RESTRUCTURING OF MV NETWORKS – AN EXAMPLE ON THE WAY TO AN EFFICIENT ACTIVE DISTRIBUTION NETWORK

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ABSTRACT

This paper focusses on network analysis, restructuring and expansion measures of an exemplarily MV network. For this analysis a GIS data based model in a state of the art network calculation tool is created. The emulation of network based electrical loads and generation units measurement data, consumption data as well as load profile meter time series data are used to establish load profiles for further network simulations. These load profiles are used to analyze and determine the initial condition of the medium voltage network in basic simulation scenarios and identify weak spots in the network. Furthermore, definitions and analysis of future network expansion scenarios including the network integration of decentralized generation units are simulated and evaluated. Finally, the initial condition of the network is compared to the network expansion scenarios.

INTRODUCTION

The growing number of decentralized generation units in historically developed distribution networks causes, in certain cases, the transgression of operational limits (equipment load factor, maximum temperature, equipment age) in the future.
To ensure a satisfactory network reliability and power quality it is necessary to perform network restructuring and expansion in medium voltage (MV) networks. Urban MV networks in particular provide opportunities for optimization and restructuring tasks, which reduce operational costs as well as losses and increase network reliability and power quality. The network expansion measures range from modifications of switching states to widespread restructuring tasks in the medium voltage network, such as the implementation of ring network structures and the related changes in protection.

In this paper a detailed computer-based simulation model of an urban MV network is presented using state of the art network calculation software. This software is suitable for load flow calculation with load profiles (automated ¼ h based time series) and reliability calculations.
These calculations are used to assess the impact of further network restructuring and expansion tasks in the MV network and to determine future equipment loads and power quality aspects including network reliability.

NETWORK SIMULATION MODEL

The analyzed network consists of about 450 km of MV lines (cables and overhead lines), 900 substations and five partial networks (NORTH,EAST,SOUTH,WEST and MIDDLE). Each subnet has its own regulating transformer, including an **O**n **L**oad **T**ap **C**hanger (OLTC).
To run the network analyses, it was first necessary to develop a simulation model of the exemplary urban MV network. For this purpose, both data from the GIS (**G**eographical **I**nformation **S**ystem) of the DSO and graphic network plans have been used for automated network data processing (e.g. switching states, types of conductors). The entire processed network data is finally written in a database and, in the next step, transferred to a network calculation program for an automatic network model set up. This process is shown in Figure 1.

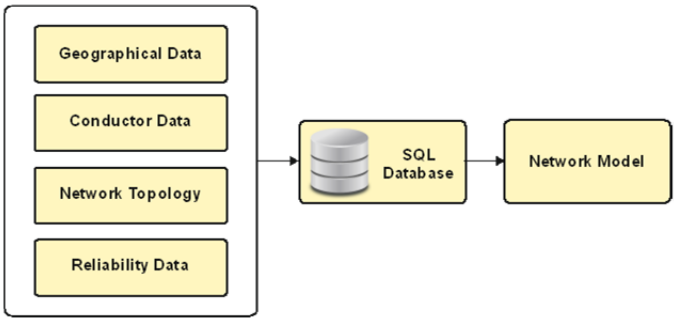

Figure 1: Network simulation model generation

Reliability Model

In order to perform reliability calculations it is necessary to expand the load flow network model with positions of different switchgears, switchbay configurations in substations (e.g. circuit breaker, breaker), typical times for switching operations (e.g. manual, automatically or remote controlled) as well as component reliability data for each type of network equipment.

Due to the historically developed network structures several different types and structures of switchgears are installed which cannot be determined and modelled. For this reason, the alignment of the switching elements in switchbays has been simplified:

- **Busbar** – Disconnecting Switch – Circuit Breaker – Disconnecting Switch - **Line**
- **Busbar** – Disconnecting Switch – **Line**

These simplified alignments allows to emulate all the switchgears in the MV network within a rewardable effort.

