Electrical Energy Storage utilisation for different operating responsible parties in the Dutch landscape

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Abstract

The exponential growth of variable renewable energy sources creates technical challenges in the electricity networks. An innovative solution for these problems is, implementing electrical energy storage into these networks. The liberalised energy system in the Netherlands gives the possibility for multiple actors to become owners of such storage system. The differences in conditions and objectives make for the storage to be used differently. The biggest distinction is made in where, before and after transmission, the cost allocation of the actor is situated. Before transmission, the storage capacity strategy is dependent on portfolio contents and balancing market incentives. After transmission, a daily cycle appears to be the best strategy to minimise costs. The shape of this daily cycle is dependent on decentralised generation of electricity. The latter case will not solve the technical challenges in the network.

Keywords: Electrical energy storage, EES, operating responsibility, balancing market, day-ahead market, imbalance volumes.

1. Introduction

Variable renewable energy sources (VRES) installed capacities are growing and due to their intermittent character the energy markets become more volatile [1]. Even-though, the forecasting software grow in accuracy the variability pose technical challenges [2]. A technical challenge is, for example, the increase in imbalance of supply and demand. Great imbalances cause for big processes to shut down to alleviate the pressure of the electricity system. The start-up of these big processes costs society a lot of money [3]. To prevent these costs, flexibility needs to be added to the system [4]. An innovative option for flexibility is Electrical Energy Storage (EES)[5]. The newest developments with regard to EES can be found in South Australia in the form of a 129 megawatt-hour electrochemical storage capacity with 100 megawatt power capacity. This storage capacity is used to conduct a case study regarding the Dutch landscape.

2. Landscape

The Dutch electricity system is dissected into three divisions namely social, technical and economic setting. The social setting is described as a liberalised industry where no parties are allowed to be excluded. Therefore any consumer is available to choose their supplier and any company is able to become a supplier if the assets produce a high enough quality of electricity. The actors in this landscape are divided into four groups. These four groups are variable energy producers, flexible energy producers, consumers and prosumers. Prosumers are defined as consumers which are able to produce their own electricity locally. The technical setting is described for the premise of energy storage possibilities. The most important production methods for variability and flexibility in the Netherlands are wind power, photo-voltaic power and gas turbine generation. These production methods have different characteristics such as variability and marginal costs of generation. The advantages of EES is the flexibility and in particular the high power and fast ramp rates [6]. A top-down representation is used to research markets for the economic setting and then a bottom-up representation is used to define the costs for the consumers. The economic setting is divided into four markets and three auxiliary services [7]. Of these four markets, two markets have decided to be most representative of the wholesale market of energy. The two markets which are chosen, are the day-ahead market and balancing market. These two markets do not close at the same time and therefore sequential optimisation can be used for the determining of the position of a portfolio on these two markets. When looking at the bottom-up representation, costs are added to the bill of the consumer. These added costs are for example energy taxes and connection fees[8]. Household consumers have a year round fixed electricity price and storage does not seem to have any benefits. The only costs they can reduce is the connection fee by taking a smaller connection and serve their peak loads with the storage capacity. A smaller connection is not possible for households but a larger consumer or an aggregated community could benefit from the implemented storage in this cost structure.

3. Objectives

The actors in the landscape are divided into the four groups established in the social setting description. These four groups are investigated for their possible objective when operating a storage capacity. This investigation is done in two parts namely literature research and expert interviews for validation. From the literature research four hypotheses are created with respect to operating storage capacity. [9]

- First for the centralised VRES operators, the objective is predicted to optimise for minimal costs for imbalances created by forecast errors. While researching minimal costs, this has been found to be the same as maximising revenue on the balancing market since the assumption is made this production technique has no variable costs. The expert-interviews have validated this objective.
- Secondly, for the next actor which is flexible energy producers (gas-fired power plant operator), revenue maximisation is suspected to be the objective for operating storage capacity. The expert-interviews have also validated this hypothesis.
- Finally, consumer incentives are investigated where there is assumed that the prosumer will have the same incentives. A hypothesis is established that the consumer would like to minimise their overall costs. The bottom-up representation in the economic landscape tells us that the energy costs are the same during the year for most consumers. Therefore, storage capacity usage can be used to decrease their connection costs. A large industrial consumer is interviewed to validate this hypothesis. The consumer emphasised the fact that energy consumption is not their main business. Energy consumption is needed for the service they deliver and delivering this service is therefore dominant over energy consumption. Decreasing energy consumption to enhance business cases is an option as long as it does not interfere with their service. This concludes that the hypothesis is correct.

