REGULARLY OPTIMIZED MEDIUM VOLTAGE NETWORK AS A TARGET FOR PLANNERS: A CASE OF HELSINKI CITY

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ABSTRACT

This paper focuses on optimizing the medium voltage distribution network in an urban area. An optimized target network is created for the planners of electricity distribution networks. The planner decides if it is beneficial to follow the plan or stay in the present network model. It has been shown in the transmission level, that this methodology has benefits. The paper presents a short formula for the planners to make the decision. For the optimization task, a new application uses a raster map of the city as one input in the process. The map assists the application to find permissible and cost optimized cable routes when supply cost, outage, and maintenance related information has been given on the raster map. The resulting target network has suitable cables and disconnectors drawn automatically on the cost optimal places. In the results, we see three optimized networks with numerical results.

INTRODUCTION

Using computer applications for optimizing the electricity distribution network has been found to be beneficial when compared to plans made by experts [1]. In this paper, we use a computer application to optimize the medium voltage network and integrate the resulting model as a target network for the human planners.

The idea of using an optimized network as a target network has shown improvements in the transmission level [2]. E.g., comparisons made between the present and target networks have found that the target network had 10–30 % lower network costs [3]. When investing from the present network towards the target network, the costs were lowered around 20 % in 40-year review period [4]. Yet in another study, where 110 kV and 20 kV levels were included, they did not obtain the target network in a 25-year review period, but still the yearly costs were 15 % lower than if other option was to continue with the present network [5]. The cost optimal target network made without the knowledge of the present network is not always the most cost efficient solution, when you consider the expansion planning from present network [4]. In any case, by following the target network, and not obtaining it, it can still be beneficial [6]. The planner must decide between 1) staying with the present network or 2) going towards the target network.

Using a raster map when optimizing the distribution network has been discussed decades ago [7], but using the raster map in a real life optimization applications has been no mainstream practice in utilities. This can be useful, as choosing proper routes and topology is one of the main tasks. The raster map helps to weight the routes by their true geographical parameters, which leads to better results. In this paper, first we shortly introduce the method of the optimizing application that gives the target network, then we state the case study area, i.e. the main peninsula of the Helsinki, and the parameters. After the parameters, we state a formula for deciding if it is reasonable to follow the optimized target network or stay in the present network model. In the results section, we see three different optimized networks in the network information system where the manual planning takes place. Lastly, we look into the numerical results of the target networks to see some interesting features.

OPTIMIZATION METHOD AND AREA

Planning process

Optimizing is only a part of the planning. Optimizer gives results based on the input, and its output is a new input for the planner. Figure 1 illustrates the planning process.

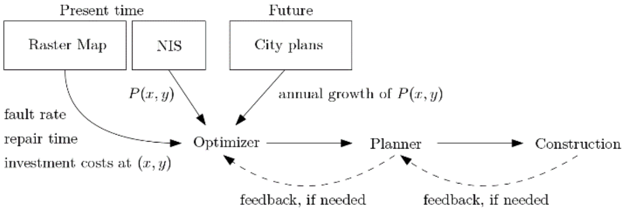

Figure 1. Information turned into a distribution network. The raster map gives the fault rate, the repair time, and investment costs. NIS gives the locations of substations. City plans give the load growth forecasts for different areas.

Optimizing application

Helen Electricity Network Ltd. has been piloting an add-on application, Trimble Optimizer, in Network Information System, Trimble NIS. One of the novelties of the application is that it uses a raster map of the city as one information source. The raster map's colors represent a trenching cost, a fault rate, and a repair time for cables.

The application uses VOH-algorithm to optimize [8]. First the application makes an initial guess of the optimal topology. To avoid local optimum solutions, the algorithm make changes to the topology. The application makes cost parameters for routes between the nodes using the raster map information [9]. For proposed topologies, the application searches optimal switches and their location based on the restrictions and parameters [10]. As a result, if the technical restrictions are not violated, the application provides topology with the lowest total cost, i.e. the sum of investments, losses, and interruption costs in a review period.

