

Size of a distributed electrical storage for a rural area with a wind farm

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Abstract

Increasing the share of renewable energies in Germany is one of the current social challenges in the context of the energy transition. However, due to the volatility of renewable energy sources also storage systems are needed to avoid grid overload and ensure a stable power supply. In this article the influence of the integration of a wind farm on the optimal storage capacity of a decentralized electrical storage system for a rural area in Germany is determined. For this purpose, different simulations of the municipality's power flows, with and without the wind farm, are carried out and a method is introduced to calculate the optimal storage capacity based on an objective function. It is also described how the operational properties of the storage change depending on the integration of wind energy systems. The simulations show that the determined optimal storage size for the municipality with and without the integration of the wind farm are almost equal. Even in combination with a further expansion of wind power units the optimal storage capacity only increases slightly while the utilization is maximized.

Keywords: Smart Grid, storage, renewable energies, wind energy

1. Introduction and Motivation

In recent years, the energy supply in Germany has changed significantly due to the expansion of renewable energies. In 2017, renewable energies accounted for 36.2 % of the electricity mix [1]. This high share can mainly be attributed to the large number of photovoltaic (PV) and wind turbines. Most of the PV systems are small rooftop systems, installed on buildings in the low-voltage grid [2]. They only have low installed capacities per system in comparison to wind turbines with installed capacities of up to 5 MW per system. Therefore, wind turbines are installed in the medium-voltage grid. While the electrical energy of the wind turbines is fed exclusively into the grid, part of the energy generated by the PV systems is consumed in the building itself. This self-consumption is currently significantly cheaper than purchasing energy from the grid [3].

A rural community was selected as the real laboratory for this study. The network structure of the municipality is shown in Fig.1. In the municipality with approx. 13000 inhabitants mainly photovoltaic systems, wind energy and biogas plants are used as renewable energy sources. In the city there is a wind farm consisting of four Enercon E82/2 turbines. Each of these turbines has a rated output of 2.3 MW, so that the total wind farm has a maximal output of 9.2 MW. Furthermore, photovoltaic systems with an installed capacity of 13 MW and biomass power plants with an installed capacity of 3 MW are available. Hydropower is negligible at only 174 kW capacity. All electrical power (production and consumption) is fed into a transformer station (TS). This is connected to the high-voltage grid on the 110 kV high-voltage level via two transformers. [4]

Due to the high volatility of renewable energies, a further increase in the share of the total electrical power mix cannot simply be achieved by a further increase in installed capacity [5]. To better balance consumption and generation, the grid could be expanded [6], demand response systems used [7] and

storage installed [8]. Studies already analysed the benefits of energy storage systems for wind power plants [9].

This paper focuses on the impact of the integration of wind power on the sizing of energy storage systems for rural municipalities.

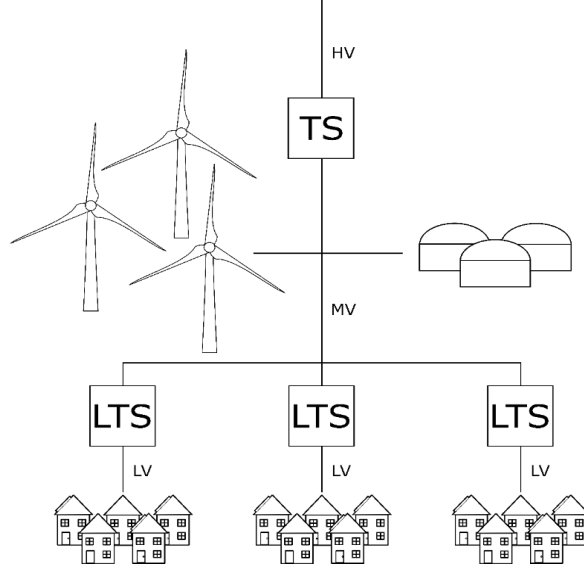


Fig. 1. The network structure of the municipality. The medium-voltage grid (MV), into which the wind farm and the biogas plants feed, is connected to the high-voltage grid (HV) via a transformer station (TS). The consumption data is obtained directly from the transformer station. The low-voltage networks with the residential buildings are connected to the medium-voltage network via various local transformer stations (LTS).

2. Method of Simulation and Data Basis

To calculate the additional storage capacity required to buffer the power of the wind turbines, the power curve of the balance area under consideration is also required in addition to the power generated by the wind turbines. In this case, this is the cumulative capacity of the transformer station in the municipality. $P_{Transformer\ Station}(t)$ Fig.2. All consumers and all producers are combined in this power curve. It makes no difference whether power was generated by CHP's (biomass power plants), photovoltaics ($12\ MW_p$ roof and $1\ MW_p$ open space) or by the wind farm. However, since the storage size required for a sensible storage of wind energy is to be determined, two simulations are combined.

