MULTI-OBJECTIVE ROLE OF A BESS IN AN ENERGY SYSTEM

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ABSTRACT

The key research objective in the paper is to optimize the operation and control of a single battery energy storage system (BESS) for multiple tasks and reveal a possible conflict of objectives between the stakeholders. The methodology to schedule the BESS for day-ahead and intra-day markets is presented together with an algorithm to define an optimal priority order of the multiple tasks assigned to the battery. The methodology is applied to a case example, where a single BESS unit is installed on a MV customer's premises and participates in four tasks. The results show that with the present market prices in Finland, the first-order priority is on the frequency regulation task. However, a battery can also execute some local grid tasks such as reactive power compensation with only minor conflict of objectives. Conversely, there may be a conflict with the other local tasks such as peak shaving.

INTRODUCTION

The undergoing changes in the energy sector emphasize the role of a BESS in an energy system. An increasing share of renewables, changes in consumption patterns in the residential sector, and tightening requirements for the reliability of supply require more flexibility at all voltage levels of the power system. Owing to the unique characteristics of a battery energy storage, such as capability of working in both the generation and load modes, fast and precise response to the control signal, capability of providing reactive power services (both supply and consumption), and relatively high efficiency, it is suitable for numerous applications.

In the literature, special attention has been paid to the use of a battery for multiple services. Various optimization methods have been implemented to co-optimize BESS operation for two applications, for instance frequency regulation and the peak shaving task [1], frequency regulation and energy arbitrage [2], [3], and multiple services [4]. To further develop the previously done research [5] , this study seeks to develop a decision-making tool that defines the optimal priority order of multiple applications and allocates the BESS capacity to them. In order to do this, the relationship and interference between the applications has to be analyzed and understood.

METHODOLOGY

A methodology was established to operate a single BESS unit for multiple services. It contains planning (Figure 1) and operating phases (Figure 2) and a decision-making platform that defines the conflicting tasks and sets their priority order.

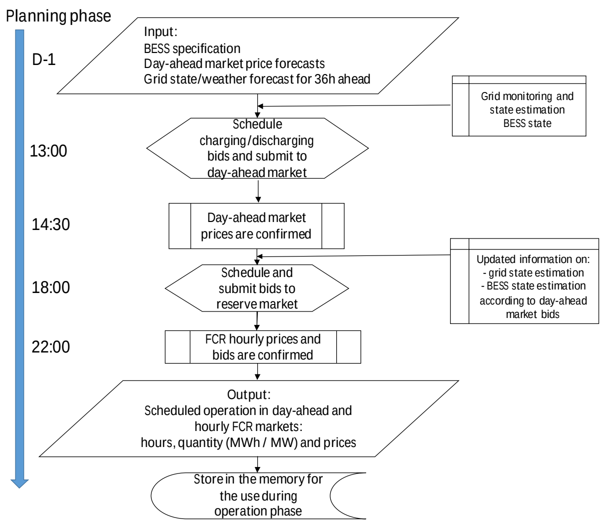

Figure 1 A planning phase of a BESS scheduling for day-ahead markets [6]

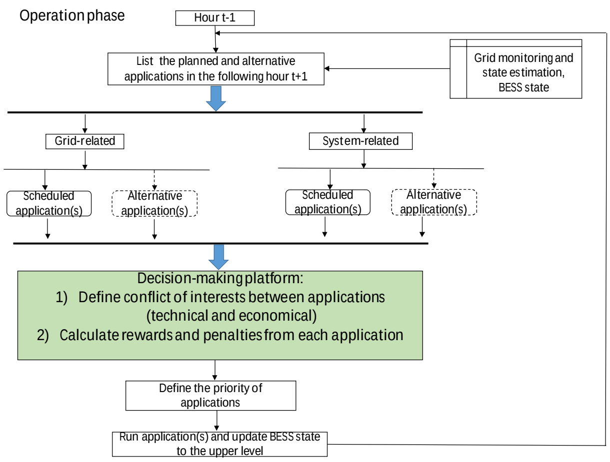

Figure 2. An operating phase of a BESS scheduling for multiple tasks (an intra-day market and grid tasks in addition to a day-ahead market) [6]