Area of study

Helsinki, the capital of Finland, is the city of the studies. There are two medium voltage levels in Helsinki, namely 10 kV and 20 kV. The 10 kV is the voltage level in the city centre and close to it, and the 20 kV is used out side the city centre.

A part of the 10 kV network is studied in this paper including the southern part of the main peninsula of Helsinki. The area has five primary substations and 402 secondary substations.

The relevant part of the raster map is shown in Figure 2. One pixel on the raster map represents about ten meters in real life.

Figure 2. The relevant 10 kV area, the main peninsula of Helsinki, cropped from the original raster map. Different colors represent different unit costs and interruption related parameters. Here roads have a darker color meaning relatively lower trenching costs. All other areas are colored in lighter grey representing higher trenching costs.

Parameters

Optimizer has many parameters. Some are numerical, like allowable voltage drop, and some are logical, like a reserve connection model. The main numerical parameters are shown in Table 1.

Many different cable types can be used, but here, according to the utility's principles, cable with cross-sectional area of 240 mm^2 is used and therefore the only included cable type in the optimization. This issue also shortens the optimizing time.

Only one fault rate parameter for the cables is applied, i.e. 0.61 faults per 100 km per year, derived from the company's fault statistics. The maximum ampacity limit for the cable is 325 A, resistance 0.14 Ω/km, reactance 0.116 Ω/km, and susceptance 0.0940 mS/km. Maximum voltage drop is 5 % in the normal operation and 9 % in a contingency operation.

Table 1. Main cost and time parameters for the optimizing application

Costs	€/pcs
– manual disconnector	4 500
– remote disconnector	4 900
– remote disconnector station	6 500
– main substation circuit breaker	20 000
– new main substation connection	25 000
	€/m
– cable, 3x240 mm^2	30
– trenching, roads	155
– trenching, other areas	900
	€/kW
– energy losses	0.05
– customer interruption cost, power	1.1
	€/kWh
– customer interruption cost, energy	11.1
	%
– interest rate	5
Times	h
– manual disconnector	0.833
– remote-disconnector	0.167
– repair	12
	a
– review period	40

The logical parameter is used to choose a reserve model. Three different reserve models are applied and thus, there are three topologies in the case study. The reserve models are 1) the cost optimal reserve model, 2) the full reserve model, and 3) the inter-substation reserve model. The cost optimal reserve model means that a reserve connection is made only, if it lowers the total costs. In the full reserve model, every secondary substation can be supplied by at least two MV feeders of one primary substation. The inter-substation reserve model has a solution where each secondary substation has two connections supplied from at least two neighbouring primary substations.

Present loads of secondary substation are from the NIS database.

Annual load growth percentages for the secondary transformers are derived from the city plans. The city plans include the location, the area, and the type of buildings, as well as the time of construction. We classify the data by the building types to residential, business, and rest. The reason for this is that distinct areas include various number of building types with their own load profiles. The floor areas of building types influence when combining load profiles.

For simplicity, every secondary substation i gets its annual load growth percentage $r_{i,j}$ based on its supplying primary substation's j total growth rate R_j. This is expressed in Equation 1.

$$r_{i,j} = 100 \times \left(R_j^{\frac{1}{T-t_0}} - 1\right), \tag{1}$$

where

$$R_j = \frac{P_{T,j}}{P_{0,j}},$$

T is the forecasted target year, t_0 is the starting year in the forecasts, $P_{T,j}$ is the forecasted peak load for the primary substation j in the forecasted target year and $P_{0,j}$ is the peak load of the primary substation in the starting year. Here, R_j is estimated for years 2030, 2040, and 2050. The starting year in forecasts is 2016. Forecasts are an output of a separate program.

For the input, $r_{i,j}$s are tabulated with their related x- and y-co-ordinates. With 402 secondary substations and 40 years period, this results into $402 \times 42 = 16\,884$ values.

Formula for deciding between the present and target network

It is not always cost-efficient to go from the present network to a target network [4-6]. We need a formula to help with the decision. This formula compares the investment costs of renewing the present network or updating it to the target network or to any other determined network. Especially in the urban area, the difference in the investment costs, i.e. the cable and the trenching costs, are the most significant part of the total costs.

