IMPACT OF VOLTAGE CONTROL BY DISTRIBUTED GENERATION ON HOSTING CAPACITIY AND REACTIVE POWER BALANCE IN DISTRIBUTION GRIDS

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ABSTRACT

Especially in rural areas many distribution grids are already close to their limits of grid integration capacity for distributed generation (DG). Therefore cost-intensive network reinforcements are required increasingly frequent. Short-term implementable solutions for cost efficient grid integration of DG in distribution grids are discussed at the examples of voltage control by DG and improved transformer control concepts. Operating range, technical potentials and the economic efficiency compared to conventional network reinforcement are worked out and evaluated. In a second step the impact of such control on the reactive power balance of the distribution grid with respect to power factor demands of superimposed grid operators is analyzed.

INTRODUCTION

Caused by rapidly increasing numbers as well as installed power of distributed generation (DG) especially in rural areas distribution grids are in many cases already close to their limits of grid integration capacity. In such cases grid connection of additional DG requires cost-intensive network reinforcements.

Therefore short-term implementable grid-focused solutions for cost efficient grid integration of DG in distribution grids of low and medium voltage level are needed, even since a local prognosis of DG-development as a basis for long term network planning is afflicted with major uncertainties. Moreover, especially in rural areas with longer distances between substations and network customers a practical solution should not consist of comprehensive application of communication technology for cost and safety reasons.

Among suitable starting points are the voltage control of DG and improved transformer control concepts. The former may even not cause any investment costs for the network operator, since this technical characteristic of DG often is part of grid codes like in Germany. In order to derive the operating range, potentials and the economic efficiency of these measures, they have to be compared to conventional network reinforcements such as installation of additional lines. Since both measures aim at influencing the voltage in the distribution networks, they will influence the reactive power balance of the distribution grid as well.Therefore it has to be analyzed, whether this copes with the power factor demands of superimposed grid operators.

ANALYSIS

An easily implemented and highly cost-efficient method for grid integration of DG is utilizing the reactive power control ability of connected generators in terms of voltage control, e.g. by characteristics in dependence of active power output or the terminal-voltage [1]. Anyway, it has to be considered, that such decentralized control is focused on local voltage requirements at the distribution level, which may not always coincide with requirements in the superimposed high voltage grid. Especially in times of high DG feed-in the voltage in the distribution grid is usually high, therefore an under-exited operation of connected generators will be applied. On the other hand, in rural regions with low load and high installed capacity of DG the high feed-in leads to wide area feed-back into the high voltage grids and therefore high network load with corresponding low voltages in these grids. Highly inductive power factors of subordinate distribution grids caused by voltage control of DG may then lead to impermissible voltage conditions in high voltage grids.

Technical Restrictions

Among the criteria for assessment of grid connection of DG given in the relevant technical directives in Germany [2,3] in practice steady-state voltage stability turns out to be the most critical, whereby thermal ratings of devices have to be considered as well. Grid perturbations issues such as harmonics or flicker are preferably to be addressed in the DG by devices such as filters and therefore will not be discussed in this paper.

Improved Grid Integration

Conventional grid reinforcements are supposed to strengthen a given network structure by installation of additional lines, cables and/or transformers or by replacing them with higher rated components, respectively. Besides high investment costs, such project driven network reinforcements may lead to inefficient grid structures in the long run, even if embedded in a long-term planning scheme, since the future DG development is hardly predictable, especially on the required local level. Therefore, short-term implementable, cost-efficient and flexible solutions are required.

These demands can be fulfilled by an improved utilization of the existing grid structure using active (controllable) grid components, such as HV/MV-transformers, switches or generating plants. In this paper the focus will be on the reactive power control by DG as well as on improved transformer control concepts [4].

In general transformer control concepts consists of a control variable, a reference variable and the control algorithm. Besides using the voltage at the low-voltage terminal as control variable any other single or even multiple node-voltages are possible, but require enhanced system observability thus additional measurements and telecommunications. The reference value is typically a fixed value slightly higher than the nominal voltage, but may be variable e.g. depending on the actual load situation as well. Determination of the actual load situation is possible by using existing current measurements at the substation, such as the transformer current, which is the summation of all outgoing-circuit currents (*conventional compounding*). In case of distribution grids with DG the estimation of the load situation by using only this single aggregated value is limited because of the summation of load and feed-in currents. A more precise estimation is achievable by considering additional information about the actual load situation respectively the system state given by the measurement of the outgoing-circuit currents (*improved compounding*) [4]. Besides using additional information about the actual load situation i.e. system state in terms of compounding, as mentioned before, the control variable may be changed. For this purpose, an algorithm based on heuristics was developed to determine the optimal control variable (*optimal node*) in a given distribution network.

