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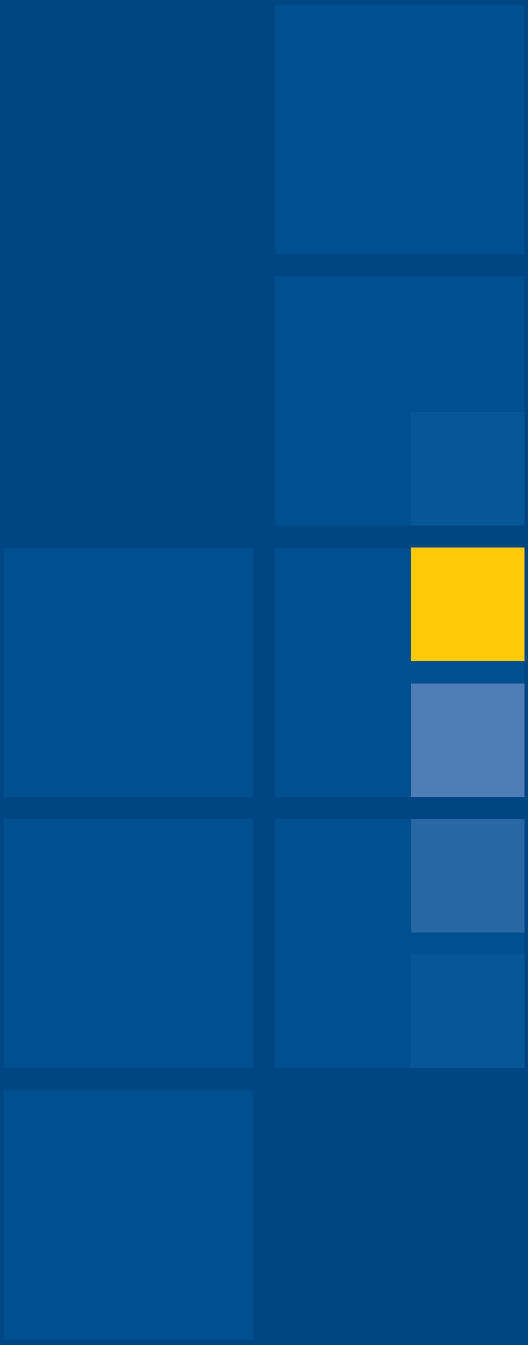
Detlof von Oertzen
May 2018



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Energy Storage Systems and their Applications in Namibia's Electricity Sector

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FOREWORD

Dear cherished reader,

Coming across this publication, the question of why a political foundation such as Konrad Adenauer Stiftung (KAS) takes interest in the topics of renewable energies and climate change is likely to arise sooner or later. At first glance, these issues don't seem to have an immediate link to the initial mission of KAS, which, in its essence, deals with the fostering of Democracy and Social Market Economy values, the strengthening of the Rule of Law, Human Rights and Gender Equality and the creation of an International Political Dialogue, through the means of civic education and the offering of platforms of different scales. However, closer inspection proves that renewable energies and climate change are inseparably connected to most of the above-mentioned topics and directly interact and influence them on numerous levels. This becomes obvious when looking at some exemplary links between renewable energies, climate change and

- Social Market Economy: Global warming and the increasing occurrence of extreme weather events such as droughts or floods already threaten uncountable livelihoods and equitable economic participation all over the world. Renewable energy technologies, on the other hand, hold an immense potential to create new decentralized employment opportunities and enable access to electricity as an important foundation of sustainable socio-economic development.
- Human Rights: The access to clean water, electricity and food security is a basic human need and a fundamental right, which will (continue to) be severely threatened by the effects of climate change. Against this backdrop, renewable energies will play a crucial part in respective mitigation strategies and approaches.
- Democracy: Democracy depends on political participation in order to be and act as a true representative of its people. This includes the access to information, communication with elected representatives and the opportunity of expressing political opinions freely – processes which, in our digital age, are only possible if access to electricity and the internet is guaranteed.
- International Dialogue and Cooperation: Climate change is a global challenge; therefore, the approach of addressing and mitigating climate change also needs to take place on a global scale. In the light of the common threat of the very basis of our existence, international cooperation and mutual efforts gain more significance than ever before.

With this in mind, we consider the dissemination of relevant information through public platforms and publications such as the one at hand as an important contribution to awareness-raising, strategic planning and sustainable policy making. This book is part of a triumvirate of publications which deal with the subjects of "Smart Grids and their potential in Namibia's electricity sector", "Economic Impacts of the deployment of renewable energy technologies in Namibia" and "Energy Storage systems and their applications in Namibia's electricity sector", which look at the status-quo of renewable energy technologies, their potential and current applications in Namibia. Against this backdrop, I would like to express my gratitude to author Dr. Detlof von Oertzen and implementation partner Mr. Harald Schütt; without their invaluable expertise and input, these publications would not have been possible.

Sincerely,

Thomas W. Keller
Resident Representative
KAS Namibia-Angola

1 BACKGROUND

Electricity is one of the key underpinnings of modern life. Yet, the generation, transmission, distribution and supply of electricity is neither trivial, nor inexpensive. While there are numerous important issues to consider before electricity can reliably be supplied to end-users, two aspects are particularly noteworthy:

a) Electricity that is to be consumed must be available in the first place. In other words, electricity is consumed at the same time as it is supplied. While this statement is strikingly simple, it emphasises a critically important characteristic of an electricity supply system, namely that the electricity supply must be matched with the momentary electricity demand at all times. In case the supply and demand are not matched, they are unbalanced, which implies that the quality of supply is affected, which in turn may negatively affect the appliances of electricity end-users as a result of voltage and/or frequency changes.

b) Most contemporary electricity supplies are centrally generated. This means that a few large-scale electricity generation units are used to supply the electricity needed. Because, in most cases, the locations where electricity is generated are often far away from where it is eventually consumed, electricity must be transmitted, distributed and supplied to end-users. This top-down supply approach characterises most modern electricity supply systems, and necessitates that suitable electricity grid infrastructure is in place to transmit the electrical energy from where it is generated to where it is consumed. Electricity is transmitted by electricity grids, which connect generating units to consumers. Collectively, the system comprising generation units as well as transmission and distribution systems are referred to as the power system.

The two characteristics of contemporary electricity supplies described above are not new, and generations of electrical engineers have perfected the current power system and the practices by which it is managed.

However, as technology advances, new electricity generation and supply models are developed. These may, in time, change long-held belief systems, and change operating realities. Of cardinal relevance to this paper is the significant erosion of prices of electricity supply equipment powered by renewable energy resources, such as the sun and the wind. This technology leap has not yet played itself out in full, yet, already today, both solar photovoltaic and wind electricity generation is cost-competitive with most other electricity generation supply technologies in use.

As the sun does not always shine, and the wind does not always blow, the electricity supply from such intermittent generation sources cannot always be matched with the prevailing electricity demand. This fact motivates the topic of the present paper: modern energy storage systems could address many of the challenges that arise when switching from an electricity supply mix that is dominated by steady electricity generation supplies, to a future supply mix in which some of even most of the electricity supplies are replaced by intermittent generation sources.

The above scenario is of cardinal relevance and importance to Namibia. Presently, the country meets more than 60% of its electricity supplies by way of imports, while only having a handful of local generation sources powered by intermittent renewables, most notably by run-of-river hydropower and solar photovoltaics. This situation will change, as several Independent Power Producers are gearing up to provide supplies generated from intermittent sources. This could, following the more traditional approaches used by electricity utilities throughout the world, necessitate significant investments in generation capacities that can be called upon as and when intermittent supplies do not deliver. An alternative to this approach is the use of modern energy storage systems: storing energy when available, and releasing it when needed.

Today, a wide variety of energy storage options are available, and can play an important role in shaping Namibia’s electricity future. The present paper highlights some important potentials introduced by modern energy storage technologies, and reflects on their applications and use in Namibia’s electricity industry.

2 PURPOSE AND SCOPE OF THIS PAPER

This paper provides a brief overview of some of the state-of-play energy storage technologies, which may become important in the effective integration of various generation options into Namibia's electricity supply mix, and in this way, pave the way towards the effective integration of intermittent renewable energy supply options into the country's power system.

