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Utility Scale Battery Storage – The New Electricity Revolution

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Summary

Energy storage is seen as the missing link in the world’s transition to a zero-carbon economy. Batteries can fill power gaps from intermittent solar and wind energy, provide frequency support on islanded and weak power systems and can be used in load shifting and peak shaving.

Based on the Levelised Cost of Storage (LCOS) analysis in this paper, Battery Energy Storage (BES) installations can cost-effectively replace diesel/HFO peaking generation plant and will shortly be able to replace Eskom winter-peak electricity based on current and projected Eskom winter peak Megaflex tariffs. Further, as Battery Energy Storage System (BESS) costs continue to drop, BESS applications will become even more viable.

Utility Scale BESSs can be installed in under 12 months and can be modularised and phased to match customer requirements. BESS systems are also environmentally friendly.

Key Words

Battery Energy Storage Systems, Levelised Cost of Storage (LCOS), Levelised Cost of Electricity (LCOE), Cyclability, Degradation, Peaker Replacement, Frequency Stability

Introduction

Energy storage is seen as the missing link in the world’s transition to a zero-carbon economy. Batteries can fill power gaps from intermittent solar and wind energy, provide frequency support on islanded and weak power systems and can be used in load shifting and peak shaving.

Lithium Ion battery prices are projected to decrease from $280/kWh in 2016 to $73/kWh in 2030 [1] as shown in Figure 1.

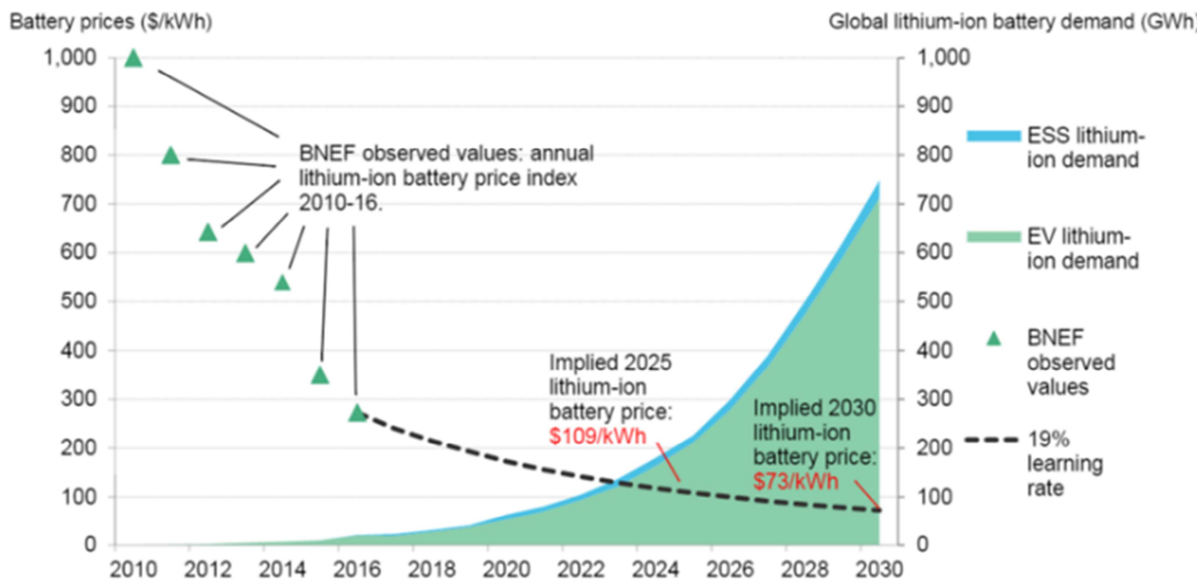


Figure 1 Projected Lithium Ion Battery Prices to 2030 [1]

Utility-scale Battery Energy Storage System (BESS) capital prices are projected to fall to below $500/kWh by 2021 [2] as shown in Figure 2.

