ANALYSIS TOOL FOR ASSESSMENT OF GRID MANAGEMENT MEASURES USING TIME DOMAIN CALCULATIONS

Franz ZEILINGER
Vienna University of Technology – Austria
zeilinger@ea.tuwien.ac.at

Matej REJC
University of Ljubljana – Slovenia
matej.rejc@fe.uni-lj.si

Alfred EINFALT, Andreas LUGMAIER
Siemens AG – Austria
alfred.einfalt@siemens.com
andreas.lugmaier@siemens.com

ABSTRACT

In order to compare the impact of passive (like network restructuring) or active (like on-load-tap-changer) grid management measures a novel tool was developed, which performs specific load flow benchmarks tests using synthetic daily load and infeed profiles.
In this paper first preliminary results of the analysis of a real urban medium voltage distribution grid with 122 substations using this tool are presented. Examples are given, of how the developed methodology can be used for the assessment of very different grid management measures and operation circumstances. By using the proposed benchmarks, a novel approach for network planning is introduced.

INTRODUCTION

A secure energy supply needs secure, reliable and fault-resistant networks. These fundamental requirements have become harder to attain, due to the increasing impact of new distributed energy generation. With distributed energy generation becoming a major factor in distribution networks, a coordinated approach for network protection and automation is necessary to operate the existing networks safely, reliably and in a fault-resistant mode. To ensure the economic efficiency an intelligent combination of traditional approaches and “Smart Grid” functionalities have to be found for network planning and operation.
The Austrian national founded project “REstrukt-DEA” focuses on the investigation of grid management measures in urban grids in order to achieve secure energy supply. The set-up of the project focuses on the problems of overloaded lines and transformers in urban distribution networks. In order to help alleviate overloaded elements, new solutions of selective restructuring of networks in combination with intelligent and active network management approaches must be developed within the project and compared to conventional solutions. In this initiative, simulation-based investigations considering possible synergies between active control approaches and restructuring were started.
Comparison of passive (like network restructuring) or active (like on-load-tap-changer, Demand Side Management or reactive and active power control of infeed-inverters) measures cannot be performed using classical methods, due to time- or grid-state dependent components. When such elements are used, investigations based on single steady-state load flow calculations are not suitable, as the influence of active components will be lost or only be examined for distinct working points. To overcome this problem a novel approach in form of a tool, which performs benchmark tests using synthetic daily load and infeed profiles, taking also the time domain into account, was introduced in [1].
This paper presents first results of the analysis of a real urban medium voltage (MV) distribution grid and is organized in four main sections in addition to the introduction: The following section describes shortly the developed and subsequently used analysis tool. Afterwards the set up considering the investigated load and topological scenarios are presented. The fourth section includes first preliminary results for the pilot distribution grids of “REstrukt-DEA” and the final section presents the conclusions and an outlook for future work.

ANALYSIS TOOL

The developed analysis tool is based on coupling PSS®SINCAL and MATLAB® to enable automated simulations of distribution networks for the synthetic daily load and infeed profiles, which were also created for the analysis tool. The structure of the tool is shown in Figure 1 and is comprised of the following modules:

- synthetic profiles,
- input data preparation,
- grids
- grid simulations and
- post processing.

The modules for synthetic profiles, input data preparation and grids prepare synthetic daily load and infeed profiles as inputs for grids with different passive and active management measures. Using the grid simulation module, a high number of load flow Monte Carlo simulations are performed for randomly selected load and infeed values. These are necessary in order to effectively compare the different grid management measures. Using the high number of input values encompasses time domain behaviour into the simulations and therefore takes the influence of active components into account. At each simulation the following benchmark tests are performed:

- voltage band violations,
- branch loading violations (defined limits for cable or transformer loading) and
- network power losses.

At the current development stage of the tool, grid reinforcements and restructuring can be compared using steady-state analysis as well as time-domain load flow analyses of the networks. The post-processing module enables an in-depth statistical analysis of the Monte Carlo simulation results.

