GENERAL PLANNING AND OPERATIONAL PRINCIPLES IN GERMAN DISTRIBUTION SYSTEMS USED FOR SIMBENCH

Steffen MEINECKE
University of Kassel, e²n – Germany
steffen.meinecke@uni-kassel.de

Annika KLETTKE
RWTH Aachen, IAEW – Germany
ak@iaew.rwth-aachen.de

Dzanan SARAJLIC
TU Dortmund University, ie³ – Germany
dzanan.sarajlic@tu-dortmund.de

Jörg DICKERT
ENSO NETZ GmbH – Germany
joerg.dickert@enso.de

Matthias HABLE
ENSO NETZ GmbH – Germany
matthias.hable@enso.de

Franziska FISCHER
NetzeBW GmbH – Germany
franziska.fischer@netze-bw.de

Martin BRAUN
University of Kassel, e²n and
Fraunhofer IEE – Germany
martin.braun@uni-kassel.de

Albert MOSER
RWTH Aachen, IAEW – Germany
am@iaew.rwth-aachen.de

Christian REHTANZ
TU Dortmund University, ie³ – Germany
christian.rehtanz@tu-dortmund.de

ABSTRACT

SimBench provides an extensive open-source dataset of typical electrical power systems with up-to-date grid data and in addition, corresponding time series for load, generation and storage. It enables multi-voltage-level analyses and increases comparability and transparency of tools and methods for developments in the field of power systems. The grid data and elaborated study cases are based on German distribution system operators (DSOs) planning and operational principles. After a brief introduction to the SimBench project, this paper presents the general and consistent principles derived for SimBench.

INTRODUCTION

Many institutions perform research in the context of continuously changing power systems, new technologies, methods and tools. To ensure that the investigation is based on realistic grids and to allow the comparison of results as well as methods, an open-source dataset of grid data is required.

SimBench

The project SimBench provides a simulation dataset with special focus on extensive compatible data to reduce study-specific assumptions and improve study results' comparability and transparency [1]. In contrast to some existing open-source test cases, the SimBench dataset includes grid models, evolution scenarios and time series of load, generation and storage for all common voltage levels in Germany. These are extra-high-voltage transmission level (EHV: 380 kV) and distribution grids with high-voltage (HV: 110 kV), medium-voltage (MV: 10/20 kV) and low-voltage (LV: 0.4 kV) level. Detailed information and SimBench grid models are available online (www.simbench.net).

General planning and operational principles

The SimBench dataset is based upon today's typical planning and operational principles of German distribution system operators (DSOs). This paper presents these general planning and operational principles, derived for the development of and the studies with the SimBench dataset. These principles specify parameters for topology, relevant study cases and operational constraints, and are suitable to be used as standard principles for study cases of distribution grids with similar initial situations such as voltage levels and three-phase wiring.

EVOLUTION OF PLANNING AND OPERATIONAL PRINCIPLES

The supply task of the distribution grid with its historically evolution and expected future transformation are the main influencing factors affecting the planning and operational principles.

There is always a trade-off between quality of power supply and economic aspects. Keeping this in mind, the paper focuses on planning and operational principles in a technical way.

Supply task

The task of DSOs in Germany is to build, reinforce and operate low-, medium- and high-voltage grids while ensuring a high level of reliability and the consideration of operational constraints like voltage limits or maximum currents. Therefore, in state-of-the-art, the "Zollenkopf criterion" (the amount of lost energy in case of a failure is constant) is applied, which leads to the variation of resupply methods depending on voltage levels, outlined in Table 1. Only the methods at HV and MV level are mentioned as (n-1)-secure in this paper.

Regarding the ability to transport power from distributed generation, (n-1)-security is not mandatory.

