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Renewable Energy Storage in the Republic of South Africa

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Abstract

The objectives were to perform extensive research on the South African Renewable Energy Storage capabilities and business case. The focus was to investigate the advantages it would bring to the country to invest in energy storage solutions to aid in not only meeting the electricity demand forecast for the next 25 to 40 years, but also focusing on the energy dips, known as the "Duck Curve". This could provide flexibility to the National Grid in parallel with reducing the carbon footprint of the current generating stations and the transmission-and distribution networks by either remodelling them, or to completely replace them with a better solution such as renewable energy with storage. The final expected output of the research would be to develop a basic spreadsheet calculator that is capable of calculating the energy and financial impact it would have when integrating a certain amount of storage into the national grid.

Key words

Energy Storage, Duck Curve, Power, Renewable Energy, Integrated Resource Plan (IRP), Republic of South Africa (SA).

1. Introduction

The objectives of this study are the following: to highlight the importance of storing electrical energy in large instantaneous capacities for both large and small utilization purposes; to investigate other electrical energy storage capabilities and comparing them to what capacity is actually required in SA for the years ahead and to evaluate the South African current resources and storage capabilities. Furthermore, to integrate the possible storage of renewable electrical energy with current technologies by exploring relevant case studies on storing renewable energy in SA and to introduce possible new locations in and more efficient ways of storing renewable electrical energy. Finally, to do a cost comparison/simulation on what benefits would lie in energy storage and build a possible calculator which could assist in showing the financial impact of a selected storage technology.

2. The South African IRP 2010

The South African Integrated Resource Plan (IRP) for electricity is a report that is developed for the energy sector to predict the future expected electrical energy demand of South Africa. The expected energy demand for SA in the year 2030 is between 345 TWh – 416 TWh. This is about 61200 MW peak power which considers the current average economic growth rate from 2013 to 2030 at 5.4% per year. There is uncertainty regarding the future energy demand caused by many variables such as the agenda to overcome the climate change by reducing flue gas emissions, industrial companies relocating, the future power station fuel availability and prices for coal and gas, and finally the cost of nuclear capacity [1].

2.1 IRP Changed Conditions from 2010

Technology options and cost change constantly and the Electrical Power Research Institute (EPRI) submitted a report in April 2012 that reflects the estimated costs for generic technologies indicating how costs have been inflated by South African consumer inflation rates, while Eskom provided a view on pumped storage costs. Uncertainty still lies with nuclear capital costs as there are many estimates and a number of expert studies reflect that the generic nuclear capital costs are between \$3800/kWh and \$7000/kWh. After inflation adjustments from 2010 to 2012, an average of \$5800/kWh was estimated to be the generic calculation for costs. The actual demand for electricity in SA was lower than expected between 2010 and 2013 as reflected in the policy-adjusted IRP 2010, which was based on the System Operator Moderate forecast where the expected energy demand was 270 TWh and only 249 TWh was used. The IRP 2010 assumed for the fleet to have an 86% average availability. This was reduced to less than 80% later on. Eskom introduced a new (80:10:10) planned maintenance strategy which focuses on the most important generators of the fleet, taking into consideration age, run time and MW output, to be maintained first regardless of the demand supply requirements. Eskom added new generators to the National Grid from the Medupi and Kusile power stations as well as from their completed pumped storage scheme Ingula, delivering an added 2670 MW from coal and 1332 MW from the Hydro-scheme. Furthermore, Eskom plans to deliver the rest of Medupi's power by the end of 2020, which are an additional 3560 MW to the grid and Kusile's additional 4450 MW by 2022. As announced on 7 March 2017, they will close down four generating stations because they have reached the end of their life and their negative environmental impact resulting in high flue gas emissions. The stations are the 3000 MW Kriel, 1000 MW Komati, 2000 MW Hendrina and the 1600 MW Camden power stations [1][2].

