SUSTAINABLE INVESTMENT STRATEGIES FOR AGING DISTRIBUTION NETWORKS

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ABSTRACT

Distribution system profitability is at risk from decreasing network fees. To meet financial targets, distribution system operators are thus obliged to curtail their re-investment, operation and maintenance budgets. Ensuring sustainability of energy supply nevertheless remains imperative.

To meet these requirements, the Asset Management department at 24/7 Netze has developed a comprehensive approach to optimize its investment strategy. This approach can be divided into four steps: asset simulation, reliability-centred maintenance planning, target network planning and net present value (NPV) analysis.

The paper describes each step in detail, as well as the models developed, especially asset simulation and reliability-centred maintenance planning, and is complemented by a case study.

INTRODUCTION

Distribution system profitability is at risk from decreasing network fees. To meet financial targets, distribution system operators are thus obliged to curtail their re-investment, operation and maintenance budgets. Ensuring sustainability of energy supply nevertheless remains imperative.

To meet these requirements, the Asset Management department at 24/7 Netze has developed a comprehensive approach to optimize its investment strategy. This approach can be divided into four steps:

1) Asset simulation
2) Reliability-centred maintenance planning
3) Target network planning
4) Net present value (NPV) analysis

The first step involves analyzing the overall distribution system using asset simulation models. Given the vast quantities of equipment involved, the infrastructure is clustered into representative groups. Each equipment group is characterized by an individual asset model which portrays the (basic) correlation between aging and failure rate development. To forecast future financing requirements, the model works with unit cost values for operation and maintenance, as well as for asset renewal. A simple system reliability model describes the correlation between individual equipment failure and distribution system reliability. Based on the data concerning the type, age and quantity of the equipment, the model enables different investment strategies to be simulated in terms of future cash flows and system reliability. One key output is the optimized allocation of financial resources to equipment groups.

In the second step, the investment budgets are allocated to individual equipment items. This is performed using the reliability-centred maintenance planning method. Here, the condition and significance of individual items of equipment is determined, leading to a prioritization of items of equipment and their financing requirements.

In a third step, the future function of those items included in the priority short list for the optimized network is investigated by using target network planning. If the respective item is required in the target structure, then its rehabilitation is approved. Otherwise it is decommissioned.

Finally, potential options (rehabilitation or network restructuring) are evaluated using NPV calculations.

ASSET SIMULATION

Asset simulation is a method used to determine the long-term development in network costs (CAPEX and OPEX) and supply reliability for gas, water, district heating and electricity networks, taking due account of different investment and maintenance strategies. The simulation allows different strategies to be systematically analysed and evaluated and is thus fundamental for the definition of sustainable investment strategies. Figure 1 shows a schematic model of the asset simulation approach [1, 2].

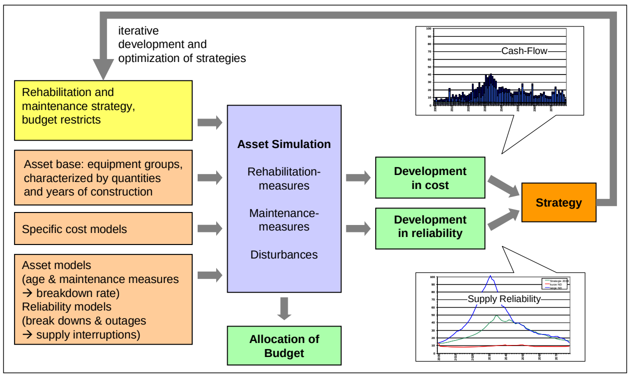

Figure 1. Schematic asset simulation model

Asset simulation considers measures conducive to evaluating and improving the condition of network equipment, including all measures such as inspections, planned maintenance, corrective maintenance, repair and rehabilitation. The main benefit of this approach is the ability to simulate different strategies by defining user-specific guidelines for the nature and timing of measures to be performed. All basic parameters, such as average useful lifetimes, can be systematically optimized in an iterative process of parameter variation, simulation and output figure analysis.

By analogy with the typical lifespan of the equipment involved, the timeframe for a typical simulation involves several decades. In view of this, items of equipment are not viewed individually, but are rather aggregated into equipment groups. The equipment groups are delineated in terms of primary characteristics such as voltage level, pressure range, technology, material or their function within the network in question, e.g. transport or distribution equipment. Figure 2 shows equipment groups as defined at 24/7 Netze for the electricity network (Figure 2 a) and the gas network (Figure 2 b).

