OPTIMIZATION AND VISUALIZATION OF DISTRIBUTION AUTOMATION UTILIZING ADVANCED NETWORK INFORMATION SYSTEM

Osmo SIIRTO, Helen Electricity Network Ltd – Finland, osmo.siirto@helen.fi

Mikko ORAVASAARI, Helen Electricity Network Ltd – Finland, mikko.oravasaari@helen.fi

Matti LEHTONEN, Aalto University – Finland, matti.lehtonen@aalto.fi

ABSTRACT

The addressed subject is the optimization and visualization of distribution automation (DA) utilizing modern network information system with advanced optimization solutions. DA optimization models require a lot of network data, network topology and customer information data and other calculated or given data. Collecting all the needed data for the optimization can be extremely complex. If the utility has already taken the huge effort of digitalizing the distribution network model into a Network Information System (NIS), the utility is able to use the advanced applications in NIS to accomplish this task. The paper describes the DA optimization model used in Helsinki and describes the process of how NIS was used together with the optimization model to find the optimal secondary substations for DA. Furthermore, this paper presents how the advanced tools in NIS like Spatial Analysis help the utility to expand the usage of the optimization model from green field installations to real case networks with constraints and already installed sites.

INTRODUCTION

There are various algorithms and mathematical models available for optimizing distribution automation. Besides initial and network data also the network topology and customer information are needed for the optimal number and location of the distribution automation. The task becomes more challenging while in many utilities, implementing DA is not a green field implementation. Also the existing distribution automation must be taken into consideration. In real cases there are also constraints in implementation. Many factors, like age and type of the medium voltage switchgear, are limiting the installation of DA on secondary substations. Thus, not all secondary substations are applicable for DA. Modern geographical network information systems provide features and qualities to support the solving of various optimization problems. This paper describes the process of combining different applications and qualities in modern network information system with DA optimization model in order to select the secondary substations for the installation of DA. The outcome is the optimization of the benefit of distribution automation taking into account network model and existing network assets. The usage of Spatial Analysis and the visualization of the DA optimization results and other needed selection factors is also illustrated.

OPTIMIZATION MODEL OF DA

An advanced DA optimization model was introduced in Helsinki. The impact of different fault events, short circuits and earth fault events, and the required time-consuming fault management process of different fault types are taken into account within the calculation of the benefit of DA. The objective of the optimization is to find the optimal number and location of automatic switches. DA effectively mitigates the unreliability costs, however there are cost required for installing, operating and maintaining DA.

The capital and installation costs can be calculated as follows [1]:

$$C^{cap\&inst} = \sum_{f\in N_f}\sum_{s\in N_s} X^{f,s} CI^{f,s} + \sum_{f\in N_f}\sum_{s\in N_s} X^{f,s} IC^{f,s} \quad (1)$$

In (1), the first and second term are total capital and installation costs of automatic switches. s and f are indices, N_s set of possible locations for automatic switches and N_f is set of feeders. The binary decision variable $X^{f,s}$ is equal to 1 if the automated switch is placed in that location; otherwise, it is equal zero. The operation and maintenance costs of automatic switches can be calculated as follows:

$$C^{main} = \sum_{t\in N_t}\sum_{f\in N_f}\sum_{s\in N_s} \frac{1}{(1+DR)^t} X^{f,s} MC^{f,s} \quad (2)$$

where t, N_T are index and set of years and DR is the annual discount rate. The expected interruption cost can be mathematically formulated as follows:

$$C^{unrel} = \sum_{t\in N_t}\sum_{f\in N_f}\sum_{i\in N_i}\sum_{j\in N_j}\sum_{k\in N_k}\left[\frac{1}{(1+DR)^t}\lambda^{sc}_{i,f,t} L_{j,k,f,t} C^{sc}_{i,j,k,f,t}\right] + \sum_{t\in N_t}\sum_{f\in N_f}\sum_{i\in N_i}\sum_{j\in N_j}\sum_{k\in N_k}\left[\frac{1}{(1+DR)^t}\lambda^{e}_{i,f,t} L_{j,k,f,t} C^{e}_{i,j,k,f,t}\right] \quad (3)$$

The first term in (3) represents the expected interruption cost of customers due to short circuit fault events while the second term is the expected interruption cost of customers caused by earth fault events. i and j are indices, N_i and N_j are set of possible fault locations and load points. $C^{sc}_{i,j,k,f,t}$ and $C^{e}_{i,j,k,f,t}$ are the damage costs imposed to customers with type k at load point j due to a short circuit fault and respectively to an earth fault at feeder f, location i, and year t. $\lambda_{i,f,t}^{sc}$ and $\lambda_{i,f,t}^{e}$ are the short circuit and earth fault rates.

