ACTIVE INTELLIGENT DISTRIBUTION NETWORKS - COORDINATED VOLTAGE REGULATION METHODS FOR NETWORKS WITH HIGH SHARE OF DECENTRALISED GENERATION

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ABSTRACT

This paper describes several voltage regulation approaches and strategies for distribution networks for achieving a cost-effective integration of high shares of distributed generation by an optimal utilization of already available network capacities.
The voltage regulation methods are examined by their theoretical potential using an approach with generic networks in a first step. Afterwards case studies for their application in a real rural low voltage (LV) network with different scenarios for the installation of new photovoltaic (PV)-systems are carried out.
Information about the pilot test phase applying these voltage regulations methods is provided as outlook.

INTRODUCTION

The strong increase of installed distributed energy resources (DER) has a major influence on network behavior. At the end of 2011 more than 65 GW of renewable generation had been installed in Germany, only PV being 24.8 GW. With regard to the voltage level, the predominant number of PV-systems is connected to the LV network (about 85% at the end of 2009).
Since the traditional dimensioning of distribution networks had not considered high feed-in, major challenges regarding the network integration of DER units occurs, especially concerning voltage band limitation.

INTEGRATION OF DER UNITS IN DISTRIBUTION NETWORKS

General Issues

In general several points have to be considered due to the integration of decentralized generation into distribution networks. On the one hand the operation conditions of the network have to be followed and power ratings of any components involved (e.g. cables or transformers) must not be exceeded. On the other hand compliance with power quality parameters as well as network protection has to be ensured.
For a relevant share of DER units the contribution to network stability and network ancillary services becomes essential. This implies that even smaller DER units connected to the distribution network must fulfill requirements concerning frequency and voltage support [1].

Voltage band limitations

Concerning the integration of DER units into LV networks the current challenge is to stay within the allowed voltage band. Figure 1 shows characteristic voltage profiles for a load case (blue) and a feed-in case (green) starting at the substation between the transmission and the distribution network, moving along the Medium Voltage (MV) feeder over the MV/LV transformer to the most afar connection point within the LV network.
In the past distribution networks have been designed with regard to the load case. Nowadays the feed-in of distributed generation, mainly wind in MV and PV in LV, leads to a voltage rise within the distribution network. Only 2% in the MV network and 2-3% in the LV network are assigned to this voltage rise, although the available voltage tolerance band is ± 10%.
This is a limiting factor for a further broad and fast expansion of distributed generation. It has to be removed by applying new voltage regulation methods in order to avoid costly network reinforcement, since network elements such as cables and transformers are by far not used up to their full capacity yet.

VOLTAGE REGULATION APPROACHES AND STRATEGIES

Today, voltage regulation within the distribution network is mainly limited to the on-load tap changer (OLTC) of the HV/MV transformer. Hereby, the voltage at the MV terminals of the transformer can be adapted to current network conditions in order to keep the voltage withing permissible limits.
However, the effectiveness of this control method is affected by several reasons (voltage level of the transmission network is not controllable by the DNO, volatile feed-in of wind and PV, spread of voltage profile of the distribution network due to feeders dominated by load or generation). This implies that new voltage regulation methods in addition to already existing ones are needed. Due to the high number of LV networks distribution network operators are interested in cost-effective solutions with long lifetime and low maintenance effort.
Following description of strengths and weaknesses of currently available and newly developed voltage regulation methods and strategies shows possibilities how to apply these approaches systematically in an optimal way with regard to the network's characteristic and topology.