The first simulation calculates the optimum storage for the entire balance area. All producers and consumers are taken into account. This results in a total storage size S_{Total} . In the second simulation, the storages are determined for a power curve modified by the wind power:

$$P_{mod}(t) = P_{Transformer\ Station}(t) - P_{Wind}(t) \quad (1)$$

If this modified power is used as the basis for the determination of the storage, the reasonable storage size for the balance area without wind turbines is obtained. For the year 2017 under consideration, this results in a storage size $S_{Without\ Wind}$.

The difference between the two storage sizes now corresponds to the storage that is needed for the storage of wind energy:

$$S_{Wind} = S_{Total} - S_{Without\ Wind} \quad (2)$$

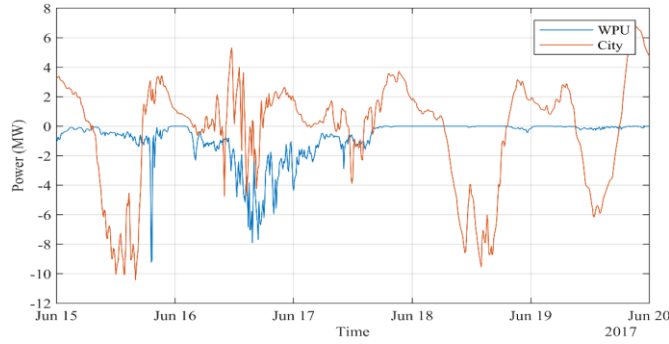


Fig. 2. power of the city and the wind farm between 15th and 20th of June. While on the first and last two days the photovoltaic systems fed in more than they consume, on the second and third day mainly the wind farm is involved in the surplus. It turns out that the feed-in capacity is up to 10 MW.

To determine the optimal storage parameters, a cost-independent objective function was developed that takes the utilization of the storage into account. A very large storage offers a lot of storage capacity, but this usually remains unused, as the storage is either not full (e.g.: low-wind weather conditions) or not empty (e.g.: windy weather conditions). Moreover, a large storage facility is associated with high investment costs. On the other hand, a small storage is fully utilized, since it always becomes completely full or completely empty. However, the storage capacity is so small that only a small part of the energy from the wind turbines is stored and accordingly only little energy can be drawn from the storage. The objective function combines these two factors and defines the optimal storage parameters. First, the used *energy* was defined as the sum of the energy consumed by the storage. Fig. 3 shows what proportion of the total fed energy without storage can be used by the storage. This is larger for a large storage than for a small storage. The aim is to use as much energy as possible from the storage, so the *energy used* and thus the storage capacity should be as large as possible.

The unused storage capacity was defined as the counter factor. It describes the difference between the storage capacity and the current charging status. The unused storage capacity increases with increasing storage capacity. Fig. 4 shows the share of unused capacity in the total capacity. To make optimum use of the storage, the unused storage capacity and thus the storage should be as small as possible. Now it is important to combine the two factors in such a way that an optimum is achieved. The two factors are multiplied by each other:

$$\text{objective function} = \frac{\text{used energy}}{\text{total fed energy}} \cdot \left(1 - \frac{\text{unused storage capacity}}{\text{storage capacity}}\right) \quad (3)$$

The maximum of the objective function for different storage capacities defines the optimum storage capacity. Time-resolved load and generation profiles $P(t)$ are used to calculate the objective function for different load and generation profiles. The power data of the transformer station .

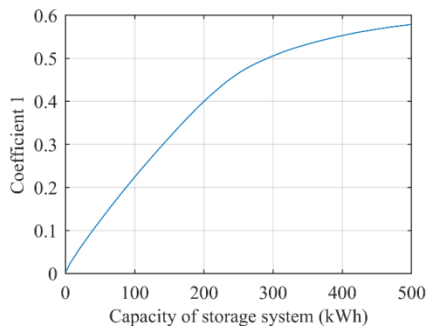


Fig. 3. The energy used by the energy store in relation to the total feed-in.

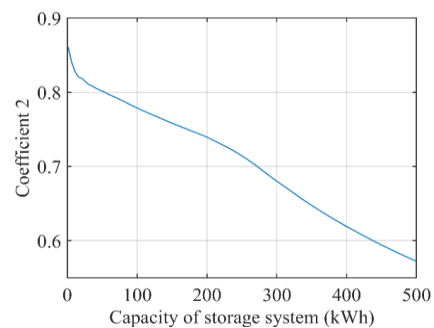


Fig. 4. The unused storage capacity in relation to the capacity of the storage system.