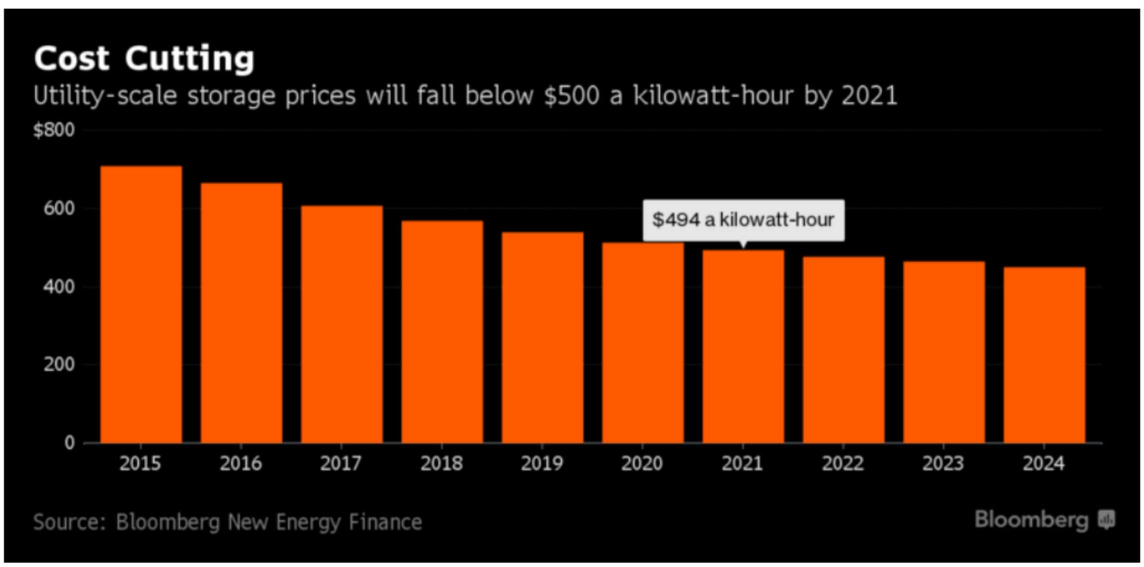


Figure 2 Projected Utility Scale Battery Storage Capital Prices [2]Figure 2

Utility-scale Battery Energy Storage Systems (BESSs) are no longer “fringe” technologies as shown by the recently commissioned Tesla 20MW (80MWh) Powerpack station for Southern California Edison (SCE) [3] shown in Figure 3, and Rongke Power’s planned 200MW (800MWh) BESS in China [4].

Figure 3 Tesla Southern California Edison installation [3]

There are several energy storage technologies available and these include electrochemical, mechanical, thermal and electromagnetic technologies as shown in Figure 4.