It is usually reasonable that we operate with the present network until it has come to an end of its lifetime [6]. At the end of the lifetime, we can invest to renew the previous network or we can invest for the target network. No other target networks than the optimized are considered, as it is the most optimal we have.

To invest in the target plan, Equation 2 must hold true [11].

$$K_{\text{target}} \leq K_{\text{present}}, \tag{2}$$

where K_{target} is the total investment cost for the target network and $K_{present}$ is the total investment cost for the renewal of the present network. Both, target and present, investments are discounted back to present value before comparison. Each is calculated

$$K_j = \sum_{i \in \mathrm{E}_j} \left(\frac{l_{\mathrm{c},i} k_{\mathrm{c},i}}{\left(1 + \frac{p}{100}\right)^{t_{\mathrm{c},i}}} + \frac{l_{\mathrm{tr},i} k_{\mathrm{tr},i}}{\left(1 + \frac{p}{100}\right)^{t_{\mathrm{tr},i}}} \right),$$

$$j = \text{a target } or \text{ a present},$$

where E_j is a set of sections in a network j. $l_{\mathrm{c},i}$ and $l_{\mathrm{tr},i}$ are the length of cables and trenches in a section i, $k_{\mathrm{c},i}$ and $k_{\mathrm{tr},i}$ the unit costs for the cables and trenches, and $t_{\mathrm{c},i}$ and $t_{\mathrm{tr},i}$ years in the future when an investment is needed for a section i for the cables and trenches. p is the annual interest rate.

The equation must consider the relevant sections from the present and target network. Figure 3, a variant of figure in [4], illustrates this point. In the Figure 3 from [11] the dashed lines are those that differentiate between the present and target network. These sections are numbered as 4, 5, 6, and 8.

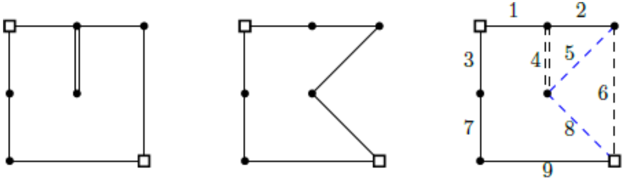

Figure 3. Small squares represent primary substations and black dots represent secondary substations. On the left is the present network, and in the middle is the target network. On the right, they are superimposed. Dashed lines are the lines that separate the present and the target network. [11]

For the topology in the Figure 3, we write

$$\underbrace{K_5 + K_8}_{\text{target}} \leq \underbrace{K_4 + K_6}_{\text{present}}.$$

Both sides of formula must fulfill the technical constraints of the network, e.g. all nodes have the reserve connection.

RESULTS

Three different reserve models were optimized for the case study purposes. Topologies of the target networks are shown in Figures 4–6. Numerical results are shown in Table 2.

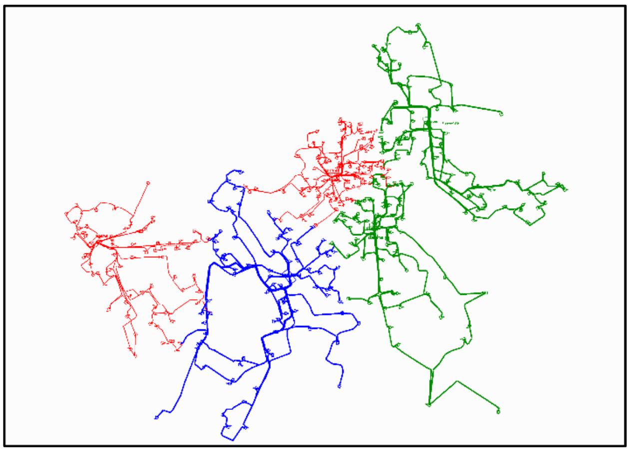

Figure 4. The resulted target network using an optimal reserve setting. Different colors represent different primary substation.

