



Flinders Island Hybrid Energy Hub A00617

Final Public report: project results and lessons learnt

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Executive summary

The Flinders Island Hybrid Energy Hub project set out to develop an innovative high-renewable-energy-penetration hybrid off-grid power system, incorporating a significant proportion of third-party renewable generation – be that utility-scale wind generation or distributed solar. A main objective was to develop scalable and modularised designs for ‘readily deployable enabling technologies’ such as batteries, flywheels and resistors, enabling significant commissioning activities to be carried out in factories, which would reduce time on site.

This objective was achieved through the development of the Flinders Island Hybrid Energy Hub and subsequently immediately applied to a third-party project at Coober Pedy, South Australia (also funded by ARENA). Though the Flinders Island Hybrid Energy Hub bore the costs of developing the deployable technology, it has also set up future projects to be commercially viable, not only with the methods developed in this project but also with the capacity gained to further refine the technology and reduce the delivery costs.

The Flinders Island Hybrid Energy Hub project successfully increased targeted levels of annual renewable contribution up to 60%, and is able to run for periods of continuous zero-diesel operation (up to nearly 100 hours continuously and for approximately 50% of the year). The project installed a 200 kW DC solar farm, 900 kW wind turbine, 1.5 MW dynamic resistor, 850 kVA diesel-UPS, 750 kW/266 kWh battery, distribution line augmentation and feeder management system, all integrated into the existing diesel power station. All these elements were integrated by implementing an advanced automated hybrid power system controller.

Challenges overcome during the project included the ability to integrate the renewable energy, both solar and wind, 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 the power supply at risk.

The hybrid energy control system was the key to successfully integrating renewable energy from solar and wind with the supporting enabling technology, namely the diesel generation, dynamic resistor, diesel UPS (flywheel) and battery. The control system was deployed to meet the practical challenges of implementing a hybrid project with high renewable contribution.

As the sophistication of power generation increases, with an increasing range of technologies deployed, it is essential that sufficient tools and training are provided to owners and operators to achieve diesel savings over the long term. During this project, we trained operators, involved them in project delivery, and delivered tools (such as remote view screens, manuals and data reporting) for monitoring the power system and ensuring optimum operation to maximise renewable contribution.

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Project overview

Project summary

The objectives of the funding agreement for the Flinders Island Hybrid Energy Hub included designing, constructing and proving the feasibility of containerised high-penetration off-grid systems as well as developing a commercial solution for high-penetration off-grid systems. These objectives are set out in full here:

1. *Designing, constructing and demonstrating the technical viability of a containerised high-penetration wind/solar hybrid energy system*
 - a) *Integrate, modularise and containerise supporting technologies*
 - b) *Develop technical capability to roll out high-penetration systems into other remote and island communities*
2. *Developing a commercially viable solution that eliminates the need for grants in high-penetration wind/solar hybrid renewable energy systems in very remote and island communities*
 - a) *Developing a containerised solution to minimise logistics and on-site activities, thus reducing cost*
 - b) *Reducing the cost of designing, constructing and operating high-penetration hybrid systems*
 - c) *Developing an implementation process that will allow minimal impact on the physical assets of an existing power station*
 - d) *Developing a product solution for systems by allowing each element to be applied as a whole or individually*
 - e) *Testing manufacture of products and engaging suppliers for portfolio supply*
 - f) *Developing a pipeline of opportunities that drive capital cost reduction of up to 30% over the next 5 years*
3. *Developing and sharing knowledge and experience in high-penetration hybrid renewable energy systems*

The project built on Hydro Tasmania's highly successful King Island Renewable Energy Integration Project (KIREIP)¹ that achieved world-leading renewable energy penetration levels in megawatt-scale systems. The innovative developments in the Flinders Island Hybrid Energy Hub project were the containerisation of the enabling technologies, which facilitated factory acceptance testing (FAT) before shipping and increased the speed of deployment on site.

One of the main challenges experienced by Hydro Tasmania on King Island was the lengthy intrusion into an operational power station. Containerising the enablers in the Flinders Island Hybrid Energy Hub project enabled the system to be built away from the power station building and connected to the system in the 11 kV switchroom.

In addition to delivering the project itself, the project team developed business capability, systems, tools and products to assist with future delivery to the broader market. One immediate example of

¹ KIREIP is an initiative of Hydro Tasmania and has been developed with the assistance of the Australian Government's Australian Renewable Energy Agency and the Tasmanian Government.
[<http://www.kingislandrenewableenergy.com.au/>]

application is the Coober Pedy Hybrid Power Project for Energy Developments Limited; a project that was also funded by ARENA. The Coober Pedy project has been operating successfully since 2017.

Project scope

Hydro Tasmania undertook the Flinders Island Hybrid Energy Hub project to create a project opportunity to refine a cost-effective strategy for delivering high-penetration renewable energy hybrid systems to the wider market.

While the concept was proven on King Island (with the enablers housed in buildings), the scalable modular solution developed in the Flinders Island Hybrid Energy Hub project is a form that can be delivered to remote locations across Australia and the Pacific.

Low-cost renewables are cost-effective solutions in diesel generation systems; however, at the time of the project, high-penetration renewable hybrid systems at a megawatt-scale were either not competitive in cost or they sacrificed system security (i.e. incurring outages), safety (of customers and equipment), or power quality (voltage and frequency control).

Hydro Tasmania had a good technical basis developed through KIREIP; however, to support delivery to remote locations, it was important to mitigate risk during delivery and to reduce costs, and therefore specifically to reduce commissioning effort on site. This required the development of standard designs so that the enabler products could be housed in seaworthy 20 foot shipping containers. It also required the development of business processes to support the roll-out of these projects.

Outcomes

Hydro Tasmania's Flinders Island Hybrid Energy Hub project provided an opportunity to develop the necessary standard designs for containerised solutions and to work through emerging challenges without the pressures of third-party contracts, whilst also supporting subsequent delivery on the Coober Pedy project.

This was the first demonstrated application of Hydro Tasmania's enablers-based, zero-diesel-capable systems to fully integrate solar generation as well as wind generation.

The project developed and matured workable designs for Hydro Tasmania's containerised enablers and associated controls including switchgear, diesel-UPS, dynamic resistor and a control system.

Regarding smaller off grid systems, Hydro Tasmania had the opportunity to engage and work with Enercon using its E44 900 kW wind turbine that is one of the only examples of a reliable mid-size wind generation technology still available in the market.

For off grid and larger grid applications, Hydro Tasmania worked with a leading supplier of batteries to get an updated view of the technologies available in the market. Hydro Tasmania has subsequently continued to see rapid evolution in the battery market through other projects in Australia (including at Coober Pedy) and also other activities in the Pacific through Asian Development Bank funded work. It is clear that the role of batteries will increase as battery functionality and reliability improves and costs fall.

