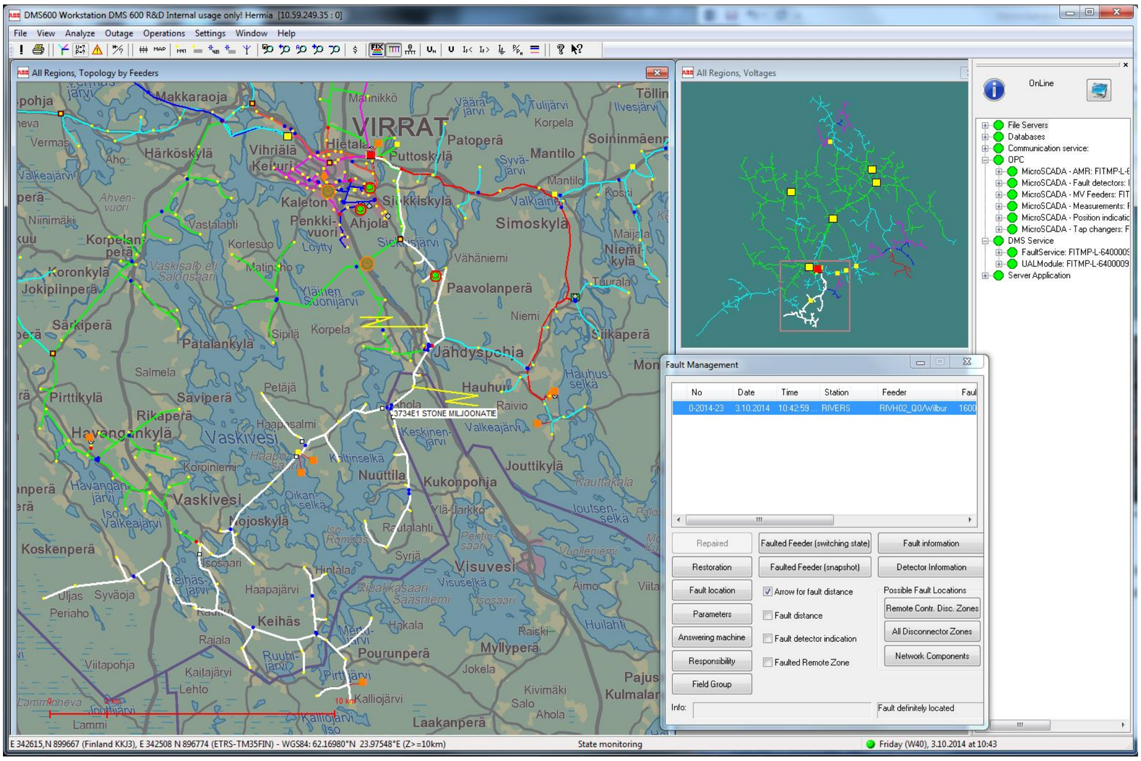

Figure 2.3 *Fault management user interface of MicroSCADA Pro DMS600.*

In Figure 2.3, there are four views in the user interface: The main network view is focused on the faulted, unsupplied feeder and the fault is shown in the fault management dialog. The auxiliary window shows an overview of the whole network and the connection status info bar shows the statuses of the DMS system. Two possible fault locations are shown as yellow lightning bolts in the main network view.

2.2 Combined SCADA and DMS System

Currently, two separate systems must be used to monitor and control the process in the main control center. SCADA system must be used to receive real-time data from the network and the DMS system must be used to manage low voltage network and to fulfill fault handling and reporting requirements. Earlier, only the SCADA system was mandatory in the main control center, but because nowadays the role of DMS system has increased, both systems are indispensable tools in the main control center. Chapter 2.2.1 describes general motivation to combine SCADA and DMS systems.

The unity of SCADA and DMS systems has been noticed also outside ABB. For example, Siemens has already combined SCADA and DMS systems under a common user environment in their Spectrum Power Advanced Distribution Management System (ADMS) [5]. In some studies, there have been development ideas that the SCADA system would be left in the background and only DMS user interface would be used to monitor and control the process [2, p.22; 3, p.43]. In ABB, a little different approach has been taken: The SCADA and DMS systems will be firstly combined under one common user interface and later into a one common system. The common user interface framework for SYS600 and DMS600 products is called MicroSCADA Pro WebUI, and it is discussed in chapter 2.2.2.

2.2.1 Motivation for a Combined SCADA and DMS System

The SCADA and DMS functionalities are overlapping in many places. Both of the systems have separate, but similar events and alarms, and different, but almost the same monitoring views. However, the systems may have completely different user experience as the systems may in many cases be provided from different vendors.

If the SCADA and DMS systems are separate, the network has to be supervised using both systems, because some status information is only available in other system. For example, the high voltage network or hydroelectric power plants can only be monitored using SCADA system and the low voltage network is only monitored using DMS system. Also, the network has to be operated using both systems, because some operations are only available in other system. For example, changing a tap changer to manual operating mode can only be executed using SCADA system, and adding a temporary grounding to the network can only be executed using DMS system. The amount of data and operations available in DMS system depends on how deeply the systems have been integrated. In the end, both systems are used for the same purpose, to monitor and control the process in the main control center.

If the SCADA and DMS are separate systems, they have to be configured to collaborate. This causes a lot of additional system administration work in the main control centers and many changes in the system have to be changed in two places. Also, in some cases, especially if the SCADA and DMS systems are from different vendors, there are technical limitations for what functionalities are possible to be integrated. If the systems were combined, there would be only one system, which needs to be configured. Also, all operations could be executed from one user interface only. This enables a possibility to create more comprehensive views in the system, which would improve user experience and increase effectiveness of the operator.

If the SCADA and DMS systems were combined, the whole network could be supervised and controlled with one unified system. The events and alarms, which occur in the network, could be seen in one view only and all the necessary operations could be executed using only one system. This improves user experience and increases effectiveness of the operator as two separate user interfaces would not need to be used.

Finally, as the development of the SCADA and DMS systems are combined, the productivity and innovation are likely to be increased: Same programming modules can be easier used for multiple purposes, same features are not implemented twice, and as the communication between the developers increases, new innovations are likely to be generated.

2.2.2 MicroSCADA Pro WebUI

MicroSCADA Pro WebUI is a project name for a new generation user interface platform, which is currently being developed. The main purposes of the WebUI are to integrate multiple systems into single user interface, modernize the user experience, enable seamless switch-over in case of server failure, and enable mobile use [4, p.4]. A high-level architecture of WebUI is represented in Figure 2.4. The parts belonging to WebUI are shown in red and external systems are shown in purple.

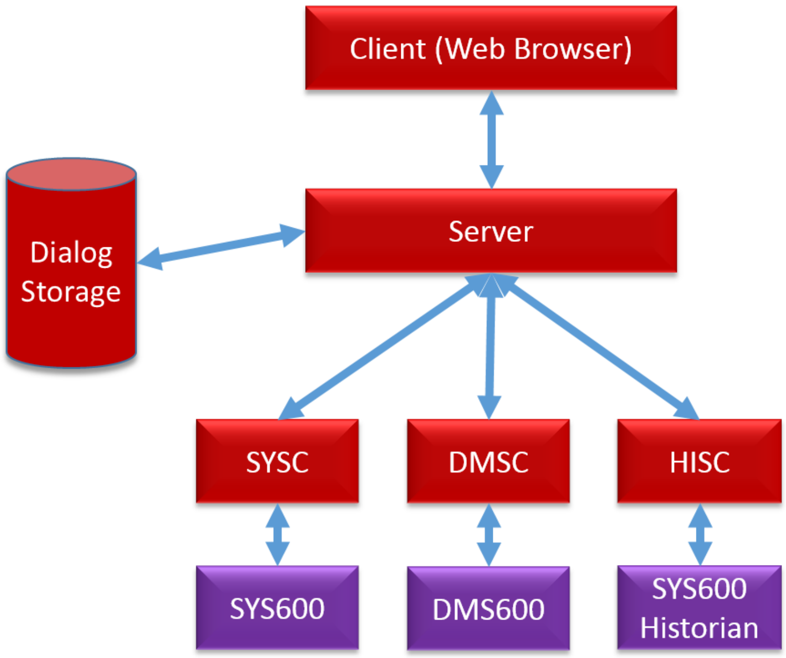

Figure 2.4 *High level architecture in MicroSCADA Pro WebUI (adapted from [9, p.9]).*

The architecture of WebUI is client-server based. The client can be any modern web browser, which supports HTML5 (for more information about HTML5, see chapter 3.1.4). This enables that the system can be used with any operating system and with any device, such as a mobile device. The server is currently implemented on Node.js platform, which is described with more details in chapter 3.4. The server communicates with external systems through communication modules, which in Figure 2.4 are called SYSC (SYS600 Connector), DMSC (DMS600 Connector) and HISC (SYS600 Historian Connector).

The dialog model in WebUI is built as follows: When a client requests a web page from the server, the server loads a *User Interface Definition Document* from the Dialog storage. *User Interface Definition Document* is a XML file, which describes how the view is to be built. The *User Interface Definition Document* is then materialized by the server and sent to the client. If the *User Interface Definition Document* requires values from the external systems, they are subscribed and forwarded to the client. When a subscribed value in the external system changes, the server forwards the updated value to the client and the view is updated automatically. [4, p.27] The visualizations generated within this thesis were implemented according to this dialog model.

One important aspect of this thesis was to act as a pilot for the WebUI. Feedback, ideas and problems that were noticed during this thesis were reported to other WebUI developers. Also, the practical part of this thesis included some development in MicroSCADA Pro WebUI, especially concerning the communication with the DMS600 system.

3. WEB TECHNOLOGIES

The web technologies used in this thesis are described in this chapter. The technologies are described at a relatively high level, focusing on the most important aspects concerning this thesis. All of the technologies are wide and complicated entities, and if one wants to go deeper into any of these technologies, more detailed information concerning each of these technologies is presented in the literature [10; 11; 12; 13; 14; 15].

First, a few general web technologies will be introduced in chapter 3.1. Second, the visualization technologies (SVG and D3.js) used in this thesis are discussed in chapters 3.2 and 3.3. Finally, the web server technology, on which the MicroSCADA Pro WebUI is based on, node.js, is introduced in chapter 3.4.

3.1 General Web Technologies

Creating a web application using best practices requires knowledge about some quite wide technologies. In this chapter, the basic technologies, that need to be understood in order to create the visualizations in this thesis, are described.

Hypertext Markup Language (HTML) is introduced in chapter 3.1.1. Cascading Style Sheets (CSS) will be described in chapter 3.1.2 and the programming language called JavaScript will be introduced in chapter 3.1.3. The latest standard of the HTML technology, HTML5, will be discussed with details on chapter 3.1.4. Finally, a summary about these technologies is given in chapter 3.1.5.

3.1.1 HTML

Hypertext Markup Language was created in the early 1990’s. The World Web Consortium (W3C) has been responsible for the standardization of HTML since it was found in October 1994 [16]. HTML 2.0 was published in 1995, HTML 3.2 in 1997, HTML 4.0 in 1997 and currently the latest published standard HTML 4.01 in 1999. The latest version of HTML standard, HTML5, is currently at “candidate recommendation” state in W3C, and there are plans to publish it as a recommendation still in 2014 [17]. However, most of the HTML5 features are already supported in the majority of web browsers so it has already become a widely used technology. HTML5 will be discussed more closely in chapter 3.1.4.

HTML is a markup language, which describes the structure of web pages [18]. It defines the content, which should be visible on the web page. The definitions are created using HTML elements such as div, image or table. The way, how the HTML element is handled, can be tuned by adding one or more attributes to the element. The attributes can be global, local or author defined attributes. Global attributes can be applied to any element, local attributes are for element-specific tuning and author defined attributes are meant for developer's own purposes. A basic html document is presented in code listing 3.1. [10]

Code Listing 3.1 *A basic HTML document.*

```
<!DOCTYPE HTML>
<html>
	<head>
		<title>Example</title>
	</head>
	<body>
		<p>
			This is an example html.
		</p>
	</body>
</html>
```

The first row in listing 3.1 tells the browser (or other reader) that this document is HTML. The second row starts an html element, which ends at the last row. The html element contains one head and one body element. The head element contains document information and metadata for the document, one of which, title, is mandatory. The body element encapsulates the content of the HTML document. In this example, the body contains one paragraph with text "This is an example html". [10]

3.1.2 CSS

Cascading Style Sheets (CSS) specify the appearance and the formatting of the HTML document. For instance, a CSS can describe the color and position of an HTML element in the HTML document. A typical way of integrating CSS to an HTML document is to create a separate CSS file and make a HTML link element to the HTML document, which includes the CSS into HTML. A simple CSS example is shown in code listing 3.2.

Code Listing 3.2 *A simple CSS example*

```
.OkButton {
	color: green;
}
```

The listing 3.2 shows content of a simple CSS file, which purpose is to make every HTML element, whose global attribute *class* is “OkButton”, green. In the example, a CSS selector, dot, is used to apply this style to all elements, whose *class* is “OkButton”. Other CSS style attributes than color could be used to specify positioning, decoration and sizing of the HTML element.

3.1.3 JavaScript

JavaScript is used to add user interaction to HTML documents. JavaScript is a programming language that is usually executed in the client side, i.e. in the web browser. For example, JavaScript functions can be used to react to user’s mouse click on an HTML element. The function can for example modify an existing HTML element, create a new HTML element, or communicate with the web server. Code listing 3.3 shows a simple JavaScript example.

Code Listing 3.3 *A simple JavaScript example*

```
function onOkButtonClicked()
{
	redirectToHomePage();
}
```

The function in Code Listing 3.3 can be attached to an HTML element as an event handler, which is supposed to fire when the element is clicked. This function simply forwards the call to another function called redirectToHomePage.

Because the status JavaScript has on client-based programming, it has become very widely used. Its flexibility and dynamic typing allows JavaScript to be used very diversely but at the same time, it can cause code to be quite confusing for unexperienced reader. Although JavaScript was developed to be executed on client-side, it can also be used in server-side network programming to create a web server. This is the case with Node.js, which will be described with more details in chapter 3.4.

3.1.4 HTML5

HTML5 is not only about the new HTML elements that it describes, but it is also a set of related technologies that are used to make modern, rich web content. Two of the technologies (CSS and JavaScript) were already introduced, HTML5 specifics will be discussed in this chapter, and Scalable Vector Graphics (SVG) will be introduced in chapter 3.3. The technologies have become so interconnected that to be able to fully use the advanced features that HTML5 specifies, all of them need to be understood. [10]

One of the major changes in HTML5 is philosophical: The semantic signification of an HTML element is separated even more than before from the presentation definition.

This means that the standard has been shifted to the direction where HTML elements create the structure and meaning to the content and CSS styles define the presentation of the content. [10] A great example about this is the b element: Until HTML5 this element was fully presentational: The content between this elements start and end tags was meant to show as bold text. However, in HTML5 the definition of b element was changed to:

"*The b element represents a span of text to which attention is being drawn for utilitarian purposes without conveying any extra importance and with no implication of an alternate voice or mood, such as key words in a document abstract, product names in a review, actionable words in interactive text-driven software, or an article lede. [19]*

The HTML5 specification also states that "*The b element should be used as a last resort when no other element is more appropriate. In particular, headings should use the h1 to h6 elements, stress emphasis should use the em element, importance should be denoted with the strong element, and text marked or highlighted should use the mark element." [19]*

From the quotes we can see that fully presentational HTML elements (such as b or table as a layout element) should be avoided. The quotes show the philosophical shift that HTML5 contributes: HTML elements are supposed to give structure and meaning of the content, and not define the visual appearance.

HTML5 has brought a lot of clarifications, new attributes and also some new HTML elements. From the new HTML elements, probably three of the most important are video element, audio element and canvas element. The video and audio elements give possibility to play video and audio in web pages without plugins. The canvas element acts as a drawing surface that can be used programmatically (JavaScript) for tasks that were commonly achieved by using a flash player.

3.1.5 Summary

It is possible to define content, styling and layout by only using HTML. For example, table-elements can be used for layout and font-elements can be used for style. However, in a modern web application it is recommended to separate content, style and behavior, i.e. HTML, CSS and JavaScript. [20] There are several reasons for this:

- Efficiency of code: The same CSS files can be used in many web pages so one doesn’t need to download them with every HTML page.
- Ease of maintenance: One can make updates to only one place.
- Accessibility: Some users are unable to visually experience the web pages, so they have to access the information using a piece of software called “screen reader”. The reader can do much better job if the web page is built with best practices.
- Device compatibility: Because styling is separated to CSS, the web page can be easily reformatted to different viewers based on the device, screen size, resolution etc. CSS also offers support for different presentation methods such as screen, printing view and mobile device.
- Web crawlers/search engines: Web pages are also read and analyzed programmatically. If the web page is not built with best practices, the best result is not achieved. [20]

This chapter described some general technologies about creating a web application with a general approach. The next chapters will be about visualization technologies and web server technology, which were used in this thesis. However, in order to understand the visualization technologies, the general technologies described in this chapter need to be understood.

3.2 SVG

Scalable Vector Graphics (SVG) is a XML based language for describing 2D graphics. It is standardized by W3C and the latest version of SVG standard (1.1 second edition) was published in August 2011 [21]. In HTML5, SVG is supported inline meaning that SVG content can be embedded within HTML markup simply by adding *<svg>* tag [12].

The basic elements in SVG are rectangles, circles, ellipses, lines, polylines and polygons. The more complex shapes can be modelled using path element. SVG also contains text element, which supports almost any text feature available in modern graphics such as decoration, formatting, aligning, rotating, spacing and internationalizing of the text. SVG elements can be stroked and filled with solid colors, linear and radial gradients and patterns. SVG supports interactivity so user-initiated actions such as mouse clicks can cause animations or scripts to execute. SVG is vector based graphics, which means that strokes and fills are rendered mathematically onscreen by coordinates. Because of this, SVG graphics will remain crisp even when zoomed in contrast to bitmap images. Also, vector images tend to be smaller in size than bitmap images, which saves bandwidth. Code Listing 3.4 shows a simple SVG example embedded within HTML markup. [12; 13; 14]

Code Listing 3.4 *A simple SVG example.*

```
<!DOCTYPE HTML>
<html>
    <head>
        <title>Example</title>
    </head>
    <body>
        <svg width=”500” height=”200”>
            <rect x=”10” y=”10” width=”40” height=”40” fill=”blue” />
            <rect x=”40” y=”30” width=”40” height=”40” fill=”yellow” />
            <rect x=”70” y=”50” width=”40” height=”40” fill=”red” />
        </svg>
    </body>
</html>
```

In listing 3.4 the HTML document is specified to contain three SVG rectangles that partially overlap. The result as a web page can be seen in Figure 3.1.

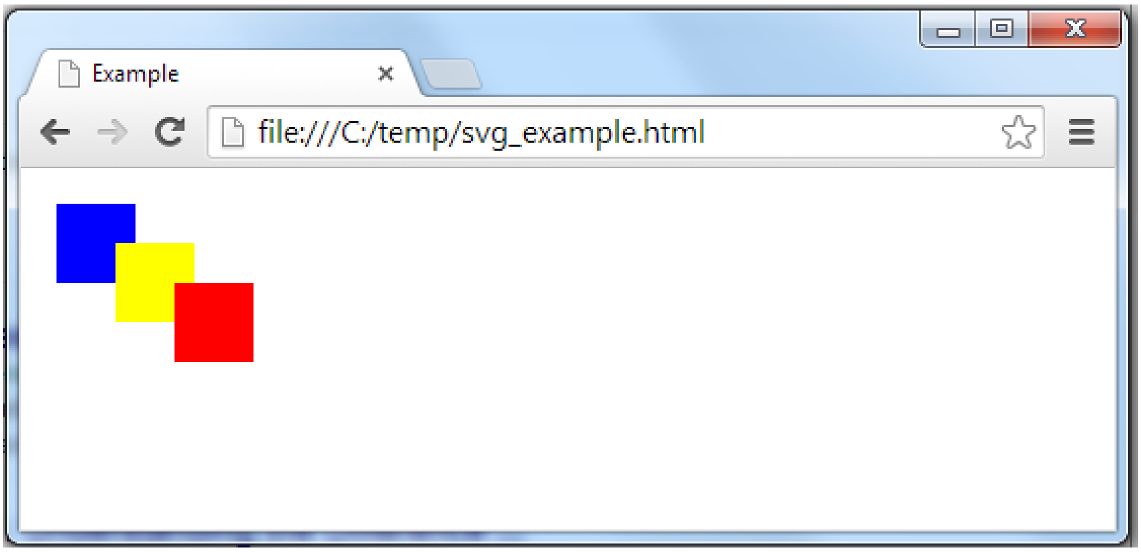

Figure 3.1 *A simple SVG example in Google Chrome web browser.*

Figure 3.1 shows the SVG elements as they appear in web browser. It can be also seen how the overlapping SVG elements are drawn: The element which is specified first is rendered first: Others are drawn on top of that element.

