Open Access Journal

Journal of Power Technologies 98 (5) (2018) 403–407

journal homepage:papers.itc.pw.edu.pl

Economic Viability of Battery Energy Storage for the Provision of Frequency Regulation Service

Christos Yianni[a,*], Venizelos Efthymiou[a], George E. Georghiou[a]

[a] *FOSS Research Centre for Sustainable Energy, Department of Electrical and Computer Engineering, University of Cyprus, Nicosia, Cyprus*

Abstract

Battery Energy Storage Systems (BESS) can provide a number of services to the power grid, with various financial potentials. This paper examines the economic viability of BESS providing primary frequency regulation (PFR) services in European markets. The current status of frequency regulation markets of mainland UK (Great Britain) and Central Europe was investigated and a techno-econometric model was developed to examine the economic viability and profitability of each market case. The results show a positive Net Present Value (NPV) for all the examined markets and a high internal rate of return (IRR). The impact of the most influential parameters such as service price and initial capital cost has been examined and analysed. This analysis seeks to inform interested parties about the viability of BESS services and to provide guidelines for future development.

Keywords: battery energy storage; primary frequency regulatio; economic viability

1. Introduction

In recent years, the increasing penetration of intermittent renewable energy sources (RES) in power grids is intensifying the need for balancing and grid supportive services. The energy supply has become less predictable and system balance more challenging. The imbalances of supply and demand are now larger and occurring more frequently, causing frequency disturbances necessitating frequency regulation (FR) services and in particular fast frequency regulation.

Battery energy storage systems (BESS) demonstrate great potential in delivering these services due to their fast response times (typically milliseconds to seconds) and variety of additional services (peak shaving, voltage support, black start etc.). Since FR is mostly a capacity service, with high power and low energy requirements, BESS can be used to provide primary frequency response and mitigate short-term frequency fluctuations. The economic viability of BESS is enhanced by its significant technical capabilities and low energy requirements. Despite the technical advantages, the future development and real growth of those technologies depend on market readiness and their competitiveness on the market.

This paper investigates the use of BESS for the provision of FR services in the European energy market and evaluates its economic viability. To this end, the paper aims to achieve the following:

- To evaluate the system requirements of BESS for FR provision.
- To examine the economic viability of BESS for FR provision.
- To investigate the competitiveness of BESS in European frequency regulation markets.

1.1. Frequency Regulation Market for Energy storage

Frequency Regulation (FR) is a balancing service which is usually procured via ancillary service markets. It is defined as the immediate and automatic response to a change in the local sensed system frequency in order to ensure the consistent system balance of generation and demand [1]. When FR service is provided by a storage unit, up regulation is provided by discharging energy to the grid during under frequency events. Down regulation is provided by charging from the grid during over frequency events [2]. This service is provided to system operators.

Traditionally, investors with generation units participate in an ancillary service market in order to make profits by reserving capacity for regulation [3]. The ancillary services market, including frequency regulation, was developed on the basis of generation provided services which makes it difficult for non-generation units, such as Energy Storage and Demand

*Corresponding author

Email address: yianni.christos@ucy.ac.cy (Christos Yianni)

Table 1: EFR service key requirements [4]

EFR Service Requirements	
Response Time, second	<1
Response Duration at Full Capacity, min	15
Minimum Capacity, MW	1
Narrow Service Threshold, Hz	±0.015
Wide Service Threshold, Hz	±0.05
Procurement Process	Tendered
Operational Availability, %	>95
Payments	Availability

Response (DR), to participate. BESS have limited energy capacity and thus significant operational limitations in contrast to conventional providers of FR services, such as open cycle gas turbines or pumped hydro storage [4]. In recent years, changes to the existing procedures and modes of operation have been made in order to remove any barriers to entry to the ancillary service market by new technologies such as ESS and DR. As a result, new categories of frequency support services and regulatory changes were introduced in various electricity markets in order to support the introduction of new technologies in the referred market and to accommodate their benefits.

