INCREASING DEMAND FOR VOLTAGE CONTROL IN SECONDARY SUBSTATIONS

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ABSTRACT

German grid operators are facing increasing challenges regarding voltage limits in grids with large numbers of installed PV systems. In order to allow for the development of advanced technical solutions to overcome these challenges and therefore to increase the capability to install PV in low voltage distribution grids, a model to assess the voltage level in grids with different levels of PV penetrations has been developed. Results show a strong need for voltage control in secondary substations and derive basic guidelines for application as well as development criteria.

INTRODUCTION

Throughout the last years, German subsidies for the installation of distributed generation from renewable sources have proven to be very effective. At the end of 2011 20 GW of photo voltaic generation (PV) have been installed – 14 GW of which are installed in low voltage (LV) distribution grids only [1] and pretty much more to come. This leads to an increased number of violations of the voltage band according to DIN EN 50160. This currently requires the expensive replacement of existing cables or overhead lines. Off-load tap changers for voltage regulation may only be operated in de-energized condition and most likely they are not the future technical solution to solve the problem with large intra-day variations of load and generation, especially with the expectation of an increasing number of electric vehicles (EV). Thus, new technological options for voltage control in distribution grids need to be worked out.

MOTIVATION AND GOAL

Different technological options to control the voltage in low voltage distribution grids are under discussion and are being investigated in different research projects such as [2]. On-load tap changers or power electronic voltage controllers in secondary substations, voltage regulating transformers, reactive power compensation as well as active and reactive power control of decentralized generation units are technically feasible. However, development of corresponding products and their installation are hindered by the knowledge about actual demand and required parameterization.

Thus, this paper firstly introduces a methodology for modeling distribution grids as well as scenarios for future PV installations in Germany. Secondly, the main results and the expected need for voltage control in secondary substations are presented.

The goal is to derive guidelines under which circumstances voltage control in secondary substations is a technically feasible and economically reasonable option as compared to classic grid reinforcement. Moreover, the goal is to approximate the number of voltage controlled substations to be required in Germany until 2030.

METHODOLOGY

The assessment of demand for voltage control in secondary substations in Germany requires adequate grid and calculation models that enable us to derive representative results. Representative grid data and models for PV feed-in are essential, appropriate calculation methods need to be derived and meaningful scenarios for calculation need to be defined.

Grid model

All results presented in this paper are based on calculations with *synthetic low voltage grid models*. As described in [3], synthetic grid models have been generated based on statistical information about German LV grids and can therefore be considered *representative* for the entirety of German LV-grids.

The grid data used describes 9 different types of grids, characterizing different areas of supply. These range from rural grids supplying single farms to city areas with a high load density. Grid models include information about typical types of buildings (rooftop area etc.) and load characteristics (number and types of households, typical consumption), which is used as a basis for assigning realistic sizes of PV installations and an appropriate number of EV.

Load flow calculations using MATPOWER [4] have been used to determine asset utilization and voltages. The model has been applied to 9.000 synthetic grid models (1.000 of each type of grid), representing in detail the variety of real LV grids.

Stochastic load and generation models

In order to determine future voltage quality and to derive required counter-measures, adequate load and generation models are required. The results presented in this paper have been derived with stochastic load and generation models.

Load profiles

Load profiles are generated based on statistical data about the following household characteristics.

- Probability of possession of 26 most common household appliances
- Typical time of use (time of day)
- Frequency of use
- Typical power consumption
- Duration of use

Algorithms described in [5] are applied to this information in order to derive household load profiles, which show typical *power consumptions for individual households* and therefore enable for a realistic voltage calculation as required. Each run of the algorithm yields a different but typical result for a household load curve. Thus, a realistic household behavior is modeled, which is different from day to day, but is similar in its characteristics. An example is shown in Figure 1 in comparison to a typical PV feed-in on a summer day

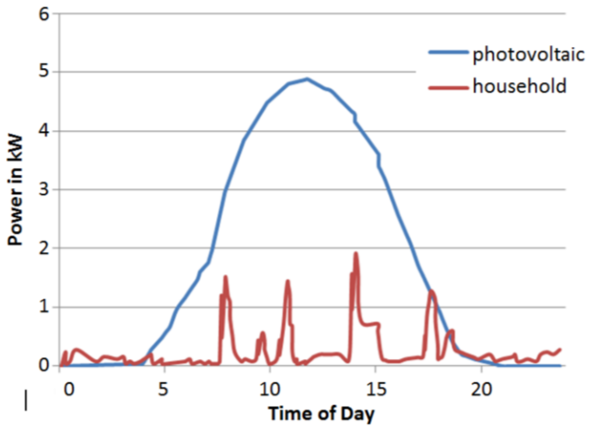

Figure 1: PV feed-in and household load in summer

Generation profiles

PV feed-in is calculated with a model for PV panels and power inverter, taking into account global solar radiation, area of PV panels as well as the efficiencies of PV panels and inverter.

