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Investment and risk appraisal in energy storage systems: A real options approach

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ABSTRACT

The increasing penetration of variable renewable energy is becoming a key challenge for the management of the electrical grid. Electrical Energy Storage Systems (ESS) are one of the most suitable solutions to increase the flexibility and resilience of the electrical system. This paper presents an innovative methodology for the appraisal of the investment in ESS. The methodology is based on the Real Option Analysis and is able to properly consider investment risks and uncertainties as well as the options available for the investor. The paper assesses the value of the option to wait for a change in the market conditions before investing and re-evaluates the profitability of the investment after each step of the development of the ESS project. In order to exemplify relevant results, this method is applied to the UK energy market and assesses the technical and economic feasibility of investing in ESS operating price arbitrage and Short Term Operating Reserves. The results show that the implementation of the Real Option Analysis increases the economic performance of ESS. Nevertheless, ESS still requires limited incentives to be economically viable.

1. Introduction

Global renewable generation increased in 2013 by 240 TWh, accounting for almost 22% of total power generation, and it is expected to grow by almost 45% by 2020 [1]. The increasing penetration of variable Renewable Energy Technology (RET) is becoming a key challenge for the management of the electrical grid, as a high percentage of RET requires flexible power systems to quickly react to the variability of supply and demand, as exemplified in Ref. [2]. Nuclear power plants are also critical if required to operate in "load following mode" because their operation costs are almost fixed and the daily variation of power rate would lead to early ageing [3].

Electrical Energy Storage Systems (ESS) are one of the most promising solutions to moderate the effects of intermittent renewable resources and to store electricity produced by other base-load plants (e.g. nuclear power plants) when is not needed and to provide the necessary flexibility required for future smart grids [4,5]. ESS support the creation of a reliable stream of power throughout the day, filling the gap between demand and supply.

In the power industry, several uncertainty factors affect the profitability of ESS, and literature (see section 2.3 and 2.3.2) recommends to assess the value of uncertainties through the Real Option Analysis (ROA), which is a valuable method in uncertain contexts [6]. This work is a further development of [3], and investigates the technical and economic feasibility of investing in ESS operating price arbitrage and Short Term Operating Reserves (STOR), i.e. doing "cross arbitrage" [4,7]. Similarly to Reuter et al. [8], this paper calculates the level of incentives that would trigger the investment in ESS. In addition, the model implements three relevant real options for the investment appraisal: the option to wait to invest, the option to build and the options to wait to build. The method is applied from the investors' point of view and uses UK data because of the availability of public information, the expected increase of renewable sources [9], the remarkable interest in further nuclear development [10].

In summary, this work addresses the following research questions:

- Which ESS are technically and economically suitable for the storage of several MWh?

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- Which are the risks and options of investing in ESS?
- How ROA can be implemented for an investment appraisal in ESS?
- What is the economic performance of ESS implementing the ROA?

2. Literature review

2.1. Overview of energy storage systems

Energy Storage refers to a three-steps process that consists of (1) withdrawing electricity from the grid, (2) converting it into a form that can be stored, and (3) converting it back and returning it to the grid when needed [11]. This process enables the storage of energy at times of either low demand, low generation cost or from intermittent energy sources and uses it at times of high demand, high market price and or when power is needed as backup.

Akinyele and Rayudu [11] give a complete overview of ESS, updating the work of Chen et al. [12]. ESS have four main components: the charging unit, the storage medium, the discharging unit, and the control unit, and can be classified by the form of storage into four different main clusters [12]:

1) Mechanical (Pumped Hydro Systems, Compressed Air Energy Storage.);
2) Chemical (fuel cells, batteries.); this cluster is sometimes further divided into Chemical ESS and Electrochemical ESS [13];
3) Electrical (capacitor, super capacitors);
4) Thermal (low temperature and high temperature storage).