4. Model

The four actors identified have an objective to utilise storage capacity. To investigate the consequences for other parties such as other asset owners and network operators, a model is made to simulate optimal market players. This model uses the 2015 market results on 15 minute granularity as an input to investigate implications of an extra storage capacity in the landscape. The last input needed is the dependency of the balancing market price with respect to the imbalance volume. For this an assumption is made that this is a linear dependent equation which could be derived from the frequency restoration reserve bids. These bids are partially disclosed on the system operators website [10]. The storage capacity simulation is now run to optimise revenues to establish a base case. From this base case, new portfolio's will be added to the optimisation with operating responsible party objectives to investigate the storage power profile. For the centralised VRES owner, a 100 MW installed capacity wind farm is added to the portfolio. This wind farm is set to create a 20% power forecast error from day-ahead market to balancing market [11]. After this a gas-fired power plant of 100 MW is added to the base case to establish optimal storage usage in combination with gas. For this simulation, the assumption is made that the gas price is fixed and the gas-fired turbine is bid marginally into the market. This gives a running profile for the gas turbine for the day-ahead market and the balancing market for gas power and storage usage. Finally, a consumer is added to the base case, for which the storage capacity will be used to minimise peak power consumption. This consumer case is run two times to check if decentralised power production changes the storage power profile with respect to the normal consumer case. This decentralised generation has the same stochasticity as the centralised VRES production. This second consumer case is called Prosumer case.

5. Results

The results are represented in two perspectives. The two perspectives taken into account are the portfolio differences with a stand alone optimisation of the storage with respect to profit which is further referred to as base case. The other perspective is the perspective from the network point of view.

The first case investigated is the variable renewable energy source case. For this portfolio, an optimisation has been done with respect to profit of the sale of energy. This is shown in the balance profile difference which is defined as the balancing power of the wind farm case minus the balancing profile of the base case. The balancing difference is plotted against the wind power forecast for these moments.

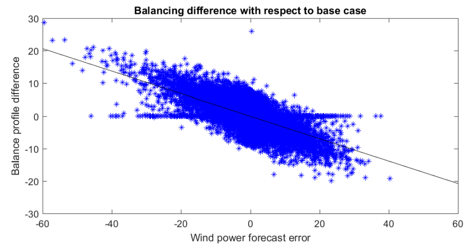


Figure 1: Wind power forecast error plotted versus the balancing profile of the storage difference with the base case

In figure 1, data points represent balancing difference for wind power forecast error on PTU level. This clearly shows a trend for preferred power output with respect to wind power forecast error. To represent this trend, a linear representation is made by calculating the minimal mean squared error with a linear equation.

$$\Delta P_{bal,t} = -0.345 * Pw_{error,t} + -0.069 \quad (1)$$

The same analysis has been done for the gas turbine and storage optimisation case which results in figure 2.

The balance profile difference is defined as storage balancing profile in the gas case minus the balancing profile of the storage in the base case. When plotting the data points against this difference, figure 2 is the result. The trend line is established by minimising mean square error. Equation 2 is the result of this calculation.

$$\Delta P_{bal,t} = -0.218 * Pg_{bal,t} + -0.142 \quad (2)$$

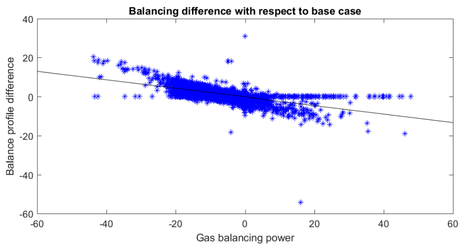


Figure 2: Gas turbine balancing positions plotted versus the balancing profile difference with the base case

This trend line takes into account the data points for which the storage was not able to change its balancing profile. Therefore, the linear equation has an offset of the realised data.

For the consumer and prosumer case, the balancing power cases are presented in daily averages. These averages are calculated for each 15 minutes. The difference in operating profile can be observed in figure 3.

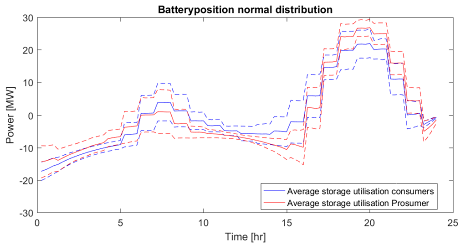


Figure 3: Average consumer versus Average Prosumer strategies

Figure 3 shows the average consumer balancing profile and the average prosumer balancing profile of the storage. The dotted lines corresponds to the line with the same colour and shows the first standard deviation from the average. The conclusion form figure 3 is the average prosumer profile has a higher peak which results in the lowest peak power needed. The difference over the year is in stead of 75 MW for the consumers, the peak demand for prosumers is 65 MW in this simulation.