SVG is an important element in MicroSCADA Pro WebUI, because it is used when creating the views such as SLD’s. This technology was also used to create the graphical elements in the visualizations introduced in chapter 6.

3.3 D3.js

D3.js (Data-Driven Documents) is a JavaScript library for creating data visualizations. It is an open source library which was announced in 2011. D3.js can use native HTML elements to create visuals, but it is most useful with SVG elements. [15]

D3.js connects data to the document. D3.js loads the data into the browser's memory and binds the data to elements within the document: If there is a new item in the data, a new element will be created. If a data member changes, the corresponding element within the document will be updated accordingly. The developer is responsible for providing the data for D3.js and defining the (SVG) elements that are used to represent the data. Also, the developer must define how the transformations and transitions of the elements must be done. D3 executes the rules developer has defined and creates a graph based on the data. [15] Code Listing 3.5 shows a simple D3.js example.

Code Listing 3.5 *A simple D3.js example [22]*.

```
var circle = svg.selectAll("circle")
   .data([32, 57, 112], function(d) { return d; });

circle.enter().append("circle")
   .attr("cy", 60)
   .attr("cx", function(d, i) { return i * 100 + 30; })
   .attr("r", function(d) { return Math.sqrt(d); });

circle.exit().remove();
```

Listing 3.5 shows a simple piece of JavaScript that uses D3.js. In the first row, a D3.js selection is used to select all SVG circle elements from the HTML document. In the second row, the data array is bound to the selection using the item in the array itself (i.e. 32, 57 and 112) as a key. The key is used to determine if the item is new or already existed. The 4th row defines that a new SVG circle element should be created if there was an item in the data that didn't exist in HTML document. The element's properties are defined in rows 5-7 and the row 9 defines that extra circle elements (that don't have a corresponding value in data array) in HTML document are removed. The Figure 3.2 shows this code in a web browser.

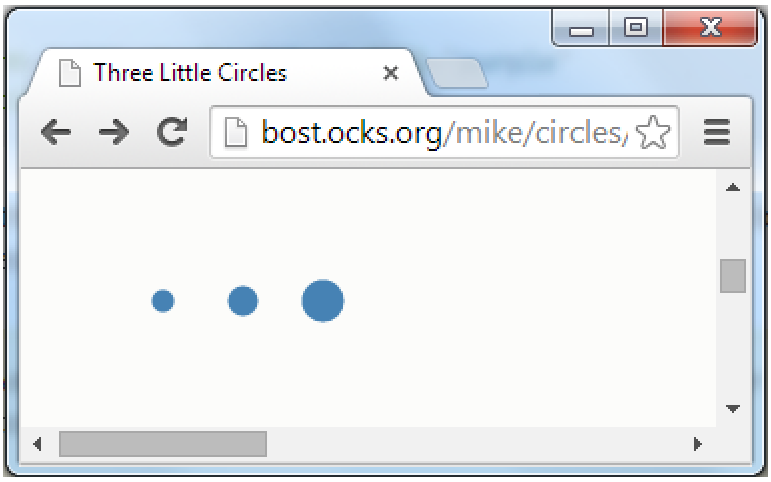

Figure 3.2 *A simple D3.js example in a Google Chrome web browser.*

The three SVG circles appear to the web browser as can be seen in Figure 3.2. The circles are next to each other because the attribute cx depended on the index that the data member was placed in the data array. The radius of the circles are different, because the r attribute depended on the value itself in the data array.

One of the great features in D3.js is transitions. Developer can easily specify a transition if an attribute of a data item changes and D3.js smoothly transforms the corresponding (SVG) element from the original value to the new value. For example, if the data represents people, whose attribute hairColor represents the hair color of the person, and the hair color changes from brown to white, the D3.js smoothly transitions the color of the corresponding person's hair from brown to white within a specified timespan.

D3.js offers D3 layouts to help developer generating the visualizations. D3 layouts modify the data so that it is easier visualized. Following layouts are currently included in D3.js:

- Bundle
- Chord
- Cluster
- Force
- Hierarchy
- Histogram
- Pack
- Partition
- Pie
- Stack
- Tree
- Treemap

Layouts take the raw data as input and they provide certain values that help the developer to create the visualization. For example, pack layout take hierarchical data as input and it provides radiuses and positions of circles which can then be used to create a visualization. An example of pack layout visualization is shown in Figure 3.3.

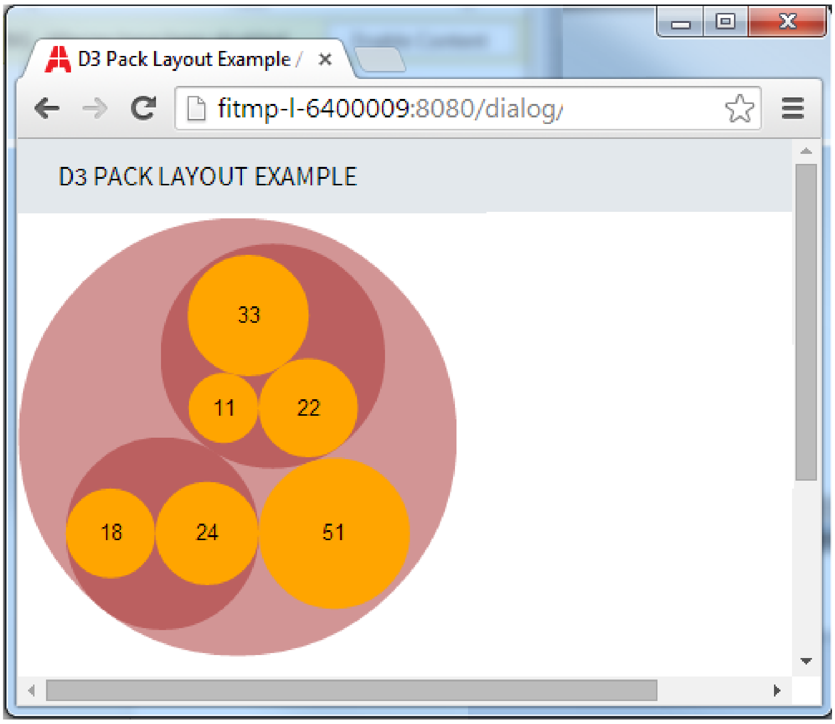

Figure 3.3 *D3.js visualization created using D3 pack layout in Google Chrome.*

The Figure 3.3 is created from hierarchical data that contained 6 leaf values (11, 18, 22, 24, 33, and 51) and their parents. When using pack layout, the circles radiuses and positions are calculated so that they fit in the graph area nicely: The leaf node circles radiuses are proportional to their value, and parent node circles are sized so that children nodes fit in.

D3.js offers also support for zooming and panning of graphs. A smooth and fast zooming can be achieved with only a few lines of code: A D3 zoom object is created and it is attached to a SVG element, which will register necessary event listeners to support panning and zooming. After that, developer can easily define what happens when the graph is zoomed. Both mouse and touch events are supported.

D3.js is a powerful library for creating data-based visualizations. A lot of mind-blowing examples can be found from the official home website d3js.org. D3.js visualization library was chosen to be included in the MicroSCADA Pro WebUI, because a declarative method for creating complex visualizations does not fit the dialog model well. Therefore, the D3.js library was found to be an elegant solution for a complex problem [9, p.11]. The visualizations created in this thesis were implemented using D3.js.

3.4 Node.js

Node.js is a server-side framework that can be used for example to build a web server. It uses V8, a high performance JavaScript engine designed by Google, to execute code. Node.js is useful for building highly scalable and fast applications and it has grown rapidly recently. [23]

The programming language in Node.js application is JavaScript. This brings technological consistency, because the same technology is used also in client side (web browser). Therefore developers can more easily work on both client and server side as they don't need to change the programming language. This is not the case with other web server technologies. [23] Also, as happens in WebUI, the same components can be reused in both server and client sides.

Node.js can handle a lot of concurrent requests because it is asynchronous in nature. It utilizes asynchronous event-driven programming at its very core but still avoids the system from locking: The requests are handled so that a callback function registered for handling that request is called. While awaiting the return, the next request can be already handled. This doesn't cause problems with concurrency, because JavaScript supports closures: Each function has access to values exactly as they were when the function was invoked. [11; 23]

Node.js consists of modules, which bring features to the framework. Some of the modules are shipped with the Node.js such as File System module, OS module, Util module and DNS (Domain Name System) module. File System module provides possibility to work with files. OS module provides environment-related functions and information about operation system. Util module contains handy utility-type functions and DNS module offers features to work with domain names and IP addresses. [11; 23]

In addition to core modules, a lot of third-party modules exist that extend the functionalities of Node.js [23]. At the time of writing, there are almost 80 000 modules available, which are developed continuously by the community [24]. The modules can be easily deployed using node package manager (npm), which is installed with Node.js.

Node.js was chosen to be the framework for MicroSCADA Pro WebUI server over a couple of alternatives for several reasons: The same programming language (JavaScript) for both client and server sides adds the minimum amount of new programming languages to be learnt. The technology seemed relatively commonly used, and by using this technology, it was possible to create a unit test framework, which suits both client and server. Because Node.js ships as a single executable and it has a minimum amount of interfaces, it is easily installed and the security risks are minimized. [9, p.12-13]

4. CUSTOMER VISITS

A compact user study was included in this thesis. Three distribution companies that use MicroSCADA Pro products were chosen and visited during spring 2014. The purpose of the visits was to get an overview of the processes in main control centers, to find out the most common use cases with as much details as possible, and to discover visualization requirements for a combined SCADA and DMS system.

Study methodologies will be described in chapter 4.1. Details of the visited companies will be given in chapter 4.2 and a summary of the most common use cases will be given in chapter 4.3.

4.1 Study Methodology

This study was done by visiting distribution company employees in the main control centers. It is the best way to understand customer processes, common tasks and problems they face in their everyday work. Also, while getting familiar with customer processes, feedback about current products and new ideas concerning a combined SCADA and DMS system were collected.

The motivation behind this user study will be covered in chapter 4.1.1. The interviewees who gave comments will be described in chapter 4.1.2. The aim and methods used in this study will be analyzed in chapter 4.1.3.

4.1.1 Motivation

With the rising of information systems, we have entered the era of cognitive information overflow. The information overflow is coming from increased automation in substations and in network, and from AMR (Automated Meter Reading). In recent years, almost all distribution companies have been equipped with AMR meters. Also, when a primary substation is renewed, the amount of data coming to control center increases tenfold. Because the operators in control centers don’t necessary have time to analyze data, especially in a major disturbance situation, the information has to be analyzed programmatically and visualized so that all required information can be received fast and the most important concerns are highlighted.

As the software business advances, user experience (UX) becomes increasingly important. User experience can be seen differently by people with different backgrounds, but generally it contains aspects such as ease-of-use, efficiency, visualization, overall feeling after interacting with a product, and providing satisfactory solutions to fulfill user needs [25]. To create modern user experience into a combined SCADA and DMS system, the problems of the current systems need to be understood.

Without understanding the processes and most common tasks in control centers on an adequate level of detail, a modern, intuitive, error-preventing, efficient and enjoyable HMI cannot be made.

4.1.2 Interviewees

Almost all control room roles and responsibilities related to distribution management were represented in customer interviews. In all control centers, there were multiple operators present giving their comments. In addition to operators, also system administrators, operative managers and planning managers gave comments and feedback during the visits. Mostly, the discussions focused on operating the network, but also network planning point of view was included.

Some of the interviewees preferred to use more DMS user interface and they knew more about the DMS system while others preferred to use more SCADA user interface and they knew more about the SCADA system. However during two first visits, the discussion shifted to be more about DMS system, maybe because there are more areas of innovation in DMS system than in SCADA system: Because the nature of a DMS system is to combine process data and the data from other systems, it enables a possibility to create an user interface where all the necessary information and controllability is provided to the operator clearly and easily.

While two first visits focused on the DMS system, the third visit discussed mostly the SCADA system. This distribution company tends to use the SCADA system a lot more than the other visited distribution companies, and their SCADA system was built up to a very advanced level.

4.1.3 Approach and Methods

Before visiting the distribution companies, background research was done by exploring other previously completed usability studies by ABB (including CosyViz Field Study Report [26]). Also, a teleconference with distribution company representatives was arranged before visits. From the teleconference, requirements concerning system supervision and fault management were collected. Using these requirements, a first draft of “Degree of isolation visualization” –view was implemented in the WebUI framework (for more information about the first draft of “Degree of isolation visualization”, see chapter 6.2.1).

To further deepen the overview of the processes, tasks and problems in the main control center, three distribution companies were visited. During the visits, the operators, managers and administrators were interviewed about their tasks and problems in the main control center. Also, the WebUI and the first draft of "Degree of isolation visualization" –view were introduced and comments were gathered. After the visits, more information about the tasks and opinions about the visualizations have been collected.

The visits were done with Antti Kostiainen, ABB Solution Development Manager, who has wide knowledge and a long experience in network management and distribution automation. Before coming to ABB, Antti had worked in a main control center as an operator. In ABB, he has worked with the customers as a project engineer for many years. Antti helped to organize the visits with the companies and he was a crucial part of discussions as he was capable of sharing ideas on so many areas of network management.

Most of the interviews happened in the main control room, although also a meeting room and SCADA control room was used. All conversations were recorded and photos were taken. Audio recordings were transcribed and a summary document was done on each visit.

All visits covered roughly the same 3 topics:

- The first draft of "Degree of isolation visualization" –view was introduced and feedback was gathered.
- Most common use cases were discussed.
- Improvement suggestions and missing features in the current SCADA and DMS systems were gathered.

In the first two visits, the "Degree of isolation visualization" –view was introduced before discussing most common use cases and future ideas. In the third visit, the "Degree of isolation visualization" -view was introduced last, which worked better as it started nice innovative discussions.

While covering the topics, general observations about work in main control center, like the environment, used tools and phone calls, were gathered.

4.2 The Visited Distribution Companies

Three distribution companies were selected into this study. Two of the selected companies, PKS Sähkönsiirto Oy and Savon Voiman Verkko Oyj (SVV), are more rural distribution companies and they use actively both SYS600 and DMS600 products. The third company, Tampereen Sähköverkko Oy, is a more urban distribution company and they use SYS600 as a SCADA system and Tekla's Trimble Distribution Management System as a DMS system.

All of the companies have multiple high, medium and low voltage levels in their electrical networks. They all have some high voltage regional network with a few connection points to the main transmission grid. In medium voltage levels, PKS and SVV have a wide electrical network with long feeders to rural areas in contrast to Tampereen Sähköverkko Oy, which has several very large primary substations feeding a mostly cable network in a quite small geographical area.

In general, SYS600 user interface is used to manage high voltage network and primary substations and DMS600 or Trimble DMS user interface is used to manage medium voltage networks and low voltage networks. However, Tampereen Sähköverkko Oy was a little different case because their SCADA and DMS systems are not from the same vendor. Because of some issues in interoperability between their SCADA and DMS systems, and because distribution network is traditionally managed using SCADA user interface, SYS600 user interface plays a relatively large role in their system: It is used a lot to monitor and control also medium voltage network. The network supervision use case will be analyzed more deeply in chapter 4.3.1.

All of the companies have also hydroelectric power production which is supervised by the operators in the main control center. Savon Voima Oyj and Tampereen Sähköverkko Oy have also heat production and distribution, but it is managed by another subsidiary. Also, they all had a separate energy department, which manages energy generation and selling, but also co-operates with the operators in the distribution department. For example, in Tampereen Sähköverkko Oy, a view of current energy generation status in SYS600 was offered to the energy department (with only viewing rights). In SVV Oyj, a plan about how the hydroelectric power plants should be operated was provided to the operator by the energy department.

4.2.1 PKS Sähkönsiirto Oy

PKS Sähkönsiirto Oy controls the electricity distribution in its operating area in eastern Finland. It is a subsidiary of Pohjois-Karjalan Sähkö Oy, or PKS Oy. PKS Oy is a corporation, which consists of 2 companies in addition to PKS Sähkönsiirto Oy: Enerke Oy is a contractor, who offers network planning, constructing, renovation and maintenance, and consulting for electricity, power and industry companies. Kuurnan Voima Oy operates the Kuurna hydroelectric power plant, which is the biggest of the hydroelectric power plants in PKS Oy with 115 GWh yearly production. [27; 28]

PKS Oy operates mainly in North Karelia, a region in eastern Finland. The amount of customers in the area is 86 300 and the electric energy consumed is about 1200 GWh.

The length of electricity network is 21 000 km. PKS Oy has about 200 GWh of own hydroelectric power production. [27]

PKS Sähkönsiirto Oy's distribution network is spread to a wide geographical area, which is mostly rural area, but some urban areas also exist in the network. Most of the network is overhead line, but the rate of cabling is increasing. There are 35 primary substations in the network with relatively long feeders.

The SCADA and DMS systems used in PKS Sähkönsiirto Oy were MicroSCADA Pro SYS600 9.3 and MicroSCADA Pro DMS600 4.4 HF4.

4.2.2 Savon Voima Verkko Oyj

Savon Voima Verkko Oyj, or SVV Oyj, provides electricity distribution services in the Northern Savo area. It is a subsidiary of Savon Voima Oyj, which, in addition to electricity distribution services, offers also electricity and heat production and sales as well as risk management unit for major customers via other subsidiaries. [29]

SVV Oyj operates in Northern Savo region of Finland. It distributes electricity to about 113 200 customers, who consume about 1800 GWh. The length of electricity network is 25 500 km. Savon Voima Oyj produces about 600 GWh electricity yearly, from which about 100 GWh is hydroelectric power production. It distributes also heat to about 3000 customers, who consume about 600 GWh of thermal energy. The length of district heat network is about 350 km. [30]

As well as PKS Sähkönsiirto Oy, also SVV Oyj operates in a wide, more rural area. Most of the network is overhead line, but the cabling rate is increasing. There are 49 primary substations in the network, and the feeders are relatively long.

The SCADA systems used in SVV Oyj were MicroSCADA Pro SYS500 and SYS600 9.3 as the deployment of the upgraded product was ongoing. The DMS system used in SVV Oyj was MicroSCADA Pro DMS600 4.4 HF4.

4.2.3 Tampereen Sähköverkko Oy

Tampereen Sähköverkko Oy distributes electrical energy in Pirkanmaa region of Finland. It is a subsidiary of Tampereen Sähkölaitos Oy with 4 other subsidiaries: Tampereen Energiantuotanto Oy controls the energy generation facilities, Tampereen Kaukolämpö Oy manages the sales of distributed heat and gas, Tampereen Vera Oy is a contractor who manages the building and maintenance of electrical and outdoor lighting network, and Tampereen Sähkönmyynti Oy manages the sales of electrical energy. [31]

Tampereen Sähköverkko Oy distributes energy to about 140 000 customers, who consume about 1800 GWh yearly. The length of electricity network is 3650 km. Tampereen Sähkölaitos Oy produces about 1200 GWh electricity yearly, from which about 54 GWh is hydroelectric power production. It also distributes about 2200 GWh heat yearly to about 5400 customers. [32]

As can be seen from the ratio between the length of the electrical network and amount of customers, Tampereen Sähköverkko Oy operates in much more urban area than PKS Sähkönsiirto Oy or SVV Oyj. The main operating area of Tampereen Sähköverkko Oy is the city of Tampere. The city center is cabled, but some overhead line still exists in the side feeders and at the end of some feeders. Also, one primary substation, Teisko, is in a rural area, and the feeders in Teisko are overhead line. Because of this, it is also the area where most of the faults occur in Tampereen Sähköverkko Oy.

