Potentials and Technical Requirements for the Provision of Ancillary Services in Future Power Systems with Distributed Energy Resources

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Abstract

A decentralized supply of electrical power based on renewable energies paves the way to a sustainable power supply without nuclear energy and without the emission of greenhouse gases. This energy transition (Energiewende) entails challenges regarding the provision of Ancillary Services (AS), associated with intermittent in-feed of Distributed Energy Resources (DER) into the distribution grids. In this paper, the demand, potentials, and technical requirements for AS provision in Germany, especially in the state of Lower Saxony, are discussed. These aspects are considered from multiple perspectives across all voltage levels. Beginning with a steady state analysis that focuses on the transmission grid, an expected increment in voltage violations and line congestions is revealed. Counteracting the resulting technical limit violations requires consideration of distribution grid flexibilities among others. To address this emerging demand, the potentials for the provision of AS by components in the distribution grids are identified. However, technical concepts are also required to exploit the potential, as DER in-feed has significant impact on the functionality of conventional protection systems. The analysis in this paper indicates the need for development of concepts to provide AS in the distribution grid and detailed technical requirements within a holistic simulative approach.

Keywords— Ancillary Services, Distributed Energy Resources, Monte-Carlo Scenarios, AC-PTDF, Demand Analysis, Demand Covering, Controllable Loads, Prosumer, Systems Engineering, Protection Systems

1 Introduction

To achieve the long-term climate targets, all energy sectors in Germany are facing a major transformation in the coming decades and will be extensively shifted towards renewable energies. Therefore, the electrical energy system will be based on an increasing integration of Distributed Energy Resources (DER), including photovoltaic (PV), wind power, hydro, and biogas plants (BGP), as well as storage technologies, electric vehicles, and flexibility capabilities of modern prosumers in general. Currently, Ancillary Services (AS) — operational management, frequency control, voltage control, and system restoration — for a safe and reliable operation of power grids are provided mainly by the synchronous generators of large conventional power plants in the transmission grid. In the future, a high quantity of decentralized generation sources, controllable loads, and storage technologies at the distribution level will contribute to the provision of AS. [1]

Hence, there is an increasing demand for further development of AS provision. This includes technical, economic, and regulatory requirements, along with a framework for the interaction of grid operation, DER, and stakeholders. These challenges are addressed within the joint project SiNED, which is further presented in [2]. The focus in this paper lies on technical investigations and the impact of AS provision on all voltage levels.

Divided into four research areas, the potentials and technical requirements for AS provision, corresponding technologies for DER, and protection concepts of a grid scenario for the reference year 2030 are ascertained. An overview of the four research areas and the involved voltage levels is presented in **Figure 1**.
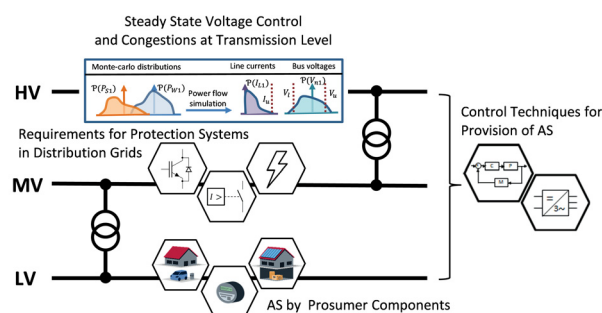

Figure 1 Investigated research areas, based on [2]

A detailed explanation of the symbols can be found in **Figure 2**, with reference to the research area at high voltage level (HVL) as indicated in **Figure 1**.

This paper is structured as follows: Section 2 focuses on estimating technical constraint violations with increased renewable in-feed in the grid. Section 3 discusses the different DER technologies for potential AS provision. Section 4 examines the possibility of providing AS by prosumer components in the low voltage (LV) grid, and discusses technological and regulatory issues. Section 5 considers the impact of high DER penetration in combination with AS provision on the functionality of conventional protection systems in the medium voltage (MV) grid. A conclusion of the presented results with an outlook on upcoming work is drawn in Section 6.

