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An Approach for Cost-Efficient Grid Integration of Distributed Renewable Energy Sources

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ABSTRACT We describe a specific approach to capacity management for distribution grids. Based on simulations, it has been found that by curtailing a maximum of 5% of the yearly energy production on a per-generator basis, distribution grid connection capacity can be doubled. We also present the setting and first results of a field test for validating the approach in a rural distribution grid in northern Germany.

KEYWORDS grid capacity management, 5% approach, renewable energy sources, electricity distribution grid

1 Introduction

To meet the challenge of global climate change, the German federal government has issued goals for the future electrical energy generation mix. In 2050, renewable energy sources (RES) should account for 80% of total electricity generation. Many other countries have also defined ambitious long-term goals for the building up of RES. As a consequence, the usage of power distribution grids in these countries is more and more determined by feed-in from distributed RES. However, traditional grid structures have not been designed to deal with large-scale integration of distributed energy resources with discontinuous feed-in profiles, such as wind and solar power plants.

The current grid system design in Germany follows a worst-case approach: The grid is dimensioned for supporting a maximum load. As a result, and due to the intermittent feed-in by wind and solar power plants, 100% grid capacity utilization only occurs for a few hours per year, namely on occasional sunny and stormy weekends when low power consumption randomly coincides with high wind and solar production.

Following current German legislation [1], the distribution grid must be operated such that it can absorb all the electricity generated from RES. Within the limits of the existing grid infrastructures and operational procedures, such operation leads to situations in which operational limits for power system equipment (e.g., transformer loads and cable loads) are exceeded or in which voltage thresholds are violated. However, grid operators may only curtail RES by feed-in management as a last resort, that is, if there are no other options available to prevent harm to the power grid infrastructure. Once they have taken this action, grid operators are immediately forced by law to expand the grid infrastructure in locations affected by curtailment (see Ref. [1], Section 12). In the early days of the German transition to renewables called "Energiewende," this was an adequate measure to promote the rapid countrywide build-up of RES capacities; today, however, more and more distribution grid structures arise with an unsatisfactory utilization rate, as explained above.

By 2025, installed RES wind and photovoltaic (PV) generation capacity in Germany is predicted to increase by 187% compared to the 2013 capacity. By 2035, an increase of 236% compared to the 2013 capacity is predicted. These numbers are taken from the main expansion scenario underlying the German grid development plan for 2025 [2]. Due to the regulatory background described above, enormous investments in grid construction are required to support the integration of RES, as long as only conventional grid expansion measures are applied in the future. This calls for investigation of methods for fine-grained active power curtailment as e.g. the 5% approach presented in this paper.

EWE NETZ is a distribution system operator (DSO) in the northwest of Germany that operates a regional grid with about 180 HV/MV transformers, 18 000 MV/LV transformers, an overall grid length of 81 000 km, and about 800 000 consumer connections with a maximum consumption load of 2.2 GW. Already, about 2900 wind turbines with an installed generation capacity of 4.6 GW peak, 57 000 PV generators (1.5 GW peak installed), and 1500 biomass generators (0.6 GW peak installed) are connected to the grid. These numbers will continue to grow in the future. For the grid operated by EWE NETZ, the average renewable generation is estimated to reach 150% of electricity consumption by the year 2020. EWE NETZ is in a process of permanent network expansion and is

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therefore constantly looking for solutions to increase network connection capacity for RES at low cost.

This article first summarizes technical possibilities to maximize grid connection capacity for RES with low costs. Next, it focuses in more detail on an approach for dynamic grid capacity management, called the "5% approach."

2 Overview of methods for increasing grid connection capacity

The conventional way of expanding grid connection capacity involves laying new power lines, adding lines with greater wire cross-sections, and installing transformers with higher capacity. However, a range of additional technical possibilities for increasing connection capacity exists today: Some based on flexible power system equipment and others on the use of information technology.