The implications for the network imbalance are fitted with a Laplace distribution function for which the equation is shown in equation 3.

$$p(x; x_0, b) = \frac{1}{b} \exp\left(-\frac{|x - x_0|}{b}\right) \tag{3}$$

The imbalance volumes can be used to create a histogram of the yearly results. This histogram is shown in figure 4.

In figure 4, the number of occurrences are set out against the imbalance volumes. This gives a histogram of total imbalances over the year. This histogram of total imbalance volumes over a year clearly has a distribution. This distribution can be described as a double exponential distribution which is also known as a Laplace distribution [12]. When fitted over this imbalance histogram, figure 5 is created.

The values represented in equation 3, can be calculated of the fitted distribution. Since, for all distributions fitted in this

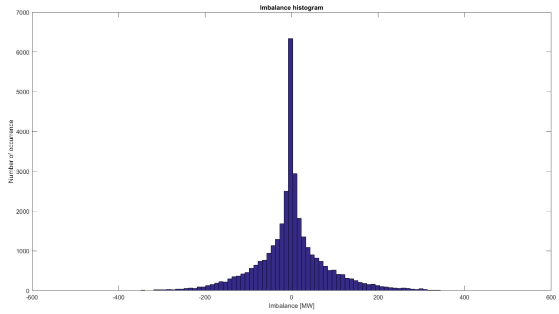


Figure 4: Network imbalance histogram

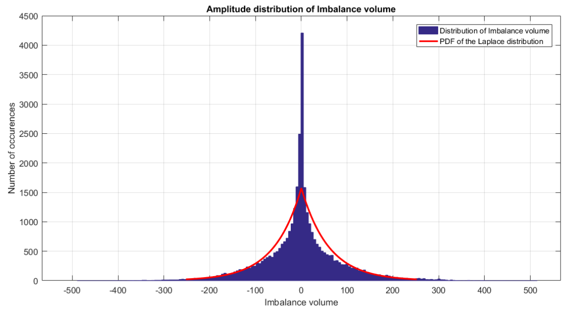


Figure 5: Imbalance histogram with fitted Laplace distribution

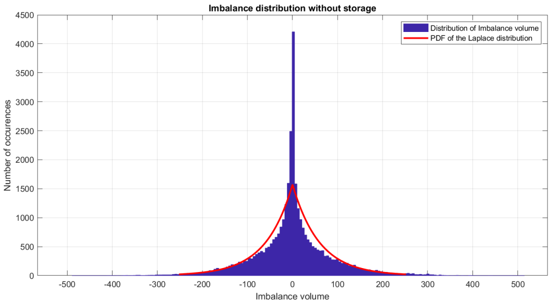
research, the mean is within a small error of zero, the value b will be portrayed as the volatility of the imbalance volumes. This value for the above fitted distribution is 118,8. The closer this value gets to 0 the less volatile the imbalance will be.

The figures show the overall imbalance created by different portfolio's. By fitting a probability density function in these data sets, more detailed analysis of the imbalance can be made.

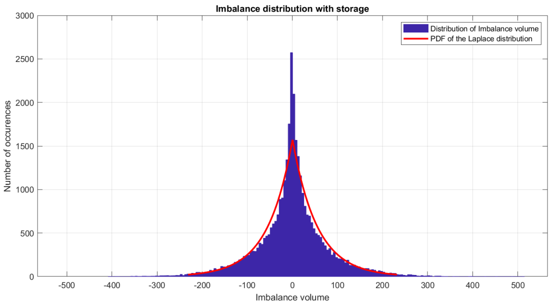
The histograms represent the number of occurrences of balancing market results for each case. Figure 6a represents the realised market imbalances in 2015. Figure 6b shows the simulated market results for the optimisation of a stand-alone storage capacity with revenue optimisation as objective. Figure 6c represents the wind farm case including the storage optimisation. Figure 6d represents the gas turbine case including the storage optimisation. For the consumer side, the results are shown in figure 7a and 7b.

The optimisation of the consumer side is not incentivised by the balancing market prices therefore these figures show little difference. Since the differences are hard to see on the graphs the following table presents the fitted probability density function factors of the Laplace distribution fitting.