As described above, the surface area of PV panels is determined internally in the grid model and therefore has a realistic size in relation to the specific grid studied in each case. Efficiencies of PV cells and inverters are set to 15 % and 95 % respectively. Global solar radiation is known from the so called “test reference years” (TRY) for 15 different regions in Germany. Figure 2 shows two different radiation profiles for a summer day in Germany. These represent extreme wheather conditions for Germany (maximum global solar radiation to be expected). Two scenarios are introduced – a “non-volatile” scenario representing a sunny day in summer and a “volatile scenario” representing a summer day with clouds moving over the solar panel throughout the day.

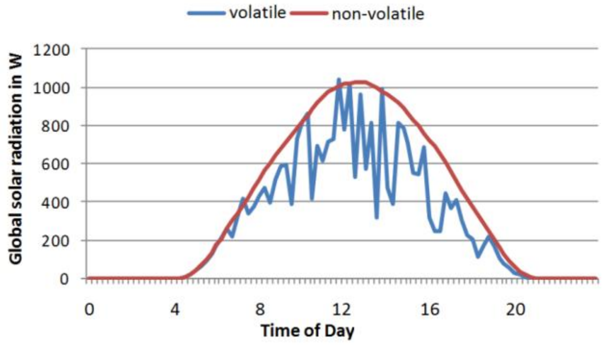

Figure 2: global solar radiation profiles

Temporal resolution and stochastic variation

Both load and generation data sets have been created in 15 minute resolution, which has proven to be an acceptable trade-off between calculation time and accuracy of the results.

Load and generation profiles are assigned to the grid models on a random basis, while taking characteristics like the size of roof-tops etc. into account. Household behavior is varied between each calculation on a random basis. PV feed-in is considered to be directly dependent on the global solar radiation, but the houses within the grid models that are equipped with PV are randomly shuffled.

Parameter variation and scenario definition

The approximation of the number of voltage-controlled secondary substations to be installed in Germany until 2030 requires the definition of future scenarios for the growth of decentralized generation on LV grid level. Two kinds of scenarios have been worked – a set of future PV scenarios and a worst case approach allowing for a more detailed look at fields of application for voltage-controlled secondary substations.

Future PV scenarios

As shown in Figure 3, two different scenarios have been examined, each providing different future developments of PV installations in rural, urban and sub-urban areas.

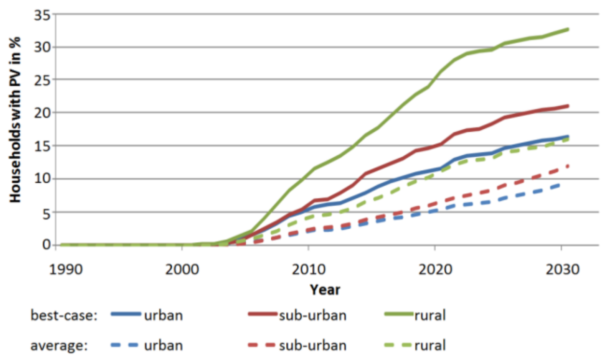

Figure 3: Scenarios for PV installation until 2030

Both the best-case and the reference scenario are dominated by installations in rural areas, where in 2030 32 % (best-case) and 16 % (reference) of all houses are expected to have PV panels installed on the roof-tops. Only 9 % (reference) or 16 % (best-case) are expected in urban areas. Calculations for future PV scenarios have been carried out for 3 exemplary medium voltage grids (rural, urban, sub-urban, *real grid data*), combined with *synthetic LV grid models*, due to a lack of a full data set (real data of MV+LV grids). All PV systems are assigned to the grid randomly.