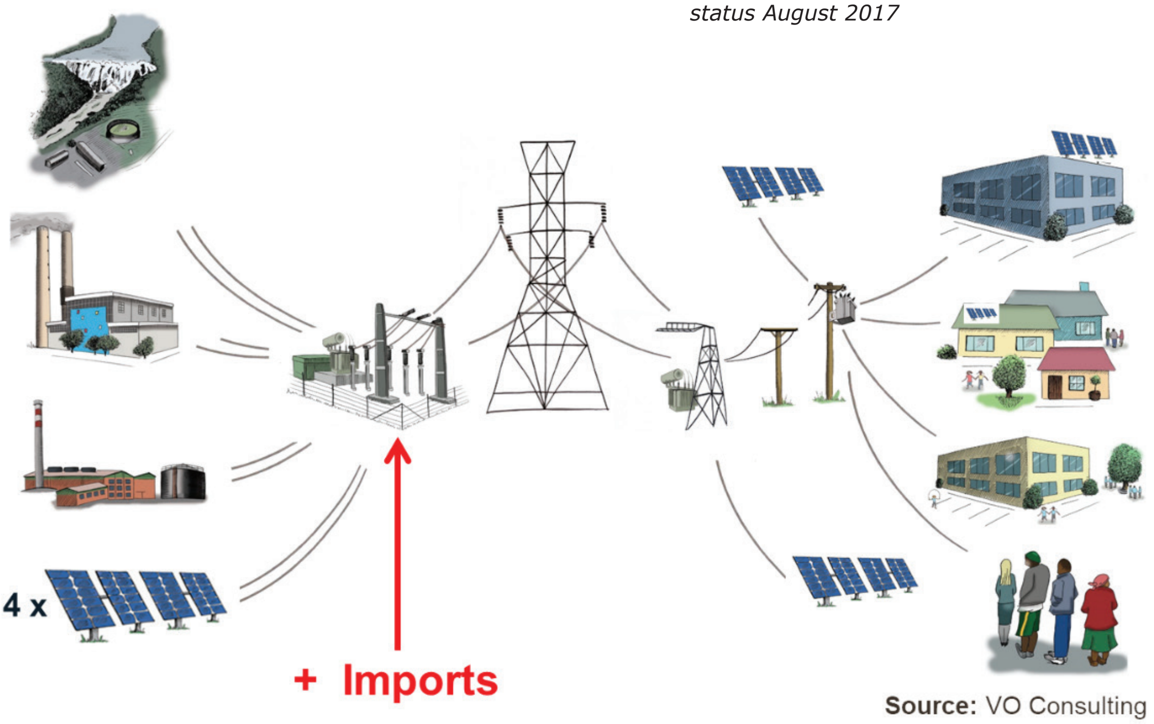
This paper is structured as follows:

- Section 3 briefly describes the broader context in which the Namibian electricity sector operates today;
- Section 4 provides a brief introduction to the general theme of energy storage and its relevance to Namibia's electricity supply system;
- Section 5 presents an overview and classifies modern energy storage systems;
- Section 6 summarises the main roles, relevance and applicability of contemporary energy storage systems and technologies;
- Section 7 reflects on important actual and potential uses of modern energy storage systems;
- Section 8 provides a brief overview of the costs of current energy storage systems, and their likely future development;
- Section 9 reflects on the development prospects of energy storage systems; and
- Section 10 concludes this paper, and pre-sents some high-level recommendations.
- A reference section lists the main sources of information that were consulted in the preparation of this paper.

3 NAMIBIA'S ELECTRICITY SUPPLY SECTOR IN CONTEXT

Namibia's electricity supply system, as depicted in Figure 1, comprises an installed generation capacity of some 509MW (ignoring the Paratus), and includes a transmission system spanning some 11 560km, a distribution system of some 22 115km. In 2017, the electricity system's peak demand amounted to 638MW (status as at end-August 2017, and excluding the demand by Skorpion), and the country is expected to consume some 4.4TWh in the financial year 2017/18, of which some 60% are imported.

Figure 1: *Namibia's electricity supply system, status August 2017*



Source: VO Consulting

The country's electricity sector, similar to the electricity sectors in other countries, faces significant changes. Amongst these are nine factors that we will call the "9 Ds", i.e.

- Decline of renewable energy technology costs;
- Decentralisation;
- Displacement of traditional supply options;
- Decarbonisation and incentives to clean the energy supply system;
- Demand side measures and demand responses;
- Digitalisation;
- Democratisation of ownership across the sector;
- Decoupling of consumers deciding to go it alone; and
- Disruption of traditional markets.

There is nothing fundamental in the list of the above D's, except that each one of these factors could bring about a substantial change in the sector and its evolution. However, when realising that many of the forces of change are not emerging alone, but rather in combination with other forces of change, their collective ability to completely change the electricity sector and the business models that underpin the sector in its present form become apparent.

The 9 Ds express that the electricity sector as we know it will change, with some of these changes expected to radically alter the face of the industry as a whole. In addition to these forces, there are some potential game changers that must be recognised as well. These game changing aspects include the following:

- the unprecedented availability of funding to support clean energy initiatives, inclu-ding through the Paris Climate Agreement
- the increasing demand by end-users to participate in the self-supply of electricity;
- the emergence of electric mobility;
- the arrival of smart grids; and
- the rapid development and arrival of cost-effective energy storage systems.

This paper focuses solely on the last of these potential game changers, i.e. the development and arrival of cost-effective energy storage options. It must be recognised, however, that some of the above forces of change will unfold their impact by arriving as if miraculously synchronised.

We can therefore not afford to merely prepare for the electricity sector's future by focusing on any one of the above factors. Rather, we have to be mindful that these forces' speed-to-market and mutually reinforcing nature will be what has to be effectively dealt with, if the disruption that their arrival will herald is to hold benefits for Namibia and its socio-economic development.

4 INTRODUCTION TO STORAGE SYSTEMS FOR ENERGY

Energy storage technologies absorb and store energy, and release it on demand. In this way, energy storage technologies can become an integral part of a modern power system. Indeed, such technologies can become the central link in future electricity supply systems, by bridging the spatial and temporal divide that often exists between electricity supply and electricity demand: as electricity supplies are seldom located where they are used, a spatial gap between generation and use is common. Also, as some electricity generation technologies are only available at certain times, a temporal gap between the supply of electricity and its demand may exist. In both instances, energy storage technologies can be most useful, and increasingly lead to their integration in both centralised as well as distributed electricity systems. In this way, and through the deliberate application and use of energy storage systems, electricity supply systems can be diversified, thereby also enabling the increased uptake of intermittent generation sources, such as those from solar photovoltaic systems, wind energy converters, and other non-firm supplies.

Energy storage technologies have the potential to address several of the key challenges faced by today's electricity suppliers as well as consumers. Specifically, and from the point of view of an electricity utility or Independent Power Producer, methods must be found to ensure that intermittent generation sources can more readily be integrated into the main supplies. This is particularly important in a country such as Namibia, which has abundant but under-exploited renewable energy resources.

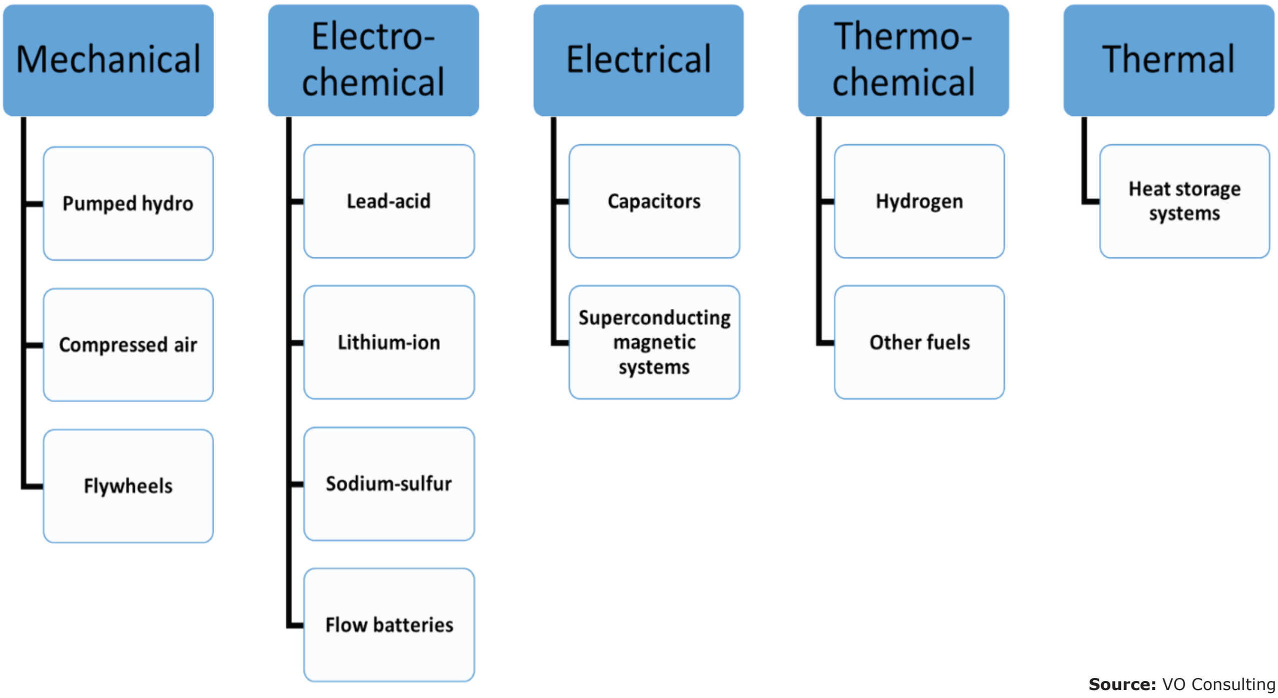
From the point of view of an electricity consumer, questions relating to the affordability, reliability and cost-effectiveness of electricity supplies are pertinent. Here one distinguishes between consumers who are already connected and therefore have access to the country's distribution grid, and may wish to lower their monthly electricity-related expenses by investing in a roof-mounted solar photovoltaic plant or small wind turbine. Such consumers may additionally wish to invest in energy storage technologies, to render themselves more independent from grid services, and to avoid steadily rising electricity tariffs. On the other side of the end-user supply spectrum are rural energy users, who are not connected to the electricity grid, and may wish to benefit from abundant solar or wind resources to generate electricity. In their case, energy storage could readily extend the supply services into periods where the sun is not shining, or the wind is not blowing, which is achieved by using modern energy storage systems.

