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Rottnest Island Water Renewable Energy Nexus Project: Practical integration challenges for hybrid renewable energy power systems

Lucas Thomson, Ray Massie, Simon Gamble
Hybrid Energy Solutions, Hydro Tasmania

Abstract

Hydro Tasmania has been engaged by the Rottnest Island Authority to design and implement an advanced hybrid off-grid system on Rottnest Island, Western Australia. This project was funded by the Australian Renewable Energy Agency (ARENA). The system achieves a higher level of annual renewable energy contribution through the innovative integration of wind and solar generation with the demand-side management of reverse osmosis desalination and a dynamic load bank.

The project aims to increase renewable contribution from 30% to 45% per annum, via the addition of: a new hybrid control system incorporating demand management of the reverse osmosis desalination system as a form of ‘energy storage’; 600 kWp DC solar for additional renewable power generation; and a 500kW dynamic resistor for increased security of supply at high instantaneous penetration levels.

This paper provides a summary of the process of utilising water desalination as a method of ‘energy storage’ to increase renewable energy contribution and assist in addressing and leveraging the opportunity that exists from the existing water / energy nexus. It outlines solutions deployed to meet the practical challenges of implementing a high renewable contribution hybrid project in the absence of significant enabling technologies such as flywheels and batteries. Also highlighted is the importance of operator involvement and performance tools to maximise diesel savings.
INTRODUCTION

1. Background on Hydro Tasmania and its role in the project

Founded in 1914 and owned by the Government of Tasmania, Hydro Tasmania is Australia’s largest renewable energy generator with over 2.5GW of hydro and wind assets in operation, producing approximately 10TWh of renewable power per year. Hydro Tasmania is also the utility responsible for power supply on the Bass Strait Islands of Tasmania (King and Flinders Islands), incorporating the roles as generator, distributor and retailer of electricity. Hydro Tasmania has a long and successful history of integration renewable energy into these remote island networks, traditionally solely reliant on diesel generation, and developing these into world leading hybrid energy power systems.

The King Island hybrid system (www.kireip.com.au), incorporating wind and solar generation, energy storage in the form of flywheels and battery, and demand management of aggregated customer load and a resistor bank, has now delivered many world first achievements. These include the first megawatt class off-grid system capable of 100% renewable operation, operation that can be sustained for lengthy periods with the record currently standing at over two and a half days. The implementation of this system has dispelled many of the myths surrounding renewable energy, with its ability to increase renewable energy use by 65% per annum whilst improving power quality and system reliability over the traditional diesel generation fleet. The project imparted substantial insight into the realities of achieving high renewable energy contribution for remote island grids.

Hydro Tasmania’s Flinders Island project, commissioned in Dec 2017, was implemented with a similar scope to King Island except with a focus on modularity for rapid deployment and cost optimisation.

Hydro Tasmania was selected by the Rottnest Island Authority in its capacity as a developer and service provider of proven integrated hybrid energy solutions, designed for long term efficient and cost effective operation. This project was developed with and supported by the Australian Renewable Energy Agency (ARENA).

2. Rottnest Island

Rottnest Island is an island off the coast of Western Australia, located 18 kilometres west of Fremantle. The island covers 19 square kilometres in land area, and is administered by the Rottnest Island Authority (RIA). Rottnest Island is an A-class reserve, the highest level of protection afforded to public land, and in addition to the protection of the natural environment, Rottnest Island has significant cultural heritage to preserve. Rottnest Island is self- sufficient in supplying electricity and drinking water to over 500,000 annual visitors. The Rottnest Island Authority has traditionally supplied an annual demand of 5 GWh and peak load of 1.2 MW through diesel and wind generation.
3. Rottnest Island Water and Renewable Energy Nexus Project Overview

The Rottnest Island Water and Renewable Energy Nexus (WREN) Project, was conceptualised after working with the Rottnest Island Authority on the development of an energy efficiency and renewable energy roadmap for Rottnest Island. The roadmap presents a staged approach to increase renewable energy contribution Rottnest Island to 65% annual average, with times of 100% renewable supply by 2023. The objective of the WREN project is to increase renewable energy contribution from 30 to 45%, using the following project components detailed in Table 1.

