Live test results of the joint operation of a 12.5 MW battery and a pumped-hydro plant

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Grid-integrated renewables affect the operational characteristics of the existing power infrastructure because of the stochastic nature of the sources. As an example, in Germany in 2017, the maximum contribution of solar photovoltaic and wind power was 55 GW while the minimum was only 7 GW – at an average national consumption rate of 60 to 70 GW. This demonstrates why for the transition towards a renewable-based power infrastructure fast-response and high-capacity energy storage systems are required to ensure a stable and economic supply. Energy storage systems allow for the increased use of renewable energy and provide ancillary services for managing the supply/demand challenges.
Existing or new build pumped storage plants are a good option for being extended by battery energy storage systems (BESS) as the techno-organisational infrastructure at the facility can be used or extended. Apart from the medium and high voltage installations with the grid interface and the corresponding control, communication and monitoring systems, experienced maintenance staff and energy trading competences are already available.
In this paper, the authors describe the grid-integration and operation of the 12.5 MW battery energy storage system with a capacity of 13 MWh installed at the Pfreimd hydro power plant group in Bavaria, Germany. The combination of the three pumped-storage units and the BESS substantially increases the flexibility of the operator's Frequency Containment Reserve (FCR, Primary Control Reserve) pool, thus offering an economic advantage through intelligent employment and integration of the technical communication network at the location.

Keywords:
Battery energy storage system, primary reserve market, frequency containment reserve

1 Introduction

Jacobsen [1] outlined that there is no technical or economic barrier to transitioning the entire world to 100 % clean and renewable energy with a stable electric grid at low cost. Nevertheless, as already seen today, with an increasing share of fluctuating renewable infeed, the dynamics and complexities in operating the power supply infrastructure increase [2-4]. Apart from pumped-hydro, network reinforcement and active distribution grid control, a further important flexibility option for mitigating the effects of volatile renewable generation getting more and more attention due to falling cost is: grid-scale battery energy storage systems (BESS).

The rapid growth of wind power and solar photovoltaic drives the need for high-capacity as well as rapid-response energy storage technologies to smoothen intermittent generation (e.g. [5]). Storage can help to limit the need for investments in grid capacity, to reduce operation costs of generation facilities and to increase the reliability of the supply. With its capability in providing a range of energy services such as grid-stability ancillary services and long-term storage, hydropower's role in renewable-based energy systems is becoming increasingly important. Pumped hydro represents the most mature energy storage technology and accounts for more than 99% of bulk storage capacity worldwide. Nevertheless, the landscape for grid-scale energy storage is evolving from being almost exclusively supplied by pumped hydro to include a number of new technologies [6].

2 Battery energy storage: Costs and market

Battery costs have fallen enormously the last years due to increased interest and deployment in storage for variable renewable energy integration. The most dramatic cost developments have been for lithium-ion chemistries, driven by the development and perspectives of the electric vehicle market [7,8]. Reference is made to Fig. 1 in which both trends are reflected.

Battery energy storage systems represent a game-changer as battery cost are expected to further drop due to the development of electric vehicles. Investment in grid-scale battery-based energy storage is ramping up quickly, having reached over US$1 bn in 2016 [10].

Due to their very fast ramping capabilities, BESS are well suitable for the participation in the Frequency Containment Reserve (FCR, "primary reserve") market. Compared to secondary and minutes reserves markets, the FCR market promises the largest benefits.

