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NETWORK DATA IMPORTS IN MICROSCADA X DMS600 SYSTEM AND DEVELOPMENT OF NETWORK DATA ANALYSIS

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ABSTRACT

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IT-systems in the Network Control Center have different interfaces to exchange data. In this Master of Science Thesis, network model data from Network Information System or Geographical Information System to Distribution Management System is under research. In this research, the network model of the power distribution network which is exported from NIS or GIS and imported to DMS is discussed.

MicroSCADA X DMS600 is a Distribution Management System by Hitachi ABB Power Grids, which offers functions to monitor and operate the power distribution network. To ensure proper functionality of the DMS600 system, the network model cannot have errors or missing component data that are used in modelling of the power distribution network.

In addition to the network data from NIS or GIS, other network data sources are utilized in DMS. The substation pictures can be imported from SCADA system and relay data, conductor type data, fuse type data and disconnector type data can be imported from catalogues or other data sources. Together all the data sources are used to build a network model used in DMS.

In this Master of Science Thesis, the status of the network data import implementations in MicroSCADA X DMS600 system is under research. Bulk import is a network data import where the whole network data is imported from the NIS or GIS at the same time to the DMS. Other practise to implement the network data import is incremental network data import. Then the network data model of DMS system is compared to the new network model and then only the changes made to the network model since previous network data import are imported to the DMS.

Network data can be in different file formats, and they have different functionalities to model the network data. The topology of the network can be modelled in the network data files or it is needed to deduce during the network data import. In addition, the network component data is presented in variously ways based on the network data file format.

The other objective of this Master of Science Thesis is to develop the network data analysis. The purpose of the network model analysis is to point out the errors in the network model so they can be corrected to ensure reliable and working functionalities in DMS. Network model analysis tool was developed in this Thesis to analyse the network model from the database of DMS600 system or the network model built in the network data import application. The analysis results contain errors and warnings of the topology of the network model as well as the attribute data of the network components. The tool saves the analysis results to the database of the DMS600 system and to the CSV-files.

Keywords: distribution management system, network model, network data, network data analysis, MicroSCADA, DMS600

The originality of this thesis has been checked using the Turnitin OriginalityCheck service.

TIIVISTELMÄ

Ville Uusitalo: Verkkodatan tuonnin nykytila MicroSCADA X DMS600 järjestelmässä sekä verkkotiedon analysoinnin kehittäminen
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Sähkönjakeluverkkoyhtiön valvomossa käytetyillä järjestelmillä on toisiinsa erilaisia rajapintoja. Tässä diplomityössä tutkitaan verkkotiedon siirtoa verkkotietojärjestelmästä tai paikkatietojärjestelmästä käytöntukijärjestelmään. Tässä diplomityössä tarkastellaan tilannetta, jossa sähkönjakeluverkon verkkotietomalli luodaan ja ylläpidetään verkkotietojärjestelmässä tai paikkatietojärjestelmässä ja siirretään sieltä käytöntukijärjestelmän käyttöön.

MicroSCADA X DMS600 on Hitachi ABB Power Gridsin toimittama käytöntukijärjestelmä, jonka avulla sähkönjakeluverkkoa voidaan valvoa ja operoida. DMS600-käytöntukijärjestelmän sähkönjakeluverkon verkkomallissa ei saa olla virheitä tai puutteita verkkolaitetiedoissa, jotta järjestelmä toimii oikein.

Verkkotietojärjestelmästä tai paikkatietojärjestelmästä tuodun verkkotiedon lisäksi verkkotietoa tuodaan myös muista lähteistä. Sähköasemakuvat voidaan tuoda SCADA-järjestelmästä, asiakastiedot asiakastietojärjestelmästä sekä reletiedot, johdinlajitiedot, sulaketyyppitiedot ja erotintyyppitiedot voidaan tuoda luetteloista tai muista lähteistä. Yhdessä eri tietolähteistä tuotu verkkotieto muodostaa käytöntukijärjestelmässä käytetyn verkkomallin, jolla mallinnetaan sähköverkkoa.

Tässä diplomityössä tutkitaan verkkotiedon tuonnin nykytilaa DMS600-käytöntukijärjestelmässä. Verkkotiedon kertatuonnissa koko sähkönjakeluverkon verkkomalli tuodaan kerralla verkkotietojärjestelmästä tai paikkatietojärjestelmästä käytöntukijärjestelmään. Toinen tapa tuoda verkkotietomalli käytöntukijärjestelmään on inkrementaalinen tuontitapa. Tällöin vain edellisestä tuonnista muuttuneet sähköverkon osat tuodaan verkkotietojärjestelmästä tai paikkatietojärjestelmästä käytöntukijärjestelmään.

Verkkotieto voidaan tuoda erilaisissa tiedostomuodoissa, joiden ominaisuuden vaihtelevat keskenään. Toisissa tiedostomuodoissa verkon topologia on mallinnettu, mutta toisissa verkkotopologia päätellään verkkotiedon tuonnin aikana. Lisäksi verkon komponenttien tiedot ovat kerrottu eri tavoin riippuen käytetystä tiedostomuodosta.

Toinen tutkimuskohde tässä diplomityössä on verkkodatan analysoinnin kehittäminen. Verkkodatan analysoinnin tarkoitus käytöntukijärjestelmässä on löytää virheet verkkotiedoissa, jotta virheet verkkotiedoissa voidaan korjata. Verkkomalliin tehtävien korjausten avulla verkkomallista saadaan luotettava ja toimiva, jota käytöntukijärjestelmä käyttää toiminnassaan. Tässä diplomityössä kehitettiin DMS600-käytöntukijärjestelmän verkkomallia analysoiva työkalu. Työkalu osaa analysoida DMS600-järjestelmän tietokantaan tallennettua verkkomallia sekä verkkotuonnin aikaista verkkomallia. Työkalun analyysitulokset sisältävät virheitä ja varoituksia verkkomallin kytkeytyvyydestä sekä verkkokomponenttien tiedoista. Työkalu tallentaa tulokset DMS600-järjestelmän tietokantaan sekä CSV-tiedostoihin, joiden avulla virheet verkkomallissa voidaan korjata.

Avainsanat: käytöntukijärjestelmä, verkkomalli, verkkotieto, verkkotiedon analyysi, MicroSCADA, DMS600

Tämän julkaisun alkuperäisyys on tarkastettu Turnitin OriginalityCheck –ohjelmalla.

PREFACE

This Master of Science Thesis was written for Hitachi ABB Power Grids in Tampere between January 2021 and June 2021. The examiners of this Thesis at Tampere University were Professor Pekka Verho and Professor Sami Repo whom I would like to thank the feedback received during the writing process and review of the thesis.

The supervisor at Hitachi ABB Power Grids was M.Sc. Jukka Nokelainen, who I would like to thank for valuable advice during the thesis process. In addition, I want to thank my colleagues at Hitachi ABB Power Grids for all the support that I have received during my time as a trainee.

Finally, I want to thank my wife Sanelma, family and friends for all the support brought me during my studies and the thesis process.

Tampere, 12 July 2021

Ville Uusitalo

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LIST OF SYMBOLS AND ABBREVIATIONS

ABB	Asea Brown Boveri
AM	Automated Mapping
API	Application Programming Interface
CAD	Computer-Aided Design
CIM	Common Information Model
CSB	Cold-Stand-By
CSV	Comma Separated Values
DMS	Distribution Management System
DMS600	MicroSCADA X DMS600 Distribution Management System
DMS600 NE	MicroSCADA X DMS600 Network Editor
DMS600 SA	MicroSCADA X DMS600 Server Application
DMS600 WS	MicroSCADA X DMS600 Workstation
DSO	Distribution System Operator
DXF	Drawing Exchange Format/Drawing Interchange Format
EMS	Energy Management System
ESRI	Environmental Systems Research Institute, Inc.
FM	Facilities Management
GIS	Geographical Information System
GUI	Graphical User Interface
HSB	Hot-Stand-By
IEC	International Electrotechnical Commission
IT	Information Technology
KML	Keyhole Markup Language
LV	Low Voltage
MV	Medium Voltage
NCC	Network Control Center
NIS	Network Information System
OGC	Open Geospatial Consortium
OPC	OLE for Process Control
PDS	Production Development Server
R&D	Research and Development
SCADA	Supervisory Control and Data Acquisition
SCIL	Supervisory Control Implementation Language
SDM600	MicroSCADA X System Data Manager
SMS	Short Message Service
SQL	Structured Query Language
SSI	Support System Interface
TAM	Telephone Answering Machine
TCP/IP	Transmission Control Protocol/Internet Protocol
UML	Unified Modelling Language
UPS	Uninterruptible Power Supply
XML	Extensible Markup Language

INTRODUCTION

The DMS (Distribution Management System) system is utilized to monitor and operate the distribution network [1, 2]. The DMS contains many features that uses the network model of the distribution network as a source data for functions and calculation. The DMS network model is required to have all the mandatory information of the components as well as topological connections between components and line sections.

However, the distribution network data model can be maintained in NIS (Network Information System) or GIS (Geographical Information System) and to utilize the same network model in DMS, the network data export functions from NIS or GIS and the network data import functions to DMS is required. To utilize the NIS or GIS network model in DMS sets requirements of the quality of the network model. Errors in the network model can cause errors in the network calculations in DMS and some features of DMS does not work properly or at all if the network model has errors. The network model analysis is utilized to trace errors that occur in the network model of the distribution network. The errors of the network model must be fixed to get working DMS with reliable calculation and deduction functions.

This thesis can be divided to two parts: first part of the thesis is a literature review focusing on distribution automation and network data imports in DMS600 system and the second part focuses on developing the network data analysis. In the first chapter of this thesis, the distribution automation and systems used in NCC (Network Control Center) are discussed and presented. In chapter 2, MicroSCADA X product family is presented where MicroSCADA X DMS600 system is presented in more detail. Then the network data imports of the DMS600 system is presented and different network data implementations are discussed. Next, the supported file formats to import the network data to DMS600 system are presented. In chapter 4, the network model analysis functions of DMS600 system are presented and discussed. The development of the network data analysis is presented in chapter 6 and future steps for the network data analysis in DMS600 system is suggested. Finally, in chapter 7, the conclusions sum up the thesis and the success of the thesis in relation to the objectives is observed.

1. DISTRIBUTION AUTOMATION

The main objective of the electric power system is to transfer energy from power plants to electricity consumers [1, 3]. The electricity power system consists of different parts: power plants, transmission network, regional networks, power distribution networks and electricity consumers [4]. The focus of this thesis is on power distribution networks.

In this chapter the power distribution network is discussed in general. Then the distribution automation of the power distribution network is presented in this chapter. Finally, the NCC is discussed and common IT (Information Technology) system used in NCC.

1.1 Power distribution network

The aim in the electric power system is to transfer energy in high efficiency. Because of the heat losses in the network, the power losses are smaller when using higher voltages. In Finland, typical voltages in the transmission network are 400 kV, 220 kV and 110 kV. In the distribution network typical voltage level is 20 kV and in low voltage networks typical voltage level is 400 V. [3, 4]

The power distribution network consists of various parts: primary substations, feeders, switching substations, distribution substations and LV (Low voltage) networks. [3, 5] Primary substations have primary transformers which transfer the electricity from the transmission voltage level to the distribution voltage level. In addition, primary substations have usually switching gear, fault indicators and measurement equipment that are connected to the NCC. In Finland, the typical voltage levels in primary substations are 110 kV on the primary side of the transformer and 20 kV on the secondary side of the transformer. [1, 3]

Feeders are lines that begin from primary substations and transfer the electricity to distribution substations or to customers that are connected to the MV (Medium voltage) network. Distribution transformers are located on the distribution substations where the distribution voltage is transferred to the low voltage. Low voltage feeders are typically connected to the low voltage busbar through fuses and low voltage feeders transfer the electricity to the customers. [3]

Distribution networks are usually built with meshed design, but they are used as radial. This means that there is more than one way that energy can be transferred and when fault happens in the network, the other lines can be used when the faulted part is isolated from the network. This way the customers do not experience as much outage time compared to the situation when there is only on path that energy can be transferred. In some rural areas, distribution networks can be built as a radial form. Then there is only one path that energy can be transferred and outage times can be longer with customers in areas where the network is built as radial. Low voltage networks are more often built in radial form but especially in urban areas they are built in meshed design. LV networks are also used in radial form. [1, 3]

Figure 1 below presents transformers, switching gear and feeders that are called primary process of the power electricity network. Primary components are active part of the network that distribute the electricity to the customers. [1]