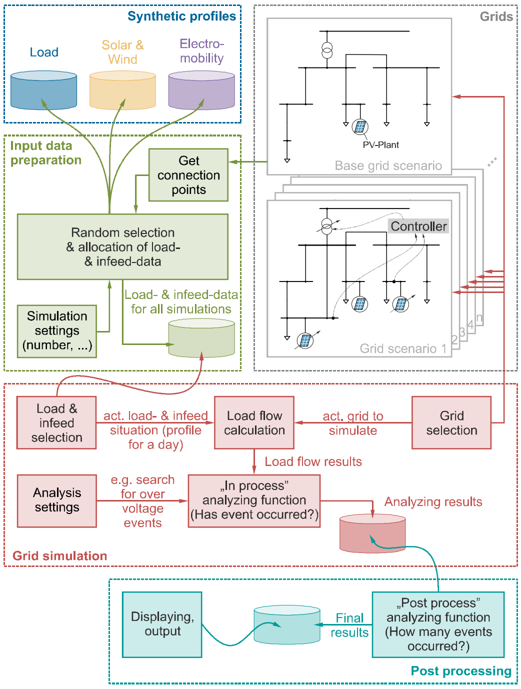

Figure 1: Scheme of the developed tool

The input data preparation module also enables an additional feature when investigating MV distribution grids. The tool provides the possibility of using results from low voltage (LV) grid simulations as input data for the MV grids. It is possible to allocate the previous gathered LV grid data to the respective connection point in the MV grid. This enables MV grids with different restructured topologies to include the same underlying LV-Grids.

ASSESSMENT SET UP

In the following section the set up for the analysis of a real urban MV grid with 122 substations using the developed tool is presented. The current state of the grid is compared to the planned restructured grid using the described benchmark tests. The set-up of the investigations is based on three different input scenarios for load increase, infeed increase due to photovoltaic power plants and new loads in the form of electric cars for different seasons and types of days. An added comparison is included in the form of a newly included active component in the form of an on-load tap changer (OLTC) in the underlying LV and MV grid.

Load and Infeed Scenarios

The goal of the selected input scenarios is to depict a wide range of possible grid conditions to see the impact of the proposed grid management measures, i.e. the passive restructuring and active OLTC component.

The summary of input scenarios is given in Table 1. The scenarios include different residential and e-mobility loads and different PV-infeed situations in the underlying LV grids.

The first scenario is described as the "base scenario" and represents the actual situation with no PV-infeed and also no e-mobility load.

The second scenario assumes low residential load, no e-mobility and high PV-infeed (described as "High infeed" scenario). In this scenario 24% of the load nodes in the LV-Grids (nodes with a customer connection) are equipped with PV plants with an average installed power of 20 kWp. The high infeed scenario represents an overly ambitious assumption for PV generation in order to encompass the worst-case scenario of high infeed.

The third scenario assumes high residential load, high e-mobility and medium PV-infeed (described as "High load"). In this scenario 75% of the load nodes also have e-mobility load. For the simulations, it is assumed that e-cars charged uncontrollably, i.e. no charging optimization algorithms. This presents a worst-case high load scenario.

Table 1: Description of the Scenarios

Res. Load	PV-Infeed	e-Mobility
Normal Load	No infeed	No e-Mobility
Low load	High infeed, 24% of nodes, infeed at node ~ 20 kWp	No e-Mobility
High load	Medium infeed, 34% of nodes, ~ 4.5 kWp	High e-Mobility, 75% of nodes

The described scenarios are extended over two seasons (summer and winter) and two types of days (workday and Sunday), which leads to a sum of 12 load and infeed scenarios.

Grid Restructuring

The two grid structures are presented in Figure 2 and Figure 3. The first shows the current state of the grid, while the latter presents the planned restructuring of the grid.

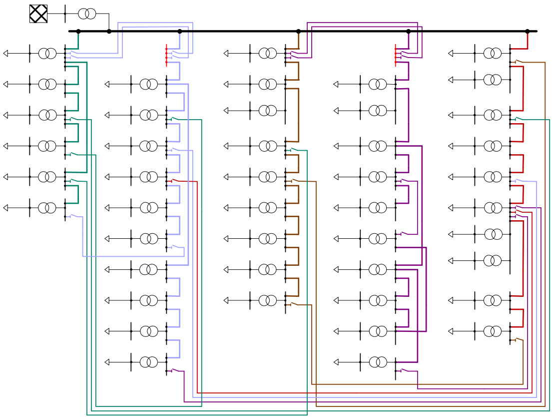

Figure 2: Detail of the investigated MV grid: current situation of five feeders

The original structure shown in Figure 2 is the result of actual grid development over time. Due to constant load increase and using the existing grid expansion plans, the grid structure evolved in the presented form. We can observe that a high number of feeders are present with unequal distribution of secondary substations, as well as a high number of possible interconnections with different distribution subgrids. The secondary substations are also not connected in an optimal route to their feeder with respect to their actual location, causing unnecessary long cable connections. All this leads to a complex and suboptimal network structure.

The goal of the restructuring process is a complete redesign of the MV grid without calling the positions of the secondary substations into question [2]. First the number of substations per feeder is planned to be increased and evened, simultaneously reducing the total number of feeders. Only interconnections at the center and end of the feeders are intended. By optimal linking of the substations, cable lengths can be reduced. The planned restructured grid is shown in Figure 3.

