FEASIBILITY STUDIES OF END-CUSTOMER'S LOCAL ENERGY STORAGE ON BALANCING POWER MARKET

Nadezda Belonogova, Juha Haakana, Ville Tikka, Jukka Lassila, Jarmo Partanen
LUT School of Energy Systems, Lappeenranta University of Technology
Lappeenranta, Finland
nadezda.belonogova@lut.fi

ABSTRACT

The objective of the paper is to develop an algorithm to estimate the profitability of energy storage operation in the balancing power market. The main reasons for this study are the fast growth of the PV battery market in the residential sector in the coming years and, at the same time, challenges related to the integration of huge amounts of renewables into the grid. The paper focuses on a single residential customer's battery storage operation. It shows that using the storage for the local services such as peak shaving, maximization of self-consumption using PV modules and operation on the spot price arbitrage turns out to be too expensive because the storage is then underutilized. The results show that the operation of a battery unit in the balancing power market as part of a virtual power plant not only delivers high profits but also ensures the profitability of the battery operation also for the local primary applications. .

INTRODUCTION

The rapid growth of the residential solar PV market has boosted the energy storage market. Not only distribution system operators (DSO) but also small end-customers are getting interested in local battery storage solutions [1]. An energy storage can limit the locally generated power output into the grid. This can deliver many benefits to both the DSO and the end-customer.

On the utility scale at the high-voltage (HV) level, the increasing amount of intermittent renewables will require additional balancing power and frequency reserves to maintain the frequency and keep the grid stable. The forecasting errors increase the trading volumes through the intra-day and balancing power markets. Moreover, the intermittent nature of renewables increases the volatility of the market prices, which provides promising opportunities for market participants to earn by price arbitrage.

The increasing penetration of energy storages in the residential sector and their use for balancing power and frequency regulation purposes will allow the substitution of a significant part of expensive and polluting spinning reserves. This, again, will cut greenhouse gas emissions.

There are high expectations for residential PV battery systems among the stakeholders, but still, it is not clear what benefits they will provide to the owners of such systems. Further questions are: Will they be used too often or too little, what is their cost-benefit ratio, and will their operation be profitable at all when used simultaneously for multiple tasks.

The fact today is that an energy storage is not profitable when used only for peak load cut or as a solar PV generation storage. In this case, the cost of use is higher than the savings [2]. Therefore, a valorization model has to be found for the battery energy storage that will reveal the revenue streams to guarantee the profitable operation of the storage. Previous research has mainly shown results either on utility scale storage operation in the balancing power market [3] or on the operation of residential storage in spot markets [4]. This paper covers the gap and introduces the novel opportunities for the residential energy storage operation in the balancing power market.

The main objective of the paper is to analyze and assess the value of an energy storage for a single residential customer in the balancing power market through price arbitrage. It is assumed that the customer has solar PV on the premises. The global question is how the energy storage has to be operated so that it meets its primary target to maintain the reliability and security of supply in the highly intermittent generation environment, and at the same time, delivers financial remuneration to the customers.

APPLICATIONS OF RESIDENTIAL BATTERY STORAGE

The primary and secondary applications of the energy storage operation are described in this section.

Primary applications

This section provides feasibility studies of energy storage operation for such applications as peak cut, self-consumption maximization, and spot price arbitrage.

The storage is considered to be underutilized or fully utilized if the annual amount of energy is less or more than minimum annual stored energy in the battery:

$$\mathrm{E}_{stored\_min} = \frac{\text{Total stored energy over the lifetime(kWh)}}{\text{Lifetime(years)}} \quad (1)$$

Annual calendar aging cost of use is calculated

$$Cost_{calendar} = \frac{\text{Total Investments}}{\text{Lifetime(years)}} \quad (2)$$

Assuming a battery of 7 kWh capacity, the minimum annual stored energy (1) and the corresponding calendar aging cost of use (2) can be calculated for the different battery types. Table 1 lists the results.

TABLE I. PARAMETERS OF BATTERY TYPES

Cost €/kWh	Ncycles	price, €/kWh	Estored_min, kWh	$Cost_{calendar}$ €/a
1000	2000	0.56	1260	700
725	3000	0.27	1890	507,5
640	3000	0.24	1890	448
860	3285	0.29	2069.55	602
1230	5000	0.27	3150	861
620	5000	0.14	3150	434
520	5000	0.12	3150	364
1500	10000	0.17	6300	1050

Charging from PV

The battery storage is charged from the excess solar PV generation and is later discharged into the loads.
The amount of excess PV generation depends on the PV size, solar irradiation, and load type.
The main idea is that when there is excess energy generated by solar PV panels, the energy storage will be reserved for that purpose and is not available for the other applications. However, if the peak cut need arises during that moment, there is less or no need at all to use the battery for the peak cut purpose. Instead, the peak power can be cut directly by the customer's own solar PV generation. In this case, the energy storage can be operated against other applications such as spot market or balancing power market. The amount of annual energy stored from solar PV is less than the minimum annual stored energy, and therefore the battery is underutilized if used only for PV excess generation storage.