The project will displace diesel generation, with a combination of solar and wind generation via the coordinated assistance of controlling demand, in the two forms of a central load bank; and in the most significant customer load, being the reverse osmosis desalination system.

The coordination of generation and load is undertaken by Hydro Tasmania’s proprietary automated control system which underpins the successful integration of the various energy sources and new enabling technologies. The Rottnest Island power system will operate with an instantaneous renewable penetration of up to 95%.

**Table 1 – Rottnest Island WREN Project details**

- **Hybrid power system controller** coordinates and dispatches generation and manages the enabling technologies automatically to ensure reliable power and maximum diesel fuel savings.

- **Diesel generation** 5 x 300 kW diesel generators, and 2 x 320 kW low load diesel generators, existing.

- **Solar generation** Installation and integration of a fixed axis 600 kW solar PV array, including 500 m underground distribution line.

- **Wind generation** 600 kW Wind turbine, existing.

- **Dynamic resistor** Continuously variable resistor of 500 kW capacity, converts excess renewable energy into fast-response spinning reserve, stabilising system frequency and efficiently managing diesel generation.
**Demand-side management (DSM) Desalination plant** reducing the energy intensity of diesel energy based desalinated water through smart control of the desalination process, representing a 145 kW load with a water storage of 14 ML. Effectively utilising water storages as a battery to store excess renewable generation.

**Remote data** performance management tools provide operator viewing via web and smart phone apps. Automated performance reporting, allowing real-time and remote monitoring and performance monitoring of the power system.

4. **Operational philosophy of WREN**

The primary driver for the WREN, as with many off-grid projects, is to reduce operational costs by displacing diesel with renewable generation. The challenge is to integrate this renewable energy, while maintaining power quality and system security. As the renewable contribution increases, so does the need to carefully manage the wider power system, including diesel generators, feeders and auxiliary systems to effectively integrate the variable renewable energy sources without putting supply security at risk.

The relative impact of this variability can be significantly greater in off-grid applications, where renewable generation can be the major source of supply, compared with a grid connected system. This manifests in significant impacts on system stability from intermittency, variability and managing contingent events. A challenge in high contribution hybrid projects, in particular in the absence of significant enabling technologies, such as flywheels or batteries, is the ability to maintain or even improve system stability under high levels of instantaneous renewable energy penetration. Running additional diesel generation, to increase the diesel reserve is the traditional solution, however, the challenge is to minimise the diesel reserve to maximise diesel savings. This requires a fast acting, coordinated, control and protection system to be in place, in order to allow the innovative load control techniques deployed to maximise the renewable energy contribution.

5. **Managing renewable energy via demand side management**

The WREN project deploys the concepts of demand side management (DSM), specifically load control and load deferral, in two very different applications to assist in increasing the utilisation of renewable energy.

A dynamic resistor acts instantaneously to assist with system stability and security, while the desalination demand management acts over hours to increase utilisation of renewable energy by ensuring renewable energy utilisation is maximised. Together these offer a cost
effective way of reducing reliance on diesel fuel for power supply without the high capital cost associated with the deployment energy storage systems.

6. Dynamic Resistor functionality

At times renewable generation will exceed the customer load producing an excess of renewable energy that is normally curtailed in traditional hybrid systems. In the absence of capital intensive energy storage systems, which act as an artificial load in these circumstances and store the excess energy, the WREN project utilises this surplus renewable energy to provide useful ancillary services, being raise and lower reserves. The surplus is converted into fast acting reserve within the dynamic resistor through rapid loading and unloading of the resistor elements, allowing faster and more accurate demand / supply balancing, maintaining high power quality. As a consequence a higher level of instantaneous penetration can be achieved and maintained over a wider range of conditions, improving the utilisation of renewable energy by reducing the level of curtailment of the solar and wind power output.

The dynamic resistor greatly improves system security by supporting the low load diesel engines to operate at 5% minimum loading, compared with 30% on standard high speed diesel generators. The dynamic resistor does this by absorbing rapid increases in renewable generation that would otherwise have resulted in a reverse power trip of the generators.

The dynamic resistor reduces technical risk, by improving system security, improves power quality and reduces diesel consumption by approximately 5%, through a combination of faster control of renewable output and the ability to operate the low load diesels at a minimum load of 5%.

