Target Network Planning and Asset Condition Assessment as Basis for an integrated Asset Management Approach

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Abstract

Due to incentive-based regulation and in particular the amendment from 2016, distribution system operators in Germany face increasing cost pressures. Structured asset management can be used as the foundation for a cost efficient use of the grid equipment. As part of this paper, a methodology will be presented for combination of strategic and operative elements of asset management in a holistic investment schedule. On the one hand, the main building block is strategic network planning for identifying the need for action based on future supply tasks, and on the other a structured assessment of the condition of current network equipment. This paper focuses on the methodology and results of the strategic network planning. The methodology for deriving an investment schedule based on status and strategy indices was applied to the distribution grid of Stadtwerke Ratingen GmbH.

1 Background and Motivation

The significantly reduced return on equity and the resulting reduction in revenue caps require distribution system operators to implement further measures to reduce their medium-term capital and operating costs. Here, structured asset management is a basis for the cost-efficient use of the grid equipment. A company that creates an adequate management system according to DIN ISO 55000 for their assets considering their life span can best exploit the efficiency potentials. Asset management is generally divided into a strategic, long-term part and an operative, short-term part. In practice, these two parts are interlinked through the skilful merging of budgets and operational needs for action.

Most “business as usual” approaches can only partially accommodate future challenges in practice as, in addition to the increased cost and efficiency pressures, network operators also see the impact of the “Energiewende” (particularly the increasing integration of decentralised generation plants) and the changes in the demand structure due to demographic change and the sector coupling resulting in electromobility and power to heat applications. Added to this is the increased use of energy storage systems.
Although the Stadtwerke Ratingen GmbH distribution grid only has around 600 feed-in plants and a relatively well-equipped network with no acute needs for action, it is still logical to set a course towards future-orientated maintenance, renewal and expansion strategies as the decisions taken today have long-term effects in the electricity network industry.

An important building block on the way is the accurate condition assessment of the grid equipment within the distribution network. The methodology for an objective condition assessment and the condition evaluation based upon it will be presented in this paper.

The analysis of future supply tasks and the derivation of the resulting needs for action can take place via strategic target network planning that comprises conventional as well as innovative grid equipment. This article will present the methodology and project phases for such a sustainable network planning. The use of this methodology allows a technical consideration of existing network structure, including future and regulatory requirements as well as a cost/benefit evaluation of different options for the expansion, remodelling and/or the upgrading of the distribution network. Based on the results, a holistic investment schedule can be derived.

2 Methodology

In this paper, the methods for objective condition assessment will be presented as well as for strategic target network planning.

2.1 Objectified Condition Assessment

An accurate condition assessment allows a paradigm shift from an event- or time-orientated to a condition orientated and forward-looking maintenance strategy. In addition to the topological and grid-related importance and the capital and operating costs, the current condition is the third major determinant in the overall evaluation index of a single grid equipment. There is need for a standardized procedure for assessing the technical condition of e.g. the secondary substations. An extensive digital list for damage evaluation with around 80 criteria, which assigns individual inspection points precisely designed evaluation rules and contains example photographs, ensures that the condition assessment can be carried out objectively and independent from the employees' area of expertise. In addition to the visual inspections, diagnostic measurements and function tests are also carried out during the inspection in order to measure the grounding resistances, partial discharges or temperature distributions for example. When the data has been collected on-site a condition value can be calculated for each equipment. These values are based on different profound assessment models and classifications that allow the reliable weighting of individual inspection points and their importance to the condition of the equipment [1]. The digital checklist as well as the corresponding damage description list are available for different electrical equipment e.g. secondary substations, cable cabinets and overhead lines.

2.2 Target Network Planning

Hereinafter, the essential components of an intelligent target network planning are introduced.

