RESTRUCTURING OF THE EXISTING MEDIUM VOLTAGE CABLE NETWORKS USING SEGMENTATION METHOD – IMPACT ON NETWORKS RELIABILITY

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ABSTRACT

The idea for the paper is to show new approach based on the segmentation concept leading to significant improvement of the network configuration (reduced number of deployed assets) and hence, its reliability. The method uses geographical location of existing distribution substations. During restructuring process assets number are minimized but, congruently, the new configuration is achieved using as many of existing assets as possible (cost minimization).
The practical survey was done basing on the digital model of real 10kV network operating in one of the biggest cities in Germany which was created using NEPLAN® software.

INTRODUCTION

The intensive post war rebuilding period and the strong economic development in the 1960ties had caused massive electricity system development and expansion throughout Europe. Many of the European medium voltage underground cable networks had been deployed in that time and nowadays they are all facing ageing problem. This issue wouldn't be such a challenge if the electricity market condition did not change. The liberalization of the latter has developed savings oriented tendency among the network operators. Although the ageing assets (ca. 75%) are offering a scary perspective for the huge maintenance investments, ageing itself, as well as the need of renewing assets, could be considered as a reasonable opportunity to develop optimized network redesign concepts.

RESEARCH OBJECT – MV CABLE NETWORK

The chosen network represents a typical distribution configuration. It is being fed by two 110/10kV transformers (one stays in reserve) and consists of 95 cable routes which connect 89 secondary (10/0.4kV) substations. The total circuit length is 41543m. Most of deployed cables (85%) have paper insulation and their cross-sections vary from 95mm^2 to 300mm^2. The network itself represents a typical city configuration: open rings with cable routes running under the streets and distribution substations located in the buildings. The simplified scheme of this structure is presented in **Figure 1.**
The age profile of this network represents the actual situation of the existing networks built in the intensive post war rebuilding period. For today, 37% of the deployed cable lengths have been in operation for longer than 50 years. This situation will become even worse, since in the coming 25 years another 41% of the deployed cable lengths will reach this age. Such unfavorable asset age have the obvious impact on the network reliability.

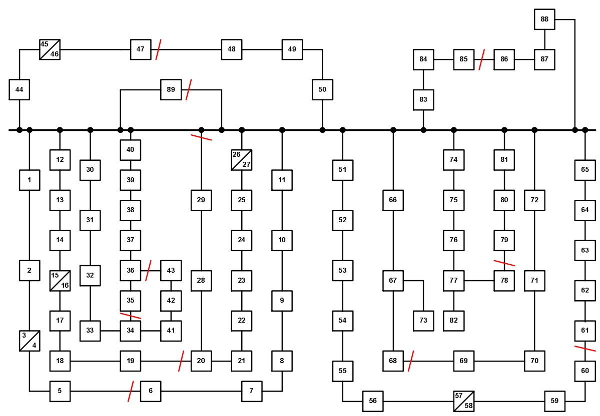

Figure 1. Simplified scheme of the 10kV 'side' of the chosen network.

Simplified scheme presented above exposes network structural "weaknesses". The substations are not proportionally apportioned in the main rings (one or few substations main rings); inner rings structures requiring extra cable connections and switching equipment are not improving network reliability [1].
Such passive structural disadvantages are additionally "boosted" by the ageing effects also. Bearing in mind the most unfavourable age profile of the cable assets, the combined impact of these two factors is already alarming for today and could be devastating for the network reliability in the future [1][2].
As it was stated in the introduction, although this scenario seems to be pretty pessimistic and offers nothing but problems and extended financial investment, it could be regarded as the opportunity to reconsider the redesign scenarios [3].

RELIABILITY EVALUATION – ORIGINAL NETWORK

The results of the original network reliability evaluation concerning assets age (implementation of the ageing factor) [1][2] are presented in **Figure 2**. The results have been presented in the pie chart form to expose equipment type impact on the network reliability.

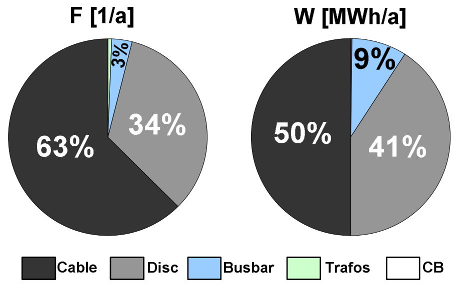

Figure 2. Reliability results of the original network showing impact of the different assets types on the total failure frequency (F) and non delivered energy (W).

