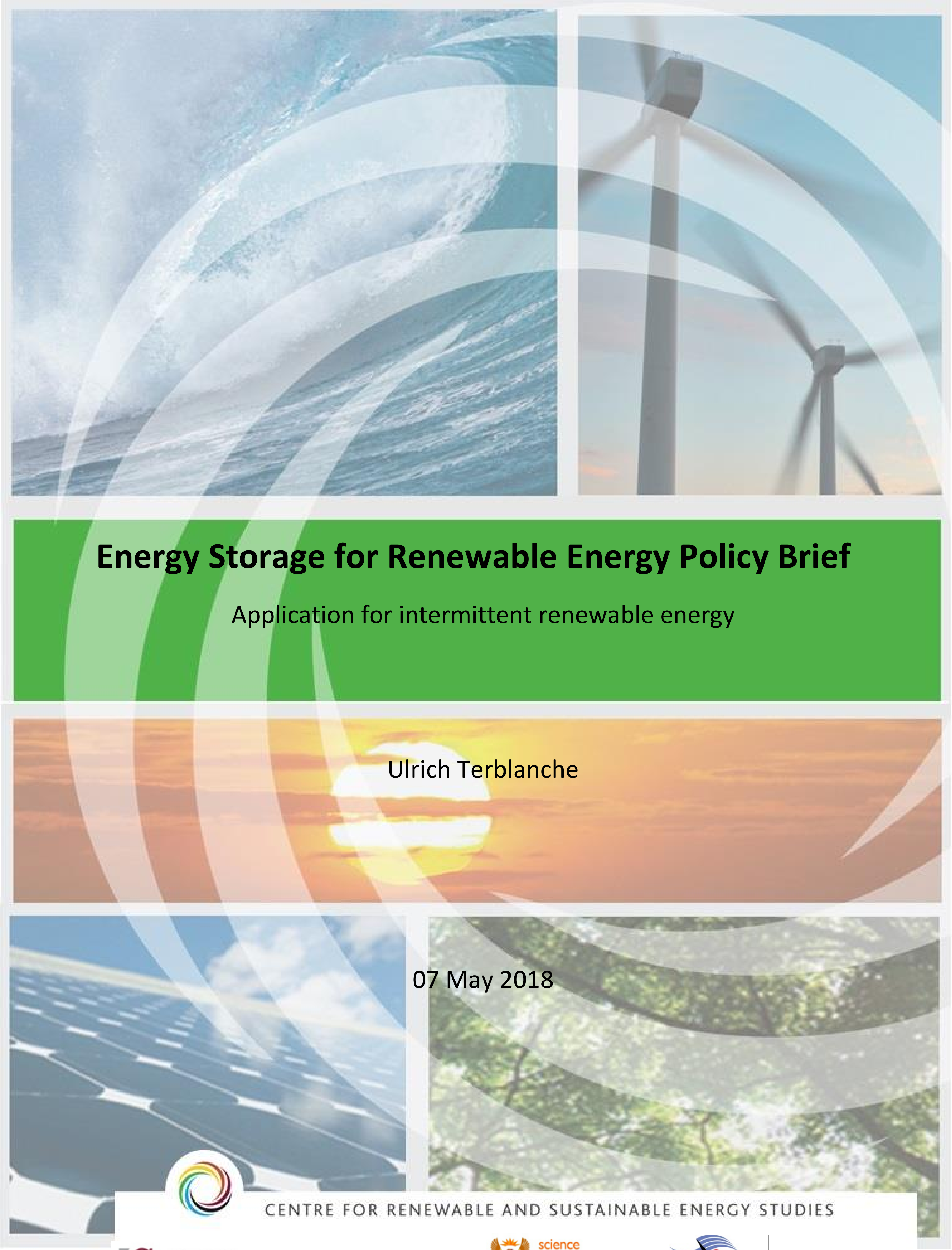

Energy Storage for Renewable Energy Policy Brief

Application for intermittent renewable energy

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CENTRE FOR RENEWABLE AND SUSTAINABLE ENERGY STUDIES

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CAES	Compressed Air Energy Storage
CRSES	Centre for Renewable and Sustainable Energy Studies
CSP	Concentrated Solar Power
dti	Department of Trade and Industry
IDC	Industrial Development Corporation
PV	Photovoltaic
REFC	Regenerative Fuel Cells
REIPPPP	Renewable Energy Independent Power Producer Procurement Programme
SMES	Superconducting Magnetic Energy Storage
T&D	Transmission and Distribution
USA	United States of America

Introduction

South Africa embarked on a programme to increase its renewable energy sources, called the “Renewable Energy Independent Power Producer Procurement Programme” (REIPPPP). The target has been set to increase the capacity of renewable energy to 3 725 MW, but later adjusted upwards to 6 725 MW, which includes a combination of resources and technologies. Over 98% of the capacity will come from solar and wind energy projects.