($P_{TS}(t)$) with a resolution of 15 minutes and the generation data of the wind turbines with a resolution of 10 minutes for the entire year 2017 were evaluated.

3. Results of the Simulation and Determining the Size of the Storage

The results, which can be obtained by evaluating the objective function for a parameter study, do not take into account economic influences such as investment costs or storage costs for electrical energy. If these things are included, the German energy price and tariff structure lead to a storage size of zero MWh, since the costs for such a storage solution are still very high [10].

For the municipality without the wind farm, the optimal storage size is 72 MWh (Fig. 5). To determine the maximum, the storage capacities were resolved finer near the maximum than for very small and very large storage capacities. The values for the objective function are slightly below 0.34. Such a storage is charged exclusively by the many PV systems and biogas plants (6 units) and discharged by the consumers in the municipality. Since the value of the objective function is greater than zero, it is clear that even without the wind farm the entire municipality has such a large installed capacity of PV and biogas that surplus energy is fed into the high-voltage grid during periods of high generation.

If the generation capacity of the wind farm is now integrated, a very similar picture emerges on the basis of the objective function. The objective function changes its shape only very slightly. The maximum that determines the optimum storage capacity shifts slightly to 70.8 MWh. The value of the objective function rises to over 0.35. If the amount of energy used (factor 1, Fig. 6. The value of factor 1 depending on the storage capacity of the combined storage system.Fig.6) and the free storage capacity (unused storage, factor 2, Fig. 7) are evaluated separately, relatively less energy is used, but the capacity of the storage is better used. The better utilisation of the storage capacity can be explained on the one hand by the reduction in storage capacity and on the other hand by the non-simultaneity of the two renewable energy sources. If you look at the absolute amounts of energy, you notice above all the reduction in energy consumption without storage. While the municipality would have to obtain 45.5 GWh of energy from the high-voltage level without the wind farm, the purchase due to the wind farm is reduced by 11.4 GWh to 34.1 GWh.

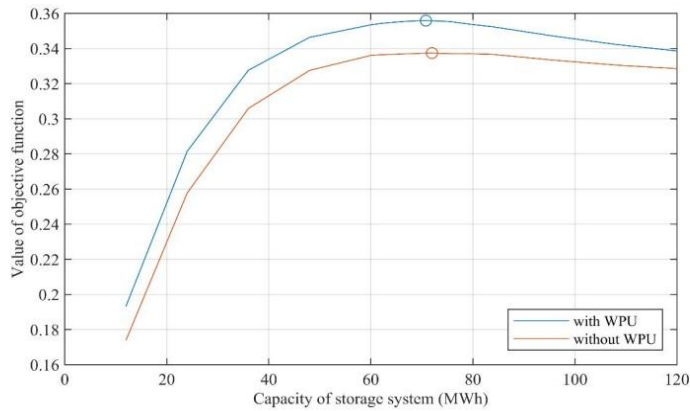


Fig.5. The value of the objective function depending on the storage capacity of the combined storage system. There is only a slight difference between the calculation with and without wind farm.

Since the wind farm has generated a total of 12.3 GWh per year, only a surplus of 0.9 GWh remains for storage. This shows that the generation of the wind farm correlates very well with the consumption of the municipality. The reason for this is the high number of electrically heated buildings, as their consumption is considerably higher in the winter months. The wind farm also generates the most energy at this time. The storage facility can reduce the energy consumption of the entire municipality further by 2.5 GWh (without wind farm) or further by 3.2 GWh. In percentage terms, this results in a reduction of 5.55 % and 9.36 %, respectively. Due to the small increase in the surplus, the expansion of a second wind

farm was included in the simulation. This will reduce the consumption of the municipality further by 9.1 GWh to only 25 GWh. At the same time, the feed-in increases to 7.8 GWh. Another simulation shows that an optimum storage size of 75.6 MWh, which is only 3.6 MWh above the optimum storage size without the wind farm or 4.8 MWh above the optimum storage size with one wind farm. The storage at this point results in a reduction in consumption of 5.2 GWh (20.23 %). Overall, it is therefore clear that further expansion of wind power on site will lead to a positive result. At the same time, the maximum feed-in capacity increases from 11.2 MW to 17.8 MW. This can be reduced either by switching off the wind turbines or by active peak shaving with the battery storage. All data is provided in Table 1.

