NEW PLANNING PRINCIPLES FOR LOW VOLTAGE NETWORKS WITH A HIGH SHARE OF DECENTRALIZED GENERATION

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ABSTRACT

This paper describes new planning principles for rural low voltage networks, which have to be significantly expanded due to the required integration of distributed energy resources. The planning principles focus on the optimized use of innovative technologies (like feed-in management and voltage controller) in order to lower the total costs of necessary network reinforcement. In order to derive these planning principles technical and economical results of multiple concrete and representative low voltage distribution networks are compared. By means of cluster analyses, dependencies between the supply tasks and the most suitable innovative technologies are examined. As a result 6 planning principles are presented and discussed as a basis for a company-specific strategic orientation for planning of low voltage networks.

INTRODUCTION

In the context of the progressive consumption of limited fossil fuels and the associated climate change the number and installed capacity of distributed energy resources (DER) integrated in the German power system is rising constantly. In low voltage networks the most common DER are rooftop-mounted photovoltaic systems connected directly to existing electrical installations. Typically, German low voltage networks cover a rather small area of less than 1 km². So a similar characteristic of solar radiation of all solar panels in the network can be expected which leads to a high simultaneity of injection. Due to only approximately 1000 full-load hours per year of solar panels in Germany, photovoltaic systems show many low-energy high-power peaks that often exceed the network's capacity.

Although overloads of network equipment may occur and even may remain undetected, the main drivers for network expansion (especially in rural low voltage networks) are impermissible voltage rises. Those deviations from the permissible voltage range specified in the standard DIN EN 50160 force DER to shut down in order to protect connected loads. Due to the high investments required when applying conventional network expansion via additional lines and transformers, many different innovative technologies were developed. These aim at reducing the total costs associated with the integration of DER. To optimize the planning strategy in this regard the present paper describes planning principles that shall determine possible expansion options by analyzing the network's structure and its supply task.

METHODOLOGY

In order to develop a planning guidance considering innovative technologies a comparison between conventional and innovative planning variants of multiple real-world low voltage networks was conducted.

Application of DER Scenarios

As a basis for the network planning three scenarios of future number, installed capacity and location of DER were developed. Those scenarios include the timespan from 2015 to 2050. The methodology is partly based on [1] and expanded in order to meet the specific requirements of this project. It is described in [2].

Planning variants

Besides the conventional network expansion there are five innovative planning variants and a combination of these. In case the applied innovative technologies can't solve the impermissible voltage rises or overloads entirely those technologies are complemented by conventional network expansion. The following sections describe all six analyzed planning variants briefly, as more detailed descriptions can be found in [3] and [4].

Conventional Network Expansion

As a reference a conventional network expansion planning (CONV) on basis of current planning and operation principles was implemented for each network and DER scenario. At this, the network was reinforced solely by standard network equipment like cables and transformers.

Regulated Distribution Transformer

A Regulated medium voltage (MV) to low voltage (LV) Distribution Transformer (RDT) decouples the voltage on the MV-side from the voltage on the LV-side via a tap-changer. Thus, the connected LV network can utilize a distinctly larger voltage range.

Line Voltage Regulator

Typically a Line Voltage Regulator (LVR) parts a single feeder into two segments with the latter segment being voltage controlled. So a feeder equipped with a LVR can utilize a larger voltage band, whereas all other feeders remain uncontrolled.

Static Feed-in Management

By means of a suitable configuration of the photovoltaic systems' inverters the Static Feed-in Management (SFM) limits the active power to a fixed share of the installed capacities regardless of whether impermissible voltage rises or overloads occur. In this analysis the active power is limited to 60% of the installed capacity per system.

Dynamic Feed-in Management

The basis for a Dynamic Feed-in Management (DFM) is a decentralized network automation system (DNA) e.g. [5]. The DNA system implements a network state estimation which is used to dynamically control the active power of DER so that the network's voltage constraints and thermal limits of the network equipment are not exceeded.

Static Feed-in Management + Regulated Distribution Transformer

In addition to the aforementioned variants a combined approach of SFM and RDT is evaluated. SFM is applied as long as no additional problems occur. If further measures are necessary a RDT replaces or complements the SFM.

Economic Evaluation

The economic evaluation includes capital as well as operational expenditures over the time period from 2015 to 2050. Unless otherwise specified all expenditures are stated as present values in 2015. In order to maintain comparability of the different planning variants, network equipment is replaced after its technical lifespan. The replacement is taken into account economically, residual values are credited at the end of the specified time period. Since the regulatory framework may change and many aspects may vary across different countries, in this paper those aspects are not considered. So from a DSO's point of view in some cases the planning variant with the lowest total expenditures may not be the most economical.

EXAMINED LOW VOLTAGE NETWORKS

In this paper a total of 14 low voltage networks were examined. All networks are located in rural areas of the northwestern and eastern part of Germany. Although all applied DER scenarios predict a massive increase of installed capacity of photovoltaic systems in some networks there are no impermissible voltage rises or overloads. Hence, for all further analyses those networks are neglected.