Renewable energy technologies utilizing wind and solar energy have variable and intermittent output capabilities, which are unlike the dispatchable sources used for the majority of electricity generation in South Africa. The variability of these sources has led to concerns regarding the reliability of the South African electrical grid, as well as the cost of reliably associated with the integration of large amounts of variable generation. The intermittency of renewable energy technologies, such as wind turbines and photovoltaic (PV) arrays, presents a major obstacle to their extensive penetration into the grid (Rugolo & Aziz, 2012). Since the wind doesn’t always blow and the sun doesn’t always shine at any given location, there has been an increased call for the deployment of energy storage as an essential component of future energy systems that use large amounts of variable renewable resources (Denholm, et al., 2010).

Energy storage technologies are valuable in most energy systems, with or without high levels of variable renewable energy generation (International Energy Agency, 2014). South Africa should support investments in research and development for early stage energy storage technologies and improvement or further exploitation of more established energy storage technologies, such as pumped hydro storage, compressed air storage, flow batteries, Li-Ion batteries, fuel cell technologies and thermal energy storage systems. Furthermore, the country should increase research into these technologies and expand the existing plants to implement and investigate the technology in a large-scale renewable energy context. The research should focus on reducing the costs, increasing localization of equipment, exploiting more resources and improving the efficiency of the technologies.

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1: Introduction to Energy Storage

Energy storage technologies absorb energy and store it for a period of time before releasing it to supply energy or power services (International Energy Agency, 2014). These technologies allow for the decoupling of energy supply and demand, providing a valuable resource to operators.

Energy can be stored in various mediums, including electrochemical, kinetic, electrostatic, thermal, among others. The mediums are utilized through technologies such as secondary chemical batteries, flywheel, molten salt and others, as discussed in next chapter. The value of energy storage technologies is found in the services that they provide at different locations in the energy system. These technologies can be used throughout the electricity grid, in dedicated heating and cooling networks, and in distributed systems and off-grid applications. Furthermore, they can provide infrastructure support services across supply, transmission and distribution, and demand portions of the energy system. They can serve as valuable tools for operators in systems with supply side variability, as is the case for many renewable energy systems. (International Energy Agency, 2014)

Energy storage has various applications, as defined by (International Energy Agency, 2014): seasonal storage; arbitrage or storage trades; frequency regulation; load following; voltage support; black start; transmission and distribution (T&D) congestion relief and infrastructure investment deferral; demand shifting and peak reduction; off-grid; variable supply resource integration; waste heat utilisation; combined heat and power; spinning and non-spinning reserve.

Energy storage applications are often divided into three categories, based on the length of discharge. Table 1 indicates the three regimes of energy storage applications commonly discussed. (Denholm, et al., 2010)

Table 1: Three classes of energy storage (Denholm, et al., 2010)

Category	Application	Discharge Time
Power Quality	Transient Stability and Frequency Regulation	Seconds to Minutes
Bridging Power	Contingency Reserves and Ramping	Minutes to an hour
Energy Management	Load Leveling, Firm Capacity and Transmission and Distribution (T&D) Deferral	Multiple hours

The first two categories of energy storage applications in Table 1 corresponds to a range of ramping and ancillary services, but do not typically require continuous discharge for extended periods of time. In the case of renewables-driven applications, this could require discharge times of up to about an hour to allow fast-start thermal generators to come online in response to forecast errors, referred to as “bridging power”. The third category (energy management) corresponds to energy flexibility, or the ability to shift bulk energy over periods of several hours or more. (Denholm, et al., 2010)

High penetration of renewable energy may require fundamental changes to the grid in the form of energy storage technologies to accommodate the increased variability of net load and the limited coincidence of renewable energy supply and normal electricity demand (Denholm, et al., 2010).