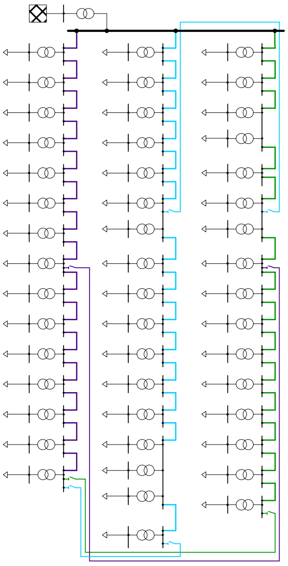

Figure 3: Detail of the investigated MV grid after restructuring: most of the substations of the feeders in Figure 2 are also part of the three new feeders

Due to the simplified structure, automation upgrades, such as the three-point-automation [3] are expected to be more effective, and the reliability should be increased.

Comparing the current and the planned grid, 13 feeders will be reduced to 9 feeders and from the 122 substations present, 10 will be connected to another primary substation after the restructuring.

This type of restructuring shows the necessity of a powerful simulation tool that can compare two grids with radically different topologies and different active grid measures, which is the goal of the authors with the presented simulation and analysis tool.

RESULTS

This section presents preliminary results of the analysis of the MV grids described in the previous section. The scope of this first analysis was to investigate two things. The first was the investigation of the restructured grid and its capability of handling the proposed infeed and load scenarios. The second investigation was to discover which grid management measures could maximize the capacity of the restructured grid. In this paper, an active measure in the form of OLTC was investigated.

Input data

For the shown simulations, the input data for the MV grid investigations was based on the power consumption of the underlying LV grids. The power consumption at the LV level is defined by using synthetic profiles for residential loads, solar irradiation and e-mobility and different LV grid models. Based on this, a multiple number of individual daily profiles are generated, which are subsequently used for the MV grid simulation. For the simulations, 122 LV substation profiles were generated, using 40 different daily load/infeed profiles for each season and day type with a 10 minute time resolution.

As the number of households per feeder was not known for the simulations, the synthetic residential load profiles were used to scale the underlying LV grids of each feeder. Based on actual measurements and by compare these with the synthetic load profiles the mean number of households per feeder was estimated. Based on these numbers the size of the underlying LV grids was assumed. As a result four different LV grids with 120, 150, 180 and 340 household loads were defined to create actual load profiles.

The comparison between actual measurements and synthetic load profiles is shown in Figure 4.

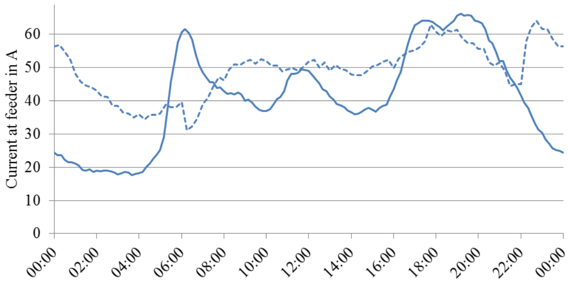

Figure 4: Comparison between the measurement (dashed) and simulation data (solid) of one feeder for a winter workday

We notice that the profiles of the measurement and simulation differ due to the fact that actual measurements also include commercial loads. As the data of the amount of commercial load is not known, the synthetic load profiles were scaled only in accord to the maximum power consumption is replicated. The shown offset between measurements and synthetic profiles represents the main disadvantage of the usage of synthetic profiles in the presented tool. In future, the integration of real measurement data in the analysis tool is planned and will help to overcome these problems. On the other side, with the synthetic profiles development scenarios can be modeled, which is not easy possible with measurement data. Because the presented profiles are only used to compare different grid management measures, their use is still acceptable, as long as only relative comparisons are made.

After the synthetic profile input preparation, Monte Carlo simulations can begin. Figure 5 and 6 show the loading of the compared grids.

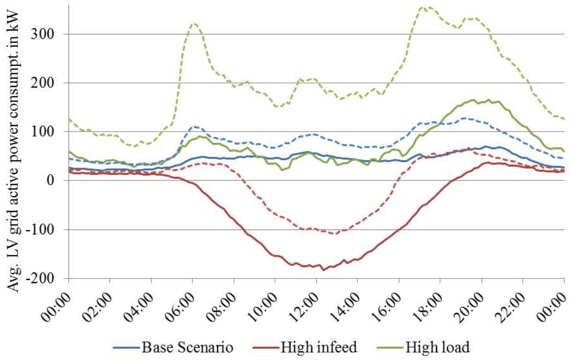

Figure 5: Average LV grid active power consumption of a workday; solid lines: summer; dashed lines: winter

Figure 5 shows exemplarily the time changes of the average LV grid power consumption for the six workday scenarios. Figure 6 shows the histograms of the active power system balance (load minus infeed) for three of the scenarios. We can observe that for the high load and high infeed scenarios, extreme values are more frequent than for the base scenario.

