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Methodology for finding investment sites that can be refurbished from a nearby medium voltage line element instead of using the existing low voltage line corridor

***Abstract**. This paper proposes a methodology for highlighting alternative investment solutions from a large number of investment projects. The methodology identifies remote connection points located far from the sub-station where electricity can be provided from a nearby medium voltage line element. The methodology uses a mathematical model to find the smallest distance between a point and a vector. This methodology was tested in Elektrilevi OÜ where it proved to be very effective. This article also includes an example of using the provided methodology.*

Streszczenie.** W artykule przedstawiono metodę rozwiązań inwestycyjnych dla dużej liczby projektów inwestycyjnych. Metoda identyfikuje punty podłączenia oddalone od podstacji gdzie zasilanie może być dołączone do najbliższego elementu średniego napięcia. **Metodologia wyszukiwania lokalizacji inwestycji możliwej do zasilania z najbliższego źródła średniego napięcia zamiast linii niskiego napięcia

Keywords: network quality, investments, distribution network, finding refurbishment projects.
Słowa kluczowe: sieci zasilające, lokalizacja źródła zasilania.

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Introduction

The lifespan of distribution networks infrastructure (power lines and substations) is very long and investments extremely resource intensive. Therefore, it is essential to invest as efficiently as possible. Distribution networks are created over a long period of time and the principles that govern these investments can change. Because of that, the original configuration of the distribution network will not always be the most optimal.

In this article we examine a method which helps network analysts find the most favorable investment sites, by finding non optimal medium voltage (MV) configurations that can be effectively used to decrease underutilized low voltage (LV) network. By taking into account the surrounding MV network, this method can find investment sites where renovation costs can be much lower than simple algorithms using only LV network would suggest. The objective of this method is to find parts of long LV feeds that can be refurbished by building a new substation area from a nearby medium voltage line element (MVLE). Ideally, we can then dismantle a large part of the LV line, thereby reducing underutilized network and increasing the overall network quality.

Because every distribution network has its own principles (which materials and solutions should be used in different situations), we only provide the methodology to find these sites and not the actual solutions.

This methodology was initially designed for the Trimble Network Information System (NIS) but can also be applied to other information systems. The Trimble NIS is a software application that can be used for asset management, network development and planning of repairs as well as documenting and managing network assets that are central to its system. Trimble NIS includes several modular industry applications:

- Power System Analysis,
- Network Planning and Construction,
- Asset Management,
- Maintenance,
- Network Investment Management [1].

This methodology was tested in Estonia's largest distribution network, Elektrilevi OÜ (ELV). ELV provides power to about 500,000 customers with a total consumption of approximately 6.5 TWh as recorded in 2013. The company manages around 63,700 km of power lines and 23,100 substations [2].

Network quality in this article, is measured by security of the supply (number of failures) and the voltage quality. For measuring voltage quality, we are going to use the Estonian standard EVS-EN 50160:2010. The standard nominal voltage for LV network is U_n = 230 V and under normal operating conditions excluding the periods with interruptions, supply voltage variations should not exceed ± 10% of the nominal voltage [3]. If the voltage does not meet the standard, then the customers in ELV network are entitled to receive a discount for the network service price.

Overview of previous studies

Previous studies have:

- Discussed problems of simulation models for modernization of regional LV and MV distribution networks and showed a computational algorithm for the needs for the network modernization [4].
- Discussed various methods of economical analysis of cross-country power networks and presented a modified variant of the annual cost method and the costs of cross-country network unreliability [5].
- Presented a method based on evolutionary strategies [6] and dynamic programming optimization [7] for designing distribution networks.
- Discussed the mixed-integer programming and the evolutionary programming methods of distribution network system planning [8].

The method discussed in this article is also designed for optimal solutions in the investments for the regional LV and MV distribution networks, but uses an approach previously overlooked.

Methodology

Firstly, we exclude all connection points that closer to their subsequent substation than the critical distance $Crit\_Dist$, using the length of the existing low voltage line. Secondly, we find those connection points, where the closest MVLE is closer than desired distance Max_Dist. MVLE can be any medium voltage cable or overhead line part, which begins (and ends) with a pole, switchboard or a turning point for a cable line.

