DEVELOPMENT OF A VANADIUM REDOX FLOW BATTERY FOR RENEWABLE GENERATION CONSTRAINT MITIGATION

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ABSTRACT

This paper presents preliminary findings from the development of a 105 kW, 1.26 MWh Vanadium Redox Flow Battery demonstration on the Scottish Isle of Gigha. Results are both technical, in the innovative solution which has been developed, and more general through the considerations of environmental, planning and safety considerations applied by the consortium delivering the project.

INTRODUCTION

There is often significant potential for renewable generation at the edges of distribution networks. One example is the Scottish Isle of Gigha where a community owned wind farm is mechanically constrained due to voltage rise on the 11 kV distribution network. To maximise renewable generation, an Electrical Energy Storage (EES) demonstration is being installed on Gigha which stores energy which would otherwise be lost due to mechanical constraint. Stored energy is then dispatched, when wind speeds reduce, without breaching the distribution network constraint. This application for EES has been widely discussed in previous CIRED conferences [1-3] and Gigha is typical of over 100 other Scottish islands with similar generation potential [4].

This paper presents preliminary findings from the development of a 105 kW, 1.26 MWh (12 hour) Vanadium Redox Flow Battery (VRFB) designed by Renewable Energy Dynamics Technology Ltd (REDT), leading a consortium including EA Technology - client engineer; Isle of Gigha Heritage Trust (IGHT) - wind farm owner; Scottish Hydro Electric Power Distribution (SHEPD) - Distribution Network Operator; and Community Energy Scotland.

Flow batteries are well suited to this application, due to the flexibility to specify capacity for stored energy separately to the rating for charge/discharge power. Furthermore, the energy may be stored for a long time between charge and discharge which is required to accommodate variation over periods of hours or days, inherent in wind generation.

The VRFB for Gigha was sized to capture 60% of the energy expected to be lost to constraint over the lifetime of the wind turbine. An assessment of the required Energy Storage was completed at the outset of the project and showed the economical solution to be increasing energy capacity rather than power. For a VRFB, increasing energy capacity simply involves increasing the volume of electrolyte and its containment [5].

BACKGROUND

Gigha

The Isle of Gigha is situated off the Kintyre peninsula in the South-West of Scotland (Figure 1). The Isle's wind farm comprises four wind turbines, with a rated capacity of 1,005 kW. Profits from the wind farm are reinvested in the community, with a particular focus on redeveloping housing. However, the fourth wind turbine – rated capacity of 330 kW – is mechanically constrained to 225 kW due to voltage rise on the 11 kV network at the point of connection. This constraint will result in the loss of around 3 GWh of potential generation over the lifetime of the wind turbine. Furthermore, the constraint effectively precludes the development of further renewable generation on Gigha: The Isle has potential for further wind and solar generation, should the distribution network have capacity.

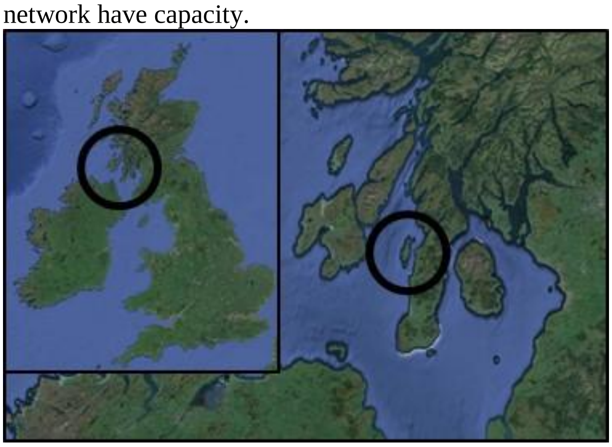

Figure 1 – Location of the Isle of Gigha

Project Background

This work forms part of a demonstration project, funded by the UK's Department of Energy and Climate Change via the Energy Storage Innovation Competition. Under phase one of this work, a feasibility study was undertaken which demonstrated the potential benefits achieved by the installation of this technology, both to Gigha and through the availability of this product for other applications. The results of this feasibility study have been published previously [5].

