BATTERY SYSTEM AS A SERVICE FOR A DISTRIBUTION SYSTEM OPERATOR

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ABSTRACT

Benefits of battery systems in the distribution networks have been widely identified, but current regulation model prohibits the distribution system operators (DSOs) from owning and operating these systems. This paper presents a novel business model where an aggregator company makes the investment to the battery system and offers the system as a service for the DSO.

This business model, and related different revenue streams and cost savings required to make the business case viable, are defined in this paper. The suggested model creates a market place for the DSO, where they can purchase reservation time from the battery, which enables them to technically and economically benefit from the battery system. This service and business model are compatible with the current regulatory environment.

INTRODUCTION

One of the main tasks that distribution system operators (DSO's) have is to ensure the security of supply to electricity customers within their networks. Current developments in renewable energy penetration and increasing utilization of electrical vehicles (EVs) are globally increasing the need for stronger, flexible and more reliable distribution grids.

As a result of lower lithium-ion (Li-ion) battery prices [1], batteries have become one reasonable solution to improve the supply reliability of the branch lines of the medium voltage (MV) network in the rural area. The battery system also enables management of peak loads, reactive power compensation and other DSO level services (see for instance [2]), and thus reduces the potential network reinforcement needs of the future (due to, for example, solar panels and EVs).

However, as these batteries could be used to provide also services in the electricity and balancing markets there has been significant controversy whether the DSO should be allowed to purchase, install and operate these batteries. One of the main topics in the discussions (e.g. in the Clean Energy package by the European Commission) is that since DSOs are highly regulated monopolies, they should not be allowed to participate to unregulated electricity markets. Additional challenges arise, as in some area's DSOs are still vertically integrated to electricity supply business [3].

This paper presents a technical concept and a business model, in which the battery is offered as a service (service level agreement, SLA) to Elenia (a Finnish DSO). The underlying concept is that both the occurrence and duration of the DSO's needs for the battery are very limited. Rest of the time the owner of the battery, in this case Fortum (a Nordic energy company), would be able to utilize the battery in other applications, such as primary frequency regulation service – frequency containment reserves (FCR), offered for the national transmission system operator (Fingrid). This combination allows actors to build a positive total business case in relation to current Li-ion prices. Anticipated revenue streams are two folded; 1) market income from the primary frequency regulation, and 2) the reduction in DSO's regulatory outage costs (ROC).

Novelty value here lies in new kind of business concept, which incorporates the value of a single battery storage from two different applications. Our work (and this project) aims to show that such a project can be economically and technically feasible and fully compatible with the current regulatory framework.

Structure of the Paper

Introduction chapter of this paper offers motivation and background for the paper. A short description of the battery system's design and placement within the DSO's network is given in Chapter 2. Two main applications are described in Chapter 3. Chapter 4 explains the basics of the business model. The principle of usage is described in Chapter 5. In addition to a novel business model, the major contribution in this paper is the final discussion chapter, providing insights on how the concept developed in the project can be used to form a DSO-level service market within the boundaries of current regulation.

BATTERY INSTALLATION LOCATION AND DESIGN

Location

As the DSO's benefits in this project are solely dependent on the local grid needs such as ROC avoidance, finding an optimal place for the battery system in the DSOs network was crucial for making a positive business case for this project. Several individual LV-networks were studied, but the ROC reduction estimations from those networks were not enough (with current battery system prices) to make a viable business case, even with additional revenue from primary frequency regulation. The costs of the battery, its grid connection and the components enabling the island use are too high compared to the ROC avoidance of one LV network.

Battery system was decided to the be installed in medium-voltage grid. The location was selected to be 31 kilometres from the supplying primary substation and at the start of a MV-branch feeding electricity to several LV-networks. This offered significantly better ROC reduction potential over LV-network installation as benefits from multiple LV-networks could be combined.

In addition, these LV-networks have been subjected to several interruptions and the related ROC history is well known by Elenia. These types of costs have been also previously discussed in other publications co-authored by Elenia personnel such as [4] [5].