Wind power output has fast ramping requirements during the entire week and during any given day. Common problems in remote wind production areas include low capacity factors for all the wind farms, impacts of line contingencies on wind farm operations, curtailment of wind farm outputs during hight production times and high ramp rate requirements (Enslin, 2010).

In most urban regions, PV flat-plat collectors are predominately used for solar generation and can exhibit power production fluctuations with a sudden (seconds time-scale) loss of complete power output. Partial clouding effects on PV array results in large power fluctuations which also affects the output of the PV solar farm with large power quality impacts on distribution networks. Fast ramping and fast power balancing, achievable with storage technologies, is required to avoid this affect. (Enslin, 2010)

The only way to turn naturally fluctuating wind or PV electricity into a dispatchable electricity sources is to have a balancing capacity (Rugolo & Aziz, 2012) in the form of energy storage systems.

2: Electrical Energy Storage Technologies

Energy storage technologies available for large-scale applications can be divided into four types: mechanical, electrical, chemical and electrochemical. Pumped hydroelectric systems account for 99% of worldwide energy storage capacity, with compressed air at a distant second (Dunn, et al., 2011).

Most technologies are still in the early stages of development, with only a few having reached maturity (International Energy Agency, 2014). Energy storage technology covers a wide spectrum, with the most mature technologies summarized from (Soloveichik, 2011) and (Denholm, et al., 2010) in the following table:

Table 2: List of energy storage technologies

Technology	Description	Status
Compressed Air Energy Storage (CAES)	CAES technology is based on conventional gas turbine technology and uses the elastic potential energy of compressed air. Energy is stored by compressing air in an airtight underground storage cavern or above ground vessel. To extract the stored energy, compressed air is drawn from the storage vessel, heated and then expanded through a high-pressure turbine.	CAES demonstration plants have been around for many years and some are still operating after 30 years.
Flow Batteries	Large batteries consisting of two liquid electrolytes (stored separately) that are pumped through an electrochemical cell in which chemical energy is converted to electricity.	Flow batteries is a recently commercialized technology with large capacity potential and deep discharge cycles capabilities, with various industrial scale installations globally and in South Africa.
Flywheels	Flywheels store energy in the form of rotating kinetic energy (Lin, et al., 2013). It features rapid response and high efficiency, making it well suited for frequency regulation.	Several flywheel installations are planned or deployed to take advantage of high prices in frequency regulation markets in the USA.
Pumped hydro storage (PHS)	The energy of the water is stored in a reservoir, as soon as electricity demand increases; the water is released from an upper reservoir to a lower reservoir through a turbine connected to an electrical generator. When the demand reduces, electrical energy is drawn from the grid to reverse the turbines	It's very mature technology, currently the largest energy storage system available, both globally and in South Africa.

	functionality from a turbine to a pump. The upper reservoir is refilled from the lower reservoir and the cycle repeated.	
Regenerative Fuel Cells	RFC using hydrogen can operate as both a fuel cell and an electrolyzer. Stored oxygen electrochemically oxidizes hydrogen to generate power.	There are pilot projects available globally and in South Africa, although this technology is not yet commercially viable.
Superconducting Magnetic Energy Storage (SMES)	SMES stores energy in a magnetic field in a coil of superconducting material. They are similar to capacitors in its ability to respond extremely fast, but it is limited by the total energy capacity.	SMES is restricted to power applications with extremely short discharge times. Several demonstration projects are deployed.
Secondary Batteries	Rechargeable storage batteries which are electrically connected electrochemical cells, such as lead-acid, Lithium-Ion, nickel-cadmium and nickel-metal hydride batteries.	A diverse and well established technology used in both small scale and large scale energy storage applications. Recent growth experienced in grid storage application for Lithium-Ion battery systems in the USA.
Thermal Energy Storage	Thermal energy is stored from the sun and later converted into electricity in a conventional thermal generator. Another example is converting electricity into a form of thermal energy that later substitutes for electricity use such as electric cooling or heating.	The storing of thermal energy from the sun is associated with CSP plants, with multiple plants operating internationally and in South Africa.

