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Forecast the grid oriented battery operation to enable a multi-use approach and discussion of the regulatory framework

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Abstract: Battery projects are getting increasingly attractive for various applications due to decreasing prices. One possible use case is also to exploit the flexibility for grid usage to avoid/defer conventional grid reinforcements and to effectively integrate decentralised renewables, active prosumers and new loads in the future into the grid. The profitability of storage assets can be improved substantially if a 'multi-use-approach' can be realised. These approaches consider grid usage in time periods with grid restrictions and system- or market usage could be applied in non-critical time periods. Based on real-world projects, approaches for such operations have been derived and implemented. Next to some elaborations on these results, the discussion on possible business models considering the regulatory framework is also a main aspect of this study.

1 Introduction and related work

The integration of power generation from renewables (RES-E) poses significant challenges for distribution system operators (DSO). In Germany, the expected reinforcement need has been calculated to amount up to 49 bn € until 2032 [1]. In addition, the Energiewende will soon bring additional challenges as active prosumers and additional loads are connected to the grid. Further studies such as [2, 3] show that storage operation in general and mid/large-scale battery introduction in particular might provide a benefit for local grid operation. According to these studies, market usage without considering grid constraints will even increase the need for reinforcements due to insufficient correlation of price signals from (spot-)markets and local grid profiles. In this context, the German association of energy and water industries (BDEW) defines the three types of flexibility use for the

(a) *market*: utilisation on the wholesale market (e.g. spotmarket arbitrage),
(b) *system*: utilisation of flexibility by the transmission system operator (TSO) to maintain system stability (e.g. as balancing power),
(c) *grid*: utilisation of flexibility by TSO or DSO to manage mostly local network situations.

The multi-purpose-use is defined as an approach for exploiting the flexibility of the storage asset while combining at least two of the three options. Some initial studies tried to evaluate if these options are more beneficial than conventional grid reinforcements (see e.g. [4]) and have shown that these situations occur, but are dependent on the specific grid constellation.

This paper focuses on the effect of storage systems for distribution grid purposes, in particular peak-shaving applications to avoid/defer conventional grid reinforcements. Due to the fact that especially in grids with lots of fluctuating feed-in of photovoltaic (PV), storage systems are not needed twenty-four-seven for grid use and thus, the multi-purpose-use of storage systems will generate additional value. The challenge presented in this paper is to create a robust method, which can forecast the unused storage flexibility one day ahead with sufficient accuracy, to enable the multi-purpose-use. The newly developed method consists of two main parts/algorithms. The first part is an algorithm that forecasts the power flow at the transformer of the distribution grid, because in this case the power flow is the basis for all flexibility calculations. For this purpose, a customised regression algorithm is used. The result of the regression algorithm is a time schedule of tomorrow's power flow at the transformer of the distribution grid. This power flow schedule is used in the second part to calculate the free storage flexibility that can be used for other (market/system) purposes. The use of this flexibility is subject to certain constraints, whereby two constraints are of major importance – power and capacity. These constraints can be visualised.

These technical elaborations are accompanied by a discussion on the regulatory framework. It is still unclear in most European countries how DSOs are able to use the flexibility from storage systems such as batteries. The capital expenditure (CAPEX) and operational expenditure (OPEX) models are presented and discussed, also with respect to the current legal frameworks and regulatory incentives for DSO. In the remainder of this paper, we will first describe one of the R&D projects in more detail. This project provides the level playing field for the approach and the forecast. Based on these insights we will discuss the regulatory dimensions and end up with a summary.

2 Project ElChe in a nutshell

The project ElChe Wettringen with a 250 kW/350 kVA/1000 kWh Li-Ion storage was realised to test battery assets focused on grid oriented operation (only). Innogy and Westnetz invested in this R&D project which is a seldom situation where solving an existing grid problem with a battery system is more cost efficient than by conventional grid reinforcements. This project has provided valuable insights into technical and regulatory issues (see e.g. [5, 6]). The first year of operation has shown a reliable and accurate technical performance for a total of 900 operating hours. It was focused on peak-shaving only. The set-up in Wettringen is now used to develop an algorithm for identifying and forecasting time slots on the next day when storage is needed to solve grid problems (in case of massive surplus of local PV feed-in) and to identify and forecast 'surplus flexibility'. In these time periods, the flexibility can be used for system/market use by being offered through an auction in a non-discriminatory way.