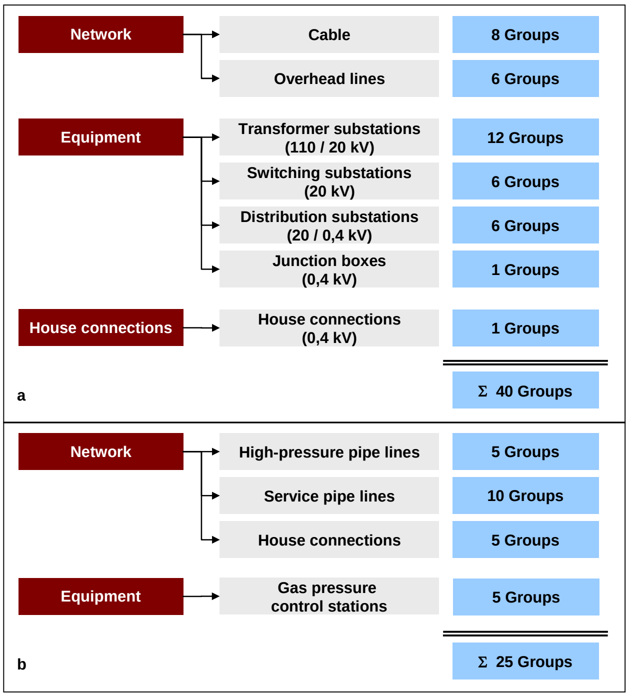

Figure 2. Equipment groups for (a) electricity network and (b) gas network at 24/7 Netze

Alongside stock quantity and equipment age, models representing the correlation between equipment condition (i.e. at least age) and the breakdown rate are crucial to the asset simulation method. The model applied distinguishes between three key components: a non age-related failure rate (e.g. due to external factors), an age-related failure rate and a reversible component (representing the maintenance-related failure rate). The model is presented in Figure 3. Together with the quantities and ages for each equipment group, the number of failures per year is calculated for the entire timeframe simulated.

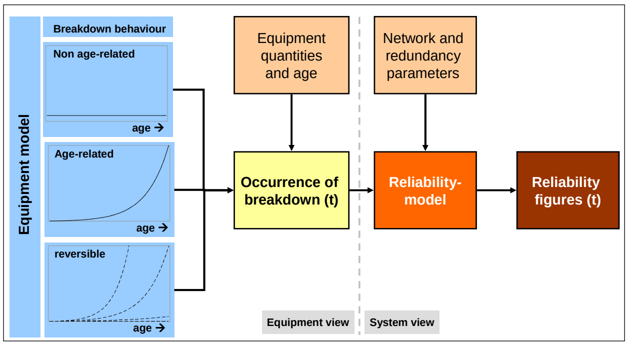

Figure 3. Failure and quality model used in asset simulation

Taking due account of characteristic parameters for the network structure and especially for redundancies in the network, the number and duration of supply interruptions are calculated based on the number of outages. These figures form the basis for deriving all relevant reliability figures (e.g. supply unavailability, SAIFI, SAIDI).

Asset simulation does not produce a list of measures for the rehabilitation and maintenance of individual items of equipment. The results rather relate to the equipment groups defined. Based on the timing of annual budget allocations, guidelines can be formulated to define the number of rehabilitation and maintenance measures for each equipment group and year.

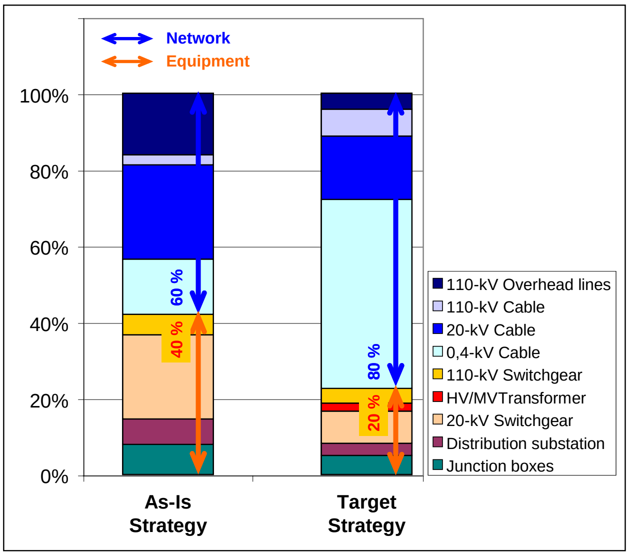

Figure 4. Budget allocation for an electricity network (pre-simulation and post-simulation)

Figure 4 portrays the budget allocation for an electricity network before and after optimization aimed at minimizing repair cost and supply unavailability (SAIDI). Unlike the outcome resulting from the actual strategy, in the target strategy a greater proportion of the budget is allocated to the network (overhead lines and cables). In terms of network components, there was a dramatic shift towards the rehabilitation of the LV cable. This is due to the high volume of potential repair costs to be avoided in this equipment group. The reduction in the budget for 20-kV switchgears contrasts starkly with the actual strategy. Two options can be considered to ensure the budget is nevertheless met: postponing rehabilitation measures or avoiding them entirely, e.g. by dismantling the equipment. This will be discussed later in the paper.