CONFLICT OF OBJECTIVES

The conflict of objectives between the stakeholders arises when the execution of one task sets limitations or totally prevents the execution of another task. There is a BESS operator who may be the BESS owner, an aggregator, a retailer or some other third party. The operator serves as a service provider for multiple stakeholders such as the TSO, the retailer, the DSO and the end-customer (Figure 3). Each of them has interests of its own, which are developed further into tasks or service requests for the BESS unit. The BESS operator then decides, which of those tasks and what kinds of combinations deliver the highest profit. The BESS operator serves as a trigger to activate the resource to provide the services. Within this manifold context, the regulatory framework and the market design play an important role in the decision-making process.

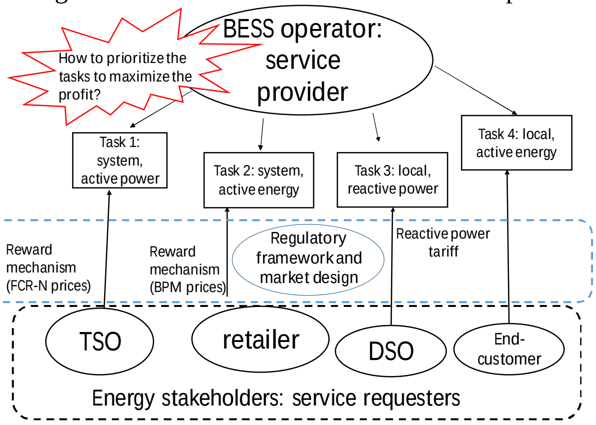

Figure 3 Regulatory framework between service requesters and providers

The conflict of interests may be either technical or economic. A technical conflict means that the BESS capacity is limited because of the capacity allocation to the higher prioritized task. An economic type of a conflict means that there is a limitation on providing the service because of insufficient reward obtained from it. When two or more tasks are executed during the same time, a conflict may occur depending on the service requested. The relationship between tasks is conflicting or non-conflicting depending on the grid and system-level state and the reward level. Each of them may request a battery to provide an active and/or reactive power and/or energy in either charging or discharging direction. In a case a battery resource is required in the opposite directions during the same hour, a conflict of objectives occurs. In an opposite case, when a battery resource is required in the same direction, there is a question of how to fairly reward the services.

PRIORITY ORDER

The priority order in which multiple tasks are executed is defined according to the established logics presented in Figure 4. The outcome of the algorithm is the selected priority order that yields the highest reward to a BESS operator. The tasks are compared in pairs, and checked for technical and/or economic conflict according to the market prices and type of service requested.

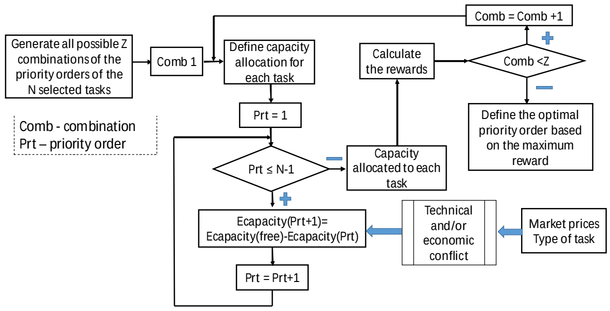

Figure 4. Algorithm to select the optimal priority order of the tasks

The priority order may be specified on the hourly, daily and annual basis. The hourly priority setting means that two or more tasks are executed simultaneously during the same hour and the capacity allocation is defined. This is valid for the tasks, which are not competing with each other technically, such as active power and reactive energy tasks.

The daily setting means that the tasks have technical conflict and therefore cannot be run during the same hour. Then, it is required to know in which hours the BESS capacity should be allocated solely for one task and in which hours for the other task.

The priority order of tasks may change throughout the year according to the varying market prices, the grid state (need to carry out grid tasks), and tariffs.