5 CONTEMPORARY ENERGY STORAGE SYSTEMS

Contemporary energy storage systems can be classified as depicted in Figure 2:

1. **Mechanical systems**, including pumped hydro-electric storage, compressed air storage, flywheels, and similar systems;
2. **Electro-chemical systems**, including lead-acid batteries, lithium-ion batteries, sodium-sulphur batteries, and flow batteries;
3. **Electrical systems**, including capacitors and superconducting magnetic systems;
4. **Thermal systems**, such as heat storage systems;
5. **Thermo-chemical and chemical systems**, including those producing hydrogen and other fuels.

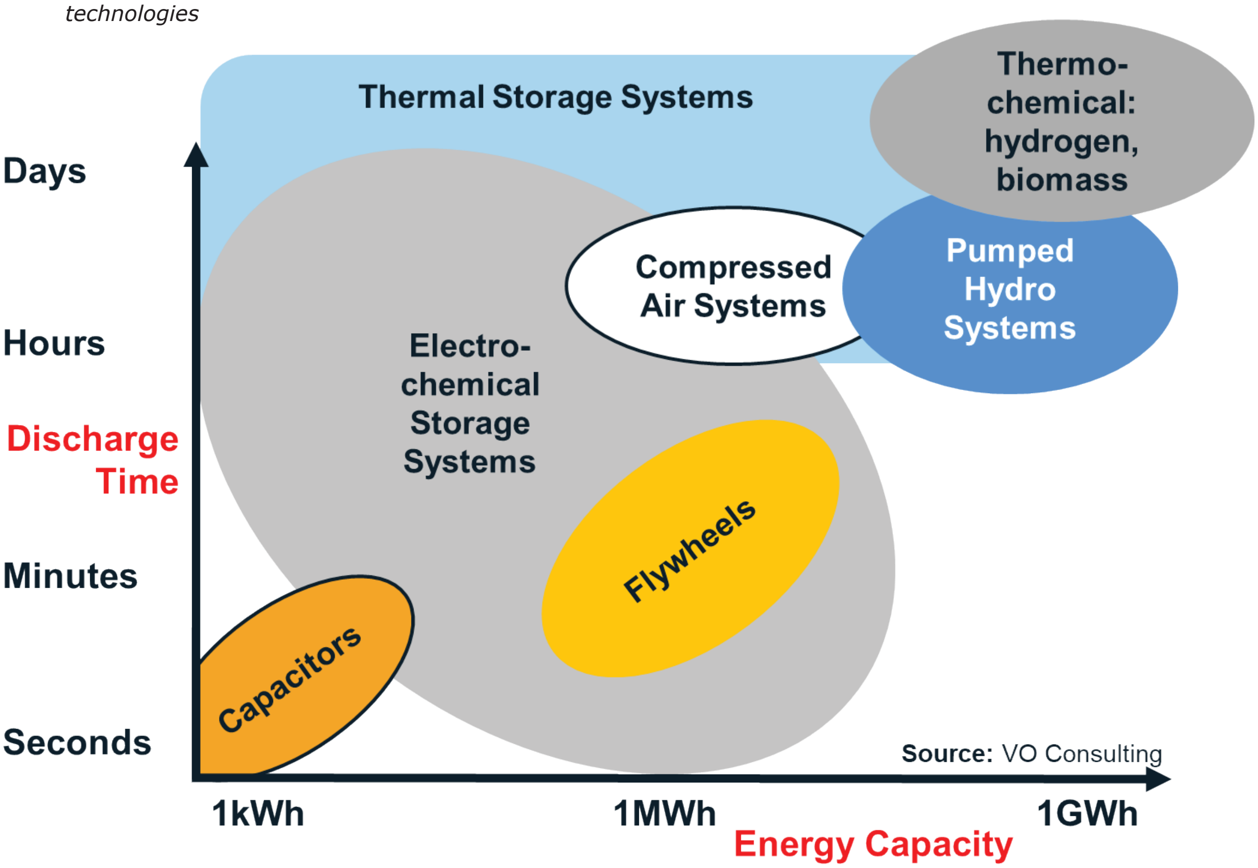
Figure 2: *Classification of contemporary energy storage systems*



Source: VO Consulting

An indicative characterisation of the discharge times and associated energy capacity of contemporary energy storage systems is shown in Figure 3.

Figure 3: *Indicative discharge times and energy capacities of select energy storage technologies*



Source: VO Consulting

5.1 Mechanical Energy Storage

5.1.1 *Pumped Hydro-Electric Storage*

Pumped hydro-electric storage systems are a mature and well-proven technology, and today represent more than 99% of all electrical bulk storage capacity.

Such systems typically consist of two or more separate water storage reservoirs at different elevations. This vertical separation is used to pump water into the higher/upper water reservoir, typically during off-peak electricity demand periods, i.e. when electricity prices are low, and releasing the stored water back from the upper into the lower reservoir during peak demand periods. On the way between the upper and lower reservoir are turbines, which drive electrical generators. Two principal factors determine how much energy can be stored and generated in such systems: a) the total storage volume of the upper reservoir(s), and b) the difference in height between the upper and lower reservoirs.

Pumped hydro-electric storage systems have power ratings that depend on the available water pressure, which is a function of the difference in height between the upper and lower storage reservoirs, the flow rate through the turbines, and the power ratings of the turbine/generator system. Such systems are generally large, i.e. both the storage reservoir(s) and turbine/generator system allow for significant multi-MW power ratings.

Pumped hydro-power storage systems are characterised by long life-times, and cycle efficiencies ranging between 70% and 85%. Their main use is to complement other electrical energy management practices, mainly in the form of time shifting of generation capacity, as dispatchable supply reserve, as well as for frequency control and as a non-spinning reserve. Regarding the integration of intermittent renewable energies into the grid, pumped hydro-electric storage systems are well-suitable to store/dispatch electrical energy when a surplus/inadequate generation is available from such sources.

5.1.2 *Compressed Air Storage*

Compressed air storage systems utilise large underground caverns, or above-ground tanks, to store air at high pressure. When electricity is available, electrically-powered compression systems feed compressed air into such storage. On demand, stored compressed air is released, and heated, and drives turbines connected to electrical generating units. Typically, the source of heat used to increase the temperature of the released air is recovered from the compression process using recuperators, and may be complemented by other heat reservoirs, or excess/exhaust heat from thermal processes.

Compressed air storage systems can be built to various scales, and in this way, provide optimal response capacities, while benefitting from local heat sources that may be available. In this way, such systems can be configured for peak shaving, frequency and voltage control, as well as for partial load shifting. These characteristics allow the use of air storage systems in combination with intermittent renewable energy applications, to ensure that the total system's power output is adequately smoothed, and meets the quality of supply standards.

Large-scale compressed air storage systems require suitable storage facilities. Impermeable underground caverns occur in select geographic settings. Some applications benefit from the existence of underground salt mines and associated cavern systems, others make use of tunnels, mine shafts and porous sandstone media. Above-ground storage facilities include compressed air cylinders.

Compressed air storage technologies include those that rely on producing liquefied air, and newer adiabatic air storage. The latter are often integrated with thermal storage systems without requiring an external fuel source to heat air during expansion.

5.1.3 *Flywheel Energy Storage*

Flywheel energy storage systems use electricity to accelerate a flywheel, driven by an electric motor connected to an electric generator. Flywheels store energy in form of rotational energy, which implies that a flywheel's inertia and rotating speed determine its storage capacity.

Low-speed flywheel systems, which are usually employed for medium- to high-power applications, are made of steel, and rotate at some 6 000 rotations per minute. High-speed flywheels are usually built from carbon fibre or similarly advanced composite materials, and rotate at speeds of the order of 100 000 rotations per minute. The most attractive characteristics of flywheel storage systems include that they have cycle efficiencies of up to 95%, a relatively high-power density, while having no depth-of-discharge effects, and being easy to maintain. However, flywheels undergo idling losses, which steadily reduce their longer-term energy capacity. The technical characteristics of contemporary flywheels imply that such systems are useful for short-term power applications requiring modest electricity capacities.

5.2 Electro-Chemical Energy Storage

Battery storage systems consist of electro-chemical cells connected in series and/or in parallel to produce electricity because of an ongoing electro-chemical reaction in such cells. Electro-chemical cells are built from electrodes of a suitable electrically conducting material, and an electrolyte. Such an assembly converts electrical energy into chemical energy, and vice versa. A battery is charged when an external voltage is applied across the electrodes, while a battery is discharging when electrons are provided from the anodes and collected at the cathodes.