RELIABILITY-CENTRED MAINTAINANCE PLANNING

Once investment budgets have been defined for each equipment group, these are then allocated to individual items of equipment. The aim here is to determine the number and order of assets to be maintained or replaced in a given time period, e.g. over the next year. This step is performed using the reliability-centred maintenance planning method. This involves determining the condition and significance of individual items of equipment, enabling equipment items and their financing requirements to be prioritized.

	Electricity 20-kV switchgear	Gas gas pressure control stations
general criteria	year of construction (resp. year of commissioning)	
	annual maintenace ost	
	time period until next planned maintenance	
	operating experience (remarable/unremarable)	
specific criteria	circuit breaker type (oil, low-oil, vacuum)	flow rate (under normal operation conditions)
	isolation (air, SF6, solid)	alternation of load (under normal operation conditions)
	protection system (electromechanical, analogelectronic, digital)	compression ratio (in/out)
	age of protection system	operation montoring (local, remote)
	age of remote control system	other gasmixture components (none, solid, liquid, both)
	age of auxilary system	redundancy needed (low, medium, high)
		safety valve (membrane-break-down-protection y/n)
	other (e.g. result of visual inspection if needed)	other (e.g. result of visual inspection if needed)

Table 1. Condition criteria for 20-kV switchgears and gas pressure control stations

Key aims when defining the criteria were: a) to minimize the number of criteria identified and b) to maximize the significance of the criteria identified. An adequate individual criterion must not necessarily provide a physical image of the condition of the equipment. Table 1 shows the criteria as defined for equipment groups in the gas and electricity networks at 24/7 Netze. Some of the criteria defined are of a general nature and applicable to equipment groups in all network categories. Others are specific to each equipment group. What all have in common is that no visual inspection is required to assess the condition of the relevant equipment. This can be carried out if needed for an individual decision. Furthermore the criteria for the gas pressure control stations are according to the rules and standards of DVGW (G495) and in allusion to the approach described in [3].

The significance of criteria is assessed by reference to network calculations, e.g. the significance of a gas pressure control station is derived from its flow rate at peak load. In the electricity network, significance is determined using a probability-based reliability calculation and accounts for the frequency and duration of supply interruptions due to specific equipment [e.g. 4].

Figure 5 (a) presents an example of the application of reliability-centred maintenance planning for 20-kV switchgears. These represent two equipment groups, namely Switching Substations (S-S/S) and Transformer Substations (T-S/S). Figure 5 (b) shows the same method applied to gas pressure control stations. The future function of those items included in the priority shortlist for the optimized network is assessed before any rehabilitation or maintenance measures are determined. This last step is outlined in the next chapter by reference to an electricity network area (MV).

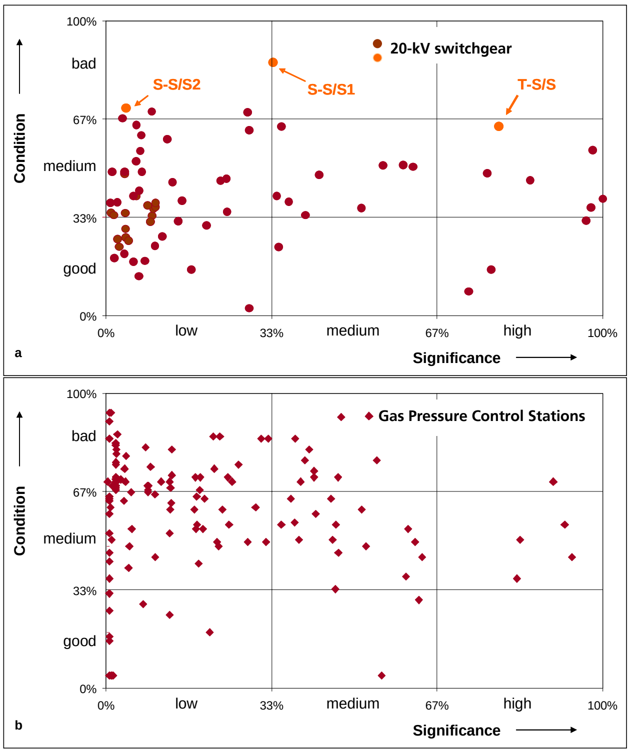

Figure 5. Condition / significance chart for (a) 20-kV switchgears and (b) gas pressure control stations

TARGET NETWORK PLANNING

Target network planning is the third step in the strategic approach adopted by 24/7 Netze. If the respective item is required in the target structure, then its rehabilitation is approved. Otherwise it is decommissioned. In Figure 5, some high-priority switchgears have been marked and clustered in terms of their local positions within the network. The cluster comprises three switchgears, one in a T-S/S and two in S-S/S. Although the rehabilitation of the switchgear in the T-S/S substation would seem highly likely to be deemed necessary, due account must also be taken of the fact that two further substations with lower priority are close to this T-S/S.