The optimization function is mathematically formulated as:

$$\text{Min} \quad C^{cap\&inst} + C^{main} + C^{unrel} \tag{4}$$

This DA optimization model is described in more detailed in [1].

NETWORK INFORMATION SYSTEM

Present-day Geographical Information Systems (GIS) are geographic database management systems with powerful visualisation capabilities [2]. GIS for electric network data management and analysis can also be called NIS. The objects in the distribution network can be categorized in NIS as:

- Points: transformers, switching devices, generators, poles, customers, etc.
- Lines: cables and overhead lines
- Polygons: Buildings and other not electrically connected assets

The objects and their properties, such as types, sizes and ratings are maintained in NIS as relational database objects [3]. The objects are digitalized in NIS so that the geographical location and electric connectivity information of the distribution network is composed. The benefit is that once the network data is maintained in NIS along with network topology and connectivity information, the utility has the ability to use the data with all the applications for network planning, asset management, maintenance and operation. Modern NIS includes various algorithms and applications, like load flow analysis and short circuit algorithm, which are needed for distribution network planning. To represent the electric demand, also the electric consumption information is needed. Usually for the electric demand is obtained via an interface to Customer Information System (CIS). To form the customer load profiles in NIS, the yearly consumption and the customer classification data is transferred from CIS to NIS. With load curve indexes for each customer class, the yearly consumption is converted to individual load curves for each customer connection point. Nowadays with automated meter reading (AMR) and smart meters, hourly measurements are commonly available. Many distribution network operators (DNOs) are thinking of replacing the customer class load profiles with DNO specific load profiles. Detailed description on how the customer classification and load profiling can be made separately or combined by using clustering algorithms can be found in [4].

Once the customer and customer class information has been transferred to NIS, the load flow analysis is needed. The load flow analysis calculates how the current, voltage, power and load vary in different points and locations of the network. The load flow analysis calculates and sets the loads also for the distribution transformers.

DATA ACQUISITION

The task of acquiring data for optimizing DA may be extremely difficult, however if the utility is maintaining the network data in NIS, most of the data needed in (3) can be collected from the NIS database. Since the network topology information is composed in NIS, the needed index information i, j, f is also formed. Discount rate DR and lifetime T of the DA are given data as well as are the installation and yearly maintenance and operation of the switches MC. Since switches are located on the distribution substations, the loads used in (3) are the distribution transformer loads in NIS database. The NIS load flow analysis calculates and divides the load for each customer. The load flow analysis also stores the calculated load to transformers. The loads on transformers are divided to sub loads for each customer class. The customer interruption costs (CIC) are usually different for each customer class [5, 6]. Thus the customer damage costs in load point j is the sum of the customer class load multiplied with CIC of the customer class.

Short circuit and earth fault rates can be company's own fault rates or commonly available fault rate statistics like in [7] can be used. Fault rates are either fault rate per unit length or fault rate per unit. With all network data with connectivity in NIS, the feeder fault rates can be calculated using item amounts and cable/line lengths in feeder and the corresponding fault rates.

SPATIAL ANALYSIS FOR THE ACTUAL SELECTION OF AUTOMATED SITES

Many optimization models like the model used in Helsinki assume that a green field installation is used and that all secondary substations are applicable for the DA installations. In real networks this is not always true, there are also constraints and existing DA installations in the field. It may be that for ex. motor controlled switches are not available for some types of MV switchgears. Thus, not all secondary substations are applicable for DA. Moreover, there might already be installed DA in the secondary substations. These two factors have to be taken account in the selection of the secondary substations for DA installations.

Database analysis and graphical visualization of all the different aspects is very informative and effective in assisting the selection of automated sites. The analyzing and visualization tool used in Helsinki is Spatial Analysis application in Trimble NIS. Spatial Analysis is an application for thematic mapping and general statistical analysis. It is a versatile tool that can be used for analyzing and visualizing any kind of network asset data or data related to it. An analysis can be based for example on network component attributes (e.g. installation year), maintenance data or network calculation results. The source data of spatial analysis can come from NIS database, some other relational database or text files. The retrieved data can then be combined with geographical data that is managed in NIS or imported from another source. When executing an analysis, the application processes source data and presents the results as thematic maps or diagrams. It is also possible to save the results in

table format for further studies. More detailed information on Trimble Spatial Analysis can be found in [8].
Spatial Analysis was utilized in Helsinki for visualizing the optimal and applicable distribution substations for DA. The result of the optimization model was first saved on the NIS server as a text file which was then defined as one of the data sources for the analysis. Next the SQL queries for combining the optimization model data with component data and network topology were formed and saved. Finally visualizations for presenting the results on the schematic network diagram map as well as on geographic network maps were created with the tools on Spatial Analysis.

