# Economic Analysis of Energy Storage System Integration with a Grid Connected Intermittent Power Plant, for Power Quality Purposes

Alejandro Nieto Vasiliki Vita Lambros Ekonomou

Department of Electrical and Electronic Engineering, City University London,
Northampton Square, London EC1V 0HB, United Kingdom

alejandro.nieto@city.ac.uk, vasiliki.vita.1@city.ac.uk, lambros.ekonomou.1@city.ac.uk

*Abstract:* - The increasing integration of grid scale intermittent power plants, like wind farms, is impacting negatively the stability of the interconnected power grid affecting the load factor of the intermittent power plant. Energy storage systems (ESS) are being considered as a potential solution for this problem since it can increase the power being exported to the grid by the wind farm, making it more stable, and therefore guarantying its economic feasibility. In this paper an economic study is carried out to analyze the economic feasibility for the integration of flywheel energy storage systems (FESS) with a wind power plant. It was concluded that the installation of the FESS is only feasible with the government subsidy in renewable energy projects, if considering that installation costs would not be reduced more than 10% of the estimated value. In addition, the integration of ESS would potentially improve the load factor of the power plant by increasing the load factor and therefore, make the project more profitable from an independent power producer perspective.

*Key-Words:* - Energy Storage Systems; Economic Study; Renewable Energy

## 1 Introduction

The continuous deployment of renewable power plants brings a considerable change that is currently facing the power system industry. The manipulation of some renewable energy sources (RESs) could become a challenge due to their intermittency and variation. During the 21$^{st}$ century, wind power plants have been the renewable technology with largest growth of installed base across the world, but especially in the European Union. This generation technology is intermittent in nature due to the constant dependence on the availability of wind resources to produce energy, which may vary from time to time. This variability which cannot be controlled from operators, may incur in additional power capacity available from traditional power plants, mainly fossil fuels, in order to balance in a second by second basis the generation and demand across the power grid. Also, more ancillary services, like demand response and voltage support, are being required to keep the balance in the frequency of the grid and voltage stability on every bus bar.

Studies proposed the integration of energy storage systems as a manner to alleviate the insufficiencies of the VAR for a short period of time, with the intention to prevent loss of load and to reduce the necessity of investing in additional pick power plants [1]. In addition, the introduction of new energy storage systems for the control of power and voltage represents an economic substitute for the upgrade of transmission lines connected to a grid in remote points, through the integration of renewable sources. This combination is expected to reduce the disconnection of intermittent power plants from the power grid, by the system operator, due to the instabilities that causes the intermittent power injected to the grid.

Currently, the demand for the use of energy storage systems is increasing. There are different drivers that are supporting this growth like: reliability and security in electricity supply; imprecise prediction of the energy generated by renewable sources and impossibility to satisfy the demand with a limited transmission infrastructure. However, since most of the energy storage systems are emerging technologies, the operational, technical performance and market integration of these into the electric grid are underdeveloped. Further studies, tests and standards must be delivered in order to integrate the energy storage systems (ESSs) with the electric converting units, based on the current electric supply system infrastructure.

In this paper, a flywheel energy storage system (FESS), which is one of the technologies being deployed for utility scale applications, will be analysed. The integration study of this FESS technology with a wind power plant will be analysed to understand the economic feasibility from the perspective of an independent power producer.

# 2 Problem Formulation

The energy storage system (EES) involves a process where the electrical energy is transformed into a particular form that can be stored and can be converted back to electrical energy when required [2]. From a grid scale perspective, this process permits the generation of electricity at low demand, when the cost of electricity is low or from intermittent energy plants and then to be used at times of peak demand, when the cost of generation is high or when there is no other sources of power generation [3].

Due to the fact that ESS can considerably reduce the cost in the operation of the electric power system, the design and operation of the power grid can change radically. For instance, with the integration of ESS load problems could be reduced, an improved stability in the grid could be achieved and the disturbances produced by power quality could be mitigated or even eliminated at all. Therefore, the ESS plays a flexible in the power grid that can guarantee a more efficient usage of the energy, especially when applicable to variable energy sources. In addition, ESS's help to simplify the integration of large scale intermittent sources by controlling in a more efficient way the voltage and frequency on the grid.