Peak Cut

As customers become more independent of the grid energy supply with PV battery systems, the retail tariffs tend to become more capacity based to compensate for the lack of energy-based income to the DSOs. This, in turn, gives a motivation for customers to keep their consumption under a predefined power level, and therefore, an energy storage will be of high importance.
A similar question is raised in this section: what should be the maximum price of stored kWh in the battery to enable its profitable operation for the peak cut purpose:

$$Savings_{peakcut} = Cost_{kW} * \Delta P_{cut} \quad (3)$$

$$Cost_{annual} = E_{stored} * price_{kWh} \quad (4)$$

where

$Cost_{kW}$, €/kW	cost of 1 kW capacity the customer has to pay according to a power-based tariff [5].
ΔP_{cut}, kW	the difference between the previous power level and the new power level, kW.
E_{stored}, kWh	annual amount of stored energy in the battery
$price_{kWh}$, cents/kWh	price of stored energy in the battery

The annual cost of stored energy is calendar aging based cost or cycle aging based cost depending on the annual energy stored in the battery.

Below Fig.1 illustrates the energies to be cut for the required peak cut level for the two different customers: with fully stored electric heating and direct electric heating loads. The load profiles of the two customer types differ in their peak-to-average demand ratio that is the ratio between the peak power and the average power. Fig. 2 and 3 show the corresponding cost and savings.

The red and green lines represent the cost of use of the most expensive and least expensive battery types considered in this study. The cost is calculated using (4). The savings are much smaller than the cost of use if the annual energy stored in the battery is less than the minimum stored energy (the storage is underutilized). If the annual stored energy is larger than the minimum value, the cost of use decreases dramatically, and the profitability of the operation is ensured. Therefore, there is an urgent need to increase the operation of the storage through other applications and thus obtain more revenue

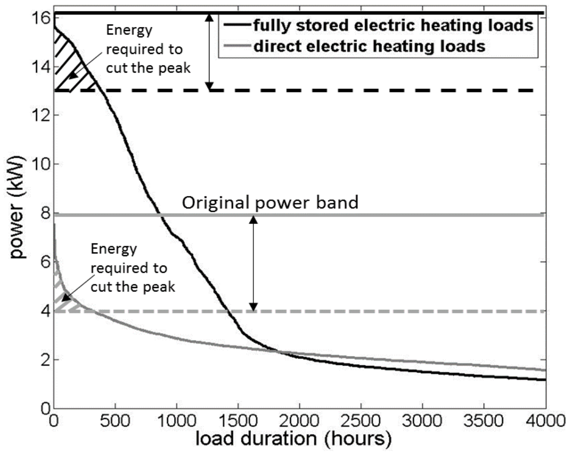

Figure 1. Energies required to cut the peak for two different customer types

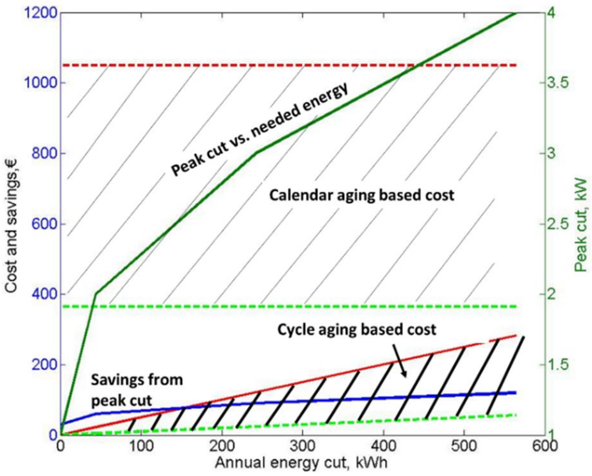

Figure 2. A single customer with fully stored electric heating loads: cost and savings obtained from the peak cut application

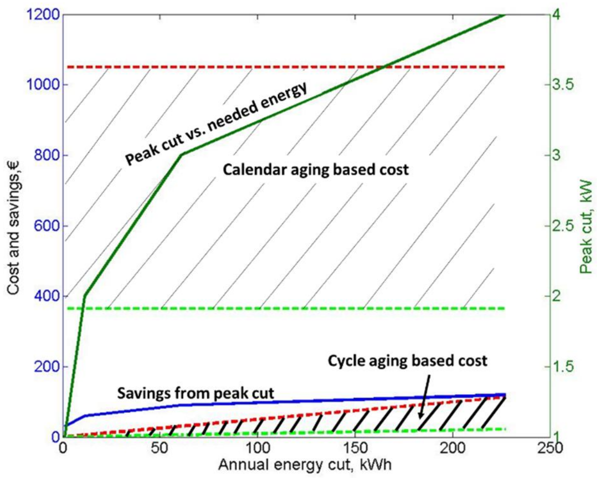

Figure.3. A single customer with direct electric heating loads: cost and savings obtained from the peak cut application

streams. Otherwise, the operation of an energy storage used only for the peak cut application is not profitable.

