Helen Electricity Network Ltd's Process Towards High Level of Supply Reliability

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ABSTRACT

This paper presents how Helen Electricity Network Ltd (Helen) managed to improve its electricity supply reliability between years 2008 and 2016. This was achieved by implementing six development tracks: 1. Investments to new substations, 2. Replacing the remaining medium voltage (MV) overhead lines with cables, 3. Investing in substation secondary system refurbishments, 4. Strengthening the fault analyzing process and training of operational staff, 5. Investing in new technologies as secondary substation automation and 6. MV earth fault compensation systems. All these actions have been economically feasible. The results of the development project have been even better than expected. The goal was to halve the annual energy weighted System Average Interruption Duration Index ($SAIDI_{EW}$) level (5 years average) from 12 mins to 6 mins, but the result was already as low as under 3 mins by the end of 2016.

INTRODUCTION

Helen Electricity Network Ltd (Helen) is a Distribution System Operator (DSO) for Helsinki which is the capital of Finland. It is city owned with its 375000 customers. Helen has historically had high reliability target levels. In the beginning of 2000's the annual SAIDI-levels varied a lot. Occasional wide substation faults degraded the results. The average SAIDI-value was in 2007-2008 over 15 minutes (energy weighted 12 mins). The average amount of yearly MV faults was ca 40 and additionally some 110 kV network and primary substation level faults occurred. In 2007 many MV primary substation level faults were experienced.

To respond in improving the reliability of the supply, the company launched in 2008 a program to halve its SAIDI level to 6 mins by the year 2015 by applying six development tracks. In this paper all these tracks are shortly described and the results presented. All the tracks had to be economically feasible. In 2008 a cost benefit analysis was made for the tracks of the MV overhead line cabling, the MV earth fault compensation and the network automation. When taking into account only the reliability improvements, the MV cabling was the most profitable before the earth fault (EF) compensation and the network automation. The results of this cost benefit analysis is presented in figure 1.

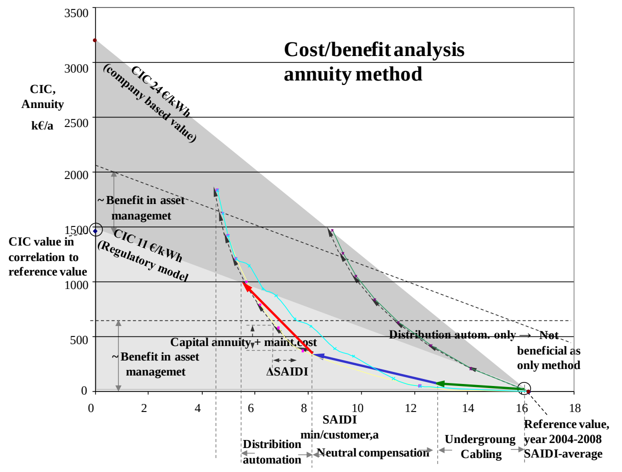

Figure 1. Cost-benefit analysis of the reliability improvement fault analysis and SAIDI target estimation. [1,2]

1 NEW HV/MV SUBSTATIONS

Firstly Helen decided to erect four new HV/MV primary substations. In 2008 Helen had 21 operating HV/MV substations, the high voltage level 110 kV and the medium voltage level 20 kV or 10 kV. One aim for the new substation capacity was to serve the increasing electricity consumption. The consumption growth had historically been 1-2%/year, in the 2010's it decreased to zero level. Another important motivation was Helen's new (since 2008) risk tolerance principle to provide a 100 % MV reserve for every primary substation. After these new substations this 100 % MV reserve principle was fulfilled for every substation. The third cause was to decrease the service area of the MV networks and thus the effect of outages, voltage dips and earth fault currents and overvoltage stresses. These new substations were installed and commissioned as turnkey projects by ABB and Siemens in 2009 (Pukinmäki 110/20 kV), 2011 (Kluuvi 110/10 kV, underground station), 2013 (Lauttasaari 110/10 kV) and 2015 (Ilmalantori 110/20 kV, underground).

All of these new substations were equipped with the state of the art technology. Substation secondary systems have been implemented with IEC61850 based substation automation and with latest numerical intelligent electronic devices (IED's). The IED's contained the covering self-supervision functionality, the MV short circuit location technology and many latest protection functions like the MV cable terminal EF protection.