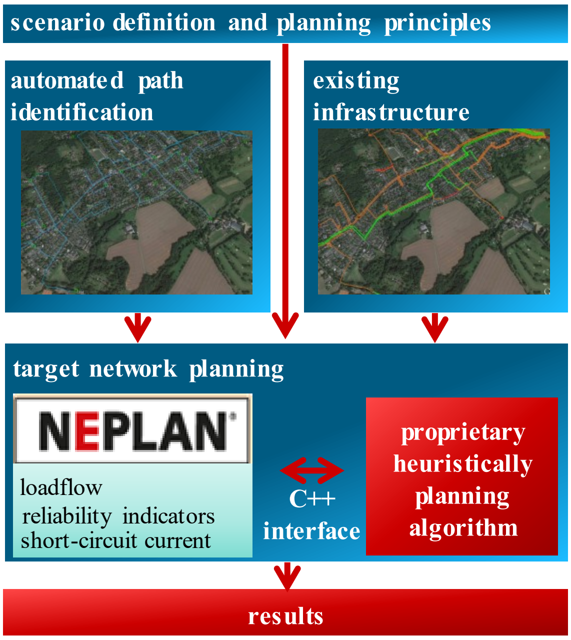


Figure 1 Overview target network planning

The components as well as their interaction are displayed in **Figure 1**. It can be seen that the network planning itself relies on three main inputs: the scenario of the future supply task and general planning principles, the existing infrastructure as well as information about possible paths for new lines. These components are explained more detailed in the following four subsections.

2.2.1 Scenario Definition and planning principles

During scenario definition, the period of time to be assessed must first be determined. Regarding the rapid developments in distribution networks nowadays, a time horizon of 10 years was defined in the project at Stadtwerke Ratingen GmbH but this time period can be flexibly adjusted to the individual needs of each network operator. Afterwards the relevant grid usage situations must be determined, strongly depending on the future feed-in from renewable energies and grid storage but also on future consumption. The future consumption is affected by demographic change and local industries but also by politically driven aspects e.g. energy efficiency measures and sector coupling. Especially sector coupling can lead to a significant increase in installed load due to high power electromobility charging and power to heat applications. All these topics are being addressed in discussions with the customer during scenario definition to derive most likely future grid situations.

In addition, the general planning assumptions are defined in terms of topology, redundancy and the technologies to be considered. It is particularly important here to define whether only conventional resources can be used as possible solutions for future grid problems or if innovative smart grid equipment and concepts should also be considered [2]. These can range from locally controlled secondary transformers with onload tap changers or AVRs up to centralized or decentralized systems controlling active and reactive power of load and generation based on an increasing observability in distribution grids [3, 4].

2.2.2 Assessment of existing Infrastructure

If the time horizon of the target network planning is short compared to the typical life span of the electrical equipment, the existing infrastructure cannot be neglected as in a green field planning approach. In order to consider the existing equipment adequately during the planning process they are being assessed with a condition index with regards to the evaluation whether an equipment should be replaced, upgraded or kept in operation in the target grid.

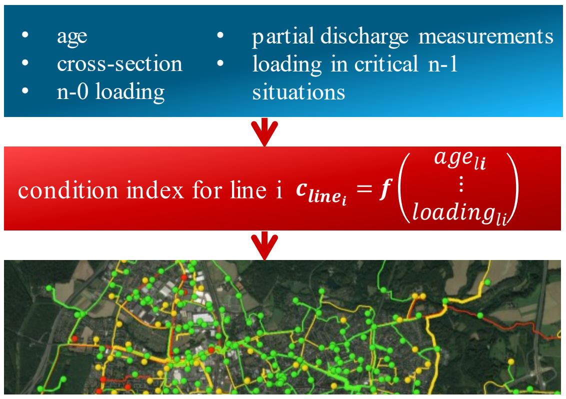


Figure 2 Assessment of existing infrastructure (exemplary for electrical lines)

As exemplary shown for electrical lines in **Figure 2**, the condition index for each line is relying on different technical parameters.

$$[0,1] \ni c_{line_i} = f(\alpha_{age}, age_{li}, \cdots \alpha_{loading}, loading_{li}) \quad (2.1)$$

The lines' parameters are individually considered using weighting factors α which can be coordinated individually with the network operator and affect the impact on the condition index (see **formula 2.1**).
The condition index for the secondary substations at Stadtwerke Ratingen GmbH is generated based on the results of their objective condition assessment (see **section 2.1**).