Price arbitrage in the spot market

The prices of the Elspot market for the Finnish area were used in the analyzes. In [6] it was shown that the operation of the large scale storage units on the day-ahead spot market is not yet profitable because of the low prices, low price fluctuation and high storage cost. Also for the residential scale, even rough estimations show that it is not profitable to operate the energy storage in the spot market.

Secondary applications:ancillary services

These applications are possible only through an aggregator service, because a residential storage unit is too small to participate independently in ancillary service markets such as the balancing power and the frequency reserve market. Distributed residential energy storages can be aggregated into a virtual power plant [7], and its total capacity is then bid to ancillary service markets.

In the paper, when the battery is operated in the balancing power market through the price arbitrage, the discharging will take place at the up-regulating prices and the charging at the spot prices. An alternative could also be to charge the battery at down-regulating prices. However, because of the poor predictability of the down-regulating prices, this option is not considered in this context. It is not known when the down-regulation hour will happen, and while reserving the capacity for that, the up-regulating peak price and the opportunity to earn may be missed.

METHODOLOGY DESCRIPTION

This section presents a methodology to define economically profitable operation of an energy storage on a single residential customer's premises in a balancing power market. The methodology is not limited to any specific balancing power market and therefore can be applied to any market environment.

Assumptions and limitations of the study

1. The cycle aging of the battery takes into account the amount of energy stored in the battery and does not consider the power rate of the battery.
2. Throughout the simulations, the charging and discharging powers are limited by the power band level and the hourly load consumption, respectively.
3. The forecast of the balancing prices is neglected.

Instead, the real historical prices and information about up-regulation hours are used in the simulations.

Constraints

The energy storage of a single customer has to be scheduled for an economical operation within the technical boundaries. The constraints considered are the customer's own PV generation, the power band limit, and the spot market profitability.

The first boundary, PV generation, means that the storage capacity cannot be bid to the balancing power market if charging from PV is possible in those hours. This is due to the fact that charging the storage from the customer's PV generation is the primary reason for the customer to purchase the energy storage. The monetary benefit for a single customer of charging the storage from own solar PV is much lower than operating the battery in the balancing power market. In fact, the profit is negative in countries where grid parity has not yet taken place, and positive in countries where grid parity has already occurred. Despite this fact, the option to charge the battery from own solar PV will be given a priority.

The second constraint is the power band level that sets limits on the charging power. However, the battery capacity can be bid to the balancing power market at the same time when there is a need for peak shaving. That way the savings will be obtained from both applications at the same time and the benefit-cost ratio of such operation will be significantly increased. This is possible only for the combination of certain applications, but is not for a combination of other applications. For instance, peak shaving can be simultaneously carried out along with the operation in either balancing power market, or spot market, or frequency reserve market.

The third boundary is the profitable operation in the spot market.

Mathematical Formulation

Two algorithms are developed: operation in the balancing power market without and with constraints set by the primary applications.

1. Cost-benefit analysis of storage operation in the balancing power market without constraints.

The storage capacity is bid to the balancing market every hour of the year. The charging/discharging powers are limited by the SOC (state of charge) level of the storage at the hour in question.

The bid formulation includes setting the minimum up-regulating price. If the settled price on the balancing market is higher than the up-regulating price offered by a single customer, the bid is accepted:

$$Price_{up} \geq price_{kWh} + Price_{spot} \quad (5)$$

The assumption is that all the charging events are carried out at the spot prices because of the poor predictability of the down-regulating prices and down-regulation hours.

$$Profit_{cycle}(t) = Price_{up}(t) * P_{discharge}(t) - Price_{spot}(t+x) * P_{charge}(t+x) \quad (6)$$

$$Savings = \sum_{t=1}^{8760} Profit_{cycle}(t) \quad (7)$$

$$Cost = price_{kWh} * \sum_{t=1}^{8760} P_{charge}(t) \quad (8)$$

$$Ratio_{benefit-cost} = Savings/Cost \quad (9)$$

2. Cost-benefit analysis of storage operation in the balancing power market with constraints set by the peak cut application.

The algorithm is as stated above but the charging and discharging powers are limited also by the power bandwidth in addition to the SOC of the battery.