Between the years 2009-2016 there were seven MV faults in the serving area of these new substations and ca 85 faults in the neighbor serving areas. These new substations have decreased the affected outage and stressed network area in these 85 cases by 21 % (decrease of cable length at neighbor substations). Also all IED and communication faults at these new substations have been detected by self-supervision before any harms to customers.

2 REMOVING MV OVERHEAD LINES

The second track was to decrease the amount of the remaining MV overhead network. The total MV distribution network length in Helsinki is about 1600 km. In 2007 the cabling rate of the Helen's MV network was already high, 97 % (Figure 2), but still 30 % of all MV faults originated in the remaining 3 % overhead line part. The overhead lines also acted as antenna for overvoltages which caused some severe faults in cable network during heavy thunder storms.

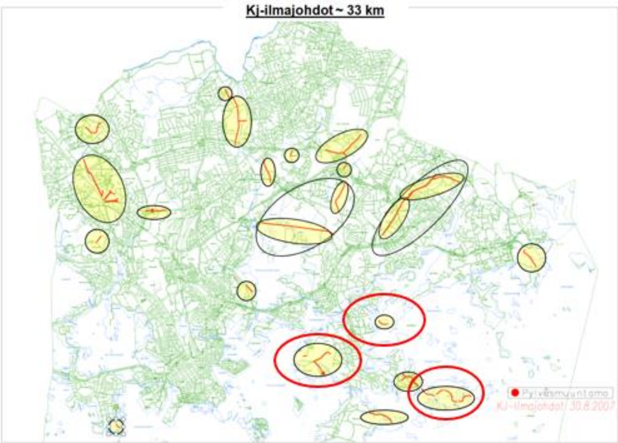

Figure 2: Helens MV overhead lines in 2007, 33 km. In 2014, altogether only 5 km overhead line left, marked with red circle.

Helen executed almost twenty MV cabling projects between 2008 and 2014. Almost 30 km of MV overhead lines was replaced by PEX-insulated cables. By the year 2015 the MV cabling rate was as high as ca 99.7 %, figure 2. After the project the percentage of MV overhead line faults was only 0-5% of all MV faults.

3 REFURBISHING SUBSTATION SECONDARY [3]

Thirdly there was a need to start the refurbishment of Helen's old substation secondary systems. Helen had large substations with a broad electronic relay generation especially at MV substations. Many substations had electronic relays from late 1970's and 1980's. The amount of protection relays was totally around 2000 units. The lifetime of electronic/static relays was estimated to be about 30 years. In 2004 and 2005 there were several malfunctions and failures of MV static relays. The manufacturer ABB stated that those relay types had some aging components. As firs aid, the manufacturer recommended a modification of the relays to get more lifetime for the protection units. The modification kits included new potentiometers, capacitors and measuring cards. Helen trained some maintenance technicians to do the modifications at the same time with the periodical maintenance operations. The suggested modification has been made for the most substations in question (except 4) in 2005-2007. After these modifications the failure rate of those protections fell down.

The age of most substations in question was around 25 years. The expected lifetime of primary systems is 40-50 years and for the secondary only half of it. The lifetime of those protections was near to its end. Also there was a demand for new technology and the new features like self-the supervision, the fault recording and other new protection functions and indications. The IEC 61850 station bus substation automation technology including station level automation was specified by Helen in 2007. The self-supervision of the IED's enables also prolonging the interval of protection maintenance tests from 3 to 6 years. This halves the costs of periodical maintenance although the costs of corrective maintenance will increase.

Four oldest substations were left out from the previous mentioned modification. The refurbishment process of substation secondary systems started from them with projects in 2007, 2008, 2010 and 2011. ABB (2 cases), VEO and Schneider were service providers. Only the major overhaul has been made for the primary switchgears. When the lifetime of the switchgears ends, the whole substation will be refurbished. Also the first generation of Siemens made IED's and automation systems from 1990's were at the end of the support from manufacturer. After these projects Helen collected experiences and made an analysis. As a result Helen specified in 2013 the next wave of the substation secondary system refurbishment projects which consisted 2-3 project packages. These packages would be executed via yearly competitive tendering process.

Helen has executed altogether six substation secondary system refurbishment projects in 2015 and 2016. All of these have been made with Siemens. The newest IED family of Siemens was accepted for use. This refurbishment plan is still continuing by two yearly refurbishment projects. By the beginning of 2020's, almost all of Helen's substations will be automated with the modern IED's and station bus automation.