Presented results are showing very common feature of any electrical network – its reliability is actually depending on the transmission means (cable/overhead lines) and the correlated equipment. In the network in question, every terminal connection is realised via a disconnetor hence their significant impact is understandable.

Figure 2 literally exposes the potential solution. The reliability of any mechanism (system) is proportional to the number of elements involved. Following such simple reasoning, network reliability can be significantly improved by reduction of the transmission assets number.

Although this idea may sound extremely banal, recalling the disadvantageous structural connections shown in **Figure 1** proves its rationality.

Many existing networks operate having disadvantageous structural connections made of ageing assets. In perspective, such networks offer nothing but increased maintenance expenses and significant reliability problems. Following [3] "*(…) the opportunity is taken to implement redesign (…)*", all of the discussed factors are nothing but the opportunity for redesign based approach – restructuring.

SEGMENTATION METHOD – APPLICATION AND RESULTS

Idea

The method uses geographical location of the existing distribution substations. In a first step, the ideal 'bee-lined' network configuration is being set. Next, the 'bee-lines' are being compared to the actual laying of the cable assets giving the possibility to use as many of the existing structures as possible to create close to target network. To minimize the investments the whole 'reaching for the target' procedure could be apportioned into two steps (two network variants analysis).

- **Target Network** – originally located substations are connected via "bee-lined" connections resulting in a new network configuration.
- **Midway Network** – network created using as many of the existing assets as possible to achieve new, semi-improved configuration.

Application

As it was stated above, the whole research part was done using digital model of the real 10kV city network operating in Germany. According to the presented method idea, the geographical location of the substations (which remain all the time unchanged) is crucial. **Figure 3** below shows the geographical original network substations positioning as well as the actual network connections.

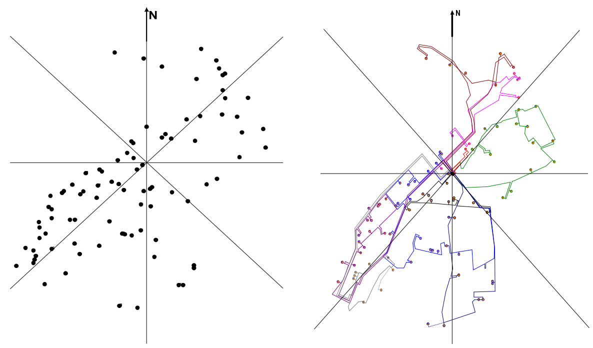

Figure 3. Original network configuration: geographical location of the secondary substations (left) and actual connections (right). Axes' crossing means the main supply point.

Step 1

The secondary (NE/NW) axes have been set as the primary since they create more-less symmetrical substations apportionment. Next to it, basing on geographical location of substations, the target network was created using so called "bee-lines". The attention was put to connect all the substations in such a way to end up with the clear ring structures. The result of the "bee-lined" connections is presented in **Figure 4**.

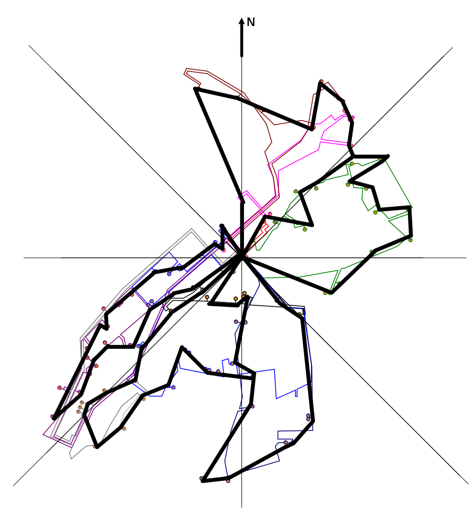

Figure 4. Bee-lined target network.

Original number of 9 main rings was reduced to 3 but two of them have "W" structure. "Bee-lined" network circuits length was limited to 15725m (62,1% length reduction).

According to the new network configuration, a corresponding digital equivalent was created. All the cable connections were modelled as XLPE insulated ones having the uniform cross-section of $185mm^2$. By appropriate positioning of the load switches, even significantly increased loading can be trouble-free maintained in an open ring feeding configuration. Simplified scheme of the target structure is shown in **Figure 5**.