Worst-case examination

The so-called "worst-case" is introduced to examine the effects of different places of PV installation in low voltage distribution grids. While a purely random approach of assigning PV to households within the given grid models has been used in the previous steps, the PV installations are now assigned to the different feeders of the LV grids as described in Figure 5. Case a) describes a grid model with PV equally assigned to households connected to the different feeders supplied by a substation, case b) does so for electric vehicles. Case c) describes a random assignment to the different feeders. Case d) actually describes the worst-case situation to be handled by voltage-controlled secondary substations with only one actuator for regulating the voltage on all feeders (which is the most likely case for the near future where OLTC-based solutions can be expected to dominate the market). For this configuration a spread of the voltage band is expected, limiting the range of OLTC actions (Figure 4).

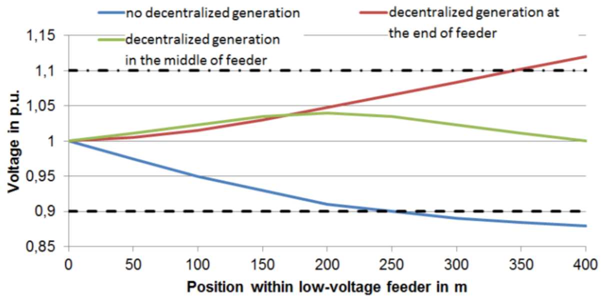

Figure 4: Exemplary voltage profiles

All cases have in common, that PV systems are linked to the grid "from the end of the feeders". Those cases are examined in the calculations, where lines remain just below the maximum allowable load, in order to only consider those cases where no replacement of lines is required.

In contrast to the future PV scenarios, these calculations have been carried out for 9.000 *synthetic LV grid models*, representing a greater variety of grids, but LV level only.

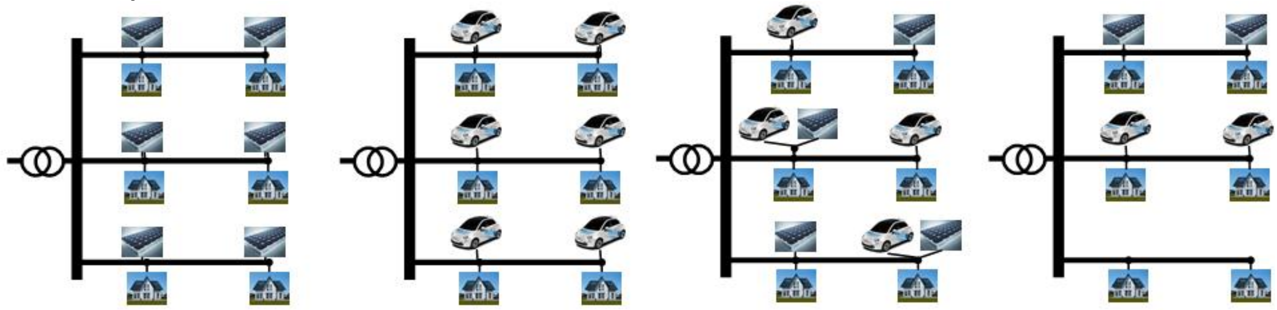

Figure 5a-d: Photovoltaic and electric vehicle placement

Evaluation criteria

Although 15 minute resolution has been used for all calculations, evaluations followed DIN EN 50160 regulations, i.e. the need for voltage-control was determined by voltages above 110 % or below 90 % of nominal voltage respectively.

Throughout the simulations maximum and minimum voltages within each grid have been stored for each time instance. In order for OLTC (or other technical solutions providing one actuator for all feeders) to be an option to solve voltage problems, it is desirable to have a rise or a fall within the grid only, but not a spread. Figure 4 demonstrates the importance, where no regulation with OLTC-based solutions is possible, but individual regulation of all feeders is required, which will be described as "single branch controller" in the following".

MAIN RESULTS

Three main results have been obtained by the given calculations – requirements for voltage in control in German LV distribution grids, basic guidelines for application and required design parameters.

Requirement for voltage control

Scenario calculations as described above have been used to determine the need for voltage-controlled secondary substations. Best-case scenario results are presented in Figure 6. As expected, the largest requirement can be foreseen for rural distribution grids, as PV installations are most common here and at the same time long feeders (often equipped with overhead lines with high resistances) are commonly found. The total demand in 2030 is expected to reach approximately 42 % in rural grids, 29 % in sub-urban and 10 % in urban grids. Moreover, especially in rural areas, where high installation rates of PV are expected until 2020, the total demand will almost be fully reached by then (39 %), leading to a need to retrofit or replace more than 1/3 of all substations within less than 10 years.

