Utilizing fluctuating feed-in characteristics of WEC for grid integration in distribution grids

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1. Introduction

Primarily driven by the Renewable Energy Sources Act as well as the corresponding act on combined heat and power production (CHP) the development of distributed generation (DG) in Germany has been quite impressive. Nowadays increasingly more countries are facing similar developments.
Especially in rural areas, in many cases distribution grids of low and medium voltage level are already close to their limits of grid integration capacity. But even in urban and interurban grids grid connection of DG becomes a problem because of overloading issues. Therefore, cost-intensive grid reinforcements to strengthen the given network structure by installation of additional lines and/or transformers or by replacing them with higher rated components, are required increasingly frequent. Besides high investment costs, such project driven grid reinforcements may lead to in-efficient grid structures in the long run, even if embedded in a long-term planning scheme, since the future DG development can hardly be predicted, especially on the required local level for the medium and low voltage distribution grids. Therefore highly cost-efficient and flexible solutions are required and should be implemented based on existing grid structures.
There are numerous studies available on the steady-state voltage issue but very few addressing overloading characteristics of grid components with respect to fluctuating feed-in characteristics of DG such as wind farms or PV-plants interacting with conventional power consumers in distribution grids.

2. Approach

Traditionally, the load factor is used to consider the daily load characteristics in the current carrying capacity calculation as shown in Figure 1.

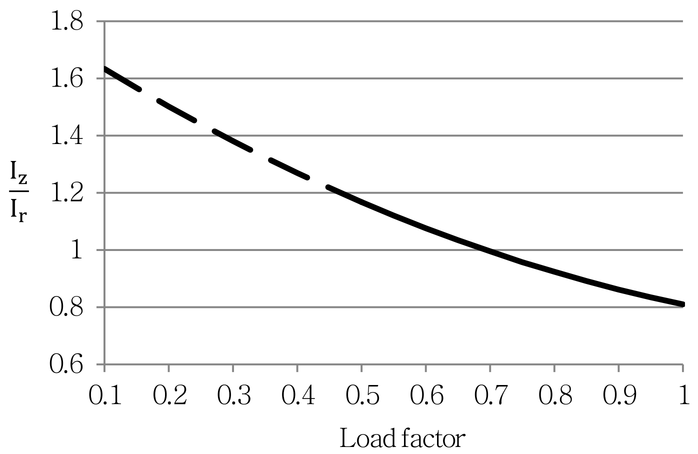

Figure 1: Relation between current carrying capacity and load factor

The current carrying capacity I_z decreases with increasing the underlying load factor. Rated current is usually defined for a load factor of 0.7.
In fact power flows and corresponding load characteristics on lines and transformers can no longer be described by using traditional load factors such as the common utility load factor (0.7) or even by assuming continuous load (load factor 1.0) appropriately. The fluctuating feed-in characteristics

of DG lead to deviating load profiles for each time sequence. The loading capacity of earth buried lines and all kinds of transformers is determined by thermal boundaries and therefore depending on the load characteristics the grid component is subject to. Besides the superimposition of consumer loads and DG feed-in the effective loading of grid components will be influenced especially by reactive power provision of DG as is often used to address the steady-state voltage issue which comes with grid integration of high amount of DG. Therefore, such effects have to be considered when determining the loading capability of grid components with respect to grid integration of DG.

Since the loading capability of grid components is highly dependent on the loading conditions before the time step under consideration, load flow calculations are performed for a sequence of one year with discrete time steps of 15 minutes.

Fluctuating feed-in characteristics of DG are considered by generating feed-in time series for each power plant while taking the distance-dependent correlation between feed-ins of each power plant into account. Time series generation is implemented by using second-order Markov chains with state transition matrices obtained from measured time series of PV- and wind power plants. A Monte-Carlo-Simulation is used to take the worst case into account and ensure valid grid operation for all possible loading situations.

Subject of this paper are grid integration issues in the medium voltage level. Therefore, low voltage grids are aggregated to one feed-in connected to the local distribution transformer and are not part of further investigations.

The operation temperature is calculated for each time step by using temperature models for transformers and earth buried lines respectively. As steady-state temperatures are not reached after the chosen time step sequence, transient thermal conditions have to be applied.

The connected power of DG in the medium voltage level is increased as long as no limits are exceeded to determine the grid integration capacity. Voltage limits are considered as well as thermal limits, depending which limits are more restrictive.

3. Main body of Abstract

The objective of this paper is to determine the increment of the grid integration capacity under consideration of thermal inertia of earth buried lines and transformers. Therefore, the thermal limit of earth buried lines and transformers is not considered as the rated current, which is defined for a predetermined load factor as mentioned before. In fact, the method takes the time-dependent temperature into account to increase the grid integration capacity for DG as long as the allowed operating temperature is not exceeded.

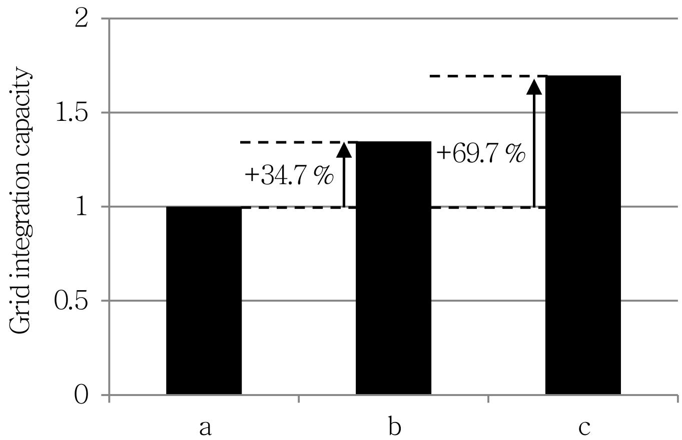

Figure 2: Grid integration capacity based on different underlying methods

A comparison between the grid integration capacities of an exemplary distribution grid based on assumed continuous load (a), the common utility load factor (b) and application of the developed method (c) is given in Figure 2, each related to the grid integration capacity for continuous load.

As seen in Figure 2, dealing with time series calculations under consideration of thermal inertia of transformers and earth buried lines allows to increase the connected power of DG significantly, since temporary operation above rated conditions is possible.
The increment of the grid integration capacity is highly dependent on the load characteristic the grid component is subject to. Since a large part of the connected power plants in medium voltage grids are wind power plants, grid components often have volatile load characteristics which lead to potentials of increasing the grid integration capacity under consideration of the method described in this paper.
In case of voltage stability issues in the considered distribution grid the benefits of the described method can be achieved in combination with voltage control methods (e.g. reactive power provision of DG).

4. Conclusion

Investigations based on the described method show that power flows and corresponding load characteristics on lines and transformers can no longer be described by using traditional load factors, since the fluctuating feed-in characteristics of DG lead to deviating load profiles for each time sequence. The investigations described in this paper further reveal potentials to increase the connected power of DG when taking advantage of the thermal inertia of earth buried lines and transformers.
Future work contains the investigation of the impact of different ambient conditions, such as grid structure, amount of grid-connected DG or laying conditions of earth buried lines.

5. Learning objectives

Loading capability of lines and transformers with respect to fluctuating load, fundamental and temporary overloading potential, options for modifying grid code requirements regarding loading capability, improved grid integration of distributed generation