3 Forecasting of flexibility

In this chapter, a technical method is described to forecast the electrical storage flexibility one day ahead. Since the battery in the pilot project of innogy and Westnetz is used primarily for grid purposes, the surplus flexibilities can be defined as storage capabilities which are not used for grid purposes. By forecasting the power flows in the grid, the usage of the storage for grid purposes can be calculated and the remaining storage capacity can be given to a third party with predefined restrictions to ensure grid stability. In order to forecast the flexibilities, a two-step-methodology was developed [7] and implemented:

- *A power flow forecast for tomorrow:* In the case of Wettringen it is possible to forecast the power flow directly at the transformer that the storage is connected to. This is possible because the power production is several times higher than the relatively steady demand and (only) PV productions is relevant in this low-voltage grid. The demand is only appearing as offset in the forecast algorithm. Furthermore, in this area of Wettringen only farms are connected which show quite stable consumer profiles and there are only small changes in consumption between weekdays and weekends.
- *Flexibility calculation:* The forecasted power flow is the basis for performing the flexibility calculations to identify the remaining storage resources which are not used in order to ensure grid stability.

3.1 Power flow forecast

As a basis for the presented approach the regression analysis was chosen because of its advantages in forecasting values in areas with unstable weather conditions [7]. Furthermore, the regression method has the advantage that it may consider demand as a part of the forecast value because demand is assumed to be constant and negligible in certain time intervals. To perform the analysis, at least two variables are needed which influence each other. In the case of Wettringen it can be seen that the PV generation in the distribution grid is so pronounced that a linear connection between irradiation and power flow can be assumed. Thus, the irradiation/power flow tuples are chosen as input for the regression analysis. However, this connection has some uncertainties. During the day the angle of the sun is changing and the weather conditions are also subject to variations. Additionally, there are seasonal changes and changes in the surroundings (e.g. trees grow larger and throw a shadow on the PV panels or the panels get dirty due to dust).

In order to cope with these uncertainties the time period as input for the regression and the forecasted time interval can be adapted. The uncertainties during the day can be linearised by changing the forecasted time interval per day. The smaller the time interval (e.g. 2 h) the fewer influences are introduced by environmental changes (e.g. due to the changing angle of the sun). To reduce the uncertainties of the seasonal changes and the changes in the surroundings the time period of historical data can be adjusted. The less the amount of days as input data the less influences are given for the seasonal changes. For both timeframes it is shown that the smaller the time frame the fewer inaccuracies on the power forecast are given. However, for a regression a certain number of tuples is needed. So the decision is a tradeoff between accuracy and number of data tuples. In this research, a time interval of 2 h as forecast interval and 10 days of historical data as

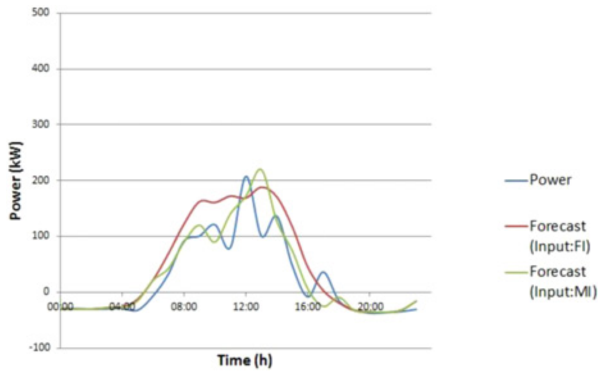

Fig. 1 *Power forecast, unstable weather condition*

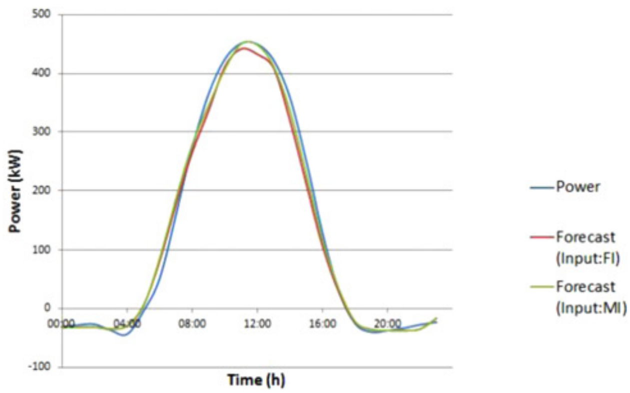

Fig. 2 *Power forecast, stable weather condition*

input for the regression analysis is chosen. This set-up shows the best results and forecasts in meaning of root-mean-square values.

In Fig. 1, the forecast of a day with unstable weather condition (7 August 2016) is depicted. The real measured power flow is depicted as a blue line. The line shows some local maxima and minima indicating that the day is in an unstable weather period and there were many clouds in the sky. Furthermore, the results of the power flow forecast can be seen. The green line shows the forecast result with measured weather data as input (MI) and the red line is the forecast result with forecasted weather data as input (FI).

The forecast of a day with stable weather conditions (8 May 2016) is presented in Fig. 2. The colouring of the lines is the same as in the previous figure. The blue line shows a pronounced PV parable meaning that this is a sunny day and there were no clouds in the sky. It is also visible that the method works very well with measured weather data (especially in stable weather periods). Sometimes a tiny shift in time can be seen, because the measurements of the irradiation are taken in a distance of a few kilometres away from the storage. The forecast with predicted weather data also shows sufficient results.