2.2 Demand Forecast Trajectories

The CSIR Green Shoots forecast predicted a 2.7% average annual demand growth of up to 2030 and a reduction to 1.9% from 2030 to 2050. This result was based on the NDP's average 5.4% GDP growth and was used as the Base Case in the IRP 2010 and most of the other test cases. The SO Moderate forecast was based on the 5.4% GDP growth with less restructuring of the industries which resulted in a 2.8% average annual demand increase up to 2030 and 2.4% from 2030 to 2050. The SO low forecast gave 1.9% to 2030 and 1.5% from 2030 to 2050, based on a 4.5% GDP. The CSIR Weathering and Storm forecast was based on a 2.9% GDP and produced a demand of 1.8% to 2030 and a demand of 1.3% from 2030 to 2050. Optimization runs from the trajectories were done and indicated that demand for new coal generation (with their life extensions added) will remain more or less unchanged because of the emission cap that is in place, leading to a demand of between 2450 MW and 2700 MW for the Green Shoots and SO Moderate predictions respectively [1].

2.3 Climate Change Mitigation

The main reason behind the IRP update was to investigate and consider options that could reduce the use of technologies with carbon emissions when it comes to power generation. Studies have shown that coal fired power station technology in SA will remain the main source of power and continue to emit flue gas at the rate it is now until 2030 when either the old coal stations run out of service and or is replaced by sufficient renewable energy sources or nuclear energy. SA's carbon dioxide emissions up to 2050 are expected to be at 428 MT/a, with a lower limit 212 MT/a. The strategies to reduce emissions are to continue with the original target of 275 MT/a which is not approved by the DEA that wanted a more moderate decline in emissions to reach 210 MT/a by 2050 [1].

2.4 Regional Developments

The policy adjusted IRP reflected 2609 MW of hydropower although it considered an additional 740 MW since more hydropower options have become available. The Inga III hydro project on the Congo River in the Democratic Republic Congo would allow SA to use 2500 MW from the facility. It is assumed to become available in 2025 in the IRP 2010 updated in 2013, but the feasibility is questionable. The Kobong pumped storage scheme in Lesotho, which forms part of the second phase of the Lesotho Highlands Water Project, aimed to provide 1200 MW of pumped storage power from 2023. The study showed that this is not the most cost effective use of capital investment as it is argued to be more of an energy displacement than addition. The other attractive four hydro projects (Boroma, Ithezi Tezi, Kafue and Kariba North Extension) selected between the year 2022 and 2024 could be viable if the original cost assumptions made were true or close to true. The only other option considered for coal in the region was the Botswana Mmamabula Project, which included 1200 MW of power from a fluidised bed combustion option with emission taking place across the border and not considered in our emissions calculation [1][4].

2.5 Embedded Generation

Since PV costs have dropped over the past decade and have become more affordable for residential, commercial and some industrial electricity consumers, more and more will start installing small scale PV power predominantly roof-top mounted to meet some of or all their electricity requirements. The IRP 2010 considers this whilst keeping in mind that not everyone can afford PV installations. Only households with relatively high lifestyles (LSM7 & higher) would be able to afford it, and only 50% of those who can afford it would actually install such technology. The calculations show that PV capacity would increase by 5 kWp annually and the households who can afford it would increase from 40% to 70%, making it 14 million out of the estimated 20 million households who would invest in PV by 2050[1].

2.6 IRP Updates

Until now, the IRP 2010 of SA was updated in 2013 and again in 2016. The main assumptions, base case results and observations are shown in this section. The purpose of the updates is to firstly compare and update estimated forecast with actual results and secondly to inform and invite the public to participate in the update consultation process. In this way the public can provide inputs on the forecast assumptions and assist to get a closer estimate of the future energy demand and possible constraints to achieving the country's energy goals. The CSIR assisted in the energy forecasts and based on their high and low forecasts, the growth rate in 2050 differs by 156 TWh. The CCIR High energy intensity forecast has an annual energy growth of 2.17% and this was used as the base case. The CSIR Low has an annual growth rate of 1.31%. It was calculated that the CO_2 emissions would drop by almost 50% from 2016 to 2050 for the advanced decline estimation and 28% for the moderate decline, which was used for the base case [3][4].