To manage the system, Hydro Tasmania's advanced control system was necessary to integrate all the generation and enabling elements along with the existing diesels and third-party-owned wind turbine (noting that the system also has an ever-increasing installed capacity of uncontrolled behind-the-meter solar).

As reported at each of the project milestones, Hydro Tasmania has achieved the original objectives of the project. The table below includes comments related to the defined project outcomes, as per the final milestone report.

Comment on progress toward achieving each of the project outcomes	
Project outcomes <i>List project outcomes as set out in the funding agreement.</i>	Achieved / not achieved (comment)
1. Designing, constructing and demonstrating the technical viability of a containerised high-penetration wind/solar hybrid energy system	<p>Achieved.</p> <p>Designs for the following containerised systems have been completed:</p> <ul style="list-style-type: none"> - Diesel-UPS - Dynamic resistor - Switchgear - Control room <p>Battery suppliers have supplied a containerised energy storage system.</p>
a) Integrate, modularise and containerise supporting technologies	<p>Achieved.</p> <p>Design philosophy has been established and standard designs created – and rolled out at Coober Pedy and now on other projects. Moving forward, as with any product, these will be subject to review as part of a robust continuous improvement process. Their application within systems is also important in the context of overall and system operation methodologies.</p> <p>Control code and new human-machine interfaces (HMI) have been developed, installed and commissioned.</p>

<p>b) Develop technical capability to roll out high-penetration systems into other remote and island communities</p>	<p>Achieved.</p> <p>Resource capability has been enhanced through recruitment of technical resources as well as working closely with key staff in our Entura business during project identification and implementation stages.</p> <p>Through delivering the suite of projects under the ARENA program, Hydro Tasmania has built its delivery team and grown its capability in core services, with resources across the whole Hydro Tasmania group.</p> <p>Standard product drawings and delivery systems (including commissioning planning) have been developed that will assist future project delivery.</p> <p>The control system itself has been successfully developed, although there will always be some system-specific design for new projects.</p>
<p>2. Developing a commercially viable solution that eliminates the need for grants in high-penetration wind/solar hybrid renewable energy systems in very remote and islands communities</p>	<p>Achieved – the process is ongoing and will continue as this market segment continues to move rapidly.</p>
<p>a) Developing a containerised solution to minimise logistics and on-site activities, thus reducing cost</p>	<p>Achieved.</p> <p>Designs have been completed for all enabling systems. On-site ‘balance of plant’ works have also been designed and tested through commissioning and operation (noting that ‘balance of plant’ works are site specific).</p> <p>The extensive functional performance testing of the containerised enablers undertaken for this project will not need to be repeated in future, as the performance is now proven. As the requirements are driven by system operation methodologies, further refinement of the proven product may be required.</p>

<p>b) Reducing the cost of designing, constructing and operating high-penetration hybrid systems</p>	<p>Achieved.</p> <ul style="list-style-type: none"> - The capital cost of the enabling equipment developed in this project is projected to be cost-competitive for future projects. - The high capital cost of the (larger) wind turbine generator reinforces that the sizing of wind generation technology is a major issue for hybrid systems (in comparison with solar PV, it is not modular). - The 'balance of plant' costs were higher than expected at this site, and further effort has already been undertaken to reduce costs for other sites (such as at Coober Pedy). The development of drawings and delivery systems has reduced construction timeframes and costs. - Drawing on learnings from across the ARENA portfolio, including the Rottneest Island WREN project and Coober Pedy, Hydro Tasmania will continue to develop advanced system operation methodologies, including tracking the technological advances of enablers, including batteries.
<p>c) Developing an implementation process that will allow minimal impact on the physical assets of an existing power station</p>	<p>Achieved.</p> <p>Issues were identified regarding establishment of adequate switching arrangements to aid maintenance practices, and ability to energise Hub systems in the absence of station services. Process improvements in these areas will be valuable to future deployments, as will testing the methodology alongside existing station operations prior to taking over the running of key station elements.</p>
<p>d) Developing a product solution for systems by allowing each element to be applied as a whole or individually</p>	<p>Achieved.</p> <p>A modular approach was integrated into the design philosophy allowing the elements to be easily combined in varied configurations for a given project.</p>
<p>e) Testing manufacture of products and engaging suppliers for portfolio supply</p>	<p>Achieved.</p> <p>Significant insights were achieved via moving into further project deployments in quick succession (both Coober Pedy and Rottneest Island).</p>

<p>f) Developing a pipeline of opportunities that drive capital cost reduction of up to 30% over the next 5 years</p>	<p>Achieved.</p> <p>The pipeline of projects identified has grown. Hydro Tasmania continues to assist its existing and new customers within Australia as well as ongoing and new international advisory roles in the Federated States of Micronesia, Vanuatu, Hawaii, Cook Islands and Samoa. A significant portion of work has been delivered in Cook Islands with additional assistance now underway.</p> <p>Hydro Tasmania is actively bidding on implementation projects in Australia and the Pacific for developers and directly for utilities, with a significant focus on system planning and delivering flexible control solutions. This includes working with partners, including control providers, developers and constructors.</p>
<p>3. Developing and sharing knowledge and experience in high-penetration hybrid renewable energy systems</p>	<p>Achieved.</p> <p>The knowledge-sharing plan is in the preliminary stages of implementation; however, significant interaction with utilities and customers continues. ARENA team members visited the site in late July 2016 and again in late November 2016 for the IPS Connect event as well as an associated professional development course run by Hydro Tasmania through its professional services business, Entura.</p> <p>Approx. 50 invitees were on site for IPS Connect (in cooperation with the University of Tasmania), building on a similar event on King Island in 2015. This was followed up by similar events on Rottnest Island in 2017 and Maui, Hawaii in 2018, where further reference was made to the ARENA-funded portfolio delivered by Hydro Tasmania. IPS Connect will be held again in Tasmania in 2019.</p> <p>Delegations from Tonga and an ADB-funded group from Russian states have visited. A Thai delegation visited in April 2017, sponsored by Austrade. Most recently, a group from China visited the Flinders Island Hybrid Energy Hub.</p> <p>Hydro Tasmania had an increased presence at the Pacific Power Association (PPA) conference in Samoa in 2017, Palau in 2018, and Rarotonga in 2019.</p>

Some further discussion is provided here of activities toward continual building of a pipeline of works.

Removal of need for grant funding for projects

Grant funding, tax holidays, rebates or renewable energy certificates are all forms of the widespread support within the electricity market be it for small communities power systems, mining activities or for different types of generation from coal, diesel to renewables.