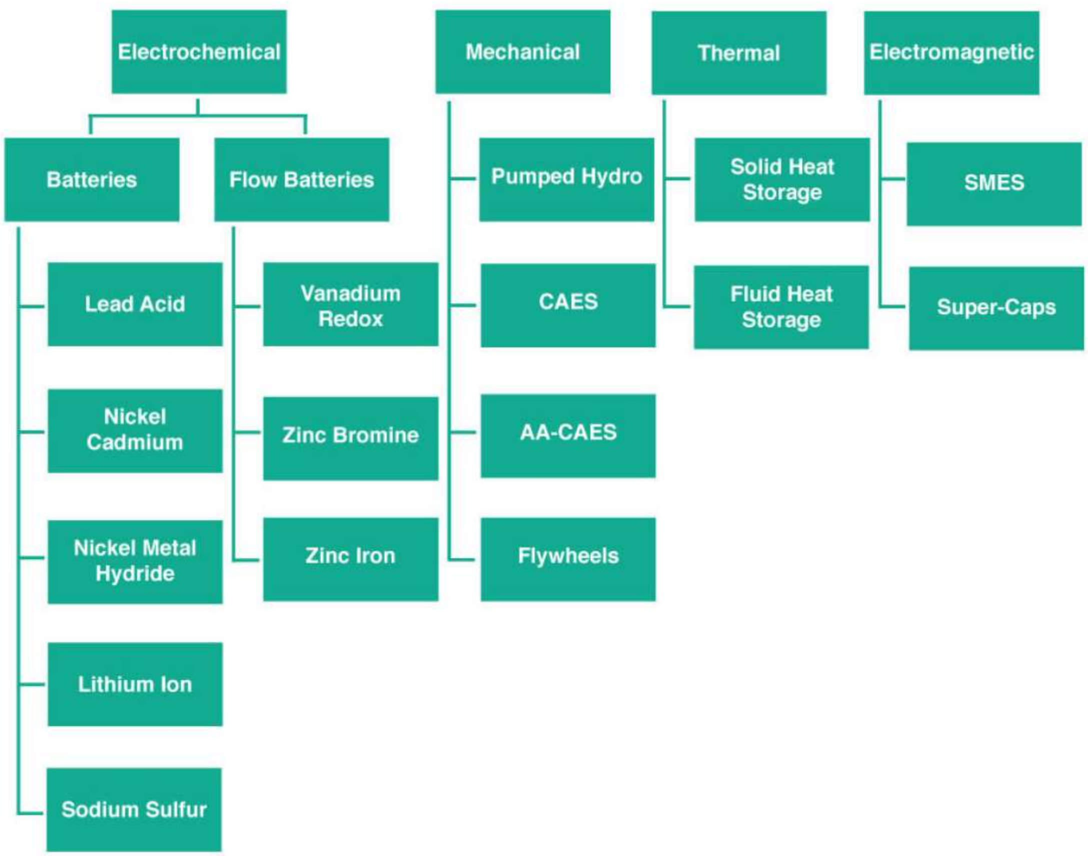


Figure 4 Energy Storage Technologies [5]**Error! Reference source not found.**

This paper is confined to utility scale electrochemical storage technologies or BESSs and an example of an ongoing "BESS peaker replacement" project in South Africa is briefly discussed as a case study.

<u>Utility Scale BESS</u>

Grid scale BESS can provide the following services as laid out in Table 1, below.

Table 1 – Services provided by Utility Scale BESS

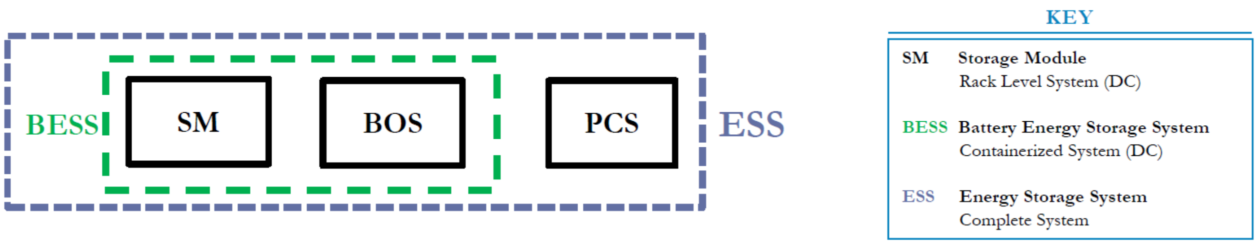
Transmission System	• Transmission grid performance plus integration of intermittent RE energy • Voltage and reactive power support • Decrease transmission losses • Diminish congestion • Defer transmission investment • Increase system reliability • System capacity adequacy • Shift RE generation output
Peaker Replacement	• Replace peaking gas turbines or diesel plant • Time shifting, spinning reserve • Speed of bringing on line
Frequency Regulation	• Raise and lower output to follow continuous changing of load
Distribution System	• Flexible peaking capacity • Capital deferral • System stability • Reduced reactive power (kVArh) charges

Table 2 shows service that can be provided by behind the meter BESS.