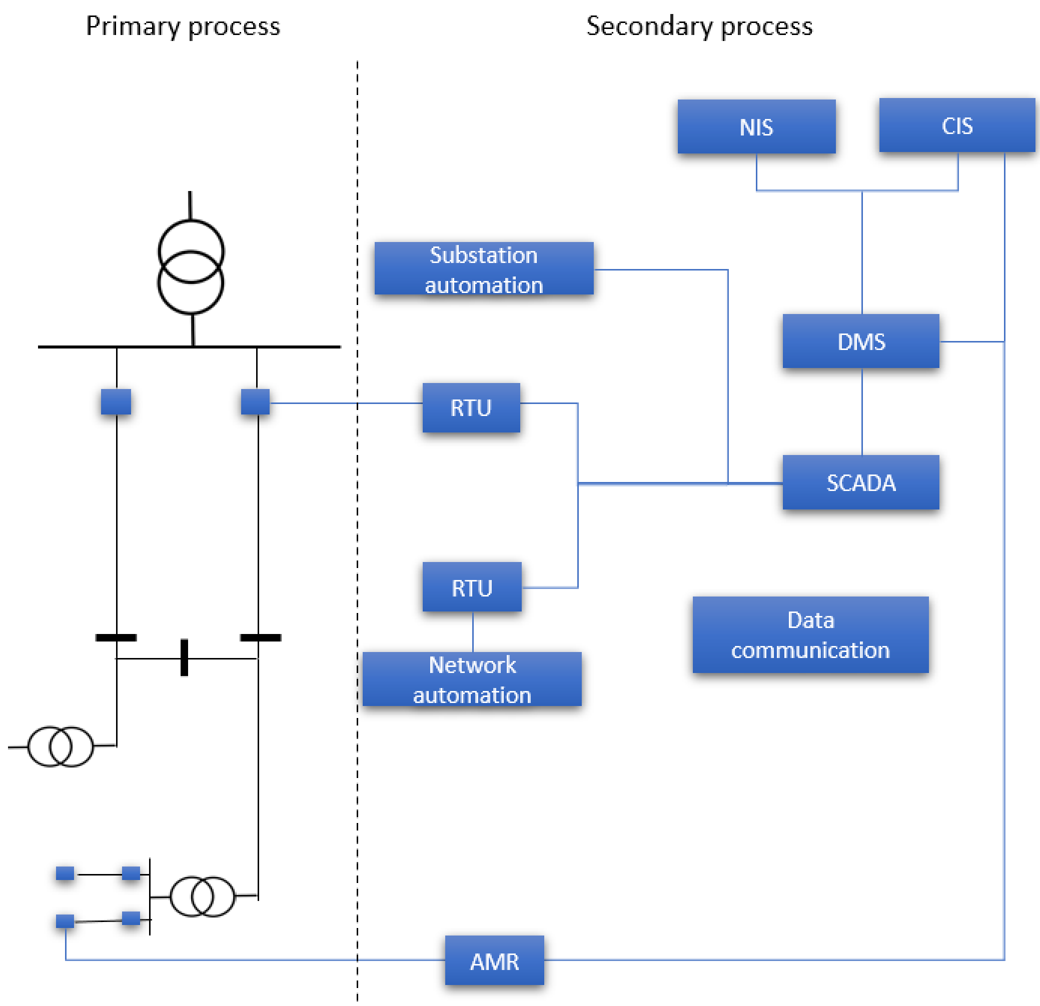

Figure 1. *Power distribution system with primary and secondary process. Adapted from [2, 5].*

In addition to primary components, Figure 1 presents the secondary process of the power electricity network. The secondary process includes the equipment and systems that are used to monitor and control the primary process, e.g. the distribution of the electricity. Common secondary process components are fault detectors, protection relays and other controllers that monitor the distribution process. These components are presented as network automation in Figure 1. The common term to describe the equipment of the secondary process is IED (Intelligent Electronic Device). [1]

1.2 Distribution automation process

Automatic functions that belong to the power distribution process are called distribution automation, e.g. control, usage and supervision in power distribution network. Distribution automation is used for example implement control functions and transfer status information and alarms. [2]

With distribution automation it is possible to save costs because automation improves usability and utilization rate. In addition, automation improves the reliability of the distribution network. [1, 2]

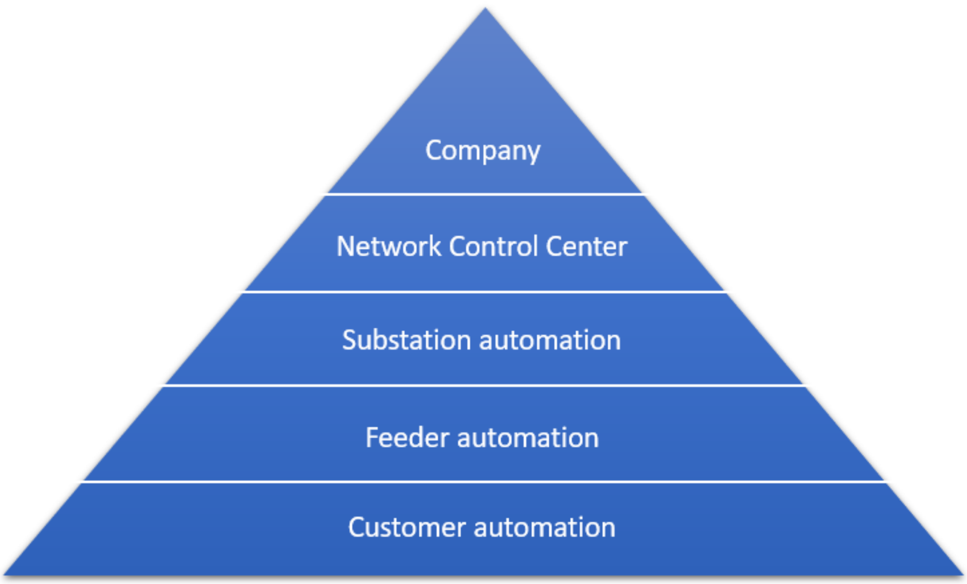

Figure 2. *Layers of distribution automation. Adapted from [2, 6].*

Figure 2 shows the different layers of distribution automation. Planning-layer describes the planning of the distribution network. For example, NIS is a system used in that layer. Operation and control -level includes the equipment in the NCC. DMS and SCADA (Supervisory Control and Data Acquisition) are the most important systems in this layer.

Substation automation includes the automation functions in the substation. Measurement and protection functions are typical applications in the layer. Functions between substation and customer automation are part of feeder automation. Automation functions along the feeders such as fault detectors and remote switches are typical applications in this layer. Bottom layer of the Figure 2 presents customer automation. Customer automation includes applications such as AMR (Automatic Meter Reading) and load control and management. [2, 5, 6]

Communication technologies are important part of the distribution automation. Communication is needed between the different layers of distribution automation and inside the layer, e.g. communication between DMS and SCADA system is a function in a layer of NCC.

1.3 Network Control Center

Power distribution network is operated by DSO (Distribution System Operator) in the NCC. NCC is equipped with various IT-systems used to operate the power distribution network. The main systems in NCC are SCADA, DMS, NIS and CIS systems which are presented in the chapters 1.3.1-1.3.5. Control and operating functions together with fault management are considered as the main tasks in the NCC [1]. In addition, maintenance planning and management, switching planning and customer related functions like support functions are important functions of the NCC [1].

The functions of the NCC stand out in situations when the state of the network is not stable. It is important that NCC and its IT systems will work during these situations because the fault management is managed in NCC. Due that some NCC IT-systems are equipped with UPS (Uninterruptible Power Supply) systems. In addition, many of the IT-systems e.g. SCADA and DMS have HSB (Hot Stand-By) functionality which means that there are another system that runs alongside the main system. When the operation of the main system gets interrupted, the other system takes over the primary system and the operation of the system can continue as normal.

1.3.1 Supervisory Control and Data Acquisition

Supervisory Control and Data Acquisition system is one of the main IT-systems in NCC. It is used to a real time control and monitor of the distribution network. SCADA system give real time information of the distribution process to DSO and DSO can operate the distribution process through SCADA. [1]. The main tasks of the SCADA system are:

- event data management

- network state management
- remote control
- remote measurements
- remote configuration
- reporting functions [1].

SCADA systems have Graphical User Interface (GUI) that the network can operated efficiently. Communication interfaces receive data from the network primary process and send data and commands to the primary process. Information of the substations and the equipment in substations are stored in the database. In addition, the information of events and measurements are stored to the database. In the center of the SCADA system is mirrored computer system which ensures the operation in disturbance situations. [1, 6]

SCADA system has communication functions to the substation automation and feeder automation through RTUs (Remote Terminal Units). Data that RTUs have collected and sent to SCADA have status information of switching devices, alarm information and voltage and current measurements. [6]

SCADA system monitors the state of the network and it compares measured current and voltage values to normal values and detects if measurements differ from normal values. In addition, SCADA system detects the change in switches and protection relays. An alarm can be raised when critical event happens so DSO can notice them quickly and can perform needed functions. [1, 6]

1.3.2 Distribution Management System

Distribution Management System is a system that consists of applications that combines the data of other systems such as SCADA, NIS and CIS [6]. The object of the DMS is to give a real-time situation of the distribution network to support DSO in decision making in operation and control functions [1, 6]. The structure of the DMS is illustrated in Figure 3.

DMS is composed of advanced logic and analysis functions. The main application functions in the DMS are network state monitoring, fault management and operation planning. State monitoring includes applications for real-time power flow and fault current calculations which are used in analysis of the state of the network. Fault management functions are composed of fault location, network restoration, event analysis and reporting functions. Voltage level optimization, switching state optimization and outage management are functions for operation planning. [1, 6]

Customer support functions can be included in DMS system. TAM (Telephone Answering Machine) and SMS (Short Message Service) integrations are common features in DMS. [1, 6] In addition, real-time outage information and service rate can be shown on a web site.

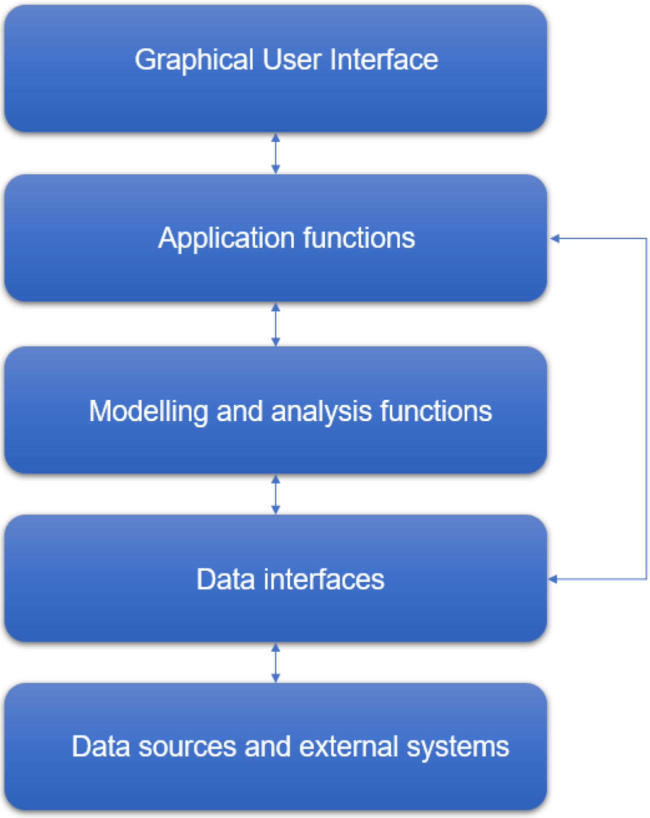

Figure 3. *The main components of the Distribution Management System. Modified from [1, 5, 6].*

The bottom layer in Figure 3 presents connections to other systems like SCADA, NIS and customer information and support functions, e.g. CIS and TAM. In addition, background maps, load models and weather information are utilized as data sources in DMS. Data interfaces connect external systems and data sources to the DMS modelling and analysis functions and application functions. Modelling and analysis functions, e.g. topological model of the network and power flow and state estimation calculations, are source data for upper-level application functions in the DMS. Application functions include applications for state estimation, fault management and operation planning. The top layer indicates the GUI for the DMS software by which user can use the applications and functions. [1, 5, 6]

Unlike in SCADA, both MV- and LV-networks are usually documented in the DMS. In addition, the data of the components can be modelled in more detail because electrical values of the components influence on calculations made in the DMS.

Networks can be presented in geographical view where the network is drawn with background maps. In addition, schematic view for the network is available in some distribution management systems.

1.3.3 Network Information System

Network Information System is a system used to manage network data. NIS is a computer system that have GUI, which is used to operate the system, and a database where the network data is stored. The main functions for NIS are data maintaining and updating, network planning and monitoring calculations. [5]

The network data stored in NIS have detailed data of the components in the network. Figure 4 shows an example of stored data for component from ABB MicroSCADA X DMS600 Network Editor. The data of the MV line have electrotechnical values which are used in network calculations. In addition, other data like installation year and owner information can be documented for the components. The data of the network components can have the geographical location so that the network can be shown in a geographic location in GUI on the map background. The network data documented on NIS can be considered as a base data for network models used in network calculations functions [1].

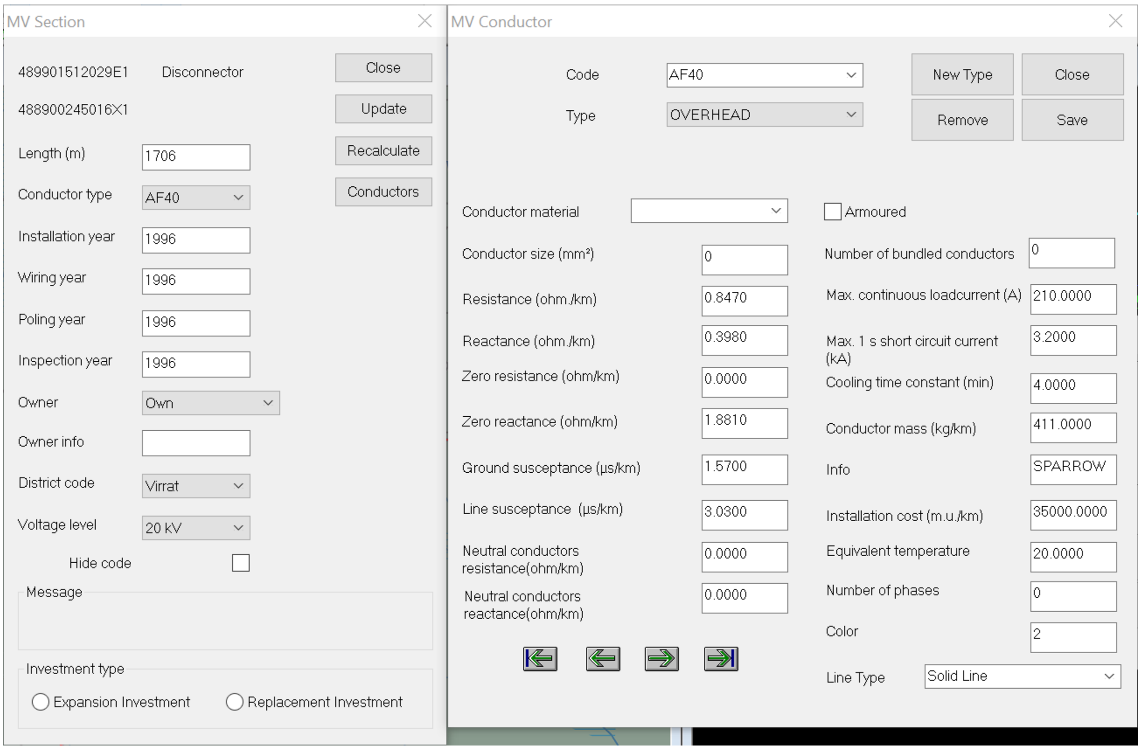

Figure 4. *The data form of MV line in MicroSCADA X DMS600 NE.*

Other terms used for similar systems are AM/FM/GIS (Automated Mapping/Facilities Management/Geographic Information System).