There are 14 primary substations in Tampereen Sähköverkko Oy’s area. The stations are much larger than in PKS Sähkönsiirto Oy’s or SVV Oy’s network, containing dozens of feeders each. The largest substation, Ratina, contains 40 feeding bays.

The SCADA systems used in Tampereen Sähköverkko Oy were MicroSCADA Pro SYS500 and SYS600 9.3, as the deployment of the upgraded product was ongoing. The DMS system used in Tampereen Sähköverkko Oy was Tekla’s Trimble Distribution Management System.

4.3 Use Cases

One of the top priorities in customer visits was to collect the most common use cases in the main control center. Gathering the most common use cases is important, because it helps to get a comprehensive overview of the work flow in the main control center, which then helps developing a product that satisfies customer needs. The use cases were collected from all companies with as much details as possible.

Based on the visits, the most common use cases in the main control center are network supervision, fault management and maintenance outage management. These use cases are described in the following chapters. The descriptions are summaries based on all the descriptions that we got from the main control centers. Fault management will be analyzed separately for normal circumstances and for a major disturbance situation.

4.3.1 Network Supervision

Network supervision is a task that is executed the most in the main control center. It includes knowing statuses for high voltage, medium voltage and low voltage networks. In addition, it includes knowing both reactive and real power flow in the network, statuses of own software systems and its interfaces to other systems, and statuses of own communication systems. In other words, it means keeping up to date with the measurement values in the network, alarms that have occurred, work that is being done in the network, power flow in the network and the status of own software and communication systems.

Both SCADA and DMS systems had to be used to accomplish this task. The following chapters will describe high voltage, medium voltage and low voltage network supervision, power management and system supervision tasks with more details.

4.3.1.1 High Voltage Network Supervision

High voltage network is supervised using SCADA user interface. DMS user interface is not used for this task, because the high voltage network is not modelled into the DMS system. The high voltage network is not usually modelled into the DMS system, because the DMS system is traditionally meant for medium and low voltage distribution management and some high voltage network management features, such as high voltage fault reporting, are missing.

Every visited distribution company had drawn their own high voltage network supervision picture into their SCADA system, in these cases MicroSCADA Pro SYS500 or SYS600. An example of such picture is shown in Figure 4.1.

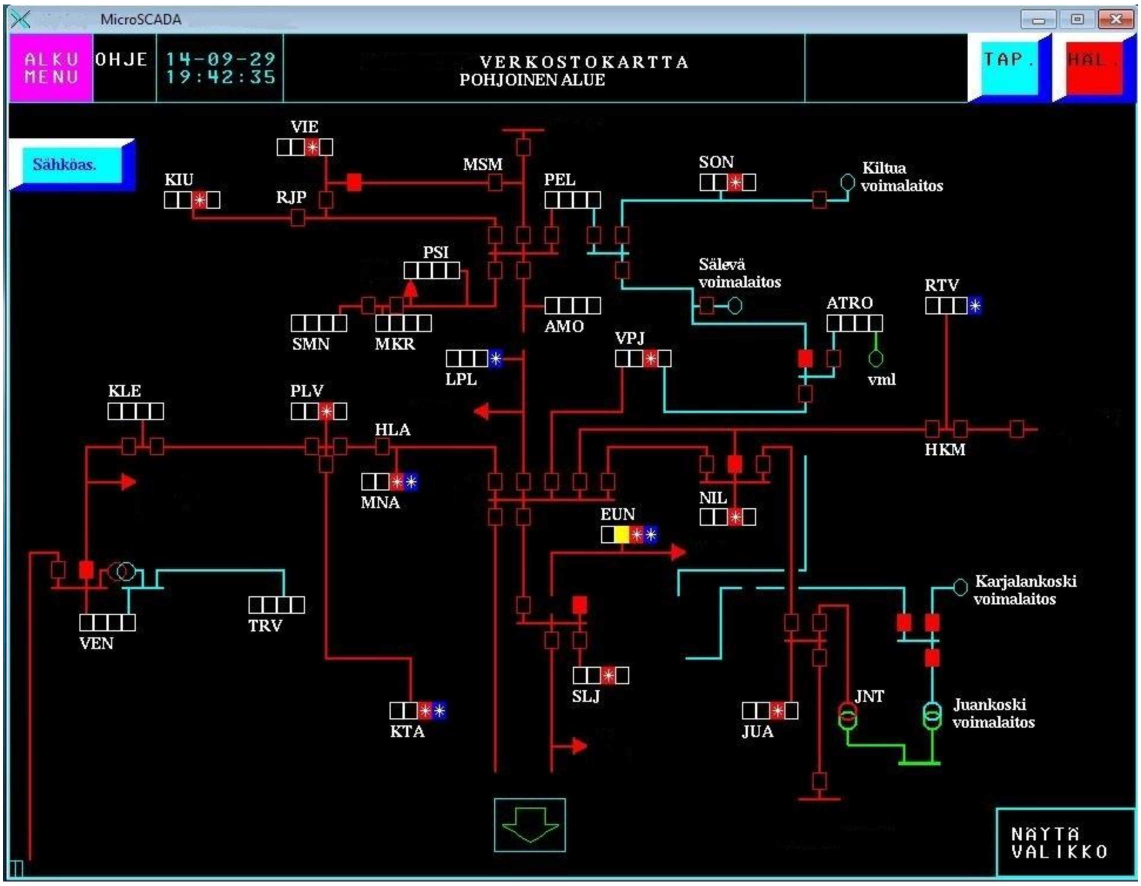

Figure 4.1 *High voltage network supervision picture in MicroSCADA Pro SYS500, in Savon Voiman Verkko Oyj.*

The Figure 4.1 shows an overall picture of SVV Oyj high voltage network. Each primary substation is positioned to a relative geographical location, and the status of the primary substation is indicated by 4 small boxes next to the primary substation code. The boxes can blink with different colors indicating that an error or warning, such as communication problem or fault, exists in the primary substation. Even though the topology between stations is minimized to straight lines for clarity, all primary substations could not be fit in one picture so an arrow button is placed in bottom of the picture for navigation.

As mentioned before, every company had their own version of this supervision picture. Because the picture is drawn by distribution company staff themselves, they all look different, although the idea and purpose are same.

4.3.1.2 Medium Voltage Network Supervision

Medium voltage network is supervised using both SCADA and DMS user interfaces. Even though only DMS user interface is used for some medium voltage management tasks, SCADA system is a crucial part of the management because it acts as a data provider and communication link between DMS system and actual network devices.

SCADA system provides measurement values and switch states to DMS system and delivers control messages to actual devices in network encapsulating communication protocols in DMS point of view. Figure 4.2 shows an example user interface for medium voltage network supervision.

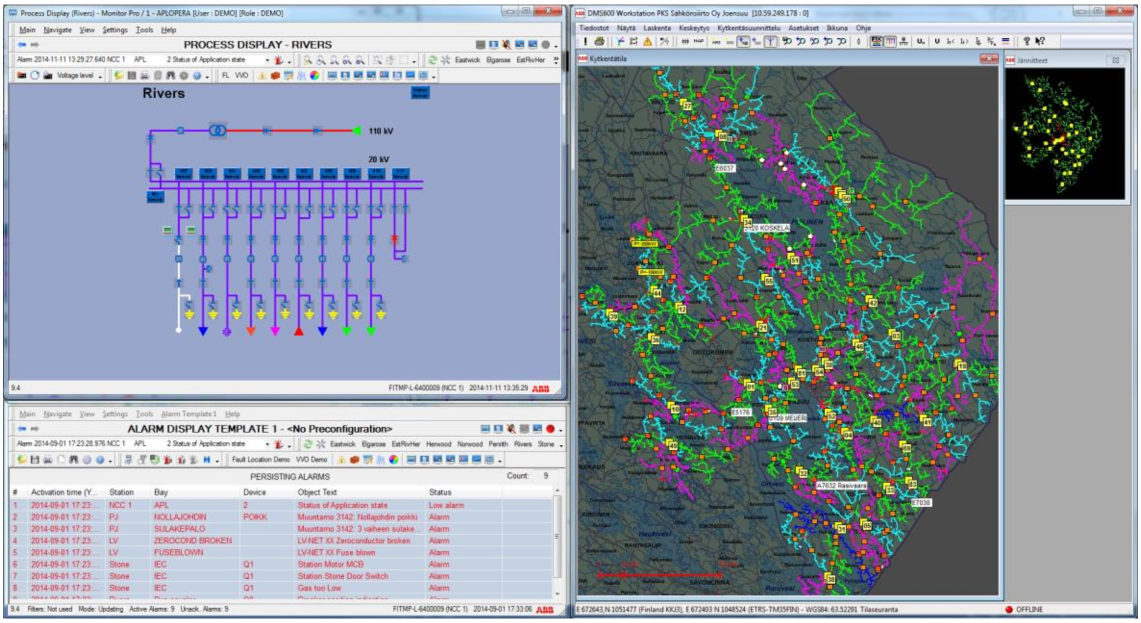

Figure 4.2 *An example user interface for medium voltage network supervision.*

The Figure 4.2 shows a typical user interface for medium voltage network management: SYS600 SLD for a single primary substation, SYS600 alarms list, and DMS600 network view. Current switching state is observed in DMS600 network view, and the alarms occurring in the network are observed using SYS600 alarms list. The SLD –view in SYS600 can be used to supervise current status inside one primary substation.

The Figure 4.2 is a good example for a more rural area distribution company, like PKS Sähkönsiirto Oy or SVV Oyj. However, the situation is different in Tampereen Sähköverkko Oy. Their urban network with huge primary substations (40 feeders in the largest substation) is so densely cabled, that a geographic view is insufficient. Instead, they use a schematic view, which is presented in Figure 4.3.

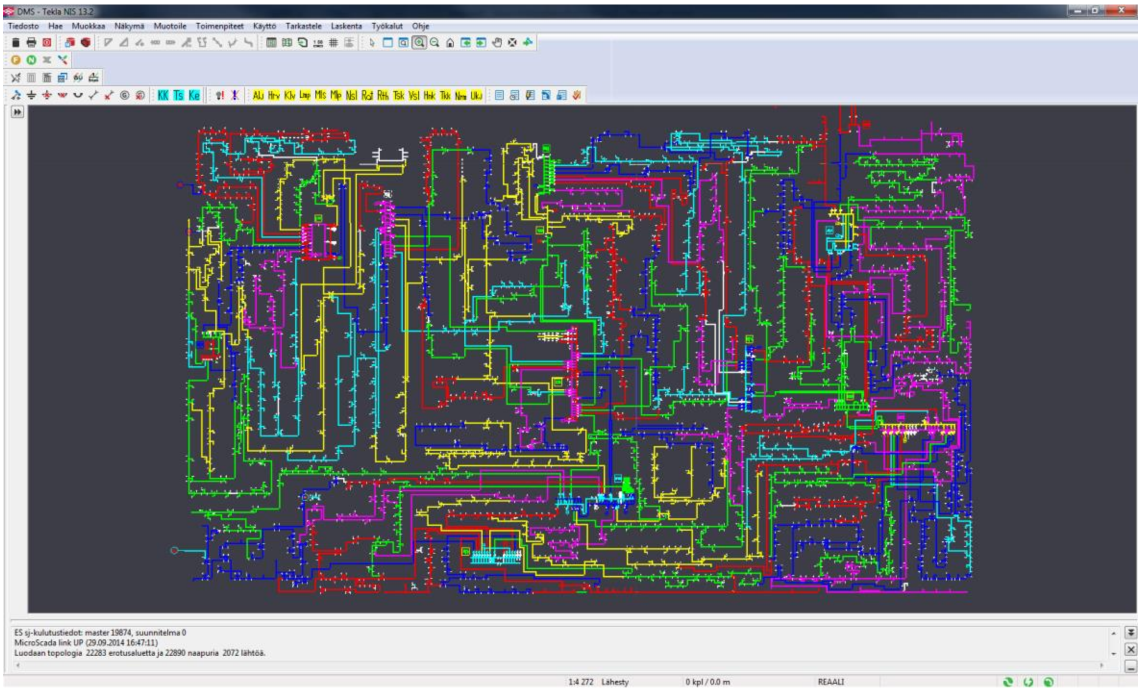

Figure 4.3 *A schematic view of Tampereen Sähköverkko Oy's medium voltage network.*

The Figure 4.3 shows a schematic view of Tampereen Sähköverkko Oy's medium voltage network. The primary substations are positioned in relative geographic location and the topology is drawn according to the current switching state. The view is created and maintained using Tekla's Trimble NIS (Network Information System).

4.3.1.3 Low Voltage Network Supervision

Low voltage network is supervised in the main control center by the same operators as with other voltage levels. It is based on DMS system and consists of AMR management, low voltage fault and low voltage maintenance outage management and reporting. Along with the increasing amount of AMR meters, the demand to control also low voltage networks among distribution companies has increased. To answer these requirements, new features such as low voltage switching planning and improvements in AMR management have been implemented in the latest DMS600 product release.

In the medium voltage network the SCADA system acts as a communication link between the DMS system and actual network devices, but in the low voltage network, the AMR system is directly linked to the DMS system. AMR measurements, events and alarms can be seen and controlled in DMS user interface. Figure 4.4 shows AMR management user interface in DMS600.

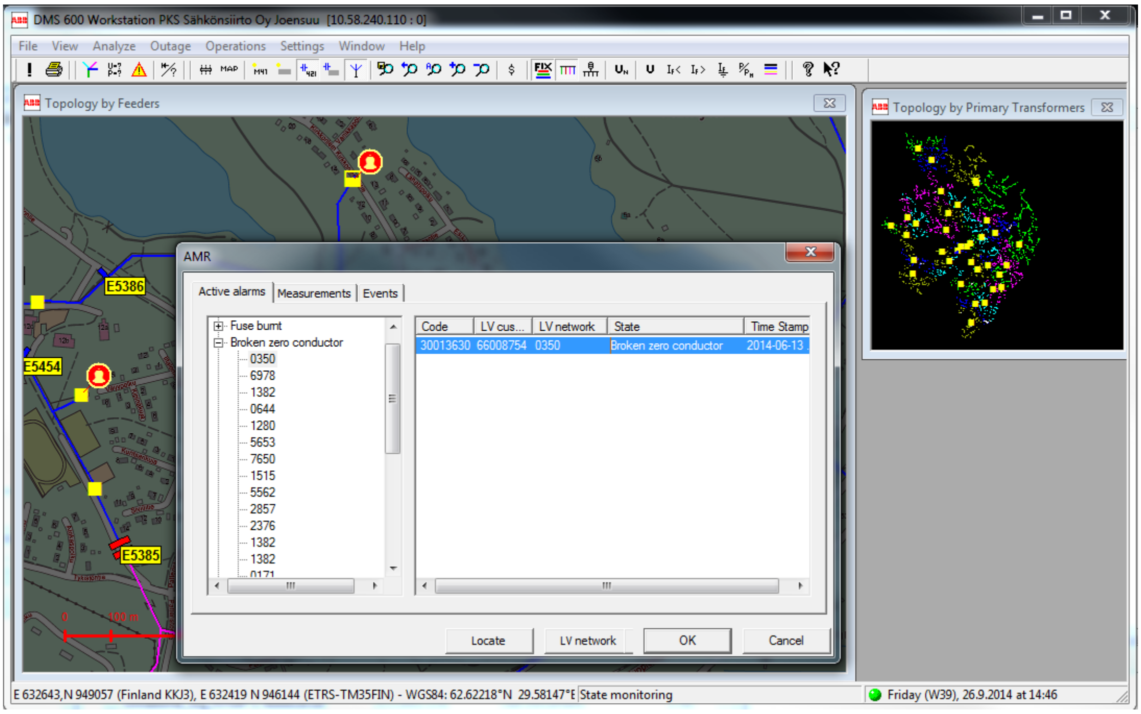

Figure 4.4 *AMR alarm management user interface in MicroSCADA Pro DMS600.*

In Figure 4.4, there are two blinking AMR alarm symbols in the main network view. In the AMR management dialog, the different AMR alarms are categorized by the type of the alarm. In Figure 4.4, there are multiple AMR alarms, caused by a broken zero conductor, in the network.

When managing AMR faults, the operator can check the measurement values to confirm the fault location: For example, if a customer is missing voltage on one phase but the customers around him have normal voltages, the customer’s own fuse has probably burnt and it is in customer’s own responsibility to fix. If the customer calls, the operator can inform the customer about this without sending a workgroup to check the situation. On the other hand, the distribution company can serve the customer by sending a SMS message, which informs about the missing voltage and required actions before he/she calls.

4.3.1.4 Power Management

All the visited distribution companies have own hydroelectric power production. The events and alarms, water levels and other controlling of the plants are managed by the operators in the main control center. Only the SCADA system is used for power management, because the SCADA system is flexible for also power management and the management pictures are drawn into the SCADA system. An example of a hydroelectric power plant management picture in SYS600 is shown in Figure 4.5.

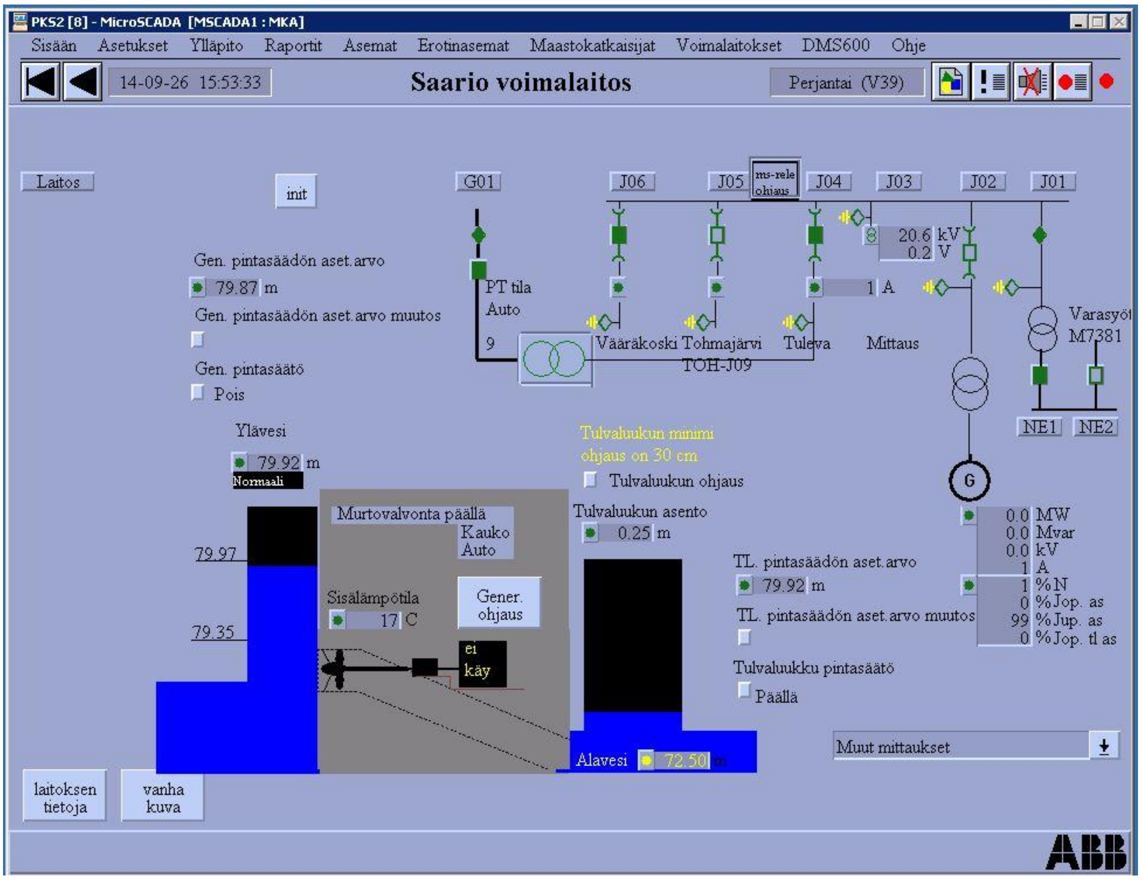

Figure 4.5 *Saario hydroelectric power plant management picture in MicroSCADA Pro SYS600 in PKS Sähkönsiirto Oy.*

Figure 4.5 shows that a visualization of the water levels in the hydroelectric power plant has been drawn in PKS Sähkönsiirto Oy. Also measurement values, controlling buttons and status information are shown in the picture. In each of the visited companies, the energy department creates a plan for each day about how the power plant generation should be controlled by the operators in the main control center. The distribution companies were visited during midwinter, so at the time the plan was simply to maximize power generation for every hour. However, during the hottest season of summer, the electricity may be so cheap that it is not financially profitable to run the power plants with maximum power generation.