2 Assessment of Potential Voltage Violations and Congestions

In this section, a steady state power flow analysis compares the potential technical limit violations at the transmission level for the reference years 2020 and 2030 (represented onwards as Ref20 and Ref30). The grid of Lower Saxony, equipped with a power flow dataset (conventional/renewable generation and load time series data in hourly resolutions) [3], [4], is adapted for the reference years [5]–[7]. A time duration of 24 hours is selected for analysis. The wind and PV generation time series are used for Monte-Carlo scenario generation. At every time step, a synthetic distribution considering n probable scenarios is determined for each DER based on the current operating point (mean μ) and a standard deviation (σ). This emulates varied renewable in-feed for which the thermal power is economically dispatched to ensure power balance. Subsequent power flow simulations determine resultant bus voltages and line currents (see **Figure 2**).
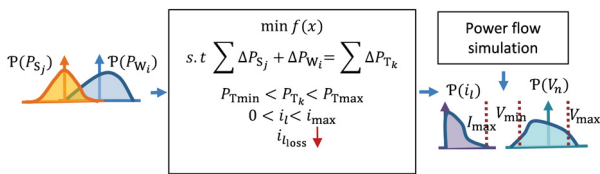
Figure 2 Simulation process for the determination of potential constraint violations (P – active power injection; I_l – line current; S_j – solar power plants; W_i – wind power plants; T_k – thermal power plants; with $i, j, k, l \in \mathbb{R}$ representing corresponding indices)

The Monte-Carlo scenario generation for different DER are modelled considering the following assumptions:

- The current operating point of the DER represents the most probable or mean scenario. This is valid considering increased reliability of forecast accuracy.

- A normal distribution is assumed for PV power plants considering the current operating point as the mean (μ) and corresponding standard deviation (σ), derived from aggregated solar generation dataset for Germany. [8]

- The wind power plant generation is modelled according to a Weibull distribution for the corresponding wind speeds. The scale parameter λ is derived from the current operating point (mean μ). The shape parameter $k = 2$ is selected to represent standard conditions in Europe. [9]

The economic dispatch problem is formulated as an optimization problem where the dispatch is adapted considering the deviations in renewable energy generation as compared to the mean operating point. This argument assumes the possibility of occurrence for different probable scenarios as emulated by the Monte-Carlo distribution. The thermal active power generation is adapted subject to maximal and minimal generation constraints as well as thermal line current limits. This accounts for contribution to congestion management during dispatch itself. The current constraints and thermal losses are modelled as soft constraints. Soft constraints allow overloadings subject to minimization. This is valid, since in this section the problem is demonstrated to explore the potential of distribution flexibilities in further works. Redispatch measures from conventional generators are not considered. At the transmission level owing to the increased R/X ratio, the active power influence on voltages is insignificant. Therefore, potential voltage violations remain uninfluenced by thermal dispatch and are investigated. Provision and corresponding application of distribution flexibilities for improvement of steady state voltage profiles is to be explored in further works.

The current and voltage sensitivities to the incremental change in active power injection are formulated. The angle and voltage sensitivities are derived from the Jacobian matrix, see (1). The deviation in bus angles and voltages are further used to calculate the deviation in line current flows according to an established AC Power Transfer Distribution Factors (AC-PTDF) formulation, see (2) [10]. The line losses are formulated considering the incremental change in power injection at the nodes neglecting the shunt power flows, see (3) [11].

$$\begin{bmatrix} \Delta \delta \\ \Delta V \end{bmatrix} = \begin{bmatrix} \dfrac{\partial \delta}{\partial P} & \dfrac{\partial \delta}{\partial Q} \\ \dfrac{\partial V}{\partial P} & \dfrac{\partial V}{\partial Q} \end{bmatrix} \begin{bmatrix} \Delta P \\ \Delta Q \end{bmatrix} \tag{1}$$

$$\Delta I = \frac{\partial I}{\partial \delta} \Delta \delta + \frac{\partial I}{\partial V} \Delta V \tag{2}$$

$$\Delta P_i = \frac{\partial P_i}{\partial \delta} \Delta \delta + \frac{\partial P_i}{\partial V} \Delta V$$
$$P_{\text{loss}} = \sum_{i \neq j}^{n} \Delta P_i \tag{3}$$