The above list only includes the most popular developments available in publication. There are many other different technologies or variations of the above being researched which are not listed. The various technologies each offer different benefits which make them suitable for specific applications. As an example, quick response times (electricity supply within seconds) are essential for power quality application whereas power management application requires a relatively slow response time (hours) (Soloveichik, 2011). The applicable uses are shown in Figure 2. (Dunn, et al., 2011)

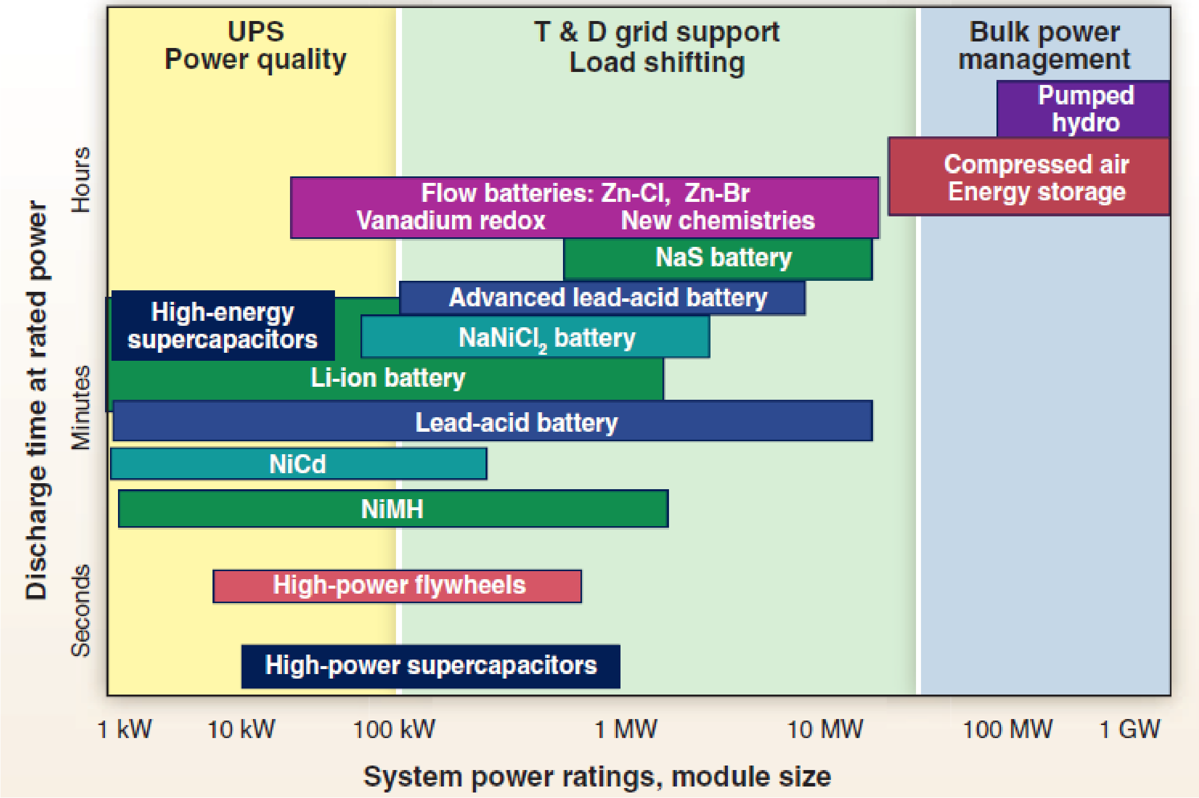

Figure 1: Comparison of discharge time and power rating for various technologies (Dunn, et al., 2011)

Variable supply resource integration, such as for renewable energy, require large (1-400MW) capacity with variable discharge duration, 1minute to hours, and a fast response time, less than 15 minutes (International Energy Agency, 2014). Based on Figure 2, the most suitable storage systems for renewable energy are flow batteries, secondary batteries such as lead acid and lithium-ion batteries, pumped hydro storage and compressed air storage. In order to reduce the effect of intermittent supply from renewable energy sources, the energy storage technology should be located near the renewable energy power plants.