Table 2 – Services provided by behind the meter BESS

Microgrid	• Support to systems that need to island • Ramping support and system stability
Island Grid	• Stability • Hybrid integration of RE
Commercial & Industrial	• Peak shaving • Demand charge savings • kVAr savings
Residential	• Back-up power • Enhances PV installation • Regulates power supply • Smooths electricity sold back to grid

Figure 5 shows the components that make up the full cost of a utility scale BESS. The main components of a BESS are: Storage Module, Balance of System, Power Conversion System, EPC costs and other costs.



Storage Module ("SM")	Balance of System ("BOS")	Power Conversion System ("PCS")	Engineering Procurement & Construction ("EPC")	Other (Not Included in Analysis)
Racking Frame/Cabinet	Container	Inverter	Project Management	SCADA Software
Local Protection (i.e., Breakers)	Electrical Distribution & Control	Electrical Protection	Engineering Studies/Permitting	Shipping
Rack Management System	Communication	Energy Management System ("EMS")	Site Preparation/Construction	Grid Integration Equipment
Battery Management System	HVAC/Thermal Management		Foundation/Mounting	Metering
Battery Module	Fire Suppression		Commissioning	Land

Figure 5 Components making up a full BESS [6]

At present, different BES technologies have different attributes, e.g. Lithium Ion batteries are portable and have high-round trip efficiencies, but they suffer from high cyclability degradation, whereas flow batteries, e.g. Vanadium Redox Flow (V Flow) batteries have unlimited cyclability with relatively no degradation but they take up more space and have lower round-trip efficiencies [5]. The flow battery process is shown in Figure 6 below.

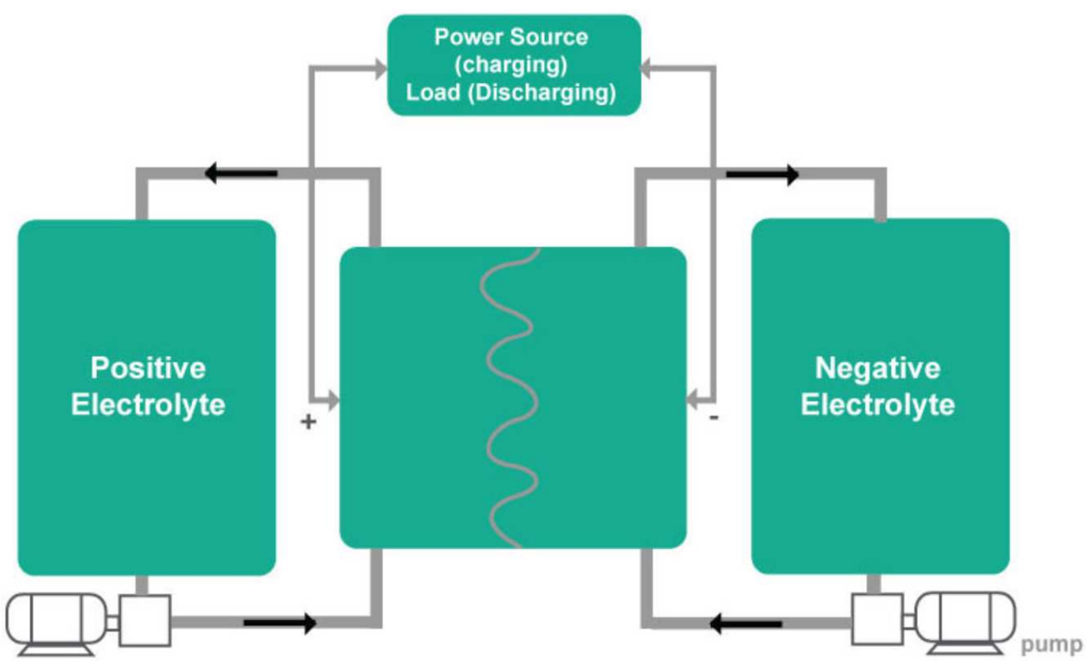


Figure 6 Flow Battery Process [5]

Battery degradation is specific to usage and environmental exposure. Key factors that affect degradation are:

- Cycle-Rate
- Temperature
- Depth of discharge (DoD)
- Rest period duration
- Average state of Charge (SoC)

Figure 7 below compares degradation between different battery storage types and chemistries [5].