The current constraints and loss minimization problems are formulated as soft constraints, see (4), considering

the respective variables represented by C and the corresponding slack variables by s_k. This enables optimal solution considering constraint violations. The objective is valid considering that only conventional generator dispatch is considered for demonstration of the problem statement. Additional flexibilities like stationary FACTS devices and distribution grid flexibilities require consideration in future works.

$$C_0 - \Delta C - s_k < C_{\max}$$
$$-C_0 + \Delta C + s_k < C_{\min} \qquad (4)$$

The economic dispatch for every Monte-Carlo scenario over the time duration of a selected n hours is carried out. The power dispatch is adapted according to (5).

$$\sum \Delta P_{s_j} + \sum \Delta P_{w_i} = \sum \Delta P_{T_k} \qquad (5)$$

Corresponding power flow simulations are carried out for analysing probability of line voltage violations (see **Figure 3**). Examination of Ref30 reveals an increased probability of voltage violations as compared to Ref20.
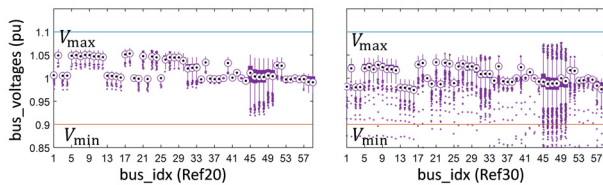

**Figure 3** Potential steady state voltage violations for Ref20 and Ref30

Analysis of potential overloads reveals an increased probability and degree of initial overloads in Ref30 compared to Ref20 (see **Figures 4-5**). Post dispatch, a reduction in overload instances is observed in both cases, although for Ref30 this effect is reduced due to increased renewable generation. This is attributed to the fact that in the scope of this paper, network expansion is not considered. In future work, the potentials of distribution flexibilities for reducing overloads require consideration to decrease cost intensive network expansion requirements.

3 Demand Analysis of Fast Activating Ancillary Services

Due to the increasing number of limit violations in the transmission grid in the future, a demand analysis for the DER in the individual voltage levels of the distribution grid will be set up within this section. Based on an estimation of the demand of AS for selected reference years, it is possible to make a statement about the development of the future demand for the AS required for a secure grid and system operation. The demands to be provided by PV, wind onshore, wind offshore, bioenergy, and hydropower are compared. For this analysis data from the 2018 Erneuerbare-Energien-Gesetz (EEG) -
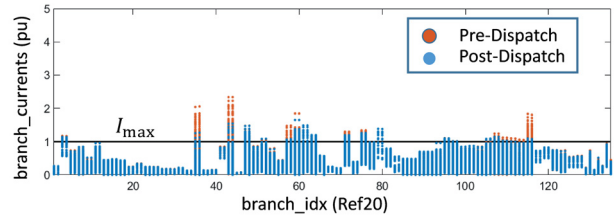
Figure 4 Potential line congestions for Ref20
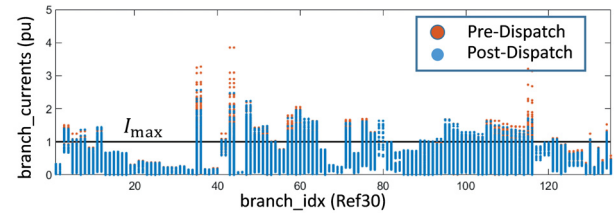
Figure 5 Potential line congestions for Ref30

