Key learnings from the establishment of a battery energy storage testing facility

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The importance of energy storage within Eskom has been identified and necessitated research to be conducted in this field. Based on the research conducted, the need for a Test and Demonstration Facility was acknowledged. A number of value streams can be derived from the installation of energy storage, 27 value streams have been identified, and the stacking of these value streams aids in the feasibility of a technology for a specific installation. In order to achieve the maximum value from a battery storage system, it must be able to perform all or as many as possible, of the activities needed by the grid. This raises questions such as; does the high power battery have sufficient energy capacity to allow load shifting? Does the high energy capacity battery react quickly enough to perform frequency regulation? Is the battery designed to provide multitasking, or is it suitable to a single value stream only? What will be the real value to Eskom of installing a specified battery technology into the grid?

Eskom Research has been investigating battery energy storage for more than ten years, during which time it has identified nascent technologies for large scale energy storage for utilities (larger than 1 MW, 6 MWh). Many of the early technologies were developed for other purposes, such as electric vehicles (EVs) and therefore exhibit features that are not a requirement for utility applications. For example, EV batteries require being lightweight and having a small footprint, whereas a utility battery does not matter how big nor how heavy it is. These unnecessary additional features add to the cost of these batteries.

The South African grid has an increasing quantity of variable renewable energy sources and the quantum of these IPP sources will further increase over the next ten years. The Irish grid became unstable when 7% of renewable energy was introduced to it and as a consequence they have been rapidly adding energy storage and open cycle gas turbine (OCGT) capacity to allow increased renewable penetration. In 2012 less than 10 MW of battery storage was installed worldwide, but in the year 2015 alone, a further 216 MW of battery energy storage was installed globally.

The Comparative Table of Energy Storage, produced annually by Eskom Research, has identified at least 50 different types of storage devices that could be used within the Eskom grid. Some devices are better suited to certain applications, whilst others may only be suited for limited support. The parallel operation of these devices under pre-determined test conditions will allow Eskom to evaluate the performance of the devices that are likely to be used in the grid and to determine their suitability and real lifetime operating costs.

Objectives

Eskom Research has recognised that the future grid will need to incorporate energy storage in significant quantities and hence requested funding for the construction of a test and demonstration facility at Rosherville in 2012. Whilst most large scale battery systems are at pre-commercial status, some are being offered on a commercial basis. These units remain expensive and are generally bespoke systems designed for the client's specific needs. Early testing of such units would allow Eskom to have a practical insight into the implementation and integration of such units into the grid and would empower to make purchase decisions based on the real operating data obtained from the facility, under South African and Eskom conditions.

With the development of advanced batteries come many technological risks and exorbitant claims by the manufacturers. Whilst these claims may be valid under specific laboratory conditions, they often prove less valid under practical operating conditions.

The use of the wrong type of device in the wrong application can increase costs considerably and also lead to early failure of the device. Comparative testing of the various types of battery will establish which technology is most suited to which application.

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Design of testing facility

Site layout and construction

The site layout was designed to suit the allocated area adjacent to two existing test facilities on site (i.e. both the flow lab and the drop-tube furnace areas). The original design, accommodated five storage units, with one of the slab areas intended to house two separate units. However, once the tenders were received, the design of the systems, and in particular the non-modular design of the General Electric system, meant that the developed area could only accommodate four units, with space for a future fifth unit being made available at the top of the site layout, as shown in Fig. 1.

The original design of the civil works included a slab of a minimum size of 12 m by 3,5 m, which was installed on the same level as the existing ground, which provided a slight fall (approximately 50 mm in each direction) for rainwater run-off. It was anticipated that this slight out of level would not affect the energy storage units and the fall would, in fact, be beneficial to avoid water build up. In the event, both manufacturers insisted on their units being exactly level (within a tolerance of less than 1 mm) and the units sit on packers under the mounting points. The BYD unit was even installed on large concrete legs, supplied by BYD, some 900 mm high, so that the unit itself would be well above any potential flood levels.