3. Problem Statement

The problem is that with electrical energy, natural fossil fuels such as coal, natural gas and nuclear fuel are burnt to produce heat in a combustor, from where the thermal energy is converted into mechanical energy by means of a steam turbine or other prime mover turning the electric generator to produce electrical energy. In other cases, water's potential energy and wind energy are converted to mechanical energy in a prime mover that will turn an electric generator. Nowhere in the above conversion processes is an option to store the energy provided because South Africa's storage capabilities are very limited and inefficient when it comes to storing electrical power in large capacities. There currently are batteries, inductors and capacitors to store our electrical energy but they are not designed for large operations such as maintaining a whole town's electrical requirements or supporting the national electrical power grid when power demand is at its peak, meaning a battery system or Uninterruptable Power Supply (UPS) for the national grid. Furthermore, since there is a global focus on crossing over to renewable energies, they would like to store renewable energy directly in a place until it is required because at the moment electricity is generated and is used as required which causes problems if demand requires to decrease or increase instantaneously. Pumped storage and CSP with molten salt thermal storage can store energy but with different conditions that to that of a battery storage type which is desired.

4. Benefits of Energy Storage in SA

4.1 Bulk Energy Services

Electrical energy time-shift is when inexpensive electricity is purchased to charge a specified storage system so that the energy can be used or sold later, preferably when the costs are high. Storage is beneficial for time-shift duty since the excess energy is stored, which otherwise would be lost or curtailed, especially from wind or PV sources. Storage efficiency and variable operating costs are important when it comes to energy time-shift transactions of economic merit. This is based on the cost to purchase, the store- and discharge energy costs and any other benefits when the energy is discharged. The number of transactions is very sensitively based on the storage efficiency and storage variable operating costs. Wind and PV can be very usefully optimized with seasonal and daytime energy storage. If energy storage is used correctly, electricity would not always have to be bought from generation via the grid to power auxiliaries for start-up and domestic applications of a certain plant or power station. If operation time is six hours and the storage plant requires to be available for 50% of that time period, the storage plant capacity usually needs to be designed according to plant requirements to meet the desired load [5][6][7][10][12].

4.2 Voltage and Frequency Regulation

Storage acts as a capacitor to the grid and therefore is a good implementation to deal with regulation issues when it comes to ancillary services. The storage system manages the many variations there are within the demand and keeps it more stable within the control area desired. This is very important since the grid frequency needs to be kept at a constant rate of 50 Hz to comply with the specific grid code requirements set by the department of energy and NERSA. Usually without storage, the generation output needs to be controlled to ensure the grid voltage and frequency stays within the desired operating limits. Storage makes the work of the controller, whether it's manual or automatic, much easier to control and it reduces wear and tear on the generation base loads because the generation base load does not shift voltage or frequency as the storage system will just "fill the gaps" or fluctuations by either charging or discharging [5][6][7][10][12].

4.3 Reserves

The spinning reserves are the first backup to the grid as they are already synchronised and just need to be stepped up to export the desired power, Non-spinning reserves are the typical diesel generators such as at Ankerlig Station waiting to kick in when called upon, but are very expensive to run. Both spinning and non-spinning reserves require about ten minutes before it is available. Supplemental reserves are the other station which is not synchronized and takes about one hour to be on load. This is to save on coal and there are already spinning reserves in place to keep the power on until supplemental reserves become available. For energy storage the reserve capacity does not need to discharge as it will act as a UPS to energize transmission and distribution lines. It just needs to be available to discharge when needed most, like after a disastrous failure on the network, with an immediate response time and a 30 minute discharge time to allow reserves to become available. This reduces shock on the grid and again wear and tear on generation base loads. Reactance at a grid level can be challenging and only specific power plants are selected to generate reactive power (VAR) to the grid. A storage system can assist or replace such power plants if strategically placed at central locations or near large loads. Storage systems that are used for voltage support is capable of operating at a non-unity power factor, giving it the ability to sink the reactive power as required and since real power is not needed from the battery in this specific mode of operation. [5][6][7][8][9][10].

4.4 Transmission Infrastructure

Storage is highly desired to perform load following. Most types of storage have the capability to operate at partial output levels with relatively modest performance penalties. The storage creates a smoother transition from the disturbed operation period to return to normal operation. The size of storage systems required for frequency response is proportional to the grid or balancing area needed. Congestion-related costs and charges on transmission can be avoided or reduced by using a storage system in the correct location downstream from the congested area. The energy will be stored when there is no transmission congestion and discharged during peak demand periods. Storage on an overloaded transmission node could postpone the need for an upgrade by a few years and is a benefit to the transmission infrastructure. Storage compensates for electrical irregularities and disturbances such as unstable voltages, voltage sag and sub-synchronous resonance. The main two advantages of transmission support with storage are transmission stability damping and sub-synchronous resonance damping [5][6][7][8][10].