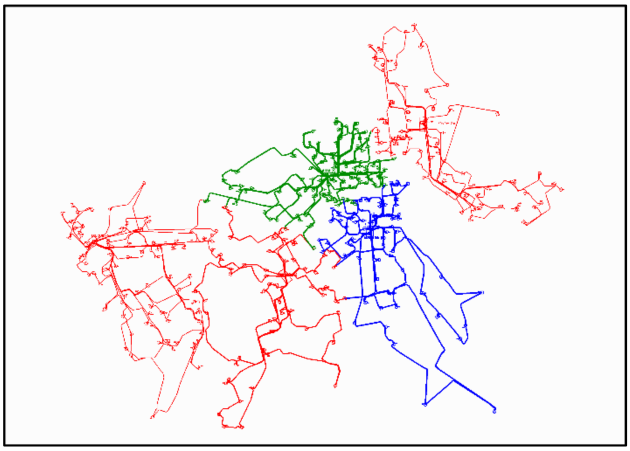

Figure 5. The resulted target network using a full reserve setting.

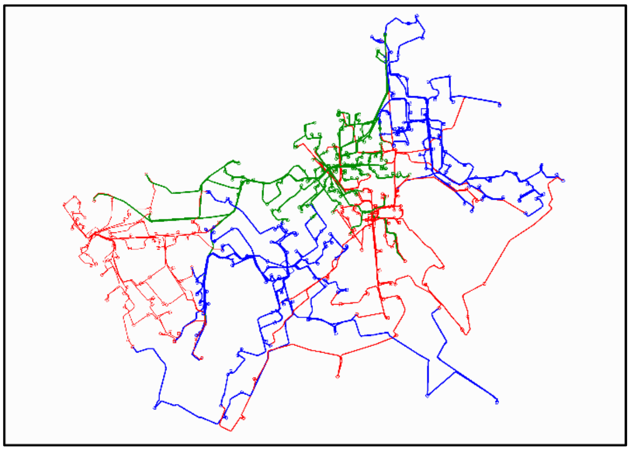

Figure 6. The resulted target network using an inter-substational reserve setting.

ANALYSIS

We can see many features from the results. For example, using the cost optimal reserve model, we do not always see a reserve connections when using the customer interruption cost parameters given by the regulatory model. This is interesting, as the national regulatory model states that weater-based maximum outage times in an urban area should be under six hours. It is also the goal for the maximum interruption time in Helen Electricity Network Ltd. This means that the cost optimal solution is not allowed. Another notable thing is that there is no remote-controlled disconnector in any target network model. This casts doubt on the fact that the remote disconnectors are installed on the grid at a constant rate.

When comparing different reserve models, there is no big difference in total costs, but only the full reserve and the inter-substational reserve models fullfill the recommended maximum outage time.

Table 2. Optimization results of the 10 kV medium-voltage network including five primary substations and 402 secondary substations.

	Cost optimal reserve model	Full reserve model	Inter-substational reserve model
	M€/40 a	M€/40 a	M€/40a
Total costs	10.55	10.89	11.31
– investments	9.18	9.42	9.77
– losses	0.98	1.17	1.22
– customer interruption costs	0.39	0.30	0.32
	pcs	pcs	pcs
Circuit breakers at primary substations	105	91	91
Switches	815	837	835
– manual disconnectors	815	837	835
– remote disconnectors	0	0	0
	km	km	km
Cables			
– 240 mm^2	96	112	123

DISCUSSION

Automating and implementing network optimizing tools to the network information system that the planners already use makes it easier to do the optimization regularly. This is important capability as new secondary substations and primary substations are regularly build to the network as well as forecasts of load growth change. When the application works as an add-on application of the NIS, it helps planners to make on-the-go optimization, as the NIS is the planning tool.

Many improvements can be done to obtain better results: the parameters could be more accurate, the raster map improved, and the main substation faults included.

In the future, Helen Electricity Network Ltd. will test brownfield optimization with the application. In this way, we can keep recently installed cables in the optimization. This might be useful, as the review time in the optimization is usually less than the life expectancy of recently installed cables. Other future studies include the major substation faults and studies with bigger cable types.

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