Battery system design

The designed battery system consists of battery packs, a power conversion system (PCS) (i.e. a grid-tie DC/AC converter system) and a management system. To connect the battery system to the MV-network and to have it perform the required operations in accordance to local regulation a MV/LV transformer, MV-breaker and related protection equipment are also required. The battery is synchronised with the AC grid by the grid-tie converter. The MV breaker is controlled by a protection relay that includes a synchronisation check function. This prevents asynchronous interconnection in case of a failure in the control system of the grid-tie converter. Figure 1 shows the main components of the battery system and the point of connection (PoC) of the battery system in relation of the MV branch and the LV networks downstream. Ownership lines are also illustrated in the Figure. Basically, the concept is that the DSO offers the service provider a DC-grid connection and invests to the components to enable that connection. The service provider procures and installs a DC battery system to the defined connection. Figure 2 shows a picture taken from the battery packs to be installed.

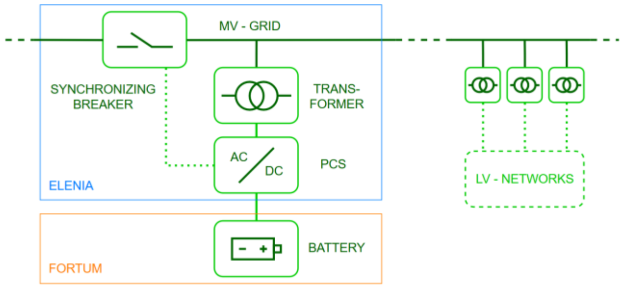

Figure 1, Conceptual drawing of the battery system and ownership lines

Figure 2 Picture of the battery system

Main design characteristics

The decision to connect the battery system to MV-grid over LV-network caused several design challenges mainly related to automatically islanding and resynchronisation the MV-branch downstream from the PoC, electrical safety, environmental conditions at installation site, and implementation of the multi-objective control. In relation to islanding, a major design point was to ensure that the battery system could supply enough short circuit current while the branch is isolated from the rest of the network. The short-circuit current is limited by the PCS and thus has to be fully controlled to prevent converter failures. In addition to current limitation also the duration of supply is controlled based on the identification of the fault type. To ensure the safety, the entire system will be stopped in case of a fault within any of the end-user's installations if the protection of the end-users installation does not operate within the required time. Several network simulations were performed to evaluate the required short circuit current capability and to ensure that even the furthest fuse could be tripped according to local regulation in an isolated state.

In addition to the short circuit capability, the basic battery system parameters such as power and capacity needed to be sized to fulfil the desired operations. The output power of the system was sized to meet the combined peak power of the LV-networks downstream with sufficient margin. Battery systems capacity was a compromise between ROC reduction and cost of the battery system (i.e. the more energy the system has, the longer interruptions it can handle, but battery system costs are heavily affected by capacity).

To enable ease of usage for Elenia, the MV-network equipment was designed to enable the battery system to island the downstream network autonomously and in the longer run to synchronize and reconnect the islanded part to the grid without operator interactions once the upstream failure has been cleared. The PCS control system and the local protection system must operate seamlessly together to enable both automatic and rapid initiation of the island operation as well as uninterruptible resynchronisation of the islanded branch with the rest of the power system. The latter requires active control of the phase sift, frequency and voltage of the island with respect to the power system in the PoC.

During the power system interconnected operation, the PCS will participate in distribution network Volt-var control. It will control both the reactive and active power flows according to the applied control strategy within the boundaries of system temperatures and current limits as well as in the limits due to PoC and battery pack voltages. Thus, multiple overlaying and parallel control loops have been implemented.

APPLICATIONS

During the initial phase of the project, it was found out that in order to reach feasible business case, several revenue streams or cost saving applications would need to be combined, since a single application such a primary frequency regulation or frequency containment reserve (FCR) usage would not be economically feasible. This finding is supported by similar results of other researchers [6]. This is also one of the reasons why such a co-operation model has been selected for further studies.

Elenia's main application for the battery system was identified to be the reduction of the customer interruption times and thus reducing ROC.

From Fortum's point of view, the main application for the battery system will be primary frequency regulation. The market name for this type of service is frequency containment reserve (FCR) in the Nordic power system.

Regulatory Outage Cost (ROC) avoidance

Financial regulation of DSOs in Finland is based on the Electricity Market Act [7], in which is stated that pricing of the DSO's should be reasonable. Foundation of this financial regulation is the calculation of reasonable returns; regulatory asset base is present value of distribution network and Energy Authority define the reasonable return on capital based on WACC (Weighted Average Cost of Capital) method. ROC has impacts on the quality adjustment of the regulation model, and it can increase or decrease the DSO’s reasonable return up to 15% [4]. ROC parameters are presented in table 1.