With respect to the generation area, the ESS can be deployed also to reduce the load during peak times and hence, decrease the utilisation of thermal power plant during peak periods. It is worth to mention that peak power plants usually work under low efficient conditions and increase the greenhouse gases emissions. Therefore, with the integration of ESS the cost of electricity during peak hours can be reduced, as well as the total emissions of greenhouse gases of a power grid [4].

## 2.1 Technical characteristics of energy storage systems

In order to compare the different types of energy storage systems in the market, it has to be defined different aspects that have to be taken into consideration. The main technical characteristics used to compare between technologies are: storage capacity; storage system power; energy and power density; efficiency; durability; response time; ramp rate; charge rate; decommissioning and disposal needs and costs; and finally the maturity of the technology [2-5].

### 2.1.1 Classification of energy storage systems

Regarding the function, ESS technologies can be classified into those that are capable of providing high power ratings with a relatively small energy capacity making them suitable for power quality purposes; and those designed for energy management usually have a large energy capacity available but low response time, as shown in Fig. 1. Pumped Hydro Systems (PHS), Compressed Air Energy Storage (CAES), Thermal Energy Storage (TES), large-scale batteries, flow batteries, fuel cells and solar fuel are located into the category of energy management, whereas capacitors/super-capacitors, Superconducting Magnetic Energy Storage (SMES), flywheels and batteries are in the category of power quality and reliability service provider. This simple classification is based on the wide range of technical parameters aforementioned of ESS [6].

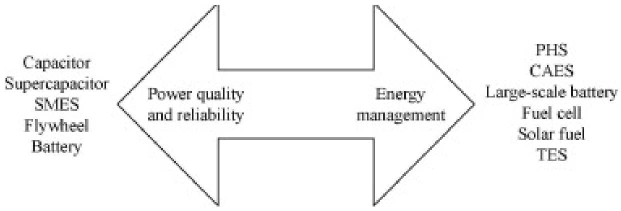


Fig. 1 Energy storage classification with respect to function [6]

Since this paper is focused on the improvement of power quality for the integration of wind farms, only energy storage technologies that can provide power quality and reliability will be considered. More specifically a flywheel will be integrated with medium scale wind power plants (considered between ranges from 50 MW to 400 MW).

### 2.1.2 Flywheel energy storage systems

The flywheel energy storage system (FESS) accumulates mechanical energy in the form of kinetic energy in a rolling mass. The kinetic energy in a flywheel is proportional to the square of its rotational speed. In (1) it is shown the energy formulae of the flywheel in which the storing kinetic energy $E_c$ is proportional to the moment of inertia $I$ and to the square of the rotational speed $\omega$.

$$E_c = \frac{1}{2} I \omega^2 \quad (1)$$

When it is required to recover the energy stored in the flywheel, the system functions as generator and is responsible for converting this stored mechanical energy into electrical energy. Reverse energy conversion, for charging the accumulator, is done by a motor drive and the machine operates as an electric motor for the grid. Typically, the steering wheel is incorporated into the motor-generator system that configures an isolated machine, connected to the grid by electrical cables [1, 4, 5].

Kinetic energy storage systems based on flywheels are characterised by being able to provide large power peaks. A flywheel is capable of storing large amounts of energy and power from kilowatt to megawatt ranges. The rapid response on the flywheels makes them useful for many applications. Also they are used to provide protection against mains voltage disturbances, especially for short-term supplement to the peaks in demand, and avoid the need for other support systems.

The state of the art technology used in flywheel systems is rated to high rotational speeds and consists on bearings that levitate by magnet forces that support a rotating cylinder with a great mass value. As appreciated in Fig. 2 the flywheel is operated in a vacuum chamber that reduces the drag force and maintains the efficiency of the system. In addition, the FESS is connected to a motor-generator system that interacts with the utility grid through advanced power electronics devices [4].