Pumped hydro storage is highly dependent on the landscape topography; limiting its viability for installation to only selective locations. Similarly, CAES store compressed air in large reservoirs, typically making use of existing geological formations and structures, such as salt caverns, aquifers and abandoned mines (Abbaspour, et al., 2013). Both these technologies can function as power management systems on a grid level, but is not sufficiently portable for implementation at project sites. Although, according to (Abbaspour, et al., 2013) among many energy-storage systems, only pumped storage and CAES systems have the capability for large-scale wind energy systems integration.

According to a (Rugolo & Aziz, 2012), solid-electrode secondary batteries are shown to have two orders of magnitude too little energy to power ratio to be well suited to storage of intermittent renewables. This does not mean that they are unusable, on the contrary, if enough battery energy is incorporated to serve in an intermittent storage scenario, the batteries would be vastly overpowered (oversized). The cost of such an overpowered storage system has kept it from broad implementations (Rugolo & Aziz, 2012). Although, multiple grid storage systems for Li-Ion batteries have been installed in recent years.

Flow batteries and regenerative fuel cells have a significant advantage over solid-electrode secondary batteries. The power and energy capacities of these sytems are separate engineering choices. The power capacity is set by the cell hardware, which is typically the most expensive. The energy capacity is set by the amount of reactant and product and the size of their respective storage tanks. Due this decoupling characteristic, one may independently size the power and energy subsystems to be appropriate for the desired scenario. (Rugolo & Aziz, 2012)

It should be noted that this chart does not include thermal energy storage, which would cover a power range of a few kilowatts (kW) for thermal energy storage in buildings to more than 100 MW in CSP plants, with a discharge time of minutes to several hours (Denholm, et al., 2010). Thermal energy storage is sometimes ignored as an electricity storage technology because it’s typically not used to store and discharge electricity directly. However, in some applications, thermal storage can be functionally equivalent to electricity storage (Denholm, et al., 2010), such as its use in concentrated solar power, where solar energy is used to heat up a working fluid/gas. The heat can then be stored in molten salt or other mediums with a high heat capacity and extracted during low solar output periods. The storage capacity is dependent on the facility size. In the case of thermal storage, the function is not to fill intermittent solar energy, but rather to extend the operation of the plant to hours beyond the normal daylight hours. It is therefore used for ensuring continuous supply and not for balancing variability.

3: Energy Storage in South Africa

In South Africa, the most commonly found energy storage application is grid management using pumped hydro storage. Following the installation of concentrated solar power plants from the REIPPPP, thermal storage has increased in its capacity and importance, as can be seen in Figure 1.

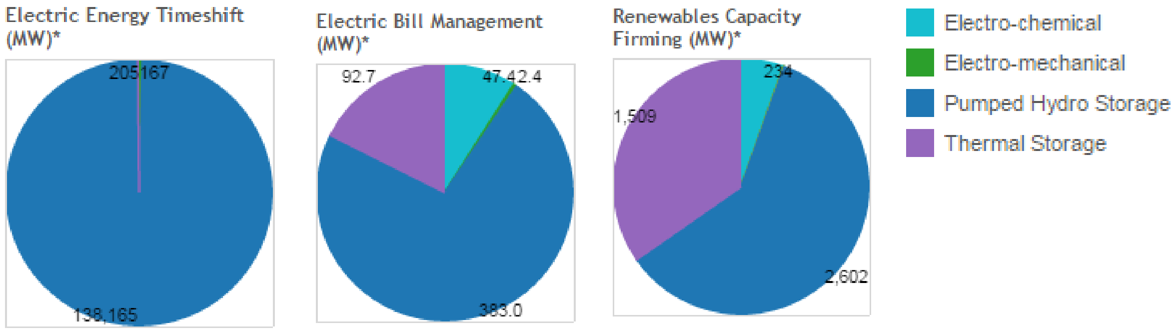

Figure 2: Energy storage in South Africa, (Source: www.energystorageexchange.org)

South Africa is host to multiple industrial scale energy storage demonstration and operating plants. Among the demonstration projects is the Chamber of Mines of South Africa's platinum fuel cell, installed in December 2014. The project was implemented in a partnership between the Department of Trade and Industry (dti), the Industrial Development Corporation (IDC), Egoli Gas and Mitochondria Energy Company.

Numerous small scale battery backup systems using chemical batteries exist in South Africa, with a large number of these installations conducted as part of rooftop solar PV installations. There are also larger flow battery installations installed at industrial facilities to provide energy during load shedding.