At the time of the Flinders Island Hybrid Energy Hub project, diesel prices were low and embedded subsidies masked the true costs of diesel. Moving towards high-renewable-penetration systems was seen as a costly exercise in the market, therefore requiring grant funding and/or government policies driving towards 100% renewable energy systems. The normalisation of higher proportions of renewables in the market has been supported by these types of ARENA-supported showcase projects along with continuing decrease of the costs of renewable energy and enablers. Since the completion of the Flinders Island Hybrid Energy Hub project, systems and pricing have evolved. Larger industrial users are now increasingly recognising the reducing costs of renewable generation and battery storage, and are looking to renewables to reduce their fuel costs.

‘Simple’ systems with low to medium renewable energy penetration, up to an annual limit of 30-40%, have typically provided the best immediate return on investment. These would include installation of solar and/or wind generation, potentially along with a battery, but without additional enablers.

Renewable energy penetration in these systems has been limited because, without enablers, choices have to be made regarding the priorities of safety (to customers and equipment) or system security (i.e. minimise customer outages) to deal with any faults in the distribution network. If there are faults in the network during periods of high renewable energy generation, these systems don’t have the capability to detect, identify and locally isolate faults within the network. The danger of keeping generation online when there are system faults is that the fault may continue to be fed, which is a safety hazard with potentially fatal outcomes.

‘Complex’ systems with high renewable energy penetration (up to 100% instantaneous) and up to an annual limit of 60-70% typically require enablers (such as the suite of products from the Flinders Island Hybrid Energy Hub project, Rottneest Island WREN and Coober Pedy) to optimise the solution. These systems would include installation of solar and/or wind generation and batteries, along with enablers, with the additional generation resulting in periods of curtailed generation and/or spilled energy. In the past, the economics of these projects has typically been negative to cost-neutral in comparison with ‘simple’ low to medium renewable energy penetration systems, though this has changed with the reducing costs of renewable energy generators and enabling technology.

Hydro Tasmania’s enablers facilitate the network operator to maintain system security in a safe manner by immediately detecting and identifying faults in the network and locally isolating those faults. In doing so, the operator can keep generation online to feed the remaining customers on the network, thus minimising the number and impact of any outages. As such, these ‘complex’ systems typically improve overall system performance in a manner more comparable with larger national electricity grids.

Enabler ‘balance of plant’ costs

‘Balance of plant’ costs were disproportionately high in the ‘immature’ designs of previous projects (King Island) and additional costs incurred on site. With these designs now fully matured on the Flinders Island Hybrid Energy Hub project and subsequently rolled out at Coober Pedy, costs will be reduced for future projects.

The initial concept was for a rapidly deployable standalone modularised system. The core of the hardware approach achieved this, but the site specific needs were slightly more complex. As an

integral part of a working utility station in Australia, the Hub project has been shaped by a utility's requirements regarding safety, ease of operation, and longer term efficiency. As such, it is now connected to the station's fuel, oil, water and fire detection systems, with buried drainage, a long-life cable management system including shielded cabling, and concrete foundations and steel platforms, steps and handrails. By way of contrast the temporary installations that were rolled out by Hydro Tasmania for the emergency diesel power generation during Tasmania's energy challenge in 2015/16 were considerably simpler.

This is telling us that in the future, the level of installation complexity or otherwise will largely be determined by the specific application of these systems and customer requirements that will require more focus upfront on these aspects.

Development of full pipeline of work

Hydro Tasmania has successfully built relationships and reputation across the Pacific through its direct relationships with utilities, such as in the Cook Islands, Hawaii, Tonga, Samoa and Yap in Micronesia, as well as with funding agencies such as the World Bank, IRENA, Asian Development Bank and active contractors (including developers and equipment suppliers). Much of this early work has been on systems with low renewable energy penetration or on smaller-scale solar/battery 100% penetration systems, but now includes the development of larger-scale systems in the Pacific.

Along with a range of different partnerships with equipment providers and developers, Hydro Tasmania has significant reach and market penetration through its own activities and those of its consulting business, Entura.

Hydro Tasmania is working on bringing opportunities with partners in the national market to reality. As mentioned above, larger industrial users have a rapidly growing interest in renewables and battery storage as technology matures and performance is proven. This is particularly evident now in the mining sector. These interests are commercially sensitive at this point, but involve independent power producers (IPPs) as well as mining and power utilities. The first of these that has been made public is the Agnew gold mine in Western Australia, for which Hydro Tasmania (through Entura) is supplying the hybrid control and integration service to the IPP.

Hydro Tasmania is also considering licensing its control systems and enabling technologies as another mechanism to penetrate the market.

Knowledge-sharing objectives

In addition to the 'lessons learnt' documentation included in this report and the performance data logged on site, knowledge-sharing activities include:

1. site visits, including for:
 - Australian & Pacific utilities
 - aid agencies
 - country delegations
 - international conference host location – Isolated Power Systems Connect
 - academic institutes
2. project website
3. participation and presentations at conferences, industry events and academic/scientific events
4. publications in media, journal articles, and industry associations magazines/websites.

These objectives are largely addressed in the comments made against the project outcomes above and in the publications and digital materials below.

Hydro Tasmania has also engaged with the local community through the school, a community open day, and through the local council.

Digital materials and media

Two videos were produced presenting this project:

- ARENA video
- Hydro Tasmania videos.

In addition, several radio programs covered the developments on Flinders Island through the Australian Broadcast Corporation (ABC).

Hydro Tasmania produced a project mobile app and project dashboard for embedding on the Hydro Tasmania website. These dashboards show real-time performance from the Flinders Island Hybrid Energy Hub system, following on from Hydro Tasmania's previously developed apps for KIREIP and also from Rottneest Island (both projects developed with ARENA's support).

The Flinders Island Hybrid Energy Hub project, alongside KIREIP, demonstrates Hydro Tasmania's commitment to development and innovation and to sharing these projects with the broader industry.

Other communication about the project has been published in third-party industry journals and publications, and Hydro Tasmania has made presentations about the project at conferences.

Transferability

As well as project opportunities in the Pacific and larger remote communities in Australia, there are applications to other isolated systems in Australia and large industrial users (such as mining activities). There are also other international markets across Southeast Asia, but the application of these systems to those locations will depend on specific goals and objectives.

Further, the knowledge and learning gained through these projects is immediately transferable to the wider market through our advisory consulting role. Further product development opportunities are being identified to better transfer these project outcomes to meet the needs of the wider market, e.g. in developing nations or mining.

Internally to Hydro Tasmania as a generator and retailer in the NEM, the knowledge gained in these complex off-grid systems is being applied to on-grid systems and designs. The challenges of integrating larger amounts of renewable energy for on-grid systems are similar, though with more commercial complexity. It is therefore possible to say that others will utilise the outcomes of these challenging off-grid projects to solve some of the challenges in on-grid projects.