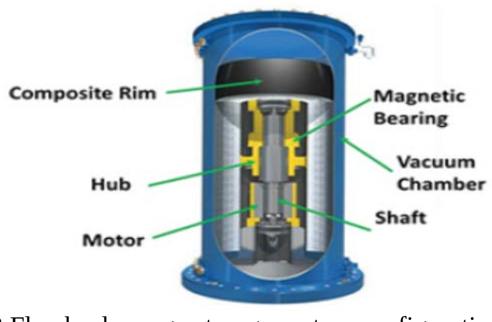


Fig. 2 Flywheel energy storage system configuration

Traditional technologies of flywheels are rated to operate up to 10,000 RPM and their rim is built with steel. However, most recent technologies achieve higher efficiency and energy density by using the following features:

- A high strength-to-weight ratio can be achieved by rotating mass made of polymer materials or fibre glass resins.
- The aerodynamic drag is minimised by a mass that operates in a vacuum chamber.
- A rotating mass of low density materials that operates at high frequency.
- In order to accommodate high rotational speed, magnetic or air suppression bearing technology is being used.

The application of energy storage systems with large wind farms has a better economic performance since the power capacity of energy storage system does not increase proportional with the total installed capacity of the wind power plant. On [1] it is revealed that, when there are several wind turbines installed in a wind farm they have a self-smooth property that intrinsically can reduce the wind farm output power fluctuations. Therefore, the ratio of the energy storage capacity and total power capacity of the wind power plant (WPP) drops with the growth of the total wind power plant capacity. It is recommended that a minimum ratio of 1:4 of total ESS capacity to WPP capacity needs to be ensure for large wind power applications in order to keep the intermittency below 10% of the rated power per minute [1].

## 2.2 Economic simulation modeling

This paper analyses the economic performance of a 99MW wind farm interconnected in a generic electrical power grid. In parallel to the renewable source, a FESS will be installed to support the performance of the WPP in order that all the potential power generated can be injected to the grid. The aim of this simulation is to analyse the economic feasibility of three different FESS of power capacities 25MW, 30MW and 40MW integrated to the 99MW wind farm, form a perspective of an independent power producer.

The economic analysis is performed using the net present value (NPV) calculation study. The NPV formula is represented in (2).

$$\text{NPV (i)} = -C_0 + \sum_{n=1}^{N} \frac{F_n}{(1+i)^n} \quad (2)$$

where $C_0$ is the initial capital employed for the project; $F_n$ is the cash flow of the project at the $n^{th}$ year; N is the lifetime of the project in years; and i is the discount rate of a project.

Firstly will be analysed the NPV for the installation of the WPP and then, it will be considered the NPV with the integration of different power capacities of ESS.

Likewise, another indicator for evaluating the feasibility of a project is the Internal Rate of Return (IRR). The IRR of an investment or project is the

effective annual rate of return or discount rate, which is fixed for the duration of the project and also makes the net present value of all the cash flows, of a fixed investment, equal to zero.
The IRR is commonly used to assess the appropriateness of investments or projects. The aforementioned process to calculate the IRR is shown in (3).

$$0 = -C_0 + \sum_{n=1}^{N} \frac{F_n}{(1 + IRR)^n} \qquad (3)$$

where $C_0$ is the initial capital employed for the project; $F_n$ is the cash flow of the project at the $n^{th}$ year; N is the lifetime of the project in years; and IRR is the internal rate of return of the project.
For completing the economic analysis a sensitivity analysis will be performed by varying independently the different parameters that are being used to calculate the NPV and IRR and, in consequence, analyse the potential impact in the financial performance of the project.

# 3 Results of Simulation

## 3.1 Economic simulation results of WPP project

Table 1 summarizes the economic simulation for the installation of the wind power plant. The NPV is positive and considerable large enough compared to the scale of the project. Also the IRR is a large value and compared to the discount rate, it can be considered that the project is totally feasible, from the economic perspective. For this simulation it was considered a load factor of 32% and an electricity export rate of 80 £/MWh due to the Contracts of Difference which is a subsidy of the UK Government for renewable energy projects [7].