Anlagenstammdaten published by the Bundesnetzagentur [12] is used.
Furthermore, a trend in the determination of the demands for the reference year 2030 is explained.
The overall significant growth of electrical energy generation will be increasingly based on a large number of decentralized and fluctuating in-feed of PV and wind power plants. The combination of a large number of different fluctuating but controllable in-feed systems leads to an increasing complexity. Through the continuous gas production in BGP, its energy generation can be shifted to times when solar and wind energy cannot provide sufficient power capacity.
A requirement for the provision of ancillary services is the controllability of the plant. For an active participation in the balancing market with PV plants a storage coupling is necessary. The flexible production and harvesting of bioenergy are, due to its controllability of electricity and heat generation, an essential element in energy systems fulfilling major tasks, e.g., climate and renewable energy targets, balancing of fluctuations of renewable electricity generation, provision of grid stability, reliability, and AS [13], [14]. Flexibly operated BGP can thus become a controllable integrator for the DER. To increase the flexibility of BGP energy production, technical changes have to be made in the energy value creation process. In a conventional BGP, biomass is fed into the digester to produce biogas, which is then burned directly in the combined heat and power plant (CHP) unit to produce electricity and heat. In this case, biogas is constantly burned in the CHP, which means that the electricity and heat are fixed. However, the disadvantage of this type of CHP is the inflexibility of biogas and electricity production. In this way, the production of electricity is not oriented to the actual demand. To increase this process's flexibility and controllability, a gas storage facility must be installed between the digester and the CHP unit. If waste

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heat is used, a heat storage tank should also be installed. Furthermore, additional CHP capacities are required to be able to process the stored biogas during demand or high-priced periods. [13] In addition, heat-controlled BGP can be utilized for the provision of AS. This requires a precise forecasting of the heat demand for accurate schedules and an intelligent integration of the BGP into a virtual power plant (VPP). [15]

In addition to the controllability, the analysis also considered the differentiation in plant size – plants with an installed power of less than 30 kW (small plants) are compared to plants with a size of at least 30 kW (large-scale plants). [12]

With regard to onshore wind technology, the evaluation shows that there are almost no installations of small onshore wind energy plants. Accordingly, the focus for the provision of AS is on large-scale plants of medium voltage level (MVL) and HVL.

The focus for covering the AS demand through PV plants is on low voltage level (LVL) and MVL.

The share of renewable energies from offshore wind turbines in the distribution grid is significantly lower compared to onshore wind turbines. Although the share from offshore wind energy increases by more than double by 2030 compared to the reference year 2018, the contribution across Germany with an installed capacity of 150 MW is very small compared to the installed capacity of onshore wind energy (2030 Germany approximately 70 GW). Therefore, the capacity provided by offshore wind turbines is initially not taken into account in further project considerations for the provision of AS. Nevertheless, the development of installed capacity in offshore wind energy shows an increasing potential to contribute to the provision of AS with renewable energies in the future beyond 2030.

This also applies to the biomass plants in the low, high and extra-high voltage levels, this technology is only taken into account in the MVL for the continuous demand coverage. Almost no small-scale biomass plants have been installed. Accordingly, the focus for the provision of AS is on large-scale plants in MVL.

A specific minimum capacity is required for the provision of balancing power. For primary power, the minimum capacity is 1 MW; for secondary control power and minute reserve power, the minimum capacity is 5 MW. Plants that fall below this minimum capacity must join a VPP in order to be able to provide the necessary MW jointly. [16] The different possibilities of participation of BGP in the electricity market can be classified according to the different periods of balancing power, up to intra-day and day-ahead trading, which can be planned in longer-term periods. [14]

All considered technologies can operate the trading of both positive and negative control power [16].

It is also conceivable to adjust the participation and framework conditions in the balancing power market in the future.

A possible concept is drawn up for the future coverage of demand for balancing control power – Frequency Containment Reserve (FCR), automatic Frequency Restoration Reserves (aFRR), manual Frequency Restoration Reserves (mFRR) – and the extent to which it is possible to take over a share of demand across all technologies is examined. Reference is also made to whether the installed plant capacity or the number of plants in the voltage levels would be sufficient to cover demands or whether further grid expansion should potentially be pursued.

