A MODEL TO OPTIMISE CAPEX AND OPEX FOR A GIVEN QUALITY LEVEL

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ABSTRACT

Today's regulatory demands are providing strong incentives for cost reduction to distribution system operators in Germany and several other countries. Various National Regulation Authorities have implemented quality regulation schemes to avoid cost reductions at the expense of quality of supply.

This paper presents an integrated model, which combines reliability calculations of electric networks and a simulation of the organisational structure of network operators. With help of this model, the impact of different grid and organisation structures on the quality of supply can be quantified simultaneously. So before implementing cost- and time-intensive investments in grid equipment and restructuring of staff organisation the resulting quality of supply and cost effects can be determined by the network operators.

QUALITY REGULATION

In various countries the implementation of incentive regulation models encourages network operators to achieve cost reductions. Experiences have shown that the exclusive focus on costs has led to a decrease of quality of supply if the network operators are not penalized for poor, respectively rewarded for outstanding quality of supply. Various National Regulation Authorities (NRA) in Europe have implemented schemes of quality regulation with incentive schemes being the most common ones [1]. The primary aim is to reach a pre-defined level of quality of supply or to keep quality of supply at a socio-economically acceptable level [2].

Before discussing the impacts of quality regulation on network operators it is necessary to explicitly define quality in energy distribution. [3] describes quality factors in the context of energy distribution and supply: Commercial quality, voltage quality and continuity of supply (reliability). Continuity of supply can be divided into two aspects: On the one hand the network operator has to provide a system which in long term meets the power demands of the customers (adequacy). On the other hand the network operator has to guarantee the electricity supply of customers in short-term (after occurrence of interruptions). As the reliability of energy networks is the most important aspect of quality of supply this paper focuses on the (short-term) continuity of supply.

IMPACT ON NETWORK OPERATORS

In case that quality regulation models are applied, network operators have to take into account the effect of changes of the system wide and customer individual quality of supply as these have direct impacts on their revenues (or approved prices, respectively). For all activities, the correlation between expenditures and their impact on continuity of supply has to be considered:

- Investments (Capital Expenditures - CAPEX) into the infrastructure of distribution systems, like e.g. adding redundant cables in ring structures or new components with lower failure rates, influence mainly the frequency of interruptions in the distribution system [4]. Investments into distribution automation reduce the interruption duration.
- Operational Expenditures (OPEX) mostly influence the duration of supply interruptions and equipment down-times, since changes in the number, type and organisation of field service resources directly impact the duration of switching and repair activities in the distribution grid [5].

Considering these framework conditions, the system operators have to find the optimal balance between costs for system development and for grid operation on the one hand and quality of supply on the other hand. This leads to some concrete questions which have to be answered by the system operators:

- How to cost-effectively reach or maintain a pre-defined level of quality?
- Which is the optimal structure of staff organisation (OPEX) and of system assets (CAPEX) to reach this goal?

DESCRIPTION OF THE MODEL

The subject of this paper is to present an integrated model, which respects all relevant fault-related aspects of network operation: On the one hand the grid-related aspects of fault events need to be taken into account; on the other hand the restoration process and the influences of the organisational structure have to be investigated.

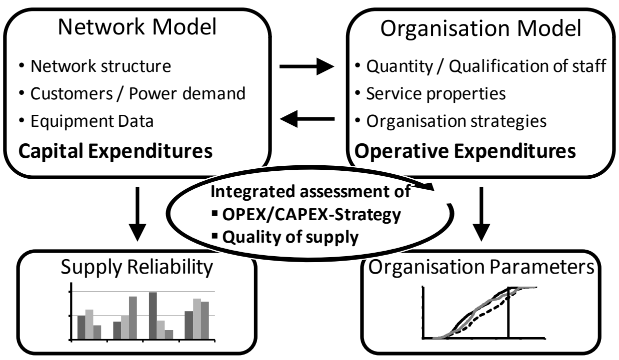

Figure 1: Integrated model

For that, the model combines the comprehensive calculation of supply reliability in the electricity distribution network with a simulation of the complex organisation of the system operators' field workforce (Figure 1), considering various boundary conditions of organisational structures and service operation.