In addition to power plant management, distribution companies have to control the power flow in the network. In normal circumstances, especially the reactive power generation and consumption has to be monitored: Fingrid, who controls the main transmission grid in Finland, has defined a maximum and minimum reactive power values for the connection points to the main transmission grid. Each of the visited distribution companies had drawn their own version of reactive power management picture in the SCADA system. An example of such management picture drawn in MicroSCADA Pro SYS600 is shown in Figure 4.6.

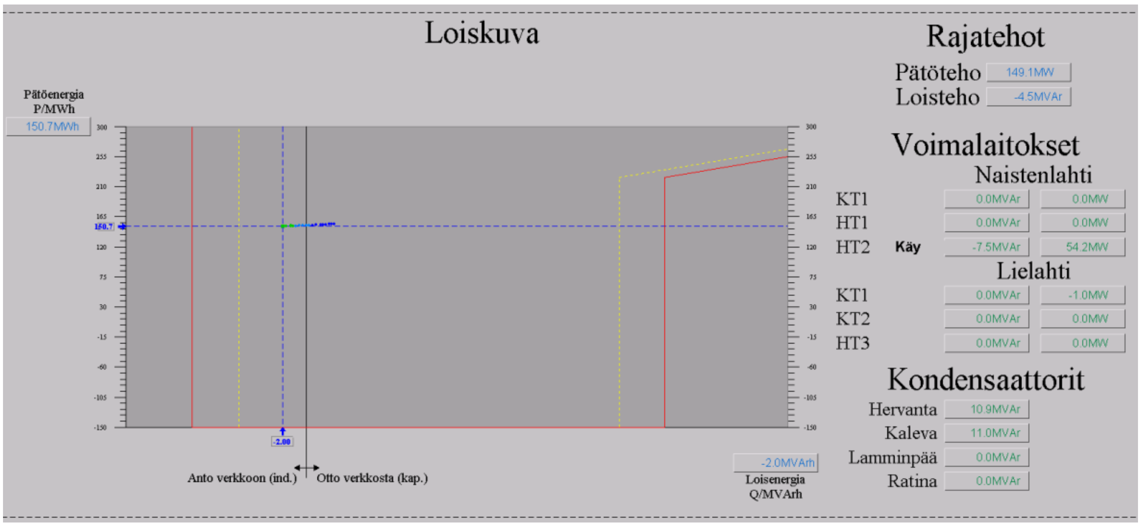

Figure 4.6 *Reactive power management picture used in Tampereen Sähköverkko Oy.*

The graph in Figure 4.6 shows the combined reactive power value of the configured connection points. The current reactive power value is indicated as a green circle in the graph. Measurement values from the last hour are visualized as a blue tail behind the current value point. This shows the direction and speed to which the reactive power value is shifting. The minimum and maximum limits are indicated as yellow and red lines. If the yellow line is crossed, a warning is generated, and if the red line is crossed, an alarm is generated. It is important to keep within these limits, because a penalty is triggered if the limits are violated.

The reactive power management picture in Figure 4.6 includes also real and reactive power values generated by the power plants in the network and reactive power generated by the capacitors in the primary substations.

4.3.1.5 System Supervision

To know that the real-time data is reliable and everything is working correctly, the distribution company's own software and communication systems have to be monitored. This means supervising that the communications to the RTU's (Remote Terminal Units) of the actual devices in the network are working, the software in the main control center is running without problems and the interfaces to external systems are working.

The method, how the communications to actual devices in the network is monitored, differs. In some distribution companies, the communication network to RTU's are provided by external communications service provider, but for example in PKS Sähkönsiirto Oy, they have a radio network of their own, which needs to be monitored. Communications supervision picture used in PKS Sähkönsiirto Oy is represented in Figure 4.7.

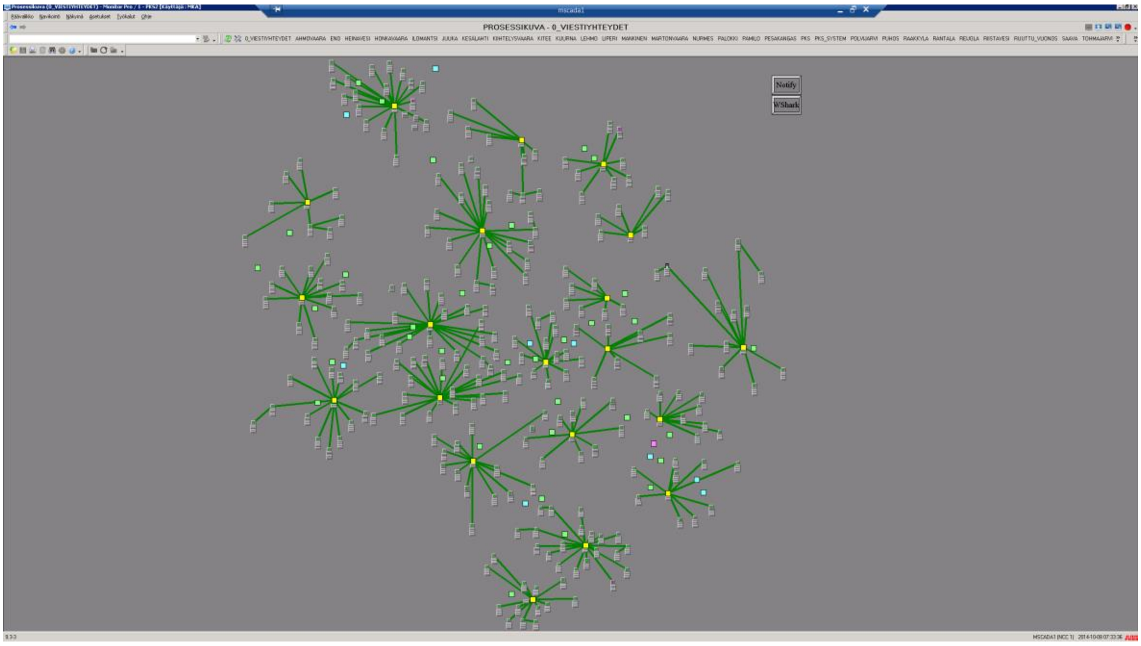

Figure 4.7 *Communications supervision picture in MicroSCADA Pro SYS600 used in PKS Sähkönsiirto Oy.*

In Figure 4.7, radios in hydroelectric power stations are shown as blue boxes, radios in primary substations are shown as green boxes and the base stations of disconnector stations are shown as yellow boxes. Radios in disconnector stations are represented as grey boxes and a successful connection between a base station and a disconnector station is indicated as a green line between the boxes. Each of the elements in the view are positioned in a relative geographical location. Using this view, the operator can see via which station(s) the communication from a disconnector station transfers. Also, if a connection is not functional, it is indicated with red color. If the SYS600 picture is zoomed, more specific information becomes visible.

The DMS600 software in the main control center was monitored using DMS600 Workstation Connection Status Info Bar and DMS Background Service Monitor, which both can be seen in Figure 4.8.

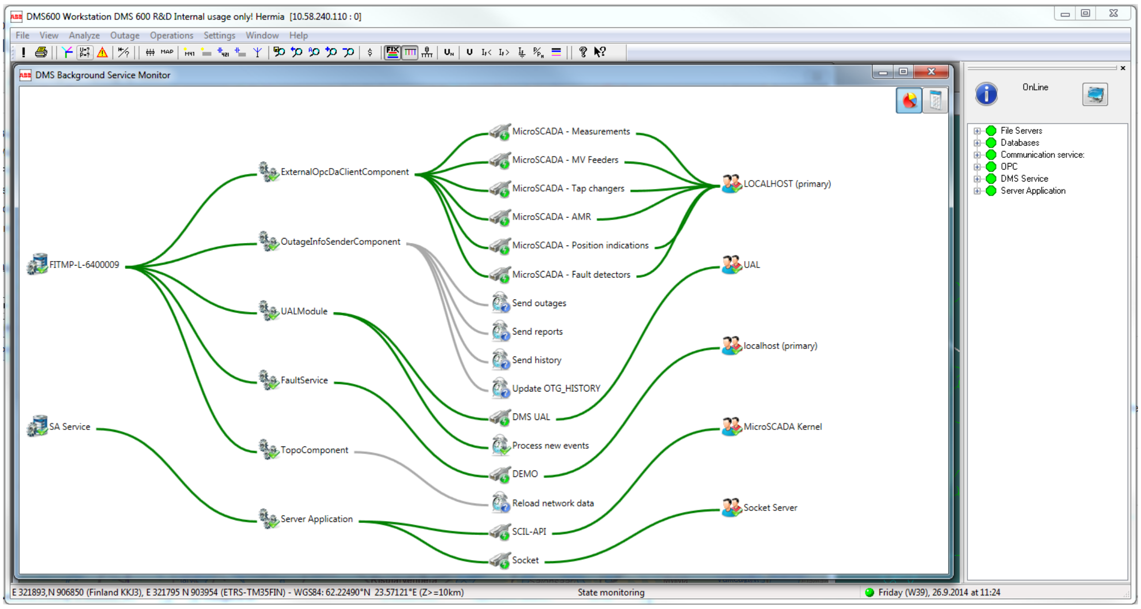

Figure 4.8 *DMS Background Service Monitor and DMS600 WS Connection Status Info Bar.*

The DMS600 Connection Status Info bar in the Figure 4.8 shows the connection statuses to the file server, database, internal communication service, OPC interface, DMS Service Framework, and SA service. The DMS Background Service Monitor shows if the components in DMS core and their API's (Application Programming Interfaces) are working properly.

4.3.2 Fault Management

Fault management is one of the most important tasks and requires immediate actions from the operator for both business and safety reasons. The faulted area has to be detected and isolated, and healthy areas have to be restored as soon as possible. Although some automatic fault detection, isolation and restoration features have been implemented to MicroSCADA Pro products, none of the visited distribution companies used them.

Chapter 4.3.2.1 will describe fault handling process in normal circumstances. The process will be described with as much details as possible from the circuit breaker trip to the point where the switching state has been restored to the pre-fault state. Chapter 4.3.2.2 will describe how the process and atmosphere in the main control center changes in a major disturbance situation.

4.3.2.1 Normal Circumstances

Fault handling process starts when a circuit breaker in the network trips (final trip only, reclosing trips do not create permanent faults). The topology is updated in both SYS600 and DMS600 products, and SYS600 immediately creates an alarm. In all of the visited distribution companies, this alarm also caused an alarm sound to be played from the speakers. The audible alarm is supposed to draw operator's attention and it was muted by the operator from a physical button next to the speakers.

Immediately after the trip, a fault package is created in DMS600 core. DMS600 processes the fault data and sends a SMS message to the affected customers. A fault handling dialog is opened in DMS600 WS and the network window is zoomed to the faulted zone.

After this, the operator starts the FDIR process. Usually the operator doesn't have much information available about the exact location of the fault, but wind direction, customer observations and own experience can be used to make the best guess for the fault location. Unless there is a reason to do otherwise, the faulted remote controlled zone is searched using split-half method: The remote controlled disconnector in the middle of the unsupplied zone is opened and power is restored to the other half. If the circuit breaker trips again, it means that the fault is in that zone and the other half can be restored. This continues until the faulted remote controlled zone is found.

After the fault has been isolated with remote controlled disconnectors, a workgroup is needed to further isolate the fault. To assign a workgroup to handle this fault, the operator either calls the contractor's supervisor or makes a new task to the work management system. The workgroup is guided to a manually controlled disconnector, which the operator has decided to be the best alternative to further isolate the fault. After the workgroup has reached the disconnector, they will call the operator for a permission to operate. As the operator controls the circuit breaker remotely in the control center and the workgroup operates manual disconnectors in the field, the fault is isolated to the smallest possible manual controlled zone. Every time the workgroup changes a switching state of a manual controlled disconnector, the operator updates the new status to DMS600 WS to keep switching state and topology up-to-date.

Finally, the workgroup searches the exact fault location in the manual controlled zone and fixes the fault. The switching state is restored to the state it was before the fault by the workgroup and the operator, again calling before each manual disconnector state change. Operator updates the manual disconnector state changes to DMS600 Workstation and operates the remote controlled switches so that the switching state is restored. The fault is marked as repaired and reported in DMS600 WS.

There may be multiple times that the circuit breaker trips during the fault detection process. Each time this happens, the whole feeder gets unsupplied. An example of how the unsupplied power may change during FDIR process, is presented in Figure 4.9. The data is from a real fault, gathered from a distribution company's database.

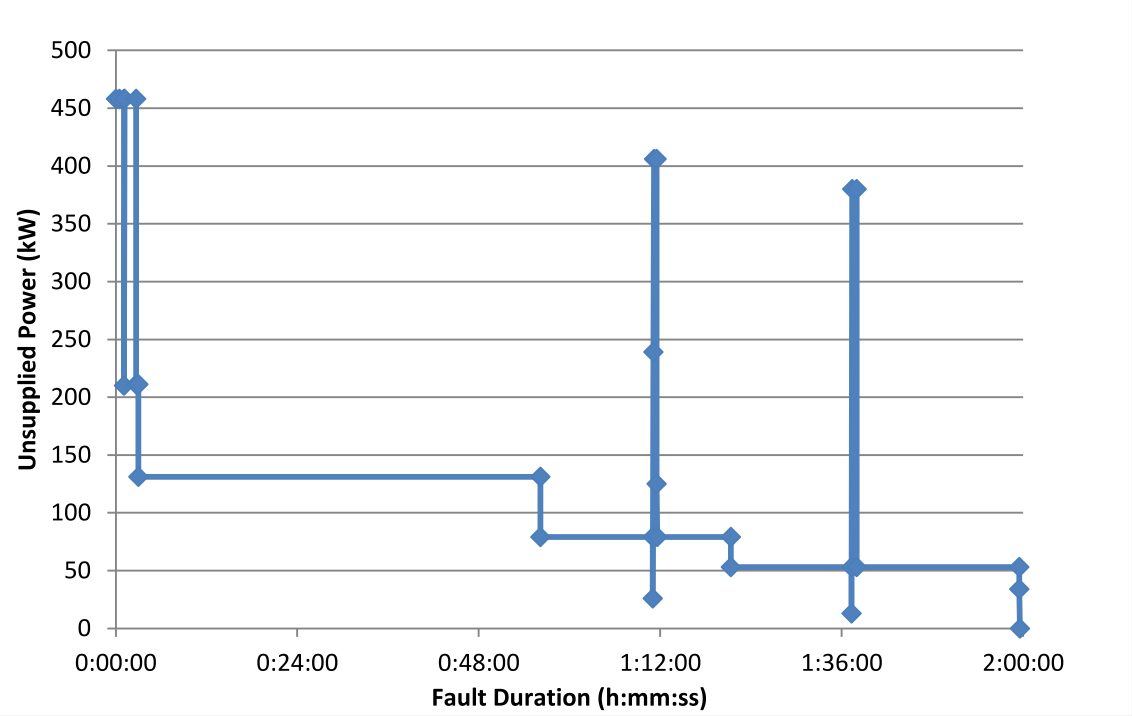

Figure 4.9 *Unsupplied power during the FDIR process.*

In Figure 4.9, it can be seen that the operator reacts to the fault fast. During the first minutes of the fault, operator tries to restore power to the feeder, but it fails. Then, the operator successfully isolates the fault with remote controlled disconnectors, and the unsupplied power drops from 460 kW to 130 kW. It takes about 50 minutes before the workgroup further isolates the fault with manually controlled disconnectors. When the workgroup tries to further isolate the fault for a second time (at point where the fault duration is 1:12:00), the whole feeder trips again. However, the power is quickly restored, and the fault is one more time successfully isolated when the fault duration is about 1:20:00. At 1:36:00, an attempt to further isolate the fault fails and the whole feeder trips. Finally, it takes about 20 minutes for the workgroup to fix the fault and after 2 hours from the start of the fault, the power is restored to every customer.

4.3.2.2 Major Disturbance

In a major disturbance situation, the environment in the main control center changes. All the operator workplaces are occupied and there are also many other actors than operators present in the main control room, such as operations manager, chief executive officer, a police or rescue authority representative, communications manager and media representatives. According to the operator interviews, the noise level in the main control center can rise to disturbing levels. In addition to the operators operating the network and communicating with each other and with workgroups, each person in the main control center are trying to find out their own interests: Chief executive officer and communications manager try to get an overview of the situation so they can forward it to the authorities and media. Operational manager is also interested in the overview of the situation so he/she can help the operators in fault management.

Operators are fully loaded in a major disturbance situation. They are constantly speaking on the phone with workgroups, as well as deciding fault responsibilities with other operators and operations manager. The network is divided so that each operator controls and is responsible for a certain region in the network. There is no time to use the work management system in a major disturbance situation: The operators just have to know which workgroups are operating in their area, and the nearest workgroup is contacted directly for the next assignment. Customer calls cannot be answered from the control center, but however, the findings coming from customer care department appear automatically to the DMS600 WS network window and may therefore be used in fault detection.

Because the operator may have dozens of calls incoming, it may take up to half hour from a workgroup to get to talk to the operator. This delay may apply to each manual switch state change in the network and is therefore a significant addition to the total fault handling time. All of the visited distribution companies had recently upgraded their phone-service: Two of the visited companies had recently implemented a waiting list, where everybody can hear each other so operator can pick the most urgent call first. In PKS Sähkönsiirto Oy, they had a third party software which combines the call waiting list and workgroup information so the operator can choose the workgroup he/she wants to communicate with.

It was implied by the operators that working is quite challenging in the main control center during a major disturbance situation. A lot of information has to be ignored due to the lack of time, and more support and guidance are needed from the SCADA and DMS systems.

4.3.3 Maintenance Outage Management

Maintenance outage management is the third most common task executed in the main control room. The amount of maintenance outages handled daily depends on the size of the company: In the visited distribution companies, about a dozen maintenance outages are handled daily. The reason for a maintenance outage can be to replace a damaged component, to make a periodic inspection, join newly built network to existing network or to do other maintenance work in the network.

The process starts at least a week before the actual outage occurs. An outage request is received via email from the contractor, or if the contractor is company’s own contractor, it may come directly to a dedicated common information system (e.g. SharePoint). If the request was received via email, it is manually transferred to the dedicated information system. The request contains the contractor, the primary substation name, the feeder name and the identification of the work plan. The identification of the work plan can be used to later determine how many outage requests there have been in a single work plan.

A switching plan is created with DMS600 WS soon after the request has been received. The plan is created using DMS600 WS Automatic switching planning –feature, or if the plan is more complicated, it may be created manually. Usually, the operator in the next shift simulates through the switchings and checks the switching plan. After the plan has been checked, it is printed out (as a word document received from DMS600 WS) and emailed to the contractor. Also maintenance outage notifications are sent to the affected customers, if there are any.

When operator arrives to work, he/she checks the switching plans scheduled for the day. At the scheduled time, the plan is opened and executed step by step in the DMS600 WS. The remote controlled switches are operated by the operator remotely and manually controlled switches are operated same way as in fault management: The workgroup calls from the field for a permission to operate on a manually operated switch and the operator updates the status to DMS600 WS.

After the execution, the switching plan is reported and archived. The reason for the maintenance outage is marked up.

5. CUSTOMER REQUIREMENTS AND IDEAS

The purpose of the customer visits was to gather requirements for a combined SCADA and DMS system. This thesis focuses on the requirements concerning visualization, user interface and the most common use cases introduced in chapter 4.3. Therefore, findings and requirements concerning other issues, such as configuring the systems, will be described only briefly in chapter 5.4.

In this chapter, most of the requirements are converted from the problems that the visited distribution companies had. For example, if a problem was that “the alarm list is unusable, when there are a lot of alarms in the system”, it would convert to a requirement such as “the alarms should be visualized so that they are usable even though there are a lot of alarms in the system”. In addition, some requirements and ideas were received directly from the customer or they were invented during the discussions, and some of them relate to the solutions that customers had already found and implemented into their systems.