An insight into the concept for covering the balancing power demand of PV in Germany for 2018 by the large-scaled wind-onshore power plants in MVL and HVL of aFRR and mFRR is presented in **Figure 6**.
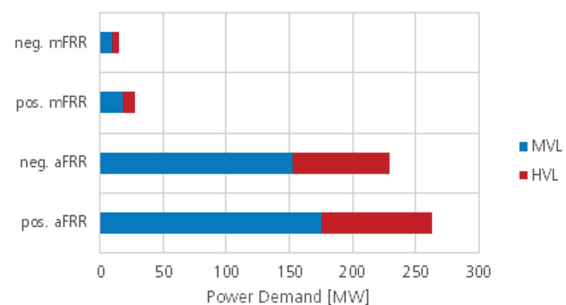
Figure 6 New estimates of demand covering by onshore wind energy plants

The total demand coverage for all five types of balancing power (FCR, aFRR, mFRR) is shown in **Table 1**.

Table 1 Evaluation of demand coverage by large-scaled wind-onshore power plants in MVL and HVL

	Number of Plants	Total Installed Power [kW]	Total Demand [kW]
MVL	12,602	21,306,591	361,996
HVL	8,528	19,170,900	178,973

Both, the balancing power demands of the MVL and the HVL can be covered with the respective installed power of the onshore wind turbines, so that there is no need for grid expansion in this respect.

If the demand covering of Lower Saxony is considered using the same concept, it can be seen that there is a deficit of installed power for covering the demand both in the MVL and the HVL. One possible solution approach would be to cover the deficit across the federal states. Alternatively, the surplus of installed power from BGP could also be used for the demand covering in MVL.

In the further course of the project, the provision of reactive power in the distribution grid is to be carried out by using a higher-level control system in the HVL and MVL. The LVL will initially continue to regulate the provision of reactive power in accordance with the Technical Connection Rules (TCR) for low voltage. Depending on the results, further measures for participation in the provision of reactive power from the LVL with PV systems or prosumers can also be taken into account. In the future, the provision of balancing control power by BGP, PV systems, wind power, and battery storage systems (BSS) will be calculated economically and technically in an

energy system optimizer. This will provide initial results and knowledge regarding optimal investment decisions, operating strategies, in-feed tariffs, and schedules for plant operators, system service providers, and investors.

For the coupling of the converters to the control system, it is necessary to consider the information and communications technology (ICT) connection and data transmission.

The provision of balancing power, especially in a VPP, requires the integration of information and communication technology in order to be able to exchange data in real-time and to be able to switch the flow of balancing power on and off fully automated.

4 Ancillary Services by Grid Serving Prosumers

In conjunction to DER in the MV grid, the LV grid is undergoing a significant transition as well. Households are no longer rigid electricity consumers but active and flexible prosumers that can adjust their electricity demand or produce energy.

Therefore, in a first step, a detailed analysis of the residential sector by building structure is carried out. As a result, four components of modern prosumer households are identified as generally suitable for the provision of AS: PV systems, BSS, heat pumps (HP), and electric vehicles (EV). The power flows of the electricity, heat and mobility sector in modern households with these components are depicted in **Figure 7**. Especially extended functions of domestic BSS, STATCOM operation or the multiple usage, in connection with EV seem to be able to positively contribute towards the stress in LV grids [17]. Estimations on the installed power for each of those components in Lower Saxony for the years 2020 and 2030 based on available literature are listed in **Table 2**. For this, the charging power of a single EV is assumed to be 3.7 kW in 2020 and 11 kW in 2030, while in 2030 only 70 % of the private EV have a charging station on private property.
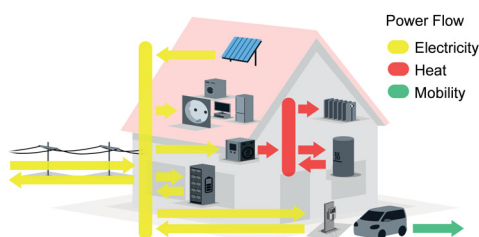
Figure 7 Power flows of various energy sectors in future prosumer households