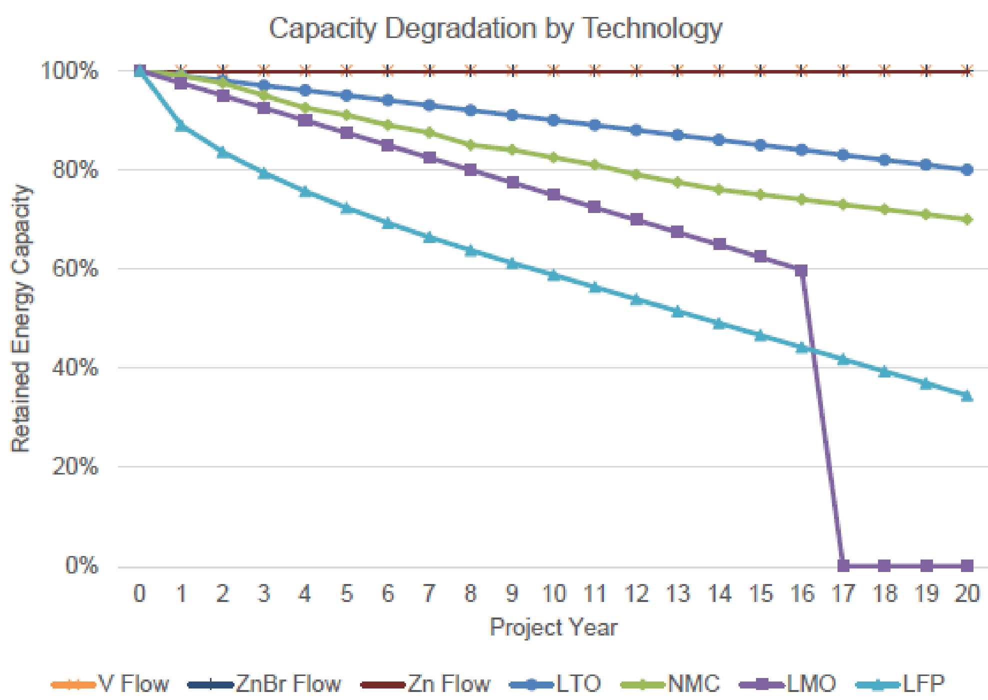


Figure 7 Capacity degradation by storage type and chemistry [5]

Due to the superior cyclability of flow batteries in utility scale applications, an ongoing South African BESS project is discussed using V Flow batteries in a "peaker replacement" application.

Based on direct budget prices received from suppliers, the author of this paper calculates a Levelised Cost of Electricity (LCOE), where a 10MW (50MWh) BESS system is contemplated. The following costs are analysed:

- Capital Cost (from supplier, including grid connection, control system and other)
- Round trip efficiency of discharging
- O&M Costs (from supplier)
- Charging Costs (based on the utility's off-peak charging tariff)
- Round trip efficiency on charging
- Tax Costs (excluded)
- Maintenance outages (excluded)

Table 3 below describes the capital, operational and charging costs used in the analysis. The last column is a one-year LCOE value for different sized BESSs.

A budget Request for Quotation (RFQ) was submitted to BESS suppliers for a range of battery capacity values, all for an energy requirement of five (5) hours/day. Suppliers responded with capital $, $/kW and $/kWh prices. Suppliers also responded with round-trip efficiency (AC to AC) values. Round-trip efficiency considers the losses involved with charging and discharging the batteries from and to the AC network.