CASE EXAMPLE

The methodology was applied to a 600 kWh/1.2 MW BESS unit located in Suvilahti, Helsinki [5]. Two system-level and two grid-level tasks were assigned to the BESS:

- primary frequency control in the FCR-N hourly market (system, active power)
- energy arbitrage in the example of balancing power market (system, active energy)
- reactive power compensation (RPC) in a distribution grid (local, reactive power)
- peak shaving on an end-customer's premises (local, active energy)

The reasons for selecting these specific applications for the analyses are the following:

1. The battery is underutilized when used only for frequency regulation service, which is a power-intensive application.
2. Due to the increasing rate of cabling in the distribution networks, combined with the changes in the reactive power usage of end customers (less consumption, more generation), reactive power infeed from the distribution network to the transmission network has increased. Therefore, starting from 2017, the TSO in Finland introduced

a reactive power tariff for exceeding a reactive power window. This creates a strong motivation for the DSOs to investigate in feasible reactive power compensation tools, BESS being one of the candidates.

3. A combination of various types of applications for BESS such as an active power-intensive (frequency regulation), an energy-intensive (energy arbitrage, peak shaving), and a reactive power-intensive one (RPC) is of interest to the BESS operators (multiple revenue streams) and involved energy stakeholders.

The data used in the simulations comprised publicly available frequency data from Fingrid and electricity market prices in Finland from Nord Pool as well as reactive power compensation needs on an hourly basis of the local distribution network in 2016.

The reactive power tariff was introduced by the Finnish TSO Fingrid and has for year 2018 a reactive power fee of 666 €/Mvar, month and a reactive energy fee 5 €/Mvarh.

Assumptions

The following assumptions were applied in the simulations:

- The analyses are done based on the historical hourly grid and market data in 2016, and thus, uncertainty is not considered.
- The PQ curve of the BESS unit in Suvilahti was assumed to be ellipse-shaped (Figure 5)
- The degradation rate of BESS power electronics has not been taken into account.

The initial parameters of the frequency regulation task were: reaction time 2 s, droop slope 0.1%, and frequency dead band ±0.05 Hz. The billable reactive power was defined according to the reactive power window of the case distribution grid.

RESULTS

The results indicate that with the present market prices and the grid active and reactive power tariff, the optimal priority of the tasks is arranged in the following order: FCR-N hourly market, RPC, and peak shaving. Energy arbitrage application did not get any priority owing to the high cost of the BESS-unit and an insufficient price volatility in the balancing power market.

Frequency regulation vs energy arbitrage

The results indicate that the priority should be set to the active power rather than the active energy task because of the higher reward level. However, there is not only an economic but also a technical conflict; a battery storage must have energy capacity needed to provide the bid power for 30 min. This requirement sets limits on the energy capacity available for the energy markets.

This means that the BESS should not participate simultaneously in the FCR-N hourly market and the balancing power market with the present market prices and rules. However, if the capacity requirement is adjusted to 15 min, the opportunity to participate in the balancing power market is higher.

Frequency regulation vs RPC

The results showed that the most beneficial operating strategy for a BESS operator is to set the priority of the frequency regulation task over the priority of the RPC task, which is the order how it is presently working [5] .

The present requirements of the Finnish TSO Fingrid state that the bid power should be linearly reached within a 3 min activation time in the FCR-N market. Based on the year 2016, there is no or a minor technical conflict when the frequency regulation task is given priority 1 and the RPC task is given priority 2. The RPC task can be carried out by the BESS to the full extent absorbing 900 kvar from the grid, except for only a few hours a year when the active power exceeds 0.8 MW. The values 900 kvar and 800 kW threshold result from the PQ curve (Figure 5). The green cut circle represents the normal operation of the BESS whereas the red circle represents the maximum operation limit. As it can be seen from Figure 5, during the normal operation, the maximum reactive power consumption/production cannot exceed ±900 kvar. The radius of the green circle is equal to 1.2 MVA.