Additionally, the commercial trade and services sector (CTS) is intensively analysed and figures to be very heterogeneous. Therefore, representative companies are selected based on their electricity consumption and potential for AS provision, among others: Agricultural farms, grocery stores, restaurants and bakeries. Shunt

Table 2 Estimation of installed power [MW] for prosumer components in the reference years for LV grids in Lower Saxony, according to own calculations

	2020	**2030**
PV systems	2,458	3,261
Domestic BSS	85	966
HP	266	662
EV	46	7,121

and delivery vehicles as well as cooling units form key components of CTS companies in this regard.

A comprehensive analysis indicates existing potentials for the aforementioned prosumer components to provide several local and global AS: Steady state voltage control, frequency control and network congestion management appear to be appropriate candidates for further investigations. Steady state voltage control by inverter-controlled prosumer components is realized by reactive power injection, thus making it a cost-free and therefore privileged option. Regarding frequency control, mFRR will not be considered for prosumer components due to its higher duration and thus the increased energy output. Network congestions in LV grids are mitigated by either reducing the in-feed from PV systems or storage, or reducing the load demand of HP or EV.

While not each component is ideally suited for all AS, **Table 3** gives an overview of how the technical and realistic potential of the components for provision of the inspected AS is estimated. Plus signs indicate a high positive impact regarding the AS, minus signs signal basically no impact at all. E.g. PV systems can serve nicely for voltage control or congestion management by reactive power injection or curtailment, but typically have no reserves for positive power adjustment in case of frequency dips. BSS on the other hand can contribute to all AS considered because of their ability to inject and purchase energy. HP seem mostly suited for congestion management by demand side management. Concerning EV, it has yet to be assessed whether they are merely considered as controllable loads or also in context of Vehicle-to-Grid/-Home due to bidirectional charging systems. With the latter, EV can also actively contribute to frequency control or basically relieve the grid through in-feed [18].

Table 3 Estimation of the potentials for prosumer components to provide the inspected AS

AS	PV	BSS	HP	EV
Steady State Voltage Control	++	++	o	++
Congestion Management	+	+	+	+
Frequency Control	–	+	–	o

Technical potentials for providing AS are restricted by framework conditions and technical issues regarding the components of the prosumers. First of all, domestic BSS are intended for the temporary storage of renewable energy, meaning the multiple use presents a problem. Secondly, the additional losses, particularly in the inverters, must be taken into account in economic evaluations of the multiple

use of BSS [17]. Also, ICT is missing in the German LV grids, so in addition to not being able to register the system state of the grid, the prosumers components cannot be remotely accessed [19]. Furthermore, minimum power requirements combined with limited plant sizes in LV grids demand the bundling of several components to form VPPs. The next steps will include a detailed study into the provision both of local and global AS. The provision of reactive power by controllable inverters will be investigated as well as potential synergies of the multiple use of storage systems. For improved simulations, standardized LV Kerber grids [20] will be applied to evaluate the realization of these potentials. In the institute's own MATLAB simulation environment eSE [21], the individual components are grouped into households and the grid calculations including potential provision of AS are performed subsequently. The displayed findings of the investigations will be integrated into eSE. Upcoming simulations will reveal the potential for prosumer components to provide AS and its impact on LV grids, and will enable a comparison of different business concepts for the prosumers. Among other things, this requires the development and implementation of an active control strategy for prosumer components in eSE.

5 Protection Systems in Distribution Grids

The provision of AS requires reliable grid operation, assigning a key role to the protection system. Distributed in-feed has a significant impact on the functionality of the protection system.