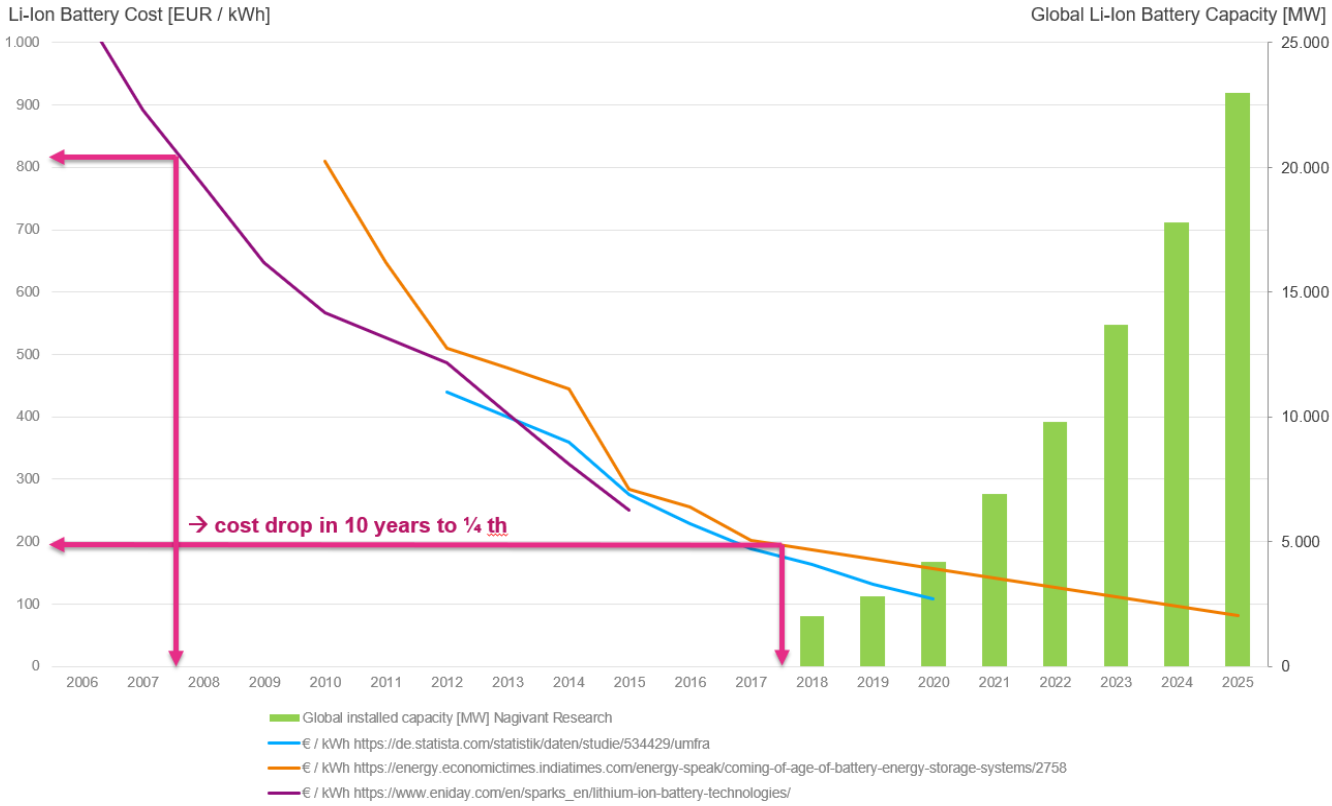

Fig. 1. Li-Ion battery cell cost drop (since 2007) and global capacity forecast (from 2018 to 2025) [9]

3 ENGIE's 12.5 MW battery energy storage system

3.1 Supply of Frequency Containment Reserve (FCR)

An innovative 13.5 MWh battery storage system was implemented by ENGIE Deutschland on the site of the Pfreimd hydro power plant group in the Upper Palatinate, Germany (Fig. 2). The existing 137 MW hydro scheme provides 5% of Germany's grid balancing energy and thus contributes to a secure energy supply. It provides grid and ancillary services comprising FCR ("primary control") of 3 times ±16 MW, automatically activated Frequency Restoration Reserve (FRR-a, "secondary control") of -75 MW to +90 MW and manually activated Frequency Restoration Reserve (FRR-m, "minute reserve") of -99 MW to +114 MW [11]. The scheme provides black start capability.

Fig. 2. ENGIE's recently inaugurated 13.5 MWh battery energy storage system

The BESS Pfreimd is operated in combination with fast-starting pumped storage units (PSU) and is mostly employed for providing ancillary services. It shows a ratio of usable storage capacity and pre-qualified FCR slightly above 1.0. According to general experience from BESS operation, the state-of-charge (SoC) of the BESS remains well balanced during regular frequency deviations of ±50 mHz. In this case, the battery storage stays in the mandatory operating range of 25-75% SoC. Outside this working range, a charge or discharge, respectively, of the storage will be necessary, thereby returning the SoC to the normal operating range.

Marketing and delivery of control reserves generally require the technical unit to be pre-qualified by the TSO. FCR capabilities can be prequalified only after demonstrating the capability to provide this ancillary service symmetrically, i.e. both positive and negative FCR, each for one hour without requiring additional charging or discharging processes.

In case of stand-alone batteries, which is not the case in Pfreimd, 25% of the control reserve capacity has to be reserved for charging and discharging processes, thus reducing the pre-qualified capacity. Both, the power electronics and the electrical network connection have to be dimensioned for 100% capacity. The 25% capacity reserve thus causes further costs which must be refinanced through a commercialization of only 75% of the maximum charging or discharging capacity. Moreover, the charging / discharging can only take place with a time lag of 45 minutes, due to so-called trading gate closure times and the quarter hour granularity of delivery times in the electricity market.

