DEFINING A DIGITALIZATION CONCEPT FOR ELECTRICITY DISTRIBUTION NETWORK MAINTENANCE

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ABSTRACT

The possibilities of utilizing the most modern digital solutions in distribution network maintenance are rapidly becoming more and more viable. In this paper a plan for a new digitalization concept is described. The concept is created at Elenia Oy (Elenia) the second largest distribution system operator (DSO) in Finland and is concept being currently demonstrated with ongoing pilot projects.

For a long time, there has been an ambition to enhance the utilization of different information sources for optimizing distribution network maintenance and to move from time- or condition-based maintenance schemes towards predictive maintenance. The frameworks have been described in various academic publications but there have been limited results of practical applications especially the kind that could be utilized with acceptable operative costs for large scale DSO's. [1, 2]

The problem was addressed by defining a new concept to implement the past research and frameworks. The concept was created in a way that the level of needed investments in new ICT-systems and equipment will remain in an acceptable level. The global megatrends like decreasing communications costs, cloud computing and cloud data storage as well as affordable sensors are one of the key enablers.

The digitalization concept consists of two additional layers embedded on top of traditional network automation i.e. network monitoring and control. The two additional layers are data-analytics combining information from many sources internal to the DSO and in the future also enriched with other information sources as well as utilizing internet of things (IoT) philosophy sensors to provide new condition analytics measurements from network components.

This paper will describe the philosophy and differences between traditional network automation system and equipment compared to the new IoT sensor system connected into a cloud-based system.

The implemented various sensors are located at primary network components such as distribution cabinets, secondary substations, high-voltage poles and primary substations. The sensors being tested are not measuring direct primary circuit electrical values but are measuring secondary values about equipment condition and safety for the public such as temperature, humidity, pole tilt angle, light inside the cabinet, acceleration and primary transformer basin water height etc.

The future research concerning maintenance digitalization will concentrate with several industry partners on developing new methods for data analytics and machine learning as well as on how to utilize existing sensor technology for improving maintenance efficiency. The future ambitions will include piloting of new types of cost-effective sensors for predictive methods e.g. cost effective on-site real time thermal imaging, monitoring partial discharges with various alternative methods.

INTRODUCTION

Elenia is the second largest DSO in Finland with over 425 000 customers and over 70 000 kilometres of total network length. Elenia is operating mostly in rural network areas with some medium sized cities and towns also included in the distribution network area. Over 41 % of total network length is constructed as underground cables and the rest is built as overhead lines.

During over the last ten years Elenia has focused heavily into improving reliability of delivery with increasing network automation significantly i.e. remotely controlled disconnectors and circuit breakers, building new modular small-scale primary substations and implementing new tree clearance scheme for trees outside line corridors. Since 2009 Elenia has constructed all newly built and replacement invested low voltage (LV) and medium voltage (MV) networks with underground cables.

The installation of a considerable number of remote-controlled disconnectors currently at 4000 pcs, modern wireless communications to primary substations and state-of-the-art network operations ICT-systems has enabled Elenia to be one of the forerunners in smart grid development with e.g. automated fault location, isolation and restoration (FLIR) functionality implemented for the whole medium voltage network already in 2011. [3]

Elenia is a white-collar specialist organisation that outsources and purchases all field activities like network construction, maintenance and fault repairing from competitive contractor market. The contractors are incentivized e.g. to improve quality of construction, project schedules and fault repairing duration. Fault repairing duration has decreased constantly since the model has been implemented in 2008.

With so many advancements already in place for decreasing the duration and frequency of outages and strategic decision for building all LV and MV network in underground cables, in reducing outage impacts in the long term the next technological step in more advanced distribution network asset management was decided to be utilization of digital technologies. The target for this development was to improve network reliability, quality of delivery and safety with optimal costs.

DEFINITION OF THE DIGITALIZATION

Currently the digitalization is influencing many industries and consumer markets with new digital solutions rapidly becoming available to improve efficiency, quality and user experience of many aspects of professional and personal lives. Because the digitalisation is now very much affecting all individuals everyone has basic understanding about it but at the same time not everyone shares the same view what the digitalization is meaning.

In this paper digitalization is defined as all new digital hardware or software solutions, applications and services with aim to change the business models and processes relating to distribution network maintenance.

The digitalization is then divided into two main branches: data-analytics and internet of things (IoT) sensors. With data-analytics covering everything from traditional data-analysis, software robotics, machine learning and artificial intelligence. Internet of things sensors are covering all new additional sensor solutions to measure new physical quantities from network components in a very cost-effective way.