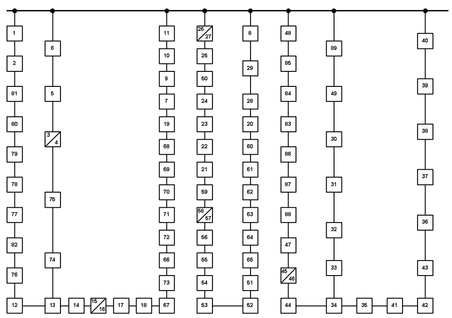

Figure 5. Scheme of the target configuration.

Reliability evaluation proved the functionality of the asset reduction concept resulting in significant reliability metrics improvement presented in **Figure 6** below:

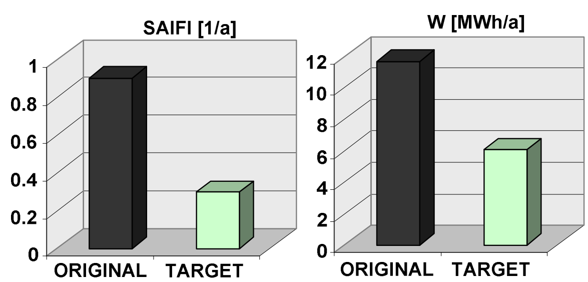

Figure 6. SAIFI and non deliver energy (W) reliability indices of the original and target networks.

The original poor system average interruption frequency index SAIFI value is resulting from the unusual and unique protection configuration applied in this particular network. It is noteworthy though, that in the target network the protection configuration scheme was left unchanged. Only by reducing cable assets the main reliability system indice (SAIFI) can be tremendously improved.

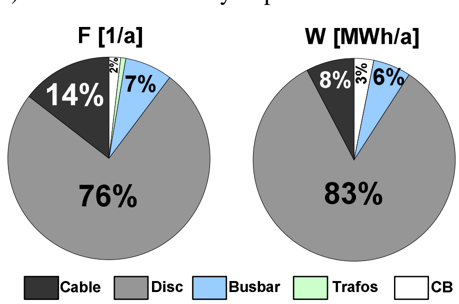

Figure 7. Reliability results of the target network - impact of the different assets types on the total failure frequency (F) and non delivered energy (W).

Figure 7 shows the impact of particular asset types on the two reliability metrics like failure frequency and non delivered energy values of the target network.

The presented results show that significant reduction of the network structures ended with entirely new apportionment. Although the cable assets length was drastically reduced, there are still 89 cable connections required to connect all the present substations which location remains the same. Every cable connection is realised via disconnector giving the load switch number of 178. Such significant number of load switches compared with the reduced cable length ended up with the clear dominance of the former.

Such apportionment has another significant advantage. The underground cables regular maintenance is significantly limited, if not impossible, due to their lying and therefore it is hardly performed (high costs/questionable effects). In opposite to cable assets, the disconnectors are easily maintained hence the influence of the ageing can be minimized or at least controlled.

Step 2

Going back to **Figure 4** it can be noted that the target network is actually already there. All that needs to be done is to reconnect it.

The target network routes, although representing "bee-lines" only, are practically matching the already existing cable routes. It means that it is possible to create the target network with relative small investment involved.

The network geographical lay-out and the actual ring connections are naturally divided into 'segments' – one or more rings groups can be treated separately allowing strategic approach (i.e the oldest rings undergo restructuring first).

The natural consequence of the strategic approach of the segmentation method is creation of the "midway" solution – an enhanced network structure featured by significantly improved performance.

Practical example – "midway" network

Figure 8 illustrates the creation method of the possible "midway" network.

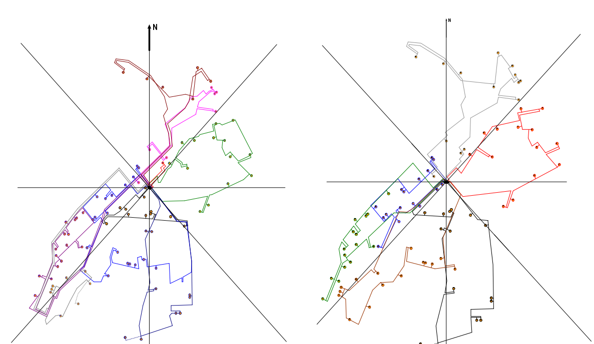

Figure 8. A possible way of constructing "midway" network: original structure on the left, "midway" structure on the right side.

