METHODOLOGY FOR DEVELOPING INNOVATIVE PLANNING PRINCIPLES

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ABSTRACT

Due to the integration of an increasing installed capacity of distributed generation into Germany's rural distribution grids, deviations from the permitted voltage range as well as grid component overload occur more frequently. Currently this leads to a cost-intensive renewal effort for grids. This paper describes a methodology to develop planning principles for distribution grids which consider innovative grid technologies in order to reduce the reinforcement costs.

At first, future requirements for rural distribution grids are formulated. For this purpose scenarios for distributed generation, electric loads and storages are derived.

By applying these scenarios to a variety of existing rural distribution grids of the HV, MV and LV levels rising problem areas caused by the changes of the supply task are clustered (e.g. overvoltage at the end of a single feeder of a LV grid). Subsequently, different problem-solving approaches with the focus on innovative technologies are analyzed and compared. Finally general planning principles can be derived that consider technical and environmental differences in German rural distribution grids.

The application of the developed methodology is outlined with help of a case study of a rural low-voltage grid. The economical benefit of the use of suitable innovative technologies emphasizes the importance of general planning principles that can be derived by the introduced methodology.

INTRODUCTION

The German power supply system currently faces distinct changes caused by the massive integration of decentralized renewable energy especially into rural distribution grids. Furthermore, new technologies like e-mobility and heat pumps, designed to reduce the carbon footprint, lead to an additional load that was not considered when planning today's grids.

Both the feed-in of decentralized energy and the aforementioned new loads cause deviations of the permitted voltage range and overloads of the grid equipment. There are different approaches to face those impermissible grid states, that can be divided into conventional reinforcement strategies and those that rely on the extensive use of innovative technologies like on-load voltage controlled MV/LV transformers or decentralized grid automation systems (e.g. [1]).

Currently there are some studies focusing on quantifying the need of expansion of distribution grids in Germany [2] and others specializing on the evaluation of single innovative components and concepts [3].

However there is no uniform strategy for planning the reinforcement of rural distribution grids with regards to the rising requirements and innovative technologies.

Therefore this paper outlines a methodology that allows the definition of planning principles that consider innovative technologies on the basis of existing distribution grids.

METHODOLOGY

The proposed methodology can be divided into four steps that are described in detail in the following sections (Figure 1). Here the focus is on steps that are exemplarily shown in the later discussed case study.

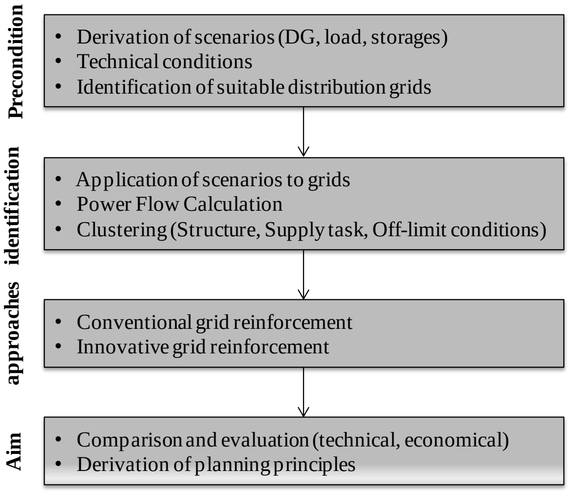

Figure 1 Steps for obtaining planning principles with consideration of innovative technologies

PRECONDITIONS

Scenarios of Distributed Generation units

To determine the future requirements for the integration of distribution generation (DG), Germany-wide scenarios of the installed capacity based on a variety of studies (e.g. [2], [4]) are derived. Therefore the target years 2020, 2030 and 2050 are considered. By the use of three scenarios for each target year – lower bound (LB), trend scenario (TS) and upper bound (UB) – the inherent uncertainties of forecasts caused by changing of technical and political parameters are quantified.

Figure 2 outlines the results, separated by different DG unit types. The installed capacity of DG doubles until 2050 (TS) in relation to the reference value of 2012. The majority of the installed capacity of DG is provided by onshore wind turbines and photovoltaic installations, followed by biomass power plants. In contrast in this project geothermal generation and hydroelectric power plants can be neglected.