These secondary system refurbishment projects have helped and will assist to keep the reliability rate of the secondary systems at a high level. These new systems also help to detect, trip and locate the faults faster and more efficiently. The periodical maintenance cost can be reduced as much as 50 %, although repair costs will raise to some extent. After these refurbishments the asset management of the substations is clear: the next phase would be the total substation refurbishment ensuring an optimal lifetime for secondary and primary devices.

4 ANALYSING FAULTS AND TRAINING STAFF

The fourth step in aiming to decrease the SAIDI values included actions in analysing faults and training staff to clear the faults. Helen has always analysed comprehensively all HV and substation faults. The protection and automation group has had a tradition and process to verify the correct operation of the protection and substation automation with a help of event and fault recordings. Concerning MV level faults only fault notification report was made by Helen's network control center. Since 2008 the fault analysis has been made also for the significant MV faults. From the beginning of 2012, Helen started a practice to do a fault analysis report of all MV faults. The report consists of fault events, customer effects, the protection analysis, the fault location and the repair analysis. All improvement needs for the fault clearing and repairing process are identified and reported. Corrective actions are observed and listed.

Some wide substation faults in the beginning of 2000's and especially in 2007 indicated that Helen had to improve the competence of its operational staff during difficult fault situations. Helen started to arrange network fault simulation exercises. Some of the substation fault simulations included also a human accidental part. The department of emergency services (fire brigade) also participated and network control center, substation and local operational staff were involved. Altogether 15 comprehensive substation fault simulations were arranged in 2008-2012. In addition, eight training simulations without fire brigade were held in 2015-2016.

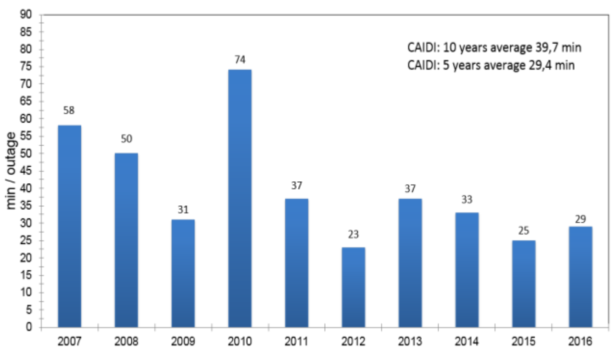

Figure 3. Helen's yearly CAIDI 2007-2016

This systematic training has improved significantly the response ability of the operational staff. For example in 2016 several substation level faults have been managed to isolate fast by the remote control without field workers. Comprehensive trainings and additional data via substation automation have been key actors in this improvement. Helen's CAIDI-values have decreased from 50 min to under 30 min level, figure 4.

5 NETWORK AUTOMATION

Helen decided also to introduce two new technologies as the fifth and the sixth measures. One was the network automation for secondary substations. In 2007, all of Helen's 2500 secondary substations were without automation and remote control. Helen had been studying the network automation already over 10 years. Until recent years the system costs -devices and communication- had been too high compared to the benefits. The cost level had changed and also new devices have become on the market.

In 2008, Helen specified a full scale secondary substation automation including a load disconnector remote control, an MV fault indication, an MV/LV alarm indication and power quality (PQ) measuring functions on the LV side, figure 4. The communication was specified via a commercial mobile network.

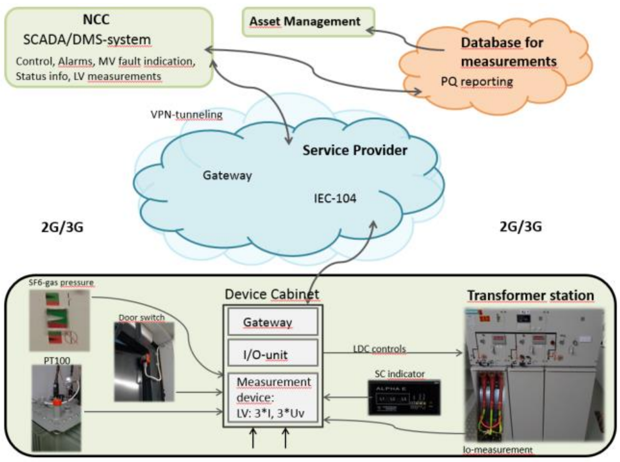

Figure 4. The principle of Helen's Network automation

The selection of the secondary substations for network automation was made by a cost/benefit analysis: the decrease in the customer interruption cost should be most significant. The network automation was installed in normally open point substations and in the half energy point of the MV feeders. This means one and a half secondary substation per a feeder (900 automations in the Helen's case).