Batteries have a considerable spread of applications. As part of a power system they may be used to control power quality, for grid energy management, and to provide ride-through power. Large-scale facilities using battery storage systems are characterised by relatively low cycling times, and high maintenance costs. In addition, and because of the chemical constituents of contemporary battery systems, disposal and/or recycling costs remain important. The sub-sections below provide brief summaries of the most important contemporary battery types.

5.2.1 Lead-acid Batteries

Lead-acid battery systems remain the most widely used type of rechargeable battery for large-scale use. Their cathodes are made of lead oxide, while the anode is made of lead, and the electrolyte is sulfuric acid. Lead-acid batteries are characterised by their fast response times, self-discharge rates of less than 0.3% per day, cycle efficiencies ranging between 60% and 90%, and modest capital cost requirements, ranging broadly between US$ 50/kWh and US$ 500/kWh.

Most frequently, lead-acid batteries are used in stand-alone power systems and back-up power supplies, as well as a variety of energy management applications, and in electric vehicles. Their application in electricity utilities is limited, mostly because of their low cycling times (of the order of a few thousand cycles only), low depth of discharge characteristics (not more than 20%), low energy densities (between 50 and 100Wh/litre), low specific energy density (between 25 and 50Wh/kg), and sensitivity to high/low operating temperatures.

5.2.2 Lithium-ion Batteries

Lithium-ion batteries have graphite carbon anodes, and cathodes made of lithium metal oxide, such as $LiCoO_2$ and $LiMO_2$, and an organic liquid electrolyte containing dissolved lithium salts, such as $LiClO_4$.

Such systems are characterised by response times of a few milli-seconds, cycle efficiencies of up to 97%, capacity densities between 1 500 and 10 000W/litre, and energy densities between 75Wh/kg and 200Wh/kg. While lithium-ion batteries can have of the order of 10 000 cycles, their cycle depth-of-discharge affects their lifetime, and charge-discharge cycles are often controlled.

Several large lithium-ion battery producers exist. In October 2016, Tesla opened the first section of its lithium-ion Gigafactory, to build battery assemblies for electric vehicles as well as for commercial and domestic power applications.

5.2.3 Sodium-Sulphur Batteries

Sodium-sulphur batteries use molten sodium and sulphur for the electrodes, and beta alumina as a solid electrolyte, which is advantageous as these materials are inexpensive, non-toxic and can be almost completely recycled.

Operating temperatures need to be maintained in the order of 600K, to ensure that the electrodes remain in their liquid states. Such batteries are characterised by energy densities between 150Wh/litre and 300Wh/litre, low self-discharge rates, and high pulse-power capabilities. Because of their high operating temperatures, annual operating cost of some US$ 80/kW/year are considerable.

5.2.4 *Nickel-Cadmium Batteries*

Nickel-cadmium batteries use nickel hydroxide and metallic cadmium for the electrodes, and an aqueous alkaline solution as an electrolyte. Both cadmium and nickel are toxic heavy metals, and need to be managed to minimise potential environmental impacts.

Such batteries have a memory effect, which manifests itself as the successive decrease of the battery's maximum capacity if recharged after partial discharge. Generally, however, nickel-cadmium batteries are robust, and have low maintenance requirements, although utility-scale applications are rare.

5.2.5 *Flow Batteries*

Flow batteries consist of two electrolyte compartments, separated by an ion-selective membrane, which enables reduction-oxidation reactions of the electrolytes. They are classified as redox-flow and hybrid-flow batteries, depending on whether all or only some of the electro-active components are dissolved in the electrolyte. When a flow battery is charged, one electrolyte is oxidised at the anode, while the other is reduced at the cathode. In this way, electrical energy is converted to chemical energy as contained in the electrolytes. In the discharge process, this process is reversed.

Flow batteries have several important characteristics: their power is independent of the storage capacity, as power depends on the size of the electrodes and the number of cells in the stack, while the storage capacity depends on the amount and concentration of the electrolyte used. In addition, flow batteries have a small self-discharge, and the costs of their components are limited.

However, flow batteries remain relatively costly to manufacture, and have generally more complex system and operational requirements than other battery types. While flow battery systems have been demonstrated at a few hundred kW and multi-MW levels, few commercially available systems are operational.

In future, flow batteries with utility-scale applications are expected to include vanadium redox systems, as well as zinc bromine and polysulfide bromine systems.

5.3 Electrical Energy Storage

5.3.1 *Capacitors*

Capacitors consist of at least two electrical conductors, often in form of a metal foil, which are separated by an insulating layer made of plastic, ceramics or glass. When a capacitor is charged, the energy is stored in the dielectric material in form of electrostatic field.

Capacitors are mostly used to store small quantities of electrical energy, and are characterised by their limited capacity, relatively low energy density, and high self-discharge losses. Typically, capacitors are used in select power quality applications, such as for high-voltage power corrections, smoothing the output of power supplies, and energy recovery in mass transit systems. When compared to other contemporary battery systems, their power densities are higher, and their charging time are lower.

Supercapacitors are a subset of contemporary capacitors, and include double-layer capacitors or ultracapacitors, containing two conductor electrodes, an electrolyte, and a porous membrane separator. They have the characteristics of traditional capacitors, as well as those of electro-chemical batteries, in that they store energy in form of a static charge on the surfaces between the electrolyte, as well as between the conductor electrodes. Supercapacitors are characterised by high cycling times, often more than 100 000 cycles, and cycle efficiencies ranging between 84% and 97%. On the other hand, supercapacitors have daily self-discharge rates ranging between 40% and 55%, and capital costs of more than US$ 6 000/kW.

5.3.2 *Superconducting Magnetic Systems*

Superconducting magnetic systems store electrical energy in the magnetic field that is generated by a direct current that is circulating through the unit's superconducting coil. Superconductivity is achieved by way of cryogenic cooling, to achieve temperature below the coil materials superconducting critical temperature. Typically, materials such as mercury, niobium, vanadium or titanium achieve a superconducting state once cooled down to low temperatures. Once such a state is achieved, currents flow without resistance, and enable the storage of electrical energy with few losses. A superconducting magnetic system is discharged using a suitable power converter, which then allows the system to release the stored electrical energy into an alternating current system.

Superconducting magnetic devices in the range between 0.1MW to 10MW have been in commercial operations, and larger systems are expected to be developed in the next decade. Their characteristics include power densities of up to some 4 000W/litre, full discharge times of less than 1 minute, cycle efficiency ranging between 95% and 98%, and system lifetimes of up to 30 years. Such devices are capable of discharging almost all the stored energy, and continue doing so over several thousands of cycles. Presently, however, their capital cost requirements of more than US$ 7 000/kW, and US$ 10 000/kWh, as well their daily self-discharge ranging between 10% and 15%, are viewed as drawbacks, and the presence of strong magnetic fields necessitates judicious management.

5.4 Thermo-Chemical Storage

5.4.1 Hydrogen

Electrolysis is used to produce hydrogen, which is then stored in high-pressure vessels until it is used. Such hydrogen can feed fuel cells to generate electricity, in a process in which the chemical energy contained in hydrogen and atmospheric oxygen is converted into electricity, while releasing heat. The process of generating electricity using fuel cells is generally much less polluting than the combustion of fossil fuels, and can be readily scaled up from a few kW, to several hundred MW.

As the process of hydrogen generation (e.g. via electrolysis) and hydrogen use (e.g. using a fuel cell) are independent processes, hydrogen can be stored until it is used. In this way, the production of hydrogen offers multiple opportunities for the application of intermittent renewable energy sources, as hydrogen can be produced as and when sufficient capacity is available. Provided that sufficient hydrogen storage capacity is available, the production of fuel is essentially decoupled from its use, i.e. the generation of electricity, which is advantageous and offers almost unlimited scales of application.

5.4.2 Other Fuels

Several approaches are used to produce a variety of fuels using solar energy. Amongst others, these include a) enhanced natural photosynthesis, b) artificial photosynthesis, as well as c) various thermo-chemical approaches. These and related approaches are used to produce fuels, including hydrogen as well as various carbon-based fuels. Such fuels can be stored, and used on demand to power engines to produce electricity. Typical energy densities range between 800Wh/kg, and 100 000Wh/kg.

In the process of photosynthesis, irrespective of whether it is the natural or artificial process, sunlight is used to convert water and carbon dioxide into oxygen and other products. On the other hand, thermo-chemical approaches to produce fuels use concentrated solar power (e.g. from concentrating heliostats) to split water into its constituents in a high-temperature environment, thereby producing hydrogen, carbon monoxide and other products.

5.5 Thermal Energy Storage Systems

Thermal energy storage systems store heat in insulated containers. Normally, a thermal energy storage system consists of a storage vessel, a storage medium, a refrigeration system, as well as the required control system, pumps and piping.

Low-temperature thermal energy systems usually consist of water-based low-temperature thermal energy or cryogenic storage system. The former uses water cooled/iced and reheating processes, suitable for peak shaving and industrial cooling, while cryogenic energy storage employs a cryogen such as liquid nitrogen or liquid air to achieve the required electrical and thermal energy conversions.

