A Vanadium Energy Storage System field trial.

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Abstract

This Paper describes the establishment of a User-based field trial of a Vanadium Energy Storage System (VESS) incorporating a 250 kW/520 kWh Vanadium Redox Battery (VRB) in Stellenbosch, South Africa. The trial has been established to show the versatile configuration and operation of VESS, with the single installation demonstrating applications ranging from sub-second UPS ride-through capabilities through to power quality and emergency power back-up. The Stellenbosch VESS Trial is significant in that it is the first large-scale commercial trial of User-based applications for the VRB outside Japan.

Introduction

The Vanadium Redox Battery (VRB), is a flow battery which operates on the V(4+)/V(5+)//V(3+)/V(2+) redox couples. The vanadium electrolyte is aqueous and, depending on the concentration of the vanadium, the nominal cell potential is approximately 1.25V. As with other flow batteries, useful terminal voltages are achieved by series connection of many cells into a "stack." Electrically, the VRB stack does not have to be charged and discharged at the same terminal voltages, and different levels of energy may be drawn from different cells or groups of cells within the stack merely by maintaining sufficient electrolyte flow into the cells demanding the higher power. However, the VRB has advantages over other flow battery technologies (sometimes called regenerative fuel cells) in that the operation involves only vanadium ions in the liquid phase. The amount of power available is related to the stack voltage and the current density established through the cell, while the energy (or ampere-hours) available depends only on the supply of charged electrolyte to the stack. In terms of an energy storage system, the VRB is particularly useful in that the power function can be made to be truly independent from the energy function. That is, the stack, which dictates the available power, can be decoupled and physically dislocated from the electrolyte volume, which dictates the total amount of stored energy. In a Vanadium Energy Storage System (VESS), the design and operating characteristics of the simple VRB are optimized and integrated with automated intelligent control and operational management electronics to a provide a versatile, flexible and scalable electrochemical energy storage system technology. The attributes and characteristics of the VRB and VESS have been previously described [1-3].

VRB technology has been under development for some time and is now considered sufficiently mature to support commercial exploitation. To date however, demonstration of the industrial use of the VRB has been largely limited to simple on-grid load-leveling and peak-shaving applications in Japan. VESS technology allows the use of the VRB for broader applications in distributed power architectures, and commercial scale field trial demonstrations are thus currently being established to allow technical and industry scrutiny of the features and capabilities of VESS. A User-based field trial of a VESS incorporating a 250 kW/520 kWh VRB was established last year in South Africa. The trial has been established to show the versatile configuration and operation of VESS, with the single installation demonstrating applications ranging from sub-second UPS ride-through capabilities through to power quality and emergency power back-up. It is significant in that it is the first large-scale commercial trial of User-based applications for the VRB outside Japan.

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The Stellenbosch VESS trial

The trial, known as the Stellenbosch VESS Trial, is installed at the University of Stellenbosch, near Cape Town, in the Department of Electrical and Electronic Engineering. The trial is an international effort, and it is appropriate to briefly explain the participants. The trial is a tri-party initiative between , who have rights to the VRB technology for the continent of Africa, Highveld Vanadium and Steel Corp, who have access to significant reserves of vanadium needed for the electrolyte manufacture, and Eskom, the national electricity utility in South Africa. The venture is to create and develop a new energy storage industry based on the VRB/VESS technology. The drivers for the venture are obvious and timely. Low cost, large-scale energy storage is seen as a critical element in the improvement path for high reliability AC and DC supply. Eskom is one of the largest electricity generators in the world and has significant distribution infrastructure throughout the continent of Africa. Power quality and reliability are increasingly strategic concerns for Eskom, and a daily practical consideration for Highveld, one of Eskom's large customers. The trial is part of an evaluation of options and solutions for power quality issues currently under consideration by Eskom [4].

System design & configuration

The Stellenbosch VESS Trial involves a 250 kW/520 kWh VESS supporting a 3-phase critical load at the $380V_{AC}$ level in a standard series-connected Dynamic UPS (DUPS) configuration. In the DUPS configuration, the UPS only needs to support the load to maintain quality of supply and hence has low operational losses. The bi-directional inverter is connected to the critical load downstream of a static switch (which isolates the line from the load during an outage).

The general implementation is shown in Fig. 1, and the general specifications of the Stellenbosch VESS are listed in Table 1.

The core system was designed as an integration of three sub-systems – (i) the electrical sub-system, comprising the inter-stack connections and the power conditioning system (PCS), which includes a bi-directional inverter; (ii) the hydraulic sub-system, comprising the electrolyte storage tanks, piping, pumps, heat exchangers, and control valves; (iii) the control sub-system, including variable speed motor control for the pumps; actuator electronics for valve control, safety and switching elements; and sensors.