4.5 Distribution Infrastructure

The distribution infrastructure could be upgraded using a storage system. It can be installed to increase the capacity and serve the load requirements during peak periods and thereby extending the life-span of the transformer. Storage can delay a possible over-investment of certain areas in the distribution network where expected growth did not happen. If the storage unit is containerized, it can be relocated to a new desired point or service station, saving on costs. Most distribution nodes only experience high loads for a few hours per day, a few days per year. In these cases storage will be a great benefit with limited or no need to discharge and it will save on charging costs. A storage system can provide voltage support to the distribution lines especially in places where customers cause large load voltage excursions on neighbouring customers in industrial areas. The voltage fluctuations can then be dampened by adding a storage system to the distribution network [5][6][7][8][10].

4.6 Customer Energy Management Services

Storage can protect downstream customers against short-duration events that affect the quality of power these customers receive on their loads and protect them against possible damage and customer dissatisfaction. The events are typical variations in voltage magnitude, harmonics, and interruptions, low power factor due to out of phase voltage or currents and variations from the grid frequency of 50 Hz at which power is delivered in SA. The customer benefits by having the option of full control of the storage system if they own it. Alternatively the utility will own it and treats it as a demand-side to service both the customer and the utilities' needs [5][6][7][10][12].

4.7 Stacked Services

Usually storage used for time-shifting can save on expenses. However, it is very low for initial costs of a storage system and more revenue needs to justify the installation of a storage system. So customers focus on stacked services, meaning the storage system should multiply revenue streams to make it an economically viable solution. Stacked services are dependent on location and many constraints for each system and therefore needs proper planning. Previous storage projects did case studies on how this can be achieved. For the purpose of keeping within the scope of this paper it will not be discussed [5][6][7][10][12].

5. Results

5.1 South Africa's Overall Power Output Results

The data in the results is based on the electricity usage and production of SA during the year 2016 (see Figure 1) and will be used as a basis for further discussions, calculations and assumptions. Also, note that November and December's results were assumed for calculation purposes to be that of high usage months as it was not yet available for the survey.

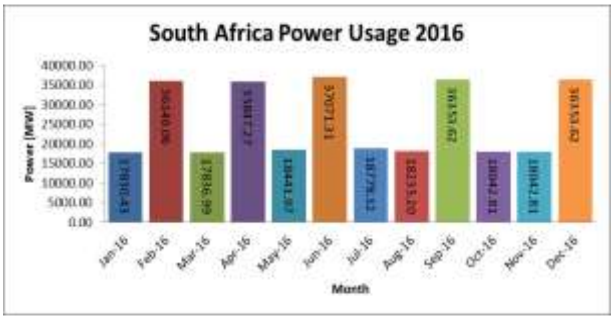

Fig. 1: South Africa's power usage per month for 2016

The information was used as the base for calculations or just an average (25748 MW) value per month over the whole year. In the months where generation is not so high, one can assume what would happen if a certain percentage of that could be stored and used during peak months, days or hours. Furthermore, the power usage or requirements per province during each month says that in SA, Gauteng and KwaZulu-Natal have the highest power usage followed by Mpumalanga and North-West. The total power from IPP's sent to the national grid, roughly 1000 MW each month, comes from IPP's (see Figure 2). On average of let's say 26000 MW, 1000 MW comes from IPP's, that is 3.85%. If the IPP's were operating at full load like most IPP's do for maximum revenue that means that it was their maximum capacity. However, if they were all operating let's assume at 70%, the other 30% could have been stored and sold at a later stage during a peak period. Looking at the months January to August at least 100 MWh in total could be stored.

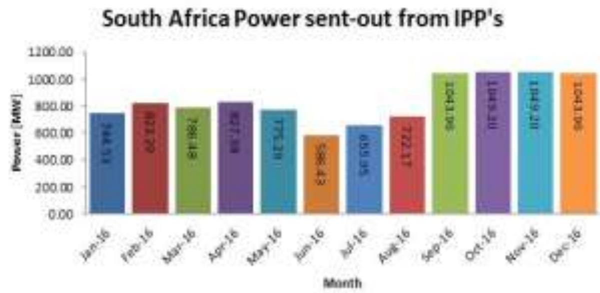

Fig. 2: Power sent-out by IPP's in SA each month of 2016

Based on the latest data received from the IRP 2010 updated in 2016, the forecast result reflects that the expected peak demand will almost double between 2020 and 2050. The same IRP 2010 reflects that the CO_2 emissions should drop below 200 MTons for SA by 2050. However, it will only really start taking effect by 2040 at the current new power plant and technology installation rate. Using the same IRP 2010 data with an added estimated calculation of 100 MWh storage per year added to the grid, this time can be shrunk as shown in Figure 3.