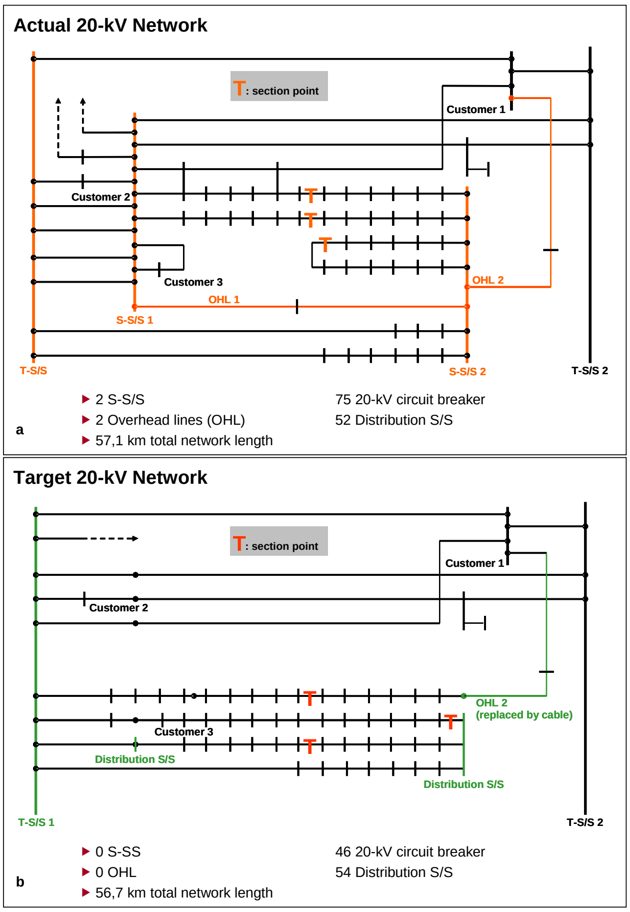

Figure 6. 20-kV network, (a) Actual, (b) Target

Target network planning is initially based on the network's rehabilitation requirement over the next 20 years. Each equipment item requiring refurbishment in that period is deemed proven in terms of its necessity for the supply function. Figure 6 shows the target network for the area covered by the switchgears in Figure 5. In future, the two S-S/S will no longer be required. One key assumption was that no network extension was needed in this particular supply area to account for renewable energy generation. In any case, the supply function can be upheld with almost identical availability levels.

NET PRESENT VALUE (NPV) ANALYSIS

Finally, the economic aspects have to be proven. A net present value analysis is therefore mandatory. As the technical refurbishment and maintenance needs are known for the next 20 years, all target network variants can easily be compared with the actual network. Firstly, the NPV is calculated for the existing network. A list of measures is thus defined for each year in the period up to 20 years ahead. The same steps are performed for the target network variants. This way, the lowest NPV corresponds to the most economical target network.

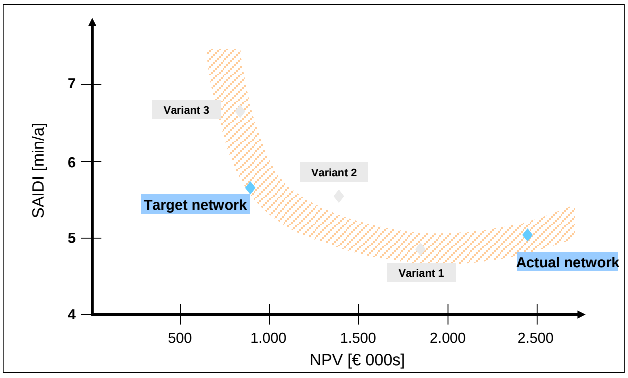

Figure 7. NPV and SAIDI of a 20-kV target network

All specific costs needed to perform the NPV analysis and specific equipment replacement or maintenance dates are taken from the asset simulation based on the same parameters. Figure 7 presents the results of an NPV analysis for the 20-kV target network referred to above. The benefit of the target network in terms of its NPV is significant, amounting to more than € 1.5 million. Although Variant 3 offers an even lower NPV, this alternative was discarded in view of its far higher SAIDI.

CONCLUSIONS

Asset Management at 24/7 Netze has developed a comprehensive approach to optimize its investment strategy. This is applicable to gas, water, district heating and electricity networks. The experience gained to date underlines the great economic potential offered by this approach. In future, the impact of smart grid technology in particular will be integrated into the models.

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