CASE STUDY RESULTS

The methodology is applied to the Nordic balancing power market up-regulating prices. The simulations are executed for the prices in year 2012, when the up-regulating prices exceeded 20 times the level of 600 €/MWh and exceeded 1000€/MWh 16 times.

The simulation without and with power band constraints yielded the results presented in Fig. 5 and 6, respectively.

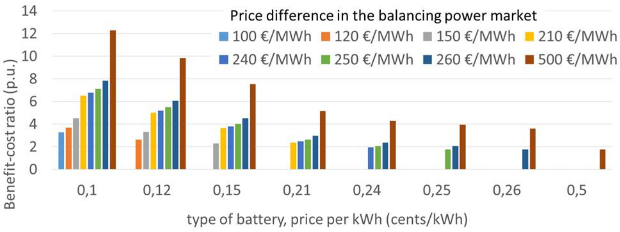

Figure 5. Benefit-cost ratio at various market price differences for different battery types, up-regulating prices in year 2012

Figure 6 shows the profits (upper lines) and costs (lower lines) obtained from the price arbitrage in the balancing up-regulating and spot market prices. The peak cut depending on the power band constraint varies from 0 to 3 kW and energy cut from 0 to 227 kWh. The analyses are done for a single customer with direct electric heating loads (see Fig.3).

The two main findings of the paper are:

1. The benefit-cost ratio is highest when the battery is operated at the highest price difference in the market, for every battery type.
2. The power band constraint does not affect the benefit-cost ratio of the battery operation in the balancing power market as the obtained savings to cost ratio remains the same as without constraints.

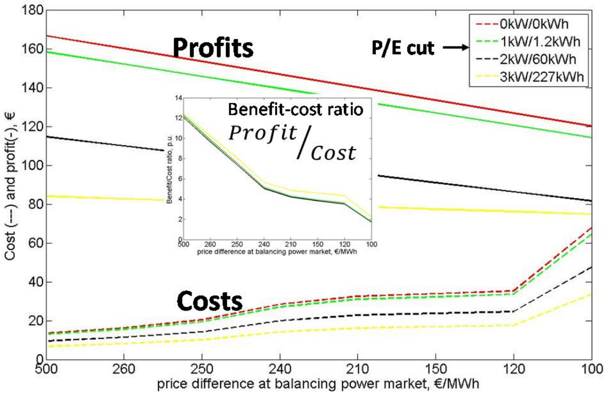

Figure 6. Profits, costs and benefit-cost ratio at various market price differences (x-axis) for the battery type 10 cents/kWh

This means that the battery operation simultaneously for peak cut application and balancing power market do not conflict with each other. It should be kept in mind that the results may vary depending on the balancing power market price levels as well as load profile of a single customer.

CONCLUSION

The paper argues that the battery operation is profitable only when it is used for the secondary applications in addition to the primary ones. The results have shown that it is possible to operate the battery against multiple incentives with the same benefit-cost ratio. The further research questions are defining the earning potential of the battery in the frequency reserve market as well as optimizing battery capacity allocation to multiple secondary applications.

REFERENCES

[1] V. Muenzel, L. Mareels; J. de Hoog,. A. Vishwanath,, S. Kalyanaraman, A. Gort, 2015, "PV generation and demand mismatch: Evaluating the potential of residential storage," in *Innovative Smart Grid Technologies Conference (ISGT), 2015 IEEE Power & Energy Society* , vol., no., pp.1-5

[2] O. Megel, J.L. Mathieu, G. Andersson, 2014, "Scheduling distributed energy storage units to provide multiple services," in *Power Systems Computation Conference (PSCC), 2014* , vol., no., pp.1-7

[3] K. Bradbury, L. Pratson, D. Patiño-Echeverri, 2014, "Economic viability of energy storage systems based on price arbitrage potential in real-time U.S. electricity markets", Applied Energy, Volume 114, pp. 512-519

[4] I. Lampropoulos, P. Garoufalis, P.P.J. van den Bosch, R.J.W. de Groot, W.L. Kling, 2014, "Day-ahead economic scheduling of energy storage," *Power Systems Computation Conference (PSCC)*, vol., no., pp.1,7

[5] J. Partanen, S. Honkapuro, J. Tuunanen, and H. Niemelä, 2012, "Tariff scheme options for distribution system operators", Report, Lappeenranta University of Technology

[6] B. Zakeri, S. Syri,, 2014, "Economy of electricity storage in the Nordic electricity market: The case for Finland," in *European Energy Market (EEM), 2014 11th International Conference on the* , vol., no., pp.1-6

[7] D. Pudjianto, C. Ramsay, G. Strbac, 2007, "Virtual power plant and system integration of distributed energy resources," in *Renewable Power Generation, IET* , vol.1, no.1, pp.10-16