Nearly 6670m of new cable assets (XLPE) were necessary to create presented "midway" network. It is equal to expenditure of ca. 1-1,5 million Euros. In this place it needs to be noted that the investment can be easily parted between the segments allowing strategic approach. The simplified scheme of 10kV side is presented in **Figure 9.**

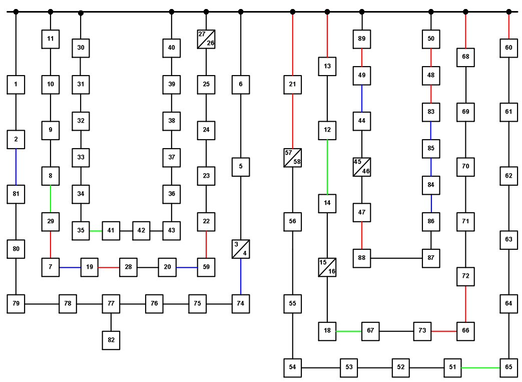

Figure 9. "Midway" network simplified scheme.

Such investment guarantees many advantages though. The new network length is reduced of nearly one-third (13685m); the number of the main rings is minimized from 9 to 6 (switchgear reduction). Reducing and deploying new cable connections change general network age profile what, if coupled with 'pure' ring structures, is beneficial for the network reliability as it is presented in **Figure 10**.

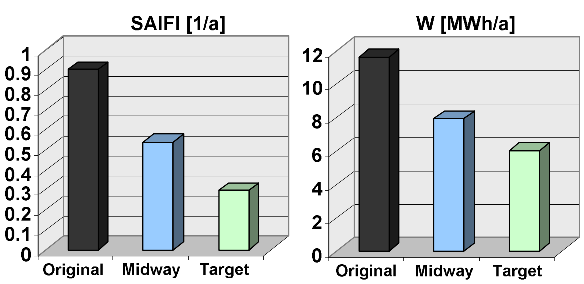

Figure 10. 'Midway' solution is offering a step to achieve target network configuration and performance.

Remaining original assets are featured with certain age and therefore have impact on the reliability results [1][2] either of the original and "midway" network set ups but still the improvement of the "midway" solution is significant (35%).

SUMMARY

The primary concern of the modern electric companies is to minimize operating capital investment (maintenance and controlling expenditures, development costs etc.) while keeping up the desired system reliability and functionality in the same time.

The underground distribution systems specific operating conditions demand individual approach. Cable networks can be regarded as 'under'-maintained because of the significant limitation of maintenance activities in case of cable assets.

The chosen network seems to be the perfect research object since it is featured with all possible structural disadvantages originating from the post war intensive rebuilding period which are typical for any cable network deployed in that time.

Among many significant problems, two require extra maturing: **ageing** and **structural configuration**. Ageing itself is an unavoidable process and it has obvious impact on the asset performance but its ratios remain unknown. This impact can be somehow managed by strategic and accurate maintenance activities. The second issue requires more investigations and investments but according to presented results it offers considerable benefits.

Actual unfavourable age profile of the existing networks can be powerful driving force to reconsider redesign scenarios. The presented segmented restructuring concept is extremely simple in its methodology and offers significant system performance improvement.

According to the recently arisen discussions which are questioning the sense of the long term system planning following previously set target structure, the proposed method is offering the short time modifications and the target structure is created basing on the existing equipment. Geographical location of the secondary substations introduces natural division (segmentation) of the whole network structures – whole process can be done in step-by-step mode and therefore can be easily adapted to the changing conditions (i.e. unpredicted events concerning serious changes in the system development planning).

The achieved results of the both new system configuration (midway and the target) are very promising. According to them, it can be stated that the method proposed makes possible to restructure the existing network with minimal cost allocation giving significant benefits of the reduced asset number (maintenance) and increased reliability.

The presented network structures are completely operational (no overloads) and can be realized with minimized investments. The developed target network of the real network used for the research study will be realized within the renewing strategy of the operating company in the next years.

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[3] CIGRE WG 37-27, "Ageing of the system – impact on planning", *Technical Report*.