Table 1 Economic analysis of WPP project

| Financial viability | | |
|---|---|---|
| Pre-tax IRR - equity | % | 10.4% |
| Pre-tax IRR - assets | % | 10.4% |
| After-tax IRR - equity | % | 7.4% |
| After-tax IRR - assets | % | 7.4% |
| Simple payback | yr | 9.1 |
| Equity payback | yr | 10.6 |
| Net Present Value (NPV) | £ | 20,300,534 |
| Annual life cycle savings | £/yr | 1,769,893 |
| Benefit-Cost (B-C) ratio | | 1.12 |
| Energy production cost | £/MWh | 73.03 |
| GHG reduction cost | £/tCO2 | (24) |

In addition a sensitivity analysis was performed, considering a potential variability in the initial cost for a maximum of 20% due to the potential increase in the commodities such as copper, which are necessary to manufacture all the infrastructure of the WPP, like conductors, power transformers, etc. Also a volatility of a maximum of 20% in the electricity export rate has been considered, due to high volatility of the energy sector, which is currently dominated by fossil fuels. The sensitivity analysis performed on net present value is shown in Table 2 with the variability aforementioned of 20% in the initial cost and export rate.

Table 2 Sensitivity analysis in VPN of WPP project

| | | |
|---|---|---|
| Perform analysis on | Net Present Value (NPV) | |
| Sensitivity range | 20% | |
| Threshold | 1 M | £ |

| | | Initial costs | | | | £ |
|---|---|---|---|---|---|---|
| Electricity export rate | | 133,492,267 | 150,178,800 | 166,865,334 | 183,551,867 | 200,238,400 |
| £/MWh | | -20% | -10% | 0% | 10% | 20% |
| 64.00 | -20% | 7,086,377 | -9,600,156 | -26,286,689 | -42,973,223 | -59,659,756 |
| 72.00 | -10% | 30,379,989 | 13,693,456 | -2,993,078 | -19,679,611 | -36,366,144 |
| 80.00 | 0% | 53,673,601 | 36,987,067 | **20,300,534** | 3,614,001 | -13,072,533 |
| 88.00 | 10% | 76,967,213 | 60,280,679 | 43,594,146 | 26,907,612 | 10,221,079 |
| 96.00 | 20% | 100,260,824 | 83,574,291 | 66,887,757 | 50,201,224 | 33,514,691 |

In addition, Table 3 shows the sensitivity analysis performed to the IRR, also considering a 20% of variability.

Table 3 Sensitivity analysis in IRR of WPP project

| | | |
|---|---|---|
| Perform analysis on | After-tax IRR - equity | |
| Sensitivity range | 20% | |
| Threshold | 6 | % |

| | | Initial costs | | | | £ |
|---|---|---|---|---|---|---|
| Electricity export rate | | 133,492,267 | 150,178,800 | 166,865,334 | 183,551,867 | 200,238,400 |
| £/MWh | | -20% | -10% | 0% | 10% | 20% |
| 64.00 | -20% | 6.6% | 5.2% | 4.1% | 3.0% | 2.2% |
| 72.00 | -10% | 8.6% | 7.1% | 5.8% | 4.7% | 3.7% |
| 80.00 | 0% | 10.4% | 8.7% | **7.4%** | 6.2% | 5.2% |
| 88.00 | 10% | 12.1% | 10.4% | 8.9% | 7.7% | 6.6% |
| 96.00 | 20% | 13.7% | 11.9% | 10.3% | 9.0% | 7.9% |

As can be seen in the tables, a threshold of 6% was set in the IRR, since the discount rate for the project was estimated to be 6%, according to [8]. This threshold has been set since it is the minimum interest rate considered for a project to be profitable in the future, considering an amount of money has been borrowed from a financial institution at a 6% year interest of interest, named also cost of capital, as per the discount rate previously assumed.

## 3.2 Economic simulation results of FESS integrated with the WPP

Taking into consideration the integration of renewable sources to the system, it is worth to mention that energy storage systems, including flywheels, are not being used on a regular basis for storing energy, due to the high cost implied for these systems. As stated in [9], the cost of a flywheel system is directly proportional to its storage time which can vary from 131 to 327.7 £/kW, with an energy storage capacity of several minutes, and from 655.4 to 1,966.2 £/kW for 1 hour of constant power being supplied. For power quality purposes, it is usually required high power capacity devices with low energy storage density; since the events to be supported by these devices last a couple of minutes before the corrective measures are being implemented to ensure the stability of the power grid.