In order to analyse the need for adaption of conventional protection systems, a review of challenges and the impact of inverter-based DER in-feed is made to address these emerging challenges and formulate technical requirements. The challenges are summarized in **Table 4** in a simplified manner, and categorized into three main issues, where the focus lies on the impact of DER and faults in a cable-dominated grid. Islanding and auto reclosing issues are not considered.

Table 4 Summary of relevant challenges for protection systems with their causes using [22] and [23]

Protection System Issue	Caused by
Blinding of Protection	Decreasing short-circuit current levels due to increasing DER in-feed
False or Sympathetic Tripping	Bi-directional current flows without the use of directional (overcurrent) relays
Loss of Coordination	DER-based local in-feed and short-circuit current contribution that differ from the conventional downstream current flow

Additionally, the potentials for AS provision of inverter-

based DER regarding [24] as the current standard need to be considered. As fault detection and fault clearing by protection systems take place within brief time frames of < 1 s, especially the AS of fault-current contribution by in-feed of a reactive current and fault ride-through (FRT) capabilities will be analysed.

A protection system is a complex system with many requirements, interfaces and design possibilities, which makes model-based systems engineering (MBSE) a valuable tool for the development of protection systems. Especially with the change to a grid characterized by renewable and distributed energy in-feed that is based on power electronics, the protection system needs to be adapted. The MBSE methodology is based on the V-model shown in **Figure 8**.
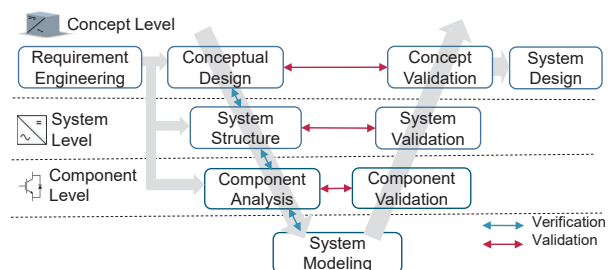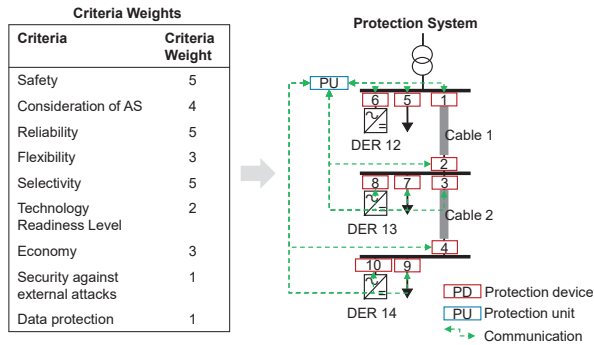

Figure 8 V-model for the protection system development

Multiple design levels ensure a structured approach and a systematic implementation of the initially defined requirements. The conceptual design describes the system objective, constraints and the system structure, expected behaviour and functionality. This is in the next step translated to the system level where the most suitable protection system structure is identified based on an assessment methodology. Verification and validation are essential in MBSE to ensure that the system is designed correctly and that the correct system design is developed.

For the system structure definition, different design elements such as the location of a protection device, the existence of a central protection unit, and the communication type were utilized for the development of possible system structures. In addition, the criteria listed in **Figure 9** were applied. These criteria together with criteria weights led to the most suitable protection system design, which is illustrated in **Figure 9**. Having identified the system structure, the next step is to include more details to the protection system design on component model according to the V-model before continuing with the system modelling and validation.

Both the challenges for protection systems and the potentials for AS provision of DER lead to the following overall technical requirements for modern protection systems. Among ensuring a reliable grid operation in general, grid protection should not be negatively influenced by the increasing deployment of DER, so that any DER operation and AS provision is possible without unintended disconnection, and fault-related AS provision, like short-circuit current contribution, should be ensured.