Phase 2 of this project involves technical design work, construction, installation and testing. The project is delivered by the consortium set out above, and is scheduled to run until March 2016. The key objectives of the project are:

- VRFB system design and engineering
- Build and test, pre-shipment
- Ship, install and commission system
- Run as a demonstration for an extended period
- Evaluate benefits compared to predictions

REDT Flow Battery Technology

The REDT stack converts electrical energy to and from chemical energy, and is a mature system which has been under development since 2001. The stack is fed by a positive and negative electrolyte which are separated by an ion selective membrane. During discharge, the positive ions migrate through the membrane and power is delivered to the load. During recharge, the polarity is reversed and the electrolyte gradually returns to the recharged condition.

The energy storage capacity of the battery is determined by the volume of electrolyte while the power capacity is a function of the stack design. This separation allows flexible specification to suite a range of applications.

A number of properties of the REDT technology led to its adoption for this project: The electrode membrane has a long operational life of 8 to 10 years (10,000 deep cycles) while other components, notably the electrolyte, retain value for significantly longer than this. Additionally, flow batteries are able to maintain charge for long durations if pumps are switched off. Finally, system maintenance and safety requirements are low which is crucial for remote applications.

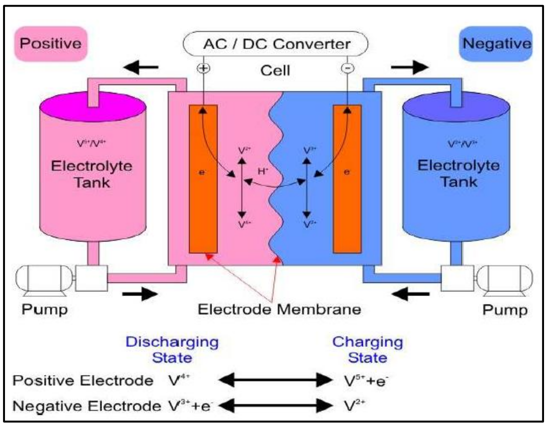

Figure 2 – The REDT Flow Battery

TECHNICAL RESULTS

Design Outcome

The design work undertaken by REDT, with support from project partners and manufacturing partner Jabil, has delivered a modular, containerised, solution (Figure 3). For Gigha this comprises as service container, a master container, and 6 slave containers. Each battery container includes a number of the stacks, described above, this number is determined to give the VRFB the appropriate power rating of 105 kW. In addition, each battery container includes electrolyte tanks, sized to give the VRFB its 1.26 MWh rating, as well as control and communication equipment, pumps and other balance of plant. By adjusting the number of containers, and the number of stacks within each container, it is possible to size a VRFB to meet specified power and energy ratings.

The containers are connected electrically, in a DC series string. This allows the voltage seen at the Power Conversion System (PCS), housed in the service container, to be large enough to meet the specification of a range of available PCSs, without need for DC:DC conversion. However, this has required significant work to ensure that an individual container can be bypassed for maintenance without disrupting the operation of the VRFB. In addition, the series connection requires that the containers are electrically isolated from the contents to avoid hazards associated with touch and step potentials.

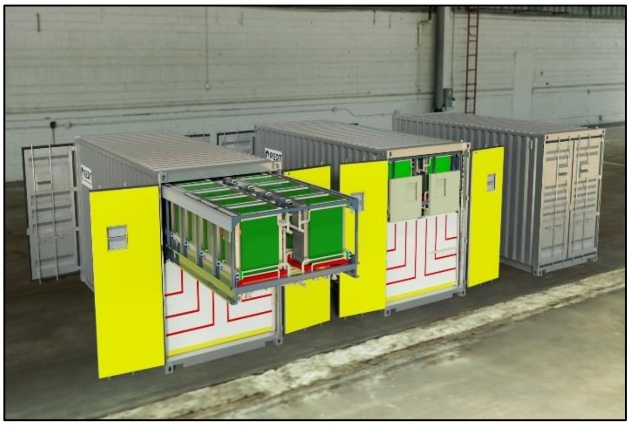

Figure 3 - The containerised REDT VRFB

Factory Acceptance Testing (FAT)

This section focuses on the electrical and network services aspects, of interest to the CIRED audience. However, the importance of FAT in verifying mechanical and chemical performance should not be overlooked.