DATA-ANALYTICS

The main targets for different data-analytics solutions are to provide data for improving the traditional maintenance process and to focus inspections or actions in a more precise way in order to improve network reliability, security of supply and safety. The data-analytics will also make it possible to implement a new layer of higher-level network monitoring in addition to traditional real time network monitoring executed by the network control centre with focus on substantially enhancing predictive network monitoring and preventing future faults and outages.

Currently there are plenty of information stored within Elenia's different ICT-systems. Attribute information about all the network components are stored in Elenia Network Information System (NIS) by Trimble. In the same system there are also all the collected maintenance information and data of the components over past years. Maintenance data consists of inspection notifications as well as the actions that has been done to maintain the component condition. All the maintenance data has a link to a specific component and date of made notification or action. [4]

Elenia has collected a lot of information about outages in both LV and MV network and that information is stored in Distribution Management System (DMS) by Trimble. Both NIS and DMS systems share the same data structure and database but the user interfaces are separate. Other sources of information within Elenia are e.g. SCADA (supervisory control and data acquisition) used in Network Control Centre (NCC) and Enterprise Resource Planning (ERP) system. Overall the data related to network components is not scattered amongst too many systems as practically everything is stored in the databases of ICT systems from two vendors namely Trimble Solutions Oy and Netcontrol Oy. [5]

Currently there are also vast resources of free open data to utilise also for DSO needs. Examples of open data sources include topsoil of poles and cable cabinet foundations, different weather information as ground frost which affects also on foundations in northern countries as Finland, the temperature and humidity etc. The possibilities to enrich DSO's own data with open data are nowadays wide.

Currently used ICT systems in Elenia are well designed and function as intended. The demand for data-analytics arise from the need to do a whole lot more with maintenance inspection, maintenance action, failure and component attribute data among others.

Presently the inspection data from specific component leads to maintenance action to that component and used NIS system allows easy planning interface of maintenance actions to all components. With more sophisticated data-analytics it could be possible to find the root causes and not only symptoms of failures and avoid breakdowns caused by underlying equipment conditions. Data-analytics allow to see network failures and corrective maintenance information as something that can be anticipated and rectified before they ever develop.

Platform for Maintenance Data-Analytics

Future developing needs for storing customer electricity metering data with more detailed intervals and including various information about network performance measured by Automated Meter Reading (AMR) system. The future requirement for much more shorter metering interval initiated a need to implement a new system for managing electricity metering data.

Elenia has selected a cloud-based system to be used for storing the data. Right from the beginning it was clear that utilising the same ideology for storing also future IoT sensor data is a very viable and cost-effective solution. The same cloud based Smart Grid Platform (SGP) will be used also in maintenance data-analytics which allows to collect all available information in the same place where the data is easily accessible for internal use and for the selected data-analytics partners. It is also important to have only one platform to focus the development and give better control and the same time limit the need for different interfaces.

Network control must be real time but the solution for maintenance data-analytics is not needed to be real time. The data transfer through interfaces between used ICT databases and SGP can be done e.g. weekly or another appropriate interval.

Resources for Data-Analytics Development

Traditionally DSO's have high knowhow of the business-critical distribution network and the electrical quantities as well as the used ICT-systems. However, data-analytics requires different skills and because of this it is reasonable to use knowhow of external service providers. On the other hand, in the first state also the DSO own expertise must be strengthened and expanded to purchase the right services and to see possibilities of the own as well as open data.

It is efficient to use only a few service partners to have a managed entity for the data-analytics. The partner also must have comprehension about the distribution network in order to be able use the DSO data. Before the actual data-analytics can be utilized the DSO's own data has to be qualified and perhaps also supplemented from other sources. This is where the knowhow of DSO's own network, the used components and other information is needed, and it mostly must be done inside the DSO company.

Software Robotics for Maintenance

The network component quantities may be wide and there are thousands of maintenance actions to be planned every year. Software robotics can help DSO employees to focus on specialist work instead of manual repetitive tasks that does not require such expertise. With the help of robotics, the maintenance prioritization work has become less time consuming which enables more detailed analysis more often thus improving the equipment reliability.

Future Concept for Maintenance Data-Analytics

Elenia has done pilot data-analytic applications and workshops with selected Finnish partners to see the possibilities of the Elenia's own data as well as combining it to the open data. From the pilots the clear conclusion is that there are many possibilities to easily have added value to asset management for optimizing distribution network maintenance and to move from time- or condition-based maintenance schemes towards predictive maintenance.

