AVOIDING MV-NETWORK EXPANSION BY DISTRIBUTED VOLTAGE CONTROL

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ABSTRACT

Thanks to the fast expansion of Dispersed Generation (DG), Germany's rural electric distribution grids are undergoing a process of rapid transformation to multi-directional energy networks. Latest analysis shows that new Voltage Controlled Distribution Transformers (VCDT) using an integrated on-load tap changer can not only be used for highly efficient LV grids, but might possibly be applied area-wide to avoid rural MV network expansion.

VCDT technology opens up the static connection of conventional local transformers between MV and LV grids. It allows for the use of the entire voltage bandwidth of EN 50160 in each voltage level in an efficient way.

In this paper, the idea of using VCDT-technology for an area-wide dispersed voltage control is at first explained, then shown in its effects on rural MV grids and finally discussed in its advantages and disadvantages.

INTRODUCTION

According to EN 50160 the voltage bandwidth in each MV and LV grid is +/- 10% [1]. With the fixed voltage ratio of conventional MV / LV transformers it is necessary to divide only one complete voltage bandwidth of 20 % into two parts for each voltage levels. Before the appearance of DG this long-time practice was no problem because of electric energy supply was unidirectional from generating plants to the consumer: Under these circumstances the feeder station would always be the point of highest voltage in a network and the voltage bandwidth is only used for the voltage drop between substation and customer. The existing – and in short-term fundamentally unchangeable – MV and LV networks are thus dimensioned with regard only to the supply function of those historical 'distribution' networks.

Today there are already lots of DG in Germany's rural distribution networks and one can expect these small and fluctuating units to grow in numbers here in Germany as in other countries as well. In 2014 or 2015, Germany's installed capacity of DG will top the conventional power plants with nearly 100 GW. This rise of DG in rural networks has required a second division of voltage bandwidth: In addition to the MV / LV separation, a division between generation and supply was necessary. The resulting fragmentation is exemplified – there are little differences between the network operators – in Fig. 1:

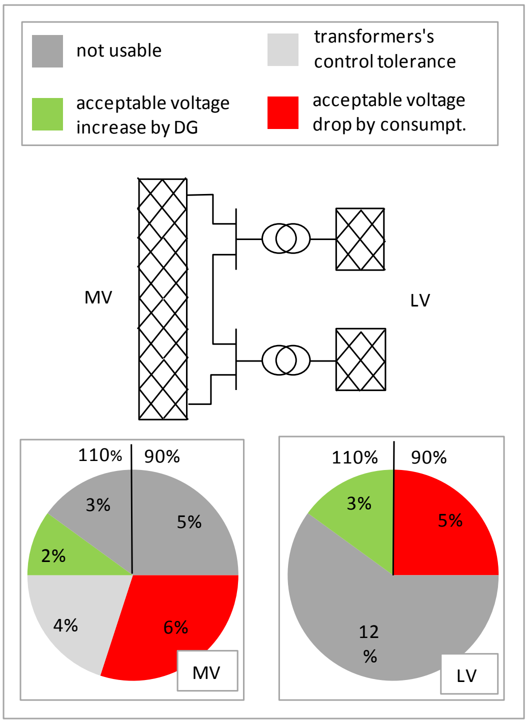

Fig. 1: Today's usable (red and green) and not usable (different shades of grey) parts of voltage bandwidth in Germany rural networks

Looking at Fig. 1 one can see how small the usable part of voltage bandwidth actually is: In MV and LV it is for each only 40% of what could be usable theoretically. Therein, the small green shown sections for DG are defined by technical guidelines [2, 3]. They were only made possible by raising the acceptable voltage increase from + 6% to + 10% on the normative side. These small sections lead to an inefficient use of the ampacity of electric lines, as it is shown in fig. 2 for an MV standard cable:

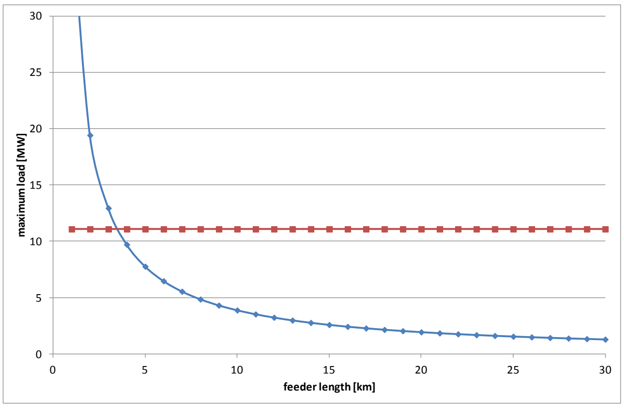

Fig. 2: Limitation of maximum load by ampacity (brown) and maximal voltage increase of 2 % (blue) for a NA2XS2Y 1*150mm² feeder

The benefits and stability of VCDT technology has been shown before on the CIRED Workshop 2012 [4]. Given a further dynamic DG development in LV and reasonably priced transformers, a high acceptance for an LV-driven use of VCDT is likely. Based on this expectation it is worth to analyze an area-wide use of VCDT, whose potential is shown in fig. 3, named Dispersed Voltage Control (DVC):

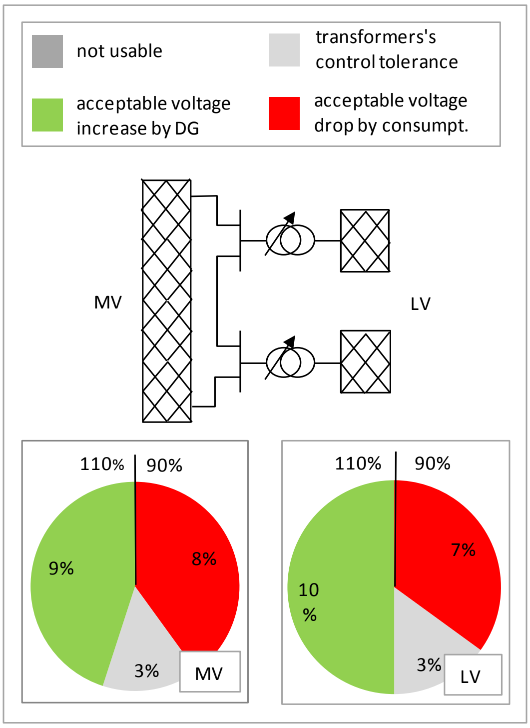

Fig. 3: Usable (red and green) and not usable (light grey) parts of voltage bandwidth in rural networks in concept of Dispersed Voltage Control

Fig. 3 shows a higher percentage of actually usable voltage bandwidth (85% instead of 40% in each case), split to both generation and consumption of electric energy. While the first requirement – more room for generation – is obvious, the second one also accounts for new consumption technologies like heat pumps or electric cars. Target of this study is to show that DVC is capable to integrate high DG levels in rural MV grids with only small, ampacity-based network extension. But first of all, the VCDT requirements for DVC have to be defined.

VCDT REQUIREMENTS BASED ON DVC

The DVC concept has additional requirements particularly for the control range of VCDT. As shown in fig. 3 there is the necessity for VCDT to adjust the complete voltage bandwidth of +/- 10% in MV to a predetermined LV value. Tap width and tap value of the tap changer have to be adapted to that condition.
As shown in a former publication, the tap width $Du_{TW,VCDT}$ can be defined to 2.5% of U_C [5]. That leads to a 3.0% control tolerance as shown in fig. 3. Targeting a maximum voltage range in MV, the resulting number of taps is

which turns out is a minimum of 9 taps.
Further requirements for VCDT technology in the DVC concept are small transformers, adapted to the structure of existing grid stations, a robust, non-sensitive construction of transformer and tap changer, a fast availability and acceptable pricing.
Based on these requirements, several rural substations at E.ON Avacon, a distribution network operator in Northern Germany, have been analyzed with respect to DVC by using Maschinenfabrik Reinhausen'S (MR) new VCDT GRIDCON Transformer technology [6].

METHOLOGY

Today there is often no more potential to integrate further DG in rural German MV grids without network extension. On the other hand this means MV networks are adequate for today's DG penetration. To show the capability of DVC, there are three steps to do:

- Step 1: Selection of suitable substations
- Step 2: Development of a resilient and specific forecast for DG and energy consumption
- Step 3: Results of network calculation

RESULTS

This chapter gives an overview after detailed simulations in two rural substations.