3.2 Pooling advantages

The combination of BESS and fast-reacting electricity generation and consumption pumped-hydro units opens new perspectives. At Pfreimd, three so-called ternary PSUs are installed. Each unit includes (1) a separate turbine; (2) a separate pump; and (3) a motor-generator mounted on two coupled drive shafts. This three-component design enables extremely short reaction times and a very high flexibility. Unlike so-called reversible pump-turbines, which are functioning as a pump or turbine, respectively, in opposed rotating directions, ternary units have very low minimum loads, and therefore a wide and controllable load range.

The present PSUs at Pfreimd therefore offer an advantage for the inclusion of the BESS since they can be used for charging and discharging processes. If the BESS is in a critical SoC, it can be switched to an asymmetric supply, thus only reacting to either positive or negative frequency deviations. In order to continue symmetric supply to the TSO, the PSUs take on the complementary part. This makes the need for capacity reserves for parallel charging / discharging unnecessary. The full capacity of the BESS is thus available for FCR.

Another option of the PSUs could be in altering the operating points of BESS and PSUs in opposite directions. This could be considered if the new prequalification conditions of German TSOs take effect, probably by the end of 2018. This process requires 5 minutes and has to be exchanged with the TSO in advance.

Conditions for achieving these advantages are the following:

- BESS and PSU have to be in the same so-called “balancing group”;
- the employment of PSUs has to be technically possible; usage of modern control technology included; and
- a battery management system has to be included in the power station system of the pump storage and communicate as necessary.

Outside of the regular frequency area, in case of a frequency deviation of ±100 mHz for over 5 minutes or a frequency deviation of ±200 mHz, the BESS will almost inevitably leave the normal operational range and will possibly have to be taken out of the supply pool. Another prequalified technical unit in the pool, being reserved for backup purposes, will take over the delivery.

This presents another advantage of Pfreimd: The pool for FCR is increased by the BESS, but supply is ensured by the PSUs and no further, additional units are required.

4 Evolution of the IGCC Frequency Containment Reserve (FCR/R1) market

In Germany, the provisioning of FCR power had been realised by each TSO separately until 2007. Since then the four German TSOs have set up a common market platform which is known as “regelleistung.net”. The common provisioning enables a larger pool of suppliers and potential cost reductions. With the aim of enabling further synergies in the common provisioning of FCR, also TSOs from neighbouring countries have joined the market which is now called the International Grid Control Cooperation (IGCC). In 2014, the Dutch TenneT joined the common auctioning platform followed by the Austrian and Swiss control power markets in 2015, the Belgian Elia in 2016 and just recently the French RTE in beginning of 2017. Furthermore, the Danish TSO energinet.dk is expected to join the soon. With a total tendered FCR capacity of approximately 1,400 MW the IGCC represents the largest FCR market in Europe. The IGCC realises the auctioning of the tendered FCR capacity in a pay-as-bid procedure.

The largest individual demand for FCR is still from Germany (620 MW in the beginning of 2018) followed by the France (550 MW). Another 80 MW are required by the Netherlands, further 70 MW by Switzerland and 60 MW by Austria. Belgium has weekly varying demands on the IGCC FCR market of some 25-55 MW [12-15].

Fig. 3 shows the evolution of the FCR market for the period 2014 to 2018. The FCR demand increased from 630 MW in 2014 to approximately 1,400 MW at the end of 2017 (dashed line). The increase in FCR demand goes together with an increase in supply due to the geographic extension of the market. However, the weekly auction results of the marginal capacity price (straight line) show a slightly decreasing tendency.