1.2. Current status of ESS in Frequency Regulation Markets

Power system operators around the globe have recognised the potential of energy storage technologies in this market and have developed enabling policies to deploy them. This paper examines the FR market status for the National Grid (Great Britain) and Central Europe. These markets consist of a combination of frequency-based balancing services and slower reserve services.

1.2.1. GB Market

In the GB—mainland United Kingdom—the National Grid has created an internationally leading service to take advantage of the fast response capability of ESS called Enhanced Frequency Response (EFR) [5]. This service is explicitly designed to be delivered by ESS, allowing for state-of-charge (SoC) management between service windows, which was not possible in the existing frequency response services. The EFR service seeks to provide synthetic inertia, emulating the behaviour of the spinning masses of gas turbines that provide inertia today. The EFR service has demanding response requirements, as presented in Tab. 1, which are well suited to being fulfilled by an ESS. The EFR service and its requirements have been selected for use in all the following case studies.

In the GB the tendering round prior to the time of writing this paper completed on 15 July 2016 and the successful tenderers were awarded a contract to provide this service for 4 years continuously (24/7) at their bid price. The total installed service capacity is 1596 MW for options tendered for the wide deadband service (service 1) and 4034 MW for the narrow deadband service (service 2). Of the 64 sites, 61 are battery assets, 2 are demand side response and 1 is thermal generation [6, 7]. It is clear that storage units were able to offer significantly lower bid prices than thermal generation units. It should be noted that a number of thermal generation units were rejected due to their inability to satisfy the technical requirements of the services.

1.2.2. Central Europe Joint Market

In central Europe a joint ancillary service market has been implemented through a collaboration between Germany, Belgium, Denmark, France, Switzerland and Austria. The unified market releases a weekly tendering process for the provision of ancillary services, including Primary Frequency Reserve (PFR) which is used in our analysis. Interested participants submit their offers for the price and capacity they are willing to provide for each service [3]. The results of the joint tendering process are published every week after the tendering round and the best offers are selected to provide each service. The successful tenderers are accepted to provide the PFR service 24 hours a day for the next 7 days at the accepted bid price. A maximum transfer (export) quantity of PFR to other countries is predefined by the market operators [8]. The bid prices are generally characterised by moderate to low volatility and some seasonal correlation.

2. Case Studies for European Markets

The economic viability of the EFR service applied on the European markets was examined. For this purpose, techno-econometric models have been developed and implemented for individual case studies. For each case study, estimates were made of financial indicators such as: net present value (NPV) of the project, internal rate of return (IRR) and discounted payback period (PPd) .

2.1. Modelling the Metrics

NPV is often used to analyse the profitability of a projected investment or a project. It is a comprehensive way of calculating whether or not a proposed project will gain value in the future. Any value above zero denotes a profitable investment. NPV can be expressed by Eq. 1 [9, 10].

$$\begin{aligned} NPV = -CAPEX - \textstyle\sum_{n=1}^{N} \frac{O\&M}{(1+r)^n} + \\ + \textstyle\sum_{n=1}^{N} \frac{STF \times (1-TAX) \times (1+ER)^n \times T \times C \times (1-DF)^n}{(1+r)^n} \end{aligned} \tag{1}$$

Where: CAPEX - capital cost of the investment, N - operational lifetime in years, O&M - annual operation and maintenance costs, C - storage rated capacity, CL - number of cycles per year, STF - service price tariff, DF - degradation factor, ER - service price specific escalation rate, T - service hours, r - real discount rate, TAX - corporate income tax rate [10].

The Profitability Index (PI) is a very straightforward measure of profitability of an investment. It quantifies the amount of value created per unit of investment cost. Any ratio above 1 indicates a profitable investment. PI could be derived from Eq. 2 [10, 11]:

$$PI = \frac{NPV + CAPEX}{CAPEX} \tag{2}$$

Additionally, the Discounted Payback Period (PPd) was calculated for each case, which represents the time period required for the cumulative discounted net cash flow to recover the initial CAPEX [10]. It is the point in time the NPV becomes positive. Finally, the IRR was calculated by using financial calculation tools in order to define the minimum accepted rate of return of the investment. IRR is the rate of return where NPV is equal to zero as described by Eq. 3 [9, 10].