Thirdly, we need to include add some background information for suitable connection points: x and y coordinates (latitude and longitude), connection point ID-code (used to distinguish different connection), size of the main fuse, yearly electrical energy consumption, name of the substation and the feeder.

Fourthly, we find the shortest distance between the connection points and the nearest MVLEs, using connection point coordinates and the start and end coordinates of the MVLEs. Finding the distances of all the MVLEs from all the connection points would be too resource consuming. To counter this problem, we compare the coordinates of connection point $P_3(x_3;y_3)$ and MVLE starting point $P_1(x_1;y_1)$. We only calculate the exact distance if the distance is less than the sum of our desired distance *Max_Dist* and the length of the MVLE. We use this sum because the closest part of the MVLE can just as well be the ending point.

The overall process is depicted in Fig. 1 (starting with yellow and ending with blue.

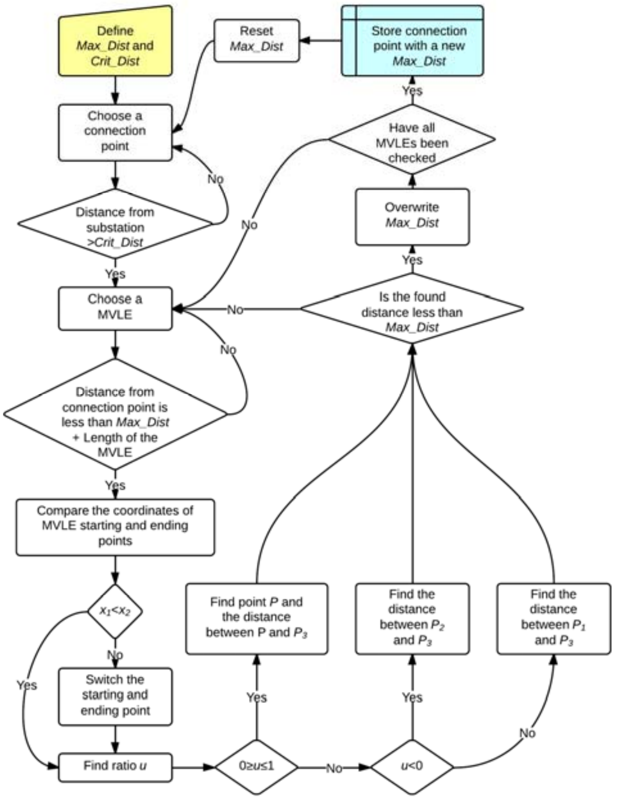

Fig.1. Schema depicting the overall process

We find this distance using the theory of distance between a point and a straight [3]. This straight passes through the starting point $P_1(x_1;y_1)$ and ending point $P_2(x_2;y_2)$ of our MVLE. Perpendicular for straight P_1P_2, that passes through $P_3(x_3;y_3)$ (the connection point), intersects with the straight passing through MVLE P_1P_2 in point $P(x;y)$ (Fig. 2 and 2). The positioning of point P can be calculated using formula 1.

(1) $$P = P_1 + u \cdot (P_2 - P_1)$$

where: u – ratio, that represents the relative distance between P and P_1.

If point P is situated on straight P_1P_2, then the distance between P_1P_2 and P_3 equals the distance between P and P_3 and 0≤u≤1 [9]. The dot product of two orthogonal vectors equals to zero, therefore:

(2) $$(P_3 - P) \cdot (P_2 - P_1) = 0$$

We replace P using formula 1:

(3) $$\left[P_3 - P_1 - u \cdot (P_2 - P_1)\right] \cdot (P_2 - P_1) = 0$$

Using formula 3, we can find ration u (4):

(4) $$u = \frac{(x_3 - x_2) \cdot (x_2 - x_1) + (y_3 - y_2) \cdot (y_2 - y_1)}{(x_2 - x_1)^2 + (y_2 - y_1)^2}$$