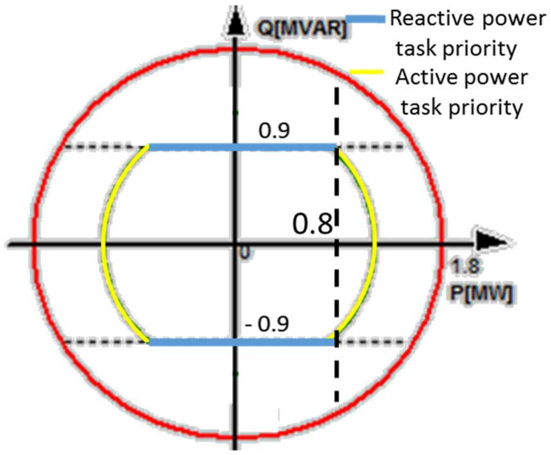

Figure 5. Operating area in the PQ-curve according to the priority of the tasks

Even during the hours when the active power exceeds the 0.8 MW threshold, it has only a minor impact on the hourly reactive power energy consumed by the BESS. BESS participation in the RPC task delivers significant savings to the DSO (up to 1600 €/month decrease in the reactive power bill).

The impact of reactive power on the active power availability, and vice versa, depends essentially on the PQ curve. Various PQ curve shapes could be considered in the future research. The impact of active power on the availability of reactive power depends not only on the PQ shape but also on the frequency quality and the operating parameters in the frequency regulation task (such as activation time).

Frequency regulation vs peak shaving

Peak shaving (and load smoothing) is an energy-intensive task, whereas frequency regulation is a power-intensive one, however requiring energy capacity according to the market rules. These two tasks may or may not be conflicting with each other depending on a number of factors. A technical conflict occurs if the amount of energy needed to cut the peak is large enough to limit the battery participation in the FCR-N hourly market. The conflict also occurs if the battery participation in the FCR-N hourly market impairs the peak shaving task and that way increases the power fees. Eventually, the BESS activity in the frequency regulation task may increase the peak powers and thus the power fees.

Both economic and technical conflicts depend not only on the services requested from the two tasks, but also on the reward mechanism for the end customer's peak shaving service. Presently, the reward mechanism is the power fee of the tariff in €/kW/month, which is charged according to the highest monthly hourly peak power value. However, the interference of the frequency regulation task with the peak shaving task gets even more significant if possibly in the future the time resolution of the billable active peak power changes (from hourly to the half- or quarter-hour mean power values).

The main question is to determine whether it is economically profitable to carry out a frequency regulation task and a peak shaving task within a selected power band of the end-customer. The power fee is nowadays charged from the large MV and LV customers, however it is also coming for the residential customers in the near future. In this regard, there may be two business cases: 1) BESS executes the peak shaving task locally on its premises; 2) BESS executes the peak shaving task of the LV customers, who order the peak shaving task from the BESS operator.

Already rough estimations show, that it is economically beneficial to use BESS for peak shaving in the LV (low voltage) network rather than in the MV (medium voltage) network. There are two major reasons for this:

1) the power fee size is increasing the further in the network the end-customer is located due to the larger share of network behind the customer. To compare, a 110 kV customer's power fee is 1.25 €/kW/month and a 10 kV customer's power fee is 4.15 €/kW/month.
2) the peak operating times tend to decrease with the decreasing voltage level and size of customer, which means that the energy required from BESS (and hence operational costs) to cut peak power is much smaller in the LV compared with the MV network.

Even though the tasks are allocated to different hours, they may still be conflicting with each other indirectly. The BESS SOC (state-of-charge) level may be saturated to the lower or upper level after the peak shaving task, and hence, be unavailable to provide the promised power bid to the FCR-N hourly market within the pre-defined power band. On the other hand, the Finnish TSO Fingrid is developing the restoration rules for the battery participating in providing primary frequency regulation, in case BESS resource saturates to the upper or lower level. This may improve the opportunity for BESS to participate in the peak shaving and other energy-intensive tasks.

CONCLUSIONS

At the present moment, the most rewarding application is a power-intensive system service such as the FCR-N hourly market. However, distribution grid-level tasks are also competitive. The right priority of tasks that delivers the maximum profit to a BESS operator is sensitive to the system market prices and rules, as well as the needs of the local distribution grid. More analyses should be carried out to define the optimum priority of tasks.

ACKNOWLEDGEMENTS

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