Examples of the above include liquid air energy storage systems, which are characterised by their high expansion ratio from the liquid to the gaseous state, exploiting the high-power densities of liquid air compared to that of the gaseous state of air. Latent heat thermal energy storage, on the other hand, employ phase-change materials as the storage media, and use the energy absorption or emission in the transition to and from liquid-to-solid. Concrete thermal storage use concrete or cast-able ceramics to store heat, which is normally supported by synthetic oil as a heat transfer fluid.

The above technologies have a variety of applications: for instance, latent heat storage can provide a relatively high storage density, which is useful in buildings and other space-limited applications. Cryogenic energy storage is expected to be used for future grid power management.

Thermal energy storage systems can store large quantities of energy without significant risks. The daily self-discharge loss ranges between 0.05% to 1%, and achieves energy densities ranging between 80Wh/litre to 500Wh/litre. Capital cost requirements range between US$ 3/kWh and US$ 60/kWh. However, the cycle efficiency of thermal energy storage systems is normally low, ranging between some 30% and 60%.

6 ENERGY STORAGE AND ITS ROLES IN THE NATIONAL ELECTRICITY SYSTEM

Energy storage systems are expected to play an increasingly important role in the electricity sector. One of the primary roles of future energy storage systems will be to facilitate the increasing integration of intermittent renewable power sources, such as solar and wind power, into the overall electricity supply mix. In this way, storage is the key to stabilise, smoothen and provide the necessary back-up to solar and wind generation sources, and in this way, enable their increased uptake and integration.

The relevance and applicability of future energy storage systems depend on where they are to be used: large-scale grid integration has different requirements than those necessary for domestic behind-the-meter applications. The following high-level summary identifies the main future uses and applications of large-scale energy storage technologies:

- **Time shifting:** time shifting refers to the use of grid electricity to charge an energy storage system when supply exceeds demand or when electricity is cheap, and the use of such stored energy in peak demand periods. To be useful grid energy management tools, storage capacities must be of the order of several MW, to several tens of MW. Applications include the use of pumped hydro, and compressed air systems, as well as the use of conventional battery systems. In future, hydrogen and other fuels, inexpensive flow battery technology and thermal energy storage technologies are expected to become important, and could potentially become relevant in Namibia, provided these are actively developed.
- **Peak shaving**: peak shaving refers to the use of electrical energy stored during off-peak periods, to compensate generation deficits during periods peak demand periods. Energy storage – depending on the scale of peak shaving necessary – can provide definite benefits and in this way, reduce the requirement to invest in expensive peak electricity generation plant. However, for time shifting and peak shaving to work, electricity supplies in off-peak periods must exceed the prevailing demand.
- **Load levelling:** load levelling is a supply-side support measure designed to level or follow changing load patterns in real time. As such, load levelling is a method of balancing fluctuations associated with a rapidly varying electricity demand.
- **Low-voltage ride-through:** low-voltage ride-through is the capability to mitigate low-voltage periods when these occur, and is a voltage control measure necessary when external voltage fluctuations occur. Such applications necessitate a near-instant response capacity, and thus ideally suited for fast-response energy storage technologies. For example, voltage fluctuations associated with having various intermittent renewable energy technologies feeding into the grid, such as for example solar PV and wind energy generation, necessitate the system operator to smoothen the power variations because of such sources, while having the necessary capacity to respond to momentary low-voltage periods.
- **Transmission and distribution stabilisation:** energy storage systems can be used to support the synchronous operation of components on a power transmission line, or to regulate the power quality in the distribution grid. These require instant response capabilities, and power capacities to match the prevailing grid demand.
- **Black-start:** energy storage systems can provide the capability to start up generation operations, for example from a shutdown condition, without having to take supplies from the grid.
- **Voltage regulation and control:** electric power systems react dynamically to changes in active and reactive power, thus influencing the magnitude and profile of the voltage in networks. In this regard, energy storage systems can be used to control dynamic voltage behaviours.

- **Suppression of network fluctuations:** while power fluctuations occur permanently on the electricity grid, their existence threatens modern power electronics components and must therefore be minimised. Energy storage systems can provide the necessary functionality to protect such sensitive system components, especially those associated with fluctuations that require fast responses, high cycling times and short-term high-power inputs.
- **Spinning reserve:** in situations where there is a rapid decrease of the load, or a fast increase of additional on-line generation facilities, energy storage systems can assume the role and function of a spinning reserve, provided such systems can respond rapidly, and maintaining outputs until the situations can be brought under control using more conventional load control measures.
- **Standing reserve:** standing reserves are used to deal with network constraints arising when the electricity demand exceeds the supply, which can happen when load forecasts are inaccurate, or in case unexpected plant outage occurs. In this way, energy storage systems are used to re-balance the demand with the prevailing supply, by providing a temporary service until other demand- and/or supply-side measures are applied.
- While the above measures are mostly applicable in the management of the electricity grid, the following are typical applications for energy storage systems on the end-user side:
- **Emergency back-up power and uninterruptible power supply:** in case of a power failure, energy storage units have traditionally been used to provide emergency back-up power services, including those needed to ensure the short-term provision of uninterruptible power supply (UPS). Applications include, amongst others, computers and related information technology, telecommunication systems, broadcasting systems, and emergency lighting systems. Such applications are usually time-limited in nature, and necessitate that energy storage systems provide supplies until the main grid supply is restored, or, in the case of UPS systems, until a system can be properly shut down. For emergency back-up power systems, instant-to-medium response times are required, as are long discharge times. In contrast, typical UPS systems offer near instantaneous power supplies, but usually do so for a very limited time only.
- **Transport applications:** increasingly, energy storage systems are finding their way into a variety of transport applications, ranging from hybrid-drive vehicles to fully electric vehicles. The increasing energy density of contemporary energy storage systems, the limited size and fast response times render them increasingly popular. In addition, health- and climate-related concerns provide political leverage to incentivise the switch from fossil-fuelled transport to cleaner alternatives, not only for individual travel, but also for applications in mass transport systems of the future.

7 ACTUAL AND POTENTIAL APPLICATIONS OF ENERGY STORAGE SYSTEMS

This section reflects on actual and potential applications of contemporary energy storage systems in Namibia's electricity sector.

7.1 Domestic Applications

Three main categories of domestic energy storage applications are evident, namely those

1. of interest to consumers who are already connected to the grid;
2. of interest to persons not having access to the electricity grid, but wishing to use electricity; and
3. of interest to persons wishing to benefit from thermal energy services.

In Namibia, all the above consumer categories exist. In so-called behind-the-meter applications, domestic end-users use a variety of battery storage systems, to augment the grid electricity supplies, and to store energy generated from own electricity generation equipment, such as solar photovoltaic installations. In addition, and more prevalent in rural than in urban Namibia, are a variety of backup power supply supplies. Some of these include electrical energy storage, which allows end-users to draw electricity even without the main electricity supply source being in operation, i.e. when the generator is not running, or in case of renewable energy installations, when the sun is not shining or the wind is not blowing. Lastly, thermal energy storage devices have been in use for several decades, and contemporary applications include electrically-powered hot water devices, solar thermal hot water systems, as well as systems heated by biomass, diesel or heavy fuel oil, and volatile waste materials.

The above uses of the various energy storage devices are most likely to continue. Future trends may likely include the increasing use of solar thermal hot water installations, instead of using electrically-powered hot water systems. In addition, middle- to high-income earners may increasingly wish to gain control over their own electricity supply, and invest in grid-connected renewable energy generation plant, most notably, in solar photovoltaic technologies. This development will shift the more traditional use of energy storage systems in the domestic sector away from merely being a convenient backup supply, into becoming a more integral part of future residential electricity supply systems. This is likely to be accompanied by a general shift towards a more decentralised provision of power generation, with domestic end-users, businesses and commercial entities producing more of their own electricity requirements, in response to declining technology costs and ever-rising tariffs of grid-supplied electricity.

While not currently available in the country, electric vehicles are expected to be mainstreamed around the world. When such vehicles eventually become commercially available in Namibia, and are accessible to more than the early adopters, they may in time, have a profound impact on domestic consumption of electricity, and the use of their on-board electricity storage systems.

Another development that may increasingly become popular is the formation of mini- and micro-grids, which rely on a variety of electricity supply technologies, as well as energy storage systems. Developments of this nature, driven amongst others by the rapid adoption of solar technologies throughout the residential sector, are expected to lay the foundation for more interactive and flexible distribution supplies, and in its wake, enhance their resilience.

International experience, especially in countries having a similar solar regime to that of Namibia, show that self-generation and investments in storage technologies need more than willing consumers: regulatory provisions are an essential ingredient, without which many of the above trends are likely to remain stifled.

7.2 Commercial and Industrial Applications

Like the domestic sphere discussed above, today's commercial and industrial applications of energy storage applications are mainly centred around hot water supplies, and electric backup applications, such as uninterruptible power supplies.