New methods for improving grid connection capacity in medium-voltage grids are based on one of two ideas: either stabilizing voltage or controlling power feed-in and thereby optimizing load flow. The low-impact operation mode (LOM) is an example of a method for stabilizing voltage [3]. It is based on assigning a constant power factor to generators such that the sensitivity of voltage toward power gradients is minimal at the grid connection point. This method relies on generators being equipped with phase-shifting controllers and results in increased voltage stability. A second method to stabilize voltage is longitudinal voltage controllers. These consist of controlled impedances that are varied to modify voltage without affecting phasing. A third method, static synchronous compensators (STATCOM), regulates voltage by injecting or absorbing variable amounts of reactive power into or from the power system.

In grids dominated by decentralized RES, maximum grid load results when high RES generation coincides with low power consumption. Thus, methods to control load flow must either be based on controlling consumers or on the curtailment of RES generators. Two methods for curtailment are currently under discussion in Germany: static and dynamic. Static curtailment limits the feed-in of generators installed within a specific section of the distribution grid to a fixed percentage of their capacity. This percentage is calculated from simulations such that no overload of grid components can occur. This method of curtailment is technically simple, since no additional information and communication technology components are needed to implement it. However, static curtailment has the drawback of curtailing more energy than necessary: A generator is curtailed even if its feed-in does not contribute to a grid overload. Dynamic curtailment, on the other hand, is more effective: Generators are only curtailed in situations where they specifically contribute to grid congestion.

Figure 1 depicts the measured reverse histogram of the annual feed-in for a typical PV generator. A feed-in that is close to the maximum generation capacity of this PV plant (300 kW) is reached only for a very few hours per year. Curtailment of the feed-in for a couple of hours per year will not substantially reduce the amount of energy available. Following this approach, a recent study conducted for the German Federal Ministry for Economic Affairs and Energy [4] showed that curtailing 3% of the yearly feed-in of wind and solar generators can reduce the costs for grid expansion needed to accommodate RES integration by 40%. Curtailment of up to 5% can actually reduce the costs by 50%. In this paper, we focus on a description of the technical implementation of this approach, based on a curtailment rate of 5%.

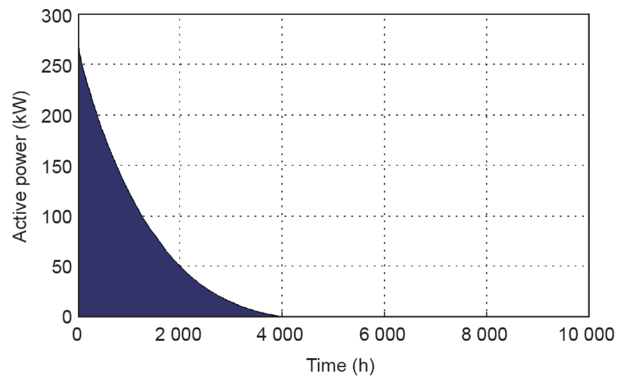

Figure 1. Illustration of the measured annual feed-in duration curve of a PV generator.

Congestion management as used for transmission grids is another method for grid usage optimization. However, in difference to the described methods of controlling grid usage by technical approaches, it is based on market mechanisms: Relying on predictions of load and feed-in, auctions for cross-border transmission grid capacities are carried out. Due to deviations from predictions, congestion management has to be complemented by markets for ancillary services. Since in Germany, no market participation has been established for DSOs, no market-based approach can currently be used there to optimize distribution grid usage. However, this is a topic of discussion and research [5].

3 The 5% approach

The 5% approach is based on the assumption that dynamic, load-flow-dependent curtailment of a low percentage of the yearly power feed-in of a RES generator, which is carried out only in a few maximum load situations, leads to a relevant increase of grid connection capacity. For each generator, this approach limits curtailment to a maximum of 5% of the generator's yearly energy production. The frequency and duration of curtailment must be reduced to the necessary minimum. This can be achieved using a fine-grained control, both in the time and power dimensions.

3.1 Assessing the 5% approach by simulation

Simulation calculations were carried out using a model corresponding to a rural type of grid operated by EWE NETZ. The model's characteristics were as follows:

- The model included a 110 kV to 20 kV transformer as the connection between the high-voltage (HV) grid and the medium-voltage (MV) grid. It also included clustered low-voltage (LV) grids.
- A typical deployment of distributed RES (wind, PV, and