TABLE I. REGULATORY OUTAGE COST PARAMETERS (I.E. UNIT PRICES) FOR 2018 IN FINLAND [4] [7]

Unexpected interruption		Planned interruption		Delayed Automatic Reclosing	High---speed automatic reclosing
€/kWh	€/kW	€/kWh	€/kW	€/kW	€/kW
13,44	1,34	8,31	0,61	1,34	0,67

Figure 3 sums up the proportional size of different interruption types and durations and their effect to ROC in Elenia's network [4]. Figure shows that a significant portion of the ROC costs occur from interruptions with short to medium duration. These interruptions are the ones that the battery system is designed to limit. As the battery system will not be used as an uninterruptible power source (UPS) (i.e. all the downstream power will not be fed through it) it will not be able to react fast enough to limit the high-speed automatic reclosing (HSAR) related costs. However, the system limits the delayed automatic reclosing (DAR) and longer interruptions. Also, the battery system will have limited energy capacity and thus it will be unable to handle the longest of interruptions. The average time that the system is capable to maintain the island mode is approximately 3 hours based on the average power of the MV-branch.

In addition to the ROCs, the Electricity Market Act defines strict maximum duration limits for outages, 6 h within urban areas and 36 h outside of them, which DSOs have to meet in their entire area of responsibility by the end of 2028 [7]. The battery system will limit the blackout durations experienced by the consumers, and effectively give Elenia more time to solve the issue in their networks.

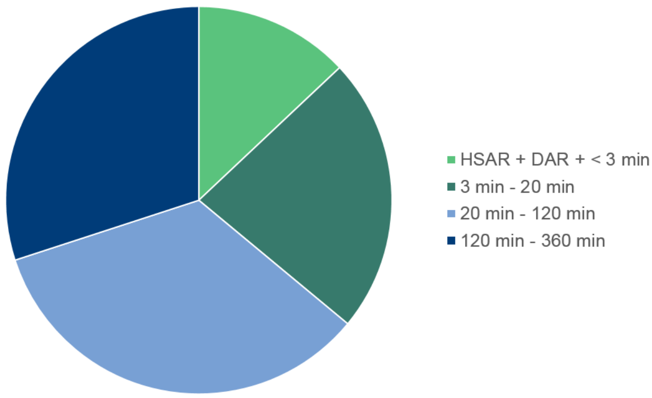

Figure 3 Total ROC per different interruption durations [4]

Frequency containment reserves

Frequency containment reserves are primary frequency regulation tools that are automatically activated when frequency deviates from nominal limits. National transmission system operators are responsible of upholding or acquiring their reserves from the markets. There are currently two types of primary reserve with in the Finnish markets, called frequency containment reserves for normal operations (FCR-N) and frequency containment reserves for disturbances (FCR-D) [8]. Li-ion batteries are technically suitable for both of these markets, but FCR-N is by far economically more interesting, at least in the current market environment.

When participating to FCR, the asset owner / operator makes an agreement with the Fingrid to adjust the power production or consumption of the asset based on the grid frequency. FCR-N activation requirement is illustrated in Figure 4.

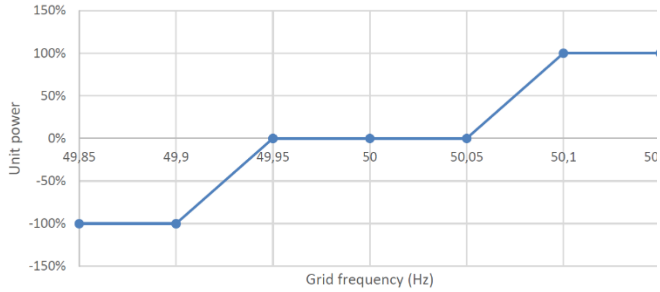

Figure 4 Operation of a reserve unit in primary frequency regulation according to minimum frequency requirements by Fingrid [8] [9]

These reserves are acquired from hourly and yearly markets, the related average prices for the years 2013-2017 are presented in Table 2. Achieved market revenue depends on the hourly / yearly price, bid acceptance and availability of the resource.