Network model

The network model performs a reliability calculation of the grid in the investigated supply area. It contains the full network with the network structure, its equipment (cables, transformers, breakers etc.), electrical parameters and customer demands, which is exported from common network calculation software. Furthermore the grade of automation is modelled to determine the requirements for manual switching operations on site performed by the field service organisation. The reliability calculation uses various outage models like active failure events, earth faults, common-mode-failures etc. to model representative sets of outages [4]. A set of manual and remotely controlled switching operations and repair activities assures the restoration of all interrupted customers in the given network structure.

Organisation model

The organisation model represents the complete organisation structure of a network operator, which is necessary to perform the required activities of the restoration process (provided by the network model) to re-supply interrupted customers after network outages and to re-establish the foreseen network structure by repair or replacement of disturbed equipment.

The structure of the supplied area is presented by a geographical **node-edge-model** in which the nodes represent the geographical location of the grid equipment of the network. Accordingly each work activity (switching, repair) of the restoration process can be distinctively assigned geographically. The edges describe the connections between two geographical nodes, i.e. the roads and corresponding travel times between two network parts; hence each part of the network can be reached from every other part by the resources by travelling along a set of edges and nodes. The required input data for the node-edge-model is extracted from the network structure without extensive manual adaptations.

The manual switching operations in the network are realised by **field service teams**, which are deployed by the network operator in case of failures. To be carried out properly certain repair processes need specialized resources. During normal working time the resources are bound to planned working tasks, which take place in certain nodes of the supplied area. During on-call service hours (nights, weekends) the personnel starts travelling to any required activity from home. To consider these characteristics, each resource is described and modelled separately with its qualification, participation in on-call service and place of residence (i.e. node).

The supplied area can be divided into several service properties in which **organisational divisions** are responsible for the execution of restoration activities. Often, the geographic division of the supply area is different during normal working hours (more, but smaller zones) and during on-call service time (fewer, but larger zones).

In practice the criterion for **prioritization** between different activities of restoration processes is based on the amount of lost load which can be resupplied by the considered activity. Furthermore the assignment of resources to the switching operations and repair activities takes into account the distance between the current node of the resources and the node of the incident. In case of repair activities, the expected duration for repair is considered [5].

The corresponding optimization problem in the implemented mathematical model is related to the k-travelling repairman problem [6]. It minimizes the average waiting time of the (load-weighted) activities (switching, repair) to be served by the available resources.

Evaluation

By means of the network model the impact of various changes of CAPEX-related activities on the quality of supply can be quantified. Investment strategies (like early replacements of aged transformers, installation of grid automation or remote control) will lead to lower failure rates on the one hand and faster restoration processes on the other hand. The impacts of changes in the organisation of service staff (OPEX-related activities) and changes in restoration strategies on the quality of supply are modelled by integration of the organisation model.

After calculation, the integrated model provides customer individual and system wide reliability indices like supply unavailability in dependence of the network and of the organisational structure [7] [8].

Furthermore, operational performance indicators are provided, like delay until arrival on site to quantify the ability of an organisation to react to outages and to ensure safe operation for the public.

EXAMPLE CALCULATION

This part of the paper presents results from an example calculation. The aim is to illustrate the basic functionalities of the overall model, to display different grid and organisation structures and to analyse the impacts of these structures on quality of supply. Furthermore an interpretation of the organisational performance indicators provided by the model is given.

Considered network

The analysed system supplies a rural area of approximately 600 km² with about 193 MV/LV substations via 175 km of 10 kV lines (Figure 2). The peak demand of 8.3 MW is supplied via two main 110 kV transformer substations. The grid structure contains several switching possibilities, either to close open ring structures or to connect parts of the grid to adjacent MV grids.

The corresponding node-edge-model is formed by 736 nodes and edges with an average travel time of 0.7 minutes, according an average speed of 30 km/h. Furthermore additional edges, representing fast travelling options for the

resources, are foreseen.
To show the fundamental functions of the model, the reliability calculation is focused on active failure events.