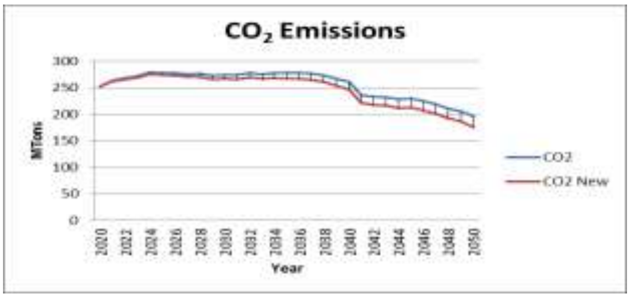

Fig. 3: 2016 updated IRP 2010 CO_2 emissions forecast

The water consumption on more dated coal fire power stations, especially, is very high and can be reduced. This is important as water is becoming a very important resource to protect as water supplies are limited and becoming less and less available due to changing weather patterns across the globe. As shown in Figure 4, one can enter a negative water usage which just means that water will start acting as a reserve rather than a shortage since renewable plants will always use water for maintenance, cleaning and cooling purposes.

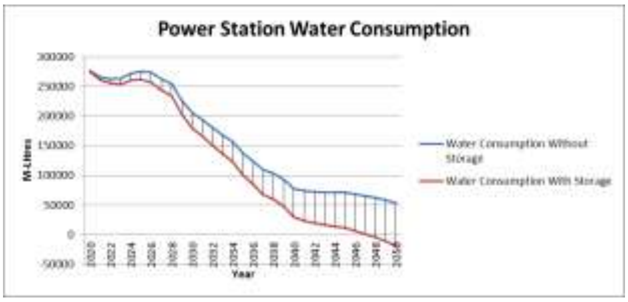

Fig. 4: 2016 updated IRP 2010 water consumption forecast

The firm reserve margin is higher based on the annual 100 MWh storage component added to the grid but is reduces at the same time by the annual increase in the peak demand. In Figure 5 it shows that the difference in Firm Reserves when adding 100 MWh storage to the grid annually.

Fig. 5: 2016 updated IRP 2010 firm reserve forecast

5.2 *Levellised Cost at 8.2% Discount Rate*

The typical load factor and levellised costs of SA's current storage and peaking are reflected in Figure 6. This includes pumped storage, compressed air storage, battery storage and demand response reserves from peaking. Note that the levellised cost for 1-hour Lithium-Ion battery storage is very high compared to the other technologies.

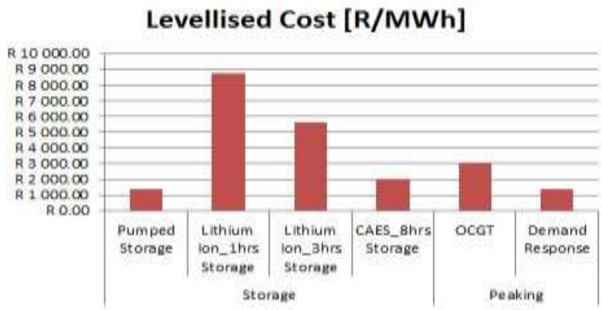

Fig. 6: Storage and peaking levellised cost

For all the renewable plants in SA the typical load factors are shown in the Figure 7 where landfill mass and biogas is the highest dropping down to the lowest which is PV and CSP technologies followed by their corresponding levellised costs.