Other solutions are being provided in the market by battery suppliers, inverter suppliers and other equipment suppliers/integrators. However, as discussed earlier, the inverter-based solutions (from battery and inverter suppliers) have typically focused on simple direct integration of renewables into systems, and have not been able to achieve (a) 'system security' (minimisation of outages) and/or (b) ensuring safety (due to providing low levels of fault current) at a system scale similar to or larger than the Flinders Island Hybrid Energy Hub. Typically these systems have been unable to detect, identify and locally isolate faults within the network.

In comparison, more complex systems with enablers facilitate the network operator to maintain system security in a safe manner by immediately detecting and identifying faults in the network, and locally isolating those faults without wholesale changes to existing protection schemes. In doing so, the operator can keep generation online to feed the remaining customers on the network, thus minimising the number and impact of any outages. As such, these systems typically improve overall system performance to a level more comparable with larger national electricity grids.

Conclusion and next steps

The Flinders Island Hybrid Energy Hub has delivered its goals, and Hydro Tasmania continues activities such as product and pipeline development.

Other steps forward have been made, in areas such as:

1. The approach for claiming renewable energy certificates (RECS) from the Clean Energy Regulator (CER) for hybrid systems, which may also benefit the broader market.
2. Lessons have been learnt for communities and small island or isolated systems where there are drivers to allow communities to continue to install behind-the-meter rooftop solar PV and distributed battery storage. Unchecked, such an approach has the potential to disrupt the system stability. By understanding the whole local energy system approaches to deal with the changing distribution of energy generation can be determined. Approaches could include, setting appropriate tariffs, technical requirements for installing more solar, batteries and/or resistors, along with distributed control schemes that limit the export for the behind-the-meter solar installations.
3. The application of hybrid energy systems to solve fringe-of-grid and/or local issues within parts of the grid, which will continue to evolve as costs change and as the shape of the grid changes due to renewables replacing dispatchable thermal generation.
4. The applications of hybrid energy systems using demonstrated containerised approaches that can save money and be rapidly deployed in local areas (as per other electrical infrastructure), through to control systems and methodologies to manage local issues.

Development of high-penetration systems that maintain system security whilst ensuring safety

As the pricing of technology in the market continues to change, particularly for battery storage, the design of hybrid renewable energy projects will continue to develop.

Hydro Tasmania's role as a solution provider for hybrid integration is built on its knowledge of delivering its own systems, such as the Flinders Island Hybrid Energy Hub project, as well as its Owner's Engineer and advisory roles across the Pacific and Australia. The Flinders Island Hybrid Energy Hub project will continue to play a part in informing our provision of technology solutions as well as our broader involvement in the off-grid sector.

Hydro Tasmania will continue to work closely with customers, ensuring we have full exposure to all technologies with a 'best for customer' approach. This may include provision of our own containerised enablers where appropriate.

Building on this project and others and the lessons learnt, we will investigate other technologies that will also facilitate high-renewable-penetration systems, such as low-load diesels, advanced inverters, and, of course, batteries as the sector continues to grow.

Batteries will certainly have a considerable contribution to make in the future. However, there are some key limitations in battery systems:

1. protection systems, in relation to fault detection, identification and local isolation and fault current provision (as discussed earlier in this report)
2. economically capturing spill of energy due to large installation of renewables within systems
3. lifetime issues around the number of cycles involved with continuous frequency regulation of excess energy at the same time as management of battery storage levels. Given their relative newness, there is still a way to go to fully understand the true lifetime of battery systems in terms of longevity and continuing reliability.

At present, the design of high-renewable-energy-penetration systems generates significant spill of energy. System design for storage has focused on power batteries, which are required to provide rapid system control to manage frequency as larger energy batteries are generally still too expensive to store a significant share of this energy. Essentially, batteries currently provide short-term power regulation in large systems. However, battery prices are decreasing rapidly, so capturing a greater percentage of energy spill through additional battery storage may become cost-effective in the near future. In addition to battery energy storage, other options to be considered on a site-by-site basis include:

- local use of industrial-sized supply of hot water or heat
- desalination plants
- generation, storage and conversion of hydrogen for use in vehicles or electricity generation
- demand-side management re domestic hot water units or controllable loads
- pumped hydro energy storage (in applications on larger grids).

Regarding the lifetime issues of batteries, if batteries are providing the full frequency control response of the system, there will be continuous throughput of energy through the battery. This adds to the number of cycles required from the battery during normal operations, which effectively reduces its lifetime. In trying to keep the battery in a reasonably tight operating range of state of charge, the extent of the power throughput is hard to predict due to variations in load and renewable generation and system inertia. As large-storage batteries get more cost-competitive and industry experience increases, this concern will reduce. This issue is of less concern where other generation can help regulate the system, and diesel generators are generally well suited to this requirement.

Lessons learnt

Lessons Learnt Report 1: Battery supply FAT lessons

Project name: Flinders Island Hybrid Energy Hub project

Knowledge category:	Technical
Knowledge type:	Risk Management
Technology type:	Storage
State/territory:	Tasmania

Key learning

Based on its experience as an owner/operator, Hydro Tasmania understands that resolving operational and functional performance issues in situ on remote sites is slow and costly. Hydro Tasmania's King Island Renewable Energy Integration Project (KIREIP)² is a highly successful project that resulted in world-leading achievements for renewable energy penetration into megawatt-scale systems. However, KIREIP was largely constructed in buildings and commissioned on site. This led to the objective in the Flinders Island Hybrid Energy Hub project of containerising and pre-testing equipment where possible.

The way batteries are used within these advanced hybrid renewable penetration systems has required highly customised products. As such, proven 'standard' pre-tested products are not available. Instead, increased levels of customisation and the unproven use of combinations of equipment correspond to higher performance risk, unless appropriately mitigated.

To manage this risk, and in line with its approach for all enabling technologies, Hydro Tasmania went to market for a containerised battery storage system as part of the Flinders Island Hybrid Energy Hub project. A containerised battery solution meant that Factory Acceptance Testing (FAT) was physically possible and could be undertaken prior to shipping the equipment to its remote site. To minimise risk for all parties, this was included as a contractual requirement. Hydro Tasmania generated a detailed specification as part of its contracting and tendering strategy and included requirements for physical design reviews and FAT testing in the contract. Hydro Tasmania subsequently developed detailed inspection and test plans (ITPs) to cover the FAT activities.

In Hydro Tasmania's broader experience with battery systems, there is still a gap in suppliers' understanding of the emerging applications of batteries and the implications for operating electricity networks. This is also true, to an extent, of the broader industry. It is therefore important to put steps in place, such as FAT and contractual mechanisms, to not only safeguard project outcomes but also to help influence the understanding and practices of the wider industry over time.