A VESS system comprising six, 100-cell, 42 kW VRB stacks, connected in series to provide a nominal operating voltage between 650-850VDC, operating at 400A, provides the DC input to an advanced bi-directional inverter (DPQC-P-250). Since the energy available in a VRB is directly related to the electrolyte condition, the system was specified to provide 250 kW DC power at the battery.

Table 1 – Stellenbosch VESS specifications

Element/parameter	Specification
System	
AC output line	380V 3 phase
Rated continuous power	250kVA
DC line voltage	nominal 700V
DC voltage range	650V – 850V
Max continuous DC current	400A
Operational run-time	2 hour @ 520kWh
VRB Stack *(see note 1)*	
Stack power rating	42kW continuous minimum
No of stacks	6
Stack dimensions	1.2L x 0.9W x 1.1H (m)
Stack weight	~1,400 kg
Electrolyte	
Electrolyte type	1.6M Vanadium in 4.0M sulphuric acid
Ionic ratio	1:1 V(4+):V(3+)
Electrolyte volume	*ca* 40 m^3 total *(see note 2)*
Operating SOC	20%-80%
BoS	
Bi-directional Inverter	DPQC-P-250 *(see note 3)*
Electrolyte tanks	4 x 2.5m^3 HDPE *(see note 4)*
Piping	uPVC pressure
Pumps & motors	4 x centrifugal pump/2.2kW
Heat exchangers	4 x 6 kW max
Valving	Manual and motorised
Control VESS	automated with remote control and manual override

Notes:

1. Stacks were manufactured by and purchased from Sumitomo Electric Industries, Osaka, Japan.
2. Calculated as worst case.
3. Eskom's own Dynamic Power Quality Converter technology.
4. Tank sizing is modular to allow growth in energy storage.
   At commissioning, only 7.5m3 of electrolyte had been installed.

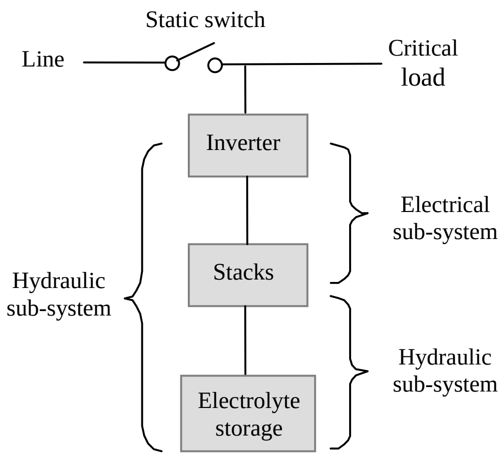

Fig 1. Generalised VESS implementation

output when operating between 20%-80% SOC using 1.6M concentration vanadium electrolyte.

The system is physically dimensioned to provide 250kW/250 kVA from sub-cycle ride-through, through to 2 hour emergency back-up.

In flow battery designs using a parallel hydraulic topology, a wasteful shunt current occurs due to the potential that exists across the highly ionic (and conductive) electrolyte. A topology consisting of two nominal 350Vdc sub-systems was chosen as a practical compromise between reduction of shunt current losses and the cost of additional Balance of System (BoS) components which arise if sub-systems of lower series voltage are used. All sub-systems are integrated and co-ordinated by proprietary VESS hardware and software. Flexible operation is implemented through an intelligent monitoring and control facility. The VESS software design allows for complete remote control of the system. VESS performance is optimised and maximised when there is communication between the inverter and the VESS controller.

The general configuration topology is shown in Fig 2. System components were obtained from various sources, and again reflected the international effort to commercial VRB technology. Stacks for the Eskom trial were purchased from a Japanese company that currently manufactures VRB stacks.[2] Six 42 kW, 100-cell stacks were used. Highveld produced the electrolyte to a purity level specified by the stack manufacturer. Eskom's 250 kVA Shunt connected Dynamic Power Quality Compensator (DPQC-P-250) was used as the PCS bi-directional inverter. This is the first construction and installation of a VRB/VESS site outside Japan, and a degree of