In Germany the reactive power feed-in of DG with grid connection at distribution level is typically given by a fixed power factor, but may also be controlled online by the grid operator. Alternatively characteristics may be applied, either in dependence of the active power output (cosφ(P)) or of the terminal-voltage (Q(V)) as depicted in Fig 1 and Fig 2. In Fig 1 P_{max} is the maximum power output of the DG, while P_{u1} and P_{u2} are parameters marking the beginning and ending of the slope in the under-excited area, in Fig 2 V_n is the nominal voltage.

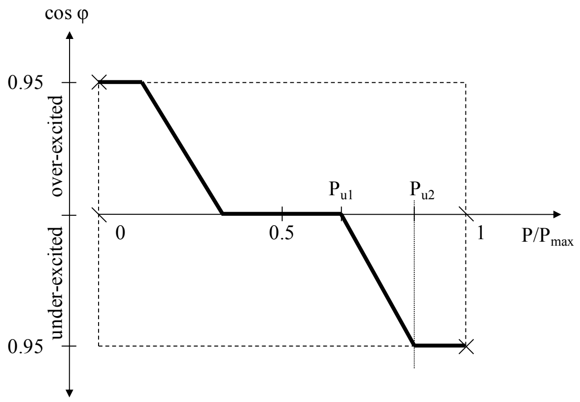

Fig 1 Principle structure cosφ(P)-characteristic

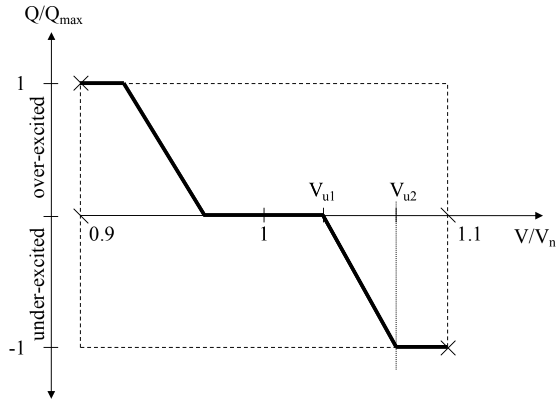

Fig 2 Principle structure Q(V)-characteristic

The reactive power capability of DG connected to distribution grids is required to be equivalent to a power factor of cosφ = $^{+}/_{-}$ 0.95 [2,3], so with little active power feed-in, the reactive power capability of the DG is negligible. Therefore the upper left area in Fig 1 as well as in Fig 2 is typically of little significance, since low voltage levels in a distribution grid typically corresponds to low active power feed-in of connected DG.

System Modelling

Since the distribution grids of the medium and low voltage level are vertically coupled regarding voltage stability and reactive power, a voltage-level overarching approach was chosen [4]. Because of the stochastically fluctuating feed-in as well as stochastic load critical system states may not be assessed a priori. Additionally the probability of the occurrence of critical system states may have significant influence on the cost-efficiency of the grid integration solution. Therefore a probabilistic approach was chosen, which also complies with the requirements in the relevant European standard EN50160 [5], where a voltage band of about +/- 10% V_n is given regarding 99% respectively 95% of the 10-minutes mean values of the steady-state node-voltages in medium and low voltage grids.

METHODOLOGY

Probabilistic Load Flow Calculation

In a probabilistic approach, the loads and feeders are modelled by distribution functions of their time dependent load characteristics, where interdependencies are considered by correlation factors. Because of the heterogeneity of these distribution functions, analytical methods are not applicable. Therefore, a simulative method to calculate the probability of occurrence of critical system states as shown in Fig 3 is used.

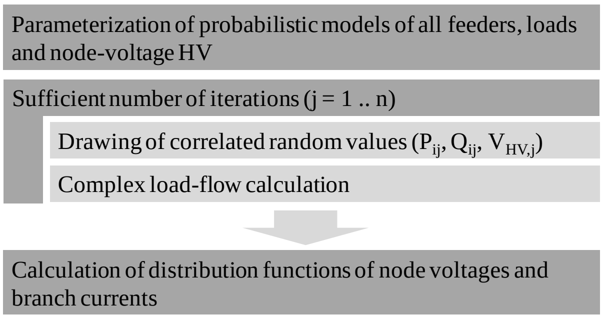

Fig 3 Probabilistic Approach

General Approach

An overview of the general methodology used in this work is given in Fig 4. The basic idea is to calculate and compare the hosting capacity (HC) of a given distribution grid with pre-defined rated power and points of common coupling (PCC) of DG. First the calculation is done without consideration of any type of controllable grid components, except for tap-changing HV/MV-Transformers controlling the voltage at the MV-busbar according to a fixed reference value.Ssecond enhanced control concepts for the tap-changers as well as an optimized reactive power control of connected DG are considered. Based on the calculated HC in these scenarios, the necessary conventional grid reinforcements neede for the same HC as well as the corresponding costs are determined, allowing both the deriving of fields of application as well as a quantification of usage of the enhanced control concepts.