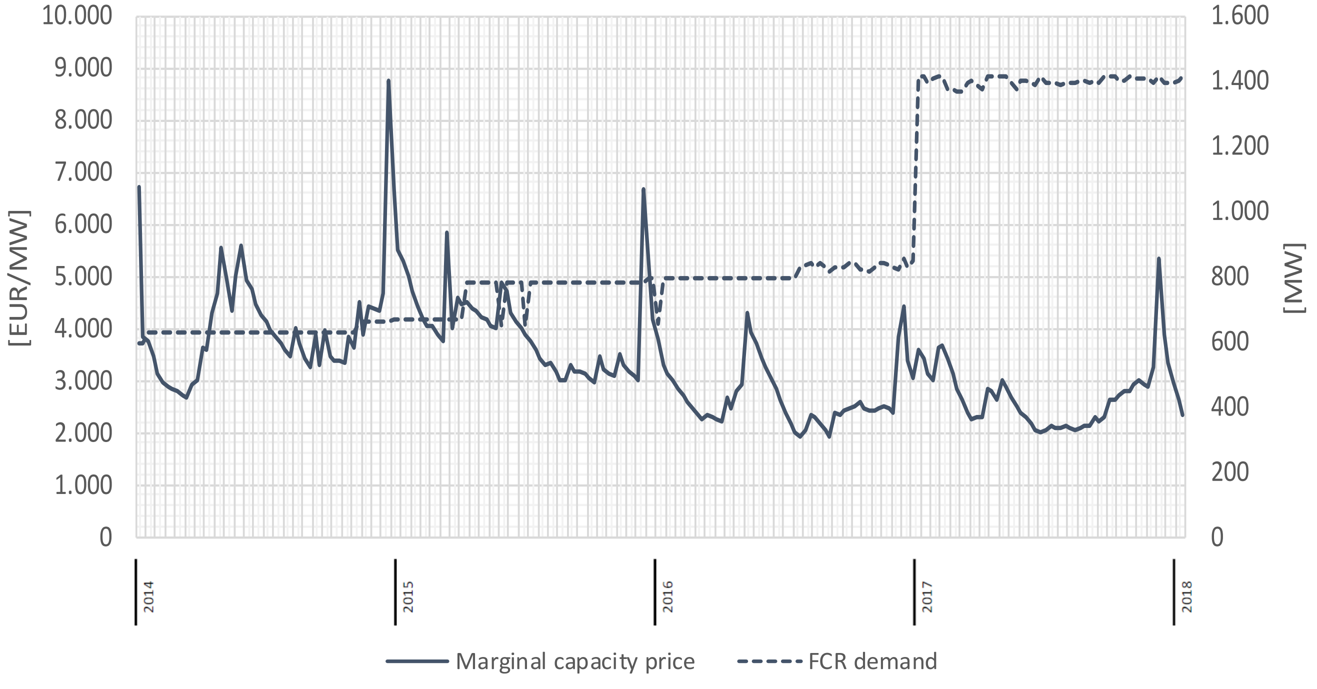

Fig. 3. Evolution of the IGCC FCR market from 2014 to 2018 [9]

The common sourcing of FCR capacity by European neighbouring countries leads to cost synergies reflected in lower marginal prices. In particular, through the joining of the large French RTE in the beginning of 2017 the market prices have come down, most probably triggered through the inclusion of (subsidised) cheap nuclear power plants. The market is characterised by some annual periodicities with peaks at the end of the year, mostly in the week of and after Christmas as essential power plant capacities are maintained in this period which leads to shortage in supply.

5 Conclusion

The dynamics and complexities of the operation of power systems are rising due to the transformation of the power systems towards renewable based generation, which are, to a large extent, subject to volatility. As a consequence, flexibility gains more and more importance in the operation of the power infrastructure.

Battery energy storage systems are characterized by their fast-ramping capabilities and are thus ideally suited to stabilize power grids with high renewable energy infeed, as generation/demand fluctuations can be compensated locally, limiting grid reinforcement measures which would otherwise be necessary. BESS are predominantly operated to provide FCR ("primary reserve") because of their very fast electro-chemical behaviour with response times in the range of milliseconds. In the beginning of 2018, in Germany around 180 MW of BESS are active on the FCR market. However, for their standalone deployment for FCR, BESS have low levels of energy capacity. PSP can provide FRR-a ("secondary reserve"), which represents a valuable contribution for the flexibility of the power system.

Existing or new build pumped hydro schemes provide the potential for being extended by container-based BESS as the techno-organisational infrastructures can be shared. Apart from the technological infrastructure (high voltage installations with grid interface as well as the control, communication and monitoring systems), the required marketing and energy trading competences are already available. BESS and PSP are natural partners, combining fast ramping functionality (battery energy storage) and high storage capacity (pumped-hydro).

The combination of the three pumped-storage units and the BESS substantially increases the flexibility of the operator's primary control Reserve pool, thus offering an economic advantage through intelligent employment and integration of the technical communication network at the location. By pooling of PSP and BESS, the control aggregate can make use of two features: fast ramping by batteries and large autonomy of pumped hydro. Today, BESS presents a mature technology with over 500 MW in operation.

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