With Hydro Tasmania's engineer present, the performance testing activities proceeded following Hydro Tasmania's ITP. Hydro Tasmania's detailed analysis of the data from the testing found it did not meet all aspects of the specification. The battery supplier then addressed the issue and the battery successfully passed FAT on a second visit held some weeks later. This was a very good outcome technically for both Hydro Tasmania and the supplier, as augmenting the equipment prior

² KIREIP is an initiative of Hydro Tasmania and has been developed with the assistance of the Australian Government's Australian Renewable Energy Agency and the Tasmanian Government.
[\[http://www.kingislandrenewableenergy.com.au/\]](http://www.kingislandrenewableenergy.com.au/)

to shipping to site solved the non-compliance with the specification in a way that would have been very difficult to do on site. There was inevitably an associated delay in the equipment arriving on site, which affected Hydro Tasmania's construction schedule and associated contracts. However, this was assessed as being a better outcome than suffering a reduction in system performance due to shipping non-compliant equipment to site and risking longer delays to rectify the non-conformance on site.

Hydro Tasmania's experiences on the Flinders Island Hybrid Energy Hub project reinforced the following key learnings:

1. As per industry standard practices, the benefits of containerising electrical equipment such as batteries are demonstrable, especially enabling factory acceptance testing of complete equipment to occur.
2. As ensured for the Flinders Island Hybrid Energy Hub project, the principal should ensure that an experienced engineer looks after its interests from initial design, specification and tendering activity, through design reviews and conducting FAT, and finally to delivery, commissioning and acceptance on site. A fundamental aspect is to ensure that the functions of the battery in the power system are clearly stated in the specification and understood by the supplier.
3. The principal is best placed to understand the requirements of the battery in its system, and, as such, should have the capability to attend FAT and conduct its own assessment of the test results to determine whether it passes or fails, rather than relying on the supplier's report. This is best achieved by having relevant skills either in-house (as is the case for Hydro Tasmania) or by retaining an independent adviser to supervise the battery supplier.

In addition to the risk mitigation measures already in place, additional key learnings largely related to the content of the equipment supply contract in ways that will further improve project outcomes:

4. In future, Hydro Tasmania will ensure that, alongside the specification, the contractual documentation also includes a test plan and a schedule that allow sufficient time for all testing and allow the supplier to appreciate the requirements.

Where appropriate, testing should replicate site conditions for the FAT e.g. by testing equipment against diesel generators and replicating specific environmental conditions.

The test plan should also include an outline of the requirements for data capture, and overall control system operations. For example, the supplier's full battery control system should be used in the test, not sending manual control signals. Setting out the required testing arrangements more fully should include describing the implications of the principal's requirements included in the specification to the supplier. The principal may also wish to bring its own data logger and analysis tools to the FAT.

More generally, as occurred for the Flinders Island Hybrid Energy Hub project, the principal also needs to ensure that the construction of the battery meets relevant standards and legislation from a safety and regulatory perspective. Sufficient time needs to be allowed within the FAT schedule for the principal's representatives to carry out this inspection.

5. Hydro Tasmania will in future ensure that the contract specifically sets out the contractual consequences of failing to pass FAT as part of the contractual 'acceptance'. The most comprehensive strategy could be to wrap those costs that are either directly incurred and/or able to be demonstrated as being incurred as a result of delays into a daily rate for liquidated damages.

Hydro Tasmania will also ensure that the contract sets out an agreed date with liquidated damages for delivery to site as well as completion of FAT.

Implications for future projects

As battery technology continues to develop, issues will be faced by all projects where batteries play an integral role in managing the network.

Batteries that are described as ‘power batteries’ have key characteristics of limited storage but an ability to rapidly charge and discharge for short periods of time and change rapidly from charge to discharge and vice versa. In these circumstances, the characteristics of the power conversion system or inverter are arguably more important than those of the battery cells.

Where batteries are used to time shift energy from periods of high renewable availability to periods of low renewable availability and/or high load (‘energy batteries’), different criteria will be important, particularly individual cell impedance, control of state of charge in battery strings, and cell life.

It is critically important to understand the value that the battery will add to the power system and the difference these characteristics make to its ability to contribute. In power systems in which the battery is used to assist high levels of renewable energy penetration, the extent to which the battery can support provision of fault current is a critical safety consideration. Fault current makes electrical protection systems work and is therefore of prime importance for the safe operation of power systems. The ability of batteries to supply fault current will be limited, and power system modelling should be carried out to ensure that achieving high levels of renewable energy penetration does not come at the expense of safety.

As the market and battery technology mature further and the level of customisation reduces, it is likely that the importance of FAT will shift from ‘product proving’ (‘will it work?’) to ‘quality assurance’ of ensuring there have been no issues with the production methods used. This principle should apply to the product as a whole, including battery cells, inverters and the supporting control system, as well as the physical installation and wiring, although it is anticipated that it will be several years before utility-scale batteries reach this point.

Even when best-practice FAT activities become the industry norm, having appropriate technical and contractual arrangements in place will continue to be important, as is the case for any and all equipment supply arrangements. There are practical limits on what it is possible to test during FAT, so other design review activities are also important.

The challenge for future projects is to manage the delivery of the project to the agreed schedule and to ensure that the supplier is on track to keep that schedule. An important component will be ensuring that the battery supplier understands the particular circumstances in which the technology is to be used, and has sufficient experience with their own equipment that they understand what the test is aiming to prove and whether their equipment will meet the requirements.

Selecting a well-credentialled, experienced supplier with a good track record of this type of installation (as Hydro Tasmania did with the Flinders Island Hybrid Energy Hub project) is particularly important. Making sure the project team has an experienced engineer (or Owner’s Engineer) and proactively managing the relationship and contract will help deliver a successful project. Using the contract as a blunt instrument to seek to recover costs should not be the main strategy to mitigate this risk.

Although battery cell pricing is generally decreasing quickly as technology develops and the industry matures, this may be partially offset by increased cost to meet these extensive requirements, until they become common practice in the industry.

Knowledge gap

Along with many other players in hybrid off-grid systems, not all suppliers (and/or their subcontractors) will have a full grasp of the unique performance criteria required in high-renewable-penetration hybrid systems. To address these criteria, it is likely that standard battery solutions will require some customisation that may not be fully appreciated in all cases. As such, it is important to set out all the requirements in full in the specification as part of the contractual documentation and discuss them with the preferred supplier to measure their understanding.

It is also critical to ensure that the specification can be tested in full in similar operating conditions to those found on site. The inclusion of a detailed test plan and associated schedule within the executed contract documentation will communicate this requirement to all parties. The testing and assessment of the performance against these criteria at the FAT itself will also be a challenge for some suppliers.