In future, and in response to escalating grid-supplied electricity prices, commercial and industrial consumers are expected to increasingly invest in their own renewables-based power generation, to reduce the electricity bills. In some instances, commercial and industrial actor may also invest in electricity storage systems, for example to lower their maximum demand and thereby lower associated charges by the supplier, and for emergency backup. Motivation for such investments would increase if the duration of grid outages or grid instability were to rise in future.

However, as commercial and industrial uses may be more bottom-line oriented than those in the domestic sector, it is important to note that current petrol- or diesel-powered stand-by generation technologies offer many of the above services, at a fraction of the cost that would be incurred for contemporary storage technologies. This implies that storage costs must decrease further before the scale and scope of commercial and industrial investments in electrical energy storage systems will significantly increase in Namibia. However, if the uptake of intermittent generation sources increases in future, a situation could arise whereby commercial and industrial actors would only be allowed to grid-connect additional intermittent plant if they added storage capacity too. If this were to happen, energy storage other than those required for hot water services are likely to increase in the sector.

7.3 Applications in the Local and National Electricity Grid

As yet, Namibia does not use electricity storage technologies in the local or national grid. This is despite the rapid rise of intermittent renewables across the country. In future, energy storage applications are expected to become more prevalent, especially in network locations that may become temporarily unstable, or be constrained. Energy storage systems are also expected to play a role in the control and management of the network frequency, to rapidly manage load and generation profiles, and to regulate power flows and voltage levels, mostly at the distribution network level.
While domestic, commercial and industrial uses of energy storage are expected to increase in future, utility-scale storage projects at the local and national

level are necessary to manage and respond to the impacts brought about because of the rapid uptake of intermittent generation technologies. In this way, storage facilities become the tools to manage and mitigate risks at local or national level. This approach, however, necessitates a shift in how Namibia's grid is designed and managed: traditionally, grid constraints were addressed through targeted infrastructure investments, for example by strengthening transmission lines, or upgrading distribution networks and associated infrastructure, or similar. As large-scale energy storage becomes more readily available, traditional infrastructure strengthening approaches are likely to be compared with the costs, benefits and speed of impact associated with the installation of storage facilities in the network. Here, the modularity of modern energy storage systems is of importance, as mitigation measures can be designed and addressed to best respond to the specific scale of a given challenge, which has cost and time advantages, in contrast to investments in large-scale infrastructure upgrades or amendments.

Irrespective of whether electricity storage is connected on the consumer side, or within the network on the utility side, it affects network-wide power flows. These need to be managed. It is for this reason that utility-scale storage is likely to be the most responsive to address overall network challenges, and in this way, create the necessary operating circumstances for the meaningful integration of domestic, commercial and industrial users in the smart(er) grid of the future.

8 COSTS AND COST DEVELOPMENTS OF ENERGY STORAGE SYSTEMS

Electrical energy storage is expected to be *the* major game changer in the energy industry in the years to come. Both contemporary and to-be-developed storage solutions are expected to revolutionise the way in which renewable energy generation will be viewed and used in future, both on- as well as off the grid.

Traditionally, energy storage systems have been expensive, and were therefore often limited to high-value or remote applications, including backup and stand-alone power systems. For such uses, lead-acid batteries have been the choice electrical backup application, including in the telecommunications sector, remote area power systems, and for applications in localities without access to the grid. Today, such electricity storage systems continue to be used, including for standard electrical backup solutions for small- to medium-scale applications. However, the limited lifetime and efficiency of lead-acid batteries render them less useful for large-scale commercial and industrial, or utility applications. While electrical energy storage systems are ubiquitous and readily available today, their uptake and use to power domestic, commercial, industrial and utility users remain limited, especially when comparing their uptake rates with the rate of adoption of renewable energy power generation technologies.

Today, significant international efforts are underway to improve electrical energy storage systems. These efforts, which are in parts fuelled by developments in the automotive sector focusing on the development of commercial electric vehicles, is likely to create the scale and scope of extensive innovations in this space. It is for this reason that it is considered likely that the large-scale production, as is commonplace in the automotive and electronic industries, will result in battery storage systems with far lower production cost per unit than has been the case in the past. Indeed, potential areas where inexpensive electrical energy storage systems are likely to find new applications include the domestic, commercial and industrial sectors, as well as in the utility space.

The cost of electrical storage systems is, and remains, a key barrier that continues to inhibit the large-scale deployment and use of such systems. As advances in the electronic consumer goods sector and the development of electric vehicles are made, and large-scale manufacturing capacity is established, costs are expected to decline more rapidly than has been the case in the past. Recent developments by various car manufacturers, including Tesla, Mercedes Benz, BMW, and others indicate that major motor manufacturing actors have entered the battle ground for battery systems, and begin to offer commercial electric storage solutions for small- and large-scale applications at competitive costs.

Regarding the characteristics needed for contemporary storage systems to be cost-effective, there are several perspectives to consider, depending on the context in which such storage systems are to be applied. Generally, electrical storage costs are expressed as a cost per useful unit of electrical energy that can be retrieved from the system. In other words, storage cost is the total cost of the battery system used to store electricity in and releasing a unit of electrical energy when required, over and above the cost to produce that energy. In addition, both the power rating (expressed in watts, kilowatts or megawatts) and the storage capacity (expressed in Wh, kWh or MWh) are important indicators used for electrical storage systems. Some typical technical and economic characteristics of contemporary energy storage system, limited to battery systems applicable in the domestic power market, are summarised in Table 1.

The range of costs per useable unit of energy per cycle as is shown in Table 1 is between N$ 2/kWh/cycle, and more than N$ 6/kWh/cycle. Such a spread is considerable. The most favourable characteristics are offered by a product by Tesla that has only recently arrived in South Africa, i.e. the Tesla PowerWall.

Table 1: *Indicative characteristics of five contemporary electrical energy storage systems*[1]

Characteristics	Unit	Lead Acid	Lithium Ion	Tesla PowerWall	LiFePO$_4$
Capacity rating	**kWh**	14.4	8.0	7.0	7.0
Power rating	**kW**	5	5	3.3	3.5
Depth of discharge	**%**	50%	100%	100%	50%
Number of cycles	**#**	2 800	6 000	4 000	3 650
Price	**N$**	129 050	274 050	59 500	57 170
N$ per rated kWh	**N$/kWh**	8 962	34 256	8 500	8 167
N$ per rated kW	**N$/kW**	25 810	54 810	18 030	16 334
N$ per useable kWh per cycle	**N$/kWh/cycle**	6.40	5.71	2.13	4.48

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[1] *Based on the following main assumptions:*

a.	*N$ to Euro exchange rate*	*14.50*
b.	*N$ to US$ exchange rate*	*13.60*
c.	*Mark-up for dealers trading Tesla*	*25%*
d.	*Discount rate*	*10%*

Based on the assumptions underlying the calculations used in Table 1, some storage systems have energy costs that are already close to Namibian electricity retail prices in 2017, while others remain considerably above those. This is significant, and illustrates that select battery storage systems available today are already at or close to grid parity, excluding the cost of generation. In this context, grid parity refers to the threshold at which electrical energy retrieved from a storage system is at or below the cost of electricity supplied by the grid.

In view of the cost of contemporary battery storage systems, the timing of an investment in such a system is important. Generally, for a domestic solar photovoltaic system with storage, storage is financially viable once the solar production cost plus the cost of storage are less than the residential tariff at which electricity is drawn from the grid, ignoring net metering provisions. This illustrates why conventional electricity storage, such as contemporary lead-acid or lithium-ion batteries, are not readily integrated into grid-tied solar power systems. However, the cost of storage is expected to decrease, and will then become an attractive addition for domestic solar PV grid-connected systems.

If battery storage prices decline in real terms by some 5% per annum, storage systems such as the PowerWall that costs N$ 2.13/kWh in 2016 would decline to N$ 1.75/kWh by 2020, and to N$ 1.38/kWh by 2025. Considering that the domestic electricity price is expected to increase at or close to 10% per annum for the next few years, e.g. until 2020, and at 6% per annum thereafter, the cross-over point where the cost of solar generation (at today's prices) plus storage is less expensive that grid power is expected in 2020, if today's price for solar photovoltaic equipment will not reduce any further in real terms. This implies that, for most domestic applications, and unless load shedding occurs regularly in future, an investment in a battery storage system that complements a grid-connected solar photovoltaic system is not yet considered viable. However, in view of international investments in battery manufacturing infrastructure and the current pace of world-wide innovation in the field, it seems likely that storage technology costs will rapidly decline in the years to come.

9 DEVELOPMENT PROSPECTS OF ENERGY STORAGE SYSTEMS IN NAMIBIA

Generally, while all energy storage systems fulfil the same principal use, namely that they store energy, their most important role and value depends on the requirements of the respective end-user. This section therefore briefly considers three distinct perspectives, i.e. the electricity end-user's view, the Independent Power Producer's view, and the electric utility view, to assess the most important development prospects for each of them, given the arrival of cost-competitive energy storage solutions.