General visualization requirements and ideas concerning network supervision, which is the most common task in the main control center, will be discussed in chapter 5.1. Requirements and ideas concerning fault management will be described in chapter 5.2 and requirements and ideas concerning maintenance outage management will be discussed in chapter 5.3.

5.1 General Visualization

The more data there is to be shown to the user, the more important task visualization becomes. In network automation, a lot of data is gathered from the network, and the amount is growing rapidly still: During the visits, it was estimated, that the amount of data coming from a renewed primary substation increases tenfold. To handle this information overflow, processing and analyzing the data programmatically is an important task, but the visualization is important as well. The main problem in visualization is how the data is represented to the user as minimized and clearly as possible, but still in a way that the user can catch all the important information needed. While the shown data is minimized, more details should be available when necessary.

Based on the customer visits, it was indicated that in normal circumstances the user interface should be restful. Any abnormality should be clearly emphasized so that it will draw the operator's attention. Also, when investigating an alarm in the system, the smallest possible amount of text should be visible. Instead, symbols, colors and animations should be used.

A few visualization issues, which should be handled in a combined SCADA and DMS system, are described in the following subchapters. Requirements and ideas related to events and alarms in the system will be described in chapter 5.1.1. Navigation and zooming in the system will be covered in chapter 5.1.2 and requirements and ideas concerning supervision and overviews will be discussed in chapter 5.1.3.

5.1.1 Events and Alarms

Currently, the list representation of events and alarms causes some visualization problems in both SCADA and DMS systems. If there are a lot of events or alarms in the system, the lists become unusable, because there are too much items in the lists. Finding the relevant information by scrolling a list is not efficient, and therefore the lists may not be used at all. This can lead to a situation, where the operator misses some very important information, because the lists are ignored. In a combined SCADA and DMS system, the events and alarms should be visualized so that they are usable even in a major disturbance situation. In the future, the amount of alarms is likely to increase as more functionalities are implemented to the system. New alarms could come for example from functionalities related to topology management or calculation.

Alarms should be analyzed so that related alarms are grouped and the root cause alarm should be highlighted. For example, when a whole primary substation becomes unsupplied, the alarm list is flooded with alarms coming from every measurement object in the station. In this case, an important alarm coming from another primary substation may drown in the list. When a root cause alarm is acknowledged, the alarms having the same root cause should be acknowledged automatically.

In a combined SCADA and DMS system, all of the events and alarms should be viewable in one place only. Currently, the SCADA-related events and alarms are in the SCADA system lists and DMS-related events and alarms are in the DMS system lists, which means that the operator has to switch between the systems to check both alarms. This is not efficient and it makes being aware of the overall situation difficult.

Alarms should be classified with different symbols and sounds and the importance of an alarm should be dynamic: Some alarms may not be important right from the start, but after couple of hours (when for example, the backup power starts to run out) the alarm may become highly important.

In a combined SCADA and DMS system, alarms could be represented hierarchically so it would be easier to see where the alarms come from, or what types of alarms there are currently in the system. For example, a single AMR alarm coming from a single low voltage network is not critical, because it is usually caused by end customer's own burnt fuse. Instead, when there are multiple AMR alarms in a single low voltage network, it usually means that there is a fault in the low voltage network, which requires operator's immediate attention. Also, from the hierarchical view, it could be easily seen for example, how many of the alarms are due to an opened circuit breaker.

Alarms should be date and time –dependent. There can be alarms in the system that are not interesting during office hours. For example, operator may not be interested in alarms that are caused by an opened door in a primary substation during office hours. However, the same alarm is relevant at midnight.

5.1.2 Navigation and Zooming

Navigation between different views and within a view should be smooth and fast. Currently, there are some issues related to navigation in both SCADA and DMS systems. In SCADA, it was found problematic that the previous view was lost when a new view is opened. For example, if a current measurement trend of a feeder is checked, the station overview is lost and it had to be navigated again. Also, finding a measurement trend for the correct measurement was found complicated.

Within a single station overview, zooming was found problematic: When the operator zooms to operate on a single feeder, the station overview is lost. For example, when the operator wants to operate two feeders into a loop, he/she cannot check if the topology or measurement values were updated on the other affected feeder, because the overview was lost.

In DMS system, a similar zooming problem was discovered. If, for example during FDIR process, the operator wanted to operate switching devices along the feeder as well as the circuit breaker in the primary substation, the operator would have to zoom in and out continuously. This was found to be so impractical that operators had decided to use both SCADA and DMS systems during the FDIR process: A SCADA station overview was used to control the circuit breaker, and DMS network overview was used to control switching devices along the feeder. Constantly switching between applications makes the navigating more difficult and it is easier to lose overview of the situation.

Also in DMS system, it was required that the zooming would be smooth all the way to the low voltage network. Currently, each low voltage network is opened separately by the operator. This was found slow and impractical.

To resolve this zooming problem, an idea was generated: When zooming to operate on a single bay, it could be opened to a new window. Also, it was indicated that it should be easier to make different layers in the user interface meaning that certain objects would only come visible at a certain zoom level. Currently, it is possible to engineer such feature into SYS600, but it was found laborious.

In a combined SCADA and DMS system, switching between geographic and schematic representation of the network should be smooth and easy. This is especially required in urban area distribution companies, such as Tampereen Sähköverkko Oy. Their network is so dense, covering only a small geographical area, hence operating the switching devices from a geographical view is not practical. Instead, a schematic view of the network is used. However, a geographical representation of the network is used when guiding workgroups. Because of this, for example during FDIR process, the operators have to switch continuously between geographical and schematic representation of the network.

5.1.3 Supervision and Overviews

As described in chapter 4.3, most of the work done in the main control center is supervision work. Usage of any supervision software is based on the overview. It is the user interface, to which is returned after a specified task, such as controlling a circuit breaker, is finished. The overview should be calm and clear, but clearly highlight any abnormality. In a combined SCADA and DMS system, there are requirements to give certain views from the system not only to operators, but also to multiple other users. The overviews could be used by:

- Operators
- System Administrators
- Management
- Planning department
- Energy department
- Contractors
- Workgroups
- End customers
- Regional authorities

Each of these roles have different requirements on the overviews, some of which are required to be accessible outside the main control center. Figure 5.1 visualizes how the required overviews could be used in a combined SCADA and DMS system.

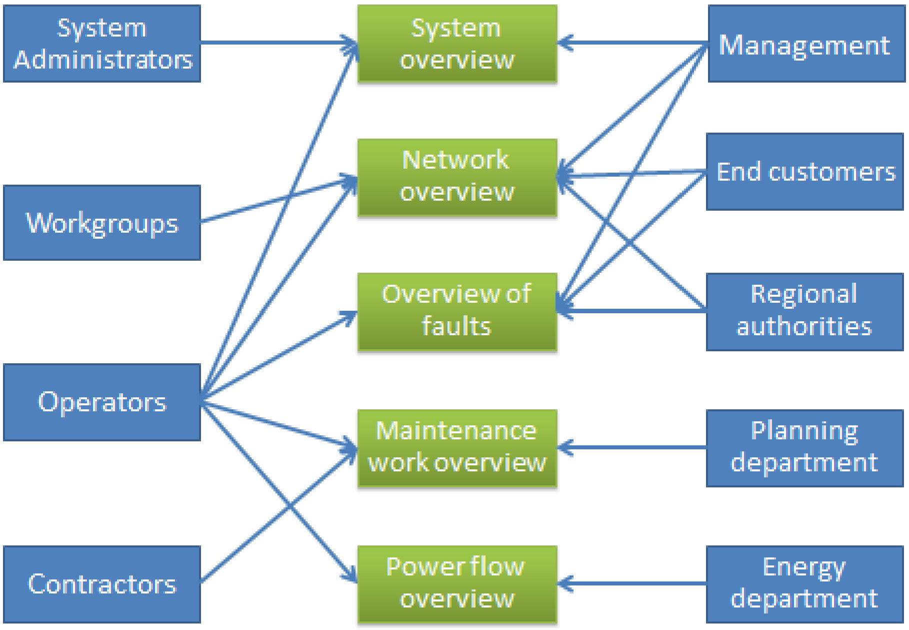

Figure 5.1 *User roles and required overviews in a combined SCADA and DMS system.*

In Figure 5.1, there are five overview categories represented as green boxes in the middle of the figure. The user roles are represented as blue boxes in both sides of the figure. The arrows visualize which overview categories are used by which user roles. The following sections will describe each of the overview categories with more details.

System overview would be used to check the status of own software systems and communication systems. It is required that it should be possible to supervise the status of the whole action chain from the opening of a circuit breaker to the updating of the unsupplied info in the distribution company's web page. Since there have been some issues with the interfaces to the external systems, it is required to be able to supervise them as well.

Network overview is primarily used to check if there are unsupplied areas in the network. It is also required to be able to share this info to regional authorities (police or rescue authority) and end customers via internet for situational awareness. In addition to the unsupplied information, operators should be able to see the real-time switching state of the whole network as well as network topology with multiple coloring methods. Because high voltage switches are operated as not electrified, video surveillance is needed to verify the operation. For workgroups, it is required to be able to see real-time switching state and to be able to operate manual operated switches from the field. Also, workgroups need to have access to photos taken from inside a primary substation: It is usual, that the workgroup is visiting the station for the first time, so the photos are very helpful when operating inside a primary substation. Currently, operators in the main control center are having trouble guiding the workgroup over the phone, because they do not necessarily know how the station looks inside.

Overview of faults is especially important in a major disturbance situation. Regional authorities, end customers and management should be able to check the current amount and statuses of the faults in the system. The operational manager and the operators need also an overview of faults in the system, but with more details and possibility to control the situation. In this thesis, the overview of faults for the operational manager and the operators was taken into special consideration, and it will be analyzed more deeply in chapter 6.3.

Maintenance work overview could be used by the operators, contractors and planning department to see when and what kind of maintenance outages there are in the network. Currently, there are visualization requirements to help see overlapping or blocking maintenance outages, and to ease scheduling them. This view was taken into special consideration in this thesis and it will be analyzed more deeply in chapter 6.4.

Power flow overview could be used by the operators and the energy department. The energy department needs to check the amount of real power generated in the system. By optimizing the power generation financially, they create a plan for the operator on how to operate the power plants. The operator needs to see both reactive and real power flow in the network. It is operator's responsibility to keep the reactive power flow in the network within the limits by controlling the capacitors in the network. It is required that the operator would be able to see not only the current power flow in the network, but also how the power flow would change after a certain switching state change. The power flow visualization was also taken into special consideration in this thesis and will be analyzed more deeply in chapter 6.5.

5.2 Fault Management

In a combined SCADA and DMS system, it should be possible to handle a network fault so that a minimum amount of text needs to be read. The current situation should be visualized with symbols and colors clearly so that it is easy to be aware of the overall situation while handling the fault. Any changes in the overall situation should happen with animation so they are easier noticed. For example in Tampereen Sähköverkko Oy, a symbol was created next to the circuit breaker object in SYS600 indicating if the fault was a short circuit fault or an earth fault.

In a combined SCADA and DMS system, it is required to have a clear view about the power flow in the network. The view is needed when considering the backup connection, especially in a major disturbance situation. It is also required to be able to see how the power flow would change after a certain switching operation. During the visits, the operators indicated that it is mandatory to know the power flow in the network so that the best alternative for backup connection can be chosen.

A few of requirements and ideas concerning fault management will be discussed in the following chapters. A requirement about automatic fault detection, isolation and restoration (FDIR) will be covered in chapter 5.2.1. Requirements and ideas about fault location indications, that would be useful in the FDIR process, will be discussed in chapter 5.2.2. Requirements and ideas concerning fault prioritization will be described in chapter 5.2.3 and special requirements about a major disturbance situation will be described in chapter 5.2.4.

5.2.1 Automatic FDIR

A combined SCADA and DMS system should be able to automatically detect, isolate and restore a fault (FDIR) using remote controlled switches. If the system automatically managed faults for a couple of first hours in a major disturbance situation, the operators would have time to be better aware of the overall situation and would have more time to manage resources and other faults.

Currently automatic fault detection, isolation and restoration (FDIR) only works in MicroSCADA Pro DMS600 and SYS600 if the fault is definitely located. However, in the visited distribution companies, the fault location data (fault impedance, fault current, or actual fault distance) was rarely received from the network because of old components, missing communication configuration or other incomplete configuration. In PKS Sähkönsiirto Oy, it was estimated that the fault data is received only in 5-10 % of faults, and even in these cases, the topology of the network may be branching so that the fault may not be definitely located to a single remote controlled zone.

A combined SCADA and DMS system is required to automatically detect, isolate and restore a fault even though fault location is not known. An idea received from the visited distribution companies was that it could detect the fault location using the same split-half method as the operator would use until the faulted remote controlled zone is found. The current FDIR process and the split-half method are described in chapter 4.3.2.14.3.2.

5.2.2 Fault Location Indications

In a combined SCADA and DMS system, multiple indications about the fault location should be used in fault detection process. In addition to the data coming from the relay, indications coming from multiple different data sources should be visualized for the operator. It should be possible to use lightning information, wind power and direction information, terrain type information, satellite photos, previous fault locations in the area, and observations coming from customer care. All this information should be saved to database so that the fault location accuracy could be analyzed and improved.

After the fault has been isolated using remote controlled switches and the workgroup is travelling to the faulted area, the operator usually has some free time to utilize the received additional information. If there were customer observations, matching lightning information or a distinct, easily fault-prone area in the network, the operator could better guide the workgroup to a correct manual disconnector, which means that the fault would be isolated much faster.

5.2.3 Fault Prioritization

When there are multiple faults in the system, it would be financially beneficial to prioritize the repairing work. The faults in a town plan area with a lot of unsupplied power should be repaired before faults, which are in rural area with less unsupplied power. Still, the Electricity Market Act regulated by the Energy Authority should be respected: Outages, which are caused by snow load or storm, should not exceed six hours in a town plan area and should not exceed 36 hours in other areas [33]. A combined SCADA and DMS system is required to visualize all the prioritization information to the operator to help prioritizing the repairing work.

It is required to easily notice faults from the system, which have not yet been restored or could be further isolated using remote controlled switches. Faults, which can be restored using remote controlled switches, should be prioritized because restoring power using remote controlled switches is fast and effective: Usually about two thirds of the original unsupplied power can be restored using remote controlled switches.

In addition to outage costs generated by a fault, also knowing the important end customers affected by the outage is significant when prioritizing faults. It should be possible to mark important end customers to the system and visualize them in the user interface. In the current DMS600 system, the important end customer types are dynamic: They are defined and maintained by the distribution company. However from the visualization and symbol definition point of view, it would be better if the most common important end customer types were predefined in the system. In this thesis, following list of important end customers was gathered from the customer databases:

- Hospitals
- Health centers
- Old age homes
- Stores
- Industry
- Office
- Primary substation
- Control center
- Internal communication station
- External communication station
- Heat plant
- Waste water station
- Clean water station
- Water pump station
- District heat station

If an important end customer becomes unsupplied, it should be highlighted in the user interface and the power should be restored with high priority. There is a backup battery in most of the important end customer sites, but the power should be restored before it runs out.

The priority of the fault could also be used with work management system. While an assignment to handle a network fault is registered to a work management system, a priority of a fault could be included. A high priority fault should be repaired more quickly than a low priority fault, and it could also result a higher payment for the workgroup.

5.2.4 Major Disturbance

In a major disturbance situation, a combined SCADA and DMS system is required to be able to handle the situation without performance issues. The server machine faces a lot of load since not only there occurs a lot of events, alarms and faults in the network, but also there are a lot of operators and office workers working with the system and checking the situation.

The system should be able to give clear overviews to different users. There are multiple actors, like management, regional authorities and media, in the main control center, who would need to see an overview of the unsupplied zones and faults. The operators in the main control center need the same clear overviews of faults, but also more specific views, which should guide and help the operators to manage all the faults. An idea, received from the PKS Sähkönsiirto Oy, was that the operators in the main control center should not need to do any switching operations within the first hours of the major disturbance situation: The system could automatically organize the network to isolate the faults to the smallest possible remote controlled zones while the operators can focus on managing the resources and being aware of the overall situation.

In a major disturbance situation, the system should be able to visualize a lot of events, alarms and faults so that they are manageable and useful. When there are a lot of faults in the system, the system should clearly visualize the amount of faults, statuses of faults and prioritization information. The alarms should be visualized so that it is easy to spot important alarms and to ignore unimportant alarms such as low voltage alarms. The statuses of faults and prioritization information should be visualized so that the operators can easily focus on the most important faults.

A combined SCADA and DMS system should support communication between a workgroup and an operator. Currently, the workgroup can wait up to half hour on the phone for a permission to operate. As was described in chapter 4.3.2, the FDIR process includes a lot of offline switchings, so the communication between workgroup and the operator should be smooth and easy. If the communication between the operator and the workgroup worked fast, it would decrease the operator's workload and result to a faster and better managed major disturbance situation.

5.3 Maintenance Outage Management

A combined SCADA and DMS system should support the operators in all of the maintenance outage management process phases described in chapter 4.3.3. When the outage request is received from a contractor, the system should provide a clear overview about already planned maintenance outages in the system to help scheduling the outage. The system should provide a clear overview for the operator to spot if there are multiple maintenances planned to the same area at about the same time. Also, if there is a need to replace a damaged network component or to do other own maintenance work, these maintenance outages could be combined to a single one. If the outages were successfully combined, not only customers in the outage area would face only one outage instead of multiple outages but also it would be financially beneficial.

When the operator starts to make a switching plan, the system should automatically provide the starting switching state based on the previous switching plans. When the operator is starting to execute the switching plan, the system should warn if the switching state in the affected area is not as it was expected to be when making the switching plan. If a feeder in the switching plan is already giving backup power to another feeder due to a fault or to overlapping switching plans, the maintenance work must be cancelled.

When executing a switching plan in a combined SCADA and DMS system, it should be possible to execute all the functionality found from SCADA and DMS systems. Currently, there are some operations, which are only possible to execute from SCADA system, which means the operator has to switch between the systems. Examples of such operations are disabling reclosings on a circuit breaker, and changing Petersen coil or tap changer to manual operating mode.

Finally, it should be possible to save the switching plan and the outage report to database including the reason for the maintenance and a responsible contractor. This enables that the maintenance outages can be analyzed and traced later.

In a combined SCADA and DMS system, managing maintenance outages in high voltage regional transmission network should be supported. None of the visited distribution companies had yet modelled high voltage network in their DMS system, but in Tampereen Sähköverkko Oy, they were planning to model the high voltage network into the DMS system and use the switching planning features in the DMS system. Nowadays in Tampereen Sähköverkko Oy, the switching plans for high voltage network are done in Microsoft Excel and executed using SCADA user interface.

5.4 Other Requirements and Ideas

From the visited distribution companies, it was indicated that current momentary measurement value is not usually that interesting, but the previous values and the history shown in a measurement trend is. In a combined SCADA and DMS system, measurement trends should be easily integrated to the views and easily accessible. If measurement trends were easily accessible, they could be used for example by the operator to check what the feeding power was before the circuit breaker opened. The operator could then use the information to decide correct backup connection or to inform a workgroup about the size of an aggregate needed. Also the measurement trends could be used to verify a switching operation or to verify outage reports by checking the measured energy of the previous year.

In a combined SCADA and DMS system, there should be only one tool to create views such as station overviews. Currently in Tampereen Sähköverkko Oy, when a primary substation is renewed, the main diagram of the substation is drawn by the network planning department using CADS –software. Using the main diagram as a base, the substation is drawn again in SCADA system. After this, it is drawn in the DMS system using the SCADA diagram as a base. None of the diagrams are exactly the same, but having to do them from scratch every time causes excessive configuration work for the system administrators. In SVV Oyj and in PKS Sähkönsiirto Oy, where SCADA and DMS systems were both MicroSCADA Pro products (SYS600 and DMS600), it is possible to import a SCADA diagram to the DMS system without having to draw it again. However, this results in another maintainable view of the substation, which should be avoided.