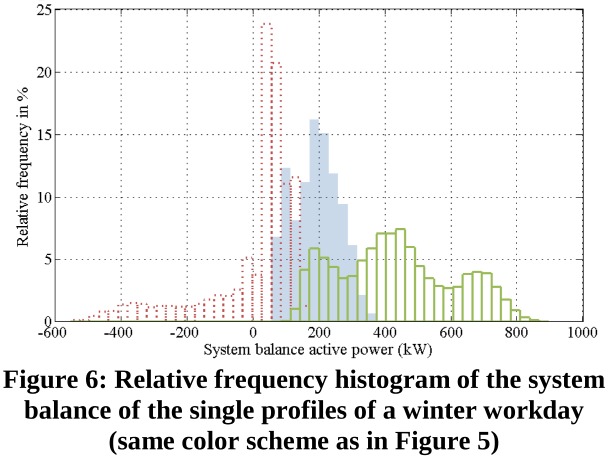

Figure 6: Relative frequency histogram of the system balance of the single profiles of a winter workday (same color scheme as in Figure 5)

Grid restructuring

The results of the analysis tool allow various ways to compare the different grid structures, e.g. only the impact on the cable loading, shown in Figure 7 as average over time and all cables.

Because more substations per feeder are located in the restructured grid, the cables near the substation experience higher loading, raising the averages. The infeed caused by PV in the second scenario has only a minor impact compared to the high load scenario, especially in winter.

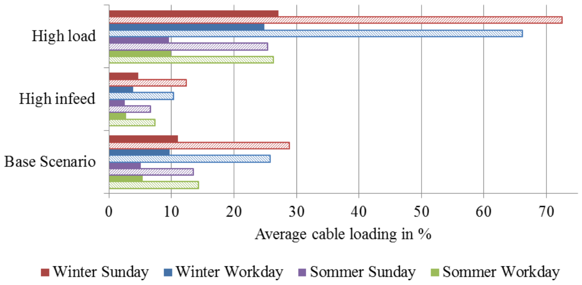

Figure 7: Impact of the grid restructuring on the average cable loading; solid: current grid; shaded: restructured grid

A more detailed view is given in Figure 8. In this figure, the percentage of cables experiencing loading higher than 50 % (upper figure) and 100 % (lower figure) is shown. It can be seen that the high load scenario impacts the most overloading cases in both of the examined grids. This would cause problems in nearby interconnected feeders in cases of sequential switching operations due to maintenance work. In comparison, the base scenario and high infeed scenario do not cause any serious overloading situations.

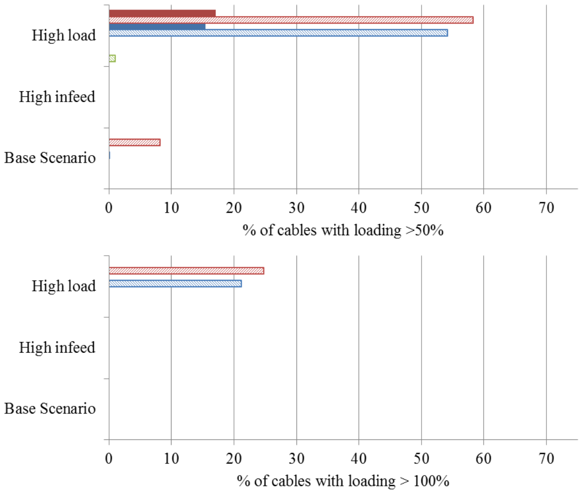

Figure 8: Impact of the grid restructuring on the % of cables with overloading

In cases of extreme overloads (higher than 100 %), only certain amount of cables in the restructured grid are affected. This represents the need for additional grid reinforcements or the need for active management measures, like controlled e-mobility charging.

Active measures

As shown in the previous subsection, only the high load scenario causes problems in the observed grids. The problems are mirrored when analyzing voltage band violations. Figure 9 shows the percentage of nodes affected by the voltage violations over time as an average over all daily profiles.