1.3.4 Geographical Information System

Geographical information system is a computer system to manage spatial and geographic data. A GIS can store various types of geographical information. Common geographic layers that are managed in GIS are different networks, e.g. road networks, water networks and power distribution networks. In addition, land survey specific management and various other industry management can be managed in GIS. [7, 8]

From the aspect of the power distribution networks, features of GIS are close to NIS. GIS is used to document and maintain the detailed network data in a geographical location. GIS have variety of analysis, planning and data management features for geographical and spatial data. [7, 8] However, GIS does not have as advanced features for the distribution power networks than NIS.

1.3.5 Customer Information System

Customer information system includes customer data of the customer that are distributed by the power distribution network. CIS database has information of the customers and data of their energy consumption. [1, 5] Consumption data can be imported to DMS system and that data is used provide source data for load flow calculations is DMS software. The implementation of the data exchange from CIS to DMS is usually done through NIS [9]. In addition, customer information in DMS software can be used in outage reporting features. The main functions of the CIS are billing functions and maintaining customer information of the distribution company [5].

2. MICROSCADA X

Hitachi ABB Power Grids’ MicroSCADA X product family offers control and automation solutions for industry, power utilities, infrastructure, transportation and renewables. MicroSCADA X product family has the following offering:

- MicroSCADA X SDM600 (System Data Manager)
- MicroSCADA X SYS600
- MicroSCADA X DMS600 (Distribution Management System)
- MicroSCADA X SYS600C
- MicroSCADA X Historian [10]

MicroSCADA X SYS600 is a SCADA system for distribution networks and transmission. MicroSCADA X SYS600C is a modular and scalable automation system that can be customized for various applications. [11]

MicroSCADA X SDM600 is a software system which has functionalities for data and cybersecurity management for communication networks of the distribution network. In addition, it offers functions for maintenance and service of the equipment in the network. [12] MicroSCADA X Historian collects data from the distribution network and helps the user to process and analyze the data of the primary process of distribution automation. [13]

MicroSCADA X DMS600 Distribution Management System has two main applications, MicroSCADA X DMS600 Network Editor (NE) and MicroSCADA X DMS600 Workstation (WS). Due this thesis topic focuses on MicroSCADA X DMS600 system, it is presented more carefully next in this chapter.

2.1 MicroSCADA X DMS600

As mentioned before, the main applications of MicroSCADA X DMS600 system are MicroSCADA X DMS600 Network Editor and MicroSCADA X DMS600 Workstation. The main function of DMS600 NE is modelling the topological network model onto the network database. DMS600 WS is an DMS application which is used to operate and monitor MV and LV distribution networks. [14]

In addition to these two main applications, DMS600 system has background applications: DMS600 Service Framework, DMS600 Server Application (SA) and DMS600 Socket

Service. Relational databases are used to store data. Figure 5 illustrates system structure of the DMS600 system.

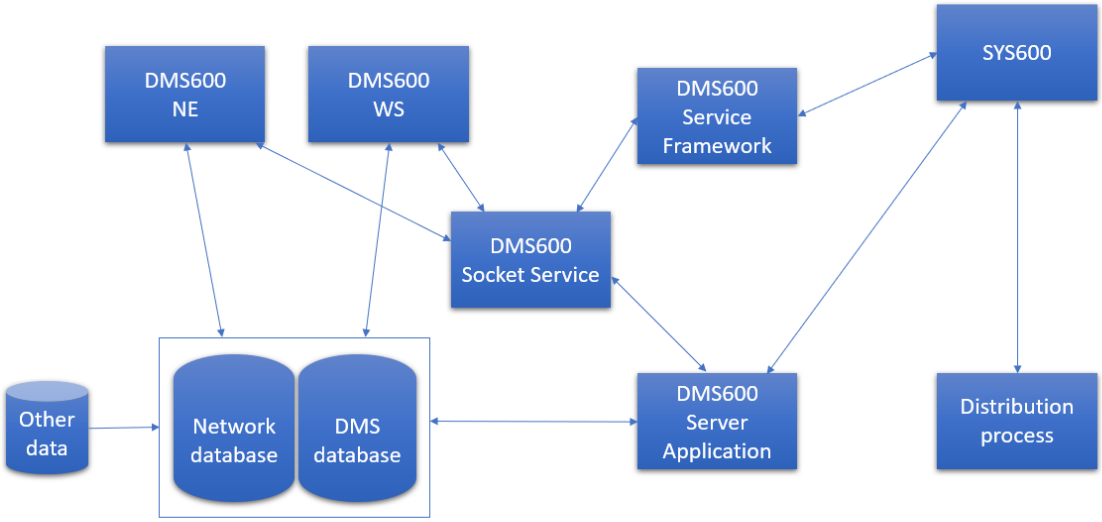

Figure 5. *System structure and communication in DMS600 system.*

DMS600 system communicates with SYS600 system through DMS600 Service Framework using OPC (OLE for Process Control) interfaces or through DMS600 SA using SCIL-API (Supervisory Control Implementation Language) and Support System Interface (SSI). In some functions OPC and SCIL-API can be used as parallel. It is possible to use DMS600 system without SCADA system or also other SCADA systems than SYS600. In this case, OPC interface is used in communication between DMS600 system and SCADA system. [14] If OPC interface cannot be used with SCADA system, SYS600 is needed between DMS600 and external SCADA software to establish communication features. [14, 15]

In addition to communication functions between SYS600 and DMS600, the other main function of DMS600 SA is communication between DMS600 software instances. DMS600 SA manages switching state, measurements and alarms from SYS600 to DMS600 WS. Furthermore, DMS600 SA handles information of a new fault and manages fault location information from SYS600. Managing fault isolation and restoration and managing the position data of fault detectors in SYS600 are functions of DMS600 SA. [14, 16]

DMS600 Service Framework is a Windows background service, which consist of different modules depending on features that are installed in the DMS600 system. Typical modules that are installed are Fault Service, Outage Info Sender, Topo Component and

External OPC-DA Client. Fault Service creates fault packages to DMS600 system. Outage Info Sender is a module that makes an XML-file of network outages including outage data, outage reports and unsupplied customer or send the outage data via Web Service. Topo Component handles the topology and switching state changes in the network. This topological model is used by other DMS600 Service Framework modules. External OPC-DA Client offers the communication module between DMS600 and SCADA system if OPC communication is used. DMS600 SA, DMS600 Service Framework is managed in DMS600 Service Monitor. DMS600 Service Framework can be configured as Free, CSB (Cold-Stand-By) or HSB. HSB mode ensures the operation of the DMS600 Service Framework when one of the computers where DMS600 Service Framework is installed becomes unavailable. [14, 16]

DMS600 system has two databases: Network database and DMS600 database. Network database includes static network data e.g. data of network components and DMS600 have data of DMS monitor and operating functionalities. Other data in Figure 5 illustrates connections between DMS600 and other IT-systems, e.g. CIS, background maps and external NIS or GIS.

DMS600 system runs in Microsoft Windows Server operating systems or Microsoft Windows workstation operating systems and supported database systems for DMS600 are Microsoft SQL (Structured Query Language) Server and Oracle.

DMS600 Socket Service handles DMS600 system internal communication via TCP/IP (Transmission Control Protocol/Internet Protocol) protocol. It is an independent application which runs in DMS600 system.

In addition, DMS600 system can be used with external NIS or GIS. The Network data is imported to the DMS600 system with Network Import Tool application which can be integrated to DMS600 Service Framework or run independently.

2.1.1 MicroSCADA X DMS600 Network Editor

MicroSCADA X DMS600 Network Editor is one of the main applications of DMS600 system. DMS600 NE is used to manage the network model and common settings of DMS600 system. In addition, other administrative tasks e.g. management of integration of DMS600 and SYS600 are done in Network Editor. [16]

The network model of the DMS600 system is saved to the database. The network model is typically geographical but DMS600 system supports also schematic network models. However, DMS600 WS and DMS600 SA use binary network data file, Network.dat, in the network modelling. The binary network data file is managed from DMS600 NE. The user updates the binary network data file when the network data has changed so other DMS600 applications get the updated network model in use. In addition, it is possible to make temporary changes to the network model in DMS600 system. These are done also in DMS600 NE and temporary network data is saved to temporary network data file Tempnet.dat. DMS600 applications combine the binary network data file and temporary network data file to model the distribution network. Figure 6 below illustrates how DMS600 system uses the binary network model file and temporary network model file.

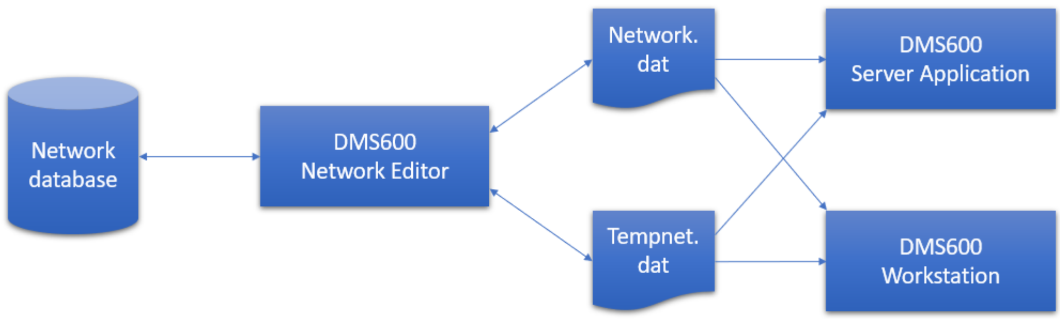

Figure 6. *DMS600 system binary network model. Adapted from [14].*

The network data model can be maintained and managed in DMS with DMS600 NE or it can be imported to the network database of DMS600 system from other vendors NIS or GIS system. After the network data model has changed, user needs to update the binary network data that DMS600 applications can use updated network data model.

The binary network data file consists of the data of the MV distribution network. When DMS applications use the LV network data, needed LV networks are loaded to the memory of DMS600 application from the network database.

2.1.2 MicroSCADA X DMS600 Workstation

DMS600 Workstation is a DMS application which is used to monitor and operate the distribution MV and LV networks. DMS600 WS utilizes the binary network model managed by DMS600 NE. [14, 16] GUI of the DMS600 WS is presented in Figure 7.

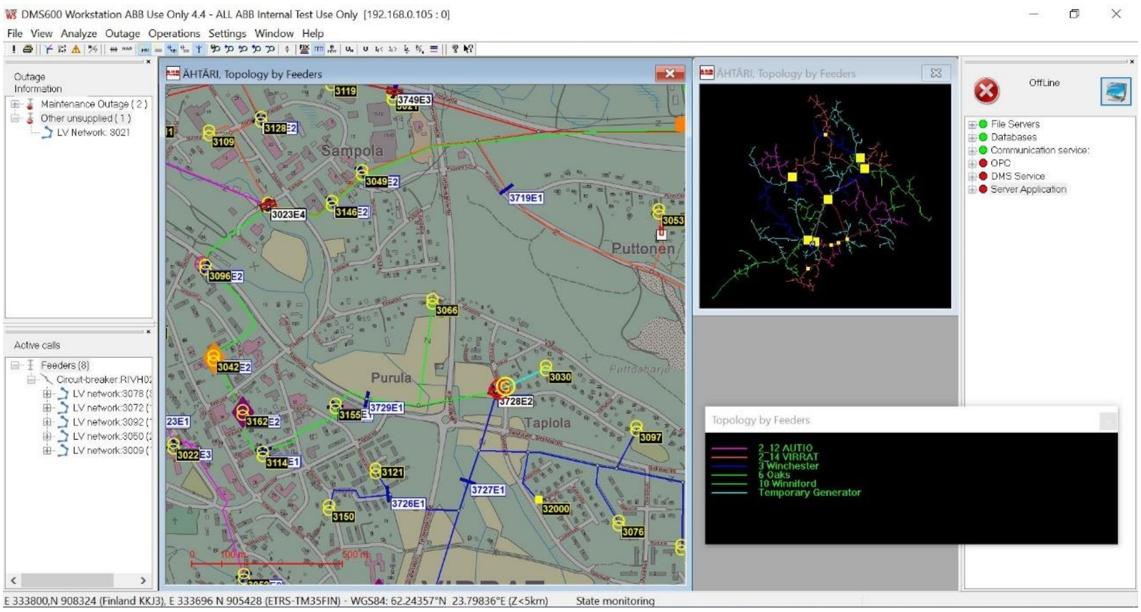

Figure 7. *GUI of DMS600 WS.*

As seen from Figure 7 DMS600 WS presents the distribution network in a geographical view with background maps. DMS600 system supports also schematic view where the distribution network has more simple structure. In addition, measurements and remote switching state monitoring and control is utilized in DMS600 WS if SCADA connection is established. It is possible also open SYS600 station diagram pictures from DMS600 WS if they are linked to SYS600 system [14, 16].

DMS600 WS has multiple functions that help to operate and monitor the distribution network. Network analysis with power flow calculations and fault current calculations advice the user from the current state of the network. Fault location and restoration functions locate the fault in the distribution network and help user in the restoration process. DMS600 WS includes switching planning functions with automatic switching sequence creation or alternatively manual switching sequence can be made. Load estimation estimates the load of the distribution network. Field crew seen in geographical view and can be managed from DMS600 WS. In addition, outage management functions and simulations of the distribution network are main functions of DMS600 WS. [16]

3. NETWORK DATA IMPORTS IN MICROSCADA X DMS600

Network data import is utilized in DMS600 system when the network data is not maintained and managed in DMS600 Network Editor but in external NIS or GIS. Network data import makes possible that the network data in DMS600 system is up to date without manual drawings made in DMS600 NE.

Network data imports in DMS600 system can be utilized with various ways depending on the customer needs for the DMS600 system. In addition, customers NIS or GIS system and the network data export options sets conditions for the network data format that is imported to the DMS600 system. This chapter presents different system architectures that are used in DMS600 systems if the network data is imported from external NIS or GIS system. Also, different network data import implementations and network data formats are presented in this chapter.