NIS will be also in the future the main system for maintenance management, but data-analytics can give more tools for the DSO through other dashboards to do the decisions to refine the maintenance program and enables the efficient use of limited resources to ensure network reliability, quality of delivery and safety of the whole distribution network.

INTERNET OF THINGS SENSORS

A lot of new data can be gathered from the distribution network by utilizing IoT-sensors. Usage of IoT-sensors enables better monitoring of network components' condition closer to real time than traditional inspections. Data can also be gathered by using traditional network automation e.g. fault indicators and remote-control systems of switchgear. These systems are not considered in this paper since they are primarily used in operating network although they also provide vital data for network maintenance. [5]

One and maybe the most important reason for creating a sensor system alongside SCADA-connected network automation is a will to be able to collect data more widely throughout the network. This means that huge number of sensors need to be assembled into different components of network. This enables data collection from big share of the network improving knowledge about network's condition and bringing it closer to real time. Cost of SCADA-connected network automation creates a need for more cost-efficient system.

Sensor Communication

IoT-sensors to be used will be installed widely around network so there is not always a fixed communication available but there are multiple suitable wireless communication technologies to be used. Elenia's network is however located mostly in the rural areas so the technology chosen must work also in those areas.

Demand for battery powered operation sets demands for communication of chosen sensors. Communication must be low power to enable long battery life. Applicable communication technologies can be low-power wide area network (LPWAN) -technologies, e.g. Narrowband IoT (NB-IoT), Sigfox and LoRaWAN. From sensors only one-way data transfer is needed, since there is only need to collect data from sensors. There is also no need to transfer big amounts of data. Instead simple alarms, numerical values or perhaps low-resolution images could be needed to transfer. In addition, there is no need for real time data.

In many applications it is sufficient to transfer measurement values between several hours or to utilize spontaneously triggered alarms with push type data transfer. These specifications enable the use of LPWAN-technologies. Additionally, the cost of these technologies is relatively low.

Physical Quantities

The physical quantities to be measured will at the first stage be mostly other than direct primary circuit electrical values. This makes it possible to use mass produced sensors that are already used in other industries. When there is no need to use sensors specified to be used in electricity networks or worse specified only for Elenia, mass produced sensors that are cost effective can be used. For example, temperature sensors have been made for a long time so there is a wide range of products available.

While planning on what quantities to measure it is vital to know what those can tell about the condition of components. Some quantities can tell directly about evolving failures like if there is abnormal sound coming from component. Other quantities however tell more about the conditions that can influence the ageing of the component. Temperature and humidity are examples of those.

Sensor Specification

Since sensors are going to be located at various primary components of distribution network, they are going be in harsh conditions. In Finland temperatures outside can vary roughly from -30 °C to 30 °C. This makes it vital, that sensors are planned so that their electronics can tolerate relatively high temperatures whereas low temperatures challenge specially battery life of sensors. In addition, some sensors will be exposed to rain, moisture and dirt so they need to have sufficient International Protection Marking (IP).

Most of the sensors must be powered with batteries. This is required to make the life cycle cost of sensors as low as possible. Installation is significant part of the cost of sensor and even small addition to the amount of manual work, such as arranging power supply for sensor, can raise the installation cost significantly. The battery life must be years, so that batteries or even the whole sensor could be replaced while performing normal inspection to component. Poor battery life must not add the need for maintenance actions for the primary component. However, there can be a few applications where external power supply could be arranged, but majority will be battery-powered.

Sensor Commissioning

To be able to install huge amounts of sensors into the distribution network, they must be very easy to install. If the installation is time consuming and complex, can it make installation costly. Best scenario is if sensors can be installed when there is another maintenance action executed at the component, for example during inspection. This lowers installation cost significantly.

The installation should not require significant wiring. It should be very straightforward e.g. inserting batteries into sensor, attaching it into the desired component using magnets, screws, tape or similar. After actual installation id-number of the sensor would be documented into NIS system in a same way as all other maintenance data from the inspection. After that the id-number could be collected into the cloud service where the data from the sensor are stored. After that the data from sensor could be combined with component it is installed to.

The commissioning process must be as straightforward as possible and besides earlier mentioned facts it must not include manual testing after installation. In the future software robotics will be applied into the process.

DIGITALIZATION CONCEPT AND INITIAL RESULTS

The digitalization concept presented in this research paper is based on two layers in addition to traditional network automation, supervisory control and data acquisition (SCADA).

There are already a lot of network automation solutions implemented and available, that could be used to collect additional data for network maintenance. Some of the main reasons and rationale for using separate sensor system are presented in Table 1.