In this work was assumed a capital cost of 327.7 £/kW of power capacity for the flywheel energy storage system to be included in the different scenarios. In consequence, the capital cost estimated for integrating an FESS of 25MW was £8.192M, for a capacity of 30MW the capital cost increase up to £9.83M and the last case analyzed with an FESS with a capacity of 40MW was estimated a capital cost of £13.108M.

In addition, for performing the economic simulation was also considered the operating and maintenance costs incurred by operation of the energy storage device over its entire lifecycle. According to [10], these yearly costs represent approximately 1.6% of the capital cost previously mentioned. Therefore, on each scenario was estimated an operating cost of 5.25 £/kW of the power capacity installed.

Considering that FESS will increase the output power stability of the renewable source, it was assumed on these simulations a load factor of 54.5%, which is the maximum available according to the wind historical record of the location. As a consequence, the electricity export rate was considered to be 50 £/MWh, which still makes the project economically feasible.

In Table 4, the results of the economic analysis simulation are presented. With the installation of the FESS, even if it has created a significant impact in the NPV by decreasing it more than 35%, the project is still being profitable in economic terms by having a positive NPV. Also the IRR is being impacted by reducing from 8.3% to 7.5%. As a consequence of the increase in the capital cost, the payback time has been slighted increased to 6 months.

Furthermore, a simulation study relevant to the sensitivity analysis of the NPV by varying up to 20% the initial cost of the project and electricity export rate was performed as shown in Table 5, while a sensitivity analysis of the IRR with also varying the initial costs and electricity export rate of 20% was performed with the results presented in Table 6.

Table 4 Economic analysis of WPP with 25MW ESS integration

| Financial viability | | |
|---|---|---|
| Pre-tax IRR - equity | % | 10.5% |
| Pre-tax IRR - assets | % | 10.5% |
| After-tax IRR - equity | % | 7.5% |
| After-tax IRR - assets | % | 7.5% |
| Simple payback | yr | 9.1 |
| Equity payback | yr | 10.5 |
| Net Present Value (NPV) | £ | 22,882,207 |
| Annual life cycle savings | £/yr | 1,994,975 |
| Benefit-Cost (B-C) ratio | | 1.13 |
| Energy production cost | £/MWh | 45.38 |
| GHG reduction cost | £/tCO2 | (16) |

Table 5 Sensitivity analysis in VPN of WPP project with 25MW FESS

| Perform analysis on | Net Present Value (NPV) | | | | | |
|---|---|---|---|---|---|---|
| Sensitivity range | 20% | | | | | |
| Threshold | 1,000,000.00 | £ | | | | |
| | | | Initial costs | | | (£) |
| Electricity export rate | | 141,750,307 | 159,469,095 | 177,187,884 | 194,906,672 | 212,625,460 |
| (£/MWh) | | -20% | -10% | 0% | 10% | 20% |
| 40.00 | -20% | £8,820,858.43 | -£8,897,929.94 | -£26,616,718.32 | -£44,335,506.69 | -£62,054,295.07 |
| 45.00 | -10% | £33,570,320.85 | £15,851,532.48 | -£1,867,255.90 | -£19,586,044.27 | -£37,304,832.65 |
| 50.00 | 0% | £58,319,783.27 | £40,600,994.90 | **£22,882,206.52** | £5,163,418.15 | -£12,555,370.23 |
| 55.00 | 10% | £83,069,245.69 | £65,350,457.32 | £47,631,668.94 | £29,912,880.57 | £12,194,092.19 |
| 60.00 | 20% | £107,818,708.11 | £90,099,919.74 | £72,381,131.36 | £54,662,342.99 | £36,943,554.61 |