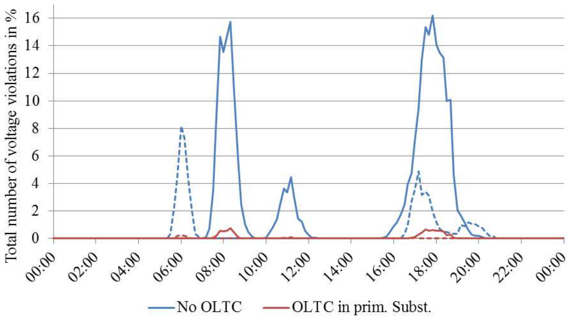

Figure 9: Average voltage violations over time in the restructured grid for the winter high load scenario; solid: Sunday; dashed: workday

In the first simulation, no OLTC was modeled in the primary substation. When adding the OLTC with ±13 steps with 1.4% U_N step size to the second simulation, the major share of violations can be eliminated, shown in Figure 10.

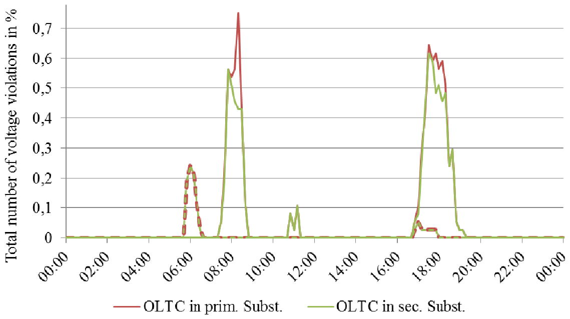

Figure 10: Voltage violations over time in the restructured grid for the winter high load scenario solid: Sunday; dashed: Workday

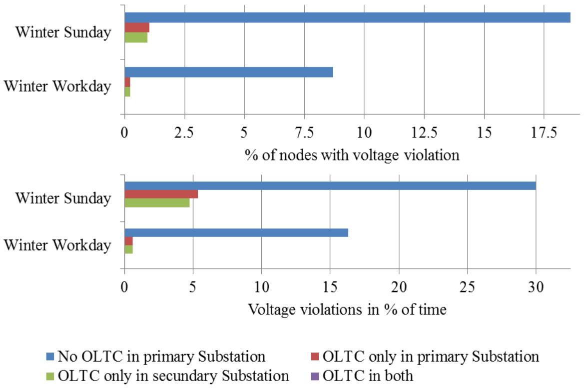

Figure 11: Comparison of the impact of OLTC to the voltage band violations

For the third simulation, OLTC with ±3 steps with 1,0% U_N step size were used and placed in the secondary substation. As seen in Figure 10 almost the same result is achieved. If the mentioned OLTCs are active in both types of substation, all voltage band violations can be completely eliminated. Figure 11 summarizes the impact of OLTCs on the percentage of nodes, which are affected (upper figure) and the percentage of daily profile time at which the violations occur.

SUMMARY AND OUTLOOK

In this paper the first analysis results using a novel methodology for the assessment of different grid management measures are presented.

The used load and infeed scenarios were selected to depict a wide range of possible grid conditions. Despite the extreme assumptions of the high infeed scenario, no overloading problems occur in the current and restructured grid. Only high load scenarios will call for additional actions such as voltage control measures or Demand Side Management in form of controlled charging of e-mobiles.

The gathered results also allow the comparison of the grids in additional ways, which are not presented in this paper, e.g. investigating the impact on the grid losses. Due to the also available information, which grid elements are affected by certain violations, is a selective application of different grid management measures possible.

The next steps within “REstruct-DEA” are the refining of the load and infeed scenarios for better matching with the anticipated future development, taking other active measures like reactive and active power control of PV-inverters or controlled loading of e-mobiles into account and apply the presented analysis to an additional model grid of a more suburban area.

Using the presented tool and methodology allows the comparison and assessment of radically different topologies and different active grid measures. By further development of the proposed methods future grid planning will be supported.

REFERENCES

[1] A. Einfalt, F. Zeilinger, M. Rejc, 2013, “Active Distribution Management vs. Selective Automation for Urban Distribution Grids“,*4th International Conference and Exhibition on Innovative Smart Grid Technologies (ISGT Europe)*, IEEE PES

[2] M. Leitner, A. Jung, T. Schuster, 2014, “Mittelspannungssystemoptimierung im urbanen Raum,” 13. Symposium Energieinnovation 2014, Feb. 2014.

[3] A. S. Bouhouras, G. T. Andreou, D. P. Labridis, A. G. Bakirtzis, "Selective Automation Upgrade in Distribution Networks Towards a Smarter Grid," *IEEE Trans. On Smart Grid*, vol. 1, pp. 278-285, Dec. 2010.