2.2.3 Automated Path Generation

The fact that only the current paths of electrical lines are known, presents a challenge for network planning. Optimal results can only be achieved if other possible paths are known in order to optimize routing and topology. A manual evaluation of possible paths is time consuming and not applicable for medium and low voltage grid planning. On the other hand the possible paths in (sub-)urban distribution grids are restricted to pavement, streets and dirt roads in most cases. Therefore, an approach has been developed to automatically derive possible paths from public geoinformation data.
In a first step the polygon courses of streets, pavements and dirt roads in the scope of consideration are extracted from the geoinformation data. These polygon courses are assessed with regard to intersections which are inserted as nodes in a mathematical graph. Subsequently the lengths of the polygon courses connecting the intersection are calculated and the courses are inserted as edges into the graph, weighted by their individual length. Information on the kind of course e.g. pavement or dirt road can be additionally added to the edges' information for future calculation of line costs (civil engineering).
Then, a comparison with existing secondary substations is carried out in order to link the existing substations with the nearest graph node. The resulting graph could be utilized directly for grid planning but if a whole city is within the scope of consideration the graph is too large. Therefore Dijkstra's algorithm [5] is used to derive the shortest connection to the nearest four (for example) secondary stations for each secondary substations. All nodes not containing a secondary substation and all edges not incorporated in one of the Dijkstra's shortest paths are removed from the graph. In this way, the otherwise extensive problem of optimisation is significantly reduced.

Figure 3 Screenshot from Google Earth visualization showing existing infrastructure and potential paths for a small part of Ratingen (Mapdata: Google)

A Google Earth visualization showing existing grid infrastructure (coloured based on the equipment's' condition index) and the automatically generated paths (white lines) is displayed in **Figure 3**.

2.2.4 Target Network Planning

Based on the input data from scenario definition, assessed existing infrastructure and automatically generated possible paths for new lines the target network planning itself takes places (see also **Figure 1**). The number of possible planning variants in distribution grids is large especially when not only considering conventional grid enforcements but also smart grid equipment and operation. Therefore a manual planning approach is not feasible and a computer assisted methodology has been developed.
The possible degrees of freedom are thereby depending on the individual planning task (medium voltage, low voltage, medium and low voltage combined, conventional enforcement and/or smart grid etc.) and include the construction and deconstruction on existing or new paths and places. Furthermore there are several technical constraints that need to be considered e.g. all customers and secondary substations need to be supplied, thermal ratings of all equipment as well as voltage limitations need to be obeyed during normal operation as well as during (n-1) conditions. At the same time the grid costs are to be reduced during optimization. For that a metaheuristic optimization approach is being used as metaheuristics have already proven to be applicable for different grid planning tasks [6, 7].
In order to evaluate the target grid the NEPLAN software package is utilized for power flow, short circuit current and reliability calculations. For the NEPLAN coupling and exchange the NEPLAN C++ interface is applied (see also **Figure 1**).
The methodology is also capable of considering the curtailment of wind and PV infeed according to the "Spitzenkappung" approaches applicable for German DSOs [8]

2.3 Investment Plan

After target network planning is completed, taking into account the condition assessment of the grid equipment, the results can be used to derive a holistic investment schedule. This schedule is obtained by comparing the actual grid and the target grid to determine required measures. Furthermore renewal measures can be identified based on the equipments' condition indices and age. The sequence and time of realization of the individual measures is depending both on technical as well as regulatory considerations. For example, the dept to equity ratio is an important factor in the German incentive-based regulation as well as the capital to operating costs ratio. These factors among others, are impacting optimal budgets and realization time of measures.
Result of the expansion planning is a technically and economically optimized investment schedule.