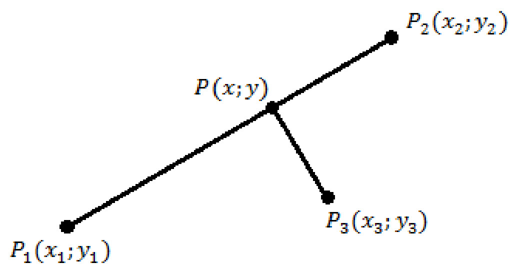

Fig.2. Distance between P_3 and P_1P_2 if 0≤u≤1

We can find the coordinates $(x;y)$ for point P by replacing u in formula 1 (5).

(5) $$x = x_1 + u \cdot (x_2 - x_1)$$
$$y = y_1 + u \cdot (y_2 - y_1)$$

Because MVLE are parts with a definite length, then we also need to consider situations where point P is situated outside MVLE and u<0 or u>1.

Fig. 3 depicts a line with a MVLE part P_1P_2. The distance between the straight passing through MVLE part P_1P_2 and our connection point P_3 is not the same as the distance between MVLE P_1P_2 and connection point P_3. In this case the distance we are looking for is either the distance between P_1 and P_3 or P_2 ja P_3.

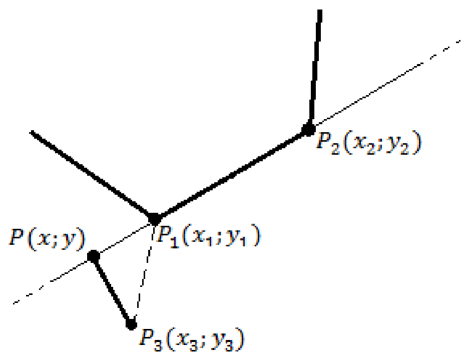

Fig.3. Distance between P_3 and P_1P_2 if u<0

The distance between P_1 and P_3 can be found with formula 6 [10].

(6) $$P_1P_3 = \sqrt{(x_3 - x_1)^2 + (y_3 - y_1)^2}$$

where: $P_1(x_1;y_1)$ – MVLE starting point, $P_3(x_3;y_3)$ – connection point.

In order to find out our current situation, we evaluate the corresponding u ratio. If 0≥u≤1, then point P is situated on MVLE part P_1P_2 and the distance we are looking for is PP_3. If u<0, then we have to find the distance between P_1 (MVLE starting point) and P_3 (connection point). If u>1, then we have to find the distance between P_2 (MVLE ending point) and P_3 (connection point).

This method only works if the x-coordinate of the starting point P_1 of MVLE is smaller than the x-coordinate of the ending point of MVLE (x_1<x_2). If this is not the case, we need to switch the coordinates of our starting and ending points before using the method. Also for the same reasons if $x_1=x_2$ and $y_1<y_2$, then we have to switch the y-coordinates of our starting and ending points before using the method.

Testing the methodology

The methodology was tested in the ELV network. The query that supports the methodology was written in SQL query language and the query was run in Oracle SQL Developer software. Oracle SQL Developer is a free integrated development environment that simplifies the development and management of Oracle Database [11].

In order to reduce the sample size, we used the following restrictions:

- *Crit_Dist* = 1500 m,
- *Max_Dist* = 100 m.

Using these restrictions, a total of 92 connection points was found on a total of 78 feeders. The location of these connection points is shown in Fig. 4 (connection points which are located close to each other are displayed as a single dot). This sample size was considered optimal for an initial testing on the basis of expert judgment, taking into account the budget size reserved to test the methodology. In order to increase the sample size, we should start with increasing the *Max_Dist* component as the increase in the solution cost would be rather insignificant.