Criteria Weights	
Criteria	**Criteria Weight**
Safety	5
Consideration of AS	4
Reliability	5
Flexibility	3
Selectivity	5
Technology Readiness Level	2
Economy	3
Security against external attacks	1
Data protection	1

Figure 9 Criteria weights (1: low impact to 5: high impact) and protection system design

A simulation environment forms the basis, mainly for the development of modern protection systems including their validation. It also serves for the definition of detailed technical requirements, validation of emerging challenges from literature review, and simulative observation of protection systems and DER performance. To allow the integration of communication and the observation of protection system and DER dynamics, MATLAB/Simulink is used as the simulation environment.

The same system, as presented in **Figure 9**, is implemented in the simulation environment, while an excerpt from the Cigré benchmark model [25] serves as a reference for the parametrization of transformers, cables and loads. **Figure 10** (left) shows a first example that is used for the simulation of fault scenarios.
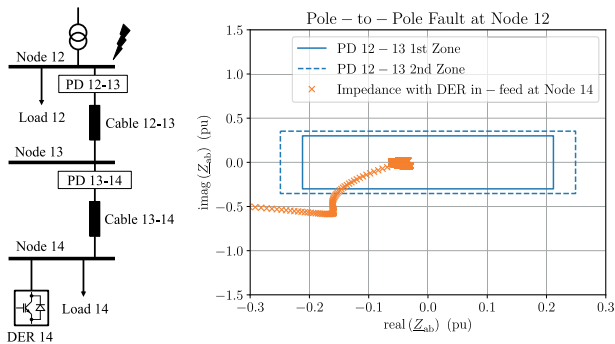
Figure 10 Adapted Cigré benchmark model excerpt (left) and impedance measurement (right)

Regarding the in-feed of DER, a hosting capacity analysis is performed to not exceed the maximum permitted power at a node compliant with [24], with respect to thermal limits and the maximum voltage deviation at each node. Control, fault detection and fault handling, especially reactive current in-feed and FRT capabilities, are also modelled and compliant with the respective standard. Core functionalities of the protection devices are distance and overcurrent protection.

For the simulation of fault scenarios, busbar and cable faults at different locations in the grid under varying DER in-feed and load conditions are considered.

The overcurrents and impedance measurements are then evaluated, to compare the impact of faults on the protection system with and without DER in-feed. Stimulation of protection devices during FRT is also investigated.

An example is shown in **Figure 10** (right), where a pole-to-pole fault occurs at Node 12 with DER in-feed at Node 14. This leads to a false tripping of protection device PD 12-13, as the measured impedance during the fault is within the 1st zone of the distance protection polygon. Without DER in-feed, PD 12-13 does not trip.

As a next step, the observed protection system issues are analysed in detail, and then classified to develop additional algorithms that can be implemented in a modular way.

6 Conclusion and Outlook

The technical considerations and challenges associated with integrating DER in the power grid are addressed in this paper. A scenario-based analysis of an exemplary future grid model with increased renewable penetration reveals a higher probability of technical constraint violations. This requires investigation of corrective measures like distribution grid flexibilities.

Based on the problem statement, an investigation on potential provision of distribution grid flexibilities considering the future power system of Germany and Lower Saxony is made. Even prosumer components are identified to be suitable for the provision of different AS, even more in future years due to the growth of their installed power. In order to cover the AS demand, a well coordinated grid operation and the associated necessary communication structure in the framework of a secure ICT connection must be ensured. Future coordinated and secure grid operation can be realised if the DER are controllable and can contribute to flexibility. By carrying out grid simulations one will be able to compare business concepts for the stakeholders and assess the effect of AS provision on the grids.

Protection concepts for increased penetration of DER are also discussed in this paper. The application of MBSE for the development of protection systems for grids characterized by DER was found to be very beneficial. It allows a system design that meets the stakeholder needs and requirements. It has been shown that conventional protection systems need to be adapted in order to ensure reliable grid operation with DER in-feed. As a next step, the technical requirements need to be defined, which is performed by utilizing the established simulation environment, including a detailed analysis of the fault scenarios with DER and protection system dynamics.

7 Acknowledgement

8 Literature

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