3 Results

The methodology described in chapter 2 has been applied to the Stadtwerke Ratingen's medium voltage grid in a joint and ongoing study. In the following sections results of the study are being presented.

3.1 Objectified Condition Assessment

In a first step the objectified condition assessment methodology was applied to all of the almost 700 secondary substations in Stadtwerke Ratingen's network area. The condition data is prepared on basis of individual reports for each station but also in an aggregated management report consisting of aggregated lists with maintenance tasks.

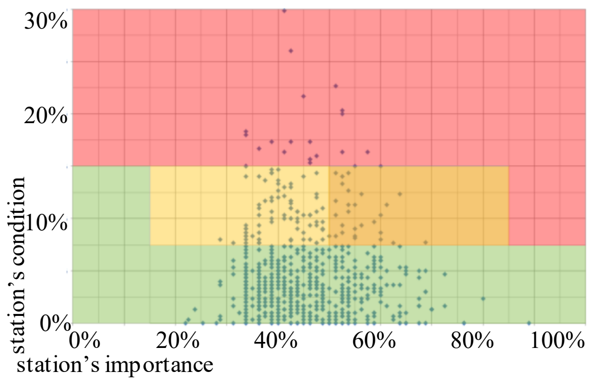
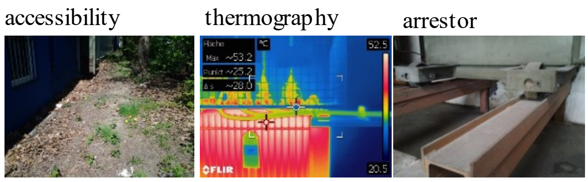


Figure 4 Condition and importance of secondary substations

Figure 4 shows the main result of the condition assessment for all stations as it displays each stations importance and condition (see also **section 2.1**). Most of the secondary stations (79.9 %) in the network area are in a good condition. Some stations are in a condition that requires maintenance measures in a medium term perspective and only a few stations (2.8 %) require immediate actions.

Besides these summarized results which are also of importance for the later expansion planning (see also **section 2.3**) individual reports for each station are available.



condition						
outside	interior	mv- switchgear	lv-switchgear	transformers	accessories	total
10%	14%	0%	0%	27; 20%	16%	11%

Figure 5 Excerpts from an exemplary secondary substation's detailed condition report

Excerpts from such a report are displayed in **Figure 5**. As exemplary shown these reports include pictures of all findings during the stations' inspections. Furthermore condition values for the station's assemblies are given as well as prioritised maintenance measures.

3.2 Target Network Planning

The timespan for the target network planning at Stadtwerke Ratingen was set to 10 years. Subsequently to the definition of the future supply task and general planning principles, departing from the methodology presented in **section 2.2,** a short term planning was performed.
The idea behind the short term planning is an optimized usage of two already existing load substations in the network area. These substations are fully equipped with medium voltage bus bars, circuit breakers and remote control but yet only used for resupply after grid failures. The target of the short term planning is a better operational integration of these stations without the need for new primary equipment. Therefore a topology optimization based on existing equipment and breakers was carried out.