The project started with Netcontrol Oy with automation of 300 secondary substations via turnkey project starting in 2008 and ending in 2013. This project was separated from secondary substation investment process. The automation "box" has been added afterwards also to newly installed substations.

After new competitive bidding in 2013 Helen continued the project with Emtele Oy. Also a turnkey maintenance agreement has been done with Emtele at the same time for 15 years. During 3 years (2014-2016) 200 secondary substation were automated. By the end of the year 2016 altogether already 500 secondary substations have been fully automated. At this moment as much as 27 % of Helen’s secondary substations have automation. When taking into account secondary substations owned by MV customers the automation degree is about 20 %. The project continues with decelerating pace: 50 yearly automations in 2017-2019.

The secondary substation automation has shortened the duration of the MV outages. In MV feeder faults usually 50 % of power supply can be fast restored via remote control, at the same time manually searchable area reduces by 50 %. In MV earth faults, where alarming earth fault protection is used manually searchable area reduces by 50 %. Feeders which have a higher percentage of automated secondary substations the advantages and fault isolation can be even remarkable. The system has been used in an approximately 80 MV fault cases. The average advantage per one outage situation is the 30 min reduced outage time for 50 % of customers and some minute’s time-saving for the rest. The average advantage in SAIDI has been ca 0.4 min/year since 2011.

The remote control of the load disconnectors of the secondary substations is mostly used in normal operation. The remote control saves the switching time in planned MV network operations. Thousands of planned disconnector operations have been made since 2011. The Helen’s network operation and maintenance personnel has got more time to concentrate on the operational and maintenance planning instead of the operational work.

The network automation has helped Helen also in the asset management and maintenance of secondary substations. The prevention of faults and the more effective maintenance has been achieved via various functionality:

- Loading and temperature measurement of distribution transformers
- SF6-gas pressure alarms
- Door alarms
- Reactive power measurements
- Monitoring and reports by PowerQ service
- Monitoring low voltage power quality
  - Voltage level
  - Voltage sags and swells
  - Voltage total harmonic distortion

Automation has been useful in many occasions:

- Some transformer overload situations detected
- Some cooling failures detected
- Some intrusions detected
- Some high harmonic distortion levels detected

6 MV EARTH FAULT COMPENSATION

The sixth track and the other new technology has been the introducing the 20 kV earth fault compensation by changing the 20 kV network earthing methodology from an isolated to a compensated mode. In the Helen’s city center 10 kV isolated network, an earth fault alarm only protection method had been successfully used already for decades. This has been possible since, in earth faults the maximum earth fault current is low enough (max ca. 50 A capacitive earth fault current), not to cause too high touch voltages. In the supply area of 20 kV medium voltage, with Petersen coils the 20 kV earth fault protection was possible to convert from the tripping to the alarm only mode. Thus almost 70 % of MV faults could be solved without significant customer outages. According to statistics approximately 70 % of Helen’s MV faults are earth faults. With an earth fault compensation around 50 % of 20 kV faults won’t cause customer outages as in the 10 kV network. The Helen’s almost 100 % cabling rate and a considerably young MV network (an average age 25 years) enable well this kind of protection scheme. The MV cable network asset management actions described in [4], have also benefitted the success of MV earth fault compensation.

Helen made several profitability analyses for the EF compensation project. The last calculation was made in 2014, where the payback time of the total investment was 12 years with 24 EUR/kWh customer interruption cost, figure 5. The total annual customer interruption cost reduction would be 0.5 MEUR/year when the asset is comprehensively in operation.

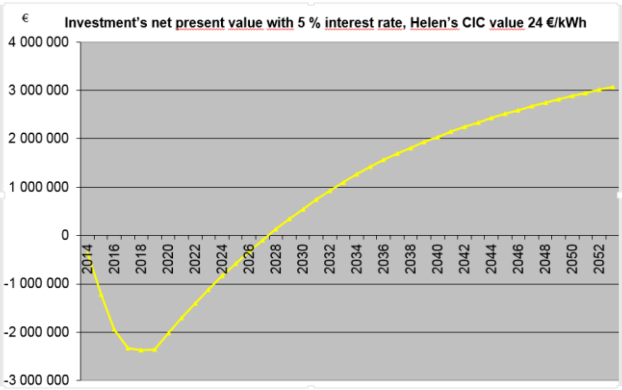

Figure 5: The profitability analysis of the Helen’s EF compensation

Helen has experienced during 1990’s and 2000’s ten MV substation busbar short circuits caused by voltage transformers stressed by a previous earth faults. The compensated MV network offers a new path for earth fault charging currents to discharge. Thus this MV network compensation should decrease the amount of voltage transformer faults.