Supply region and supply task

From a technical perspective, the supply task is relevant for the planning and operation of an electrical power system. However, the supply tasks differ considerably depending on the supply region from urban, with high load density, to rural, with low load density. The population density allows assumptions regarding the load and

Table 1: Resupply methods depending on voltage levels

Voltage level		Resupply method
HV		(n-1)-secure with instant reserve, automatic switching
MV		topological (n-1)-secure with quick reserve, remote or manual switching
LV	urban	topological (n-1)-secure, manual switching
	rural	not topological (n-1)-secure, relocatable emergency power unit

topology characteristics. In urban areas, only cables are used at MV and LV level, whereas in rural areas a mix between overhead lines and cables exists.

A HV grid supply region typically has a larger extend and includes both, urban and rural regions. Nevertheless, a classification in mainly urban and mainly rural grid structures makes sense to distinguish metropolitan regions from less populated countryside.

At MV level, areas can be categorized more specifically, e.g. into urban, suburban and rural. Areas with a high number of commercial and industrial consumers, which are directly connected at MV level and could have specific supply contracts as well as clearly differing load profiles, may also be added to the list of MV grid categories.

At LV level, the type of settlements and buildings describe the supply area best. For example, a housing estate indicates that mostly (or only) household loads need to be taken into account, whereas a business estate poses a different supply task. Beside the estimation of the expected loads, the type of settlement indicates and restricts the topology and characteristics of a grid, e.g. if a radial or meshed topology has to be preferred and which line lengths are expected. Depending on the population density, a distinction between urban, suburban and rural areas can be made [2].

Evolution of power systems

The components of energy systems are designed for a long service life, which usually ranges from 20 years for secondary equipment and 40 to 100 years for primary equipment. Therefore, planning and operational principles must take into account not only the current situation of the supply task and the grid, but also need to estimate the future transformation. The current situation with its consisting components meeting the supply of load and feed-in power similarly arose from past expectations of the future and the actual development.

Change in load

Approximately until the turn of the 1990s, a steady increase in electrical load, not caused by population growth but by economic growth, led to expectations of further increasing loads in Germany. From the 1990s the emerging stagnation of the loads led to assumptions of constant loads [3, 4], where increased demand and increased energy efficiency are balanced. The anticipated e-mobility and increasing use of heat pumps and air conditioning are leading to the expectation of future load increase. However, a location-specific estimation of load change is necessary as the expected load may differ regionally.

Table 2: Standard cable and overhead line *(OHL)* types as well as transformer rated powers

Voltage level	Line types and transformer sizes
HV	OHL: AL/St 265/35 Cable: 2XS(FL)2Y 1x630 RM/50 64/110
HV/MV	S_r: {25, 31.5, 40, 63} MVA
MV	Cable: NA2XS(F)2Y 3x1x{150, 185, 240, 300} mm^2 *(OHL: Al 48-149 mm^2)*
MV/LV	S_r: {100, 160, 250, 400, 630} kVA
LV	Cable: NAYY-J 4x{150, 240, 300} mm^2 For house and special connections: NAYY-J 4x{35, 70, 95} mm^2 *(Insulated OHL: NFA2X, 4x{70, 95} mm^2)*

Change in generation

The goal of decarbonizing power generation to mitigate the climate impact calls for an expansion of distributed energy resources (DER). In extensive studies various DER expansion scenarios are examined (e.g. grid development plan, federal state scenarios) to estimate grid expansion [3, 4, 5]. Furthermore, smart solutions are investigated, which are supposed to reduce costs for grid expansion and DER integration. To determine appropriate planning and operational principles, considering smart solutions, every DSO needs to estimate future DER capacities for its supply region in spatial resolution.

Adjustment of planning principles

Due to the components long service life, fast changes regarding principles can be unfavorable in terms of installation costs. Thus, today's determination of planning principles needs to take existing assets into account.

In case of reinforcement or grid expansion, only standard equipment are implemented to decrease maintenance and warehousing costs and to allow flexible reconfiguration. Table 2 summarizes the standard line types and common transformer sizes considered in SimBench. Table 2 also shows frequently existing overhead line types (mainly used in rural regions) in italics and brackets. In regions with special requirements, e.g. high amount of distributed generation, different equipment might be used.