3.1 DMS600 network model

The network model of the DMS600 system contains information about the components and line sections of the power distribution network. In addition, topological connections and geographical coordinates are included in the network model of the DMS600. The network model in DMS600 can contain only MV network or both MV and LV networks. The network model is stored and maintained in a database. However, DMS600 NE, DMS600 WS and DMS600 SA use a binary network model which is a DAT file which is made by DMS600 NE. In addition, there is a temporary network function in DMS600 which allows user to do temporary network changes. These changes are saved differently to the database than the original network model. [16]

When the network model is imported to the DMS600 system, many sources of the network data is utilized. Figure 8 shows the different sources which are used in DMS600 network model when network data import is utilized.

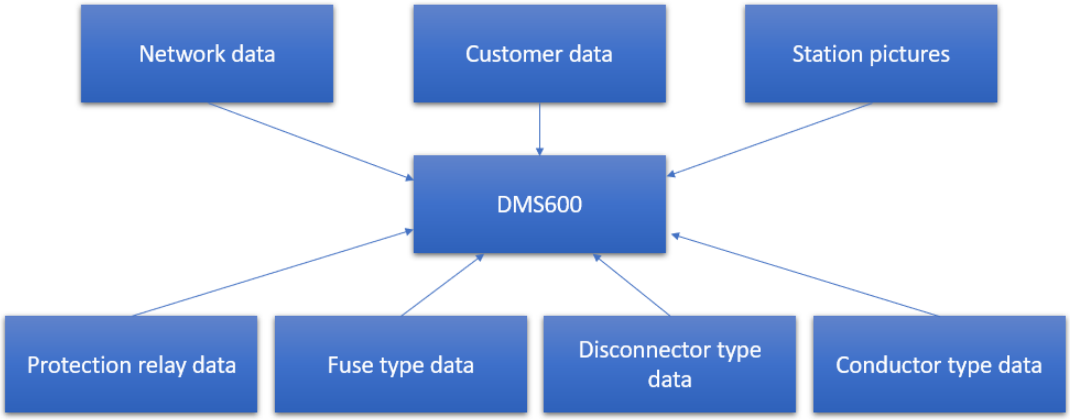

Figure 8. *DMS600 network model data sources.*

The topological network data and information of the components in the network are imported from external NIS or GIS system. The network data is exported from NIS or GIS and then imported to the DMS600 system using network data import functionalities in DMS600 system depending on the used network data file format.

In addition to the network component data, other sources of the network data can be used. Conductor type data, fuse type data, disconnector type data and protection relay data can be imported from lists or catalogues. This can be a part of the network data import or this can be an independent function which is imported to the DMS600 database when needed.

Customer data can be imported to the DMS600 system. External NIS or GIS system usually does not have the information of the customers, so customer data is imported from the CIS. The customer data can be imported to the DMS600 database using database import features or DMS600 built in functionality. In addition, if load curves are utilized for the customer load calculations, load curve data is needed to import into DMS600 system.

It is possible to import station pictures to the DMS600 system from MicroSCADA SYS600 if the COM interface between DMS600 and SYS600 is established. The station pictures are imported to the database of the DMS600 and then it is possible to open SYS600 station pictures from DMS600 background map. [16] However, when station pictures are imported from SYS600, station pictures cannot be imported from network data files exported from NIS or GIS system. This needs custom engineering in network data import application.

3.2 Network data import implementation

Network data imports in DMS600 system are done with Network import tool. It can be a Windows executable which is launched by user and run the network data import to the DMS600 network database manually. Network import tool can be integrated with DMS600 Service Framework when it is possible to import the network data both manually and automatically. Figure 9 below presents the network data import process.

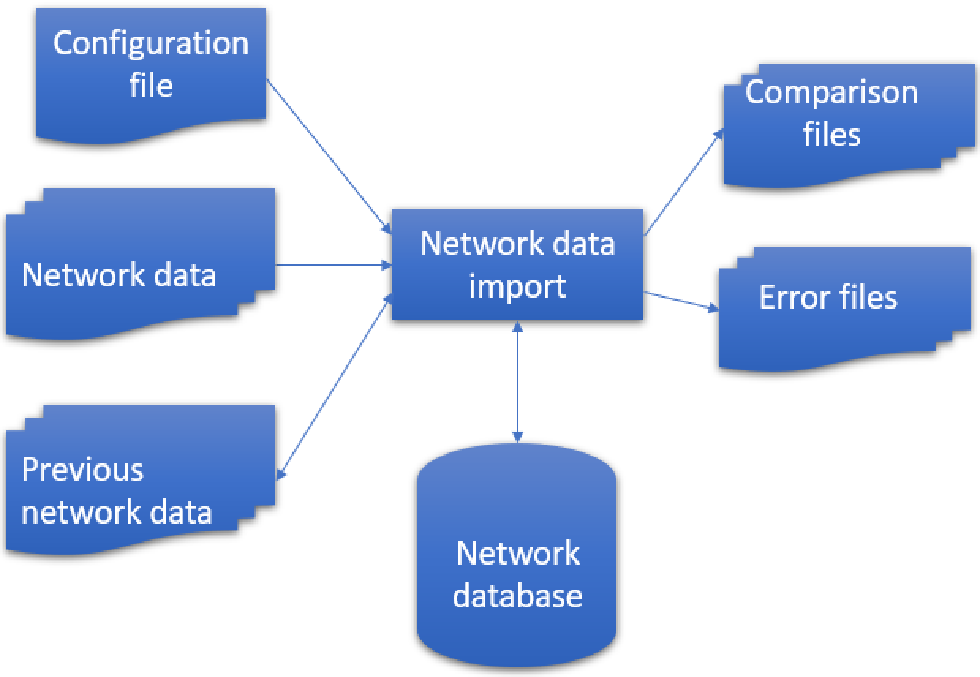

Figure 9. *Network data import in DMS600 system.*

Network data import application, i.e. Network import tool, imports the network data from files that NIS or GIS have exported. The network file format depends on customers NIS or GIS system and therefore usually DMS600 system with external NIS or GIS needs customized network data import application.

Network import tool uses a configuration file, which is in XML (Extensible Markup Language) file format. Configuration file includes general settings of the network data import and file paths to the files that are imported to the DMS600 network database. The settings in the configurations include both file specific and import specific settings. For example, shapefile import configuration file has file specific mapping settings, e.g. which values of the file are imported. Examples from import specific settings are network type (MV or LV network or both) and network data type (shapefile, CIM, etc.).

Network import tool analyses the network model which is built during the network data import and writes found errors and warnings to the CSV-files. In addition, it is possible to write errors and warnings to the database and they can be viewed in geographical view in DMS600 NE or DMS600 WS. Analysis of the network data is presented and discussed more careful in chapter 5 in this thesis.

Network data import application can generate comparison files which include changes in the network data in CSV-files. Comparison function uses current and previous network data files that network data import application is utilizing. Comparison files give useful information to the user about changed parts of the network since last network data import.

Network data import application consists of different phases which are file reading, network model building, network data analysis and network data import. First, the network data files are read by the network import tool and saved to the memory. After the read phase is complete, the network import tool application builds the network model based on the data that is read from the network data files. In addition, network analysis functions by network data import application have been completed at the same time. Finally, when the network model is built, the network model is imported to the database of the DMS600 system. If the comparison function is used in the network import application, the comparison module compares current network data and previous network data before the import phase. The comparison files and result files are saved to the CSV-files before the import phase of the application.

Traditional way in to import network data to the DMS600 system is a function which is integrated to the DMS600 NE. The network data is read from the specific CSV-files where MV network is in one file and LV networks are in separate files. The network data is not saved in this case to the database of the DMS600 but straight to the binary network files used by the DMS600 NE, DMS600 WS and DMS600 SA. LV networks are only loaded to the memory when they are utilized by each DMS600 program.

Compared the traditional network data import where network data is not stored to the network database of the DMS600 system with the network data import application which stores the network data to the network database of the DMS600 system has many advantages. When the network data is stored to the database, the network data can be utilized more efficiently by different applications which need network data, e.g. DMS Service Framework applications for outage management and reporting functions. In addition, specific version of DMS600 NE is needed if integrated import function is in use.

3.2.1 Bulk import

Bulk import in network data import application is a network data import practice where the data of the whole network is read and imported from the network files. The network data import application reads the whole network and before import phase starts, the current network model in the DMS600 network database is removed by the deleting scripts.

Bulk import function is a straightforward way to import the network data from the network data files to the network database of the DMS600 system. Figure 10 below illustrates the phases of the bulk network data import.

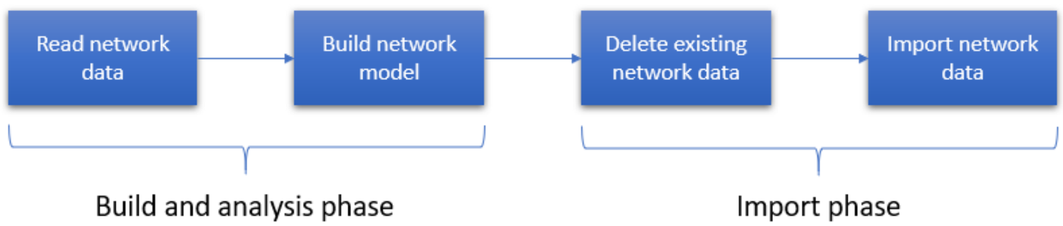

Figure 10. *Phases of the bulk network data import.*

The bulk network data consists of the phases presented in Figure 10. Build and analysis phase of the bulk network data import application include read phase of the network data and network model building phase. Behaviour of these phases depends on the used file format of the network data received from NIS or GIS. if CIM files are used as source files, the network data is read entirely before network model building and saved to the memory of the network data import application due the structure of the CIM files. If shapefiles, KML files or CSV files are used then the network data is read and network model is built component by component. Analysis functions of the network data are integrated to the build phase of the network data import application.

The import phase of the network data import application includes deleting phase of the existing network model and importing the new network model. Delete phase of the network model is implemented by using SQL scripts that delete the existing network model from the database of the DMS600 system. When the delete phase is completed, the network model made by the network data import application is inserted to the database of the DSM600 system.

Bulk import for the network data is utilized traditionally in integrations between network data received from NIS or GIS and DMS600 system. It is appropriate approach for the systems where the network data is completely maintained in NIS or GIS systems and no changes in network data is made in DMS600 system. This needs network data engineering from both NIS or GIS and DMS600 side to get the network data in condition that it can be utilized in DMS600 system.

The time required to run the import depends on the size of the network as well the file format used in the import. Bulk import approach for the network data can be seen ineffective in networks when there are no changes in the network data, or the changes are minor compared to the previous network data import. In addition, the changes made to the network data in DMS600 database disappears when the bulk network data import is run again. Hence, if the editing of the network model is needed in DMS600, temporary network model is utilized. This approach causes engineering if the imported network data has changes in the area that have been edited in DMS600 system.

3.2.2 Incremental import

Instead of the bulk network data import, the other way to import the network data to the DMS600 system is incremental network data import. Instead of that network data is imported completely by each import, incremental network data import only imports the changes made to the network data after previous network data import. The phases of the incremental network data are presented below in Figure 11.

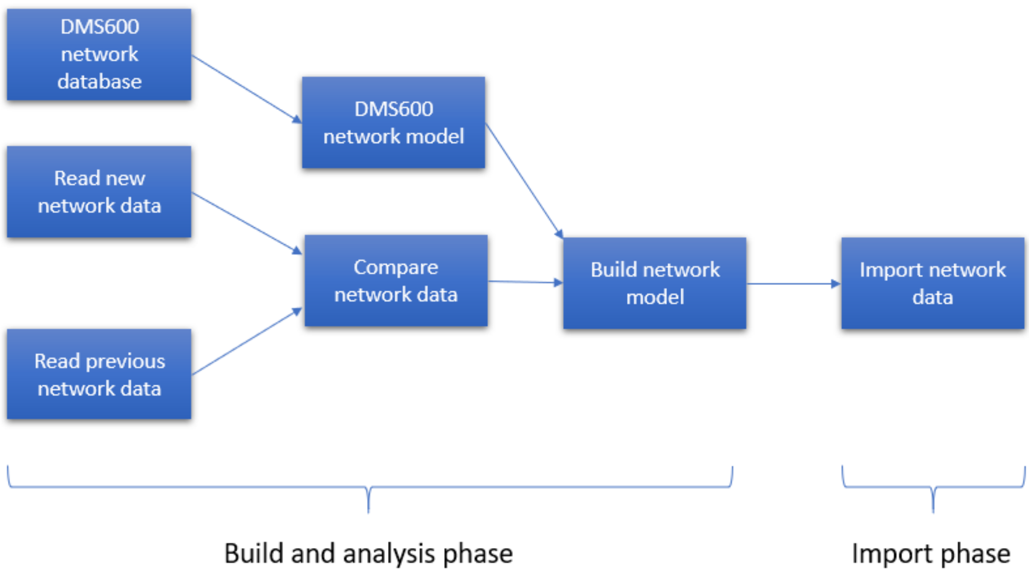

Figure 11. *Phases of the incremental network data import.*

The incremental network data import module starts with build and analysis phase where the new and previous network data is read and compared. The network model is built by the network data import application based on the comparison results and the existing DMS600 network model. Compared to the bulk network data import module, the existing network model of the DMS600 system is required in the incremental network data import module.

The network data import data application compares the new network data and the previous network data and organizes the network data to added, changed and removed component data. The data that has stayed same will be ignored in the incremental network data import. Added network data is imported as in bulk network data import but connections to the existing network model are checked and if connections are found, added components are attached to the existing network model. Changed components are updated if attribute data, e.g. conductor type, have changed. If the topology of the component has changed, connections to the existing network model are checked and attached to the existing network model. Removed components are removed from the existing network model.

After the comparison stage of the previous network data and the new network data, incremental network model is built. The existing network model of the DMS600 system is used with new network data to build incremental network model. First, components that are removed from the new network data are removed from the incremental network model and they are collected into the memory of the network data import application. Then changed components are handled in the network data import. Changed data of the component is found in comparison stage, so in building stage the changed component is searched from the DMS600 network model and will be added to the incremental network model with updated information. Finally added components are handled and added to the incremental network model.