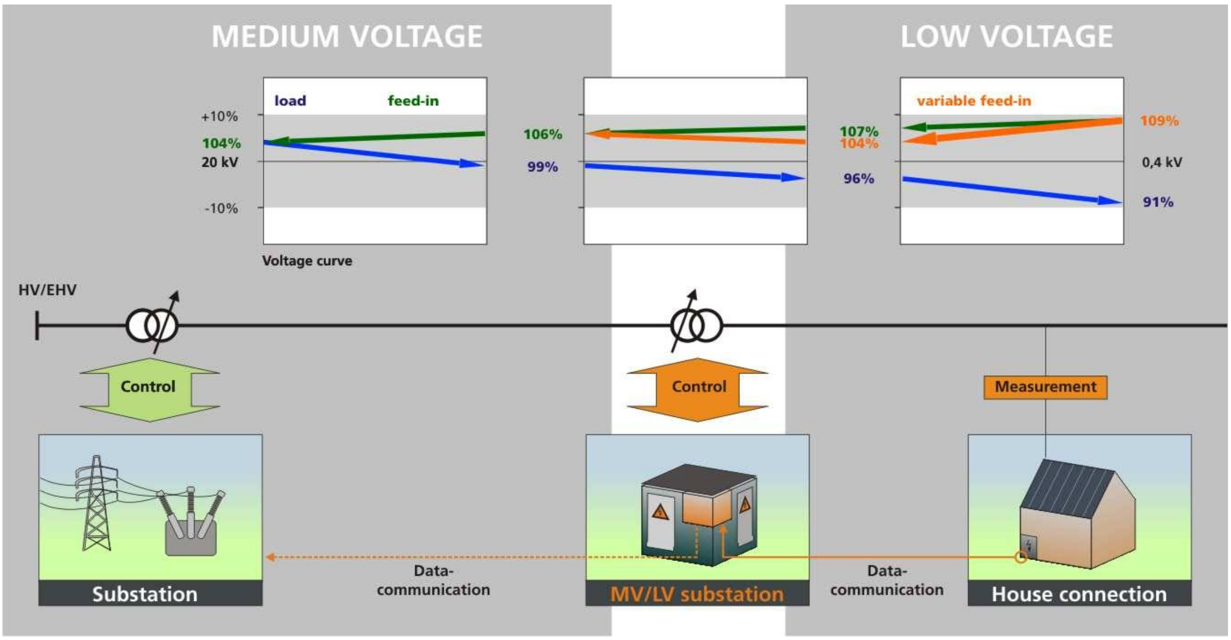

Figure 1: Voltage profiles in the distribution network (MV+LV) for different load and feed-in cases.

Active DER units

In current LV distribution networks, grid-connected PV-systems are the dominating DER units. According to [2], since January 2012 PV-plants in Germany have to provide reactive power as a function of the injected active power in order mitigate the voltage rise in distribution networks. Reactive power can also be supplied according to a Q(V)-characteristic [4] or with a constant power factor. Drawbacks of the feed-in of reactive power are additional losses in the DER unit and network losses due to the additional reactive power flow.

Another possibility to reduce the voltage rise is to reduce the active power. This is of course the less favorable option, as it lowers the amount of PV-energy used in the power system. According to [2] and [3] respectively, DER units have to reduce the feed-in of active power when the frequency exceeds 50.2 Hz or the DSO sends a corresponding control signal (depending on the rated power of the PV-system).

Active Substation

A very effective way of controlling the voltage can be provided by an active substation which features an OLTC in the substation of the MV/LV transformer. The voltage level at the LV bus bar of the transformer is no longer dependent of the fluctuating voltage level at the MV side, but it is controlled within a certain control range around a set-point due to the variable transformation ratio.

The dimensioning of commonly used transformers (±2x2.5%) has to be adopted in such a way that a voltage set-point of about 100% can be assured at the LV terminals of the transformer over the whole operating range of the MV network (19kV – 21.4kV). Hereby, the allowable voltage rise due to the feed-in of DER units would increase from currently 3% up to 8-10% (cp. orange voltage curve in Figure 1). The usage of this wider voltage band allows such a high increase of DER units that a restriction of new installation is no longer caused by voltage band limitations but by the exceeding of the ratings of existing network elements. Additionally, since 10% of the voltage band is still reserved for the load case, feeders dominated by loads are not negatively influenced by this voltage regulation method.

This concept requires some more effort at the substation due to the OLTC and the measurements, but works without any communication to units in the LV network.

Smart Substation

The active and reactive power feed-in of the DER units can also be controlled remotely, e. g. by sending control signals from the smart MV/LV substation depending on measurements at the substation itself or using measurement information of the DER units. This kind of central control results in a higher flexibility, but also in higher effort due to the required communication infrastructure between the DER units and the substation.

Active and Smart Substation

The active and smart substation combines the possibility of influencing the voltage level at the substation as well as at the connection points of the DER units. Voltage and power measurements of the DER units can be used to influence the set-point of the OLTC. Also the P/Q-set-points of the DER units can be varied according to measurements at the substation. Additionally measurement values of certain characteristic network points can be used for the optimization of the voltage regulation.