TARGET GRID TOPOLOGIES

Target grid topologies are especially considered for grid expansion and modification. In Figure 1, typical busbar arrangements and terms are given, which are used in the following to explain the grid topologies.

High voltage level

In Germany, HV grids as a whole are weakly meshed and operated by various DSOs. In normal grid operation, each grid is usually operated separately, although they can be

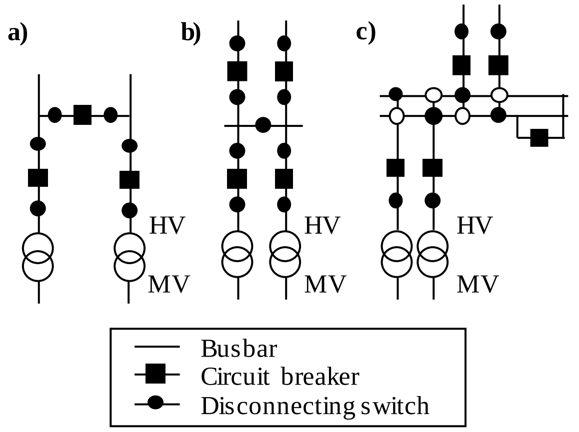

Figure 1: Busbar arrangements: (a) Simplified H-arrangement, (b) H-arrangement, (c) Double busbar

connected to neighboring grids. Due to the past development of the grids, they cannot be described by a consistent structure. In contrast to the lower voltage levels, HV grids usually are supplied by several substations. The design of the connections to the EHV grid is usually redundant, using parallel transformers as well as double busbar settings with horizontal busbar couplers (see Figure 1 for examples of substation structures). The reliability of the grid as well as the possibility of changing the grid topology, for example in case of a line outage, highly depends on the busbar setting. In general, as the (n-1)-security constraint is decisive for planning and operation of the HV grid, EHV/HV substations at HV side are connected with parallel lines, whereas the redundant connection of renewable generation units is not mandatory.

Medium voltage level

To comply with the (n-1)-security, the HV/MV transformers are set up in parallel. The busbar settings comprise all: looped in H-arrangements, simplified H-arrangements and double busbars. Since HV switches are more expensive than MV switches, the cost-availability-optimum often is a looped in H-arrangement at HV side and a single busbar with vertical busbar coupler at MV side.

The (n-1)-security constraint forces DSOs to use reconfigurable topologies. However, for reasons of costs, MV grids often use protection devices, e.g. independent maximum current time protections, which require radial topology. Combining this, target MV topologies often are simple open ring systems or open ring systems with supplied remote station. Nevertheless, because of past power system evolution and former planning principles, in today’s grids different topologies exist. These include e.g. topologies with base and remote stations or more complex ring structures, like triple-systems. Since stations are expensive to invest in and complex to handle, modified grids typically do not include other stations in addition to the supplying HV/MV substation. However, in special cases with already integrated distance protection and meshed topologies with stations, DSOs maintain their structures. In addition, for example at rural MV grids, secluded homesteads and DER can increase ring line lengths so that radial lines can be an effective instrument, especially for DER, because no (n-1)-security constraint is required. In case of load supply, an optimum between investment and operation costs of loop lines against radial lines with the availability of relocatable emergency power units for (n-1)-security has to be found.

Low voltage level

In general, each LV grid is supplied from one MV/LV substation by one single transformer. Typically, LV grids are implemented using radial topologies. Ring and meshed topologies occur sometimes in urban and business areas and are operated radially. Connections are realized via cable disruption cabinets. Due to reasons of low investments, planning expenditure and protection demand, DSO currently prefer radial systems, although there is no reserve for loss of lines. For sufficient availability, (n-1)-security is not required at LV level. In newly planned LV grids, the use of cable disruption cabinets is decreasing, if they are utilized at all.