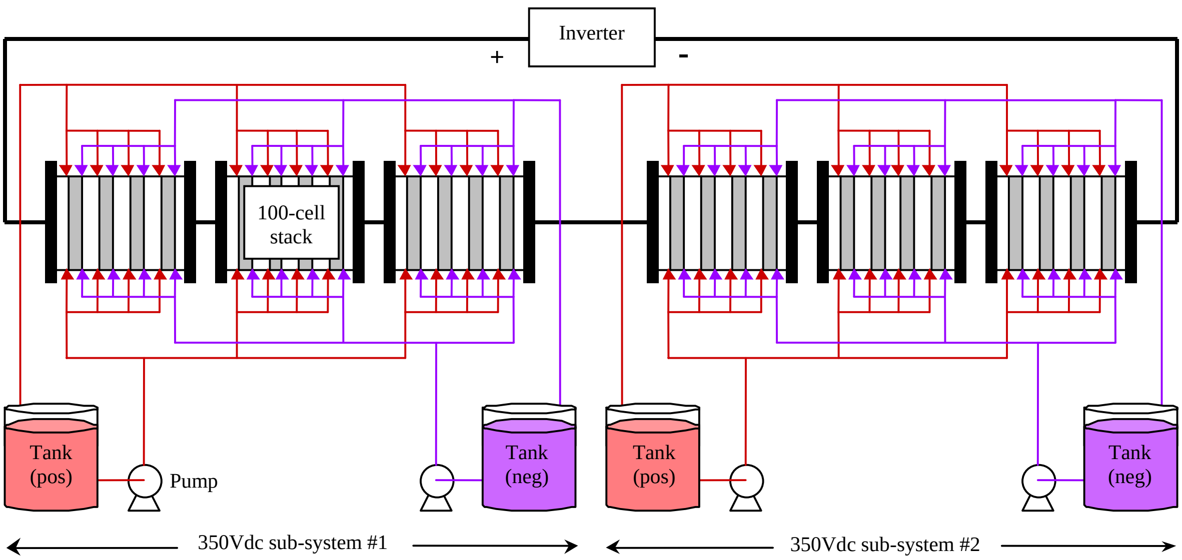

Fig 2. VRB configuration comprising two sub-systems

[2] Stacks were manufactured by and purchased from Sumitomo Electric Industries, Osaka, Japan.

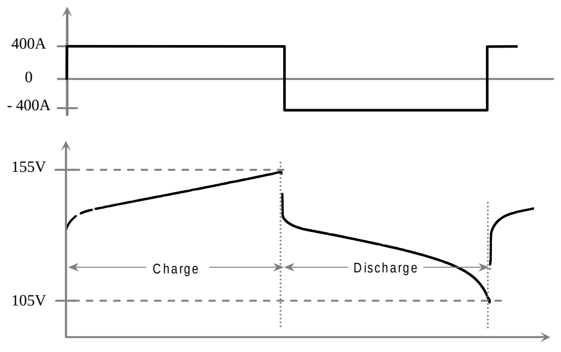

Fig 3. Typical stack charge/discharge profile

collective wisdom had to be developed as the project developed. The size of the installation was made generous to allow access during construction and later performance evaluation. While the configuration of the VESS is modular, "standard" fittings for a VRB installation do not yet exist, and many parts associated with the electrolyte piping had to be prepared at site at the time of installation. Future installations will exploit the component "standards" which have evolved from this work. The PVC piping and the pump systems were locally supplied. Proprietary VESS hardware and software was provided to by Telepower Australia. A local domestic engineering firm carried out the civil works needed to house the VESS.

As an electrochemical system, the VRB can achieve high voltaic and coulombic efficiencies. Typical voltaic efficiency of 92% and coulombic efficiency of 96% have been reported. The individual stack performance was verified at the place of manufacture prior to shipping, and then re-tested once installed at Stellenbosch. The typical discharge and charge curve at 400A for one of the 100-cell stacks is shown in Fig 3. Note that the time scale is not specified. The time of the discharge depends on the amount of charge electrolyte supplied to the stacks. For the Stellenbosch VESS Trial, the run-time design is for 2 hrs, but if the run time design was only for 20 minutes, at 400A, the curve behaviour would be the same. Each of the stacks individually exhibited a DC efficiency, at the rated 400A, between 82-85%. In the installed infrastructure, the measured DC efficiency for the stacks was found to be 81%-82%.

Table 2. Performance results

Parameter	*Performance*
Battery	
Stack efficiency	82% - 85%
Battery DC efficiency	81% - 82%
Energy density	*ca* 20 Wh/l
System	
Conversion efficiency	*ca* 95%
Round trip	*ca* 78%
Pumping loss @ max p ower	10.2 kW (*ca* 5%)

The VESS was found to operate exactly as designed and expected, and a short summary of the performance of the VESS is listed in Table 2. Examples of the time performance of the VESS which demonstrates both medium to longer time scale standby behaviour and shorter-time scale ride-though response are shown in Fig 4 and Fig 5. As can be seen in Fig 4, the completion of a charge cycle is witnessed by the decay in the battery current over approximately two hours, after which the battery is subjected to a series of discharge and charge demands, each lasting approximately 5-10 minutes. As can be seen, the individual stack potentials track each other remarkably well. Later, the battery is subjected to discharge and charge cycles at a much higher demand rate. As can be seen, the current and the total battery voltage appear to have no trouble in tracking the demand. The similarity of performance of the individual stacks is similarly remarkable, and no one stack is showing any particular performance difficulty. The short time scale ride-through response for both the DC (battery) side and the AC line is shown in Fig 5.