In order to provide expansion scenarios for all examined grids the Germany-wide scenarios are regionalized by application of a distribution formula that rely on statistical data like the population density (cf. [2]). A further regionalization step assigns the installed capacity to each of the considered voltage levels.

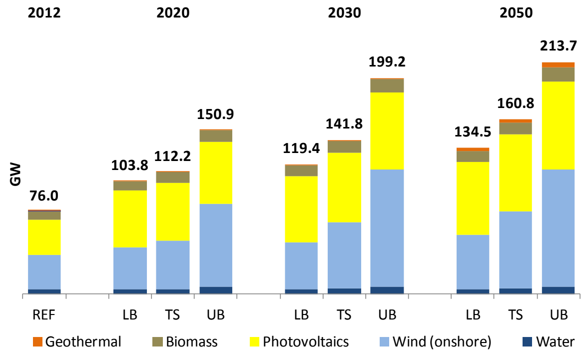

Figure 2 Scenarios of the installed capacity of different DG unit types in Germany.

Load development

In the past, LV distribution grids in Germany have been frequently designed without knowing the actual power flow. Hence, with consideration of an additional safety margin most LV grids are oversized regarding to the maximum load situation.

Usually not until the exhaustive integration of new loads like heat pumps and electric vehicles the operating point of maximum load can cause an overload of the grid equipment.

In contrast, with the rising number of DG units the minimum load at maximum feed-in gets more important. Therefore, a standard load approach based on simultaneity factors is no longer sufficient. Instead, load curves of loads connected to the LV grid are generated by using a statistical model, that implements characteristic LV consumers (like refrigerators, washing machines, lighting, multimedia devices etc.) and their typical usage.

The examination of load curves at the MV level relies on summed load curves of LV grids and separately modeled individual loads of the connected industry.

Suitable distribution grids

The methodology claims to generate general planning principles on basis of a limited number of real distribution grids. For that reason the chosen grids should cover an extensive range regarding its technical and environmental characteristics (structure of supply, population density, average feeder length etc.). In this case this is ensured by checking the grids' characteristics against a list of criteria.

PROBLEM IDENTIFICATION

In order to reveal the necessary grid reinforcement the described scenarios (LB, TS and UB) are applied successively to all examined grids.

More often, the power flow caused by DG temporarily leads to significant deviations from the permitted voltage range in distribution grids and an overload of the grid equipment [1]. Especially in LV and MV grids with a high amount of PV feed-in, situations with a high simultaneity only take place a few hours a year [1].

By means of a load flow calculation as well as the use of applicable standards and directives (e.g. [5], [6]) off-limit conditions are analyzed.

In preparation for developing planning principles typical problem areas are separated.

SOLUTION APPROACHES

Conventional grid reinforcement

In this paper the term "Conventional grid reinforcement" refers to the replacement or additional installation of grid components like transformers and cables as well as the optimization of the topology.

Innovative grid reinforcement

There are a lot of innovative technologies that may help reducing the necessary grid reinforcement. To define a set of key technologies that shall be considered in future grid planning guidelines, the following steps are conducted:

A technical analysis categorizes the technologies by their functionalities (Table 1).

Subsequently, cost scenarios for distinct products are used to define general cost scenarios for the application of innovative technologies and functionalities that represent the basis for a comparison of different planning variants.

This paper focuses on technologies implementing the functionality of voltage control.

Table 1 Extract of the considered functionalities and technology examples

Functionality	Technology example
Voltage control	- On-load voltage controlled transformer - Power factor control - Active Power control
Prevention of overload	- Decentralized grid automation systems
Optimization of transmission capacity	- High temperature conductors - Superconducting transmission systems
Automation of grid operation	- Decentralized grid automation systems
Balancing of production and consumption	- Controlled operation of energy storages - Demand side management

On-load voltage controlled MV/LV transformer

Conventional MV/LV transformers are not suitable to change their transformation ratio under load. So deviations from the set point voltage of the MV grid propagate to the LV grid. For that reason the permissible voltage increase caused by DG is strictly limited by the directive VDE AR-N 4105 [6].

The controlled transformer is able to adjust its voltage at the low-voltage side via a tap changer or power electronics. In case of a voltage measurement at the bus bar of the MV/LV substation, the voltage at this node can be assumed to be approximately fixed. This allows the system operator to use the complete voltage range stated in the standard DIN EN 50160 [5] deducting the tolerance of the control system.