DEFINITION OF RELEVANT DIMENSIONING CASES

For grid planning, relevant dimensioning cases are considered to design power system assets. These cases rarely occur but have to be managed safely by the grid. A simple and widespread approach to define relevant cases is to assume scaling factors to multiply with maximum powers of load and DER generation. Table 3 illustrates the complete SimBench set of active power scaling factors *p*. The reactive power of loads can be assumed by a power factor cos(φ) of 0.93 (underexcited) for all high load cases and 0.90 (underexcited) for both low load cases. As the reactive power control of the DER sets the reactive power value, no values for the power factor are given for DER.

In the past, the most important scenario was high load and low DER generation (hL, considering faults: n1). Because of a significantly increase of DER, the scenarios high DER generation combined with low load (ℓW and ℓPV) has already become a further determining scenario. Such scenarios may result in overvoltage. In addition, the scenario high load and high DER generation (hW and hPV) can overload lines and transformers, which are uncritical in other scenarios, especially in meshed grids. Wind and PV time series show that maxima usually do not occur simultaneously [6, 7]. Without differentiation, the need for grid expansion may be overestimated. Therefore, it is recommended to use scenarios with both in separate, high wind generation and high PV generation (ℓW and ℓPV). In grids, with one dominant generation type, PV or wind, the remaining high generation scenario often can be neglected.

A more complex and computationally extensive approach for grid planning is to derive parameters from measured

Table 3: Active power scaling factors of relevant study cases in SimBench

Acro-nym	Scenario description	Load	Generation		
			Wind	PV	Others
		p	p	p	p
hL	high load, low DER generation	1.00	0	0	0
n1	high load, low DER generation & contingency case	1.00	0	0	0
hW	high load, very high wind, high PV, high other DER generation	1.00	1.00	0.80	1.00
hPV	high load, high wind, very high PV, high other DER generation	1.00	0.85	0.95	1.00
ℓW	low load, very high wind, high PV, high other DER generation	0.25 (HV), 0.10 (MV/LV)	1.00	0.80	1.00
ℓPV	low load, high wind, very high PV, high other DER generation	0.25 (HV), 0.10 (MV/LV)	0.85	0.95	1.00

power time series or to analyze all time steps. If such data is available and reliable, overestimation or underestimation of grid expansion demand may be further reduced and some critical load-generation-cases may be identified. Time series provided in the SimBench dataset allow to perform such time series-based approaches.

High voltage level

The VDE-AR-N 4121 guideline provides scaling factor recommendations of a high load, low DER generation case and a low load, high generation case for the HV grid [8]. Similar to the guidelines, high scaling factors up to 1.0 are given in Table 3. Likewise, the low load active power scaling factor is set to 0.25. Within SimBench more dimensioning cases are elaborated, distinguishing between generation types and providing reactive power loads.

Medium and low voltage level

The scaling factors need to be applicable for study cases with single grids at each voltage level. At lower voltage levels the smaller grid areas and lower plant numbers lead to higher simultaneity. As a result, at MV and LV level the active power scaling factors are assumed more conservative than at HV level. In general, the scaling factors can be reduced in larger regions and generation numbers or with more information.

Since MV grids are usually supplied by tap-changer transformers, the MV busbar voltage can be controlled. Consequently, planning scenarios may expect the MV busbar voltage to be adjusted appropriately. In the relevant dimensioning cases of SimBench, the voltage set point should be assumed unfavorably. For low load, high generation scenarios (ℓW, ℓPV) the voltage set point is 1.015 p.u. and for high load scenarios (hL, n1, hW, hPV) 1.035 p.u. which are the MV busbar voltage limits illustrated in Figure 2.

PLANNING AND OPERATIONAL CONSTRAINTS

The technical constraints for planning and operation of the grid are defined by voltage and current limits. The EN 50160 standard comprises important, obligatory voltage constraints for all DSOs [9]. For the current limits, the maximum steady-state loading is limited to 100 % of the long-term assets capacity. Some DSOs make exceptions, e.g. allowing a temporarily loading of 130 % of maximum steady-state loading for MV/LV stations. However, for benchmark assumptions we recommend respecting 100 % of maximum steady-state loading as fixed constraint for normal operation as well as for contingency situations. To ensure (n-1)-security, assets under load but without no-load reserve should be constrained to 50 % loading.