A number of grid scaled energy storage plants are also available in South Africa, mostly pumped storage and thermal energy storage plants. Eskom is currently operating two pumped storage schemes, namely Drakensberg and Palmiet. Both these power plants are used to supply electricity during peak demand times, the Drakensberg scheme has a 1 000 MW capacity and the Palmiet scheme has a 400 MW capacity. Kaxo Solar One is a 100 MW capacity CSP plant built by Abengoa Solar, located near Pofadder in the Northern Cape Province. The plant incorporates a 2.5 hour storage system using molten salts. The thermal storage allows the plant to operate beyond the normal daylight hours.

4: Cost of Storage

The economic question of energy storage technologies is very complicated, as it requires the intersection of a detailed technical understanding of the storage devices with a profound understanding of the markets, most of which have yet to be demonstrated on any significant scale. An in-depth economic analysis requires answers to questions such as how much storage is required to match a given intermittent source, what efficiency can be expected, and what are the costs. (Rugolo & Aziz, 2012)

As stated before, only a few storage technologies have been deployed at large scale (greater than 100 MW). Estimated prices for emerging technologies may be for a semi-custom product (and consequently very high) or projected costs based on mass production (and perhaps overly optimistic) (Denholm, et al., 2010). As with any generation technology, large variations in prices occur from year to year due to commodity prices and the global economy. Therefore, cost estimates of storage technologies from different years may reflect market conditions as opposed to real differences. (Denholm, et al., 2010)

Storage technologies offer different classes of services and are comprised of an energy component and power component. The total cost of a storage device includes both components, with the limits of the target application. As a result, a direct comparison of a PHS device with a flywheel, for example, has limited value (Denholm, et al., 2010). However, cost comparisons have been done by (van Niekerk & Hameer, 2015), the most relevant cost parameters are listed below.

Table 3: Capital energy cost for energy storage systems

Technology	Capital energy cost [ZAR/kWh]
Advanced lead acid batteries	3 000 – 5 000
CAES	1 000 – 2 000
Flow batteries	5 000 – 20 000
Li-ion	9 740 – 66 000
NaS	3 000 – 13 000
Pumped hydro storage	1 000 – 5 000
Thermal energy storage	30 - 800

From Table 3, thermal energy storage, compressed air energy storage and pumped hydro energy storage have the least capital energy cost compared to batteries (van Niekerk & Hameer, 2015). It should however be noted that the data was collected from the year 2010 to 2013, as the technology is rapidly changing in the field of energy storage more recent data should be used (van Niekerk & Hameer, 2015).

Conclusions and Recommendations

The only way to turn naturally fluctuating wind or solar resource technologies into a dispatchable electricity source is to incorporate another dispatchable source of electrical energy in the form of elecrtical energy storage. The reduction in intermittency on the grid can allow for more renewable energy penetration but it will come at a cost.

The most suitable technologies for the South African renewable energy plants are identified as:

- Compressed Air energy storage
- Pumped Hydro Storage
- Flow Batteries
- Regenerative Fuel Cells
- Advanced secondary batteries, such as Li-Ion based batteries

Due to the diverse functionality, technology and requirements, it is not possible to accurately determine the costs of the various technologies. There are also no grid scaled installation available to source costings from in South Africa or surrounding regions with international installation costs not openly accessible or not sufficiently recent.

It is recommended that South Africa focus on further research into the most suitable technologies in order to reduce the cost and improve the marketing ability. The technologies indicated either consist of multiple mechanical parts or relies on precious metals, such as platinum and palladium, found in South Africa. Therefore, sufficient scope for localized sourcing of materials and parts for manufacturing of the systems is available.

Where pilot plants already exist, it should be carefully monitored and the data made available to academic institutions in South Africa to advance research and contribute to the improvement of the technologies. Furthermore, pilot plants should be investigated at a utility scale, specifically for solar PV and wind power plant integration.

Thermal storage, as used by the CSP plants, has a potential to become more cost effective, with an abundant solar resource in South Africa and the increasing capacity added through the REIPPPP. Therefore, the opportunity exist to research and develop cost effective and locally applicable thermal storage solutions. (van Niekerk & Hameer, 2015)

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