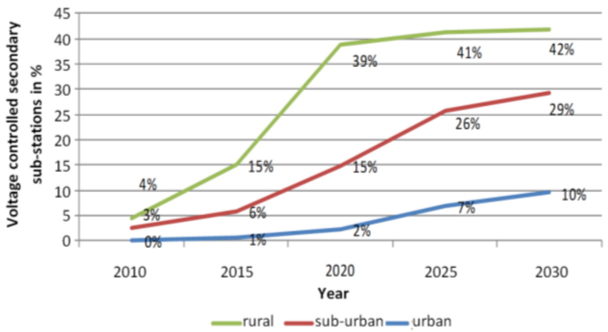

Figure 6: Voltage-controlled secondary substations required in rural, urban and sub-urban grids

Guidelines for application

A more detailed picture of the need for voltage control in different areas of supply is given in Figure 7 and relates to the scenario described in Figure 5a, where only PV was taken into account in addition to household load profiles. Voltage control is predominantly required in rural grids, especially in grids with long feeders and a rather high density of houses (type 2). 70 % of these grids need voltage control, 15 % of which can only be effectively realized by single branch controllers. As this type of grids makes up roughly 22 % of all German LV grids, this result is even more important. Calculations as described in Figure 5b-c have been carried out, but lead to similar results. Effects of PV on the voltage in LV levels dominate all other technologies.

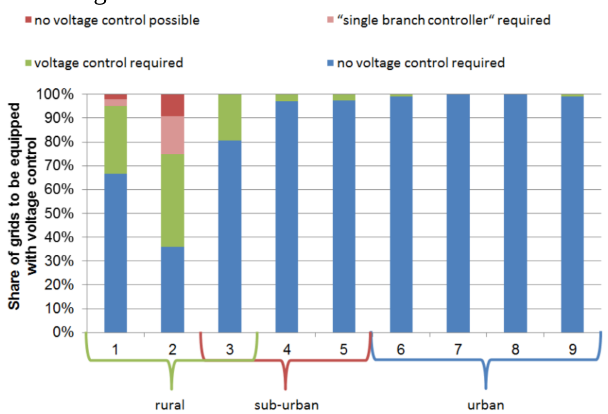

Figure 7: Types of voltage control in different LV grids

Design of voltage controllers

Finally, the maximum required regulation capabilities have been examined as basic design criteria. Again, rural grids and PV strongly dominate the results as shown in Figure 8. About 30 % maximum regulation capability (downwards) is required in order to keep the voltage within the given limits at all times, whereas only 16 % are required in grids of type 1 and only 9 % are required in grids of type 2 in order to keep the voltage within the given limits in 95 % of all 15 minute intervals. New control algorithms need to be developed, taking into account asymmetric regulation capabilities and asymmetric load conditions.

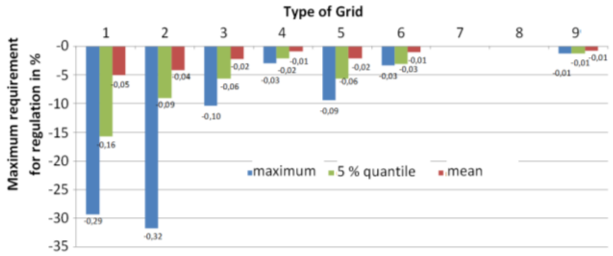

Figure 8: Required regulation capabilities

CONCLUSION AND OUTLOOK

The development of a stochastic load and generation model for the assessment of voltages within LV distribution grids has been shown.
The application of this model to a variety of synthetic LV grid models has proven the need for voltage control in secondary substations especially in rural areas, where more than 1/3 of all substations have to be retrofitted until 2020. Technological development will be required in order to allow for "single branch control".
The regulation capabilities strongly vary depending on the goal to be achieved, which leads to new research question, such as the optimal combination of different technical options for voltage control (e.g. secondary substation in combination with reactive power compensation). Furthermore, optimal algorithms both for the combination of different technologies and for the application within different types of grids need be worked out.
RWTH Aachen University and Maschinenfabrik Reinhausen GmbH will continue to pursue these questions within a joint research project expected to start in spring 2012.

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