Fig. 7: Renewables levellised cost

5.3 *Energy Storage Efficiency Calculator Results*

An attempt was made to build an energy storage calculator in MS Excel to establish the benefits there are in implementing a certain amount of storage to the SA grid and the possible cost savings it would have. There are some advantages in CO_2 emission reduction and water consumption reductions over the next 40 years. There were some assumptions made to calibrate the calculators' accuracy and efficiency. For example, with solar, only 8 hours of the daily operation with a "bell-curve" incline and decline in solar power. It is capable of calculating the results over a day or a month. The October 2016 results were used as default calibration stretching over 31 days for a monthly period and 24 hours of a normal day. The calculator is very basic and possibly in future further research; one can develop accurate software to increase the accuracy of calculations. The immediate objective is only to get an estimated financial component and prove that there will be a positive effect in implementing storage of SA's energy business model. For the purposes of this paper only the monthly curves are shown in Figure 8. It shows how the storage reduces the load following responsibility away from coal as more storage is implemented. The curves look very similar to the daily curves with small changes. Mathematically it is megawatts of power being absorbed and released by the storage systems doing the load following parts, enabling the coal base-load stations to run at optimum outputs and taking away the up and down ramping and inefficiencies and the storage graph looking like "white noise" over the period of a month.

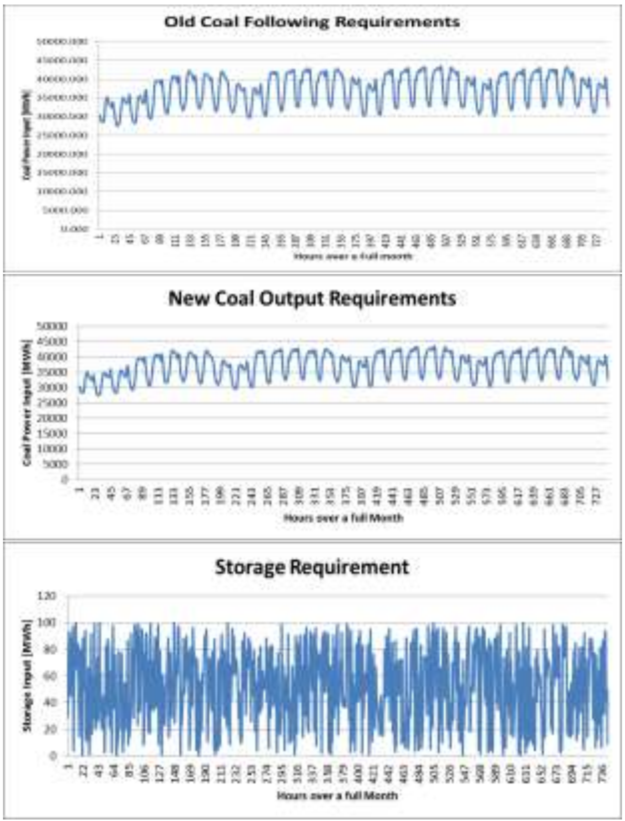

Fig. 8: Monthly results calculation

6. Conclusion

The objective of this study was to highlight the importance of storing electrical energy in large instantaneous capacities for both large and small utilization purposes. It investigated other electrical energy storage capabilities and compared them to what capacity is actually required in SA for the years ahead and to evaluate the SA current resources and storage capabilities. The IRP 2010 updates were investigated and it was found that storage does not form part of the major plan to ensure energy sustainability for SA for the future. Although the renewable energy mix will increase over the next 30 years and will take a large portion of the energy responsibility, it is without storage for now. The only big storage projects SA invested in as to date is pumped storage facilities. Taking into consideration the positive effects storage can bring to the SA National Grid, it is a good idea to implement storage into to the IRP plan as this will provide flexibility to the National Grid and reduce the time it takes to meet the reduction of CO_2 emissions and energy demand forecasts, as well as extend many asset lives of other stations. Furthermore, integrating the possible storage of renewable electrical energy with current technologies is definitely possible as it has been done across the world on other projects with positive results. The new locations in SA for energy storage will have to be evaluated as the storage phenomenon to South Africans is taken more seriously and more resources must become available to assist in this evaluation because the whole transmission and distribution grid will have to be considered as well as geographical locations. Battery technology is used on platforms that include households, small businesses, e-mobility (vehicles), railways, etc. SA, compared to other countries is lagging far behind and will most probably, according to us, only catch up by 2030 when the energy race will become entirely green. Investors will need to consider larger hydro projects such as the Inga project, possibly with storage units in the future, to give each neighbouring country a backup supply. This research used real data from 2016 and showed how energy storage could reduce load following requirements from base load stations and emergency reserves and the savings that are possible in terms of costs, time and equipment life time. A basic energy storage and cost savings calculator was built in MS Excel which is useful to do basic estimates.

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