This knowledge gap will reduce in line with reducing customisation as the market and technology mature further. In the meantime, suppliers with proven relevant project experience should be considered by project proponents. It is also important to consider the delivery arrangements being proposed and the track record of the delivery team (including the main subcontractors). To avoid impacts on the schedule and performance, it is important to have a clear understanding of the head contractor's and subcontractors' responsibilities ahead of FAT, delivery and SAT (site acceptance testing).

As well as 'battery performance issues', it is also critical to ensure that the containerised design and physical layout meets any and all relevant regulations for electrical installations as well as building codes. The principal may have better knowledge of these local requirements in comparison with international suppliers. Or, more likely, the principal may require stricter adherence to these codes than a supplier may recommend.

There are practical limitations on what can be fully inspected and rectified during FAT, with some issues needing resolution later, either post-FAT prior to shipping to site or even on site. This judgement and prioritisation of issues is an important element of conducting a successful FAT. However, sufficient time needs to be allowed for these actions to be taken on site, hence the recommendation to include agreed test plans and a schedule for FAT.

Background

Objectives or project requirements

A battery can play an important role in a high-renewable-penetration hybrid power system. A range of enablers has been installed as part of the Flinders Island Hybrid Energy Hub project, and these enablers assist in the safe and reliable operation of the power system with less reliance on diesel and greater use of available renewable energy generation sources.

For such a hybrid project site, when the battery has sufficient charge and is available for operation, the battery is required to respond to requests to charge and/or discharge power over extremely short timescales to manage frequency within the system (caused by fluctuating customer load and variable wind and solar renewable energy generation) and to be available to provide short-term supply to customers for particular contingency events (i.e. loss of generation or sudden increase in customer load).

For this project and other recent projects, Hydro Tasmania paired the battery with our proprietary dynamic resistor technology to balance system generation and customer load, thus controlling frequency and voltage in periods of high use of renewable energy. When the battery is charged, the battery can either charge or discharge to rapidly balance out any difference due to variability in the renewables and changes in customer demand. The resistor can also be loaded up with excess renewable generation and provide this balancing mechanism by varying how much power it discharges on a short timescale when the battery is either unavailable or is fully charged.

While batteries in many smaller systems are used to store excess solar energy in the day and discharge through the night, this is not the case on Flinders Island or systems of a similar megawatt size due to economic reasons. The large amount of energy transfer through the battery cells would lead to short cell life, and the cost of early cell replacement would need to be taken into account in calculating the economics of installing a battery. Instead, the battery is used to balance the amount of renewable generation with customer load, thus supplying more of the customer load from highly variable renewable sources.

The battery needs to respond to these system control requests quickly and accurately across a large power range, and to do this reliably across a range of 'states of charge' i.e. whether the battery is fully charged or partially charged.

This is the required performance of the battery, and this 'performance envelope' and the general characteristics of the output and behaviour of the battery was subject to FAT, particularly its speed of response to a power setpoint, including testing the speed at which the battery can change from charge to discharge, which typically needs to happen in less than 50 milliseconds.

Process undertaken

Hydro Tasmania analysed the Flinders Island power system and ran numerous scenarios through an energy model to determine the optimal power and storage ratings for the battery. A specification was written detailing the performance and other technical requirements, and a typical usage profile was issued with the specification that showed charge, discharge and idle periods over a one year period with data points at 10 second intervals. This highly detailed requirement statement was used to select the preferred tenderer and to draft the FAT (factory acceptance testing) and SAT (site acceptance testing) test plans to ensure they reflected likely operational conditions.

The supplier produced a detailed battery and inverter design which was subject to Hydro Tasmania's review and comment prior to commencing manufacture of the containerised battery solution. This design process started during the tender assessment process regarding the biggest battery that could be fitted into a 20 foot shipping container. This design process continued after the award of contract, with review of drawings and some calculations of the containerised battery by the principal. During this design phase, there were also several conversations regarding the required performance and setting out the testing requirements to be conducted at FAT and the testing that would be necessary to be conducted on site as part of SAT.

FAT testing was then undertaken and the results were assessed prior to determining whether the battery had passed FAT or otherwise. Once the battery had passed FAT, it was shipped to site where it was subject to the SAT process. SAT re-ran some of the FAT tests to ensure that there had been no damage in transit and added further tests on the live system that were not possible to replicate under factory conditions. Following completion of SAT, the battery was commissioned onto the power system and a tuning process was undertaken to optimise control settings.

Lessons Learnt Report 2: Comparison of elements of the KIREIP and Flinders Island Hybrid Energy Hub projects

Project name: Flinders Island Hybrid Energy Hub project

Knowledge category:	Technical
Knowledge type:	Technology
Technology type:	<Choose an item>
State/territory:	Tasmania

Background

Objectives or project requirements

This report compares aspects of Hydro Tasmania’s King Island Renewable Energy Integration Project (KIREIP) and the Flinders Island Hybrid Energy Hub project, with further comparison of relevant Hydro Tasmania projects and consideration of impacts on future projects.

The individual project objectives were very similar and included:

- achieving safe implementation
- saving diesel through use of renewable energy
- achieving 100% renewable operation
- proving new technology and techniques (zero-diesel operation for KIREIP, containerisation for Flinders Island Hybrid Energy Hub)
- meeting time and cost targets.

The premise of the Flinders Island Hybrid Energy Hub project was to take the technologies researched and developed for KIREIP³ and make the solution more readily deployable in remote locations. The differing deployment methods limit direct comparison of the two projects.

Key learnings

This goal of making the technologies developed in KIREIP more readily deployable in remote locations was primarily to be achieved through modularisation, such as containerising hardware products and standardising the solution elements. Hydro Tasmania executed its modularisation solution for the first time in the Flinders Island Hybrid Energy Hub project.

Due to the differing deployment methods between the two projects, a direct comparison of each element is not possible, as many of the costs of the ‘building blocks’ of the technologies were not actually part of the KIREIP project, or were delivered in different ways.

KIREIP was implemented through a more traditional on-site construction approach, with two significant building packages: the first was the design, planning and construction of the permanent

³ KIREIP is an initiative of Hydro Tasmania and has been developed with the assistance of the Australian Government’s Australian Renewable Energy Agency and the Tasmanian Government.
[\[http://www.kingislandrenewableenergy.com.au/\]](http://www.kingislandrenewableenergy.com.au/)

power station building extensions for the new switchroom, diesel-UPS bays, office and control room and dynamic resistor enclosure, and the second was the design and construction of the battery enclosure.

For KIREIP, construction of the power station extensions took 8 months and was very intrusive as it required connection of the new building elements into the operating power station, with subsequent transfer of existing operational generators and customer feeders to the new board without interrupting customer supply.

Learnings from implementing the power station extensions led to the KIREIP battery building being constructed separately from the power station, connected by underground cables. In both cases high-quality permanent buildings resulted, but at high capital cost and with significant intrusion over a long period of time into power station operations.