Table 6 Sensitivity analysis in IRR of WPP project with 25MW FESS

| Perform analysis on | After-tax IRR - equity | | | | | |
|---|---|---|---|---|---|---|
| Sensitivity range | 20% | | | | | |
| Threshold | 6% | % | | | | |
| | | | Initial costs | | | (£) |
| Electricity export rate | | 141,750,307 | 159,469,095 | 177,187,884 | 194,906,672 | 212,625,460 |
| (£/MWh) | | -20% | -10% | 0% | 10% | 20% |
| 40.00 | -20% | 6.72% | 5.33% | 4.15% | 3.13% | 2.24% |
| 45.00 | -10% | 8.65% | 7.15% | 5.88% | 4.78% | 3.83% |
| 50.00 | 0% | 10.46% | 8.84% | **7.48%** | 6.31% | 5.29% |
| 55.00 | 10% | 12.18% | 10.44% | 8.98% | 7.74% | 6.67% |
| 60.00 | 20% | 13.83% | 11.97% | 10.42% | 9.10% | 7.96% |

Table 7 shows the results from the economic analysis being performed considering an integration of a FESS of 30MW. The NPV is being to almost 10% in comparison to the case of a 25MW FESS. The IRR is also being reduced by 0.2% and the payback time increased by two months.

Table 7 Economic analysis of WPP with 30MW ESS integration

| Financial viability | | |
|---|---|---|
| Pre-tax IRR - equity | % | 10.3% |
| Pre-tax IRR - assets | % | 10.3% |
| After-tax IRR - equity | % | 7.3% |
| After-tax IRR - assets | % | 7.3% |
| Simple payback | yr | 9.2 |
| Equity payback | yr | 10.7 |
| Net Present Value (NPV) | £ | 20,486,840 |
| Annual life cycle savings | £/yr | 1,786,136 |
| Benefit-Cost (B-C) ratio | | 1.11 |
| Energy production cost | £/MWh | 45.86 |
| GHG reduction cost | £/tCO2 | (14) |

The results of the sensitivity analysis of the NPV by varying 20% the initial costs and electricity export rate, like the previous scenarios is being shown in Table 8, while the sensitivity analysis results of the IRR for the case study of integrating a 30MW FESS are shown in Table 9.

Table 8 Sensitivity analysis in VPN of WPP project with 30MW FESS

| | | |
|---|---|---|
| Perform analysis on | Net Present Value (NPV) | |
| Sensitivity range | 20% | |
| Threshold | 1,000,000 | £ |

| Electricity export rate | | Initial costs | | | | (£) |
|---|---|---|---|---|---|---|
| | | 143,401,915 | 161,327,154 | 179,252,394 | 197,177,633 | 215,102,872 |
| (£/MWh) | | -20% | -10% | 0% | 10% | 20% |
| 40.00 | -20% | £ 6,838,393.46 | -£11,086,845.91 | -£29,012,085.29 | -£46,937,324.66 | -£64,862,564.04 |
| 45.00 | -10% | £ 31,587,855.88 | £13,662,616.51 | -£ 4,262,622.87 | -£22,187,862.24 | -£40,113,101.62 |
| 50.00 | 0% | £ 56,337,318.30 | £38,412,078.93 | **£ 20,486,839.55** | £ 2,561,600.18 | -£15,363,639.20 |
| 55.00 | 10% | £ 81,086,780.72 | £63,161,541.35 | £45,236,301.97 | £27,311,062.60 | £ 9,385,823.22 |
| 60.00 | 20% | £105,836,243.14 | £87,911,003.77 | £69,985,764.39 | £52,060,525.02 | £34,135,285.64 |

Table 9 Sensitivity analysis in IRR of WPP project with 30MW FESS

| | | |
|---|---|---|
| Perform analysis on | After-tax IRR - equity | |
| Sensitivity range | 20% | |
| Threshold | 6% | % |

| Electricity export rate | | Initial costs | | | | (£) |
|---|---|---|---|---|---|---|
| | | 143,401,915 | 161,327,154 | 179,252,394 | 197,177,633 | 215,102,872 |
| (£/MWh) | | -20% | -10% | 0% | 10% | 20% |
| 40.00 | -20% | 6.56% | 5.17% | 4.00% | 2.99% | 2.10% |
| 45.00 | -10% | 8.47% | 6.98% | 5.72% | 4.63% | 3.68% |
| 50.00 | 0% | 10.27% | 8.66% | **7.31%** | 6.15% | 5.14% |
| 55.00 | 10% | 11.98% | 10.25% | 8.81% | 7.58% | 6.51% |
| 60.00 | 20% | 13.62% | 11.77% | 10.24% | 8.93% | 7.80% |

Finally, the results of the economic study simulation for the integration of the 40MW FESS with the WPP are shown in Table 10. It is clear that the NPV has been reduced significantly by almost 30% compared to the integration case of a 25MW FESS. In addition, the IRR was reduced to 0.5% and the payback time has been increased by 4 months.