Import phase of the incremental network data import starts with removal of the removed components. Removed components are removed with SQL scripts from the database tables where they exist. Then added and changed components are inserted to the DMS network database. After import is done, imported network data files are copied so comparison in the next network data import can be done.

Advantages of the incremental network data import compared to the bulk import is that incremental network data import takes less time to complete because normally only small part of the network data from previous import has changed. In addition, changes made to the network in DMS600 do not be erased after the import like in bulk import. On the other hand, when the region where changes have been made in DMS600 changes in network data files, it might cause topological errors in the network model, e.g. the connection issues with the network components.

3.3 Network data imports in system level

DMS600 system runs on Microsoft Windows Servers and typically DMS600 system is run on one or two servers simultaneously. If DMS600 is run by two servers, it typically has HSB functionality. The network data import can be done straight to the production system or the network data can be imported first to the PDS (Production Development Server) where the quality of the imported network data can be checked before importing it to the production system.

The network data import module can be integrated to the DMS600 NE, DMS Service Framework or it can be independent executable which is run when needed. If the network import module is integrated to DMS600 NE or DMS Service Framework, also automatic network data import is possible, e.g., network data import is made in every night or once a week in a defined time.

3.3.1 Network data import to DMS600 production system

Network data import can be utilized in DMS600 production system. Traditionally this kind of approach has been utilized in DMS600 system. External NIS or GIS exports the network data to the disk which is available for the DMS600 system. It is also possible that a TCP/IP message or a SOAP message is sent from the DMS600 system to NIS or GIS when new network data is needed. In addition, the network data files can be transferred to the DMS600 system manually but then the up-to-dateness of the network data is on the responsibility of the user of the DMS600 system.

Figure 12 below illustrates the network data flow from NIS or GIS system when the external network data import is an independent executable or integrated to DMS600 Service Framework. External NIS or GIS system exports the network data to the destination where network data import application can read the network data files. Typically, this is a shared disk, where network data export of the NIS or GIS system saves them, and DMS600 network data import can read the files. Functionality of the import process in Figure 12 is discussed in chapter 3.2.

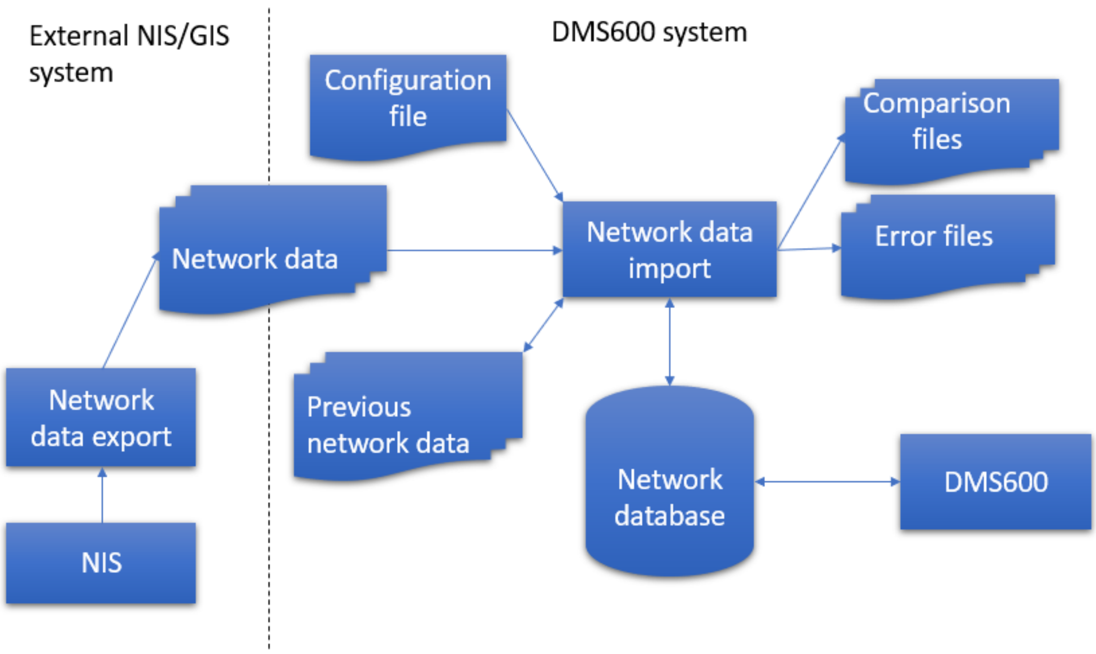

Figure 12. *Network data flow to the DMS600 system.*

If the traditional network data import implementation is utilized in DMS600 system, DMS600 NE reads the MV network data and saves the network model to the binary network file which is used by DMS600 NE, DMS600 WS and DMS600 SA. This kind of approach causes limitations to the utilization of the network data because the network model is not saved to the database of the DMS600 system. For example, some integrations in DMS600 system require that the network model is saved to the DMS600 network database. On the other hand, when the network model is imported by DMS600 NE only to the binary network file, the network import process is efficient. This kind of approach is possible, if the network model is utilized only by DMS600 NE, DMS600 WS and DMS600 SA.

The network data import to the production system can cause malfunctions in the DMS600 system if there are errors in the network data. Functionalities of the DMS software hypothesize that the network model has no errors and calculations and deductions made in the DMS system gives wrong results if the network data has errors.

When the network data is imported to the DMS600 system it is possible to restore the previous network model to the DMS600 if the imported network data has errors. If the network data is imported to the database of the DMS600 system it is possible to restore the database network model to the earlier network model. If the network data is imported by DMS600 NE to the binary network file, the earlier binary network file can be restored. However, these functions are needed to do manually and if the network model in DMS600 system is not examined after import, errors in the network model can exist.

In addition, assumption in this approach of the network data import is that the network data exported by NIS or GIS has no errors on it and possible errors in the network model are fixed in the NIS or GIS before exporting and importing the network files to the DMS.

3.3.2 Import using Production Development Server

Network data import can be utilized in a way that the network data is imported to the Production Development Server (PDS) before importing the network data to the production server. With this kind of approach, the network model can be tested and previewed before it is transferred to the production server. Figure 13 shows the network data flow from external NIS or GIS system to the DMS600 production system.

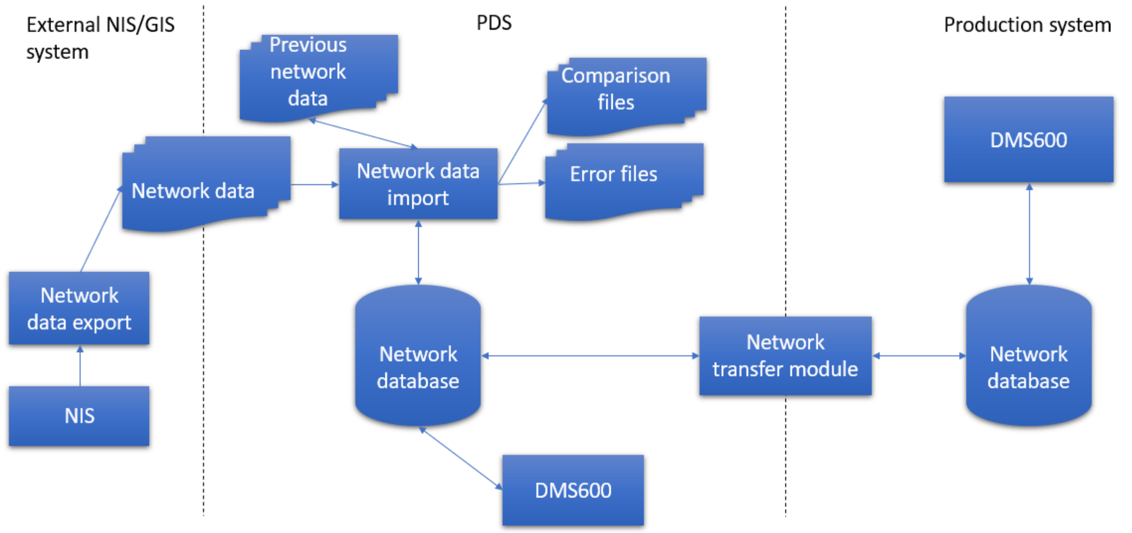

Figure 13. *Network data flow to the DMS600 system when PDS is utilized.*

Figure 13 is similar compared to Figure 12 when the network data is made to the production system. In Figure 13 the network data import is executed in PDS and it is transferred from there to the production system. The network data transfer application transfers the network model from PDS database to production server database incrementally so only changed made from the previous network data transfer is transferred to the production system to avoid the capacity overload of the database.

When PDS is utilized, the network model is built completely in PDS before transferring it to the production system, e.g. station pictures from SCADA and data from catalogues are imported to the PDS. The network model can be tested and modifications to the network model can be made without a fear that it affects on production server. The network model can be transferred to the production system when the network model has no errors. In addition, PDS has DMS600 NE and DMS600 WS installed so the main functionalities of the DMS600 system can be tested in PDS and malfunctions caused by errors in the network data can be noticed before utilizing the network model in production server.

PDS enables a server to test the imported network model between NIS or GIS system and DMS production system. On the other hand, PDS complicates the system structure of the DMS system and needs an extra server to utilize. One possible solution is to utilize the PDS database to the same server than the production server. Then there is no need for an extra server but two databases in production server can cause some problems in DMS600 system functionalities especially when PDS database is used at the same time with production database. This kind of approach has not been utilized, but this might be a one solution to test the imported network data before utilizing it in a production system.

3.4 Supported network data file formats

Network data format used in the network data import depends on the external NIS or GIS and their network data export functionalities. DMS600 system has been utilized with several different external NIS or GIS systems and therefore DMS600 system supports several different file formats to import the network data. DMS600 system supports following network data formats:

- Shapefile
- CIM file
- KML file
- CSV file
- DXF file

Supported file formats are presented next in this chapter and discussed more carefully. The network data formats are different by the structure and features of the network data. The size taken by the network in different file formats vary and topological information of the network depends on the used file format. Even the same file format used by other utilities might differ so that the same import configuration cannot be utilized in different environments. The network data import application needs usually engineering resources when utilizing the new integrations between NIS or GIS and DMS system. Network models in NIS and GIS systems from other vendors are documented in various ways so that has an influence in the network data files.

3.4.1 Shapefile

Shapefile is vector-based file format to present geographic data. The technical description of the shapefile is created and maintained by ESRI (Environmental Systems Research Institute, Inc.) [17].

Shapefile file set consists of several different files where the data is stored. There are three mandatory files for the shapefile file set: a main file (.shp), an index file (.shx) and a dBASE table (.dbf). The main file of the shapefile file set is a direct access file where shape and its vertices are described. The index file has the indexes for each record to the corresponding main file record from the beginning of the main file. The dBASE table have information for each shape record with one record per feature. [17]

In addition, there are other files that can be included to the shapefile file set. Common files that are included in file sets are geospatial data in XML format (.shp.xml) and projection description (.prj) which have information of the coordinate system of the shapefile file set. The file name prefixes must be exactly same for all the files that belong to the same file set. [17]

ESRI Shapefile Technical describes the shapefile shape types which are presented in Table 1. A shape described in shapefiles can be a point, a multi-point, polyline or polygon. The shape types can be in different spaces which is indicated in the last letter of the shape type. If the extra letter does not exist in the shape type it means that the shape type is presented in X, Y space. M in the end of the shape type indicates additional coordinate called measure M. Z as a last letter of the shape type stands indicates that shape type has Z-coordinate besides X- and Y-coordinates. In addition, Z type includes additional M measure. Other supported shape types are null and MultiPatch. Null is a shape type which has no geometric data and MultiPatch consists of multiple surface patches. [17]

Table 1. *Shapefie shape types [17].*

Shape types in X, Y space	Point	MultiPoint	PolyLine	Polygon
Measured shape types in X, Y space	PointM	MultiPointM	PolyLineM	PolygonM
Shape types in X, Y, Z space	PointZ	MultiPointZ	PolylineZ	PolygonZ
Other shape types	Null	MultiPatch		

Figure 14 below illustrates the distribution network part modelled with shape file and with DMS600 network model. Shape network model is viewed with QGIS software on the left side and the DMS600 network model is viewed with DMS600 NE on the right side. In the shapefile format, the network components are in separate layers and in the network data import, the layers are connected to build topological network model in DMS600 system.

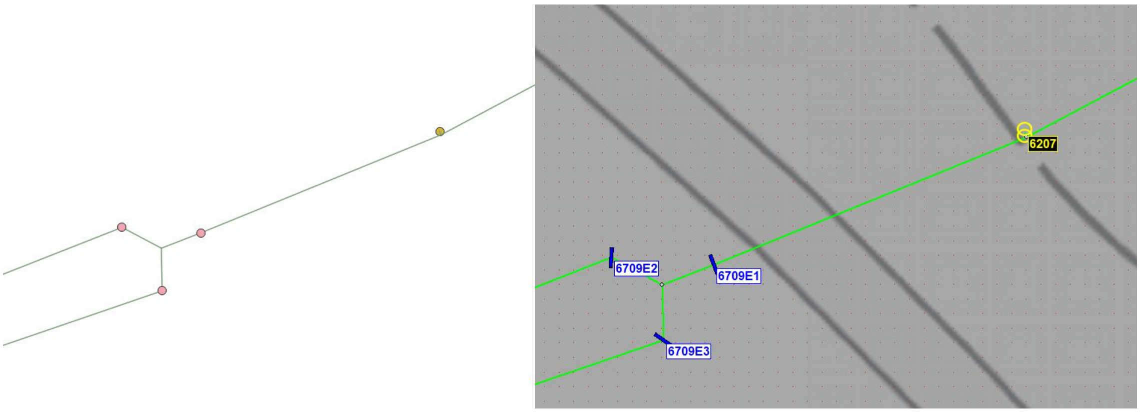

Figure 14. *Shapefile network model opened in QGIS left and same network model opened in DMS600 NE right.*

Shapefile is a common file type used to exchange data from GIS to DMS. ArcGIS is a common GIS for utilities to manage the network data and shapefile is easily exported from the ArcGIS software. The shapefile format does not have topology information of the network, so the connection of the shapes needs to be implemented during the network data import. This can cause problems in areas that have many shape objects close to each other, e.g. line sections that go through the same poles but are not connected topologically. On the other hand, the popularity of the shapefile format in network data exports makes the implementation of the import module efficient due shapefile imports exists on other utilities. In addition, one of the advantages of the shapefile format can be seen that it can be previewed easily with 3rd party application, e.g. QGIS. This helps in engineering process when implementing the network data import from GIS to DMS.