The Gigha VRFB system is a first in class system. Therefore, the FAT is required both to verify functionality; to provide final opportunity for design adjustment prior to deployment; and to verify of the safety procedures developed at the outset of the project. The use of REDT's well proven stack technology, with commercial PCSs has minimised the risk of component failure. However, significant integration testing is still required.

On a functional level, SHEPD and EA Technology are required to witness validation of power quality compliance, to ENA Engineering Recommendations G5/4 and G59/3 [6,7]. This is particularly critical to functions which require the VRFB to rapidly change its charge/discharge rate. It is considerably more challenging to maintain harmonic distortion limitations during changes in charge/discharge rate than for static operation. This is an aspect which should not be overlooked in FAT and commissioning tests for future EES systems.

In addition, verification of successful interconnection between the wind turbine and VRFB control system is required. It is critical to ensure that the mechanical constraint is correctly lifted when the VRFB is able to import generation above the constraint. In addition it is necessary to demonstrate that a communication failure results in reinstatement of the mechanical constraint under all circumstances.

In addition to capturing constrained wind energy, the VRFB is able to operate in order to accrue revenue from trading energy (i.e. arbitrage) and to act for System Operator balancing services such as Firm Frequency Response (FFR). In order to demonstrate this, the VRFB must show that it is able to respond to an FFR call, or remote instruction to charge/discharge (via satellite communications). In addition, the necessary response time and frequency sensitivity are tested by requiring the VRFB to match charge/discharge profiles such as that shown in Figure 4.

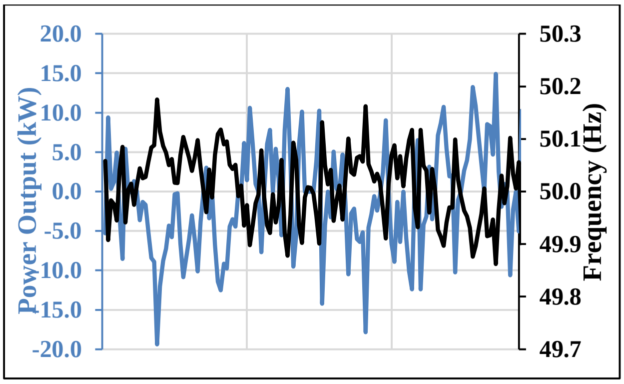

Figure 4 – Test Profile for 12 Hour FFR Call

PROJECT LEARNING

Safety and Environment

Significant effort has been expended to develop a robust safety case and environmental impact assessment for the VRFB. This was undertaken from the outset of the project to allow the design to be led by safety requirements. In particular, this led to the decision to use a containerised design which effectively removed the potential for whole system loss of electrolyte, amongst other hazards.

The project has engaged with relevant stakeholders including the local community; regulatory bodies concerned with safety and environmental protection; emergency services. This work has been aided by a number of properties of the VRFB. Particularly that the electrolyte is non-flammable and non-explosive. In addition, whilst there is a significant amount of stored energy, it is possible to mix the electrolyte without damage to the system.

The principal hazard associated with the VRFB arises from the presence of a large volume of corrosive electrolyte. This has been well mitigated by a layered defence and allocation of the electrolyte between containers. Electrolyte is stored in reinforced tanks, and pumped at low pressures. In the event of a failure, each container includes a bund tank which is capable of storing the electrolyte safely. Finally, in the event of catastrophic incident, such as an aircraft impact, the area around the VRFB has been prepared with an innovative limestone gravel mixture. This neutralises any electrolyte soaking into the ground allowing safe disposal without damage to the surrounding environment.