Vanadium Flow round-trip efficiency values are in the 75% area. If was assumed that the 25% losses can be split evenly between charging and discharging, so a 12.5% efficiency "over-sizing" is required on the capacity and capital cost of the BESS for the dis-charging cycle. Therefore:

Capex cost = Capex Cost x 1.125

In addition, energy requirements to charge the battery at e.g. at off-peak times also need to be "over-sized". Annual energy requirements can be derived by multiplying the BESS capacity by its daily charge duration multiplied by 365 days and by 1000 (to convert from MWs to kWs). This value is then multiplied by 1.125 to account for losses in the charging cycle. Therefore,

Charging Energy = BESS Capacity (MW) x charge duration x 365 x 1000

and

Charging Cost = Charging Energy x Charging Cost ($/kWh) x 1.125

The cost of charging is assumed to match Eskom's off-peak Megaflex tariff [8] and is assumed at USc0.05/kWh and it was assumed that the charging duration matches the discharge duration.

Finally, operating costs are assumed at 2% of capital costs per year.

The LCOE (or LCOS) for the first year can be calculated as the total cost for year one divided by the energy discharged in a year, i.e.:

LCOE for year one = total cost in year one/total discharged energy in year 1

The LCOE for year 1 is in the range of $1.63/kWh to $2.1/kWh. This is a high LCOE and it is unlikely that at these values, a BESS for one year only will be financially viable.

Beyond one year, a Discounted Cashflow (DCF) analysis is required with discounted capital and operational costs in the numerator and discounted discharge energy (kWhs) in the denominator. A Weighted Average Cost of Capital (WACC) or Discount Rate of 10% is assumed in the DCF analysis.

LCOE values range from **USc23/kWh** to **USc36/kWh** for different capacity battery banks and for project durations ranging from 10 to 30 years as shown in Table 4 below.

For a "Peaker Replacement" V Flow battery application, the Lazard Levelised Cost of Supply (LCOS) study [6] indicates a LCOS breakdown as follows:

- Capital LCOS - $206/MWh (46.8%)
- O&M LCOS - $72/MWh (16.4%)
- Charging LCOS - $55/MWh (12.5%)
- Tax LCOS - $32/MWh (7.3%)
- Other LCOS - $75/MWh (17%)
- Total LCOS **-** $441/MWh (**USc44.1/kWh**)

The capital LCOS comprises half of the total LCOS. If tax is subtracted (to be consistent with the case study) and if charging and other costs are reduced by half to reflect lower costs in South Africa, this results in a LCOS of $338/MWh (**USc33.8/kWh**). (For interest, the Lazard Report [6] shows a total LCOS for a Li-Ion battery solution as: $285/kWh (USc28.5/kWh)).

The Greensmith Report [5] shows LCOE prices for V Flow as **USc45/kWh** in 2016 and **USc25/kWh** by 2020.