Load Modelling

For the emulation of electrical loads and generation units' real world measurements, consumption (standard load profiles) and load profile meter time series data are merged to establish load profiles of every substation for ongoing simulations (Figure 2). These ¼ h based load profiles are used to analyze and determine the initial condition of the medium voltage network in basic simulation scenarios and to identify weak spots in the network, which require network restructuring and expansion measures. In general, all loads were assigned with an active power factor cos(φ) = 0.95 (lagging).

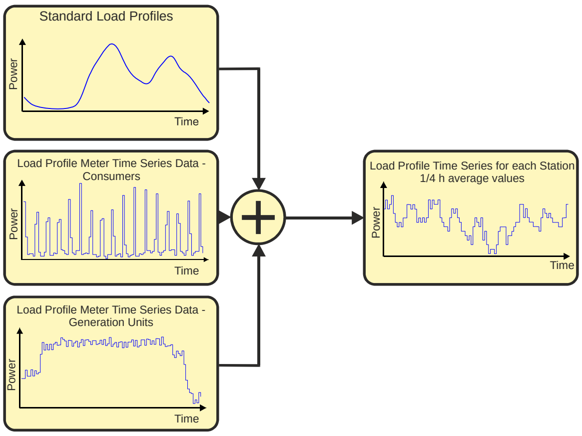

Figure 2: Computation of load profile data

Model Evaluation

To evaluate the simulation model of the MV network, the network based loads and generation unit measurements were made in selected network parts. These measurements show that the results of the simulations are in an acceptable range compared to the measured values in selected branches and substations.

NETWORK ANALYSIS

For load flow calculations and network analysis the following limits for the evaluation of the equipment load factor (ELF) are applicable:

- Normal Loading ($ELF < 0.40\ p.u.$)
- Increased Loading ($0.40 \le ELF < 0.60\ p.u.$)
- Overloading ($ELF \ge 0.60\ p.u.$)

Due to the (n-1) criteria, the limit of equipment load factors (overloading) is set at 0.60 p.u. [2][3].

The following limits for an acceptable voltage range have been defined:

- $\Delta U_{MV} = \pm 0.07$ p.u.

To ensure compliance with Austrian grid codes the maximal voltage rise caused by decentralized generation is defined within $\Delta U_{DGU} = + 0.02$ p.u. [4].

Initial Network – Investigated Scenarios

Three different investigation scenarios have been defined to identify weak spots in the initial condition of the analyzed network:

- Scenario 1: High load with local generation
- Scenario 2: Low load with local generation
- Scenario 3: High load without local generation

In the scenarios investigated, the load proportion is based on the load model mentioned previously. Within this load model the power demand (or generation) of all substations is summated and the sorted load duration curve is calculated (Figure 3). Due to this load duration curve and different quantiles (95% quantile for high load (P_{Q95}), 5% quantile for low load (P_{Q05})) several load scenarios are defined and simulated.

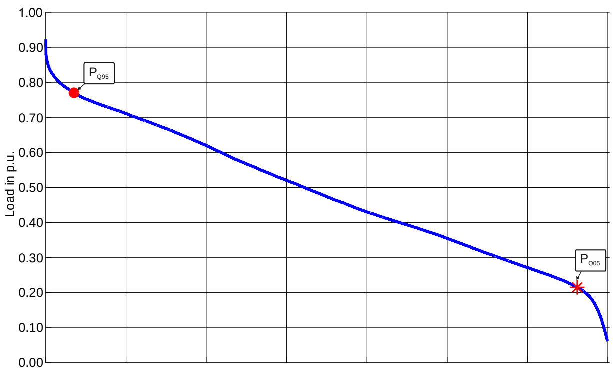

Figure 3: Sorted load duration curve

Scenario 1 (high load) is used to find undue equipment load factors and determine possible regions of the network for expansion or restructuring tasks.
Improper voltage rises caused by the combination of low load, local generation of medium sized power plants and long cable lines can be detected trough simulations in scenario 2 (low load with local generation).

To determine the impact of high load and the outage of local power plants, scenario 3 (high load without local generation) respects the same load conditions as in scenario 1 with the difference that not all local power plants in the MV network are in an active operation state (e.g. due to maintenance). This results in a higher power demand, which has to be covered by the upstream HV grid.