Table 10 Economic analysis of WPP with 40MW ESS integration

| Financial viability | | |
|---|---|---|
| Pre-tax IRR - equity | % | 9.9% |
| Pre-tax IRR - assets | % | 9.9% |
| After-tax IRR - equity | % | 7.0% |
| After-tax IRR - assets | % | 7.0% |
| Simple payback | yr | 9.4 |
| Equity payback | yr | 10.9 |
| Net Present Value (NPV) | £ | 15,696,106 |
| Annual life cycle savings | £/yr | 1,368,458 |
| Benefit-Cost (B-C) ratio | | 1.09 |
| Energy production cost | £/MWh | 46.83 |
| GHG reduction cost | £/tCO2 | (11) |

As far concerning the sensitivity analysis of the economic study, Table 11 shows the variations of the NPV with respect to the changes of 10% and 20% of the initial costs and electricity export rate. Likewise, Table 12 shows the sensitivity analysis that was performed to the IRR by varying up to 20% the parameters used for the analysis. The integration of a 40MW FESS resulted to the increase of project's risks compared to the other cases of 30MW and 25MW ESS. Basically the project becomes unfeasible by having a negative NPV if assumed an increase of costs of 10% and keeping the electricity export rate as estimated initially to 50 £/MWh. For the sensitivity analysis of the IRR, this case also produces an unfeasible scenario since the IRR is expected to be lower that the discount rate estimated of 6%.

Table 11 Sensitivity analysis in VPN of WPP project with 40MW FESS

| | | |
|---|---|---|
| Perform analysis on | Net Present Value (NPV) | |
| Sensitivity range | 20% | |
| Threshold | 1,000,000.00 | £ |

| Electricity export rate | | Initial costs | | | | (£) |
|---|---|---|---|---|---|---|
| | | 146,705,131 | 165,043,272 | 183,381,414 | 201,719,555 | 220,057,696 |
| (£/MWh) | | -20% | -10% | 0% | 10% | 20% |
| 40.00 | -20% | £ 2,873,463.52 | -£15,464,677.85 | -£33,802,819.23 | -£52,140,960.60 | -£70,479,101.98 |
| 45.00 | -10% | £ 27,622,925.94 | £ 9,284,784.57 | -£ 9,053,356.81 | -£27,391,498.18 | -£45,729,639.56 |
| 50.00 | 0% | £ 52,372,388.36 | £34,034,246.99 | **£ 15,696,105.61** | -£ 2,642,035.76 | -£20,980,177.14 |
| 55.00 | 10% | £ 77,121,850.78 | £58,783,709.41 | £40,445,568.03 | £22,107,426.66 | £ 3,769,285.28 |
| 60.00 | 20% | £101,871,313.20 | £83,533,171.83 | £65,195,030.45 | £46,856,889.08 | £28,518,747.70 |

Table 12 Sensitivity analysis in IRR of WPP project with 40MW FESS

| | | |
|---|---|---|
| Perform analysis on | After-tax IRR - equity | |
| Sensitivity range | 20% | |
| Threshold | 6% | % |

| Electricity export rate | | Initial costs | | | | (£) |
|---|---|---|---|---|---|---|
| | | 146,705,131 | 165,043,272 | 183,381,414 | 201,719,555 | 220,057,696 |
| (£/MWh) | | -20% | -10% | 0% | 10% | 20% |
| 40.00 | -20% | 6.23% | 4.87% | 3.71% | 2.71% | 1.83% |
| 45.00 | -10% | 8.13% | 6.65% | 5.41% | 4.34% | 3.40% |
| 50.00 | 0% | 9.91% | 8.32% | **6.99%** | 5.85% | 4.85% |
| 55.00 | 10% | 11.59% | 9.89% | 8.47% | 7.26% | 6.20% |
| 60.00 | 20% | 13.21% | 11.39% | 9.88% | 8.60% | 7.48% |

All projects produce a considerable high net present value, above £15M, and an internal rate of return higher than the discount rate for the project of 6%. However, even if all projects have positive results, it is worth to highlight that the incorporation of flywheel energy storage systems significantly improve the financial performance of the project.