9.1 The End-User Perspective

From the perspective of an electricity end-user, electricity storage systems hold the following main development prospects:

a. **Time shifting/cost savings:** for end-users on time-of-use electricity tariffs, electricity storage systems can effectively be employed to reduce total electricity costs by reducing consumption in high-cost peak demand periods, and recharging such storage systems in off-peak times.
b. **Emergency power supply/uninterruptable power supply:** some end-users may rely on equipment that necessitates continuous electricity supplies, including those using critical information and telecommunications technologies. In such cases, electricity storage systems may be useful, and substitute emergency stand-by generators, or be used as uninterruptible power supplies.
c. **Electric vehicles:** increasingly, electric vehicles are entering the market space, and begin to be cost-competitive with petroleum-powered vehicles. This development is the result of intense research and development efforts, and the mainstreaming of high-performance electrical energy storage systems such as lithium-ion, nickel-cadmium and other battery storage systems used in such mobile applications. Increasingly, such energy storage technologies are expected to find additional applications, for example contributing to power domestic or commercial uses while being connected to the power grid, known as vehicle-to-home and vehicle- to-grid applications.

9.2 The IPP Perspective

From the perspective of Independent Power Producers generating electricity using intermittent supply sources, electricity storage systems hold the following main development prospects:

a. **Time shifting:** when generating electricity using intermittent sources, the timing of such supplies may be out of step with the prevailing demand. For an Independent Power Producer, using such technologies it may be of benefit to store electrical energy in times where the given supply exceeds the demand, and provide additional power from the storage system in times where the demand exceeds the given supply. Such a design also creates opportunities to sell in peak demand times, and thus benefit from high time-of-use tariffs, while limiting sales in low-demand periods.

b. **Demand-supply response control:** the quality and reliability of intermittent generation sources varies significantly throughout any given day, as such sources are determined by prevailing weather patterns. To this end, energy storage systems can be useful, to store electrical energy during maximum supply periods, and provide additional power from the storage system when the off-take exceeds the given supply.

9.3 The Utility Perspective

From the point of view of an electricity utility, such as NamPower or the various main electricity distribution entities operating in the country, electricity storage systems hold the following main development prospects:

a. **Power quality management and control:** one of the important functions undertaken by an electricity utility, such as NamPower, is the control of voltage and frequency. This is generally achieved by adjusting supplies to the changing demand patterns. Specifically, voltage is generally controlled by taps of transformers, and reactive power with phase modifiers, frequency is controlled by adjusting the output of generating units. Here, electricity storage systems can provide frequency control functions, and control voltage fluctuations in networks.

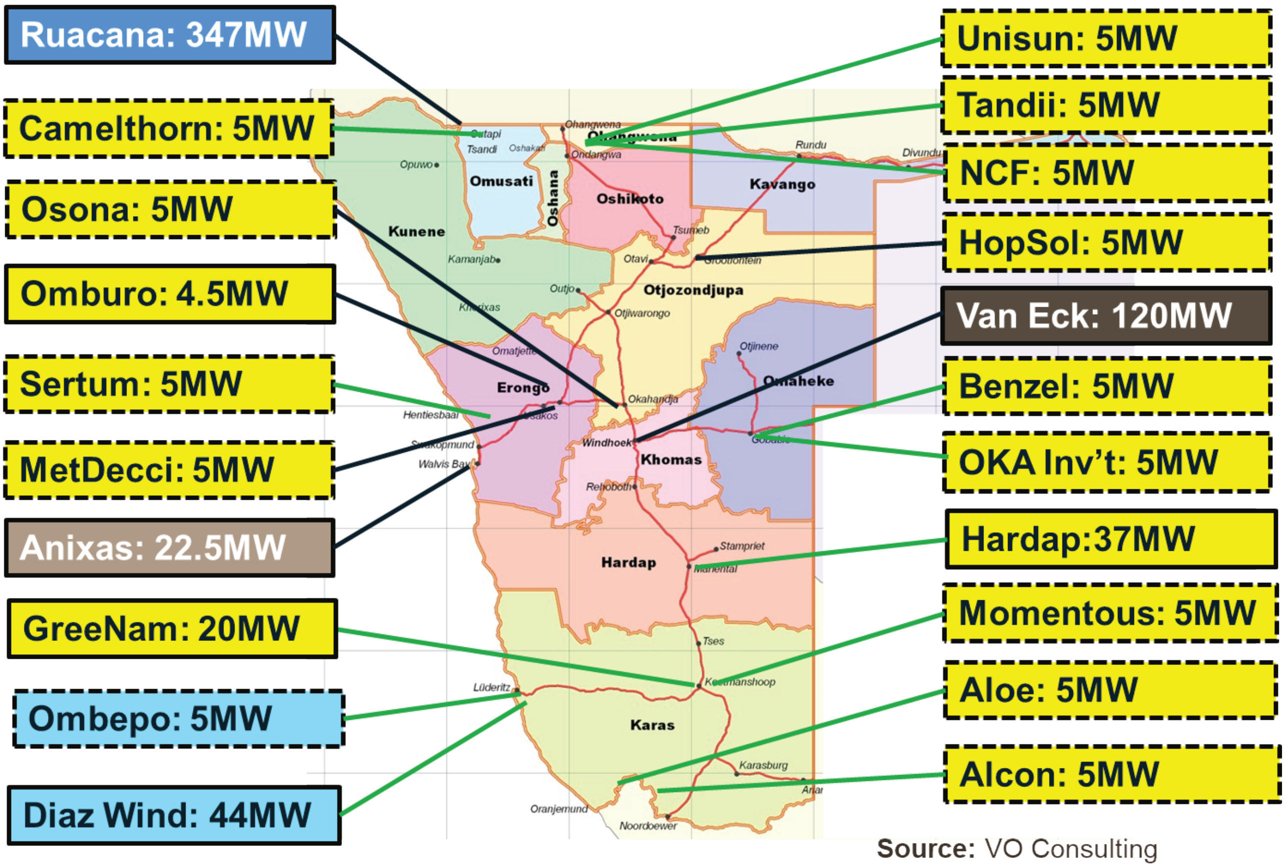
b. **Time shifting:** in some instances, temporary changes in the peak demand may best be addressed by using suitable storage, including amongst others, pumped hydro-electric storage systems. By time shifting electricity supplies, overall generation costs can be reduced. This is achieved by storing energy at off-peak times, for example at night, and having this available for dispatch in peak demand periods.

c. **Network efficiency improvements:** occasionally, power networks can be congested, which may occur when transmission/distribution lines are not sufficiently reinforced to meet the demand for power. In such cases, large-scale battery storage systems installed at appropriate substations may mitigate the congestion, and be used to delay network reinforcements and upgrades.

d. **Emergency power supply for protection and control equipment:** a reliable power supply for protection and control is of critical importance for electricity utilities, and backup battery storage systems are frequently used as an emergency power supplies.

Namibia's electricity sector is witnessing a rapid increase of intermittent electricity supply options, as illustrated in Figure 4. This has marked implications for the national system operator, as is illustrated in the so-called 'duck curves' in Figure 5 on the next page.

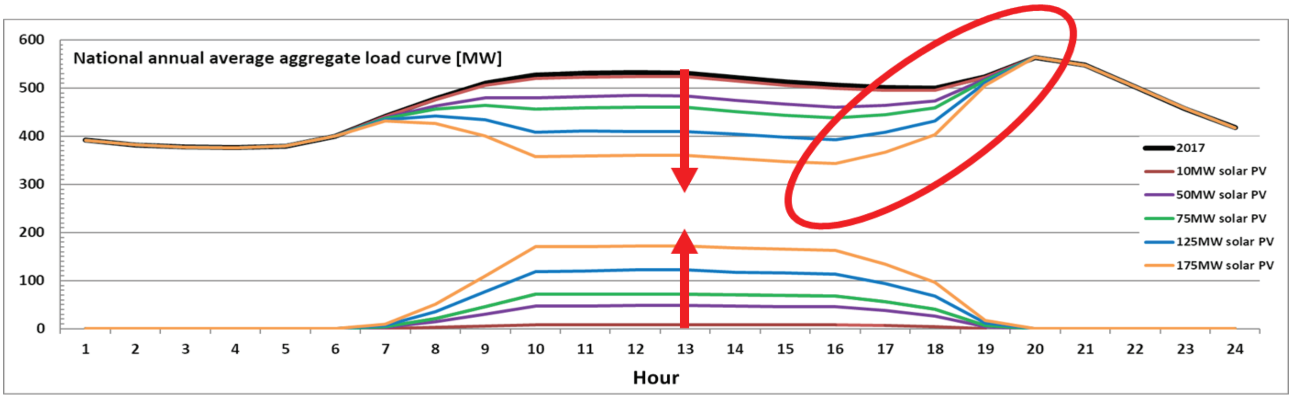
Figure 4: *Expansion of Namibia's electricity generation capacity with intermittent energy supplies*



Source: VO Consulting

Figure 5 illustrates the changing national average annual aggregate load curve as solar photovoltaic generation capacity is added. The lower family of curves show the contribution of increasingly larger solar PV plant contributing to national supplies, indicating capacity additions of 10MW, 50MW, 75MW, 125MW up to 175MW. Such plant produce during the day only, as indicated by their contributions between approx. 7am and 7pm. This capacity addition has far-reaching implications on the national load curve: the day-time demand that is not met by solar PV plant reduces as more such generating options are added to the grid. However, towards sunset, there is a marked ramp-up of the national load, as solar PV plant successively seize production for the day. This phenomenon shapes the neck of the 'duck', necessitating that other generation capacity is rapidly made available, at a ramp-up rate ranging between a few MW per hour, up to almost 100MW per hour, to meet the demand requirements in the peak demand times as highlighted by the red oval in Figure 5.