Renewable Incentives

One of the key learning areas for this project has been the impact of EES on the various incentive schemes associated with renewable generation. A number of schemes operate in Great Britain, administered by Ofgem, as part of Government policy to increase low-carbon generation [8].

Within GB there is presently little official guidance on the impact of EES on the various incentives. This project has engaged with Ofgem to gain an understanding of the present position for the three renewable incentives applicable to the Gigha system. This has resulted in the installation of a three-meter system which allows the measurement of energy flows to/from the grid, wind turbine and battery for each half-hourly period.

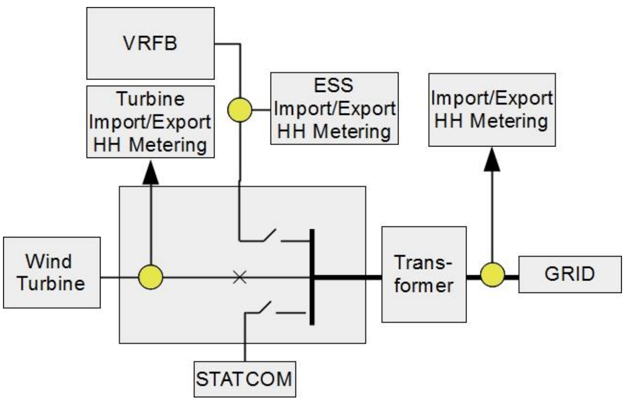

Figure 5 – Schematic of Metering Connections

Feed-in Tariff (FiT)

The Feed-in Tariff pays renewable generators for their generation and export, at prices which are set annually for different renewable technologies [9]. It is a requirement of the legislation enacting the FiT that payments are made based directly on meter readings. Therefore, given a generation meter (as shown in Figure 5) it is possible to claim FiT generation payments, with an EES as an eligible load. However, it is not possible to demonstrate, using an individual meter reading, the proportion of exported generation due to wind generation or energy imported from the grid. Therefore it is not presently possible to claim FiT export payments.

Renewable Energy Guarantees of Origin (REGO)

Under EU law all member states maintain a REGO scheme to measure the relative proportions of energy generated. The impact of EES on an installations REGO status is comparable to the FiT generation tariff, in that a generation meter ensures that the REGO can be claimed based on generated energy, regardless of the use of the VRFB.

Levy Exemption Certificates

The income from Levy Exemption Certificates (LECs) provides the smallest contribution to total revenue of the eligible renewable incentives. However, this incentive requires individual consideration from Ofgem via an application process which is ongoing. Therefore, it is not possible to provide clear learning for similar projects.

Outcome of Renewable Incentives Work

It has been possible to proceed with this project without impact to the generator's ability to claim the various renewable incentives which underpin their business case. FiTs and REGO have been shown to be unaffected, whilst LECs are subject to individual consideration via an application process.

However, if future EES installations are to facilitate greater numbers of low-carbon generators there would be significant benefit in formal clarification from Government and regulators. This should overcome the present risk that Energy Storage may have a negative impact on a generator's revenue, despite increased generation. At present, the lack of clarity on this issue forms a barrier to deployment of Energy Storage for use with renewable generation; despite the significant societal benefits which could be accrued.

Stakeholder Engagement

Distribution Network Operator (DNO)

This work has benefited from the direct involvement of the DNO from the project outset. This has allowed rapid identification and resolution of a number of concerns which are likely to be common to similar installations in the future:

Adherence to Restrictions in the Existing Connection Agreement

The installation of the VRFB does not affect the terms associated with the existing connection agreement for the wind farm (i.e. exported power and required power factor). However, the addition of the VRFB makes verification difficult for the DNO. Given half-hourly metering, it would not be possible to show if the VRFB was causing additional export during transition periods; similarly the interaction between Statcom and VRFB would be difficult to monitor to verify power factor. As a result, SHEPD have required that factory acceptance testing and commissioning testing both demonstrate a 7-14 day period of operation with high resolution data recording showing the VRFB effectively managing the removal and reinstatement of the wind turbine's mechanical constraint without breaching the 225 kW export constraint, or deviating from the power factor requirement of 0.85.