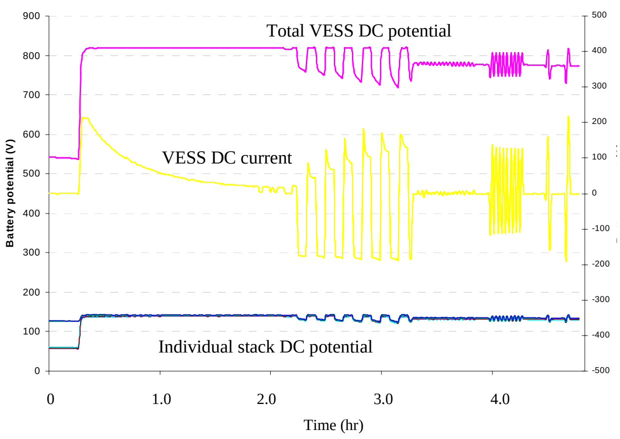

Fig 4: Medium-to-long time response

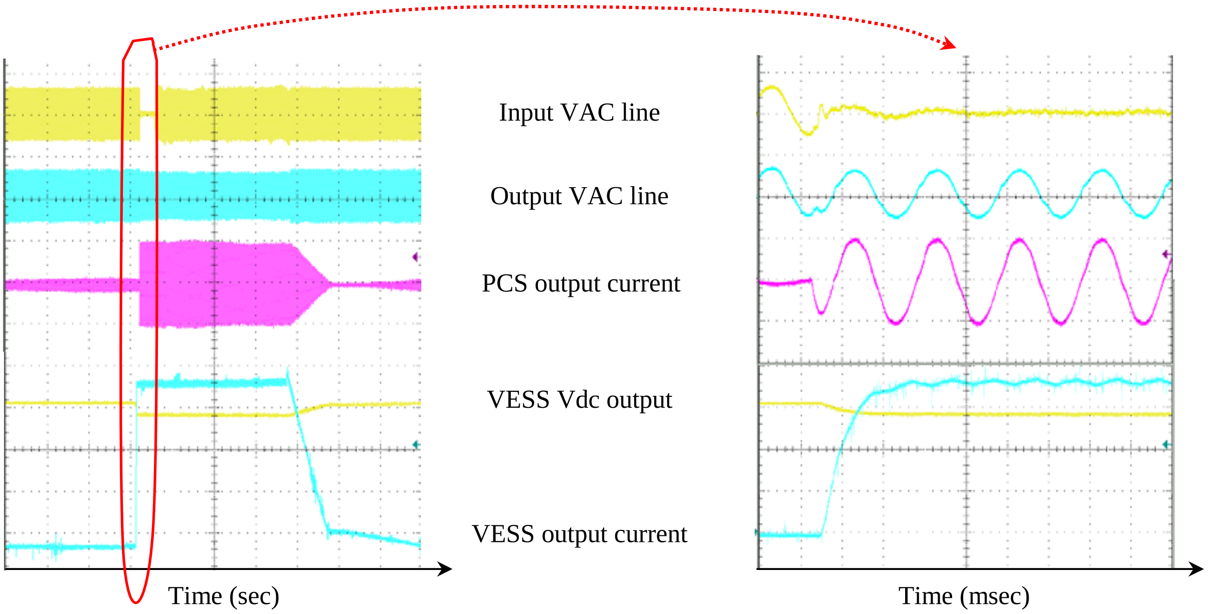

Fig 5.: Short-time response

Fig 5 shows the failure of the AC input line, and how the AC output waveform is maintained by using the battery as a true UPS. Of particular interest is the battery current response is less than one-half cycle. Notice also that the PCS maintains output well after the input line failure has cleared, and has an orderly release of the battery after demand.

Conclusion

This paper has reported on the successful establishment of a trial of a 250 kW/520 kWh VRB/VESS to demonstrate medium to large scale energy storage for power quality and high reliability stand-by power applications.[3] The trial is scheduled for a 6-12 month period of testing and applications-based performance evaluation. Core competency and new knowledge in the design and installation of VESS has now been developed. The results of the trial to date identified pathways towards modular and lower-cost components, and have verified the VESS as a versatile and practical energy storage technology.

References

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2. J.M. Hawkins & T. Robbins, 1999, "Vanadium Energy Storage System Concepts for Tele-communications Applications", INTELEC'99, paper 27-3.
3. J.M. Hawkins & T. Robbins, 2001, "A field trial of a Vanadium Energy Storage System", INTELEC'01, paper 32.1.
4. D.W. Blake et al, 2001, "Update on Energy Storage Based Power Quality Applications in South Africa", ESA Spring meeting 2001, Chattanooga, USA.

[3] A video "walk-through" of the Stellenbosh VESS installation can be seen at the