Step 1: Selection of substations

Rural MV grids are different than urban and suburban networks in certain aspects. Among these aspects are a large supply area, long feeders, low transmission capacity – all of them results of a small population density related to little industrialization. Historically, the technical challenge of these grids was voltage stability and reliability, not ampacity. The meshing rate is low.
For this study, substations with these characteristics have to be found. Decent but not extraordinarily high level of DG and different network structures have been chosen. The two substations selected are Nettlingen near Hanover / Lower Saxony and Osterweddingen near Magdeburg / Saxony-Anhalt, as it is shown in fig. 4:

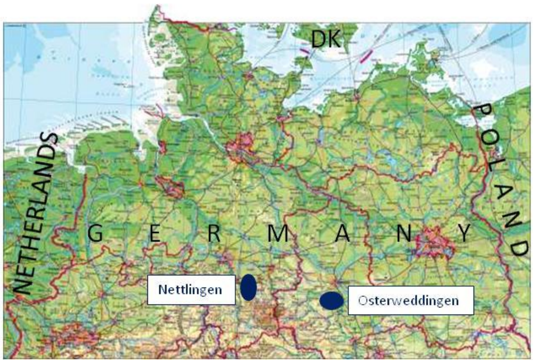

Fig. 4: position of the substations in Northern Germany [7]

The main attributes of the selected substations are:

	Nettlingen Substation	Osterweddingen Substation
area	300 km²	160 km²
inhabitants	26,900	16,400
DG today	23.1 MW	14.5 MW
Maximum load today	28.5 MW	9.2 MW
Cables + lines MV	212 km	160 km
Grid stations MV/LV	229	98
feeders at substation	8	8
network structure MV	loop system	radial system

Both substations are representative for E.ON Avacon and don't show worst-case-situations.

Step 2: Forecast of network function

The major developments regarding DG in rural areas in Northern Germany are wind generation – connected to MV and HV (which is not the focus of this study) – photovoltaics in LV and MV and, in smaller scale, biomass plants, mostly in MV grids, but sometimes connected to LV. For this analysis, a localized, settlement structure-based DG forecast is developed. For the results it is important to place further DG correctly – that means plausible regarding to capacity and position – in the distribution network.

In the same way, a model for further development of heat pumps, electric cars and demographic effects on private households in rural areas is built up. This cautious model sees a 25 % of heat pumps and 10 % of e-cars in the long run (more detailed information is shown in [8]).
Fig. 5 shows actual and further load of the two substations:

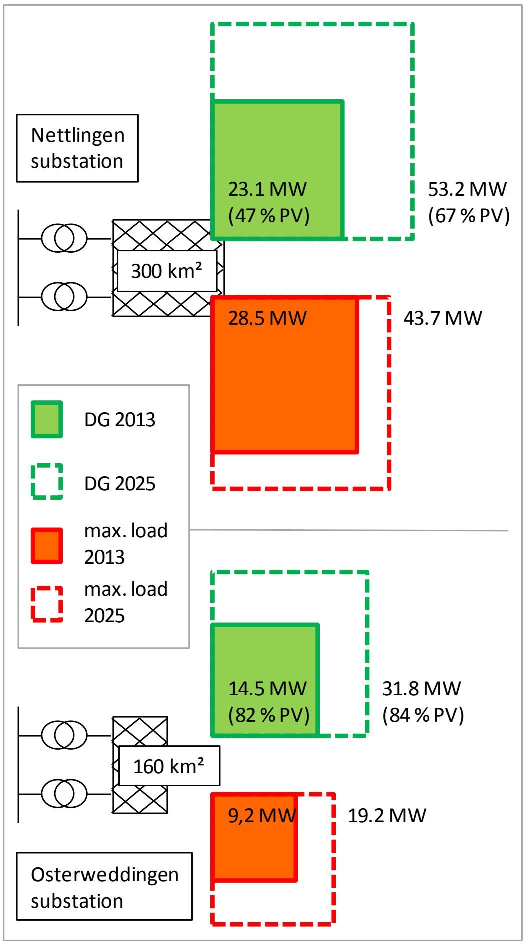

Fig. 5: Development of DG and load in both substations

Fig. 5 shows the estimated capacity growth for both load and DG and points out why DG will be the defining factor for future networks. In Osterweddingen substation, there is an additional 100 MW concentrated wind generation, directly connected to HV and hence not considered any further.