Protection Requirements

In common with other grid-scale energy storage demonstrations, the Gigha VRFB has been required to comply with the protection requirements for distributed generation in GB (i.e. Engineering Recommendation G59/3) [7,10]. G59 requires that the Energy Storage system disconnect in the event of loss of connection to the grid, or specified deviation from nominal voltage and frequency values. In addition, power quality requirements including total harmonic distortion (THD) are specified, both by G5/4 and G59/3 [6,7]. G59/3 compliance has been relatively easily ensured by including a G59/3 relay within the VRFB. However, it has been vital to demonstrate that the VRFB can change its charge and discharge rate, in-line with wind generation, without exceeding THD limitations. This has particularly driven the specification of the VRFB's Power Conversion Systems.

Community Engagement

As a community owned Isle, Gigha is an atypically engaged community. The project has benefited from positive support by residents who, in effect, have a financial incentive to support the VRFB installation. The project has positively engaged with the community, particularly on environmental and safety considerations. In addition, the planning approval for the project was gained without objections from neighbours. However the process was still slower, and more challenging, than expected. This is consistent with a number of grid-scale Energy Storage projects in GB [10].

ONGOING WORK

Within the Current Project

Ongoing work within the current project is primarily focussed on demonstrating the functionality and reliability of the VRFB. In addition, the financial and technical benefits due to the VRFB will be evaluated at the end of the project, following collection of all available data.

In the Future

The intended use for the VRFB at the end of this project has not been finalised. However, the intention is to utilise the VRFB to earn revenue for the Gigha community through shifting wind generation and arbitrage functions. In addition, the system is capable of operating in various balancing and settlement markets. However, the relatively small size of the system means it is necessary to access these revenues through energy aggregators [10].

There is also scope for using the VRFB, in conjunction with the local generation, flexible load and single point of connection to develop a prototype network which can operate self-sufficiently under fault conditions.

CONCLUSIONS

Preliminary results from a demonstration project installing a VRFB Energy Storage system on the Scottish Isle of Gigha have been presented. It has been shown that a containerised solution, where power and energy can be specified separately, is well suited to renewables application in remote locations. Further developments to be investigated include utilising the VRFB for System Operator balancing services; provision of standby power under fault conditions; and energy trading.

ACKNOWLEDGMENTS

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REFERENCES

[1] T. Miller, M. Edmonds, 2013, "Energy Storage can Enable Wider Deployment of Distributed Generation", *CIRED conference, Sweden*, paper 0904

[2] B. Gemsjäger *et al.*, 2013, "Application Possibilities and Economical Aspects of Electric Storage Devices in Distribution Networks", *CIRED conference, Sweden*, paper 1291

[3] E. Tröster, T. Ackermann, B Betz, 2013, "Using Storage to Integrate Renewables into the Distribution System – A Case Study", *CIRED conference, Sweden*, paper 1335

[4] Scottish Enterprise & EA Technology, 2010, "Energy Storage Foresighting Workshop", *Glasgow*.

[5] S. D. Wilson, J. Samuel, G. Simmonds, 2013 "An energy storage system for the Scottish Isle of Gigha", *IET Power in Unity Conference Proceedings*, p. 2.11

[6] Electricity Networks Association, 2005, "Engineering Recommendation G5/4-1"

[7] Electricity Networks Association, 2013, "Engineering Recommendation G59 Issue 3"

[8] R. Haas *et al.*, 2011 "Efficiency and effectiveness of promotion systems for electricity generation from renewable energy sources – Lessons from EU countries", *Energy*, vol. 36(4), 2186-2193

[9] Ofgem, 2014, "Feed-in Tariff Annual Report 2013-14", available: https://www.ofgem.gov.uk/publications-and-updates/feed-tariff-fit-annual-report-2013-14

[10] Energy Storage Operators Forum, 2014 "A Good Practice Guide on Electrical Energy Storage", available: http://www.eatechnology.com/products-and-services/create-smarter-grids/electrical-energy-storage/energy-storage-operators-forum/esof-good-practice-guide