It can be concluded that the results of the forecast are massively dependent on an accurate weather prediction. Note that the forecasted power flows are not the goal itself, but they are used to calculate the free flexibility of the storage. Hence, a high accuracy of the forecast is needed in times when the storage is used for grid purposes. This is the case when PV production is high and this in turn implies that there is a stable weather period so that the low accuracy in time periods with unstable weather conditions is uncritical for the multi-use approach.

3.2 Flexibility calculation of the storage asset

The next step is to calculate the storage flexibilities using the forecasted power flow. In the case of Wettringen with regard to the power flows, a threshold for the peak shaving algorithm of the battery is defined to avoid/reduce too high reverse power flows stressing upstream grid assets [transformer high voltage/medium voltage (MV), MV grid assets, transformer MV/low voltage (LV)] and increasing the voltage values in the relevant LV and MV grids. According to that threshold, the power flow in the distribution grid can be divided in different areas. The first *area* is relevant if the power flow resulting from the PV generation is higher than the threshold (red area). In the current test period, this limitation has been set to 370 kW. The power value exceeding the threshold has to be buffered in the battery so it can only be used by the DSO. The second area is the area directly below the threshold (amber area). In this area, the potential power usage of the inverter (250 kW in Wettringen) has to be limited for a possible third party. Otherwise there is the possibility that the power flow would manually be raised again over the threshold (e.g. the power production in the LV is at 250 kW and the battery would discharge with 200 kW. Thus, the resulting power at the transformer would be at 450 kW and higher than the limitation). The third area would be at power values below the threshold minus the inverter power. In this area, the inverter can be used without limitations (green area). These areas (green, amber, red) are oriented on a stoplight concept for the *technical* operation in grids.

To be able to use the flexibility of a storage system with regards to the grid requirements, a third party needs additional information. This information can be described as time schedules, which specify how the flexibility with regard to the constraints will be used. The ranges of the free flexibility can be defined by the capacity (kWh) and power (kW) constraints of the storage asset. The capacity constraint has to ensure that at the beginning of the red area there is enough free capacity to buffer the PV peak. Hence, the third party can use the battery and exploit the capacity as long as the forecast of the power flow indicates that capacity will have to be reserved for grid issues. The second constraint is derived from the power flow at the transformer. Here, the communication of the power constraint and the measured as well as the predicted power value is very important again to avoid local grid violations. For instance, if the power flow in the grid increases above a certain threshold, the storage inverter can no longer be used to its full potential for a third party, because otherwise the power at the transformer exceeds the transformer threshold. These two constraints can be visualised in a three-dimensional (3D) graphic.

The combination of the capacity and power constraints are depicted for a specific summer day in Wettringen in Fig. 3. This approach and, thus, such results from the calculations have been implemented with day-ahead predictions for the operation mode of the battery. Note that in the centre of the figure a gap can be seen around noon resulting from the 'red-area' due to the primary usage of the battery for PV-peak shaving. The bar in the middle of the gap visualises that there is battery capacity available but in these time periods no power flexibility is free. In this case, there is a certain amount of capacity with zero power flexibility useable by a third party. Furthermore, at the top of the figure the shape of a hopper is visible caused from the power constraints in the amber and in the red area. With this graphic all important information are shared and the third party can use the free flexibility, because they can use every possible charge and discharge curve as long as it stays in the 3D object.

With this approach it is proven that a multi-use-concept to maximise the potential of storage usage can be realised in practice. One main question is still if and how regulation should be adjusted to enable this level-playing field.

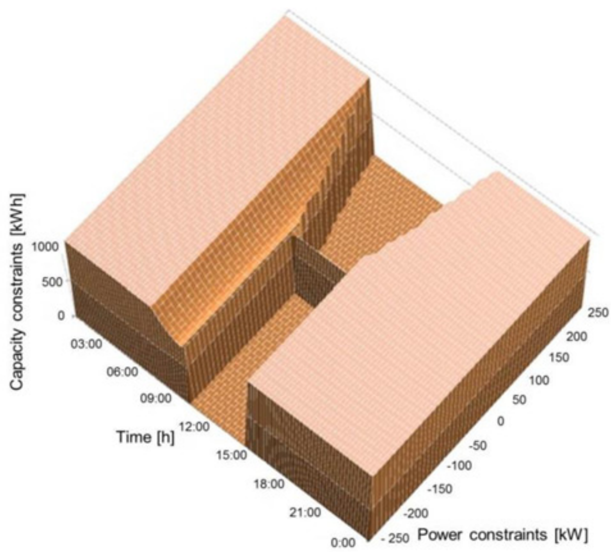

Fig. 3 *Plot of 'free flexibility' considering power/capacity constraints for a summer day*

4 Regulatory discussion

As shown in the previous chapters, storage assets such as batteries can provide a benefit to both grids and for system-/market usage. Inspired by UKPN [8], we differentiate four different models for the ownership and operation of flexibilities in general, but in particular for batteries. These models are listed in Table 1 and explained in more detail in this chapter.