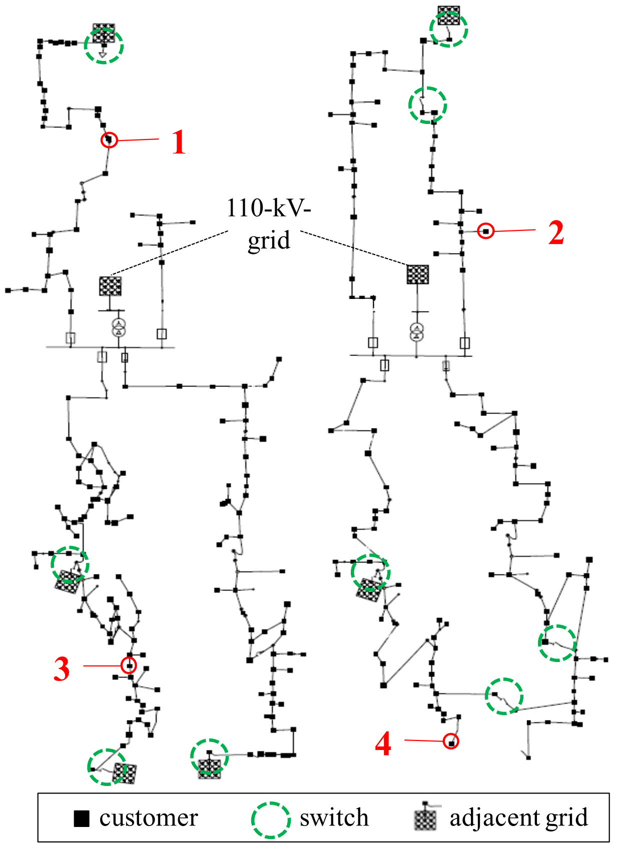

Figure 2: Topology of analyzed distribution grid, considered customers 1-4

Investigated organisation / network schemes

Scheme I forms the base case of the considerations. This scheme considers four employees for performing restoration activities in the supplied area during normal working time. During on-call service hours (nights, weekends) one resource is set in charge for manual switching operations and repair activities.
The local MV switches in the grid are manually controlled and switching operations have to be performed by resources on site. The circuit breakers in the HV/MV substations are remotely controlled.
Scheme II is the organisational extension of Scheme I. To perform faster local switching operations and repair activities during on-call service hours a second resource is scheduled. The grid structure is not modified.
In **Scheme III** all local switches are equipped with remote control and can be operated from the network control centre by the network operator. By that, the delay of switching operations is independent of the operational structure. The switching activities to isolate the disturbed equipment from the network still have to be performed by resources on site. The number of service staff is not modified in comparison to Scheme I.

Quality of supply

In the following, the results of the calculation for the quality of supply are analysed for four exemplary customers (No. 1-4, Figure 2).
Figure 3 shows the expected duration of interruption of the exemplary customers. As customer 2 and 4 are connected to single feeders (in the MV grid) the expected duration of interruption in general is longer than of customer 1 and 3 which are connected directly to main feeders. Customer 1 is located in a remote place of the node-edge-model.
Comparing the results of Scheme II and I, the expected duration of interruption is decreasing for customers 1, 2 and 4. Here, the geographical model with the nodes of residence of the resources participating in on-call service shortens the duration of interruption. In contrary, customer 3 has to suffer longer interruptions in case of additional on-call service personnel (Scheme II) – here, the geographical model together with the nodes of residence of the resources leads to an extension of the expected duration of interruption.
By equipping each local switch with remote-control in Scheme III the expected interruption duration of the customers can be decreased significantly due to the promptly executed switching operations and the independency of these from the organisation structure.

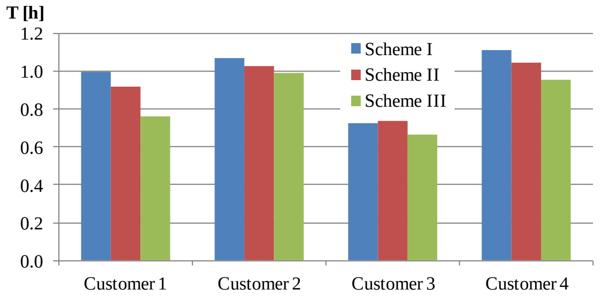

Figure 3: Expected duration of interruption of exemplary customers

The organisation structure and the grade of automation are not influencing the frequency of interruptions of customers. Nevertheless the influence of the structure of the example grid on the interruption frequency is evident. Figure 4 shows that customer 3 is connected to a feeder with a significantly higher number of equipment than customer 4, whereas customer 2 is connected to a feeder with a low number of failure sources, which leads to a lower expected interruption frequency.