$$0 = -CAPEX - \sum_{n=1}^{N} \frac{O\&M}{(1+IRR)^n} + \\ + \sum_{n=1}^{N} \frac{STF \times (1-TAX) \times (1+ER)^n \times T \times C \times (1-DF)^n}{(1+IRR)^n} \quad (3)$$

For better comparison, all prices were converted to EURO/MW per hour of service. The weighted average accepted price for each market is calculated using one year of published price results and used in the NPV analysis. The weighted average price was obtained from Eq. 4.

$$\begin{matrix} Weighted \\ Average\ Price \end{matrix} = \frac{\sum_{n=1}^{N} Accepted\ Price_n \times Capacity_n}{\int_{n=1}^{N} Capacity\ Offered} \quad (4)$$

2.2. Technical and Financial Parameters

The validity and accuracy of the econometric results depends on the parameter values and assumptions made. Realistic values were used for all parameters, based on financial and technical data collected from the literature and other independent sources [8–16]. For all the examined cases the EFR service requirements were applied as presented in table 1. Initially, a reference case estimation of the NPV for a 1 MW Lithium-Ion battery system was performed. The key technical and financial parameters are presented in Table 2.

3. Results and Discussion

Published results from tendering processes for 2017 were used for the Central European (CE) markets and the 2016 tendering results for the GB market. The minimum and maximum accepted price as well as the weighted average price for each market are presented in table 3. As can be seen, the weekly tendering prices present a higher range and volatility compared to the four year fixed contracted prices. Despite the higher price volatility of the Central European markets, there is an opportunity for bidders to receive higher contracted prices than the long duration fixed contracts. Overall, the weighted average contracted prices (WACP) for those CE markets are higher compared to the GB market.

The NPV through the lifetime (15 years) of the systems has been estimated and presented in Fig. 1. All examined cases have presented a positive NPV and a very positive profitability index PI. The Netherlands market case presents the highest NPV due to the high accepted service prices and the GB case the lowest. Generally, the CE market cases present higher NPV than the GB market. It has to be noted that the different taxation policies of each country should be taken into account. The PPd is between 5 to 6 years for all CE

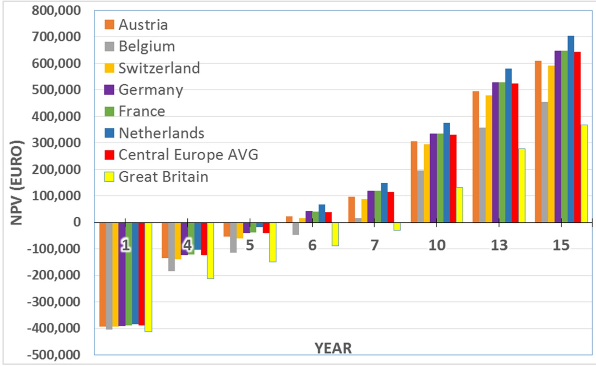

Figure 1: NPV for 15 years for the examined market cases

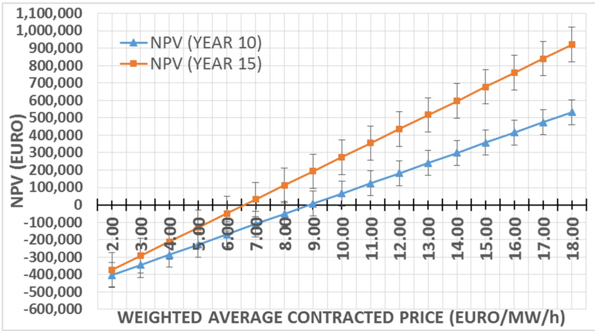

Figure 2: Effect of WACP on NPV at years 10 and 15 over WACP

cases and 7 to 8 for GB. The IRR is calculated as higher than 12% in all cases, which denotes a very attractive investment. The most important results are summarised in table 4.