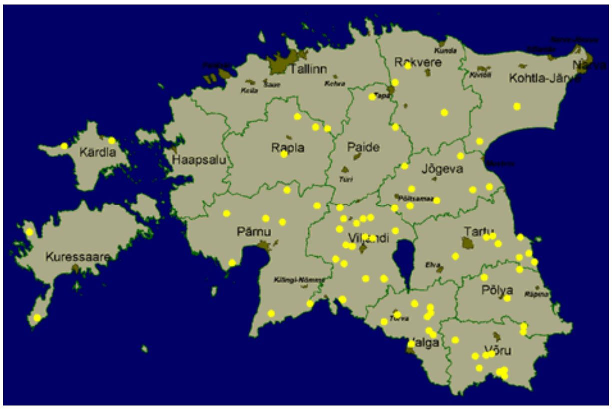

Fig.4. Connection points found by applying the proposed Methodology

Fig. 4 shows that the majority of the connection points found are located in the south-eastern region. Generally, this is in rural region where consumption is rather fading and, therefore, large-scale investment does not have perspective. Therefore, it is necessary to invest optimally, which this methodology strongly supports.

All found feeders were further examined to ensure that:

- Investment is sensible,
- There is no error in the data,
- They not currently being refurbished.

Investment is considered not sensible, if there is currently no valid network contract or the last year's electrical consumption was 0 kWh. It is not clear whether the consumption in these connection points will recover or if the connection point vanishes completely (e.g. with the old homestead). Five feeders were left out because of zero consumption. Also, after completing finalized investment solutions, five feeders were considered without long-term perspective because of changing MV network.

After further examination, 47 solutions were sketched to refurbish a total of 48 feeders. Two feeders are being refurbished with a common solution because they were located side by side. The diagram of found feeder's distribution is shown in Fig. 5.

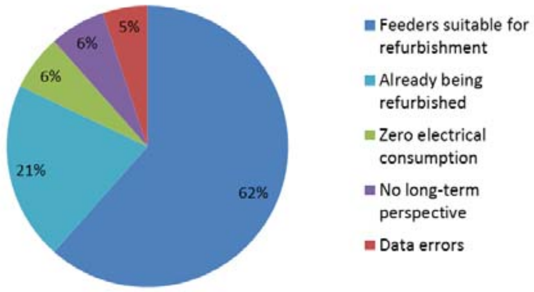

Fig.5. Distribution of feeders found by the methodology

To refurbish all of the 48 feeders, ELV would need to install approximately 30 km of LV line, 2.3 km of MV line and 42 substations. By this refurbishment, they can also dismantle approximately 33 km of underutilized low-voltage network, which prevents ca 200 failures a year and resolves voltage quality problems for 102 connection points.

The benefits of the methodology

This methodology helps to find the optimal investment sites, which using algorithms that calculate the cost for solutions along the existing LV line corridor appear to be too expensive.

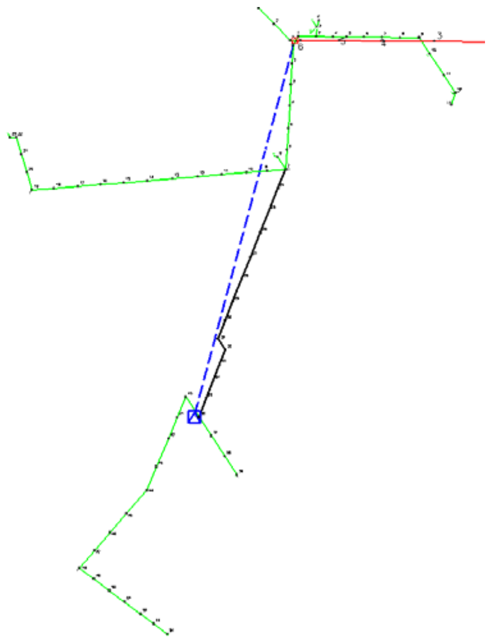

Fig.6. Solution along the existing LV line corridor

To illustrate this Fig. 6 and 7 describe the same network area. On these figures MV lines are indicated in red and LV lines in green, blue line indicates the new MV network and black lines indicate dismantled LV network. Because the existing LV line is too long for providing proper voltage quality, let us assume that a new substation is required to refurbish the whole LV area.