The simplified process model of the data acquisition, DA optimization and visualization is illustrated in Figure 1.

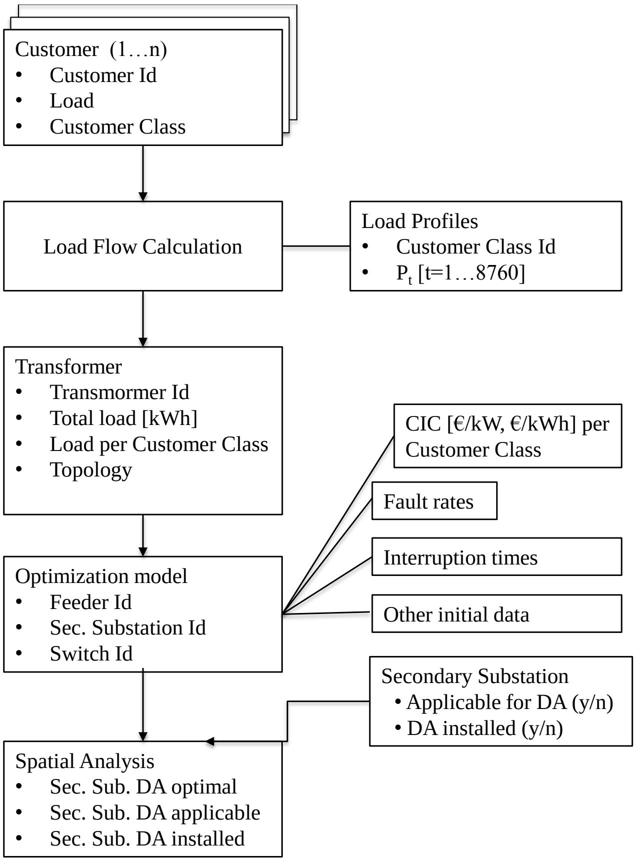

Figure 1. The generation process of the optimization and visualization of distribution automation.

The final outputs shown in Figure 1 are:

- Optimal secondary substations for DA
- Secondary substations that are applicable for DA
- Secondary substations with existing DA

The visualization of these results both on the schematic network diagram map and on the geographical network map are illustrates in Figure 2 and Figure 3.