It should be noted that a considerable saving can be achieved on future units by the use of foot pads, for example using large paving stones, which can be approximately levelled when installed at the predetermined location of the mounting points, rather than a full slab. The BYD small container has been installed partially in this fashion, as BYD wished to have a space between the two containers.

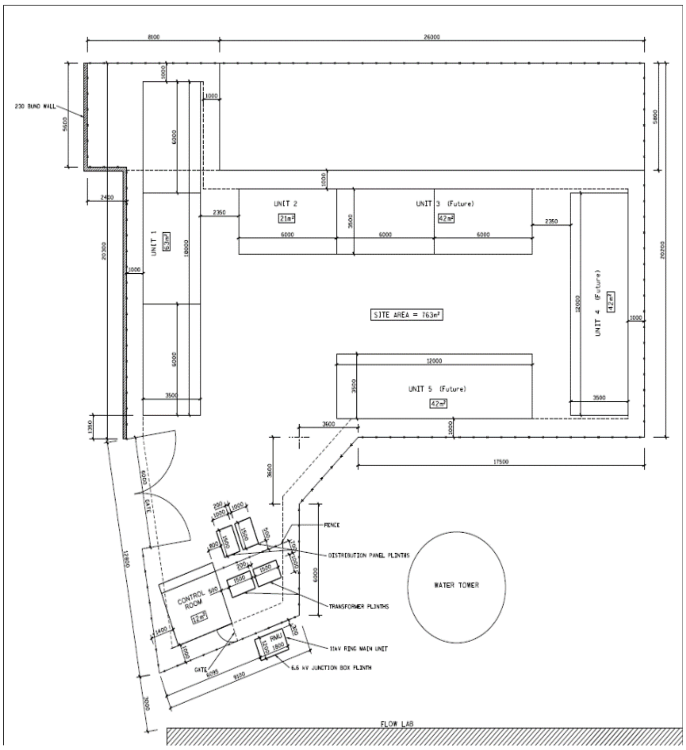


Fig. 1: Site layout.

Battery systems

An open tender was issued for the supply, delivery, installation and maintenance of battery energy storage systems with a capacity of 200 kW 1,0 MWh. It was a requirement that the systems must include all equipment to operate as standalone units in totality; therefore it needed to include a power conversion system, a battery management system (BMS), air conditioning units or heating systems and internal fire protection equipment required to protect the battery.

An additional requirement was for inclusion of current transformers and connection to the respective BMS to collect and record data from the system, as the AC charge and discharge as well as the DC charge and discharge will be monitored during the testing period in order to evaluate the individual performance of the battery and the power conversion equipment, to determine the availability and round trip efficiencies of the battery energy storage systems.

Two units were selected for the test facility, which included a BYD lithium-ion phosphate battery and a General Electric sodium nickel chloride battery.

Data recording and control equipment

The system consists of an outside 400 V control cabinet, which contains the main incoming (1 MW) breaker and five separate battery unit breakers of 200 kW each. Each breaker is monitored individually via current transformers and voltage transformers contained in this cabinet.

The results are displayed on the metering cabinet inside the control room, as per Fig. 2, and are also displayed on the graphical computer representation (Fig. 5).

Fig. 2: Control room metering and protection cabinet.

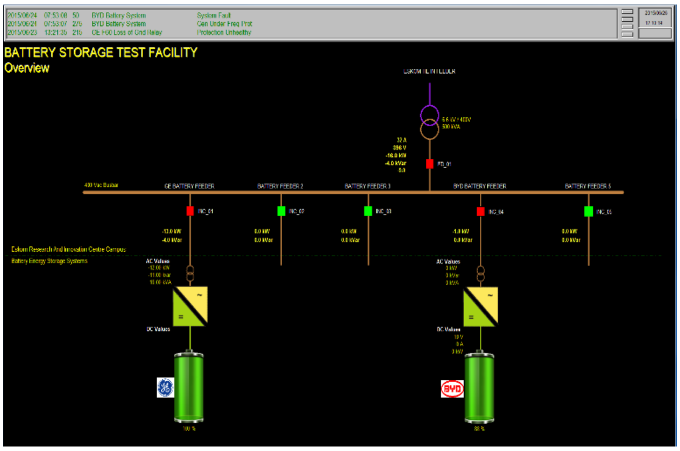
In addition a grid control panel (Fig. 3) is also inside the control room, which incorporates all the grid protection equipment. This includes a “loss of grid” protection relay; an F60 grid protection relay, which monitors frequency, voltage, and droop or sag events, and prevents “dirty” power from being sent into the grid. An ION 7650 meter is also included, which monitors the quality of supply, including the various harmonic components which could result from the battery inverters. This information is also trended within the Citec system.