Standardized simple solutions are based only on the existing LV feeder (Fig. 6). However, our proposed method is able to detect the nearby MV line, which will clearly result in a more feasible solution. The cost difference between the standardized solutions and our new proposed solution is determined by the cost of length difference of old and new cable line (Fig. 7). More accurate cost calculations will help the planner to find more favourable investment sites.

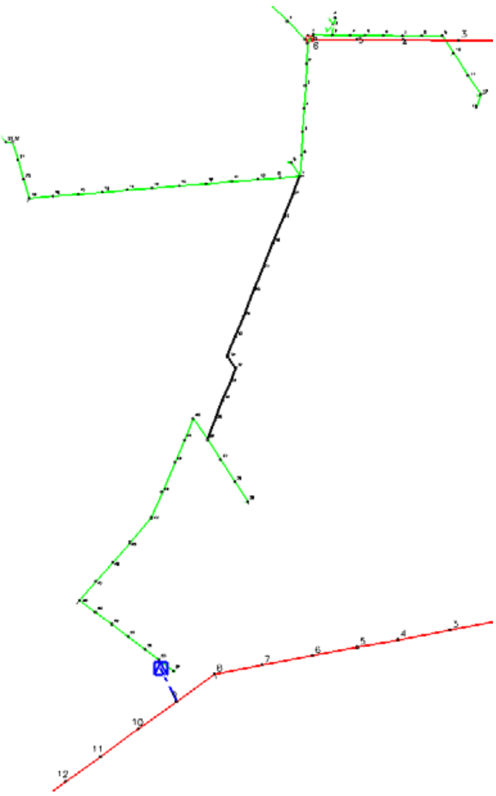

Fig.7. Solution using a nearby MV line

Fig. 8 shows Mihkli substation feeder F3, one of the network sites found using the proposed methodology.

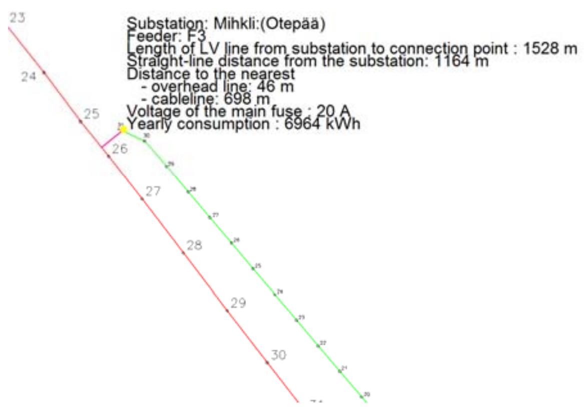

Fig.8. Example: Mihkli substation feeder 3

As seen on Fig. 8, the closest MV line (shown in red) is only a few dozen meters from the customer connection point, while the distance from the old substation along the existing LV line (shown in green) is more than 1,500 meters. Straight line distance from the nearest MV line is marked violet. As this client consumes electricity all year round, the refurbishment of the given project seems to be reasonable. The decision to go forward with any investment should always be done case by case and cannot be added to the methodology based on simple grounds.

Summary and outlooks

To conclude, this paper describes a methodology that helps network planners to find favourable investment sites. This method calculates the distance between a connection point and the nearest MVLE. If this distance is a lot smaller than the distance between the connection point and its substation (using the existing line corridor), then the optimal solution may be to build a new substation area and connect our customers to the new substation.

This method was tested in ELV network and 83% of the connection points found were considered effective (21% of which were already being refurbished). Therefore, the results were very good and this method can and should be used for network investment planning. However, the decision to go forward with the investment should always be done case by case. The restrictions used to test the methodology were chosen to provide a suitable number of feeders for testing and do not pose any actual limitations. The restrictions can be changed in order to provide more potential investment sites.

With small changes, this method should also be able to find nearby substations or LV line elements, therefore negating the need for a new substation and reducing the potential investment cost even further. Future research should evaluate how to implement such a methodology in an actual planning process. Also, there is a need for a methodology that evaluates the actual needs of a customer and its future outlooks.

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