The approach also meant being reliant on construction contractors being aware of the challenges of working in remote locations with the associated restriction on materials and resources, and planning for this from the outset. Similarly, equipment testing on site meant significantly more time on site for any personnel, and hence incurred more cost.

For the Flinders Island Hybrid Energy Hub project, a new approach was needed for a modular and containerised solution enabling as much off-site construction and testing as possible. This change in approach is shown in *Figure 1*. On the top left is the traditional construction approach taken on KIREIP to house the new equipment, while on the top right is the concept developed for the Flinders Island Hybrid Energy Hub with the equipment deployed in modules and a single connection point to the existing power station. The photo at the bottom shows the final Flinders Island Hybrid Energy Hub arrangement.

As a result, the Flinders Island Hybrid Energy Hub project had significantly less impact on the station due to the containerisation strategy, due to manufacture and testing being carried out off-site and due to the simplified connection arrangements of a separate single 11 kV cable connection from the main station board to the Flinders Island Hybrid Energy Hub container farm behind the power station.

The comparisons included in *Table 1* show that the site time for the Flinders Island Hybrid Energy Hub project was significantly reduced compared to KIREIP and the risk was significantly reduced as well, due to the ability to conduct FAT prior to shipping to site.



*Figure 1 – Change in deployment approach – King Island approach (top left),
Flinders Island approach (top right, bottom)*

As well as developing and proving a new deployment approach, the Flinders Island Hybrid Energy Hub project also aimed to reduce the costs of components and solutions compared to KIREIP. It is difficult to directly compare KIREIP and the Flinders Island Hybrid Energy Hub project given the significantly different approach. Although the cost of supplied hardware elements can be compared, this is merely a comparison of the market price of equipment that is largely out of our control. It is easier to compare the cost from the Flinders Island Hybrid Energy Hub project and the ‘next’ project’s estimated cost, as the Flinders Island Hybrid Energy Hub project represents the approach we will adopt in future.

The initial expectation was that savings could be achieved during the project. With significantly more development of the modularised approach required than had originally been anticipated, savings were lower than anticipated. However, a direct comparison can be made between the Flinders Island Hybrid Energy Hub project and the ‘next’ project in Coober Pedy, which, although larger in scale, uses the same elements.

For the Coober Pedy project, Hydro Tasmania supplied and commissioned the hybrid energy enabling components under commercial contract to the principal (Energy Developments Ltd). The Coober Pedy project very rapidly followed the Flinders Island Hybrid Energy Hub project. Hydro Tasmania bore the development risk and costs on the Flinders Island Hybrid Energy Hub project as it was our own asset, and we utilised the designs and new approach on the third-party Coober Pedy project.

Two main products were developed by Hydro Tasmania on the Flinders Island Hybrid Energy Hub project and subsequently deployed to Coober Pedy: the flywheel system and the dynamic resistor. These saw cost reductions of approximately 30% and 40% respectively. This was not only due to the removal of the development cost on Coober Pedy, but also due to the reduced time needed to manufacture and commission on site.

As a broad comparison over the development history of Hydro Tasmania's enabling technologies, the site development and commissioning time on KIREIP can be measured in years, which reduced to months on the Flinders Island Hybrid Energy Hub project, and down to weeks at Coober Pedy.

From projects subsequent to the Flinders Island Hybrid Energy Hub project, including Coober Pedy, Hydro Tasmania has seen costs continue to fall with further reductions possible on some of the key enabling technologies due in large part to the modularisation approach.

Third-party suppliers of storage and solar equipment in the marketplace are continuing to find savings and cost reductions. This continues to reduce prices for project proponents and the project as a whole. Cost reductions in the solar and battery sectors are partly due to a very large increase in volume.

Wind generation prices remain challenging on off-grid sites due to the infrastructure required for installing large equipment in remote locations, the limited size of the market for suppliers, and the movement of the technology towards bigger machines for utility-scale developments (due to realisable cost savings). Sourcing wind turbines for off-grid projects is also challenging due to very few machines less than 1 MW being available in the market. This significantly limits the choice of supplier available for projects of this nature. Proponents considering projects in remote locations will need to continue to be mindful of these logistical factors when determining the appropriate mix of renewable energy generation alongside the necessary enabling technologies. However, as off-grid projects become larger, in the tens of megawatts, and the availability of class III wind turbines increases, large multi-megawatt wind turbines are becoming an option for such projects, provided the logistics can be accommodated and there is a moderate wind resource.

Key learnings are:

1. As is common across a wide range of industrial applications, the benefits of containerising electrical equipment, such as Hydro Tasmania's enablers, are demonstrable through reduced costs and delivery timeframes. When appropriately deployed, they also mitigate risk and reduce impact on existing operational stations.
2. Further incremental savings within off-grid systems will be possible moving forwards, with respect to all new and novel technologies (including batteries and enablers).

Implications for future projects

Because of the risk mitigation made possible through FAT of containerised products, alongside the reduced site time and the impacts on operational stations, the modular containerisation approach developed in the Flinders Island Hybrid Energy Hub project is suitable for a range of projects in the future where high renewable energy penetration is desired. In general, containerising batteries and other technologies is becoming more commonplace as an effective delivery method to remote locations (such as delivery of batteries in the Pacific). However, where a station overhaul is required for other reasons, there may be some elements where containerisation does not add significant advantages.

The following table sets out scope elements for the two projects and compares the different approaches.