3.4.2 CIM

The Common Information Model (CIM) is a standard developed and maintained by IEC (International Electrotechnical Commission). The standards which are related to the CIM are IEC 61968 Application integration at electric utilities and IEC 61970 Energy management system application program interface, EMS-API (Energy Management System-Application Programming Interface). IEC 61968 standards include definitions for interfaces for maintenance, construction and customer operations for distribution management as well as interfaces for meter reading and control. The CIM network model is presented in standard IEC 61968-11: Common information model (CIM) for distribution. IEC 61970 contains standards for application program interfaces and data exchange in CIM format.

From network model exchange point of view the special standard is IEC 61970-552: CIMXML Model exchange format. [18-20]

CIM network model is defined in standards IEC 61970-301 Common Information model (CIM) base and IEC 61698-11 Common information model (CIM) extensions for distribution. The CIM specification is modelled using UML (Unified Modelling Language) and it is defined using object-oriented modelling techniques. The CIM model consists of classes which presents components in the electricity network such as transformer or circuit breaker and these classes have attributes which include data belonging to the component. CIM classes are generalized from general classes to more specific classes. In Figure 15 is an example of the generalization in the CIM network model. [21, 22]

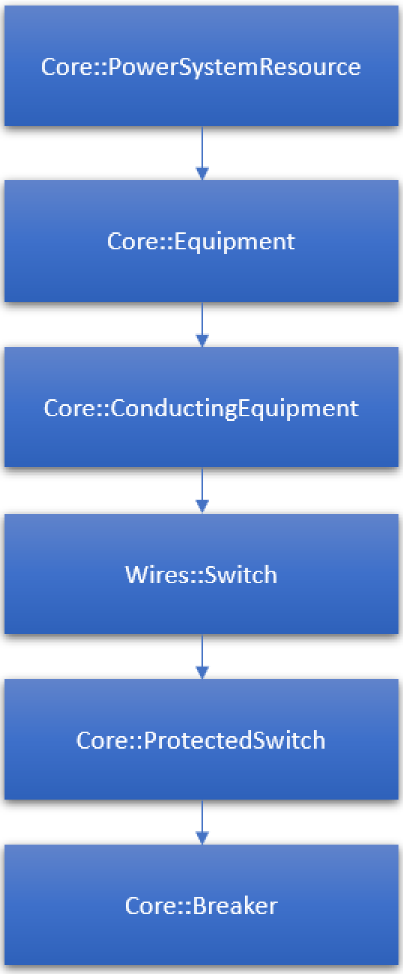

Figure 15. *An example of generalization in CIM network model. Adapted from [21]*

An example of the generalization of the CIM network model in Figure 15 shows that Core::Breaker, which is an actual component, is inherited from multiple more general classes.

Standard IEC 61970-501 describes the file format used in data exchange in the CIM network model. The CIM model is exported from NIS or GIS to XML documents which uses CIM RDF schema. The CIM files follow the XML notation with RDF elements.

The CIM network model includes the topology information of the network. Figure 16 illustrates with an example how the topology is done in the network model in the situation with circuit breaker connected to two line sections. Cim:Breaker and cim:ACLineSegment are the actual components in the network and cim:Terminal and cim:ConnectivityNode describes connections with components. The network component has cim:Terminal and cim:Terminal has cim:ConnectivityNode. If two or more cim:Terminals have the same cim:ConnectivityNodes they are connected to each other.

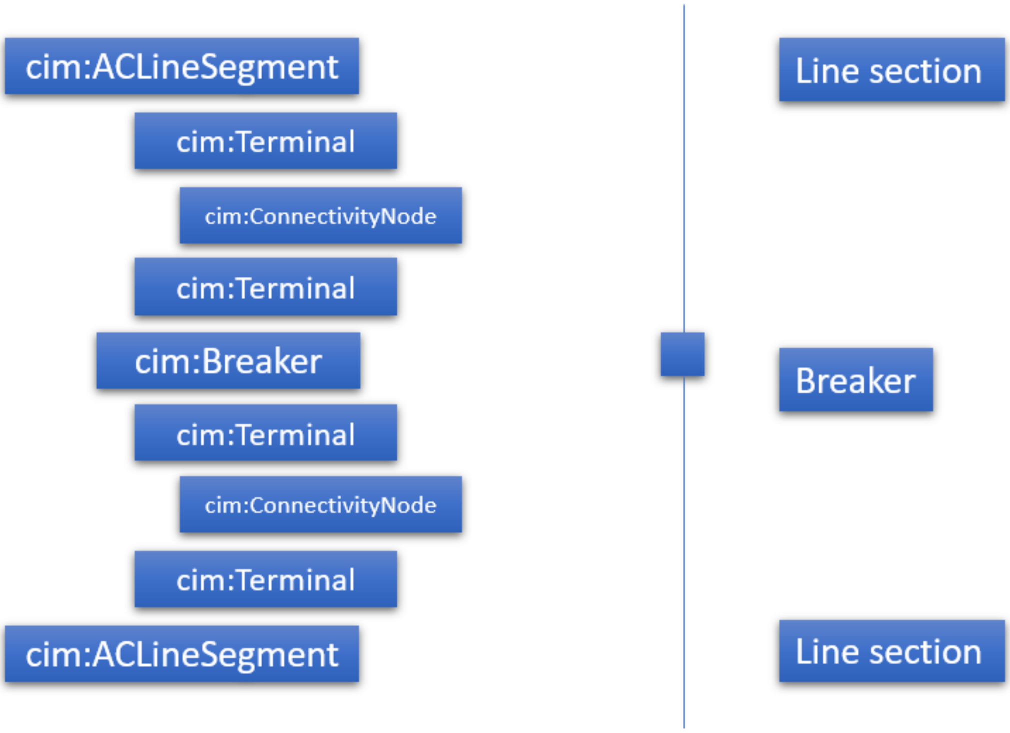

Figure 16. *Topology in the CIM network model.*

The connectivity information is an advantage when importing CIM network model to the DMS600 system as many other network model formats does not have the connectivity information. The network model cannot be exported to the 3rd party software as the file structure depends on the software that have exported it. In addition, engineering is needed when implementing the network data import in new interfaces between different utilities.

3.4.3 CSV file

A text file in a CSV-format is a very common data format to exchange data from a system to another. There is no official specification for the CSV-file structure although it is widely used in the IT systems. The file structure is simple: each row of the file is a data object and attributes of that object is separated by comma or another character. [23, 24] An example of the simple CSV-file is presented in Figure 17 below. It describes a phone book with a first name, a surname and a phone number.

```
First name, Surname, Phone number
Matti, Meikäläinen, +358401234567
Maija, Meikäläinen, +358509876543
Teemu, Teekkari, +358441234567
```

Figure 17. *An example of the structure of the CSV file format.*

For the network data exchange between NIS or GIS and DMS, Hitachi ABB Power Grids has made with NIS suppliers a document which describes the interface when the network data is imported to DMS600 system [25]. The document describes the rules for the file naming and the format of the file structure. The file type is a text file which structure follows the rules of a CSV file format. The file structure consists of rows where attributes are separated by semicolon and every line has to end with semicolon and a line break. [25]

The MV network is exported from NIS or GIS to the file named network.txt. It has all the components and data needed in DMS600 system for the MV network. Components in their geographical location and topological connections for the components are also included in the network.txt. In addition, network.txt supports conductor type data, fuse type data and relay data so they can be imported with the network model. [9, 25]

Figure 18 illustrates one MV line section in CSV file format. MMNS attribute indicates the MV line section and MERP attributes sections points with geographical coordinates. MMNS row include the codes to connect the line to other components as well as conductor type, length and other attributes.

```
mmns;2875124;MM;1613211;2828650;20Sw;61.554490;1;;;;;1;0;0;0;0.000000;0;
merp;643532635;960337700;
merp;643528777;960337410;
```

Figure 18. *Example of MV-line data from CSV file.*

CSV network data import also supports import of the LV networks. A CSV-file contains one LV network, e.g. the part of the network feeded by distribution transformer. The name of the file is the corresponding MV-LV substation. The structure of the file is same as in the MV network file network.txt. [25]

The customer data of the distribution network can be imported to DMS600 system in a file named customer.txt. The document [25] describes the mandatory data that are needed for the customers in the DMS600 system. However, it can also include other data for the customers which can be imported to the database of the DMS600 system. The customer.txt is imported to the database with a SQL procedure [9].

In addition to the network model and customer information described in [25], DMS600 has other CSV-file imports. The fuse type data and conductor type data are usually imported from catalogues and they are typically exported for the DMS600 in CSV-file format. These files are imported to the DMS600 network database using SQL procedures. In addition, protection relay data for the DMS600 can be imported to the database from the CSV files using relay import application or SQL scripts [26]. DMS600 has also function to import free database objects from CSV file to the database of the DMS600 system. A free database object is a component in the network which has geographical location and can be seen in the geographical location alongside the distribution network.

The CSV network data import, e.g import of network.txt and LV network files, is an efficient way to import the network model to DMS600 system. The file structure is designed in a way that the information of the network includes the mandatory information of the components and topological connections in a way that they are easily imported to the DMS600 system. Disadvantages of the CSV network data import are that it cannot be opened with 3rd party applications to preview and if there are errors in the CSV-files, it is not easy to locate them due the CSV-files are needed to check manually to locate the possible error in the file.

3.4.4 KML

KML, officially named OpenGIS® KML Encoding Standard, is a XML based file format to present geographic data. It was created for use with Google Earth, originally named Keyhole Earth Viewer. KML is maintained by the Open Geospatial Consortium, Inc (OGC) and the latest version of the KML standard is 2.3 and it is being retained for compatibility to earlier versions of the standard. KML can be presented in KML files but also KMZ files exist. KMZ files consist of zipped KML files and in large file sets it is useful to use KMZ files instead of KML files. [27, 28]

Hence, KML follows the XML notation, KML file consists of XML fields, which include the data that are saved to the KML format. An example of a simple KML file which have one placemark and geographic location to that point is presented below in Figure 19.

```
<?xml version="1.0" encoding="UTF-8"?>
<kml xmlns="http://www.opengis.net/kml/2.2">
  <Placemark>
    <name>Simple placemark</name>
    <description>Attached to the ground. Intelligently places itself
       at the height of the underlying terrain.</description>
    <Point>
      <coordinates>-122.0822035425683,37.42228990140251,0</coordinates>
    </Point>
  </Placemark>
</kml>
```

Figure 19. *Example of KML file format. [29]*

The KML file presented in Figure 19 starts with the XML header row which tells the XML version and encoding of the file. Then KML namespace declaration which is closed in the end of the file. Between the KML fields is the actual geographic data which consists of the Placemark object and it has name for the Placemark as well as Description and coordinates inside the Point object. The coordinates of the Point have latitude, longitude and height.

In addition to Placemark objects, KML standard has other data types as well. LineString elements are used to create Path objects which have multiple coordinates separated by a whitespace. Other commonly used object is Polygon. Polygons are created by Linear-Ring elements which have coordinates for every corner of the polygon separated by a whitespace.

Power distribution networks presented in KML file format consists of Placemark objects which present the components and Path objects which present the lines of the networks. KML standard does not have any fields for the electrical data of the components so custom fields are needed to use if electrical data of the components is needed to import with KML files. In addition, the connectivity of the components is not defined in the standard, so connectivity tolerance is needed to use in network data import process. This can cause problems in the import process if there are many network components close to each other.

As an XML based notation, KML files are easy to parse and there are 3rd party applications that can preview the KML files which is useful in engineering phase when the network is imported to the database of the DMS system.

3.4.5 DXF

DXF file is a file format developed by Autodesk, Inc. to exchange data between CAD (Computer-aided design) programs and between CAD program and other programs. DXF file format is a vector-based file format to save graphical data. [30-32]

The DXF file consists of different sections which are listed in a list below:

- DXF HEADER
- DXF CLASSES
- DXF TABLES
- DXF BLOCKS
- DXF ENTITIES
- DXF OBJECTS
- DXF THUMBNAILIMAGE [32]

DXF HEADER includes the information of the settings of a variable saved in the file. DXF CLASSES section in a DXF file have the information of the classes that appear in the DXF BLOCKS, DXF ENTITIES and DXF OBJECTS sections. DXF TABLES section contains tables which can contain a variable number of entries and DXF BLOCK contains an entry for each block in the file. DXF ENTITIES has data of the graphical objects and DXF OBJECTS information of non-graphical objects. DXF THUMBNAILIMAGE is optional section, and it exists only if a preview image has been saved with a file. [32]

For the distribution network, an important part of the file is DXF ENTITIES hence it has the information of the geographic objects. However, DXF does not have the information of the coordinate systems so the scale and coordinates for the network have to be implemented during the network data import. In addition, DXF file does not have topological connections between components so the topology of the network is deduced in the network data import [30, 31].

The DXF network data import in DMS600 system is an application which can be launched from DMS600 NE. The data that are imported to DMS600 need to include at least line data. In addition, component data can be included in DXF files. [31] When the network model is imported to the DMS600 system, it is manually edited to add missing components and connections to get a working network model for DMS600 system.

The DXF tool also have possibility to export the DMS network model to the SQL database tables. In addition, incremental data import features have been implemented to the DXF network data import.

4. NETWORK DATA ANALYSIS

The objective of the network data analysis is to find errors from the network model. The errors in the DMS network model will affect to the functionalities of the system. DMS network calculations utilise the electrotechnical values of the components, so missing electrotechnical data causes errors in the system. The topological connections of the network model are required to be in order due differences in the network model topology compared to the real distribution network will cause errors in the functionalities of DMS.