According to the research by Helen and Vaasa University in late 1990's earth faults in isolated networks cause higher transients in low voltage networks than earth faults in compensated networks. The compensated network allows also an improvement of the voltage quality.

Helen started this earth fault compensating project in 2008, the first installation was a pilot for the Pukinmäki substation 2009. After some collection of experience the project was continued in 2012 with two installations. In 2015 and 2016 there was six additional commissions. At this moment nine out of 13 Helen's 20 kV substations has the earth fault current compensation. The rest four substations will be compensated within the becoming two years. First seven turnkey projects have been delivered by Multirel Oy using the a-Eberle and EGE technology. Last projects are and will be implemented by Maviko Oy with the Trench technology.

The earth fault compensation in cabled networks with alarm only EF protection mode was new in Finland. Helen started with the centralized compensation principle, the basic rating for the coil was 400 A. The compensating rate was 10 A overcompensating. An additional 10 A resistor was switched for a moment in parallel of the coil after an earth fault initiation. The previous 200 A earth fault current level at 20 kV decreased to a level of 10-20 A.

At every commission phase of new EF compensating devices Helen has done earth fault tests with live network. At first the tests were made daytime but after some network faults during the tests in 2012 the tests have been moved to nighttime to minimize possible harms to customers. Most of the tests could have been performed without customer effects. These tests have been very useful not only to perform the system and protection final site acceptance test but also to get experience to improve protection algorithms against intermittent earth faults in the compensated network. Also secondary substation EF indications have been improved via these tests. Several protection manufacturers have got recording data from Helen's earth fault tests. Novel functions for intermittent earth fault indication have been tested and presented.

Helen's experience has been that almost all earth faults in the compensated cable network start as an intermittent (re-striking) type. Helen has used the present protection IED's for the earth fault detection but additionally special EF indication devices have been introduced. Special devices contain transient, harmonic and intermittent functions for EF indication. Additionally an admittance method is used in the two newest installations. The experience has been very good. Helen has at this moment very reliable methods for the substation feeder level fault location.

Several 20 kV MV earth faults (14/20) have already been isolated with a sustained operation without customer interruptions. There has totally been 20 "natural" earth faults in the 20 kV compensated network by the end of the year 2016. Fourteen of them (70 %) could have been solved without major customer outages. Sometimes very short operational cuts have been needed. These 14 faults result totally to about 1.4 mins saving in the SAIDI value since 2013. The rest of the cases have evolved instantly or later to short circuits or to cross country faults and a protection tripping has been necessary. In some cases, the fault isolation procedure has been already possible to start before customer outage → shortened outage time.

RESULTS

Helen has reached its SAIDI level target by the year 2015. During the years 2011-2015, the average $SAIDI_{EW}$ was 3.5 mins/customer/year, well below the objective level. The direction of the reliability level is still downwards, in the year 2016 $SAIDI_{EW}$ was only 1.9 mins resulting 2.8 min average value for the years 2012-2016, figure 6. Helen's reliability level has accomplished a remarkable high class. These results have been achieved without additional internal resource costs and all the investments have been cost-effective.

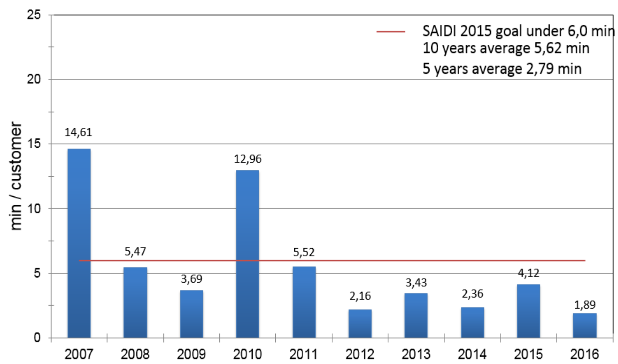

Figure 6. Helen's $SAIDI_{EW}$ 2007-2016

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