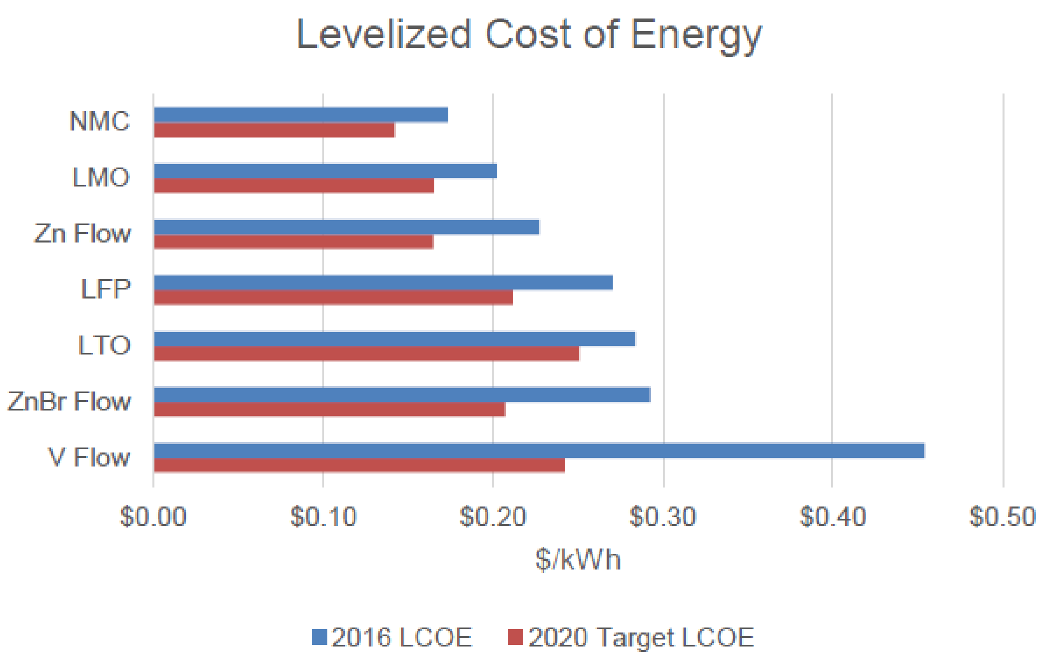


Figure 8 Levelised Cost of Energy (LCOE) [5]

From the case study and from two literature reviews, it appears that a reasonable LCOE estimate for V-Flow BESS technology in the short term can be budgeted as between **USc23/kWh** and **USc45/kWh**, depending on the size and other factors of the project.

Table 3 – Capital, Operations and Charging Costs for BESS systems

Capacity (MW)	Hours used every day	Installed Cost ($/kWh)	Installed Cost ($/kW)	Capex ($)	Round trip efficiency/2	Oversized capex to take into account round trip efficiency ($)	Energy in Year (kWh)	Operating Costs/year (2% of capex) ($)	Charging cost ($/kWh)	Total charging cost ($)	Round trip efficiency/2	Oversized charging cost to take into account round trip efficiency ($)	1 year LCOE $/kWh
1	5	650	3 250	3 250 000	0.875	3 656 250	1 825 000	73 125	0.05	91 250	0.875	102 656	2.100
5	5	600	3 000	15 000 000	0.875	16 875 000	9 125 000	337 500	0.05	456 250	0.875	513 281	1.943
10	5	550	2 750	27 500 000	0.875	30 937 500	18 250 000	618 750	0.05	912 500	0.875	1 026 563	1.785
20	5	500	2 500	50 000 000	0.875	56 250 000	36 500 000	1 125 000	0.05	1 825 000	0.875	2 053 125	1.628

Table 4 – LCOE values for various plant life durations

Capacity (MW)	1 Year	10 years	20 years	30 Years
1	2.10	0.36	0.30	0.28
5	1.94	0.34	0.28	0.26
10	1.79	0.31	0.26	0.24
20	1.63	0.29	0.24	0.23

The values in Table 4 above are compared with broad-estimate LCOE values for traditional generation technologies as shown as follows [7]:

- Diesel/HFO generation: USc40/kWh
- Battery storage: USc23/kWh – USc45/kWh
- Coal generation: USc10/kWh
- Hydro generation: USc6/kWh
- Nuclear generation: USc10/kWh

From this preliminary analysis, BESS installations can replace diesel/HFO peaking generation plant and will shortly be able to replace Eskom winter-peak electricity based on current Eskom winter-peak Megaflex tariffs [8] as BESS costs continuously decrease.

BESSs can also provide frequency support for islanded or weak power systems or systems with high levels of intermittent and non-synchronous Renewable Energy (RE) generation rather than standby diesel/HFO power plant.

Utility Scale BESSs can be installed in under 12 months and can be modularised and phased to match customer requirements. BESS systems are also environmentally friendly.

Conclusions

Based on the Levelised Cost of Storage (LCOS) analysis in this paper, Battery Energy Storage (BES) installations can cost-effectively replace diesel/HFO peaking generation plant and will shortly be able to replace Eskom winter-peak electricity based on current and projected Eskom winter peak Megaflex tariffs. Further, as BESS costs continue to drop, BESS applications will become even more viable.

BESSs can also provide frequency support for islanded or weak power systems or systems with high levels of intermittent and non-synchronous Renewable Energy (RE) generation.

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