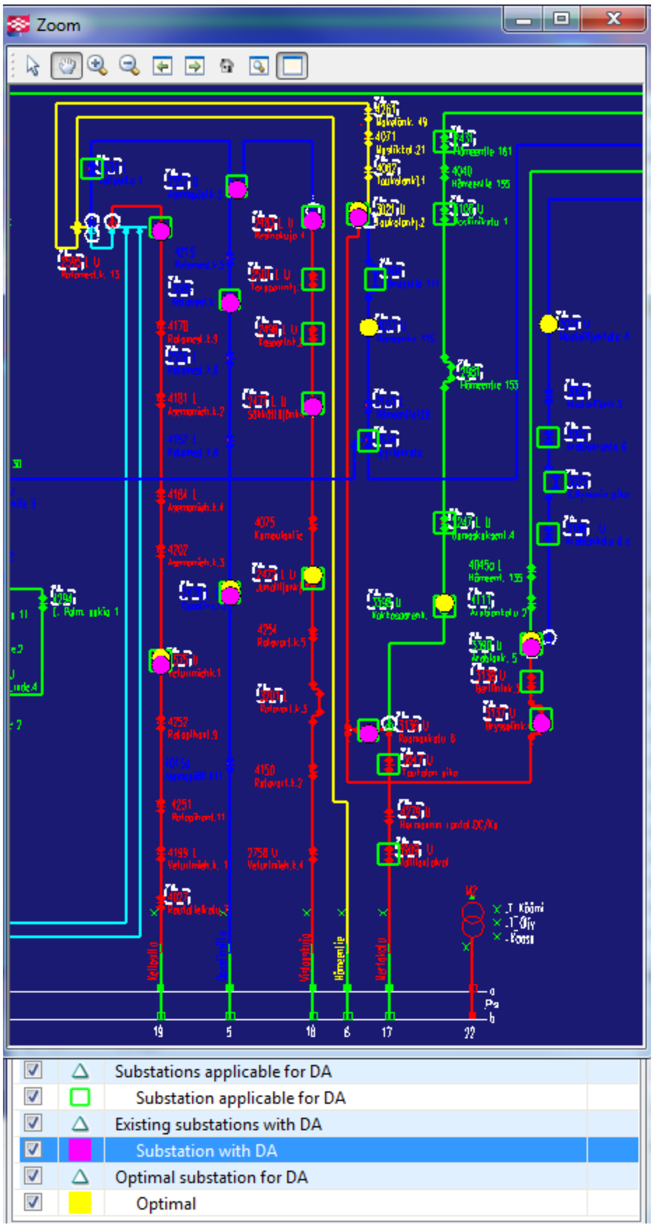

Figure 2. The illustration of applicable secondary substations for DA, existing DA substations and suggested optimal distribution automation secondary substations on network diagram.

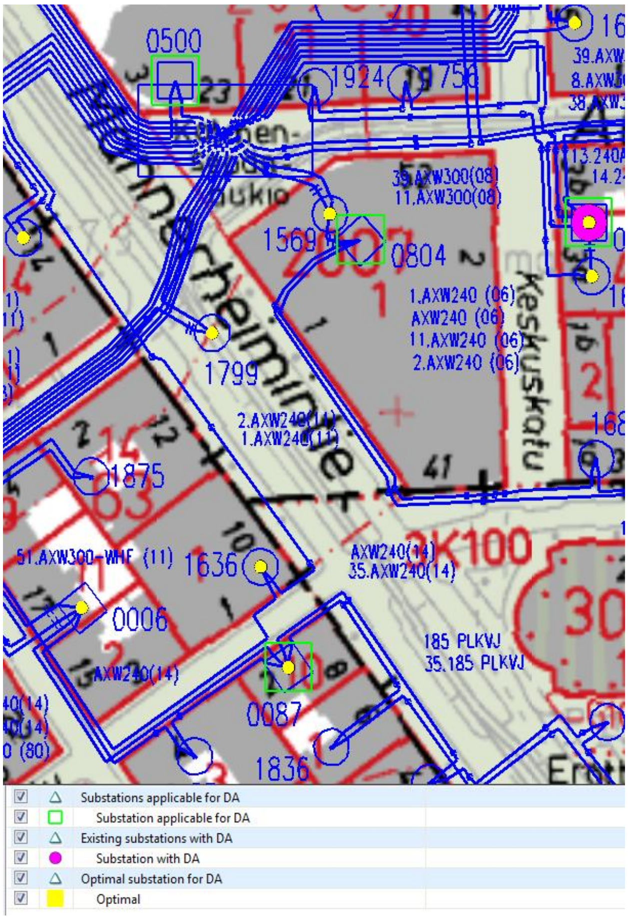

Figure 3. The illustration of applicable secondary substations for DA, existing DA substations and suggested optimal distribution automation secondary substations on network map.

Visualizing the optimization results, applicable sites and existing DA sites with different tags on the map, assists the actual selection of secondary substation for DA installations. For example the optimization model suggest one secondary substation in the feeder and that secondary substation in question is not applicable for DA. However, if there is near an applicable site, the applicable site can be chosen for the installation. If there is no applicable site near the optimal site, the planning engineer can reject the site or suggest the retrofit of the primary equipment on that secondary substation.

CONCLUSION

This paper describes the generation process of optimizing DA and using network information system both in acquiring necessary data for optimization model and in supporting the selection of the actual secondary substations for the installation project. The effort of collecting and calculating all the initial network and customer data needed for optimization can be extremely complex and laborious. However, once the utility has implemented the network data in NIS, the utility can benefit from the advanced applications and qualities and in modern NIS. Load flow analysis, interface to CIS and network topology information together with database features enables the calculation and the collection of the data for the DA optimization model. The utilization of NIS and advanced optimization model accelerates the planning and implementation of cost-effective DA.
Many DA optimization models, like the one used in Helsinki, assume that all the secondary substations are applicable for the installation of DA. In real cases many factors like the age and the model of medium voltage switchgear are limiting the installations. Also the models assume that there is no existing DA. Using Spatial Analysis and visualizing optimal and applicable secondary substations together with existing DA on the network map, assists the selection of alternative sites for DA. The presented method extends the utilization of optimization models from only green field applications to distribution networks with limitations and with existing DA installations.

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