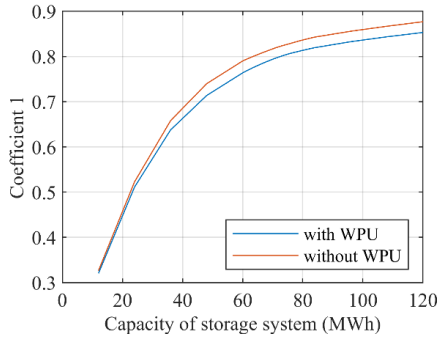


Fig. 6. The value of factor 1 depending on the storage capacity of the combined storage system.

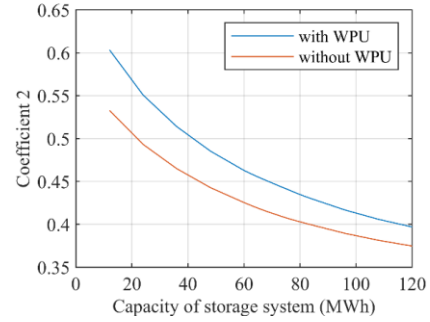


Fig. 7. The value of factor 2 depending on the storage capacity of the combined storage system.

Fig. 8 shows the results of the simulation for the municipality including the wind farm with a storage capacity of 70.8 MWh. The figure outlines one week in June, during which almost all electricity consumption can be covered by the storage and direct consumption. Only on one day the storage is not sufficient and energy must be drawn from the grid (grey). Despite the high capacity, not all the energy can be stored on days with high power generation and is fed into the grid. Although the storage can cover a large part of the demand, an implementation is not worthwhile due to the high costs according to the current status.

Table 1. Comparison of storage systems with and without wind power:

system property	without WP	with WP	with 2 WP
Energy consumption without storage	45.5 GWh	34.1 GWh	25 GWh
Feeding without storage	3.1 GWh	4 GWh	7.8 GWh
Optimum storage size	72 MWh	70.8 MWh	75.6 MWh
Used energy	2.5 GWh	3.2 GWh	5.2 GWh
Energy reduction for the HV-Grid	5,55 %	9,36 %	20,23 %
Average unused storage capacity	42.4 MWh	39.1 MWh	35.3 MWh

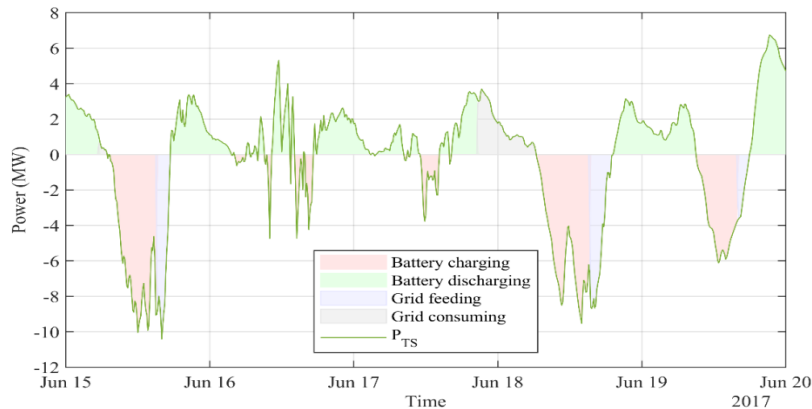


Fig.8. The power curve of the city with signalled charging and discharging times, feed-in and consuming of energy.

4. Conclusion

The use and the optimum capacity of electrical storage systems can be simulated using real load profiles. It is shown that the optimal storage size of 72 MWh for the municipality without wind energy under consideration is similar in size to the integration of wind energy (70.8 MWh, deviation -1.6 %). This results on the one hand from the similarly large installed generation capacity of the wind turbines of 9.2 MW and the total PV systems with ~13MW, but on the other hand from the only slightly increased surplus. This is due to the non-simultaneity of the energy producers, as the wind farm feeds mainly between autumn and spring. Since electrical heating is also used during this period, the consumption of the municipality is usually higher than the output generated. Therefore, the energy is consumed directly. An expansion of the wind turbines will lead to an increase of the fed in energy. This is another indication of the non-simultaneity of the energy generators. A promising possibility to significantly increase storage efficiency and storage utilization is the control of biogas plants in the city area (currently these plants will operate at constant power). These could then act as further storage facilities and significantly reduce the volatile share of renewable energies within the municipality, thus reducing the load on the electrical storage facilities.

Conflict of Interest

The authors declare no conflict of interest.

Author Contributions

J. Ü. Wrote the paper and developing the concept. F.B. carried out the optimization and analyzed the data. K. F. Developed the method of simulation and the objective function. All authors had approved the final version.

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