Figure 3 illustrates the assumptions made in this paper regarding the tolerable node voltages. They can be seen as an example that fits to the later discussed case study.

To integrate as much DGs as possible the LV bus bar voltage should be as low as possible, whereas the voltage must not fall below the tolerable minimum voltage (90% of nominal voltage) simultaneously even in case of a high load. By means of a load flow calculation it was determined, that a reserve of 6% of the nominal voltage is sufficient to handle all load situations in the later discussed specific LV grid. Considering a control tolerance of 2% [3] the lowest possible voltage set point at the LV bus bar is 98% of the nominal voltage.

In this case the DGs may cause a voltage increase of 10% of the nominal voltage while complying with the standard DIN EN 50160 [5].

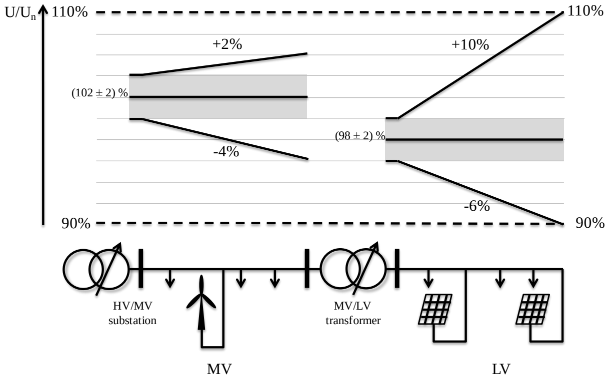

Figure 3 Admissible voltage increase by DGs when using a controlled transformer regarding the grid discussed in the case study

Power factor control

By controlling the power factor of a DG unit it is possible to decrease the voltage at the node of feed-in. Nevertheless, the usage of power factor control increases the line current and therefore the line losses.

In this case study the control was assumed to set a power factor in the range of 0.95 (ind.) to 1.

Active power control

The control of active power is assumed to be implemented by an autonomous decentralized grid automation system. By the usage of sensors the system is able to identify the grid's state variables like node voltages and branch currents. If a deviation of the permitted voltage range or a component overload is detected the system decreases the active power of appropriate actuators (DG units) until the state violation is cleared (cf. [1]).

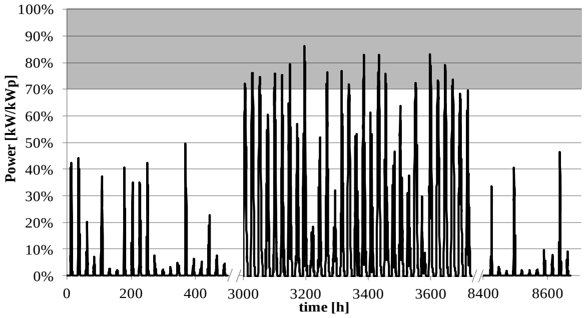

Figure 4 Annual Power curve of a PV system

Especially for highly volatile DG units like photovoltaic installations the peak power occurs only a few hours per year with only a minor loss of energy (Figure 4). Especially in these cases the active power control can be useful.

AIM

In order to derive new planning principles the different reinforcement approaches are compared and evaluated regarding technical and economical aspects. Important technical criteria are inter alia the new grid capacity, the reliability of supply and the complexity of operation.

By considering various grids of the HV, MV and LV levels it is ensured that the knowledge gained by the comparison can be adapted to other existing grids and may be used as a basis for universal planning principles accordingly.

The final aim of the methodology is the development of a grid planning guideline that allows the user to choose technically appropriate and economically optimized planning solutions.

CASE STUDY

This paper gives a brief demonstration of the described methodology. Therefore a grid expansion planning of a rural LV grid located in Northern Germany is conducted. In the grid 45 LV loads are supplied by a 250 kVA transformer. Today the installed capacity of photovoltaic installations per citizen is about three times higher than the Germany-wide average.

The presented expansion planning considers the target years 2020 and 2030, each with the lower bound and upper bound scenario. Four different technology options are analyzed.