High voltage level

In the HV level, the voltage limit, given by the EN 50160 standard, should not exceed ± 10 % of the nominal voltage [9]. Not considering the technical possibility of short-term line overloading due to thermal inertia, in planning and operation of high voltage grid, the current has to be limited to 100 % of the thermal rated current. Both, the voltage limit and the maximum current have to be observed in normal state as well as in (n-1)-situations.

Medium and low voltage level

The EN 50160 standard requires for the MV level voltages below 1.1 p.u. for 99 % of all 10 minute intervals in a week and within 0.85 p.u. and 1.15 p.u. for all such intervals. The voltage on LV level should be within 0.9 p.u. and 1.1 p.u. in 95 % and not below 0.85 p.u. in the remaining intervals [9]. In addition, there are standards and guidelines regulating DER integration [10, 11] and extension of cable service [12]. As a consequence of DER integration regulation, the voltage rise caused by DER is limited to 2 % in MV and 3 % in LV respectively. However, there are no other fixed constraints how to set voltage limits in planning and operational principles, which results in different limits between DSOs. As nowadays the HV/MV transformer tap usually controls solely the MV and LV voltage, the voltage constraints of MV and LV grids must be considered together. Assuming ± 1 % range for MV transformer step and ± 1.5 % for voltage decrease and increase at MV/LV transformer, the voltage constraints of Figure 2 result for normal operation conditions. The future installation increase of MV/LV transformers with on-load tap changer may allow relaxing the DER voltage rise limit and widen the MV level voltage limits of Figure 2. For (n-1)-security cases, an additional 5 % voltage drop could be allowed.

The presented general voltage limits used for SimBench may differ from real DSO planning and operational principles, because DSOs adjust their planning and operational principles to the specific supply tasks. Especially DSOs operating the MV and LV voltage level

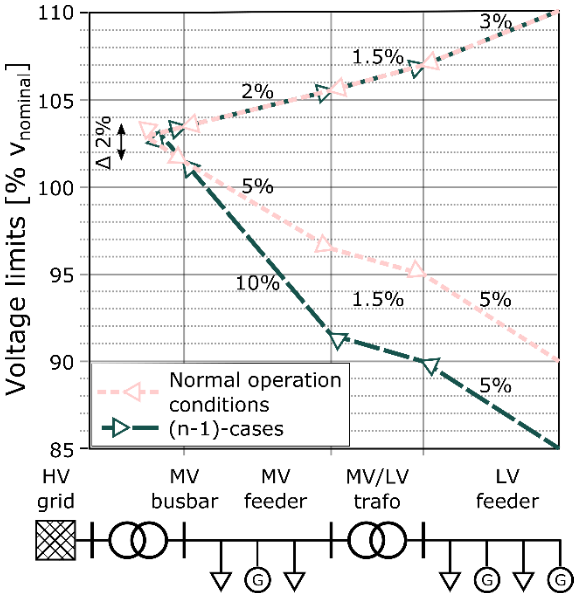

Figure 2: Voltage limits at MV and LV levels for relevant dimensioning cases in SimBench

can adjust limits appropriately by experience and full grid information, particularly for grids that include homogenous feeders in terms of generation and load. For the grid operation, this could mean decreasing the MV busbar voltage in low load cases (ℓW and ℓPV) to increase the voltage rise at MV level for wind driven grids or at LV level for PV driven LV grids.

CONCLUSION

Typical German DSOs planning and operational principles are considered to provide appropriate open-source datasets and dimensioning cases in SimBench. This paper describes the main facts on planning and operational principles, the supply task and power system evolution used for SimBench. The discussion on target grid topologies shows that many topologies exist and highlights the most relevant, e.g. weakly meshed at HV level, open-ring structures at MV level and radial feeders at LV level. To perform comparable case studies, especially with SimBench grids, load and generation scaling factors are given for six elaborated cases. The resulting power systems are published at www.simbench.net.