Fig. 3: Control room grid protection panel.

The information from these two cabinets is collected by the D400 interface, which in turn provides both the Citect server and the data collection computer with this information. The Citect server also has an internet interface, which allows for remote interfaces, via the Team Viewer software programme. The D400 interface is the standard interface used by Eskom at all its power stations and sub stations, and could be connected to Eskom's national control at Simmerpan, if required at some point in the future.

Fig. 4: Battery back up and communications panel.

The information is displayed on the desk top computer screens in the control cabinet and all operator interfaces are controlled through this interface. The system is controlled via individual schedulers for each battery within the system, which can be accessed via these screens. The scheduler can be set to provide different output modes for specified periods of each day, so that the units can be charged during the off-peak night time period and discharged at pre-determined times each day. Alternatively, the systems can be manually operated (typically by central control) when grid demand reaches a set level, or they can be programmed to maintain a variable output from a renewable resource. The system is designed such that we can simulate variable outputs from a theoretical renewable source, or that we can connect to a real source remotely, via the internet. In this way, the ability of the energy storage systems can be demonstrated to provide a totally firm, despatchable output from a fluctuating source of supply.



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2015/06/24   07:53:08   50    BYD Battery System          System Fault
2015/06/24   07:53:07   275   BYD Battery System          Gen Under Freq Prot
2015/06/23   13:21:35   215   GE F60 Loss of Grid Relay   Protection Unhealthy
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Fig. 5: Desk top overview screen.

Fig.6 : Incoming RMU and 6,6 kV transformer.

The design of large energy storage systems includes an isolation transformer between the system inverter and the grid. This isolation transformer ensures that the storage system output is matched to the grid and also prevents any stray currents or electrical problems within the storage system from impacting on the grid.

The simplicity of the system allows centralised control, for example from Eskom central control centre, to occur, as well as duty cycle development and simulation to be done by the qualified research staff.

Testing profiles

Testing is conducted over a 90 day test basis, with various modes of output being tested for the full duration of the testing period. These include, but will not be limited to:

- *Load shifting*: six hours continuous output at 200 kW per battery, off-peak charging available for eight hours per day, each day for the 90 period.
- *Wind smoothing*: a typical wind farm daily profile established from a South African wind facility, (under afternoon storm conditions) which is used to supply the battery and/or grid, on a daily basis for 90 continuous days, with the battery expected to absorb and discharge to smooth the output.
- *Solar smoothing*: a typical solar output established from a South African photovoltaic facility (under cloudy conditions) is used to supply the battery and/or grid, on a daily basis for 90 continuous days, with the battery expected to absorb and discharge to smooth the output.
- *Power quality*: the battery will operate at the top end of its charge and smooth out frequency and voltage changes resulting from demand changes.
- *Other*: the facility is a tool for Eskom to simulate actual conditions and to complete predictive testing prior to selection, design and installation of battery energy storage systems on the network.

Analysis of results

Test 1 successfully demonstrated that load shifting using energy storage can be smoothly achieved and that the Eskom base load units could be more efficiently operated to minimise costs and emissions, by introducing widespread energy storage. The economic feasibility is still to be determined, based on the future capital costs of such systems and on their lifetime, as demonstrated in the on-going testing.

Test 2 has shown that an energy storage system, combined with a solar system can provide despatchable power, even under the harshest solar performance. The profile replicates (and exaggerates) an intermittently cloudy day with high ramp rates and solar output changing from 100% to 25% in a few seconds. The storage system recognises these changes and compensates for the output, either by providing additional energy to the grid, or by absorbing excess production. Furthermore the storage system absorbs energy during the night time off-peak period, and thereby allows the solar system to provide despatchable energy (at a predetermined level) from 06h30 to 21h00.