4.1 Model 1: DSO asset (only)

In most member states (MS) of the European Union it has not yet been specified how TSO and DSO are allowed to own and operate batteries for grid optimisation. According to the Clean Energy Package proposed by the European Commission on 30 November [9] 2016, TSO and DSO should be allowed to own and operate storage only in exceptional cases. Still, the legal framework is

Table 1 Models for storage usage in grids

Model	(1) Only concentrated on distribution grid	(2) CAPEX model ('contracted DSO')	(3) OPEX model ('contracted service')	(4) Only market – without grid consideration
ownership of storage	DSO	DSO	third party (storage operator)	third party (storage operator)
regulatory consideration	storage as a grid asset, only grid optimisation is possible. Storage potential not completely used	see (1), in addition: DSO leases ' surplus to third parties on a non-discriminatory basis	DSO contracts flexibility; additional OPEX for grid operator for compensating third party	storage only for system (frequency)/market (arbitrage) use
legal framework	in most MS unclear	in most MS unclear	possible, compensation unclear	possible
incentive/impact for the DSOs (focus Germany)	given (as for 'normal' grid assets), but efficiency possibly affected in a negative way	given (as for 'normal' grid assets), probably reducing the revenue cap (and increasing the efficiency)	not attractive as an OPEX-component (especially in incentive regulations)	risk of increased reinforcement needs in the grid due to insufficient correlation of steering signal to local grid constraints

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currently different in different MS. In this model, the potential of the storage system is not completely used due to the fact that in non-critical time periods the system cannot be used for other applications. This is relevant as long as the system should be used by one stakeholder only, e.g. because of unbundling reasons.

4.2 Model 2: CAPEX model

In this model, the DSO is the owner of the battery and decides on size, dimensioning and location. Hence, the investment induces CAPEX for the DSO. The operation of the asset for market and system use is auctioned and realised by a third party. This enables the 'multi-use-operation', e.g. with approaches presented in this paper including forecasts on grid limitations and offers of 'free flexibility' to the market. Such contracts could be realised, e.g. on an annual basis considering expected operation modes for the grid (operating hours, time and lead time of usage). In this model, the revenue for tendering the flexibility to the market will be considered as revenue for the TSO/DSO and hence increase the efficiency of the system operator reducing the costs for the end-consumer in the end.

4.3 Model 3: OPEX model

The OPEX model is also focused on 'multi-use-operation'. However, the owner and sole operator of the battery assets is a third party (such as a separate storage operator). To enable grid usage of the battery, the DSO needs to define the place and the size of the asset in advance. Any mobile usage of the asset (e.g. to overcome local, but temporary grid problems) has to be covered with additional agreements in the contract. Such arrangements are more complex than in the CAPEX model. Furthermore, the DSO has to be guaranteed a reliable operation by the storage operator. The compensation for the third party by being paid by the DSO (OPEX) and corresponding rules for behaving 'grid friendly' have not been implemented in most countries. In addition, the TSO/DSO has to be incentivised to use OPEX instead of CAPEX due to the Averch–Johnson effect, which leads to regulated utilities being too capital intensive [10].

4.4 Model 4: market only

The last presented model reserves battery storage for market and system use. This is only efficient as if grid reinforcement is always more efficient than the use of flexibility from batteries for these applications, which is not the case. In addition and as mentioned beforehand (see e.g. [2, 3]), this perspective will lead to increased reinforcement needs due to insufficiently correlated steering signals from market-/system operation to local and grid oriented usage.

After explaining these models in a nutshell, it becomes evident that further activities are required in this context. The CAPEX and OPEX models will have to be tested and evaluated in practice (see e.g. also [11] for a project focussing on the OPEX model). According to our opinion, an open competitive approach to models 1, 2 and 3 is crucial to guarantee the efficient introduction of storage systems. Hereby, the regulatory (dis-)incentives for the DSOs should be taken into account. It should be a main aspect of future R&D activities.

5 Summary

Summarising the insights of this paper, an algorithm for identifying and forecasting 'surplus flexibility' of storage systems in grids is presented. This approach enables the 'multi-use-operation' of storage assets such as batteries for an efficient introduction to grids and systems. We highlighted and analysed the regulatory options for batteries. A suitable regulatory framework has to be implemented considering an open competitive approach which leads to efficient solutions.

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