The dynamic resistor is installed in a kiosk arrangement at the rear of the Rottnest Island powerhouse, as shown in Figure 1.

![Dynamic Resistor: switching kiosk (left) and load bank](image)
Hydro Tasmania has utilised its proprietary dynamic resistor technology successfully at both King and Flinders Islands, where larger 1.5 MW load banks are utilised. At these locations, in addition to the functions of providing reserve and protecting diesel engines, the dynamic resistor is also utilised to control system frequency, allowing diesel engines to operate more efficiently at minimum loads for extended periods.

7. Desalination demand side management

The second application of demand management utilises surplus renewable energy over longer timescales, shifting controllable and interruptible load, in the form of reverse osmosis desalination, to better match available renewable energy. The objective of the demand side management within the WREN project is to reduce the diesel-based energy intensity of desalinated water, through smart control of the desalination process and water storage.

The desalination plant is an ideal target for demand management because of both its size, being one of the largest loads on Rottnest Island at 145 kW, and also being a discretionary load, deferrable and interruptible, due to 15 ML, or nearly 20 days of potable water storage.

The WREN project has been designed, through the selection and sizing of the renewable generation, to have only a small amount of surplus renewable energy, in the order of 150 MWh per annum, or less than 6% of total renewable generation.

Modelling indicated solar energy provided advantages of resource diversification, being complementary to the wind generation, and alignment with both the daily and seasonal load of Rottnest Island, refer to Figure 2 and Figure 3.

Figure 2 - Nominal customer demand, solar and wind resource, daily profile, January
By diverting ‘surplus’ renewable energy into the desalination plant, and reducing curtailment or loading of the dynamic resistor at this time, this effectively utilises the desalinated water produced for later consumption as a form of energy storage. Using surplus renewable energy to directly serve customer load, avoids round trip efficiency and parasitic losses, in the order of 15%, associated with battery energy storage. In addition, the 150 MWh of modelled surplus renewable energy is too small in this application to recover, through additional diesel savings, the additional capital cost of battery storage.

Hydro Tasmania’s hybrid control system will schedule the discretionary utilisation of the desalination plant, to assist in matching the renewable generation with Island demand, reducing the diesel required to create water. This concept is shown in Figure 4. The DSM module will be used to schedule (turn on and off) and, where practical, interrupt (fast stop) the desalination load. The control system will consider power system conditions, such as availability of excess renewable generation, as well as water storage levels, plant and operational constraints. Plant and operational constraints that will impact on the ability to control the desalination plant include, minimum run times, impact of interruptions on membrane filters and saline bores, minimum water storage requirements and maintenance requirements.

A number of changes are required to the desalination plant, refer to Figure 5, including instrumentation and control upgrades, to provide effective and safe integration, without impacting on plant operations or maintenance. These changes include the installation of power, flow and level sensors on water storage tanks, saline bores and the reverse osmosis plant itself. Instrumentation required to automate the starting and stopping of the plant, includes; metering, bypass flow valves, turbidity sensors and level sensing.

**Figure 3 - Forecasted customer demand 2023, solar and wind resource, seasonal profile**
Figure 4 - Water Renewable Energy Nexus Overview, managing surplus renewable energy

Figure 5 - Desalination plant overview
8. Integration of equipment

As the sophistication of a system increases, with the inclusion of multiple variable generation sources and enabling technologies, upgrades and integration of existing equipment, such as diesel unit controllers, updated feeder management systems and renewable energy controllers are required. Existing equipment/controllers can often be outdated or unable to provide control information at the required resolution or speed to effectively integrate.

When integrating either existing or new equipment in a hybrid configuration such as the Rottnest WREN, it is vital that the systems are able to ride through system disturbances and maintain the connection to the grid, where safe to do so. This can often require modification of equipment, ranging from minor firmware or setting changes, through to upgrades or even replacement of controllers.

Standard off the shelf equipment, such as wind turbines or solar inverters are primarily designed and setup for on-grid installations. Hybrid system designers need to have a detailed operational engineering understanding, to be able to configure or even customise the control and protection systems, for site specific off-grid use. Accessing detailed engineering information from suppliers, often international, can be challenging, when combined with limited understanding of the unique challenges in off-grid applications.