The results above clearly show that WACP is a very important parameter for the profitability of each case. Next, the sensitivity of NPV to WACP was investigated. All other parameters were left unchanged, as defined in table 2. The NPV at year 10 and year 15 over WACP is illustrated in Fig. 2. Positive NPV occurs for WACP higher than 9 EURO/MW/h for year 10 of operation and higher than 6.5 EURO/MW/h for year 15 respectively. This denotes a profitable investment, even with low WACP.

Another very important parameter is the initial CAPEX cost. For this analysis, the sensitivity of NPV to the initial CAPEX was investigated. All other parameters were left unchanged, as defined in table 2. NPV at years 5, 10 and 15 over CAPEX are illustrated in Fig. 3. The NPV becomes positive in 5 years for CAPEX lower than 430 kEuro/MW and in 10 years for CAPEX lower than 760 kEuro/MW. This denotes a profitable investment, even with relatively high initial CAPEX. For comparison, the current prices for commercial scale battery storage declined to a range of 350 to 440 kEuro/MWh by the end of 2017 [12]. For these CAPEX values, the aforementioned investment lies well within the profitable range.

Table 2: Technical and Financial Parameters used in the techno-economic model used for EFR applications [10]

TECHNICAL		
Power, MW	1	Typically the Minimum Power required for participation in FR service market.
Capacity, MWh	0.5	±15min of Service is the Minimum Requirement for this service (0.5 MWh).
Degradation per Year, %	2	Degradation of Capacity due to high cycling utilisation
Cycle Efficiency, %	90	Does not affect the system economics as energy is not accounted for this service.
Availability Factor, %	98	Estimated after analysis of 1 Year of Frequency Data.
Lifetime, years	15	Estimated lifetime for new Li-on batteries [12].
FINANCIAL		
Specific Capital Cost (ENERGY), kEUR / MWh	470	Price for Commercial Lithium Ion Battery Systems at end of 2017 (Price include Suppy and Installation [1, 11–14]) Takes into account the interest rate and the risk or uncertainty of future cash flows [15].
Specific Capital Cost, kEUR / MWh	250	
Real Discount Rate, %	3.0	
Income Tax, %	20.0	Same corporate income tax rate used for all cases for better comparison.
Residual Value, %	0.0	Assume no resale value at end of operational period.
Weighted Average Contracted Price (WACP), EUR / MW/h	11.2-15.4	Min and Max contracted prices. Details in Table 4 [7, 8].
Maintenance Cost, kEUR / MWh	4.9	Corresponds to 1% of the Initial CAPEX [12, 15].
Maintenance Cost Increase, % / Ann.	1.0	Assuming Increased maintenance requirements through the years.
Annual Increase of WACP, % / Ann	1.5	Annual Escalation rate of the FR service price, additional to annual inflation rate [15, 16].

Table 3: Summary of Tender Results for the examined markets for 2017 [7, 8]

Market	Contracted Service Period	MIN Contracted Price (EUR/MW)/h	MAX Contracted Price (EUR/MW)/h	WACP (EUR/MW)/h
Austria	Weekly	10.33	31.25	14.14
Belgium	Weekly	11.39	13.46	12.24
Switz.	Weekly	10.48	31.00	
Germany	Weekly	10.48	23.81	14.61
France	Weekly	7.33	31.69	14.63
NL	Weekly	10.65	31.08	15.32
C. Europe Market (Average)	Weekly	7.33	31.69	14.56
GB	4 Years	8.28	14.16	11.16

Table 4: Summary of Results

Market	NPV yr 10, kEUR	NPV yr 15, kEUR	IRR, %	PPd, Year	Profit Index
Austria	306.6	608.6	17.4	5.7	2.25
Belgium	195.6	454.9	14.2	6.7	1.94
Switz.	294.5	591.7	17.1	5.8	2.22
Germany	334.0	646.3	18.2	5.5	2.33
France	335.0	647.8	18.2	5.5	2.34
NL	375.4	703.7	19.4	5.2	2.45
C. Europe Market (Average)	331.1	642.4	18.1	5.5	2.32
GB	132.7	367.9	12.2	7.5	1.76