Figure 5: *Emergence of the duck curve in Namibia's average aggregate annual load curve*

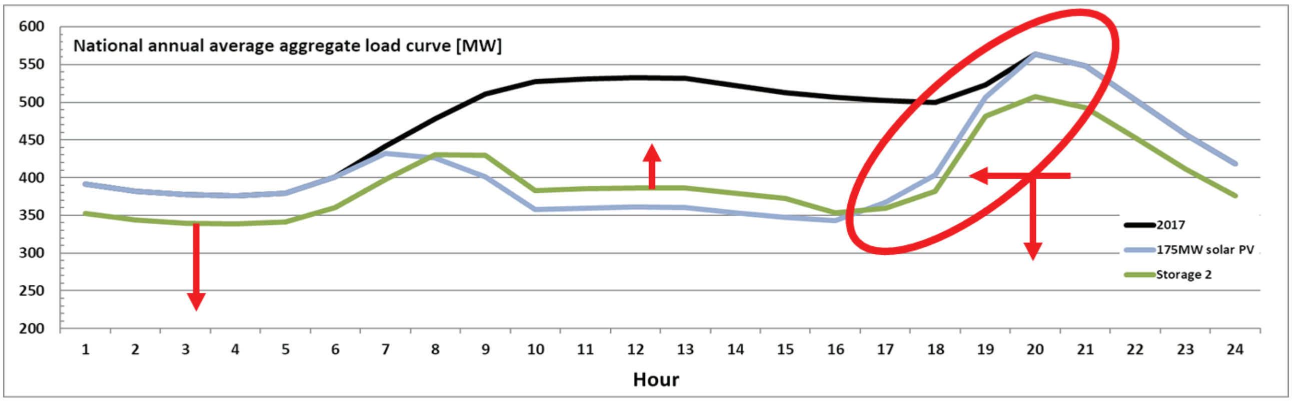


Source: VO Consulting

As large-scale energy storage is integrated into the national electricity system, the impacts of an emerging duck curve can be mitigated. Figure ***6*** illustrates the load curve, and the ramp-up phase leading to the peak-demand period of the day. Here, energy storage can, for example, be used to shift the timing of the peak, and to lower peak demand. This is advantageous, as it allows for the more optimal utilisation of locally abundant energy resources, specifically the intermittent supply options such as solar and wind.

There are, however, further important and far-reaching impacts arising as large-scale storage systems are integrated into the national power system: these can readily influence the total aggregate demand at any given time. In this way, electrical storage will profoundly change the national electricity market. They are expected to have far-reaching repercussions for non-adaptive electricity utilities, in that they will necessitate the fundamental reform of the business models of utilities, to escape the utility death spiral.

Figure 6: *The duck curve and the impacts of energy storage*



Source: VO Consulting

10 CONCLUSIONS AND RECOMMENDATIONS

Today, the application and use of energy storage technology remains limited in Namibia. However, because of considerable international efforts in the past years, especially those focusing on the development of energy storage capacities for electric vehicles, substantial improvements in terms of the reliability, affordability and safety of the next generation of energy storage technologies are considered most likely. Namibia will not be shielded from such developments, and may indeed benefit from being prepared for the successive integration of energy storage systems, at national and local network level, as well as in commerce and industry, and by domestic end-users.

Amongst the most pronounced barriers faced by energy storage technologies today is the complete absence of any regulatory guidance or provisions. Also, the proper valuation of long-term costs and benefits of various storage systems remains incomplete, which hides their potential benefits while singularly focusing on their (often considerable) capital cost requirements. In addition, several technical questions remain, which perpetuate the economic uncertainties associated with these technologies.

However, as storage projects are introduced, the policy, regulatory and end-user fraternities are likely to get a better understanding of the true implications of modern energy storage systems, and their likely value for the country's electricity utilities, current and future Independent Power Producers, and individual end-users. Today, consensus exists that energy storage technologies are essential if intermittent renewable energy sources are to play a more pronounced role in the country's electricity mix. While some storage technologies are mature or near maturity, most are still in the early stages of development, and will require further research and development efforts before their potential can be fully realised.

In contrast to the wide array of uncertainties associated with contemporary energy storage systems, some important facts remain: a) Namibia is well-endowed with both solar and wind resources, and their integration into the country's electricity supply mix necessitates storage technologies, and b) the rapid decline of prices of electricity supply equipment powered by intermittent renewable energy resources has rendered such technologies cost-competitive with most other generation technologies, and therefore makes these increasingly more popular.

Combining Namibia's competitive advantages in the field of renewable resources in general and the country's solar resources in particular, with contemporary technology developments that favour the rapid adoption of renewable energy technologies bodes well for the long-term future of energy storage technologies in the country. The following critical actions are therefore required to ensure that Namibia's power system optimally benefits from modern energy storage:

1. create the relevant provisions in the country's legal and regulatory provisions to enable the use of both large- and small-scale energy storage technologies;
2. create a transparent pricing mechanism for grid services provided by energy storage;
3. ensure that the design of new transmission and distribution infrastructure accom-modates the integration of storage systems;
4. adopt international best practice safety and performance standards to guide the implementation of energy storage technologies, where viable;
5. incentive the uptake of energy storage projects by NamPower, electricity distributors, and the private sector; and
6. avoid electricity infrastructure investments that turn obsolete when game changing technologies such as large-scale electric storage systems arrive.

Based on the above, this paper concludes with a handful of take-away messages:

a. Energy storage technologies will affect the business models of all electricity utilities;
b. Cost-effective storage will further incentivise grid defection;
c. Utilities without an adaptation strategy to future-proof their business in a rapidly changing environment will be challenged, and their business models must adapt to new operational realities;
d. Namibia will more optimally benefit from its plentiful renewable energy endowments if the arrival of large-scale energy storage is well-planned

– to minimise the potential negative impacts on the electricity sector value chain in its entirety;

e. Storage costs are decreasing, and combined with rapidly declining renewable energy cost developments, the repercussions for non-renewable energy generation are considerable;

f. The value proposition of "intermittent renewable energy supplies plus storage" fulfils most of the 9 Ds, which is a value proposition that will be hard to beat; and

g. Storage will profoundly influence the uptake and use of intermittent renewable energy technologies, and it is therefore imperative for Namibia to turn this into a benefit for the country's development.

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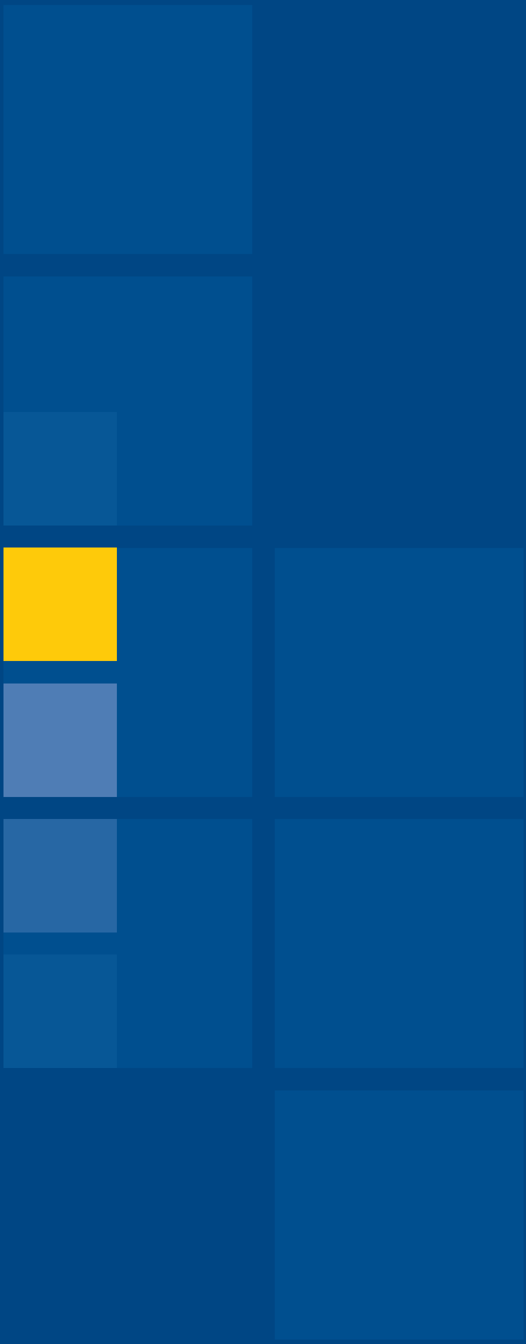

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