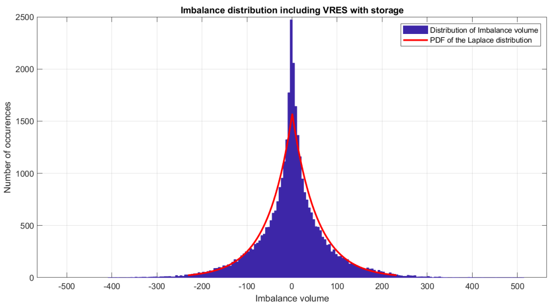
The numbers fitted to the distributions found before and after simulation, result in a negative effect for behind transmission implementation of storage for the overall imbalance in the system under 2015 conditions. While the optimisation of the storage capacity for the balancing market shows better overall performances with respect to network imbalance. At least one conclusion can be determined which is that the use of the balancing market has positive influence on balancing. Since it has



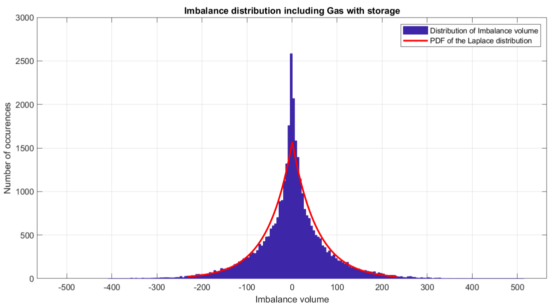
(a) Input imbalance distribution



(b) Base case imbalance distribution



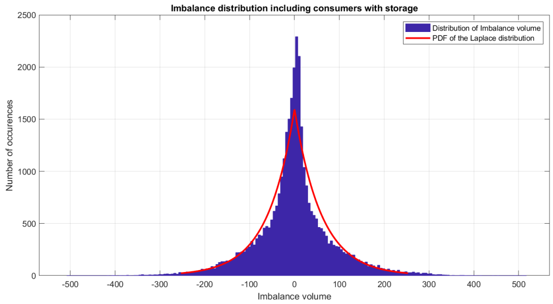
(c) VRES case imbalance distribution



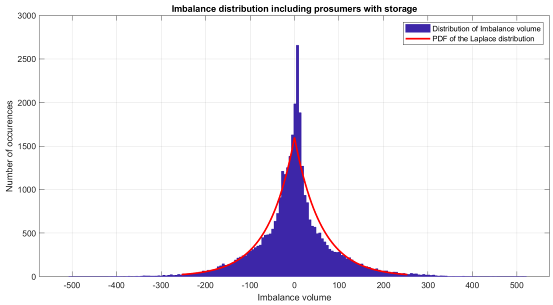
(d) Gas case balance distribution

Figure 6: Simulated imbalances with storage implementation at different operating responsible parties

been designed to do so, it is a working design for the scenario run of the year 2015.



(a) Histogram of imbalances with consumers



(b) Histogram of imbalances with prosumers

Figure 7: Simulated imbalances with storage implementation at different operating responsible parties behind transmission

Table 1: Laplace b-factor per case

B factors	
Input Imbalance	118.79
Base case	109.23
VRES case	109.16
Gas case	109.37
Consumer case	119.37
Prosumer case	119.65

6. Conclusion

After analysing the results of the simulation, some rectification need to be made for the results. These results are made in a model with multiple assumptions such as the all-knowing optimisation of the market to be a realistic operating profile for the storage. Also, the assumption is made that the 20% stochastic deviation of the forecasted power is realistic. All of these assumptions will need a sensitivity analysis. Still some conclusions can be made. First of all, storage optimisations can be divided into two categories. The first category is before transmission since these companies have the same economic structure. Therefore, their use of storage capacity looks very much alike. Still some extra synergy can be found while optimising for the wind farm case due to the variable character of this energy production. The flexibility of the storage capacity is able to shift some load to more favourable imbalance volume periods. The next conclusion can be made is about the added benefit of storage capacity next to extra flexible capacity in the form of a gas-fired power plant. In this case, the storage still optimises with respect to the market and market results are found to be still very volatile even after adding extra flexible capacity. Therefore, even with the decreased benefit with respect to the wind farm case, the balancing still favours the network balance. The second category of storage usage is after transmission. The costs structure changes and therefore an other optimisation has been done. This optimisation does not favour the imbalance of the network but there is not concluded is has a negative effect. The optimisation after transmission results in an average daily cycle for which in the end energy retailers can respond in the market due to this change. This optimisation does favour local distribution networks since the peak demand periods are lowered by substituting network power by storage power. The prosumer case is even more able to diminish the peak power by an extra of 10%. Finally, the research is concluded by concluding; The change of ownership does have influence on the usage of the storage. The biggest difference of storage usage is due to the fact that the cost structure of the owners change due to the location in the network. The storage operational responsibility in the system has influence on the implications of network imbalance volume. To minimise societal costs, the focus on implementing storage capacity should be on the supply side of the electricity system.

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