In a combined SCADA and DMS system, it should be possible to add notes to the views with different types and symbols and with a filtering possibility. The symbol of the note should already tell the operator the meaning of it, which means the operator would not necessarily need to open the note. It should be possible to filter them or leave out altogether, because there may be so much notes in the network that the overview of the network suffers.

6. VISUALIZATION CONCEPTS

In this thesis, a few of the requirements and ideas presented in chapter 5 were taken into special consideration and implemented into a prototype level. Most of the visualizations belong to the new fault management dashboard. In addition, visualizations related to maintenance outage management, power flow and load rate are discussed in this chapter.

A brief technical description about how the visualizations were implemented is given in chapter 6.1. The iterative development of the visualizations developed in this thesis will be described in chapter 6.2. The vision of fault management dashboard consisting of 4 separate visualizations is discussed in chapter 6.3. A visualization created to help maintenance outage management is introduced in chapter 6.4 and a view meant to visualize power flow and load rates in the network is discussed in chapter 6.5.

6.1 Technical Description of the Visualizations

The visualizations were made as dialogs in the MicroSCADA Pro WebUI, which was introduced in chapter 2.2.2. The WebUI is developed using client-server architecture. In the server side, a data provider component, a module called OutageDataProvider, was implemented into the DMS System within this thesis. It was implemented using C# programming language and it uses SQL queries to dig out required information from the DMS600 database. The data provider stays up to date with the outages in the system and provides the information, which is to be visualized in the client side.

The OutageDataProvider reacts to specified internal communication messages in DMS system. Immediately after a message about changed data is received, the data in the module's memory is updated from the DMS600 database and only the changed data is sent to the client. Also, a fault simulation feature was implemented in OutageDataProvider module: Using DMS Background Service Monitor, it is possible to start a simulation system, which means that the OutageDataProvider will keep the system in a situation in which there are 20 faults in the system all the time. The faults are isolated and restored according to a standard FDIR process and as soon as one fault is repaired and removed from the system, another fault is created. This was very useful feature when the visualizations were demonstrated to distribution companies and co-workers, and it helped to gather feedback during the iterative development of the visualizations (discussed in chapter 6.2).

The communication between the DMS system and the WebUI happens via another module in DMS Service Framework, DMSC. The basis of the DMSC module already existed, but a few improvements to the module were implemented during this thesis. Also, a message protocol, which is used in communication between the DMSC and other modules in DMS Service Framework, was specified. Two new internal message types were created: MSG_FROM_DMSC and MSG_TO_DMSC. The former message type is used when the WebUI subscribes a new value from DMS system, for example when a web page is loaded and initial values are needed. The latter message type is used, when a module, such as OutageDataProvider, provides the subscribed data value to the DMSC and eventually to the WebUI.

The visualizations were implemented as *user interface definition documents* according to MicroSCADA Pro WebUI dialog model, which was introduced in chapter 2.2.2. The *user interface definition documents* implemented within this thesis are XML files, which contain CSS styling for both HTML and SVG elements in the view, necessary view-specific JavaScript, and HTML basis. JavaScript was used to initialize and update the view, to subscribe values from DMS system and to handle the D3.js visualizations. Additionally, three reusable modules used by aforementioned views were created in WebUI dialog storage. The modules are called FV_DataModel, FV_Icons and FV_BackgroundGradients and they contain common JavaScript code for the fault management visualizations. FV_DataModel –module contains the data subscription functionality and the model, how the data is stored in the web browser's memory. FV_Icons -module contains code, which handles the icons for faults and for important end customers in the visualizations. FV_BackgroundGradients –module contains code to handle background coloring functionality.

6.2 Iterative Development of Visualizations

The visualizations in this thesis were developed using iterative development method. The development of the visualizations started in the early 2014: First the development environment and the required technologies were familiarized and the OutageDataProvider was implemented in DMS600 system. Also some internal communication improvements were required to get the data from the server (DMS600 system) to the client (web browser).

The visualization work in this thesis started with the development of the "Degree of isolation visualization", before the distribution companies were visited. Because of this, and because customers appeared to have a clear requirement to better visualize faults in the system, the fault management dashboard was specially focused in this thesis. The chapter 6.2.1 describes the development of the "Degree of isolation visualization" before the distribution companies were visited. Chapter 6.2.2 discusses the received feedback during the visits and chapter 6.2.3 describes the development and feedback process after the visits.

6.2.1 Development before the Visits

At the early phase of this thesis, a requirement concerning fault management was received from customers: It was required that it should be possible to clearly see faults in the system, which have not yet been taken over. Based on this requirement, a first draft of "Degree of isolation visualization" was created. During the implementation process, feedback and ideas, such as logarithmic horizontal axis, was received from co-workers, which further improved the view. The first draft of the view was completed in February 2014 and it is represented in Figure 6.1.

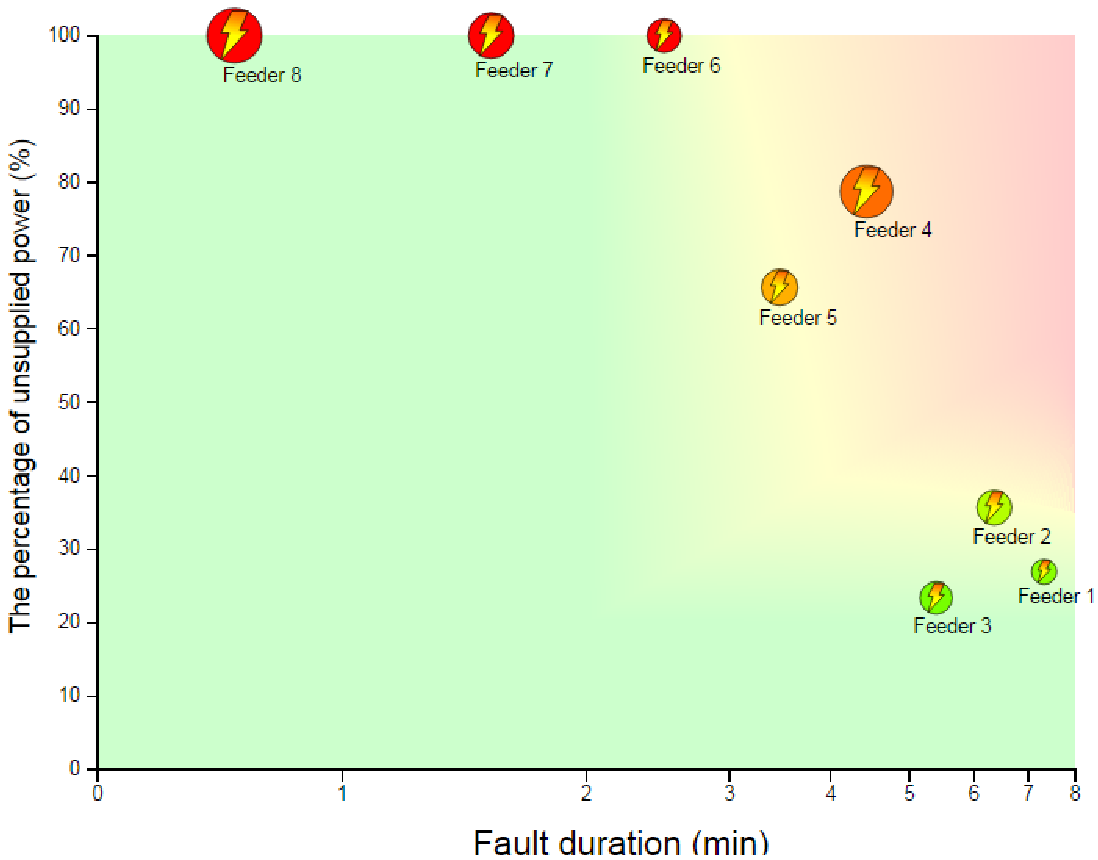

Figure 6.1 *The "Degree of isolation visualization" in the beginning of the development process.*

In Figure 6.1, faults in the system are represented as circles. The fault duration is represented in horizontal axis and the degree of isolation is represented in vertical axis. The circle color also shows the degree of isolation: When the fault has not been isolated at all and 100% of the original power is still unsupplied, the circle is red, and if all the originally unsupplied power has been restored, the circle is green. The radius of the circle represents the customer outage costs caused by the fault relative to the customer outage costs of the other faults: The fault causing the least customer outage costs is the smallest circle and the fault causing the most customer outage costs is the largest circle.

When a fault occurs in the system, a fault circle appears to the upper left corner of the view and starts to travel horizontally as the fault duration increases. If the fault is isolated, or the circuit breaker trips again, the fault circle moves vertically. All the changes in the view happen with animations so they are noticed more easily.

6.2.2 Feedback during the Visits

During the visits, the first draft of "Degree of isolation visualization" was demonstrated to the customers. Feedback, additional requirements and ideas were gathered: It was indicated that the view is a useful tool for the operator, when the fault is being restored using remote controlled switches. Also, it gives a clear overview of faults in the system for everyone in the main control center. Overall, the customers felt that the view is a fresh and welcomed innovation into the electricity distribution industry, which tends to stick with old habits.

A few improvement suggestions were received during the visits: The view could better guide the operator by indicating if it is still possible to further isolate the fault using remote controlled switches. During a major disturbance situation, it is usual that the backup connection is not available when the fault occurs, but it becomes available later after another fault has been repaired. It was indicated that the travelled path of the fault circle could be visualized in the same graph as a tail and the whole FDIR process during a major disturbance situation could be analyzed later by simulating through a certain time interval. It would be useful to see the average fault isolation times from the system in real-time: If the fault isolation time starts to increase, it means that the operators in the main control center are overloaded and cannot operate effectively enough anymore. If the history of FDIR process was stored, it could also be used to monitor workgroup's effectiveness.

Also, customers required that the important end customers, represented in chapter 5.2.3, should be included in the view to help the operator in prioritization. The important end customers could be visualized as symbols around the fault circle. Also, the new requirements of the Electricity Market Act concerning outage duration could be indicated in the view: An alarm should be generated if an outage is about to exceed six hours in a town plan area or 36 hours in another area.

During the visits, it was speculated if the view becomes unclear and messy if there are a lot of faults in the system. In this case, the fault circles may be overlapping. For example, during a major disturbance situation, there may be over 100 faults in the system. An idea was generated, that the faults could be filtered based on the fault handling areas: One operator would only see faults inside a certain geographical area. Later, as this was discussed more, it was pointed out that a storm usually is directed to a certain part of the network causing a lot of faults to a single fault handling area while other fault handling areas are left without faults. Eventually this discussion led to a new model of fault management in the main control center, which is discussed with more details in chapter 6.3. In this model, one of the operators in the main control center acts as a fault coordinator, who only focuses on giving faults to other operators so they can handle the fault further. At this point the idea of “Responsibility visualization”, which is described in chapter 6.3.4, was found. In the new fault management model, the huge amount of fault circles in “Degree of isolation visualization” is handled by filtering the view so that the operators only see faults they are responsible for, and the fault coordinator only sees the faults that are not yet anybody’s responsibility.

During the visits, it was found that the radius of a fault circle is not a clear way to visualize the customer outage costs caused by the fault. The relative radius of the fault circle does not provide the operator enough information about the severity of the fault, and it was not found practical if the operator has to check the radius of the fault circle to get this critical information. At this point, the idea of “Customer outage costs visualization”, which is described in chapter 6.3.2, was found.

6.2.3 Development and Feedback after the Visits

After the visits, the requirements were analyzed and a few of them were turned into visualization proposals, from which a couple of were selected to be implemented in this thesis. The selected visualizations will be introduced in chapters 6.3 - 6.5. The visualizations were implemented during spring 2014. During the implementation, feedback and ideas were received continuously from Antti Kostiainen, Solution Development Manager in ABB Oy, as well as other co-workers.

In summer 2014, the fault management dashboard visualizations were firstly completed, as well as a demo to show this functionality. The demo is run by the OutageDataProvider module in the DMS Service Framework. It keeps the system in a situation where there are continuously 20 faults in the system. The faults are isolated, restored and repaired in a way it could happen in a real environment, and new faults are created to random locations as old faults are removed. The responsibility of the fault is given to one of the four fictitious operators in the demo system: Erik, Angelina, Peter or Catherine. The purpose of the demo was to make such changes happen in the network that the visualizations could be demonstrated. The demo environment was set up and running in a server machine, which was available via internet for the distribution companies to explore. After this, opinions, feedback and improvement suggestions were asked from PKS Sähkönsiirto Oy, SVV Oyj, Tampereen Sähköverkko Oy, Koillis-Satakunnan Sähkö Oy, and co-workers in ABB Oy.

Opinions and ideas about each of the fault management visualizations as well as the wholeness itself were received. The feedback was positive. The views were found new, modern and innovative and it was indicated that these views could result in a good fault management dashboard. Interaction with the network view was suggested: when a fault circle is clicked, the network view could be zoomed automatically to the corresponding faulted zone. Like in previous feedbacks, there were some concerns about how the visualizations can handle a lot of faults, such as in a major disturbance situation.

The “Customer outage costs visualization”, described in chapter 6.3.2, was seen as a good tool to detect outage costs. The repairing of a short-term fault is guided by the outage costs, with a few exceptions concerning important end customers, and the repairing of a long fault is mainly guided by the important end customers. Therefore, it was seen important, that the important end customers should be visualized clearly in this view. The “Geographical visualization”, described in chapter 6.3.3, was seen as a tool to handle workgroups: The workgroup locations and responsible areas could be added to the view. On the other hand, it was seen as an alarm view: If the view combined alarms from both DMS and SCADA systems, it would be possible to see alarms coming from a single primary substation. The “Responsibility visualization”, described in chapter 6.3.4, was seen as a good tool for managing the faults. At the same time, the whole idea of an operator responsible for a fault was questioned: Each operator operating on a fault could be responsible for his/her own actions, and static fault handling areas could be used to divide the faults to the operators.

After the demo, some improvements were still implemented into the views: The “Responsibility visualization” was remade using D3 pack layout, which was introduced in chapter 3.3, and a few minor fixes was made to other views as well. Since then, the views have been used in multiple demonstrations, from which even more feedback have been received, for example from Caruna Oy. The further development of the visualizations, such as finalizing the appearance, will probably continue after this thesis has been finished. Also, because there has been interest in the deployment of the visualizations from several distribution companies, the visualizations will be probably deployed soon into real environments.

6.3 Fault Management Dashboard

During the customer visits, a new fault management model was invented. In the latest major disturbance situation in PKS Sähkönsiirto Oy, they had already adjusted their fault management methods towards this model, and as the model was discussed in the customer visits, it was seen as an effective model to handle faults in a major disturbance situation. To avoid confusion, it would be rational to use the same model in normal circumstances as in a major disturbance situation.

In this model, the operators in the main control center are working according to one of three roles: Fault coordinator, initial fault handler or conclusive fault handler. One of the operators in the main control center acts as a fault coordinator: The job is to assign faults to initial fault handlers or to conclusive fault handlers depending on the status of the fault. When a new fault occurs, the fault coordinator assigns the fault to an operator working as an initial fault handler. The assigned operator is chosen based on the workloads and/or responsible geographical areas.

The operator working as an initial fault handler focuses on the former part of the FDIR process. The operator detects, isolates and restores the fault using remote controlled switches. The operator notes the fault location indications given by the system and the possible backup connections, and restores power when possible. After the fault has been isolated to the smallest possible area using remote controlled switches, the operator assigns the fault back to the fault coordinator. The fault coordinator assigns the fault further to an operator working as a conclusive fault handler. The operator is again chosen based on the workloads and/or responsible geographical areas.

The operator working as a conclusive fault handler focuses on the latter part of the FDIR process. The operator knows the amount and locations of the faults, the prioritization information of the faults, and the locations of the workgroups that are operating in his responsible area. The operator manages the work groups by assigning tasks to them, guiding them to a certain disconnector and communicating with them about the permissions to operate. The operator working as a conclusive fault handler takes care of the fault until it is fixed and the electricity is fully restored. After this, the operator assigns the fault back to the fault coordinator, so it can be checked if a previously unavailable backup connection is now available. The fault coordinator then marks the fault as repaired so that it disappears from the user interface.

In this model, the roles are flexible. In the beginning of a major disturbance situation, there has to be one fault coordinator, but the rest of the operators could work as initial fault handlers until the situation has calmed down. After most of the faults have been isolated using remote controlled switches, some of the operators can move to work as conclusive fault handlers. After no more faults occur in the system, the fault coordinator can work as an initial fault handler simultaneously. On the other hand, in normal circumstances, when there are only one or two faults in the system, all of the three roles could be handled by the one operator working at the time.

Based on this model, a vision of a new fault management dashboard was invented. The vision can be seen in Figure 6.2.

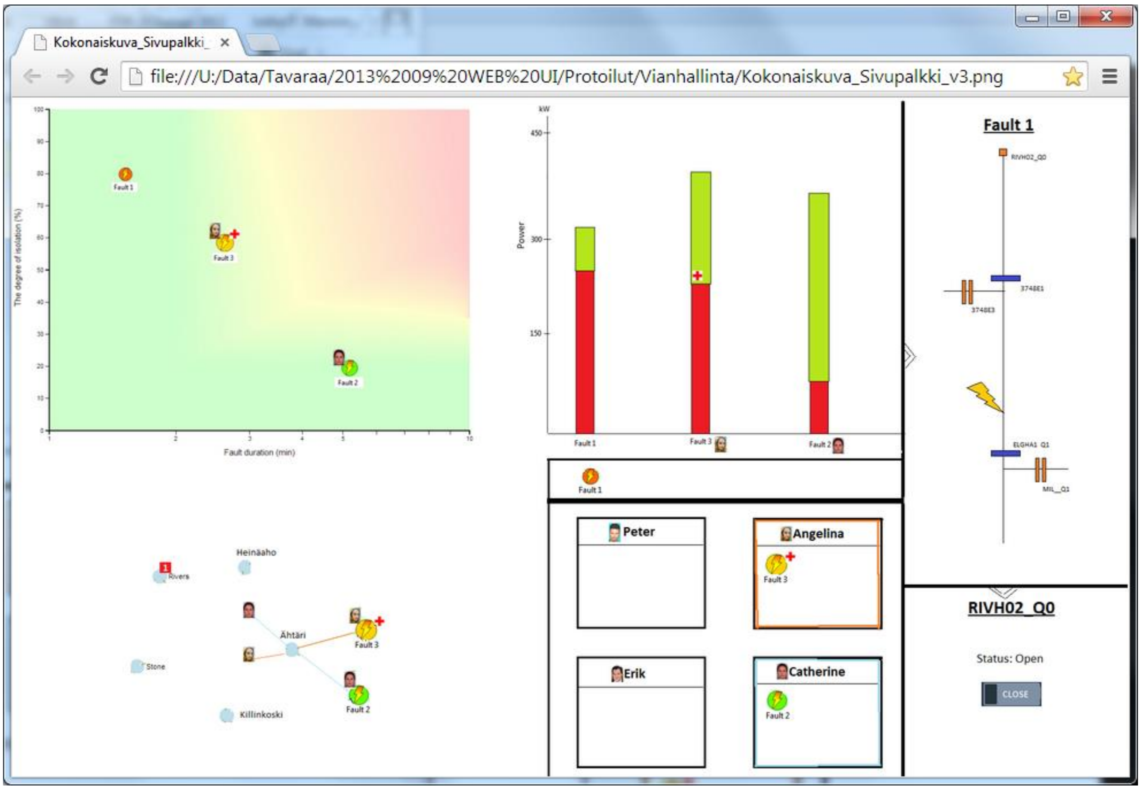

Figure 6.2 V*ision of a new fault management dashboard, when there are three faults in a combined SCADA and DMS system.*

The new fault management dashboard in Figure 6.2 consists of five separate visualizations. In the upper left corner of the dashboard, there is a "Degree of isolation visualization", which is described in chapter 6.3.1. On the right side of the last, there is "Customer outage costs visualization", which is described in chapter 6.3.2. In the lower left corner of the dashboard, there is "Geographical visualization", which will be covered in chapter 6.3.3 and on the right side of the last, there is "Responsibility visualization", which will be discussed in chapter 6.3.4. There is a sidebar on the right side of the dashboard, which shows a simplified schematic view of the faulted feeder with remote controlled switches and backup connection possibilities. When selecting the visualizations, which will be implemented within this thesis, the sidebar was decided not to be included in this thesis and therefore it will not be further discussed.