	Field Communications network connected to a SCADA system and IED equipment	**Sensor network connected to a cloud-based system and sensor equipment**
Communication type	Two way	One way
Cost of installation	Medium	Very low
Cost of operation	Medium	Very low
Reliability criteria	Very high	Medium
Bandwidth and response time criteria	High	Low
Commissioning and testing requirements	High	Low
Equipment type	Specialised industrial systems	Publicly available IoT sensors
Changes and development in ICT-systems	Labour intensive	Easy
Growth potential of information amount	**Linear**	**Exponential**

Table 1. Different requirements between field communication network connected to a SCADA system, traditional intelligent electronic devices (IED) and sensor network connected to a cloud-based system and sensor equipment

The whole digitalization concept for electricity distribution network maintenance as a summary is presented in the Image 1.

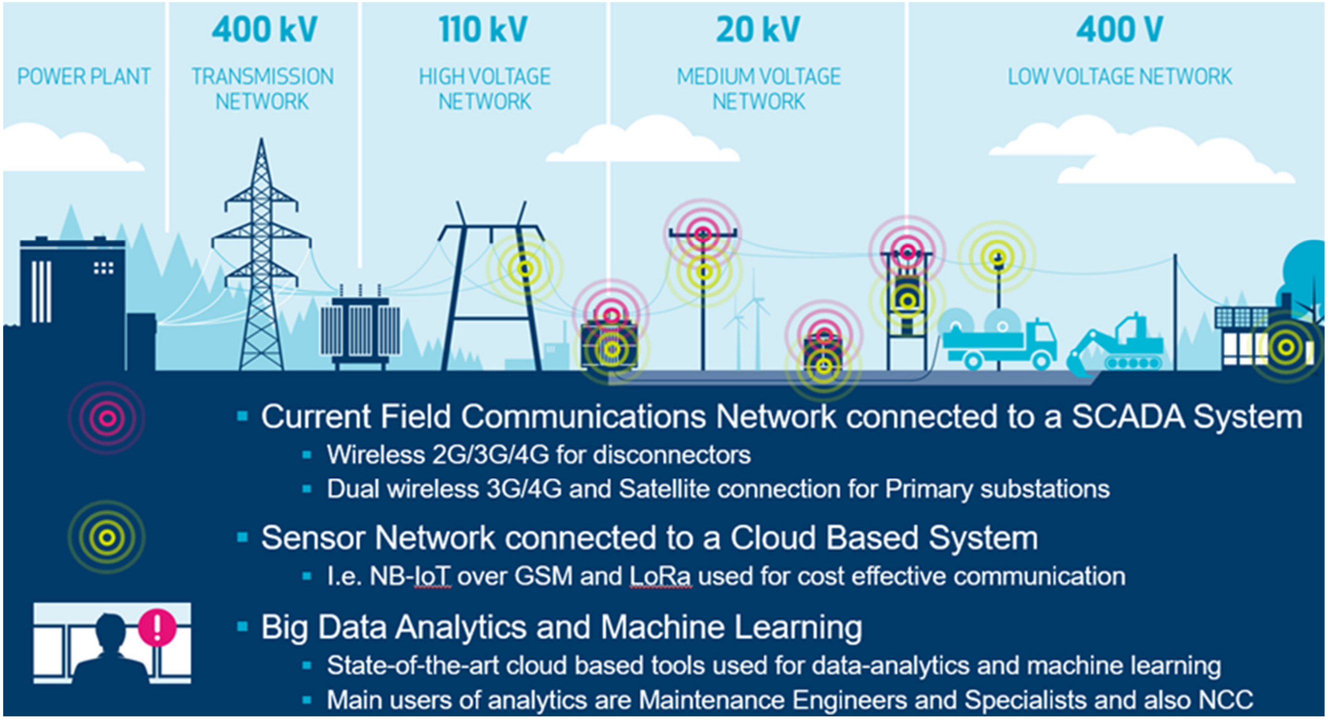

Image 1. Digitalization concept in brief

SUMMARY

The research in the next stages will be concentrating on further proof of concepts and production implementations of data-analytics as well as defining the specifications and techno economic viability for large scale implementation of IoT sensors.

When the IoT sensors will be installed in larger scale more research will be needed in utilization of various sensor information sources e.g. defining thresholds for measurement values that need reaction.

At the first stage the improvements from digital solutions, data-analytics and sensors will be implemented to enhance the maintenance management of the distribution network but naturally when there is more experience from the new technology it is viable to start integrating some parts of new digital solutions to support real-time network monitoring and controlling.

Through this concept definition it has been established that digital solutions that are applied in many other industries are also applicable for maintenance management of electricity distribution networks.

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