Initial network results

Scenario 1: High load with local generation

Figure 4 shows the calculated equipment load factors in scenario 1 separated on the five subnets of the analyzed MV network. As can be seen in Figure 4 the maximum equipment workload is around 0.60 p.u. (EAST) which is already classified as an overloading.

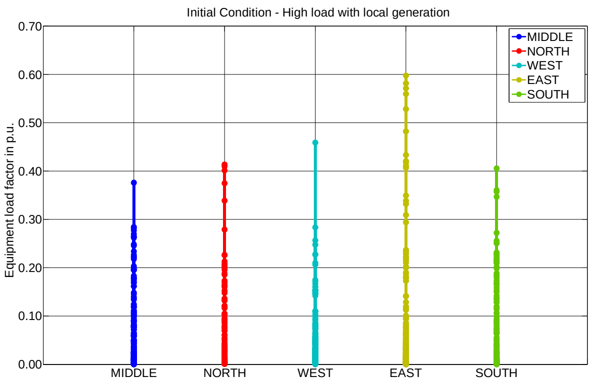

Figure 4: Scenario 1 – Equipment load factors

In future the rising demand for electrical power will require measures to stay in the defined limits and to maintain the (n-1) criteria. In this investigated load case no violation of the defined voltage range have been taken place.

Scenario 2: Low load with local generation

Due to the marginal network load in this scenario no violation of equipment load factors and no invalid voltage values appear - see Figure 5.

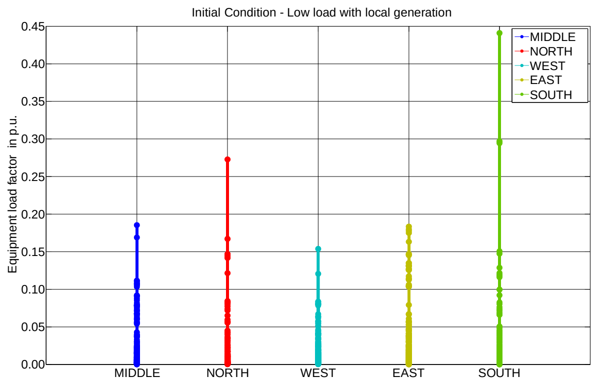

Figure 5: Scenario 2 - Equipment load factors

The result of subnet SOUTH (Figure 5, green) shows higher equipment workloads than are to be found in the high load scenarios. This raised workload is a direct result of the CHP plant installed in this subnet. The low load and the constant power feed in by a CHP plant causes a reversal of the local power flow and a return feed to the upstream HV grid.

Scenario 3: High load without generation

In this scenario no local generation unit in the MV network is in an active operation state. For this reason the whole power demand has to be covered through the upstream HV grid. Figure 6 shows the effect of the load increase on the equipment load factor.

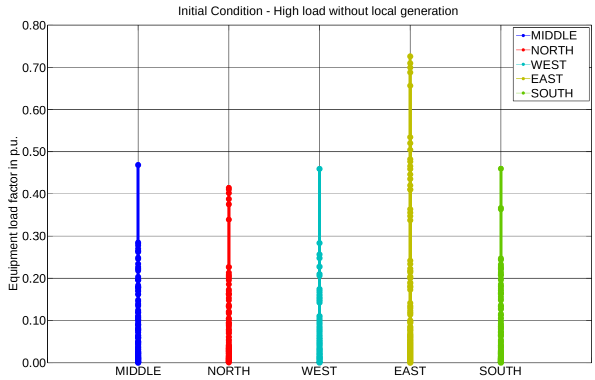

Figure 6: Scenario 3 - Equipment load factors

The impact of the power generation outage can be seen particularly clearly in the subnet EAST. In this subnet the equipment load factor rises above 0.70 p.u. This is classified as an overloading and therefore violates the (n-1) criteria. Restructuring tasks and additional network expansion would have to be completed in order to comply with the (n - 1) criteria.