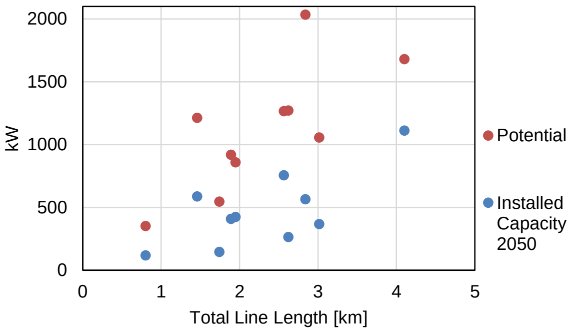

Figure 1: Characteristics of the examined networks.

Taking into account all networks, technologies and scenarios the data basis for this analysis consists of 540 different target networks. Figure 1 displays the theoretical potential for installing photovoltaic systems (rooftop-mounted only) and the installed capacity for the upper DER scenario in the year 2050 in relation to the total line length. As can be expected there is a slight dependency between both variables.

NETWORK PLANNING RESULTS

In the following section aggregated economic results of all examined networks are presented. Figure 2 shows the possible reduction of the total expenditures when using the most competitive innovative technology instead of following the conventional network expansion approach.

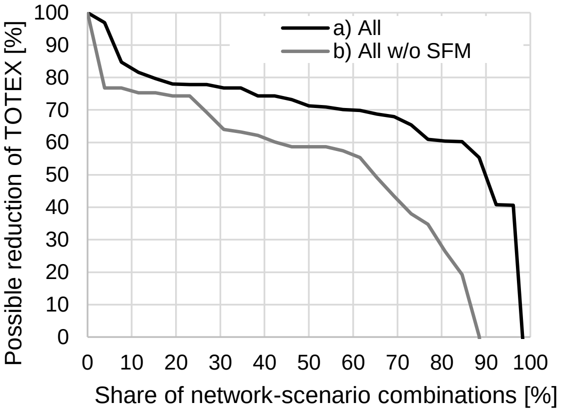

Figure 2: Possible reduction of the total expenditures when using the most competitive innovative technologies a) with and b) without consideration of SFM.

As can be seen in curve a) the use of innovative technologies leads to considerable savings of at least 60% in 75% of the analyzed networks. This results in an average reduction of total expenditures of about 67%.

In some cases SFM may be difficult to apply though: The activation and monitoring of the SFM as well as the compensation of curtailed energy involves administration effort. Additionally, most other innovative technologies admittedly involve higher expenditures, but provide significantly more reserve for future DER systems. So DSOs have to monitor and process the networks less frequently.

Even if SFM is neglected in almost 90% of the network-scenario combinations there is another advantageous innovative technology which leads to an average saving potential of about 58% of total expenditures (curve b)). Whenever conventional network expansion remains the most competitive planning variant the network's expansion need in the considered network were rather low.

Figure 3 compares the range of total expenditures in relation to the installed capacity of DER in 2050 (hereafter referred to as “specific expenditures”) for each considered technology.

Despite the minimum specific expenditures being rather low, with a spread between minimum and maximum values of 259 EUR/kW and a median of 140 EUR/kW the conventional network expansion is not very robust regarding changes in the supply task.

The planning variant with SFM features lowest specific expenditures at the lower end of the range. Nevertheless, the median as well as the spread between the minimum and maximum values of both voltage regulating technologies RDT and LVR are lower than with SFM.

In addition to a slight cost advantage the RDT can replace a conventional distribution transformer at the end of its life. Furthermore even the MV network may benefit from the use of RDT.

So in the context of uncertainties of DER forecasts the use of RDT presents a favorable expansion strategy with average specific expenditures of 59 EUR/kW. A demand-based application of both SFM and RDT combines the advantages of low minimum of specific expenditures with the low average specific expenditures of RDT.

Although the application of DFM was not the most economical planning variant in the examined networks the required DNA system is a prerequisite for many smart-market applications. Considering this, the DFM planning variant gets more and more important.

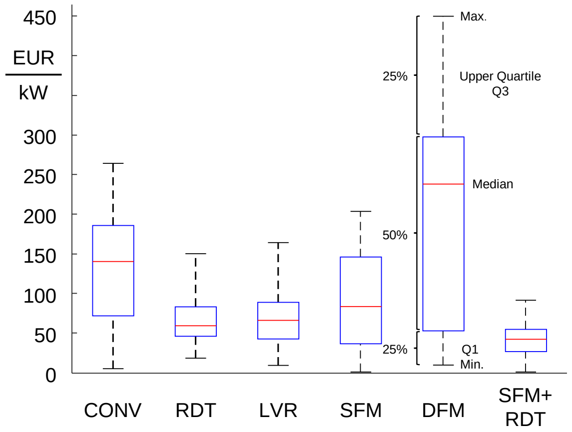

Figure 3: Overview of the specific total expenditures of all examined networks per technology until 2050 (present value 2015).