Due to the positive results obtained in all simulation scenarios, all projects analysed with FESS integration can be defined to be feasible and economically viable, with the case of FESS integration of 25MW being the most profitable amongst the other possibilities, due to the highest net present value and interest of return rate. However, there is a slightly difference in NPV among the scenarios of ESS with 25MW and the 30MW of capacity of about 10%. By comparing it to the 40MW ESS capacity, there is a significant difference of 32% and 25% percent of the NPV when comparing it to the 25MW and 30MW respectively.

However, the calculation of the NPV and IRR assumed a fixed scenario along the all lifecycle of the project, which in reality this does not happen, especially considering the long length of the project of 20 years.

## 4 Conclusion

The economic analyses of the different FESS cases, has shown that all projects are considered feasible since the NPV is positive and higher than £1M and the IRR is higher than the discount rate of the project. However, different future scenarios were also considered to analyse their impact on the feasibility of the project. In the case were the installation costs increase 10% due to the rise in commodities prices like steel or cooper, the installation of a 40MW FESS would not be feasible any more.

In addition, the integration of energy storage systems with the wind farm will allow an increase in the load factor of the power plant, by reducing the probability of being disconnected from the power grid for impacting the stability of the network. With the increase in the load factor, the profitability of the project will improve and, therefore, a lower electricity export rate would allow the project to be economically feasible, from an independent power producer perspective.

From an economic perspective point, and considering load factor of 32% of the wind farm without ESS, it can be considered as a very risky investment, since the project is highly dependable in government subsidies to be economically feasible.

Likewise, it is worth to mention that considering an expected scenario where the subsidy that currently receive the power producing companies from the UK government will end in the mid-term and, the initial cost of the project will not vary from the one initially estimated, then the installation of an integrated FESS would only be feasible for the 30MW and 25MW cases studied. Hence, considering that initial costs of the project is not expected to decrease significantly in the short term, there is a low economic risk for the installation of energy storage systems with wind power application.

*References:*

[1] L. Jianlin, L. Liang, Y.S. Li, H. Dong, Study on energy storage system smoothing wind power fluctuations, *International Conference on Power System Technology (POWERCON)*, Hangzhou, China, 2010.

[2] H. Ibrahim, A. Ilinca, Techno-economic analysis of different energy storage technologies, *Energy Storage - Technologies and Applications*, InTech, DOI: 10.5772/52220

[3] R. Walawalkar, J. Apt, R. Mancini, Economics of electric energy storage for energy arbitrage and regulation, *Energy Policy*, Vol. 5, 2007, pp. 2558–2568.

[4] IEC Market Strategy Board, *Electrical energy storage*, White paper, International Electrotechnical Commission, 2011

[5] J. Eyer, G. Corey, *Energy storage for the electricity grid: Benefits and market potential assessment guide*, Sandia Report SAND2010-0815, Sandia National Laboratories, 2010.

[6] H. Chen, T. Ngoc Cong, W. Yang, C. Tan, Y. Li, Y. Ding, Progress in electrical energy storage system: A critical review, *Progress in Natural Science*, Vol. 19, No. 3, 2009, pp. 291-312.

[7] Department of Energy and Climate Change, *Consultation on directions to offer Contracts for Difference: government response*, URN 14D/185, 2014, www.gov.uk/decc

[8] Oxera Consulting, *Discount rates for low-carbon and renewable generation technologies*, Oxera, 2011.

[9] G. Prodromidis, F. Coutelieris, Simulations of economic and technical feasibility of battery and flywheel hybrid energy storage systems in autonomous projects, *Renewable Energy*, Vol. 39, No. 1, 2012, pp. 149-153.

[10] R. Sen, A. Mishra, Comparison of flywheel with electromechanical batteries for energy storage in decentralised applications, *6th International Mechanical Engineering Conference & 14th Annual Paper Meet (6IMEC&14APM)*, Dhaka, Bangladesh, 2012.