Electronic Voltage Controller (EVC)

Another approach for influencing the voltage profile of a LV network is to use power electronic units which are able to inject an additional series voltage into a feeder. As described in [5], such an EVC can be based e.g. on the concept of the Unified Power Flow Controller. EVCs are able to control the voltage of a feeder steplessly and can be integrated into a network either as part of the substation or as distributed equipment in LV feeders. Therefore, one advantage of this approach is the possibility to install an EVC in a specific feeder without necessarily affecting the whole network. This can be more favourable than a smart substation in case of networks where some feeders exhibit a high penetration of DG while others are dominated by loads.

ASSESSMENT OF VOLTAGE REGULATION METHODS

The different voltage regulation methods are evaluated with regard to the possible increase of the hosting capacity of the LV network. At first generic networks are being used. In a next step, the methods are applied to a real German LV network located in north of Hesse.

Generic networks

A homogeneous 4-feeder network with NAYY 4x150mm² cables is considered, with a voltage of 106% at the MV side of the transformer (630kVA, $u_k = 4\%$). Furthermore it is assumed that 5 PV systems are connected in each feeder. By varying the length of the feeder the short circuit power (S_k) as well as the network impedance angle (Ψ_k) is influenced at the connection point.

In the case of voltage regulation by reactive power a maximum permissible voltage of 109% and a minimum permissible voltage of 96% is assumed in the LV network. Here the maximum voltage rise caused by DER units is 3%. The controllable MV/LV transformer is assumed to have an OLTC with a range of ±2x2.5%.

Figure 2 shows that voltage control by reactive power leads to an increase of the PV-system hosting capacity by a factor of 1.5 up to 2. This underlines the importance of reactive power capability for PV-inverters.

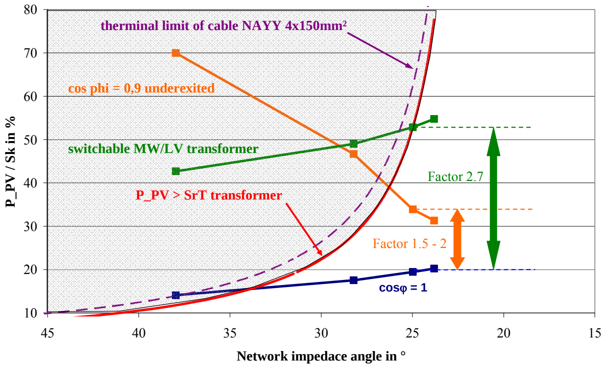

Figure 2: Maximum permissible installed capacity. Indicated points refer to feeder length 100m, 300m, 600, 900m. S_k and Ψ_k refer to the weakest point in the network.

In long feeders however the voltage regulation by reactive power provision is relatively limited. In this case controllable MV/LV transformers are preferred. Herewith, an increase by a factor of about 2.7 is reached. This factor is dependent on the dimensioning of the transformer taps but nearly independent of the network data at the network connection point as long as constraints of the network assets do not apply.

LV network Case-Study

Figure 3 shows a simplified network diagram of the studied LV network with currently already 236 kW of PV-systems installed. Within this LV network a case study is carried out, in order to examine the potential for additional PV-systems applying afore mentioned voltage regulation strategies. At first additional PV-systems are distributed randomly within the network area. In a second case study the application of an EVC in a long branch of the network with a high feed-in at the end of the feeder is evaluated.

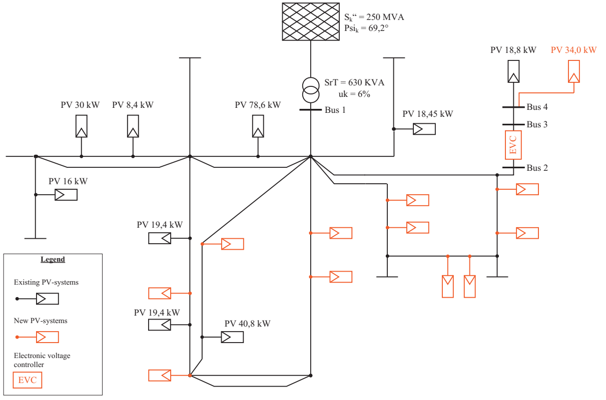

Figure 3: Sketch of the studied LV network.