The fault management dashboard is meant to give the operator all the information that is needed in the FDIR process. In the new fault management model, the views in the dashboard can be used by any role, although some of the views are dedicated to a specific role. Following subchapters will specify how the views could be used by operators working according to the roles in the new fault management model.

6.3.1 Degree of Isolation Visualization

The "Degree of isolation visualization" is a tool mainly for an operator working as an initial fault handler in the new fault management model. The operator can use the view to see if there are faults in the network that have not yet been isolated. Also, the operator can use the view to prioritize isolating the faults so that important customers are taken into account and the faults, which can be restored the most, are restored first. An operator working as a fault coordinator can use this view to see an overview of the faults in the network and the statuses of the faults in the network: If the situation in the network changes so that a fault can be further restored using remote controlled switches, the operator working as a fault coordinator can use this view to notice it. For example, when a circuit breaker of a faulted feeder trips again and the whole feeder becomes unsupplied again, or a backup connection becomes available, this view is useful. An example of "Degree of isolation visualization" can be seen in Figure 6.3.

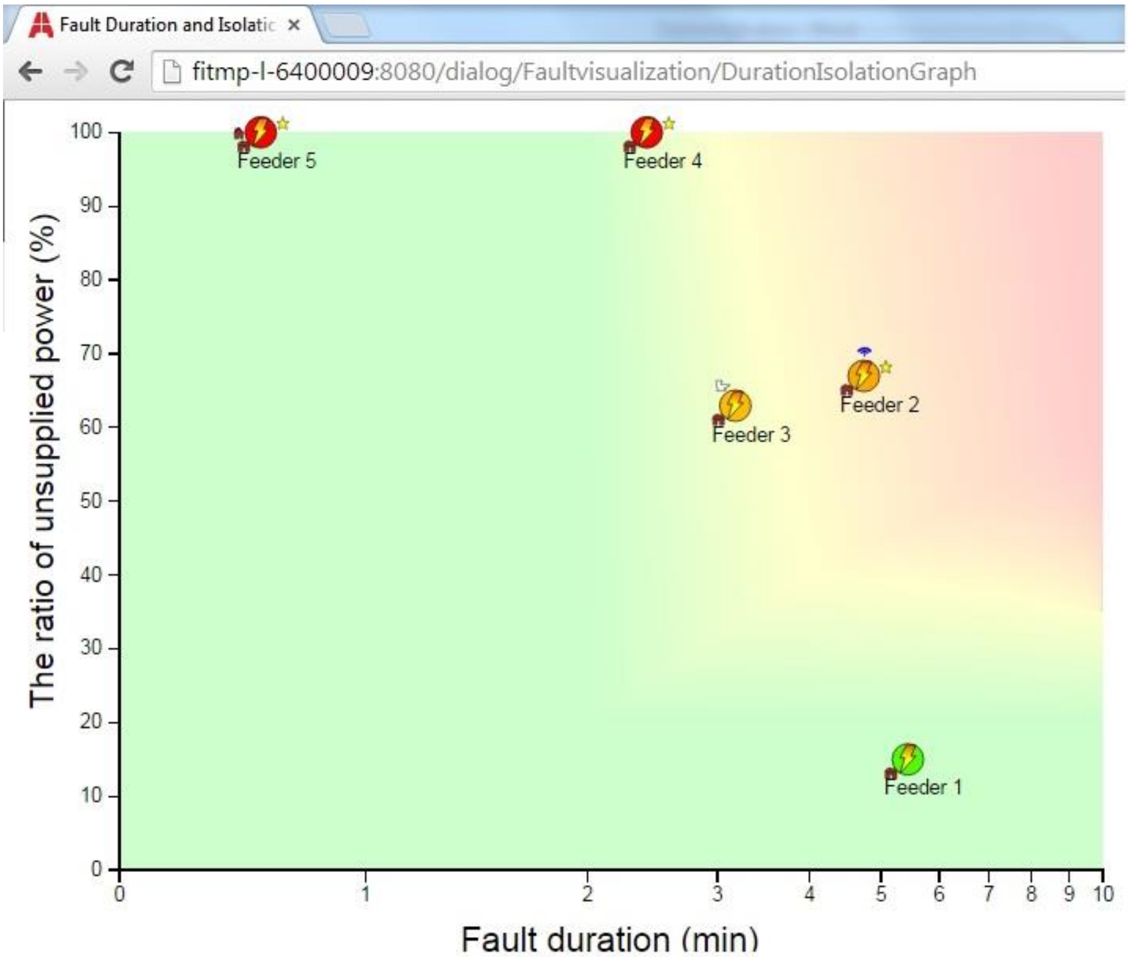

Figure 6.3 *"Degree of isolation visualization" in Google Chrome web browser.*

In the "Degree of isolation visualization", the faults in the network are represented as circles. The horizontal axis represents the duration of the fault and the vertical axis represents the percentage of unsupplied power. The degree of isolation is also visualized using the color of the fault circle: A red fault circle has not been isolated at all, but a green fault circle has been fully restored. The name of the faulted feeder is shown under the fault circle. The important end customers, which were described in chapter 5.2.3, are shown as symbols around the fault circle. For example, a blue connection icon is shown on top of the fault circle, if an internal or external communication station is unsupplied. There is also a symbol in the lower left corner of the fault circle indicating the town plan area ratio of the fault: If a majority of the unsupplied customers of the fault is in a town plan area, a symbol representing an urban area is shown, and if a minority of unsupplied customers of the fault is in a town plan area, a symbol representing a rural area is shown.

In Figure 6.3, there are five faults in the network. Two of the faults have not been isolated at all, two of the faults have been slightly isolated, and one of the faults has been almost fully restored. There are a few important end customers unsupplied in the network due to the faults, which are represented as symbols around the fault circle. The oldest of the faults has lasted almost six minutes and the latest fault has only lasted for 30 seconds.

When a new fault occurs in the network, a new fault circle appears in the upper left corner of the view. It starts to travel horizontally as the duration of the fault increases. When the fault is restored or the circuit breaker of the faulted feeder trips again, the fault circle travels vertically. The movements of the fault circles are animated so it is easier to notice changes in the view. This helps detecting, for example, when a circuit breaker of a previously restored fault's feeder trips again due to another failure in the network. The background of the view is colored so that it suggests an optimal path for fault circles: It should be isolated fast so that it travels on the green zone all the time.

This view, as well as all other visualizations in fault management dashboard, offer also a tooltip, which shows specific information about the fault. An example of a tooltip is shown in Figure 6.4.

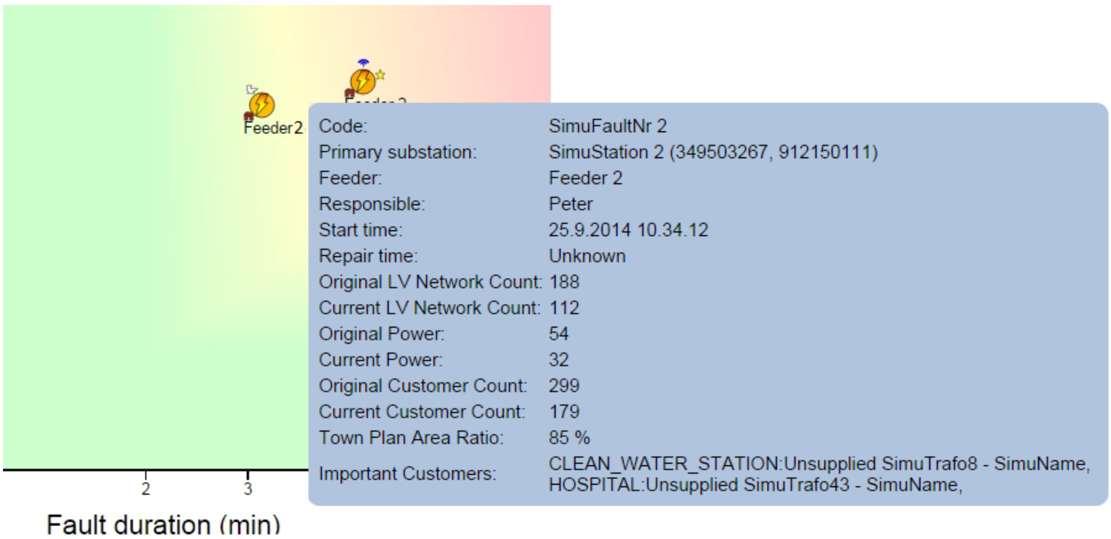

Figure 6.4 *A tooltip in "Degree of isolation visualization".*

Tooltip appears when the cursor is hovered over a fault circle. It shows information about the fault in a textual format. It is useful when some specific information is needed, such as primary substation name, responsible person name, town plan area ratio or exact important end customers and their low voltage network codes and names.

The purpose of the “Degree of isolation visualization” is to show critical information needed in the FDIR process. Primarily, it is used to see if there are faults in the network, which have not yet been isolated and restored using remote controlled switches. When this view is used, it should be prevented that a fault can be “forgotten” in the network. Such memory lapses can cost a lot of money. On the other hand, the view shows overall information about the faults and their statuses in the network: It shows the durations of the faults in the network and important end customers, which are unsupplied due to the fault. When using this view, it should be prevented that a fault lasts longer than it is regulated: If a fault has lasted so long that the timelines of six hours in a town plan area or 36 hours in other areas are closing up, the faults should be fixed immediately.

6.3.2 Customer outage costs Visualization

The “Customer outage costs visualization” is a tool mainly for an operator working as a conclusive fault handler in the new fault management model (introduced in chapter 6.3). The operator can use this view for workgroup management: From this view, the operator can see the customer outage costs caused by the faults and important end customers that are still unsupplied due to the fault. The workgroups can be guided to restore and repair faults, which generate the most customer outage costs and have the most important end customers still unsupplied.

On the other hand, the view can also be used by operators working as initial fault handlers or as a fault coordinator: They can use this view to prioritize the faults and to see the overview of faults and their statuses in the network. In addition, this view can be used by everyone in the main control center, including managers, to see the amount of money saved when restoring power to the end customers. This brings an important aspect, enjoyability, to the user interface. An example of “Customer outage costs visualization” is represented in Figure 6.5.

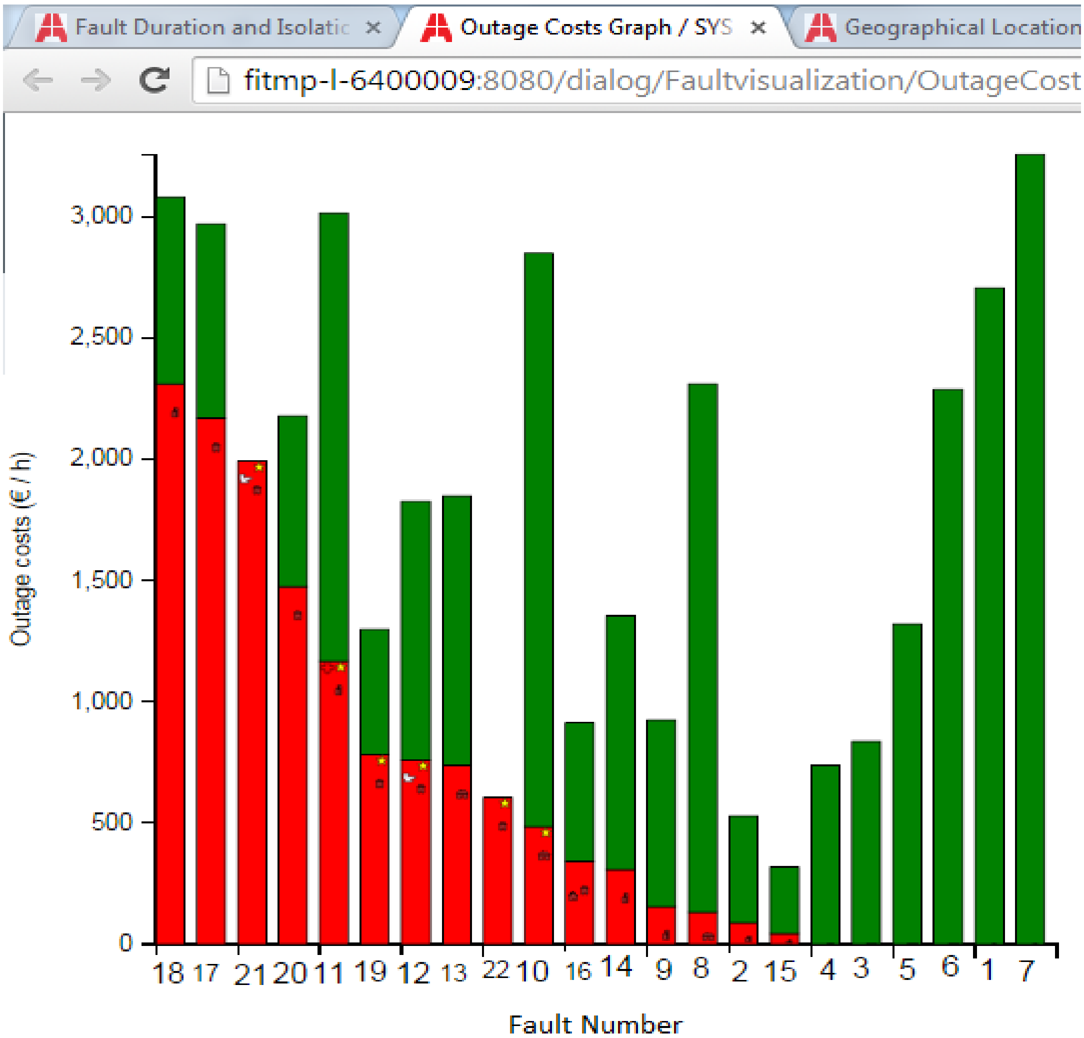

Figure 6.5 *The "Customer outage costs visualization" in Google Chrome web browser.*

In "Customer outage costs visualization", faults are represented as poles. The vertical axis in the visualization represents customer outage costs and the horizontal axis represents the fault's number or faulted feeder name. A red part of the pole describes the customer outage costs, which are still being generated due to the fault, and a green part of the pole describes the customer outage costs, which have been restored and thus do not create customer outage costs anymore. The faults are ordered in the view so that the fault generating the most customer outage costs is located in the left side of the view and the faults, which have been fully restored are in the right side of the view ordered so that the fault, which had most customer outage costs in the beginning is located in the most right. When the fault is marked as repaired in the system, it is removed from this graph. If there are important end customers unsupplied due to the fault, corresponding symbols are shown in the red part of the pole. The same tooltip as in "Degree of isolation visualization", which was represented in Figure 6.4, is also available in this view.

The customer outage costs used in the view are calculated using the time-dependent part of the total customer outage costs, because the constant part of the customer outage costs is not relevant when prioritizing the faults. The equation used to calculate customer outage costs in this thesis is based on the equation, which is used when reporting outage information to Finnish Energy Industry (ET) [34]. The equation used in this thesis is

$$KAH = h_E \cdot P \cdot (\frac{KHI_{2013}}{KHI_{2005}}) \qquad (1)$$

where

KAH = Customer outage costs of a fault [€/h]
h_E = Customer outage unit costs in the value of year 2005 [€/kWh]
P = Total unsupplied power caused by the fault [kW]
KHI_{2013} = Consumer price index of year 2013
KHI_{2005} = Consumer price index of year 2005

In this thesis, a fixed value of 11 €/kWh was used as a value of h_E, because it is the value, which is used when reporting unannounced outages to Finnish Energy Authority [35]. The quotient of KHI_{2013} and KHI_{2005} is 118.4 [36].

The purpose of the "Customer outage costs visualization" is to help prioritizing the faults. The view sorts the faults based on the customer outage costs caused by the fault: The fault causing the most customer outage costs should be prioritized over a fault, which is causing less customer outage costs. On the other hand, important end customers can shift this prioritization so that the fault causing less customer outage costs should be prioritized over the fault causing more customer outage costs. This view gives an overview of the faults in the system and their statuses, and it motivates the operators as it informs the operator about the actual amount of money saved when the power is restored to the customers.

6.3.3 Geographical Visualization

The "Geographical visualization" is a tool mainly for an operator working as a fault coordinator in the new fault management model (introduced in chapter 6.3). The operator can use this view to see how the faults in the network are distributed geographically. By using this information, the operator working as a fault coordinator can assign faults to operators working as initial fault handlers or as conclusive fault handlers, who are responsible for the geographical areas in question. Because this view gives a simple overview about the geographical distribution of the faults in the network, it can be used by everyone in the main control center. In Addition, if workgroup locations and responsible areas of the workgroups were added to this view, the view would be useful also for an operator working as a conclusive fault handler: The operator could use this view to see which workgroup should be guided to work with which fault so that the workgroups shouldn't need to travel long distances or back and forth. An example of "Geographical visualization" is represented in Figure 6.6.

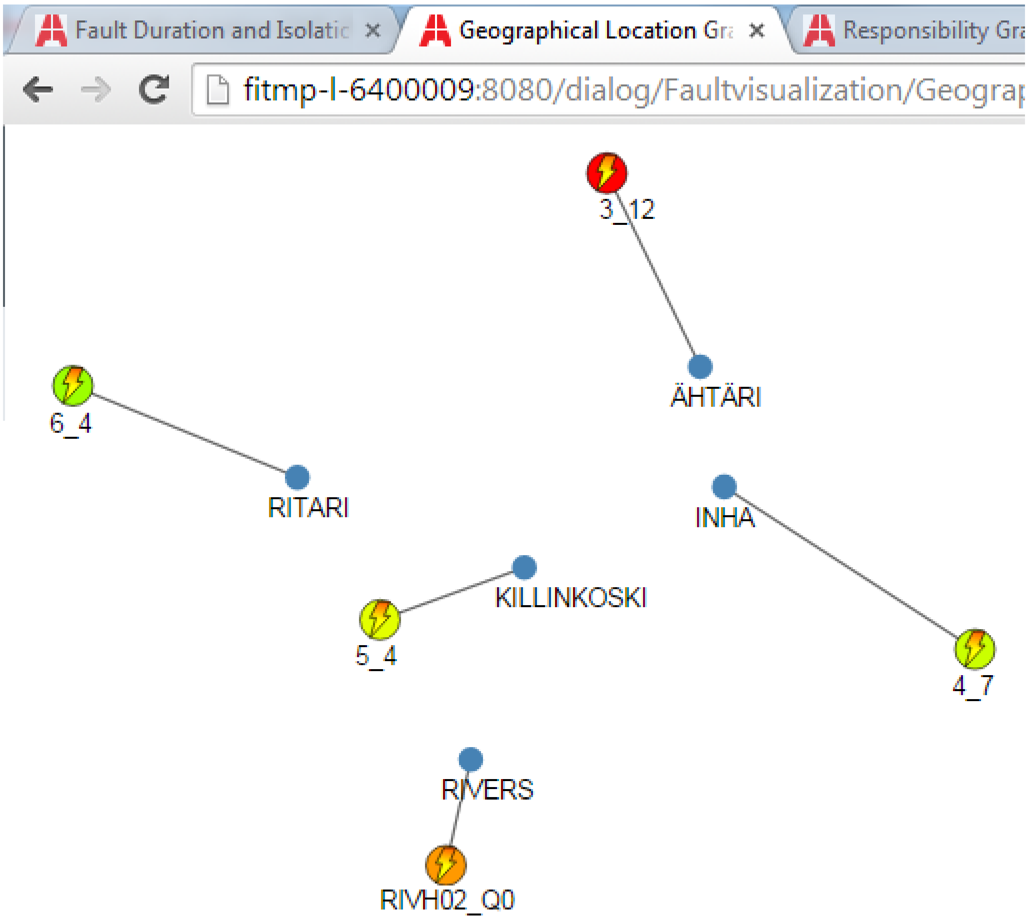

Figure 6.6 *The "Geographical visualization" in Google Chrome web browser.*

In the "Geographical visualization", the faults are again represented as circles. The code of the faulted feeder is shown under the fault circle and the color of a circle represents the degree of isolation the same way as in "Degree of isolation visualization". The primary substations, which currently have faults, are represented as blue circles and the name of the primary substation is shown under the blue circle. The blue circles, representing primary substations, are positioned in a relative geographical location: The primary substation, which is the most northeast in the network, is positioned in the upper right corner of the view, and the primary substation, which is the most southwest in the network, is positioned in the lower left corner of the view. The fault circles are positioned to a relative average coordinate of the unsupplied secondary substation's coordinates. Therefore, the relative geographical location of the fault and the direction, in which the faulted feeder points to, can be also seen in this view. The same tooltip as in "Degree of isolation visualization", which was introduced in Figure 6.4, is also available in this view.