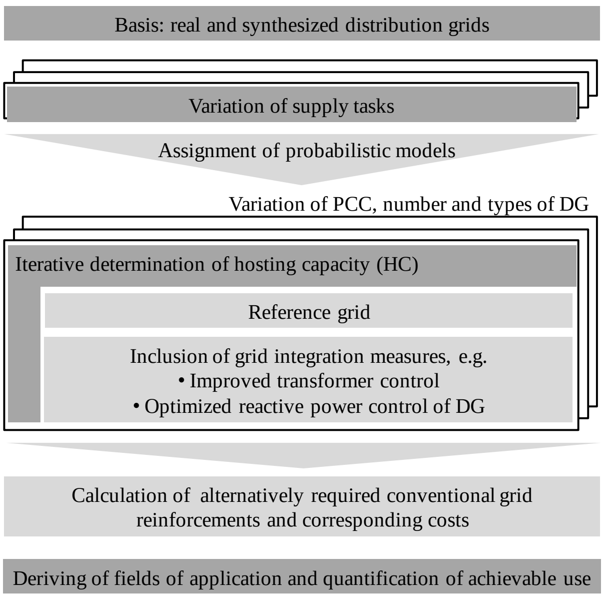

Fig 4 Overview general methodology

RESULTS

Using the above stated methodology multiple combinations of medium- and low voltage grids varying PCCs as well as types and rated power of DG were calculated. In the following, some exemplary results for the HC and the reactive power balance at the substation will be discussed.

Hosting Capacity

The voltage drop along a single line is determined by their complex impedance as well as the complex line current. Most MV- and LV-grids are operated radial although the basic structure may be some kind of ring or even meshed. Therefore the total line length as well as the line parameters should have main influence on the resulting HC. In Fig 5 the HC in dependence of the total line length in a rural MV-grid is depicted using conventional as well as improved transformer control concepts. Starting point and therefore reference (100% total line length) for the variation of the grid extension was a mixed suburban/rural 10-kV-grid. Generally a significant enhancement of the HC is achievable by using improved transformer control concepts, such as the optimal node control. Compared to an optimized reactive power control of connected DG the performance of the optimal node transformer control concept delivers benefits especially in case of extended grid structures, which is typical for rural areas. This is because the reactive power capability of DG is related to the concurrent active power output, which again is related to the grid extension as stated before.

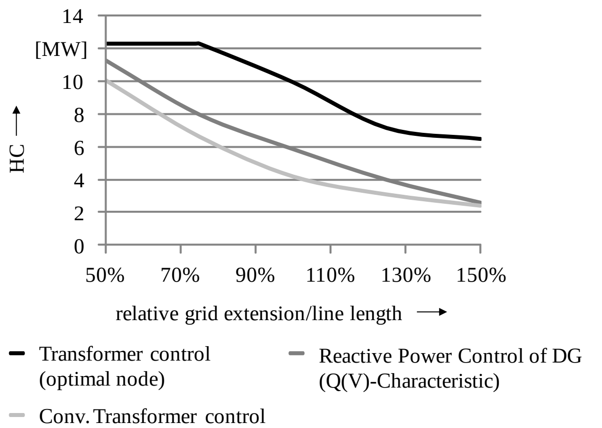

Fig 5 Hosting capacity in dependence of the relative total line length

The results for different line types in an exemplary LV-grid as depicted in Fig 6 are grouped in overhead-lines (OHL) and underground cables. The calculation was done without any kind of control, with reactive power control of connected DG and, assuming there is a tap-changing transformer in the MV/LV station, for two different transformer control concepts. Except for the NYY-type underground cable the difference in HC using tap-changing MV/LV-transformers in combination with improved transformer control concepts compared to the other alternatives, especially the optimized reactive power control of connected DG, is significant. Anyway, when it comes to costs, the optimized reactive power control of DG is to be preferred because of high prices for tap-changing MV/LV-transformers.