Step 3: Results of network calculations

Conducted network calculations analyze load situations without DG in (n-0) and (n-1)-case and DG-dominated load flow with 100 % maximum DG feed in and 30 % load. The comparatively high assumptions for the minimum load scenario of 30 % have been made with respect to the leading role of PV in future networks. In a few years time the critical low or negative load situation in rural networks will no longer be windy nights but

sunny holidays or weekends.
Fig. 6 and Fig. 7 show the main results of each substation feeder of Nettlingen substation:

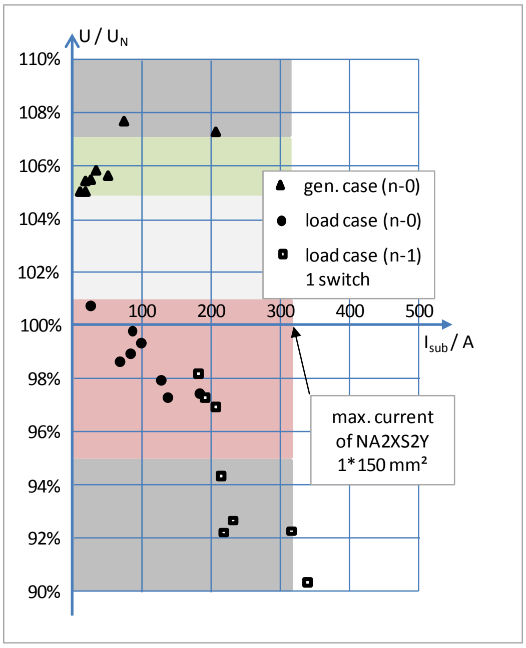

Fig. 6: Maximum voltage levels and maximum feeder current related to each substation feeder at Nettlingen 2013 – colours in dependence to fig. 1

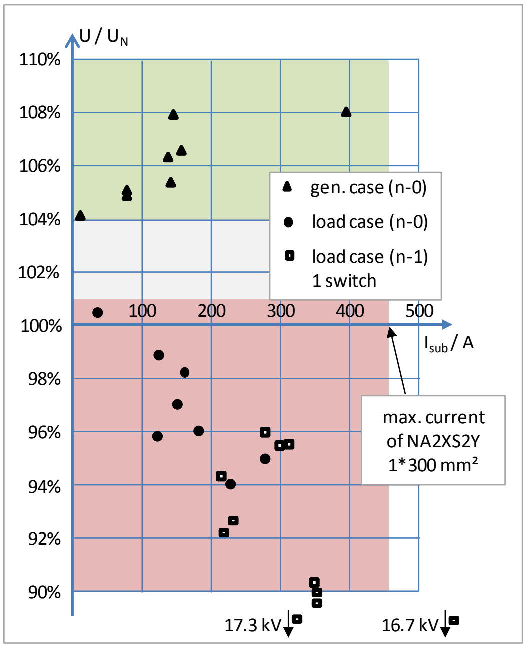

Fig. 7: Maximum voltage level and maximum feeder current related to each substation feeder at Nettlingen 2025 – colours in dependence to fig. 3

Fig. 6 shows that today the particularly close-drawn voltage boundaries may be troublesome. In contrast, DVC technology with its better use of voltage bandwidth – shown in fig. 7 – will be able to handle the extended generation and consumption level of 2025 without any problems.

CONCLUSIONS AND OUTLOOK

Theoretic analyses show that DVC is a promising approach to integrate lots of additional DG with little or none extra network expansion. At the same time, high rates of heat pumps and e-cars can be integrated easily in existing MV grids. The next steps at E.ON Avacon are

- an extended study with more substations
- in-depth study about (n-1)-conditions
- development of network planning rules for the application of VCDT technology under standard conditions

In February 2013 E.ON Avacon starts a field study with DVC using MR GRIDCON technology in Nettlingen's substation by changing the transformers in two entire villages. First results may be presented in June.

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