Case Study: Voltage control for the entire LV network

Figure 3 shows the results for the increase of the hosting capacity within the LV network. Without any voltage regulation, new installations would be limited to about 15% of the currently installed rated PV-power. Furthermore if only newly installed PV-systems provide reactive power, an increase of about only 24% could be reached. If in contrast all installed PV-systems would provide reactive power, the increase would rise up to 83%. An even higher share of PV-systems can be reached with a controllable MV/LV transformer; an increase of up to 160% becomes possible. As the potential for new PV-systems has been limited by the voltage rise in the case of reactive power, now the limitation is reached due to the power ratings of the network components.

Furthermore it is found that a combination of controllable MV/LV transformer and reactive power provision does not increase the hosting capacity, since the additional loading through the reactive power reduces the capacity for active power injection.

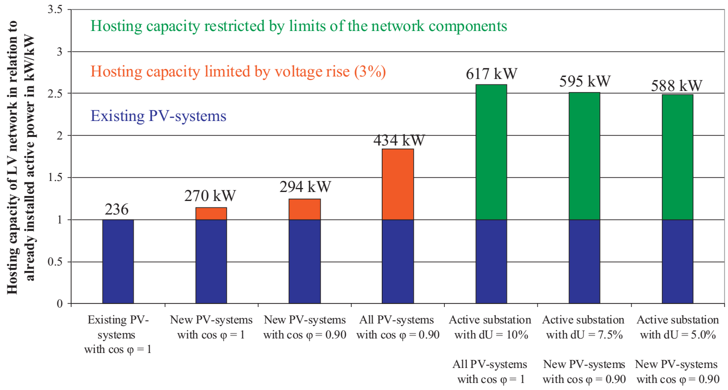

Figure 4: Increase of hosting capacity using different voltage regulation methods in a real LV network

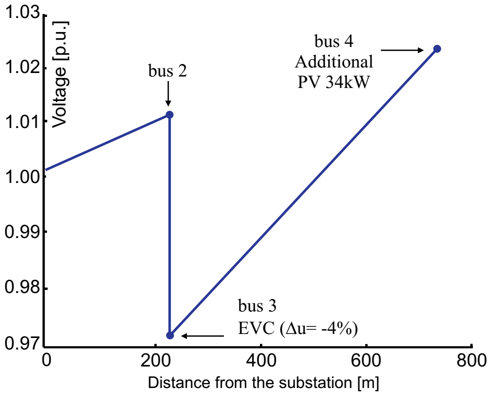

Figure 5: Voltage profile of long feeder with EVC installed at bus bar 3

Case Study: EVC in long feeder

Figure 5 shows the result of a simulation of the LV network with an EVC installed at bus bar 3 (see Figure 3). By decreasing the voltage by 4% at this bus bar, an additional PV-system with 34kWp can be installed at the end of the long feeder. Therefore, the EVC makes it possible to increase the hosting capacity of the feeder by a factor of 1.8.

FIELD TEST

At the moment the project partners are preparing a field test in the LV network of Felsberg-Niedervorschütz, which has been used in the case studies, in order to test afore described voltage regulation strategies under real terms. The network is operated by German grid operator E.ON Mitte AG, which also participates in the project and supplies 1.5 Mio customers with electricity and gas.
A newly developed controllable MV/LV transformer (by the project partner J. Schneider Elektrotechnik GmbH) will be a main component for the pilot tests. Furthermore, also smart PV-inverters with reactive power capability are used within the LV network. While communication links between the smart substation and the DER units will be established based on IEC 61850, the communication with the central control unit of the network operator is going to be based on IEC 60870-5-104. The pilot test phase is intended to start in the summer of 2012.
First results concerning the pre-tests of the controllable MV/LV transformer in the IWES SysTec laboratory are expected during May 2012. Additionally it is planned to set up a prototype of an EVC for testing such a system as part of intelligent distribution networks.

SUMMARY

Several voltage regulation strategies are evaluated with regards to their effectiveness to increase the hosting capacity of LV networks for DER units. It is proven by case studies for generic and real network topologies that reactive power provision and controllable MV/LV transformers are the most promising strategies. Furthermore, it is shown that EVCs can improve the voltage profile especially in long feeders of a LV network.

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Only the authors are responsible for the content of the publication.

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