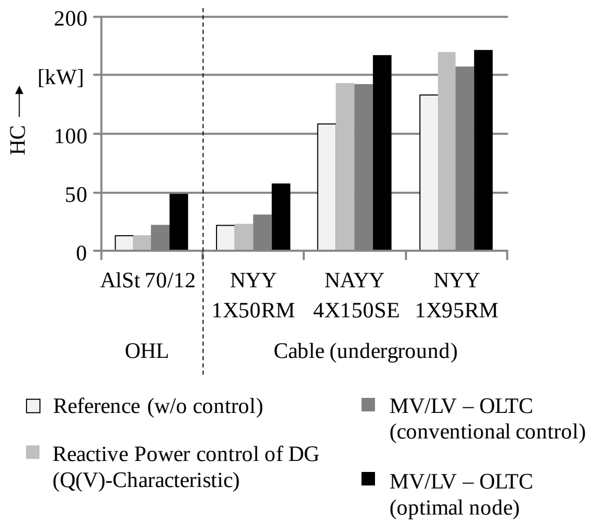

Fig 6 Hosting capacity for typical line types

Reactive Power Balance

Decentralized control mechanisms for reactive power supply of DG in distribution grids such as Q(V) or conventional (direct) voltage regulation are typically focused on local voltage requirements at the distribution level, which may not always coincide with requirements in the superimposed high voltage grid. In Fig 7 the discrete probability density function of the reactive power balance at the substation for a mixed urban/industrial/rural MV-grid using two different control modes for the reactive power control of connected DG is given. Differences are small since both control concepts use the terminal voltage of the DG as input variable.

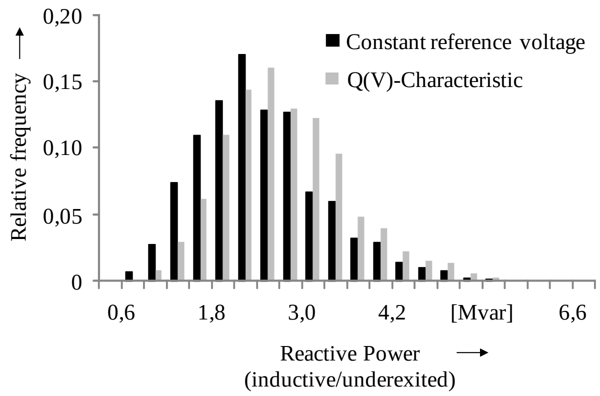

Fig 7 Influence of voltage regulation methods for DG on the reactive power balance of distribution grids

Compared to improved transformer control concepts as well conventional grid reinforcements (Fig 8) there is a significant shift towards the inductive area, because of the additive reactive currents by DG. Such effects are typical for rural grids as in Fig 8, while in urban and suburban grids the total time in which a voltage regulation by reactive power supply of DG is necessary is negligible. As was stated before, highly inductive power factors of subordinate distribution grids may result in impermissible voltages in superimposed high voltage grids. Therefore at least in rural grids the reactive power control of DG should consider reactive power balance issues as well, e.g. by using DG near the substation for reactive power balance issues, while using distant DG for voltage control.

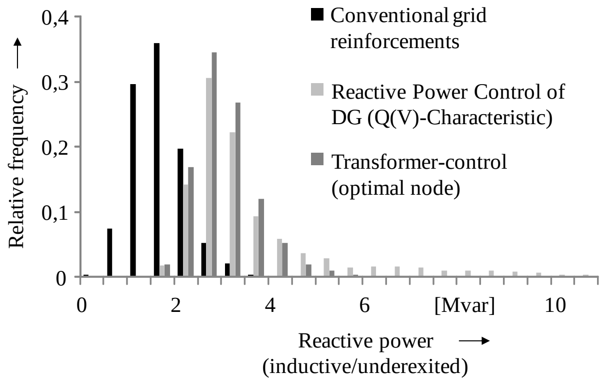

Fig 8 Influence of voltage regulation by DG and tap-changing transformers on the reactive power balance

CONCLUSION

At the example of voltage control concepts for DG and improved transformer control concepts the achievable hosting capacity as well as effects on the grid-wide reactive power balance grid with respect to power factor demands of superimposed grid operators was analyzed. As for the hosting capacity improved transformer control concepts offer the highest benefits, but require tap-changing transformers. In case of reactive power control by DG especially in rural grids a significant shift of the reactive power balance in times of high DG feed-in may occur, which may lead to impermissible low voltage levels in superimposed grids. Therefore in such areas DG near substations or directly connected to them should contribute to reactive power balance issues instead of voltage regulation issues.

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