ANALYSIS OF NETWORK RESTRUCTURING AND EXPANSION

In the expansion scenario “Ausbau 2014” several measures in the subnet EAST are in the scope:

- Changed switching states
- Partial integration of other subnets (SOUTH)
- Installation of new lines
- Implementation of ring network structures

In “Ausbau 2014” the interconnection of further decentralized generation as a part of the future active network plays an important role. For this reason, the network connection of two already planned large DG units (CHP – Plant (10 MW), PV – Plant (2 MW)) is focussed on in particular.

In order to assess the impact of these network restructuring and expansion measures the following scenarios in the subnet EAST are investigated:

- Scenario 4: “Ausbau 2014” high load
- Scenario 5: “Ausbau 2014” high load + CHP
- Scenario 6: “Ausbau 2014” high load + PV
- Scenario 7: “Ausbau 2014” high load + CHP + PV

Analysis of network restructuring and expansion - results

Scenario 4: Ausbau 2014 – High Load

The results of the network analysis in scenario 4 show the positive impact of the restructuring and network expansion measures in the subnet EAST (Figure 7).

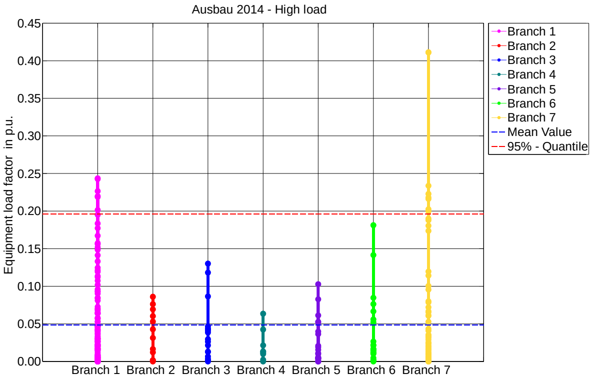

Figure 7: Scenario 4 - Equipment load factors

Through the new structure (ring) and partially new branch apportionment the maximum equipment load factor decreases from 0.60 to 0.42 p.u.. These results fulfil the (n-1) criteria.

Scenario 7: Ausbau 2014 - High Load + CHP + PV

In order to determine the interaction of decentralized generation units and new network structures, scenario 7 investigates the interconnection of two DGUs (CHP + PV). As can be seen in Figure 8, the interconnection of the mentioned DGUs has almost no impact on the equipment load factor (in comparison to Figure 7).

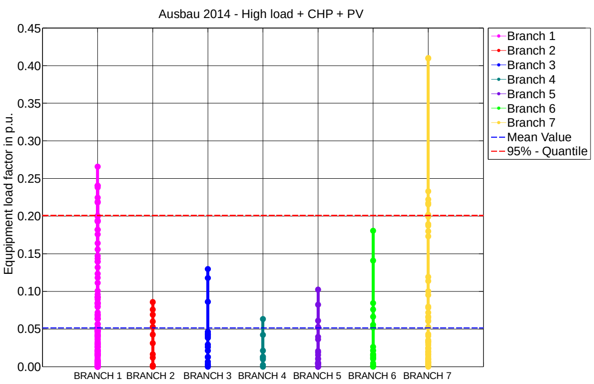

Figure 8: Scenario 7 - Equipment load factors

Through this large amount of local power generation nearly the entire power demand is covered locally. Due to this the equipment load factor of the HV / MV transformer decreases by about 67 %. In low load situations there is a reversal of the local power flow and a return feed to the upstream HV grid.
The interconnection of the two DGUs also complies with the allowed voltage lift given by Austrian Grid Code TOR D2 [4].

RELIABILITY CALCULATIONS

To investigate the influence of the mentioned network restructuring and expansion measures a reliability calculation has been made in addition to the load flow calculations. The reliability calculation is a network planning tool based on probabilistic network data (e.g. interruption statistics), which compares different (n-1) safe planning options and network structures or evaluates optimized switching states. In this paper the reliability calculation is used to determine the reliability level of both the initial condition and “Ausbau 2014” using reliability data from [5].
The reliability level of every substation has therefore been estimated and compared.