One drawback of the Test 2 demonstration is that under real conditions the daily "set-point" will need to be determined prior to the day's known solar output. The set-point is the pre-determined level at which the combined system will despatch power into the grid. In the case of Test 2, this was 160 kW, based on the total amount of energy produced by the solar system, plus the stored capacity of the storage system, averaged over the defined period. However, under realistic operating conditions, this will require an element of day ahead forecasting to anticipate the solar output for the coming day.

However, the consequences of this day ahead forecast being wrong are severely mitigated by the energy storage system. In the event that the forecast is too conservative, the despatchable output will be achieved throughout the day, but the full capacity of the storage system will not need to be used. In the event that the forecast is overly optimistic, the set-point output will be achieved from the start point (6h30) to an end point somewhat earlier than desired, based on the total output of the solar system. This endpoint will be determined by when the battery reaches its end of charge state, whereupon the battery will simply stop providing energy until it is allowed to recharge overnight. No damage will be done to the system and hopefully, the six, or more, hours warning of solar underperformance will allow alternative sources of energy to be activated.

The results of the testing to date have clearly demonstrated:

- Battery energy storage is effective at grid scale.
- It has been possible to test two different technologies under directly competitive conditions that replicate the probable operational duty cycles that battery energy storage will be required to perform in South Africa. Further testing will be carried out to establish the longevity of these technologies. Hopefully, further technologies will be added to the test programme to fully achieve the original objectives.
- The identification of which technologies are best suited to which applications is an on-going exercise, although the results to date suggest that the one system under test is not suitable for use within Eskom.
- The batteries will need to be used to the end of their useful lives before generic estimates of life can be made. However, indicative performances at the end of the first three year test period can be estimated.
- The project has successfully established round trip efficiencies for both of the technologies. These efficiencies differ under different operating cycles. The lithium ion system has an operating round trip efficiency of between 78 and 81%, whilst the other system is between 65 and 72%.
- It is believed that the lessons learnt during this research project would allow Eskom to go out on commercial tender for energy storage devices and to successfully integrate these devices into the grid.

Whilst further test work is needed and the incorporation of additional units for comparative testing is necessary, the project has successfully established a valid and respected test and demonstration facility. Furthermore, it has answered, or will answer with further testing, all the original research questions posed at the outset of the project.

This project has highlighted the importance of testing the units under conditions matching the application it is intended for, as flaws and non-performance of the unit can be addressed prior to installation and thus mitigating the risks when installed on site.

Acknowledgment

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References

[1] Eskom Research Report – Day By Day Demand Data Analysis to Establish Storage Capacity Required - RES/SC/08/29121

[2] Sandia National laboratories Report SAND2010-0815, Energy Storage for the Electricity Grid: Benefits and Market Potential Assessment Guide. Jim Eyer & Garth Corey

[3] Eskom Research report – Evaluation of the Energy Storage cost in South Africa - RES/SC/10/32328

[4] Eskom Research Report - RES/SC/10/32329 – Update of |Review of Daily Demand Data Based on New 20 Year Projections

[5] Chemical Batteries & Ultracapacitors for Smart Grid Technologies, by NanoMarkets. Eskom reference papers, May 2010.

[6] Eskom Scan report - RES/SC/11/33976, Impact and Needs of Energy Storage on Wind Farm Supply as per IRP 2010, March 2012

[7] Energy Storage Needs for Photovoltaic Applications in Respect of Demand Cycles based on IRP 2010 - RES/SC/11/33980 Peter Langley and Pat Frampton

[8] Navigent Research Energy Storage Tracker 1Q16, Business Wire, 09th Feb 2016

[9] Eskom Research Report – Emissions Benefit of Energy Storage - RES/SC/12/34642 – Peter Langley and Pat Frampton.

[10] Authoritative Dictionary of Standards Terms (7th ed.), IEEE, ISBN 0-7381-2601-2, Std. 100.

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