TABLE II. AVERAGE HOURLY AND YEARLY PRICES FOR FCR-N BETWEEN 2013 AND 2017 [10]

	Average hourly price [€ / MW / h]	*Yearly price [€ / MW / h]*
2017	20,87	13,00
2016	16,80	17,42
2015	22,32	16,21
2014	31,93	15,80
2013	36,33	14,36

BUSINESS MODEL

In the upon agreed business model (Figure 5), Elenia invests in the equipment related to grid protection and islanding. Fortum makes the investment to grid connection and to the battery system. Fortum then offers the battery system as a service to Elenia with a fixed annual service cost. In addition to the fixed service cost, Elenia can purchase reservation time with a fixed hourly price.

Fortum will receive revenue from the services fees paid by Elenia. These fees include the service level agreement (SLA) related payments (for the battery-as-a-service) and the reservation-based fees. In addition, Fortum will get revenue from Fingrid from the FCR services the battery system is used to provide.

Elenia will get ROC savings from reduced amount and duration of serviced interruptions experienced by the electricity consumers in the LV-networks downstream the PoC.

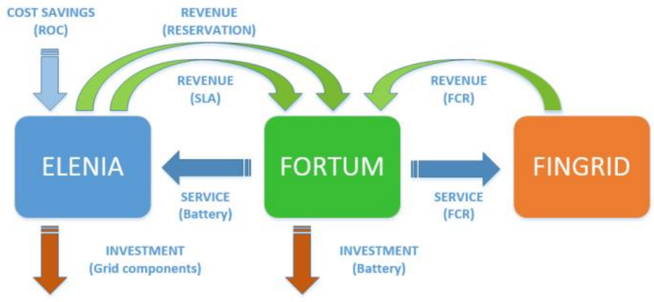

Figure 5 Simplified business model illustration

PRINCIPLE OF OPEARTION

During normal operations Fortum will offer the battery system and its capacity to the hourly FCR-N markets. In the case of a grid failure upstream of the PoC, the related automation and protection equipment will isolate the MV-branch downstream from the PoC and the remainder battery capacity will be used to supply the island network. However, as the battery system will be constantly offered to the FCR-N markets the momentary state of charge (SoC) of the battery system depends on the grid frequency behavior. For this reason, Fortum won't guarantee any capacity for this application. Historically the frequency behavior in the Nordic frequency area has been quite stable and long lasting downwards activations of FCR-N (that would totally deplete the battery capacity) have been relatively infrequent, so there is a high statistical likelihood that there will be at least some energy in the battery system in the case of an unexpected service interruption upstream from the PoC.

However, the co-operation model is designed to give Elenia an option to purchase reservation time. For example, in the case that Elenia has reviewed a notification on potential grid disturbance such as storm fronts etc. they can issue a request for reservation. Fortum will then recharge the battery and seize any operations to the battery. Basically, ensuring that the battery system will be at full SoC ready to supply energy to downstream customers to minimize the effects of the grid disturbances to the end users and simultaneously limiting the ROC. Most of the interruptions occur during exceptional weather conditions, so the timing of interruptions is reasonably well predictable.

DISCUSSION

As described in the article, DSOs (along other actors in the electricity systems) have identified that battery systems could provide them technical and financial benefits. Especially if the battery systems price development continues as it has been forecasted by several analysts (including [1] [11] [12]). However, due to the specific and regulated role of the DSO's, owning and operating battery systems can be interpreted as something that could distort the energy markets. Current regulation states that the DSO cannot own the batteries, but it can buy the services of battery capacity from the market.

The suggested business model answers to that need. In the model Fortum can make a commercially viable business case to own and operate the battery system and also to offer its services to the local DSO.

The model creates a market place for the DSO to purchase backup power services, enabled by the battery system, without participating to the energy markets as such. This model allows DSOs to utilize the battery that is also used in the electricity market (by Fortum). Thus, the battery can be utilized as efficiently as possible thereby improving the cost efficiency of the battery system. This makes the model profitable for both Fortum and the DSO.

While the model relies currently heavily on the market revenue from primary frequency regulation and ROC these are not the only revenue streams that have been identified to be accessible during the lifetime of the battery system. Feasibility of other (DSO and TSO) level services, such as reactive power compensation in the DSOs network, will be investigated later in the project.

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