4. Conclusion

In this paper, the economic viability of the primary frequency regulation (PFR) service provided by BESS in the European and British markets was examined. A review of the current status of the European Frequency Regulation Market and energy storage was made. A techno-econometric model was developed to examine the economic viability and profitability of various cases. The results yielded a positive Net Present Value (NPV) for all the examined markets. The markets with higher weighted average contracted prices (WACP) enjoyed higher NPV, higher internal rate of return and lower discounted payback period. The limits of profitability were identified for the most important parameters, such as WACP and initial CAPEX cost. This analysis can be useful for potential investors and stakeholders. The results denote a profitable and attractive investment, although the individual risks should be accounted for different cases depending on the applicable regulations and uncertainties of each country of application.

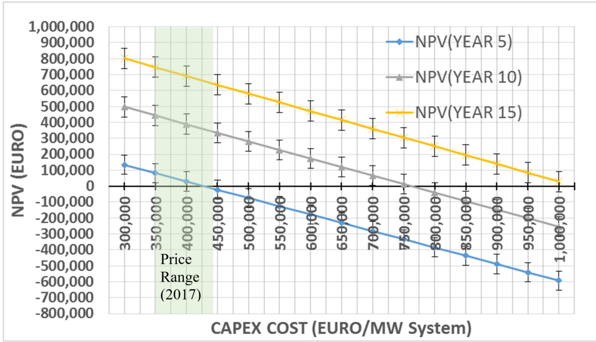

Figure 3: NPV at years 5, 10 and 15 as a function of initial CAPEX of the system

References

[1] G. Fitzgerald, J. Mandel, J. Morris, H. Touati, The economics of battery energy storage: How multi-use, customer-sited batteries deliver the most services and value to customers and the grid, Rocky Mountain Institute.

[2] C. Pieper, H. Rubel, Revisiting energy storage: there is a business case, The Boston Consulting Group (02).

[3] V. Pandurangan, H. Zareipour, O. Malik, Frequency regulation services: A comparative study of select north american and european reserve markets, in: North American Power Symposium (NAPS), 2012, IEEE, 2012, pp. 1–8.

[4] D. Greenwood, K. Y. Lim, C. Patsios, P. Lyons, Y. S. Lim, P. Taylor, Frequency response services designed for energy storage, Applied Energy 203 (2017) 115–127.

[5] U. Energy, Ancillary services report 2017, Available online at:[Accessed 22 July 2017].

[6] E. Ares, G. Grimwood, Energy Storage in the UK, House Commons Libr., no. 07621, p.32, 2016.

[7] “enhanced frequency response (efr) national grid uk.” [online]. available: https://www.nationalgrid.com/uk/electricity/balancing-services/frequency-response-services/enhanced-frequency-response-efr.

[8] “regelleistung.net internetplattform zur vergabe von regelleistung.” [online]. available: https://www.regelleistung.net/ext/tender/?lang=en. [accessed: 20-feb-2018].

[9] “net present value - npv,” 2017. [online]. available: http://www.investopedia.com/terms/n/npv.asp. [accessed: 21-oct-2017].

[10] C. yianni, m. florides, s. afxentis, v. efthymiou, and g. e. georghiou, “economic viability of battery energy storage system applications,” 2018 ieee int. energy conf. energycon 2018, pp. 1–6, 2018.

[11] F. Cell, H. J. Undertaking, Commercialisation of energy storage in europe, Final Report (2015) 52.

[12] Lazard, “lazard’s levelised cost of storage v3.0,” november 2017.

[13] “energy storage & battery technology,” no. march, pp. 1–5, 2017, sandbag.

[14] B. Lee, M. Lapides, P. Archambault, I. Matsubashi, R. Koort, M. Sugiyama, The great battery race framing the next frontier in clean technology-electrical energy storage, Goldman Sachs.

[15] I. Pawel, The cost of storage–how to calculate the levelized cost of stored energy (lcoe) and applications to renewable energy generation, Energy Procedia 46 (2014) 68–77.

[16] J. Neubauer, M. Simpson, Deployment of behind-the-meter energy storage for demand charge reduction, National Renewable Energy Laboratory Golden, CO, 2015.