Precondition: Application of the DG scenarios

This case study is limited to the consideration of new photovoltaic installations. The share of other DG types in the installed capacity of DG in the examined grid is negligible small.

Figure 5 illustrates the regionalized scenarios of the future installed capacity of DGs connected to the specific grid. Additionally, the installed capacity in the reference year 2012 and the rooftop PV potential are shown.

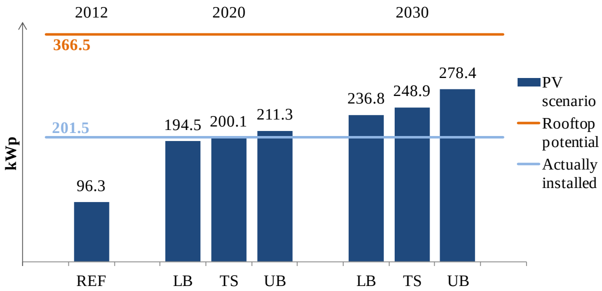

Figure 5 Adaption of the Germany-wide PV scenarios to the grid area

As already mentioned, the PV penetration in the examined grid area is notably above average. This causes the 2020 scenarios to be on the same level as the reference value of 2012. All scenarios do not conflict with the rooftop potential of the grid area.

Problem identification

Since the maximum feed-in situation is relevant for the grid's dimensioning, in this paper the maximum load situation is not discussed.

Even in the lower bound scenario of the target year 2020 the PV feed-in causes a voltage rise that is non-conforming to the directive AR-N 4105, especially in the northern part of the grid area (Figure 6). In contrast, there is no grid overload in any of the examined scenarios.

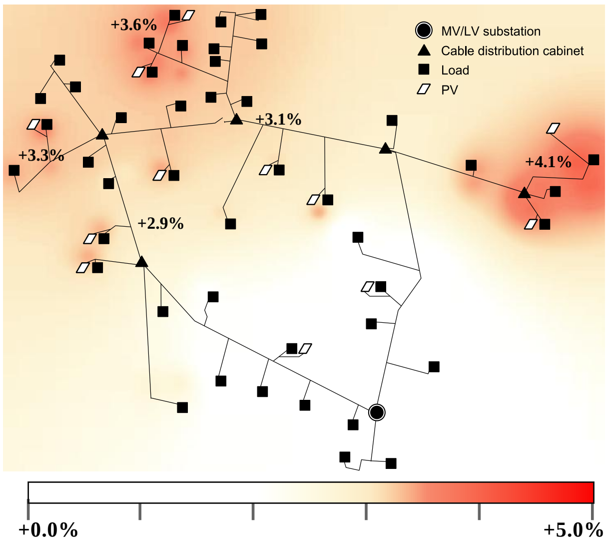

Figure 6 Voltage rise without reinforcement (2020, LB)

Solution approaches

The following section describes all examined planning variants. The year of investment is supposed to be five years ahead of each target year.

Variant 1: Conventional reinforcement I

Distant cable distribution cabinets are connected directly to the substation's bus bar via parallel cables (NAYY 4x240) of a total length of 495 m for 2020 and additional 176 m for 2030.

Variant 2: Conventional reinforcement II

The grid is divided into two separate LV grids by installing an additional MV/LV substation in the northern part of the grid area. An additional cable (136 m) has to be installed for 2030 to ensure voltage stability in the eastern part of the grid area.

Variant 3: On-load voltage controlled transformer

The conventional MV/LV transformer is replaced by a controlled transformer of the same apparent power (250 kVA) and placed in the existing substation.

Variant 4: Decentralized grid automation system

In this variant the installation of a decentralized grid automation system is evaluated. The system is used to provide reactive as well as active power control. Figure 7 displays all measures designated in this planning variant.