The analysis of the network data is done in several ways in the DMS600 system. DMS600 NE and WS has network data analysis functions. However, when the network data import from external NIS or GIS is utilized, the errors in the network model are needed to find out before network model is imported to the DMS600 system, especially if the network data is imported to the production system and not to the PDS system. The errors that will affect on the topology of the network model or calculation functions of the DMS600 system are needed to collect and show to the user of the system. Then the missing data and errors can be fixed in GIS or NIS and the network data can be imported with corrected data to the DMS600 system.

4.1 Need for network data analysis

As stated earlier, the objective of the network data analysis is to find errors and faults from network model and present them to the user so the errors of the network model can be fixed and corrected data can be imported to the DMS600 system. Need for network data analysis has become from network data imports from external NIS or GIS systems.

One option is to use DMS600 NE to document the network components and topological model of the distribution network. When the network model is drawn and documented with DMS600 NE, the mandatory data for the components are checked before saving. In addition, topological connections are checked when the network is drawn with DMS600 NE. These validation functions of the network data in DMS600 NE prevents the errors in the DMS600 network model.

However, when the network data import from external NIS or GIS system is utilized, the information is not checked by DMS600 NE if the network data model meets the requirements of DMS600 network model. Analysis of the imported network data model will check the errors that exists in the network model and show the analysis results to the user of the system.

4.2 Network data analysis during network data import

Network data analysis functions are performed during the network data import so that the errors and missing information in the network data are noticed before the imported network model is imported to DMS600 system. In addition, other objective to perform analysis is to notice the user to acknowledge the errors in the network data and make actions to fix the network data errors.

The errors that network data import application collects during the execution can be categorized to two different error categories: topology errors and source errors. Furthermore, the errors are sorted to different error lists based on the error type that they present.

Topology error is an error type that affects on the topology of the network model. Topology errors are collected by examining the network model during the network model building by network import tool application. Topology errors that are collected are switches that have more than two lines connected, line ends that have no component at the end, components that have equal coordinates and unconnected components.

The presence of the topology errors depends on the used network data format in the network data import. If the network data files include the topological information of the network, CIM network data, the amount of the topology errors is infrequent compared to the network data formats that do not have topological data included. However, the quality of the network data in NIS or GIS and the network data export from NIS or GIS have an influence on the topology errors in the network data import.

Source errors are collected during the network data import when network data is read and during the network model building. Source error is an error type which indicates the lack of information in the network data or faults in the component data. Source errors that are gathered are components having no code, components having illegal code, components having duplicate code, components having invalid location, components having missing attribute data, components having illegal attribute data and duplicate line sections. In addition, if MicroSCADA SYS600 connection is established, it is possible to add OPC codes for the switches and search OPC code errors. This functionality requires that OPC codes of the components are exported from SYS600 to the text file. Network data import application can search the OPC codes from the text file and add OPC codes for the components. An error is added to the error list if the component that should have OPC code does not exist in the text file.

Volume of the source errors depends on the documentation made in NIS or GIS. If the electrotechnical values required by DMS600 system are not documented in NIS or GIS or the documentation is incomplete, it is reflected in the amount of the source errors. In addition, inadequacies in the network data export affect on the amount of the source errors if the network data export is not implemented for all the required data attributes in DMS600 system.

The errors generated during the network data import are inserted into CSV lists where the information of the errors is presented. Source errors and topology errors are saved in separate lists and if SCADA related errors are examined during the import they are inserted in separate list. In addition, the errors are saved to the DMS600 database and they can be presented in the DMS600 system with graphical database queries where user can see the errors in the user interface of the DMS600 system in the geographical location. It is also possible to generate reports with SQL Server Reporting Services based on the error data in DMS600 database.

4.3 Network data analysis in DMS600 NE and WS

Analysis of the network data is made also in DMS600 Network Editor and DMS600 Workstation. This thesis is focusing on the network data analysis during the network data import, so analysis made in DMS600 NE and DMS600 WS is not presented carefully in this thesis. The basic functionality of the network data analysis in DMS600 NE and DMS600 WS is presented in this chapter.

From the source error point of view, DMS600 NE has functionalities to check that mandatory information for the components are inserted when components are added to the DMS600 system. For example, there are checks for component code that there is a code, it has no duplicates, it has no illegal characters, and it is not too long. In addition, when editing the existing components same checks are done when trying to save the component. However, these functions are only relevant when the network is edited in DMS600 NE, not in cases when the network data import from external NIS or GIS is utilized.

The topology analysis for the network model is made both in DMS600 NE and DMS600 WS. The results of the analysis can be seen in Notices and Events dialog, where notices and alarms of the DMS600 system is shown to the user of the software [16]. When the error is clicked, the error is located on the geographical location and user can easily see where the error in the network is located. Examples of the errors that DMS600 NE and DMS600 WS can analyse are voltage level difference between line sections with no transformer, more than two lines connected to the switch, more than one feeder is connected to the same circuit breaker and unsupplied line section.

5. DEVELOPMENT OF NETWORK DATA ANALYSIS

In this thesis, network data analysis made in the network data import application is under research. The result is to make a library to network data import application which can be run alongside the network data import or independently to analyse the existing DMS600 network model in the database. This way same analysis features made in the network data import application can be utilized with the existing network models in other DMS600 systems.

The development needs are discussed first in this chapter. Then the developed C# library and its main functionalities are presented. Finally, the future work of the network data analysis features is considered.

5.1 Development needs of the network data analysis

Network data analysis made during the network data import contains already analysis functions of the network data. However, different network data import implementations for different network data import file formats have different analysis functions. In addition, the analysis functions of the network data in the network data import application needs development to analyse the network model more carefully than it presented in chapter 4 in this thesis. The main objective of the development of the network data analysis is to collect existing analysis functions under the same library, where the analysis functions can be utilized more efficient than currently. In addition, the analysis features are developed in this thesis.

One option that is not implemented is to analyse the DMS600 network model that is already in use. When the network model analysis functions are implemented also to the database network model, it makes possible the analysis of the network for existing customers' DMS600 network model. With analysis results it is possible to increase the quality of the documented network model in DMS600 system and find errors that might exist in the network model in use.

The analysis of the network model is needed for both MV and LV networks. However, currently some network model analysis functions are only made for the MV network. For example, topology error functions are mainly for MV network. The one objective is to develop LV network model analysis.

Temporary changes of the line sections that are made in DMS600 WS have not been analysed at all currently in the network data analysis. User can make temporary line state changes to simulate temporary generator, temporary earthing and open line section in DMS600 WS. The objective is to include DMS600 WS temporary changes to the network data analysis and notify the user if the temporary changes are affected in the network data import. If the line sections are affected during the network data import, the temporary changes disappear in DMS600 WS so it is important to notify user if the line sections with temporary line state changes are affected in the network data import.

5.2 Network model analysis tool

In this thesis, Network Model Analysis Tool was developed. Network Model Analysis Tool is an application which can run independently to analyse the network model from the database of the DMS600 system. In addition, Network Model Analysis Tool can be integrated to the network data import when the analysis of the network model is made during the network data import from the imported network model.

When Network Model Analysis Tool is run independently, e.g. it analyses the network model saved to the database of the DMS600 system, the functionality of the application is described in Figure 20. First, the network model is read from the DMS600 database using SQL queries. Then the DMS600 network model is built for network data analysis. When the network model is built, the analysis of the network model begins. Analysis functions are run by asynchronous tasks which makes the analysis efficient, so the analysis does not take too much time to perform. Finally, the results of the network data analysis are saved to the CSV-files and to the database of the DMS600 system.

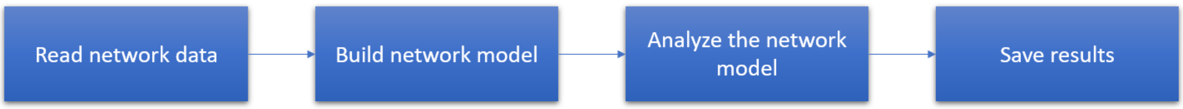

Figure 20. *Functionality of Network Analysis Tool when the database network model is analyzed.*

Figure 20 and Figure 21 below shows the functionality of the Network Model Analysis Tool in the case when the tool is integrated to the Network data import application. Figure 21 illustrates the case when the Network Model Analysis Tool is integrated to the bulk network data import. The functionality of the network model analysis works same in all use cases. It will start the network model analysis when the network model is built.

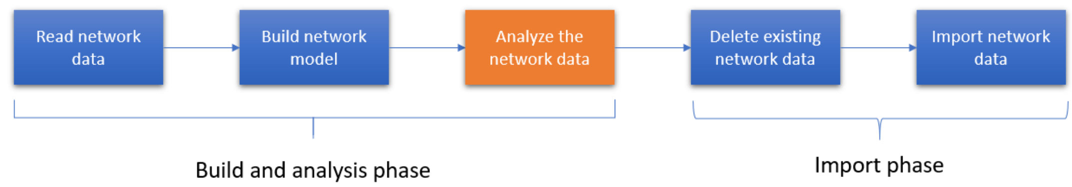

Figure 21. *Network data analyser integrated to the bulk network data import.*

Network Analysis Tool uses a configuration file, which is XML-file and follows the same structure than in network data import application so the same configuration file can be used for the network data import and network data analysis. The configuration file has settings for the directory where the error files from the network data analysis are saved. In addition, the configuration file has settings for the coordinate system where the results of the analysis are saved. The results are saved in the coordinate system of DMS600 system but also in other coordinate system is possible so the error files can be shown in external NIS or GIS system or in another network viewer.

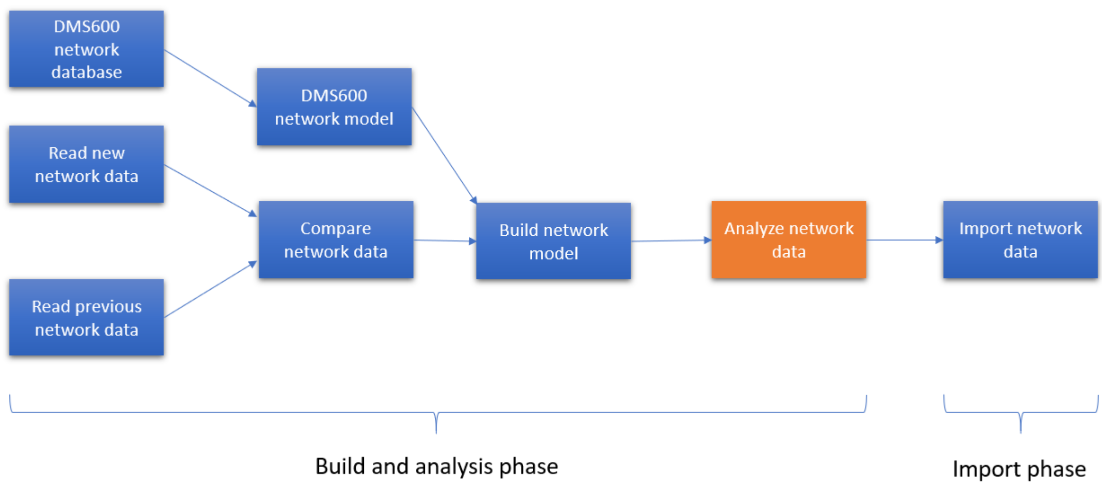

Figure 22. *Network data analyser integrated to the incremental network data import.*

Network Model Analysis Tool analyses both topology errors and source errors of the network model. The following errors that effect on topology of the network are analysed in the developed tool:

- Line ends that have no components in MV and LV networks
- Unconnected components in MV and LV networks

- Switches that have less than two or more than two lines connected
- Voltage level changes between lines without transformer attached.

Source errors are analyzed also in Network Model Analysis Tool, which are errors from component attribute data. Components that are analysed are listed below:

- primary transformer
- distribution transformer
- line section
- disconnector
- circuit breaker
- fuse
- fault detector
- generator
- capacitor
- conductor joint
- shunt reactor.

In addition, type data for conductors, disconnectors and fuses are analysed in Network Model Analysis Tool. Type data errors contains source errors of missing electrotechnical data of the component types as well as missing or illegal type codes.

In addition, Network Model Analysis Tool analyses if the line sections that have temporary changes made in DMS600 WS have affected. If the line section is removed or changed topologically since last import, the error type “temporary line change is affected” is added to the topology errors. The line state changes of the affected line are removed from the database of DMS600 system to avoid unnecessary data in the database.

5.3 Analysis results

The results from the network data analysis are saved to the CSV files and to the DMS600 database. Topology errors and source errors are saved to the separate files and they have time stamp when the files are created. In the DMS600 database topology errors and source errors are written to the separate tables. The error data contains general information of the errors. Their objective is present the error data clearly and in a way that it is effective to fix the errors that appear in the network.

The results that are saved in the database of DMS600 system can be shown in DMS600 NE and DMS600 WS with graphical database view function. Figure 23 below illustrates the topology error found from the distribution network. Different colors present different error types. Red dots in Figure 23 present line end with no component, green dots unconnected nodes, blue dots voltage level difference between line sections with no transformer, yellow dots switches with one connection and purple dots switches with too many connections.