The purpose of the “Geographical visualization” is to give a clear overview about the geographical distribution of the faults. This helps the operator working as a fault coordinator to assign faults to operators working as initial and conclusive fault handlers. Using this view, the fault coordinator can decide the responsible fault handling areas dynamically depending on the situation. This means that the static predefined fault handling areas, which were seen problematic, are not needed. Dynamic fault handling areas help the fault handling process for example in a situation, where a storm causes a lot of faults in a smallish geographical area. This view can also help noticing, when a backup connection becomes available: When a fault is repaired, and the previously faulted feeder can now be used as a backup connection, the nearby faults can be seen in this view easily because the faults are positioned in a relative geographical location. In addition, if the locations and responsible areas of the workgroups were added to this view, it could be used to monitor and manage them.

6.3.4 Responsibility Visualization

The “Responsibility visualization” is a tool mainly for an operator working as a fault coordinator. The operator can use this view to see how many and which faults do each user in the system have and what are the statuses of the faults. Therefore this view can be used when deciding to which operator a fault is assigned. Also, this view can be used when deciding how many operators are needed to be working in the main control center and how many of these operators should work as initial fault handlers or conclusive fault handlers.

This view can be used also by initial fault handlers or by conclusive fault handlers: It is currently the only view out of the four visualizations made in the fault management dashboard, which include user interaction with the system in addition to monitoring the system. Using this view, the responsible operator of a fault can be changed using drag-n-drop functionality. An example of the “Responsibility visualization” can be seen in Figure 6.7.

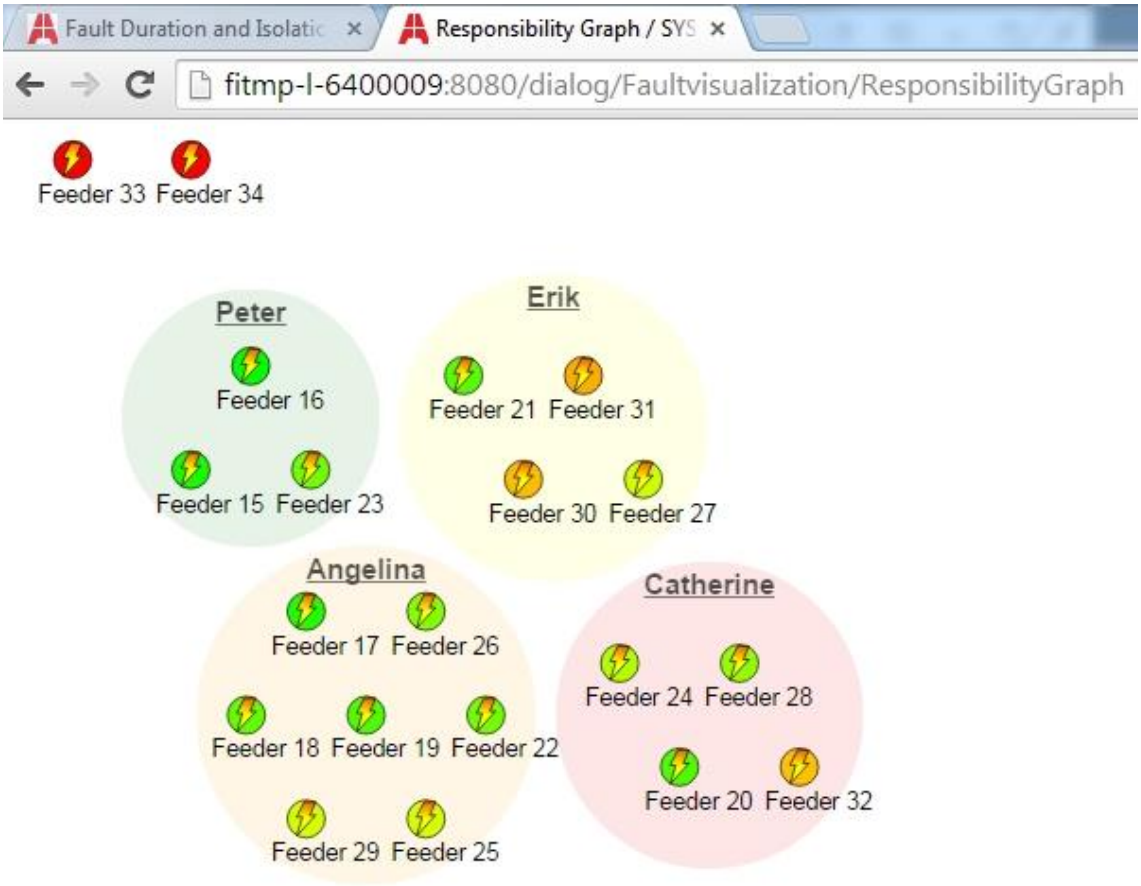

Figure 6.7 *The "Responsibility visualization" in Google Chrome web browser.*

In the "Responsibility visualization", the faults are again represented as circles. The code of the faulted feeder can be seen below the fault circle, and the color of the circle represents the degree of isolation the same way as in "Degree of isolation visualization". The operators, who are logged in to the system and/or have faults, which are their responsibility, are shown as larger circles each with different background colors. The name of the operator is shown at the top of the large circle. Each large circle contains the faults which are the operators' responsibility. The positions of the fault circles and the radiuses of the large circles are calculated using the D3.js pack layout, which was described in chapter 3.3. The faults, which have not yet been assigned to anyone, are shown at the top of the view. The faults can be assigned to an operator by drag-n-dropping them on a large circle, which represents an operator. The same tooltip as in "Degree of isolation visualization", which is represented in Figure 6.4, is also available with this view. In addition, another tooltip is available in this graph: When mouse is hovered over a large circle, which represents an operator, a tooltip is shown, which shows information about the operator such as when the operator has logged in, what computer was used, and how many faults the operator has.

The purpose of the "Responsibility visualization" is to show a clear overview of faults and the responsible operators, and offer a possibility to enjoyably assign faults. By using this view, the operator working as a fault coordinator can see, how many faults each operator has and what are the statuses of the faults. This information can be used to determine which operator would be the best choice to further handle the fault. When a new fault occurs, the operator working as a fault coordinator can use this view to assign the fault to the best initial fault handler. As the fault has been isolated by the initial fault handler, the fault is assigned back to the fault coordinator using this view. After this, the fault coordinator assigns the fault to the best conclusive fault handler using this view. Finally after the fault has been repaired, it is assigned back to fault coordinator, who can check if the restored feeder can now be used as a backup connection for another fault.

6.4 Maintenance Outage Management Visualization

During the customer visits, it was indicated that it was not possible to see certain information concerning planned maintenance outages clearly from the current system. It was required that there should be a clear overview of maintenance outages in a combined SCADA and DMS system, which should help scheduling the maintenance outages, spotting overlapping maintenance outages and combining both external and internal maintenance needs to a single outage.

In this thesis, one visualization of maintenance outages was implemented. In “Maintenance outage visualization”, the maintenance outage plans are represented as a Gantt chart (For more information about Gantt chart, see [37]). An example is shown in Figure 6.8.

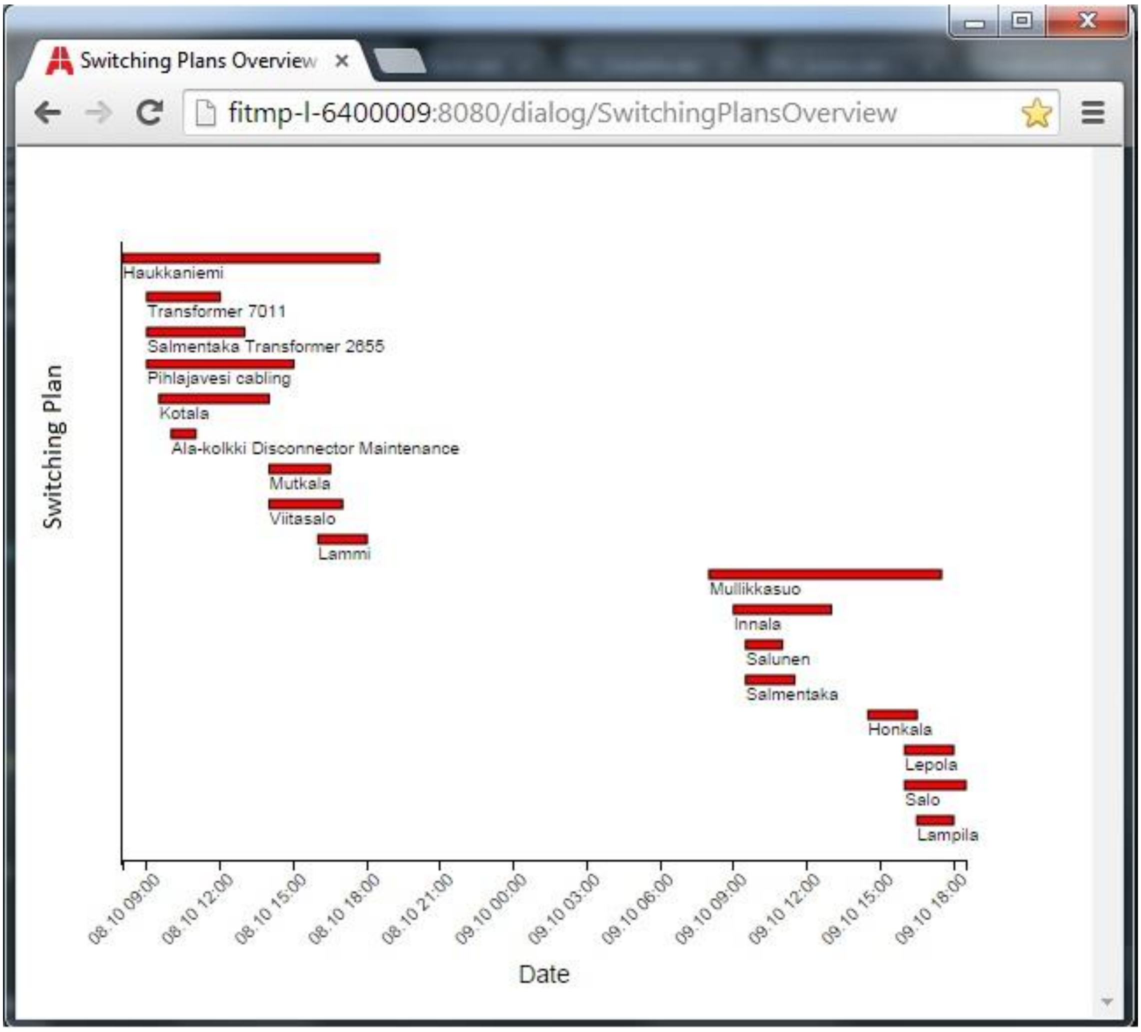

Figure 6.8 *The "Maintenance outage visualization" in Google Chrome web browser.*

In the "Maintenance outage visualization", the maintenance outage plans in the system are represented as red bars, each positioned horizontally in the view. The horizontal axis represents time span, in Figure 6.8 from the current date two days forward. The length of a red bar visualizes the duration of the maintenance outage plan. The name of the maintenance outage plan is represented under the bar. The maintenance outage plans are sorted so that the one starting earlier is upper.

The purpose of the "Maintenance outage visualization" is to help operators to notice overlapping maintenance outages and to help scheduling the maintenance outages. As it visualizes the starting times of the maintenance outages, it can be avoided that all of the switching plans start at the same time. Instead, they can be scheduled to start sequentially, so the operator has enough time to focus on all of them. Also, if the maintenance outages were filtered by a certain geographical area, the view could be used to combine a need of company's own maintenance work to an existing maintenance outage plan. If the maintenance outages were filtered by a responsible operator, the view could be used to see if an operator has too many switching plans scheduled at a certain time.

6.5 Power Flow and Load Rate Visualization

In a combined SCADA and DMS system, it was required that the power flow and load rates of the network should be visualized clearly. A concept, how the power flow and load rates could be visualized, was invented in this thesis, and it is presented in Figure 6.9.

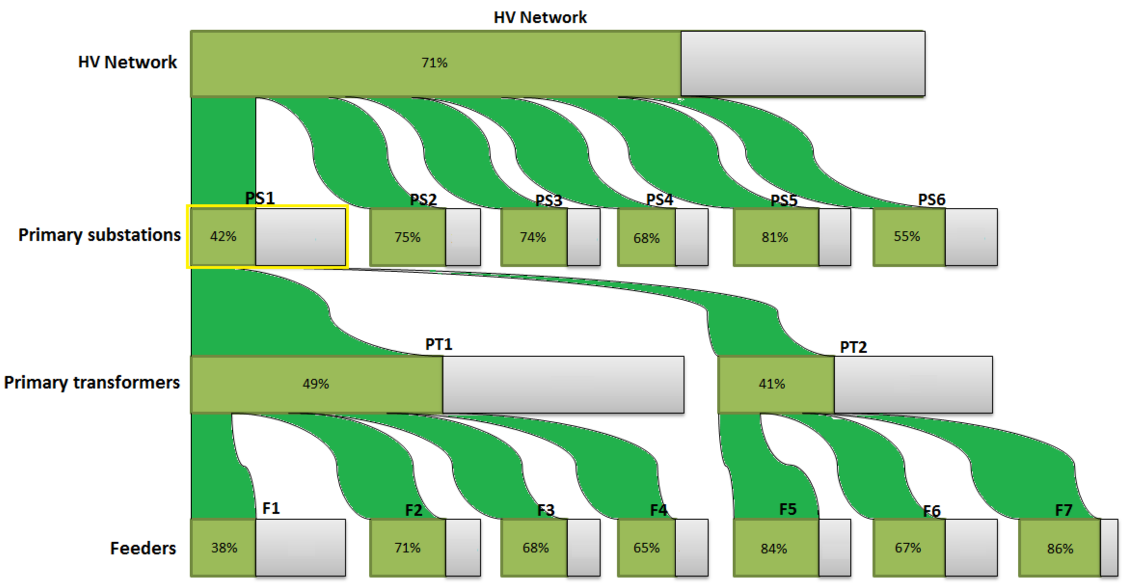

Figure 6.9 *Concept of the "Power flow and load rate visualization". The primary substation "PS1" is selected.*

The "Power flow and load rate visualization" consists of four levels. The uppermost level is high voltage network level, followed by primary substation level, primary transformer level and feeder level. In Figure 6.9, the power in the high voltage network is distributed to six primary substations. The first primary substation ("PS1"), which is currently selected in Figure 6.9, has two primary transformers. The first primary transformer ("PT1") feeds power to four feeders and the second primary transformer ("PT2") feeds power to three feeders. The load rates in the network are visualized as green and grey bars. The size of the green bar and the percentage in it represents the current real power with respect to the maximum allowed real power. Absolute values could be available in tooltip, or if desired, the percentages could be replaced with absolute values.

The load rate in the feeder level represents the electric current compared to the nominal electric current of the circuit breaker. The load rate in the primary transformer level represents the load power compared to the nominal power of the primary transformer. The load rate in the primary substation level represents the average load rates of the primary transformers in the primary substation or alternatively, the absolute power values could be represented. The load rate in the HV network level could represent the average load rates of the primary substations or alternatively, the absolute power values could be represented.

The purpose of “Power flow and load rate visualization” is to help operator in case of failure. It visualizes, how much power can still be taken from a certain feeder, primary transformer, or primary substation. If a feeder becomes unsupplied, this view can be used to determine the best alternative to be used as a backup connection. If a primary transformer is damaged, this view can be used to check how the load of the damaged primary transformer could be shared to other primary transformers. Ultimately, if a whole primary substation becomes unsupplied, this view can be used to check how the load can be distributed to other primary substations.

The “Power flow and load rate visualization” could not be implemented as a web page in this thesis due to a several technical difficulties: The process points in SCADA system are application-specific, which means that the necessary measurement values cannot be received without configuration work. Therefore, since this view cannot be generated automatically but it would have required a lot of configuring, it was seen that this view is not worth creating within this thesis.

7. CONCLUSIONS

This thesis consisted of a user study, followed by requirements analysis and implementation of visualization concepts. The user study concentrated on the use of the SCADA and DMS systems in the main control center of a distribution company. The most common tasks were disclosed in this thesis and represented with examples of user interfaces used to handle each task. As can be seen from the examples, it is required to be able to create many kinds of monitoring user interfaces in a combined SCADA and DMS system. During the study, it was found out that the operator has to constantly switch between the user interfaces to perform daily tasks.

Using the problems, feedback and ideas gathered from the user study, visualization requirements for a combined SCADA and DMS system were discovered. It was found out that a combined SCADA and DMS system should offer clear and calm overviews of the system for multiple different users. Specific visualization requirements concerning events and alarms in the system, navigating and zooming in the system, supervision and overviews of the system, fault management, and maintenance outage management were discovered in this thesis. It was noticed that especially when a lot of events happen in the system, such as during a major disturbance situation, a combined SCADA and DMS system should clearly visualize the faults and alarms in the system to help the operator handle the situation.

Based on the visualization requirements, a few concepts were developed. A new model for fault management, and a fault management dashboard, which supports the new fault management model, were invented. Four visualizations, which are included in the fault management dashboard, were discussed and implemented iteratively using the gathered feedback. In addition, a visualization for maintenance outage management was implemented and a concept of power flow and load rate visualization was designed.

This thesis piloted the WebUI, a common user interface platform for a combined SCADA and DMS system in ABB MicroSCADA Pro product family. During the thesis, problems, improvement ideas and feedback about the WebUI have been shared with the developers, and some improvements, especially concerning the communication with the DMS system, were implemented. The visualization prototypes created in this thesis have received positive feedback about the modern look and feel. They have been used in many demonstrations and thus participated with the sharing of information. Also, because many distribution companies have shown interest in the deployment of the visualizations, they will probably soon be taken into use in real environments.

In this thesis, it has been presented that many benefits are achieved and the efficiency of the operators would increase if the SCADA and DMS systems were combined. The WebUI was noted to have good potential to become a successful user interface for a combined SCADA and DMS system: It integrates the systems in a simple and effective way, and no major weaknesses were found in the architecture.

7.1 Future work

There are some improvements still needed for the fault management dashboard visualizations invented in this thesis. The locations and responsible areas of workgroups should be visualized in the fault management dashboard views and the required user actions should be implemented to the views. Filtering possibility needs to be implemented into each of the fault management dashboard views and some finalizing work is needed, for example concerning appearance and symbol management. As the visualizations are currently developed as separate views, they should be combined into a one dashboard. This requires some integration work, but it also enables new features as the views become interconnected.

The DMS system should be developed so that it would be possible to automatically visualize if the fault can be further isolated using remote or manual controlled switches. The possibility to further isolate a fault should also be visualized in the fault management dashboard views. In addition, the topology handling in DMS system should be improved so that it would be possible to not only create a schematic view of a feeder but also schematic and semi-schematic views of the whole network.

Maintenance outages should be visualized so that the affected geographical area would be clearly visible. This visualization would help the operators to combine different maintenance outages to a single one. To help implementing new views, which visualize also SCADA process data (such as "Power flow and load rate visualization"), it should be discussed, whether the SCADA system could be improved to provide process data in a more hierarchical and standardized way. For example, if one wants to subscribe an electric current measurement value of a feeder, it would be found from a process point address, which is generated as a combination of standardized codes for the primary substation, feeder, and current measurement.

There are a couple of new features required for the WebUI: Delivering user actions to the external systems could be improved and the symbol management for the views should be developed into the WebUI. The dashboards, which combine separate views to a single user interface, and the interaction between the views in a dashboard is to be implemented. A drawing tool, which helps system administrators in a distribution company to easily create new views, is to be created.

Based on the experience gained from this thesis, the WebUI can become a successful user interface for a combined SCADA and DMS system. While combining the systems enables new features for the operators, there are a lot of visualizations to be implemented to fulfill all the requirements and to support all the features in both SCADA and DMS systems.

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