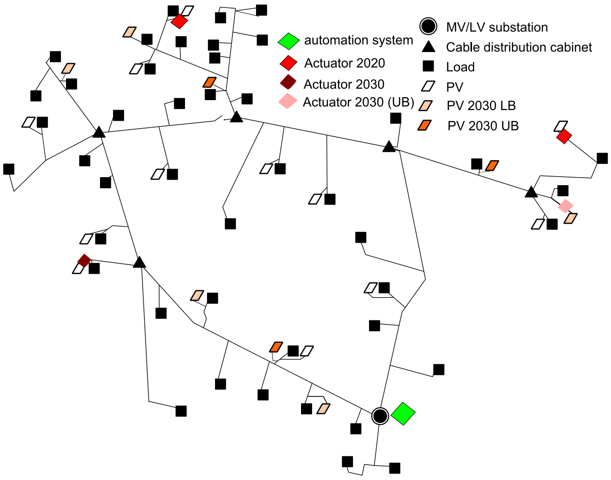

Figure 7 Measures in variant 4

Aim

Technical evaluation

Basically all variants can maintain voltage stability compliant with DIN EN 50160 (Figure 8). The reorganization of the grid (Variant 2) shows a greater potential for integration DG units than planning variant 1 and provides the opportunity to restore the power supply by switching operations after a local fault condition.

The replacement of the substation's transformer by a controlled transformer (Variant 3) solves the voltage stability issues in all examined DG scenarios until 2030. With this technology option it is not necessary to limit the DG unit's feed-in. Therefore the installation of a controlled transformer is highly recommendable, especially if the actual transformer reaches the end of its lifetime. However, currently there are no long-term experiences with the robustness of the tap changer.

The planning variant 4 shows some drawbacks: The active power control directly affects the operation of DG units owned by customers. In this case study less than 8% of the annual energy would get lost due to feed-in limitations. Furthermore, the lifetime of such systems can be assumed to be about half the length of conventional grid equipment (cf. [1]). Suitable decentralized grid automation systems are currently under development or even in a pilot stage. Decentralized grid automation systems will show their full potential when they are combined with additional innovative components and concepts like controlled charging of energy storages.

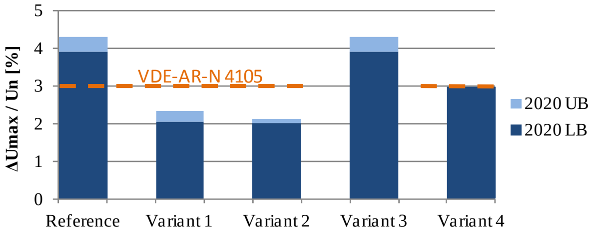

Figure 8 Maximum voltage rise after grid reinforcement

Economical evaluation

The economical evaluation considers investment costs solely (net present value in 2015). Operational and maintenance costs as well as costs for compensation of energy not fed-in due to active power control are neglected. Figure 9 sums up the investment costs of all considered planning variants.

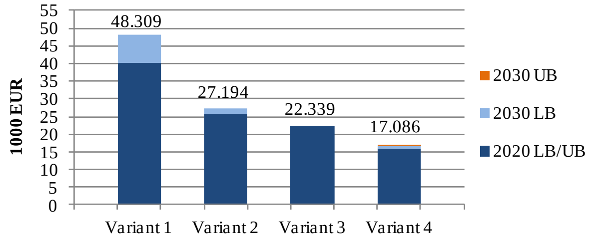

Figure 9 Investment costs per planning variant

The conventional grid reinforcement variant 2 is both technical and economical superior to variant 1. It benefits from an existing MV cable that can be used to supply the new substation. The economical advantage of both innovative variants (variant 3 and 4) over the conventional approaches is obvious. The discussed technical aspects may decide case specific which innovative variant should be preferred.

CONCLUSIONS AND OUTLOOK

The increasing installed capacity of DG issues a challenge to rural distribution grids that involves great costs. From this perspective the development of new planning principles under consideration of innovative technologies is inevitable. Therefore a methodology was presented, that allows the development of new planning principles. With help of a case study this methodology was demonstrated briefly.

It has been shown that the investment costs for the reinforcement of the examined existing rural LV grid can be reduced by about 50% when using innovative technologies. The installation of a controlled transformer is highly recommendable, if the voltage increase is the limiting factor for integrating DGs into LV grids. Decentralized grid automation systems can maintain compliance to applicable standards regarding voltage stability too. Especially whenever additional innovative technologies like electric vehicles or storages are integrated suchlike systems should be considered.

In the context of the presented project the evaluation will be expanded to MV and HV grids as well as to further innovative technologies. The examination of a wide range of existing rural distribution grids increases the validity of planning principles that will be derived.

NOTIFICATION

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