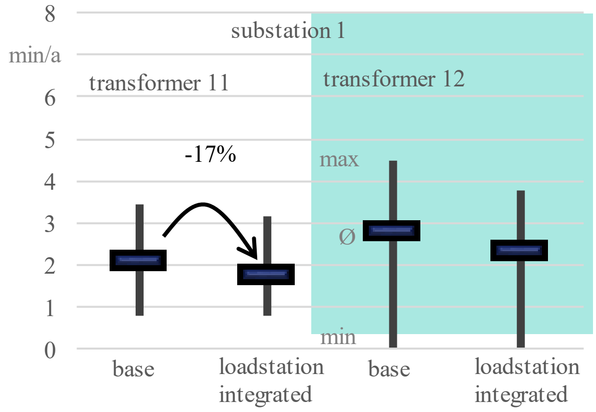
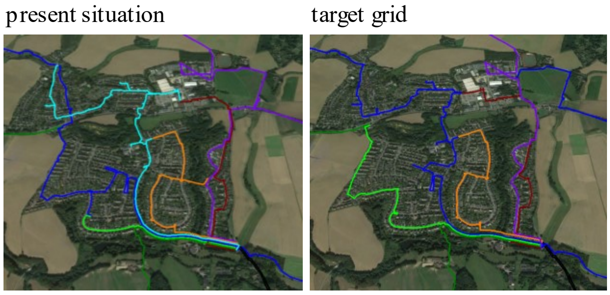


Figure 6 Impact of short term planning on average unavailability in part of scoped distribution network

It can be seen in **Figure 6** that the average unavailability in the network area holding one of the load substations can be reduced by almost 20 % by topology optimization measures, operational integration of the substation and an adjustment of the protection schema. As the German regulation scheme includes a quality regulation, an improvement of security of supply can lead to financial benefits for the network operator. At the same time these topology measures impact the overall grid losses.
Next to the short term planning the target grid planning was carried out as described in section 2.2. Thereto the automated path generation (**section 2.2.1**) was applied on the network area of Ratingen to derive potential future paths for the target grid. Also the existing infrastructure needed to be assessed. The assessment of the secondary substations relies on the results of the objectified condition assessment (see also **section 3.1**). For the medium voltage lines technical master data provided by the network operator as well as results from load flow and contingency analysis have been used to calculate the lines' condition index according to formula 2.1.
After the input data preparation the target grid planning took place. As the Stadtwerke Ratingen have already done several target grid planning studies and network optimization in the past, their distribution grid is in a good shape and can stand up to the supply tasks defined for the future scenario. Nevertheless the target grid planning methodology identified optimization potential.



new construction	removal	resolved “three-legs”
1300 m	2600 m	5

Figure 7 Present situation and target grid planning results for an exemplary part of the Stadtwerke Ratingen network area

In total a deconstruction of about 10 km medium voltage cable is possible by the construction of about 4,5 km of new cables, resulting in savings of almost 6 km. With regard to a current overall length of around 400 km the savings amount to almost 1.5 %.
At the same time 16 (operational) “three-legs” could be resolved resulting in savings due to a reduced number of switch fields in secondary substations and an optimized grid structure leading to benefits in terms of fault localization and grid restauration.
The results are displayed exemplary for a part of the Stadtwerke Ratingen network area in **Figure 7**. The lines are coloured based on the feeder configuration. It can be seen that besides the overall saving of over one kilometre medium voltage cable the grid structure can be significantly optimized resulting in five resolved “three-legs”.

4 Summary and Outlook

German distribution system operators are facing complex challenges. The establishment of structured asset management according to DIN ISO 55000 series is the basis for a cost-efficient use of existing equipment. By utilizing the above methods and in particular the combination of operative condition evaluations and strategic target network planning, possible efficiency potentials can be disclosed as shown in the exemplary results for Stadtwerke Ratingen.

As a last step in the ongoing study with Stadtwerke Ratingen the investment plan needs to be derived based on the results from target network planning (see also **section 2.3**). This last integral part of the study is currently ongoing and will be finished soon. Furthermore SPIE is currently applying the objectified condition assessment methodology to Stadtwerke Ratingen’s cable cabinets.
By conducting the study and applying the methods described above,
Stadtwerke Ratingen GmbH has taken important steps towards a future-proof asset management. The next logical step is a certification according to DIN ISO 55000 which Stadtwerke Ratingen is pursuing.

5 Literature

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