IDENTIFICATION OF COST RELEVANT STRUCTURAL CHARACTERISTICS FOR MEDIUM VOLTAGE NETWORKS

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SUMMARY

Electrical networks have taken a natural monopoly position also in the liberalized energy market. For that reason, regulation authorities have to create mechanisms that guarantees a permanently low-priced but also safe electricity supply. This includes an efficiency evaluation of the grid operators. Up to now strong efficiency statements have not been possible because of the insufficient knowledge of the reason-effect relation between structural characteristics of the supply area and the network structure necessary to fulfil the requirements. This paper will therefore present cost-determining structural characteristics for medium voltage networks using a method based on the model of the network planning process.

INTRODUCTION

The regulating methods generally usable for the regulation of the electrical networks require appropriate structural characteristics. Thus, the structural conditions of the supply area which have significant influence on the network costs and which cannot be affected by the network operator can be considered adequately within a individual price and revenues regulation.

The currently valid structural characteristics for the MV network are not the result of an extensive research [1]. Against this background any tests have failed to expose the correlations between network tariffs and different structural characteristics using statistical methods [2]. The shares of the network tariffs which are largely independent of the structural characteristics of the supply area are the main reason for the test results. In addition, real networks have not been optimal for the present task of supply at any time. Finally, different quality characteristics of the networks are not considered. For that reason, this paper chooses an alternative method. It is based on the simulation of the network planning process for synthetically produced supply areas close to reality. By this means the minimal expenses for building and operating an electrical network can be determined depending on structural characteristics.

ANALYSIS AND MODEL BUILDING

Limitation of Network Area

MV networks are supplied by HV networks and are used to connect direct MV customers and wider distributing MV/LV substations (MLS). Position and load of the HV/MV substations and the MLS are the result of the network planning. In principle, the MV networks can be optimized at the expense of neighboured voltage levels. The therefore generally required voltage-level comprehensive network planning is feasible at the most for principle investigations deriving usable practical models to dimension HV/MV substations and MLS.

The results of such investigations [3] prove that the load of each HV/MV substation can be determined depending on the average MV load density of the supply area and the used MV line type (fig. 1).

![Fig. 1: HV/MV substation load depending on the MV load density](image1)

The load of the MLS can be calculated with the required accuracy using the known LV load density distribution and the coherence demonstrated in fig. 2 [4].

![Fig. 2: MV/LV load substation depending on the LV load density](image2)

The following fundamental LV planning criteria have to be considered:

- LV fuse for protection of the LV standard line type,
- voltage reduction reserved for the LV level as well as
- number of the LV lines fed from the MLS.

In contrast to the MV load density only the areas of the supply area covered with buildings are considered when calculating the LV load density. For that reason, an explicit consideration of the HV and LV networks is not necessary.

Valuating the Suitability of Structural Characteristics

Beside the structural characteristics which have to be investigated the degree of performance of the task of supply, i.e. the achieved supply quality of the MV network also affects the amount of the arising costs. Thus, evaluating the suitability of
structural characteristics one has to oppose the costs (expenses) and the resulting supply quality (benefits).

The total cost consists of indirectly and directly network depending costs. The directly network depending costs are those directly arising from the installation and operation of the MV network and including the costs for network investments, system management, maintenance as well as network losses. Furthermore, there are indirectly network depending costs for administration, taxes and insurance as well as miscellaneous mainly independent of the structural characteristics of the supply area. For that reason, the investigations within this research work refer to the directly network depending costs (MV network costs).

The system area relevant for the calculation of the MV network costs restraints to the MV lines and their switchgear sections in the HV/MV substation. All impacts on the MV network costs combined to the way of financing and the time of investment will not be included by the structural characteristics of the supply area that have to be investigated. For that reason, a standard cost model will be used evaluating the suitability of the structural characteristics. This model is based on

- the number of operational equipment for the MV network,
- the average investment and operation costs of each type of operational equipment as well as
- the usual operating life time for each operational equipment group.

The underground work costs arising of the cable laying depend on the site of the laying [5]. If the area is closely built-up and ground sealing and excavation by man are necessary the underground work costs will rise adequately. The final amount of the underground work costs depend on the regional circumstances such as the ground properties as well as the local impacts such as the kind of surface engineering. Assuming that the local impacts within the MV network balance averaged load density specific underground work costs according to fig. 3 will be implied.