Results

Figure 9 shows the evaluation of results from the reliability calculation for each substation. Non-availability has been chosen as the evaluation parameter and depicted as the difference between the initial condition ($Q_{i,initial}$) of the network and “Ausbau 2014 ($Q_{i,Ausbau2014}$) (Equation (1)):

$$\Delta Q_{i,norm} = Q_{i,initial} - Q_{i,Ausbau2014} \qquad (1)$$

The implementation of the ring network structure is shown in Figure 9 (green lines). The initial condition of the network is depicted using black lines (Figure 9). Substations, which are directly connected to the ring structure or are related to other restructuring measures, receive a large impact regarding reliability (green marked substations). The brightness of the green marked substations depends on the difference to the initial condition. At yellow marked substations there is no change in reliabilty in relation to the initial condition.

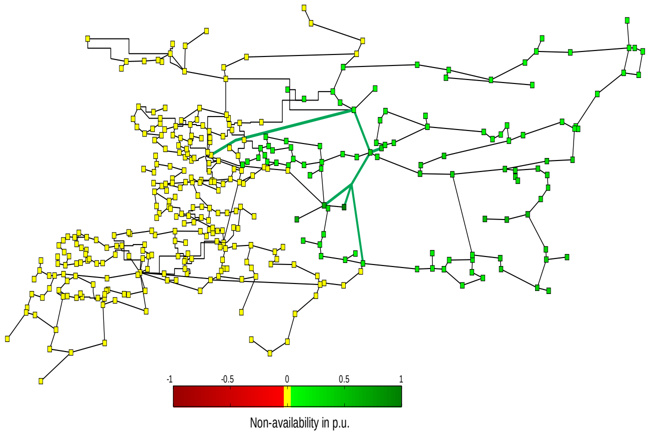

Figure 9: Network non-availability $\Delta Q_{i,norm}$

CONCLUSION

In this work several different load scenarios have been investigated to identify weak spots in the MV network. Due to the results of the network analysis (initial condition), limit value violations regarding equipment load factors have been detected in scenario 1 (initial condition with high load) and also in scenario 3 (initial condition with high load without local generation). To fulfill the limits and also the (n-1) criteria network, restructuring and expansion measures at selected branches become necessary.
The impact of these expansion and restructuring measures is depicted in Figure 10, which shows a comparison of calculated equipment load factors of the initial condition and "Ausbau 2014" in the subnet EAST considering different load cases.

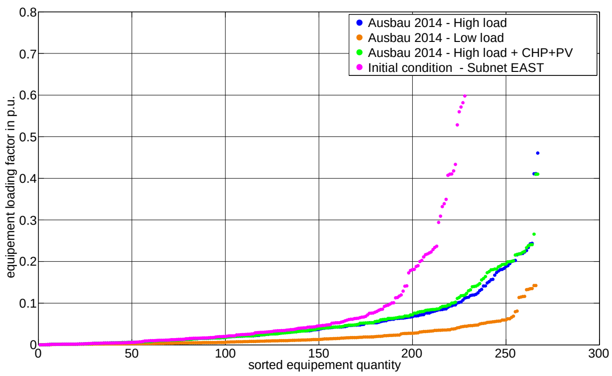

Figure 10: Comparison analysis results initial network – "Ausbau 2014"

For "Ausbau 2014" the maximum equipment load factor is calculated with about 0.46 p.u. (transformer) as well as the max. workload of a distribution line with about 0.42 p.u. which are both within the defined limits.

As can be seen in Figure 10 the equipment load factors decrease in the subnet EAST and the quantity of the network equipment (lines) increases because of the partial integration of the subnet SOUTH, which is depicted as a flattening of the equipment load factors curves of "Ausbau 2014". In all investigated scenarios no violation regarding voltage limits and voltage lifts through decentralized generation units appear.

Finally a reliability calculation has been done which includes a comparison of the initial condition with "Ausbau 2014". This calculation reveals a positive effect on substations in branches, where expansion and restructuring measures are implemented in the network and this lead to a reduction of non-availability and power outages.

To guarantee a reliable and high quality supply of electrical power (including further decentralized generation) in the future it will be necessary to complete further network expansion and restructuring tasks. This will result in new potential for the optimization of technical and economic parameters

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