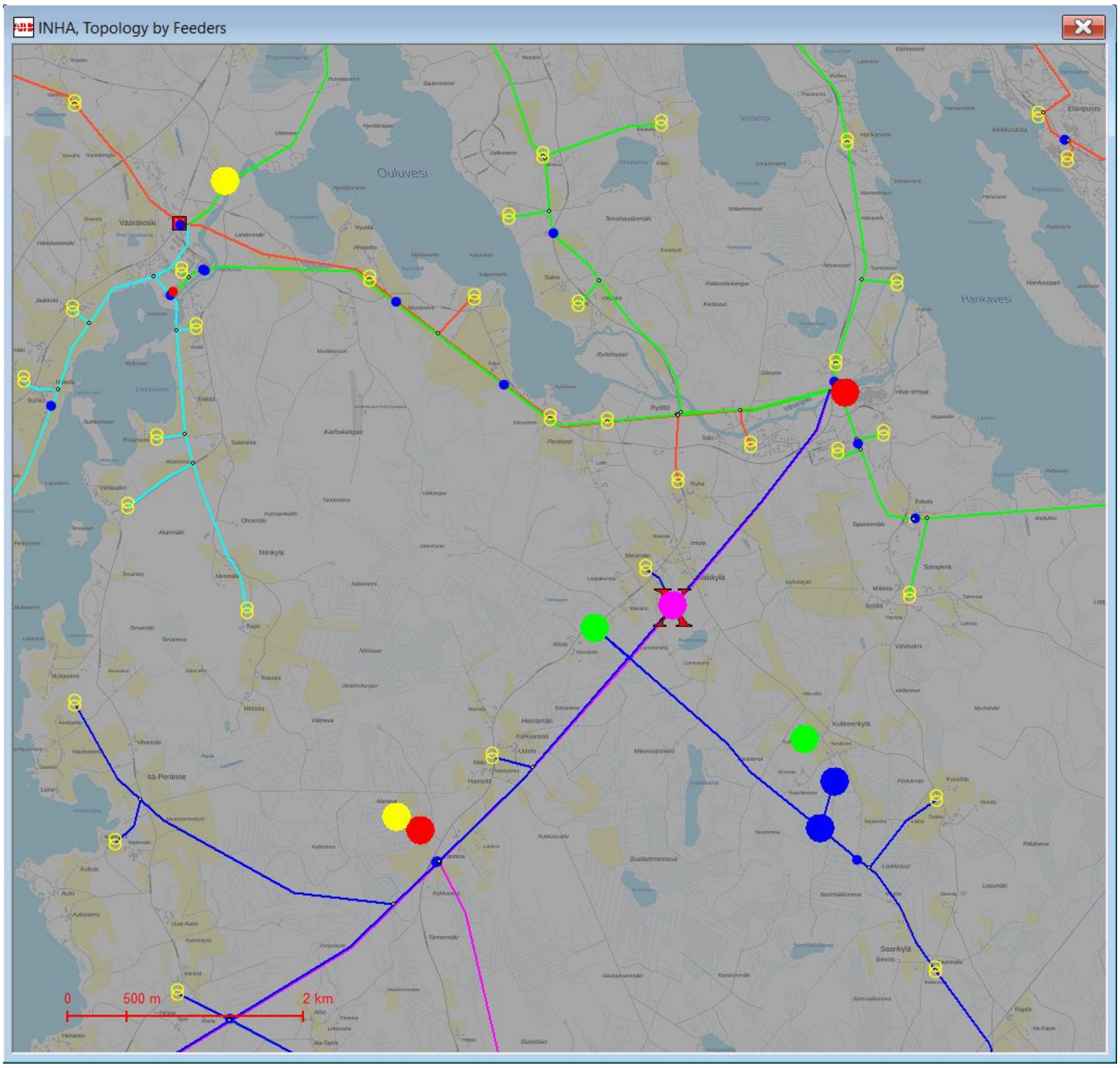

Figure 23. *Graphical database view to show topology errors in DMS600 NE.*

Figure 24 below shows the CSV-file format of the same topology errors as in the Figure 23. One row in the CSV-file contains one error and following information of each error is shown in CSV-file:

- component type
- component code

- x coordinate
- y coordinate
- voltage level
- network type
- error type
- description
- severity
- affected feature.

The component type and component code contain the component type and component code of the DM600 system. The coordinate system of the coordinates in CSV file can be defined in the configuration file. The coordinate system used CSV file in Figure 24 is ETRS-TM35FIN. Voltage level is voltage in kilovolts and network type is MV or LV network. Error type contains data of the error type which are discussed in chapter 5.2. Description field has a more detailed description of the error type. Error severity defines the error importance, possible severities are info, warning and error. Affected feature tells where the error is affecting in DMS600 system, possible values are topology, informative, MV calculation or LV calculation.

	A	B	C	D	E	F	G
1	COMPONENT TYPE	COMPONENT CODE	X-COORDINATE	Y-COORDINATE	VOLTAGE LEVEL	NETWORK_TYPE	ERROR TYPE
2	Node	507934841575X1	353224.786180138	6934893.17938995	20	MV	LOOSE_LINE_END
3	Node	349931624171X1	349624.417346965	6931171.70635949	20	MV	LOOSE_LINE_END
4	Node	352931882949X1	352882.010951235	6931949.92090885		MV	UNCONNECTED_NODE
5	Disconnector	6065M1	353135.702497781	6931581.41904928	15	MV	VOLTAGE_LEVEL_DIFFERENCE
6	Node	507930803864X1	353014.315892764	6931187.70179152	20	MV	VOLTAGE_LEVEL_DIFFERENCE
7	Disconnector	1234	349424.617189031	6931283.10477181	20	MV	SWITCH_ONE_CONNECTION
8	Disconnector	123456	347965.796431776	6936683.29952854	20	MV	SWITCH_ONE_CONNECTION
9	Disconnector	5432	351760.030256765	6933080.68586699	20	MV	SWITCH_TOO_MANY_CONNECTIONS

H	I	J
DESCRIPTION	SEVERITY	AFFECTED_FEATURE
No component at line end.	WARNING	TOPOLOGY
No component at line end.	WARNING	TOPOLOGY
No sections connected to a node.	ERROR	TOPOLOGY
Voltage level difference between line sections with no transformer.	WARNING	TOPOLOGY
Voltage level difference between line sections with no transformer.	WARNING	TOPOLOGY
One section connected to a switch.	WARNING	TOPOLOGY
One section connected to a switch.	WARNING	TOPOLOGY
Three or more line sections connected to a switch.	ERROR	TOPOLOGY

Figure 24. *Same topology errors than in Figure 23 in CSV-file.*

Figure 25 present topology error located in the substation in the DMS600 system. Topology error is indicated with red dot which indicate in this case loose line end. The error is not visible to the user when operating the DMS600 system with outer zoom levels. When zooming in, the error comes visible to user and zoomed case is presented in Figure 26 below.

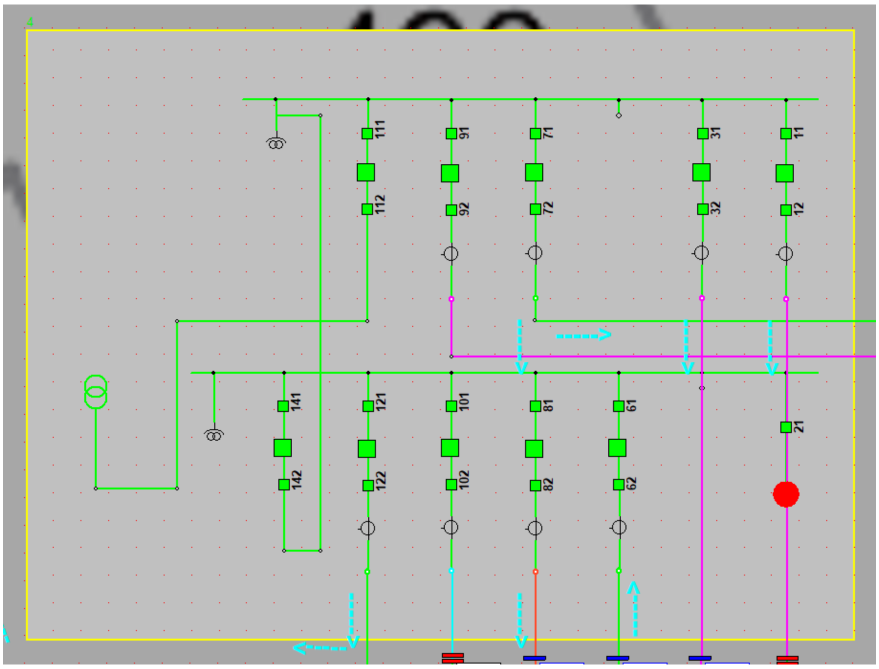

Figure 25. *Substation with topology error in DMS600.*

In Figure 26, the topology error type loose line error is zoomed in DMS600 system to demonstrate that it is challenging to notice the errors from the network model without network data analysis. In outer zoom levels the network seems to be fine but when zooming in it is noticeable that the lines are not connected but they are very close to each other. With network analysis results it is straightforward to point out the errors in the network model so the errors can be corrected.

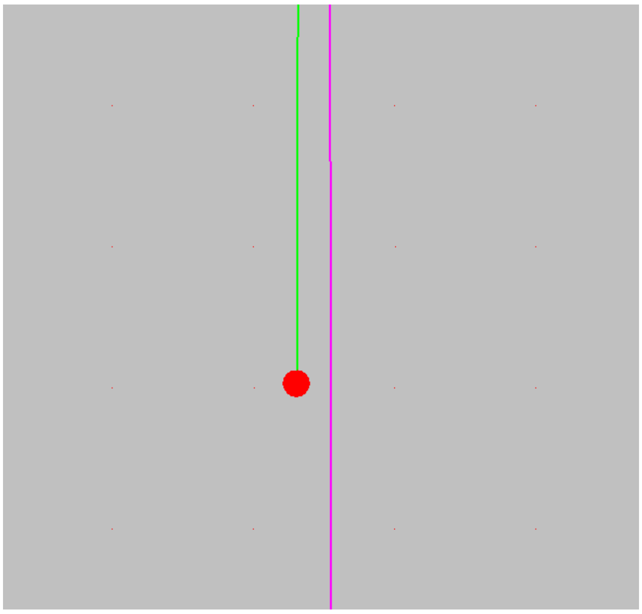

Figure 26. *Same topology error than in Figure 25 zoomed in.*

There are some errors in the error lists that are not errors in the network. For example, border switch that have connection to other company's distribution network has only one connection in the DMS600 system. However, it is important to show the switches with one connection to show possible error locations. One option is that user can clear the unnecessary errors from the error lists so they are not shown when the analysis is done next time.

5.4 Future work

The Network Model Analysis Tool developed in this thesis contains the analysis functions for the network model analysis and this application can be integrated to the network data import application. For the future, if the network data analysis is developed, future analysis features should be implemented to this application. When all the analysis functions are under the same library, it is easy to maintain network model analysis features.

Currently the network data analysis functions do not support analysis of the temporary network made in DMS600 NE. When temporary network is included to the network data analysis, the analysis of the network data improves, and it gives valuable information to user if the temporary network is affected during the network data import. If the network parts with temporary network modifications are changed in the network data import, temporary changes will disappear and can cause problems in the network topology and the user do not know currently if the temporary network is affected during the import. Now, the only option to verify the temporary network after network data import is to do it manually. Temporary network should be read to the memory of the network import application and check if the temporary network is affected in the network data import and notify the user of the network components that are affected.

DMS600 NE and DMS600 WS can show the error lists with graphical database queries functionality as shown in Figure 23. However, when examining the errors in the DMS600 NE or DMS600 WS, the user can only set the coloring of the dots located in the geographical location of the errors. Graphical database queries feature should have tooltip or text label to show more information of the errors so user could easier see which errors are shown in DMS600 NE and DMS600 WS.

As mentioned in chapter 5.3, one development aspect in the network data analysis is that user can clear the unnecessary errors from the error lists. If the error is not an error or it does not matter the user, the unnecessary errors are not shown next time analysis is done. One option to implement that is to show the errors in GUI and when user have checked the errors, they are saved to the database and read to the memory when running the analysis next time so unnecessary errors can be cleared.

Other tools to analyze the network data should be considered in the future. Because some of the network data formats, e.g. CIM and CSV, does not have possibilities to preview the network data before the network data import, network data preview functions in the future will improve the import process, especially when implementing the network data import. In addition, with network data previewer the analysis results of the network data analysis can be presented to the user.

6. CONCLUSIONS

In past few years, the network data imports in MicroSCADA X DMS600 system from external NIS or GIS system have increased. Network data import to DMS600 system is required to get the network model of the distribution network from NIS or GIS. However, different NIS and GIS systems have varied network data export possibilities and the file format to exchange the network data varies which NIS or GIS system is utilized. One focus of this thesis was to give an overview of the supported network data import file formats in DMS600 system.

Different file formats used in network data exchange interfaces depend on their file structure and features. Some of the files used in the network data exchange are not designed to transfer the data of distribution networks. For example, shapefile, KML and DXF does not have built in topological information of the network components. CIM and CSV network data formats have the information of the topological connections of the distribution network so when these formats are used in network data imports the connections are not needed to implement in the network data import. The more things to deduce in the network data import, the more errors there are after the network data import in the network model of DMS600 system.

In addition to the network data import, there are also other network data sources which are utilised in the DMS600 system. The substation diagrams can be imported from MicroSCADA SYS600. Conductor type data, disconnector type data and fuse type data can be imported from the different type catalogues. In addition, customer data can be imported from the CIS. The data from the different sources is combined in DMS600 system to create the network model of the DMS600 system.

Network data can be imported to the DMS600 system in various ways. The network data can be bulk import when the whole distribution network is imported at the same time. The bulk import can be continuous or the network can be imported only once. In addition to bulk import, incremental network data import in DMS600 system can be utilized. Then the previous network data is compared to the previous network data and only changed network parts are imported to the DMS600 system.

The network models of external NIS or GIS systems vary from the network model of the DMS600 system. Due the differences in the network models, there might be errors in the DMS600 network model after the network data import. To trace the errors in the network model, the analysis of the network model is required.

In this thesis, first main objective was to research the network data imports in the DMS600 distribution management system. Hence, the network data imports in DMS600 system have developed widely in past years, the research and the documentation of the network data import implementations and supported network data file formats were presented and documented in this thesis.

In addition, the other objective of this thesis was to develop new network data analysis application. The network data analysis application combines existing analysis features from different network data import modules to the same application. In addition, new features for the network data analysis were developed. The developed features include analysis of the LV network and temporary line state changes of the distribution network. The existing network model of the DMS600 system can be analysed with the developed application so the network model of the current systems can be analysed. The network data analysis application writes error lists of the errors that were found from the network model. With error lists the errors can be corrected in the NIS or GIS system and the quality of the network model in the DMS600 system increases. Development made in this thesis increase the quality of the network data analysis with versatile analysis features.

In DMS600 system, the reliable network model is required. If there are errors in the network model, functions of the DMS are unstable and calculation results are unreliable. When the imported network model is carefully analysed and then errors are fixed, the network model meets the demands of the requirements of the features in DMS600 system.

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