### Fig. 3: Assumed coherence between underground work costs and local load density

Within the investigations temporally constant structural characteristics of each single supply area are assumed. Neglecting the residual values and assuming a cyclical renewal of the operational equipment at the end of the usual operating life time the evaluation can be provided independent of the considered time based on the annual MV network costs. These are referred to the annual peak load of the single MV network in addition.

Voltage quality and supply reliability are the relevant aspects for the evaluation of the supply quality of a MV network. The voltage quality is assured if the boundaries of voltage and short-circuit current feasible for the MV level are restrained. The voltage limits at the connection of the MV customers can qualitatively be evaluated using the results of the load flow calculation. Applying simulation processes enables a quantitatively evaluation based on probabilities [6]. The adherence of technically required minimum and maximum values of the short-circuit current can qualitatively be controlled by a calculation of the short-circuit current. Furthermore, the short-circuit current at the connection point of the MV customer is a measure for the resistance of the network if short-time voltage effects occur.

A qualitative evaluation of the supply reliability of the MV network is possible using the deterministic (n-1) network security criteria. In the MV planning practice only the compliance of the (n-1) criteria after a system transfer is required as the cost of materials for the required circuit breaker and protective equipment will be too high. The calculated probabilities referring to the frequency and duration of loss of load of network customers within the scope of simulative reliability analysis enable quantitative statements concerning the supply reliability of a MV network.

Within the scope of network planning a quantitative evaluation of numerous planning alternatives is not recommended because of the complex calculating efforts for the named simulation process. According to the general planning practice this research work evaluates the supply quality of a MV network controlling the compliance of

- the permissible voltage boundaries,
- the limits of the short-circuit current as well as
- the (n-1) criteria after system transfers.

### Characteristics of the Task of Supply

The number of MV customers and MLS in the supply area define the supply area significantly by their geographic and electrical characteristics.

Usage of electrical energy is normally connected to the usage of buildings. Therefore most of the MV customers and MLS can be found in the parts of the built-up supply area. Additionally, there is a linkage between the usage of buildings and the relative frequency of MV customers and MLS. In areas used mainly for habitation and agricultural purposes MLS appear almost exclusively. In areas used by trade and industry, however, MV customers dominate. Other parts of the built-up supply area show equal shares of MV customers and MLS. The rest of the supply area is open space with singular appearance of MV customers. Therefore the model distinguishes between four kinds of land utilization and the according kinds of customers (table 1). The shares for each kind of land utilization can be taken from statistics like land registers.

<table>
<thead>
<tr>
<th>Land utilization</th>
<th>Customers</th>
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<tbody>
<tr>
<td>Habitation</td>
<td>MLS</td>
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<tr>
<td>Habitation/Trade/Industry</td>
<td>MLS, MV Customers</td>
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<tr>
<td>Trade/Industry</td>
<td>MV Customers</td>
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<tr>
<td>Open space</td>
<td>MV Customers</td>
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Table 1: Land utilization and kinds of network customers

Dependent on the share of open space and the wide-ranging...
concentration of built-up area a differentiation between urban and rural supply areas is used. Urban supply areas are additionally differentiated by city center, transition zone and outskirts because of different shares of the four kinds of land utilization. For rural regions the connected built-up areas are relatively small in comparison to the total supply area. Therefore it is sufficient to model the supply area of only one HV/MV substation with a cyclic repetition to avoid boundary effects. Urban supply areas, however, make it necessary to consider the whole supply area.

MLS supply the LV customers in areas at least partly used for habitation. Position and load of MLS are determined using the LV load density distribution. Fig. 4 shows the cumulative relative frequency of the LV load density in rural supply areas based on the data of existing MLS. High values of the load density are connected to a dense cultivation.

In contrast to the load of the LV level, that is distributed over a certain area from the MV point of view MV customers can be considered as punctual loads or injections where most of the customers can be modelled as loads. Fig. 5 shows the cumulative relative frequency of the load of MV customers for rural supply areas with a differentiation in areas with and without cultivation. Very high loads mostly occur in industrial areas.