On the Rottnest Island WREN project, both configuration of in-built protection settings, and modification and replacement of equipment was required to effectively integrate and achieved required response times. Significant detailed engineering was required to coordinate and optimise both the wind turbine, including replacement controllers and the solar farm protection and inverter settings, to ensure system stability was not impacted.
To effectively coordinate the integration of the wind, solar, diesels, low load diesels, feeder management system, dynamic resistor and desalination plant Hydro Tasmania deployed its proprietary hybrid power system controller and upgraded individual unit controllers to achieve seamless autonomous integration. This system is based on years of practical operational use on complex hybrid power systems that Hydro Tasmania’s own and operate.

9. **Realising diesel savings**

Whilst the sophistication of the hybrid system can increase, it is important that hybrid power systems remain simple to operate and maintain.

It is not uncommon for hybrid system operators to run systems sub-optimally, or to disable automated features due to limited understanding of system operation, poor design or faulty equipment, this can significantly reduce diesel savings over the life of the project, and reduce business case returns. One typical example is the manual scheduling by operators of an extra diesel engine to increase reserves above that required, incurring a large increase in diesel fuel costs over the project life. With high renewable contribution hybrid systems such as the Rottnest WREN, automated control is necessity due to the importance of sequencing and timing of response of the large number of system components. As response time scales are often sub-second in nature, operator intervention, such as manually setting diesel requirements or curtailing generation is not practical.

The inability to realise project benefits can be avoided by ensuring a high level of system operator involvement in the design and implementation of the project; thorough understanding of operations through training programs and adequate system documentation; and via sound maintenance practices.

In addition to working closely with the system operators in the design and implementation phase, ongoing support through the provision of appropriate performance monitoring tools such as real-time remote system viewing, data historian and automated performance reporting, on-line documentation are key to realising fuel savings.
Hydro Tasmania has provided the Rottnest Island Authority with all of these systems, an example of the remote operator screen is shown in Figure 8 and Figure 9.

Figure 8 - Rottnest Island, web based remote operator view screens

Given the popularity of Rottnest Island with the Western Australia community and international tourists, achieving over half a million visitors annually, Hydro Tasmania has also developed a smart phone application to assist in engaging visitors with the water / renewable energy nexus story, shown below in Figure 9.
10. Success and Outcomes

The Rottnest Island Water and Renewable Energy Nexus (WREN) project, is the culmination of a series of projects over a sustained period of development, that will significantly increase the use of renewable energy in an off-grid network, maintaining the quality and security of power supply, and reducing the use of diesel fuel and in turn greenhouse gas emissions.

The WREN project is a leading example of the effective integration of demand side management with a hybrid diesel, wind and solar energy system to achieve a 45% annual renewable contribution. It represents a real world, full scale demonstration of how to leverage the water energy nexus to the benefit of system operators and consumers with global application.

The use of demand side management of reverse osmosis desalination as energy storage will provide an important case study as to the value of utilising existing equipment on off-grid islands to assist in managing and integrating high levels of renewable energy.

Off-grid power systems are invariably diesel based and expensive to operate due to high fuel costs. These power systems are now obvious targets for the installation of renewable energy to lower the cost of energy, and in many cases assist in the pathway to self-sufficiency. Hydro Tasmania’s experience via operation of its island systems and through
development of projects such as the Rottnest WREN, indicates that communities and system operators need to be very mindful of and carefully plan the deployment of such systems, taking care to “reinforce” the system through well integrated enabling technologies.

The Rottnest WREN project offers lessons for other utilities or community groups interested in implementing high levels of renewable energy. In particular the project highlighted the need and value of detailed engineering planning and working closely with operators and suppliers to ensure equipment is procured and configured to suit the unique requirements of off-grid systems in the role of managing variability and supporting renewable integration.

The WREN project will also benefit from broader learnings of the essential role of power station operators in achieving diesel savings over the long term. WREN operators are being supported with the right training, and assisted with remote viewing and performance tools, providing the asset owner with confidence that the system will be operated in a manner which will achieve diesel performance targets.

For further information please contact us at hybridenergysolutions@hydro.com.au