ESS can also be classified according to several other parameters, such as the quantity of energy stored, the rate at which energy can be absorbed, the efficiency of the ESS, their cycle life, their applications [14] and according to the implementation within the power grid [15]. Denholm et al. [16] list the different applications of ESS depending on the combination of discharge time, response time and benefits provided to the grid (see a description of benefits in Ref. [17]).

Following the research of Locatelli et al. [3], this work focuses on large ESS operating price arbitrage and STOR. Price arbitrage is one of the most common application of large-scale ESS and refers to the practice of purchasing low-cost off-peak energy in order to sell it during periods of high prices. Off-peak prices normally incur during the night, when the energy demand is lower. STOR is one of the services provided by UK National Grid, and it provides electricity to match demand and production.

The minimum requirements for a power plant willing to operate STOR are [18]:

- offer a minimum of 3 MW generation;
- have a maximum Response Time for delivery of 240 min, although typical contracts are for 20 min or less;
- be able to deliver the contracted MW for a continuous period of minimum 2 h;
- have a recovery period after provision of Reserve of not more than 1200 min;
- be able to deliver at least three times per week.

As in Locatelli et al. [3], price arbitrage and STOR are the most relevant for the integration of large amount of electricity, especially from wind farms. In fact, due to the large deployment of wind farms, the grid is affected by balancing problems, and reserve services are required. ESS can be used in alternative or to complement gas turbines in order to tackle the balancing problems, to generate electricity when prices are high and to store it when prices are low. However, only few technologies meet the aforementioned requirements and the most adequate ESS for price arbitrage and STOR are Pumped Hydroelectric Storage (PHS) and Compressed Air Energy Storage (CAES), as they both fulfil the above-mentioned requirements. Currently there are several PHS systems (e.g. 7.6 GW in Italy, 7.6 GW in Germany, more than 20 GW in the US.), and two CAES systems installed in the world [19].

2.2. ESS' risk analysis

Chapman and Ward [20] assert that: *"it is useful to define risk as an uncertain effect on project performance rather than as a cause of an (uncertain) effect on project performance"*

Moreover they point out that:

- uncertainty is related to *"the lack of certainty"*, which concerns of variability and ambiguity;
- variability is related to "*performance measures like cost, duration, or quality"*;
- ambiguity is associated with "*lack of clarity because of the behaviour of relevant project players, lack of data, lack of detail, lack of structure to consider issues, working and framing assumptions being used to consider the issues, known and unknown sources of bias, and ignorance about how much effort it is worth expending to clarify the situation"*.

This paper discusses risks and corresponding causes, as several uncertainties affect the Net Present Value (NPV) of ESS during their life cycle. Then it uses the ROA to manage the variability of the uncertainties.

Investors look for investments with the highest return at the lowest possible risk, so a risks' taxonomy is extremely important. As in Blythe and House [21], risks are here classified as:

1) techno-economic risks, that are related to the specific technology;
2) market risks, that are the factors that affect the electricity supply system;
3) regulation and policy risks.

Table 1 classifies the most relevant external and internal investment risks in ESS, and their respective causes: external risks are related to market and policies concerns, while internal risks are the technology-specific. Table 2 highlights the causes of the risks with the highest impact and highest probability to occur. In summary:

1) one of the major external risk for the NPV of ESS is the high unpredictability and volatility of electricity prices, mainly caused by the increase of renewable power plants, and wind farms in particular.
2) the introduction of incentives or the publication of long-term and stable energy policies specifically designed for ESS would have a major impact on the NPV of the ESS. For instance, the increase of intermittent renewables intensifies the volatility of electricity prices during the peaks. Therefore, the increase of intermittent renewables is twofold: it favours the absolute revenues, but it may decrease their relative value for power installed due to the higher price volatility. In order to overcome to this trade-off, fixed tariffs per kWh sold specifically designed for ESS would be valuable to guarantee ESS profitability.
3) natural gas has a relevant impact on the Life Cycle Cost (LCC) of a CAES, as 85–90% of the Variable Operative Costs (VOC),