Figure 4: Expected interruption frequency of exemplary customers

As the organisational structure of the network operator and the grade of automation do not influence the interruption frequency of customers, the expected non-availability of supply (Figure 5) shows the same effects as the expected duration of interruption.
Keeping the presented results of the quality of supply in mind, Scheme III is leading to the highest quality of supply.

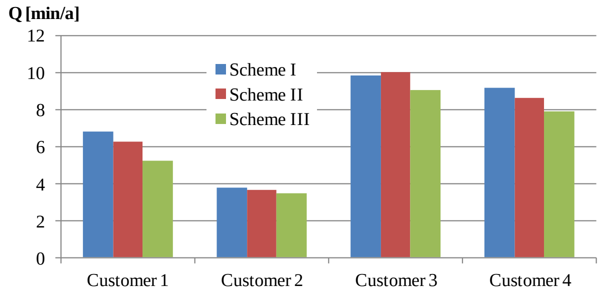

Figure 5: Expected non-availability of exemplary customers

Operational performance

To evaluate the influence of Scheme II and III on the operational performance indicators, Figure 6 shows the duration until arrival on site for the supplied area. It shows no significant difference between the base case (Scheme I) and the grid structure with a higher grade of automation (Scheme III), as the remotely controlled switches do not promote the resources to be faster on the site of the incident to assure safe operation. Only 79% of the failure sites can be reached by service personnel within 45 minutes.
Contrary to Scheme I, the additional resource during on-call service hours leads to a shorter average travel time of the resources. This promotes the safe operation of the distribution system in Scheme II, as 97% of all failure sites are reached within 45 minutes.

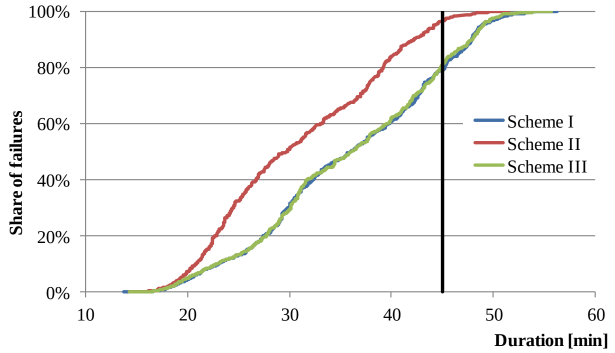

Figure 6: Expected duration until arrival on site

The results show that Scheme III is only preferable, if the focus is on the reliability parameters of the customers in the considered network and the operational performance indicators are disregarded. If the duration until arrival on site (level of operational safety of the grid) is not acceptable for the network operator in the base case (Scheme I), Scheme III is not the preferable option to improve this operational parameter. As Scheme II leads to a significantly higher level of operational safety of the grid, additional resources to take part in on-call service should be foreseen.

CONCLUSIONS

By setting quality standards and transferring these into monetary terms, the National Regulation Authorities in various countries try to avoid undue impacts on quality of supply from cost efficiency strategies and actions implemented by the network operators.
To consider the impact of investments in grid equipment and of restructuring the staff organisation on the quality of supply before the actual implementation of these measures, an integrated model and related analysis methodologies are required.
This paper presents a combination of reliability calculations and of simulations of the field service organisation of network operators, which displays all relevant aspects of network architectures and organisation structures to simultaneously evaluate CAPEX- and OPEX-related activities and their impact on quality of supply. Common reliability indices are provided to compare different investment strategies and organisation structures.
As the distribution system operators are in charge to ensure operational safety of the distribution system during normal working time and on-call service hours, the presented model provides also operational performance indicators. By these the level of operational safety of the network and the influence of modified organisation structures is evaluated.

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