Acknowledgments

The authors appreciate the support of the industry working group, consisting of DREWAG NETZ GmbH, ENSO NETZ GmbH, NetzeBW GmbH, Syna GmbH and EnergieNetz Mitte GmbH. This publication is based on findings from the research project SimBench, which is supported by the Federal Ministry for Economic Affairs and Energy and the Projektträger Jülich GmbH (PTJ) (FKZ: 0325917). The authors are fully responsible for the content of this publication.

Supported by:
Federal Ministry for Economic Affairs and Energy
on the basis of a decision by the German Bundestag
SimBench

REFERENCES

[1] Project SimBench, https://www.simbench.de/en

[2] C. Kittl, D. Sarajlic, and C. Rehtanz, “k-means based identification of common supply tasks for low voltage grids,” 2018.

[3] A.-C. Agricola, B. Höflich, P. Richard, J. Völker, C. Rehtanz, M. Greve, B. Gwisdorf, J. Kays, T. Noll, J. Schwippe, A. Seack, J. Teuwsen, G. Brunekreeft, R. Meyer and V. Liebert, 2012, *Dena-Verteilnetzstudie - Ausbau- und Innovationsbedarf der Stromverteilnetze in Deutschland bis 2030 Dena [Dena distribution grid study - extension and innovations needs of German distribution grids until 2030]*, Deutsche Energie-Agentur, TU Dortmund

[4] J. Büchner, J. Katzfey, O. Floercken, A. Moser, H. Schuster, S. Dierkes, T. Van Leeuwen, L. Verheggen, M. Uslar and M. van Amelsvoort, 2014, *Moderne Verteilernetze für Deutschland (Verteilernetzstudie) [Modern distribution grids for Germany (distribution grid study)]*, Bonn, BMWi

[5] M. Braun, I. Krybus, H. Becker, R. Bolgaryn, J. Dasenbrock, P. Gauglitz, D. Horst, A. Scheidler and J. Ulffers, 2018, *Verteilnetzstudie Hessen 2024-2034 [Distribution grid study Hesse 2024-2034]*, Fraunhofer IEE

[6] M. Stappel, A.-K. Gerlach, A. Scholz and C. Pape, 2015, *The European Power System in 2030: Flexibility Challenges and Integration Benefits*, Fraunhofer IWES

[7] T. Hammerschmidt, A. Gaul, T. Christ and C. Rehtanz, 2012, "Simultaneity of PV- and wind power-generation from distribution grid perspective" *CIRED 2012 Workshop: Integration of Renewables into the Distribution Grid*, 1-4

[8] VDE-AR-N 4121:2017-07, *Planungsgrundsätze für 110-kV-Netze [Planning principles for 110-kV-grids]*

[9] Standard EN 50160:2011-02, *Voltage characteristics of electricity supplied by public distribution networks*

[10] W. Bartels, F. Ehlers, K. Heidenreich, R. Hüttner, H. Kühn, T. Meyer, T. Kumm, J.-M. Salzmann, H.-D. Schäfer and K.-H. Weck, 2008, *Technische Richtlinie: Erzeugung am Mittelspannungsnetz [Technical guideline: Generation in MV grids]*

[11] VDE-AR-N 4105:2011-08, *Erzeugungsanlagen am Niederspannungsnetz - Technische Mindestanforderungen für Anschluss und Parallelbetrieb von Erzeugungsanlagen am Niederspannungsnetz [Energy resources in low voltage grids – minimum technical requirements for connection and parallel operation of energy resources in LV grids]*

[12] VDE-AR-N 4220:2015-08, *Bauunternehmen im Leitungstiefbau – Mindestanforderungen [Underground cable construction companies: minimum requirements]*