NETWORK-SPECIFIC STRATEGY

To derive generalized planning principles the influence of different network-specific parameters on the optimal expansion strategy have to be analyzed. In this section the applied methodology and results connected to the parameter “Installed capacity of DER” are described exemplarily.

Methodology

At first, all considered networks are clustered considering the installed capacity of DER. For this, the k-means algorithm with a predefined number of 3 clusters was applied. The result of the cluster analysis is shown in Figure 4 a). Hereafter, for each cluster it is determined how often each examined planning variant is the most economical.

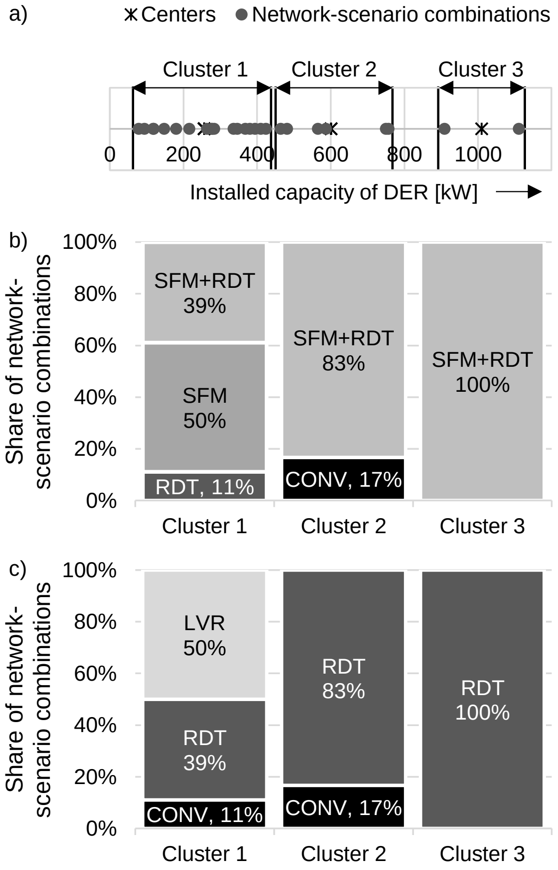

Figure 4: Cluster analysis of the networks’ total installed capacity of PV systems. a) Definition of clusters. b) Share of networks that can be expanded optimally with the respective technology. c) Same as b), neglecting SFM.

Results considering SFM

In networks with a rather low installed capacity of DER (cluster 1) the result of Figure 4 b) suggests the use of SFM, RDT or a combination of both technologies. Typically the sole application of SFM is the most economical solution whenever there are only minor deviations from the permissible voltage band or overloads. With a rising installed capacity SFM may not be sufficient to cope with the arising problems in the network and either the use of RDT or if necessary the combination of SFM and RDT is recommendable. Especially for clusters 2 and 3 the aforementioned technology combination prevails.

Results neglecting SFM

In cluster 1 the LVR can partly replace SFM if only one feeder is affected by impermissible voltage rises. In most other cases the use of RDT is more economical. If a higher share of DER is installed (cluster 2 and 3) in most networks the RDT is the most economical solution.

PLANNING PRINCIPLES

Taking account of the analysis of the planning results two general and four technology specific planning principles can be extracted:

I. Innovative technologies significantly reduce expansion expenditures in the majority of networks.
II. A joint expansion strategy for MV and LV networks should be considered, as the expansion of LV networks have direct impact on MV network expansion needs.
III. If only minor impermissible voltage rises occur LVRs can substitute conventional network expansion economically, especially in networks with only one affected feeder.
IV. If a high DER-induced network expansion need is identified in most cases the use of a RDT is recommendable. Frequently, even with an increase of installed capacity of DER no further expansion measures have to be carried out.
V. If the increment of installed capacity of DER in the examined network is flattening SFM can avoid additional measures frequently.
VI. If in the context of smart market applications (e.g. supply of load flexibility) DNA systems gain currency an implementation of DFM can replace SFM.

CONCLUSION AND OUTLOOK

The massive integration of photovoltaic systems into LV networks causes the need for extensive network expansion. Hereby, in many cases the conventional expansion approach leads to high expenditures that can be reduced significantly by shifting the expansion strategy towards innovative technologies (like static feed-in management or voltage regulators). In this paper it has been shown that innovative technologies can reduce the expansion costs in 75% of the examined network-scenario combinations by more than 60%.

To provide guidance for an optimized use of innovative technologies the planning results of 10 LV networks were analyzed in detail. On this basis 6 planning principles were formulated that determine the most promising and appropriate technologies for a given network-specific supply task.

The contributions of this paper are embedded in a planning guideline which will be published in 2016. It will cover planning principles for HV, MV and LV distribution networks.

NOTIFICATION

The contribution is embedded in the governmental funded project “Neue Planungs- und Betriebsgrundsätze für ländliche Verteilungsnetze als Rückgrat der Energiewende“ (New planning and operation guidelines for rural distribution grids) with its main target to develop and publish a planning guideline for rural distribution networks with a high share of DER.

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