A few MV customers inject power from dispersed generation, however. To prevent short-circuit power from false activations the total injection in a feeder has to be lower than the total load. So injection has not to be considered here.

METHOD FOR IDENTIFICATION OF STRUCTURAL CHARACTERISTICS

According to the objective of this paper to show the effects of single structural characteristics on the network costs a four-step method is chosen. At first a synthetic supply area with given structural characteristics is generated to formulate the planning task. In step 2 for this planning task the cost-optimal MV network that fulfils the (n-1)-criterion is calculated. A computer based optimization algorithm, which is able to determine cost-minimal MV networks subject to capacity constraints, is used here [7]. Finally the annual MV network costs are calculated based on the number of operational equipment. For a bandwidth of structural characteristics a sequence of supply areas and planning tasks is generated randomly. After a sufficient number of repetitions of this process and by varying only one of the structural characteristics a possible interrelationships of this characteristic and the MV network costs can be found and quantified.

RESULTS

The exemplary examinations consider rural supply areas as well as urban ones. MV networks were calculated using a voltage of 20 kV and the standard cables :PE-X 150 mm² (rural supply areas) and PE-X 240 mm² (urban supply areas). In the following as an example the results for rural supply areas are shown.

Homogeneous Supply Areas

For homogeneous supply areas and the costs for underground work described in fig. 3 results of examinations showed that the area related annual MV network costs depend on the MV density of connection points and the MV load density. The interrelationships between these structural characteristics and the MV network costs are non-linear. With a load that is equal for all substations in the homogeneous case load density can be transformed to density of connection points mathematically. Results also showed that choice of cable types and voltage boundaries effect the MV network costs.

Heterogeneous Supply Areas

Based on the results for homogeneous supply areas structural characteristics with influence on density of connection points and load density were examined for inhomogeneous supply area. The average density of connection points is determined by the number of MV customers and MLS in the supply area. Using the correlations shown in fig. 2 the number of MLS depends on the LV load density in areas with habitation. With the average density of connection points given the average load density can be influenced by varying the load of MV customers.

In a first point of investigation the LV load density was increased gradually from 1 to 5 MW/km². For all other structural characteristics average values of rural supply areas were used. For every LV load density 50 synthetic supply areas were generated and the MV network optimization with the following cost calculation were accomplished. The resulting average values of the load related annual MV network costs are shown in fig. 6 as vertical bars separated in the shares for lines, switchgear sections and losses. With increasing LV load density the load related MV network costs decrease following a power function. More than 85% of the MV network costs are allotted to the lines. Besides the smallest and largest arisen MV network costs are represented as thin lines. The remaining degrees of freedom within the generation of the supply
areas cause an almost constant relative deviation of 15% from the average values. The usage of the results obtained for homogeneous supply areas leads to heterogeneous supply areas to a 35-40% over-estimation of the MV network costs (fig. 6). The functional interrelationship between the connection point density and the MV network costs is similarly.

Because of the non-linearity aggregated structural characteristics are basically not appropriate for estimation of MV network costs of heterogeneous tasks of supply and, depending on that, for a sufficiency evaluation of grid operators. In principle, the segmentation of heterogeneous supply areas in smaller quasi-homogeneous shares and the application of the interrelationships for homogeneous area to these shares are admissible. This method requires a criterion in order to test these sub areas for extensive homogeneity, particularly in terms of the connection point density. This is necessary because the MV network costs change with the degree of heterogeneity of the connection point density considerably.

REFERENCES

CONCLUSION
The sense of this paper is the analysis of the reason-effect relation between structural characteristics of the supply area and the minimal MV network costs to fulfil the corresponding supply task. In the course of evaluation homogeneous and heterogeneous as well as rural and urban supply areas considered were. A result was that there exist non-linear and in principle equal interrelationships between the load density resp. the connection point density and the MV network costs.

Fig. 6: Load related annual MV network costs depending on load density

Fig. 7: Load related annual MV network costs depending on load density and number of MV customers in open space

Finally, the comparison with the urban supply areas shows that the share of the open space affects the load related MV network cost significantly.