Table 1 - King & Flinders Island project comparison

Scope element	KIREIP	Flinders Island Hybrid Energy Hub	Cost	Time	Comments
Works and interruption to station operations	Enablers largely integrated into the existing station requiring building works and significant intrusion to the operational station.	Containerised enablers were placed outside the station and connected into the station through an 11 kV switchroom.		Time taken requiring significant intrusion into power station was reduced from approx. 12 months on KIREIP to 8 weeks on Flinders Hub.	Not only is the timeframe important from a system operational perspective, but also from a safety perspective regarding operators and commissioning crew.
Battery storage (BESS)	1.6 MWh / 3.0 MW peak, 2.0 MW continuous rated BESS installed in a permanent building, Ecoult Ultrabattery advanced lead acid. Order placed 2012.	266 kWh / 750 kW peak, 500 kW continuous rated BESS installed in a shipping container, Toshiba Lithium Titanate. Order placed 2015.	KIREIP battery capital cost was 4.4 times the Flinders Hub containerised battery including enclosures and direct site works. KIREIP battery 7 year cell warranty; Flinders Hub battery 20 year cell warranty.	KIREIP: 19 months from order placement to commissioning, 9 months on site plus 6 months building construction. Flinders Hub: 15 months from order to commissioning, 1 month on site plus 5 weeks foundation construction. Flinders Hub battery had about 15% site hours compared to KIREIP battery.	KIREIP battery 4x power rating and 6x storage rating compared to Flinders Hub battery. Cost / MW comparable. KIREIP cost / MWh lower, but note much shorter cell life warranty period (and some limitations associated with using the full MWh).
Control system	New PLC (programmable logic controller) based control system and HMI (human machine interface) including developing new control code.	New PLC-based control system and HMI including updating control code to reflect project learnings.	Flinders Hub control costs were approx. 54% of KIREIP costs. KIREIP had 8 scope elements; Flinders Hub has 6.	Time comparison not possible as KIREIP was developed sequentially as scope elements were delivered; the Flinders Hub control code was developed as one activity.	Significant cost reduction through re-use and improving older PLC code and HMI compared to developing new code in its entirety.
Dynamic resistor	Pre-existing 1.5 MW dynamic resistor not included in scope; scope did include re-housing in permanent building.	Completely new 1.5 MW dynamic resistor included in scope including containerised housing.	Flinders Hub container cost approx. 80% of allowance for KIREIP building costs. Equipment costs not considered.	Flinders Hub containerised dynamic resistor was manufactured and tested off site, total site time approx. 8 weeks to install, commission and test. Re-housing KIREIP dynamic resistor took approx. 5 months for building	Containerised housing is cheaper than permanent building and resulted in about 60% saving in site time.

				construction and re-installing equipment.	
Scope element	KIREIP	Flinders Island Hybrid Energy Hub	Cost	Time	Comments
Diesel UPS	2 x 1 MVA Hitzinger D-UPS housed in new permanent engine bays attached to the existing power station.	1 x 850 kVA Hitzinger D-UPS housed in newly designed shipping container.	Cost per unit was similar between the two projects allowing for building and containerisation. Subsequent containerised projects were cheaper per unit.	Site time for Flinders Hub unit was approx. 4 weeks to install and 4 weeks to test and commission. KIREIP included 5 months building construction, 1.5 months to install and connect. Commissioning took approx. 6 months due to the innovative nature of the work.	Cost levels similar for the first prototype units. Significant saving in site time for installation (~80% reduction) and particularly commissioning (~85% reduction).
Wind generation	Pre-existing 3 x 250 kW Nordex (1998) 2 x 850 kW Vestas (2003), not covered by KIREIP scope.	1 x 300 kW Enercon privately owned wind turbine, not in Flinders Hub scope. 1 x 900 kW Enercon wind turbine in project scope.	n/a	n/a	No cost or time comparison possible.
Solar generation	Pre-existing 95 kW dual axis tracking solar PV.	New 175 kW fixed solar PV in project scope.	n/a	n/a	No comparison possible.
Smart grid / DSM	Distributed installation to interrupt load.	No DSM installation.	n/a	n/a	No comparison possible.
Bio-diesel trial	Trial of 20% and 100% biodiesel, installation of blending plant.	No biodiesel installation.	n/a	n/a	No comparison possible.
Scope element	KIREIP	Flinders Island Hybrid Energy Hub	Cost	Time	Comments
New switchgear and station electrical upgrade	11 kV main bus switchgear installed in a new switchroom. New station ancillary boards and DC supplies installed.	Containerised 690 V switchgear installed for the Flinders Hub enabling equipment. Minor work on main 11 kV bus and station ancillaries.	KIREIP switchgear was 22 cubicle 11 kV distribution grade board; Flinders Hub switchgear was a 4 cubicle 690 V modular board, no comparison possible.		Comparison of switchgear cost not possible.

Lessons Learnt Report 3: Containerisation of enablers

Project Name: Flinders Island Hybrid Energy Hub project

Knowledge category:	Technical
Knowledge type:	Technology
Technology type:	Hybrid
State/territory:	Tasmania

Background

Objectives or project requirements

The objectives of the funding agreement for the Flinders Island Hybrid Energy Hub project included developing and proving the feasibility of containerised high-penetration off-grid systems and a commercial solution for high-penetration off-grid systems. These objectives are set out in full here:

- Designing, constructing and demonstrating the technical viability of a containerised high penetration wind/solar hybrid energy system*
 - Integrate, modularise and containerise supporting technologies*
 - Develop technical capability to roll out high-penetration systems into other remote and island communities*
- Developing a commercially viable solution that eliminates the need for grants in high-penetration wind/solar hybrid renewable energy systems in very remote and islands communities by:*
 - Developing a containerised solution to minimise logistics and on-site activities thus reducing cost*
 - Reducing the cost of designing, constructing and operating high-penetration hybrid systems*
 - Developing an implementation process that will allow minimal impact on the physical assets of an existing power station*
 - Developing a product solution for systems by allowing each element to be applied as a whole or individually*
 - Testing manufacture of products and engaging suppliers for portfolio supply*
 - Developing a pipeline of opportunities that drive capital cost reduction of up to 30% over the next 5 years*
- Developing and sharing knowledge and experience in high-penetration hybrid renewable energy systems*

This report sets out learnings associated with containerisation of power system equipment including benefits and drawbacks and provides guidance on some practicalities for consideration when using a containerised approach. Standard designs have been developed for:

- 850 kVA Diesel-UPS (D-UPS) unit
- 1.5 MW and 3.0 MW dynamic resistors
- low-voltage switchgear for easy connection of enablers
- a control container.

Modular transformers and containerised battery units have been delivered by third-party suppliers.

Key learning

A key learning from the Flinders Island Hybrid Energy Hub project is that containerising power system equipment as a solution in the market is a low-risk, practical and cost-effective way to implement power system projects in remote areas. There are some areas where containerisation has disadvantages over housing equipment in permanent buildings, but they are relatively minor and the benefits generally far outweigh the disadvantages.

Benefits

Containerised equipment can be tested in the factory before it is shipped, allowing any problems or areas of non-compliance to be resolved more quickly and easily than after shipment to a remote area. Passing factory inspections or tests also provides good commercial protection to the customer by providing a clearly identifiable payment milestone point. Payment of a significant proportion of the contract sum can be made conditional on successfully demonstrating that the equipment to be shipped passes inspections and tests in the factory prior to shipment.

Containerising equipment in a factory environment allows the work to be carried out in a controlled environment with specialist skilled resources and standard working conditions with higher quality and fewer defects resulting than if equipment is installed and commissioned on site. Problems identified during factory testing and commissioning can be fixed far more easily than on a remote site with few local facilities.

Undertaking fabrication, installation, testing and commissioning in factory conditions is generally cheaper and has lower fatigue and safety risks than carrying out similar work on remote sites. This is particularly the case where the level of skills and capability near the remote site is low, as is often the case.

Containerisation avoids the need to construct permanent buildings in remote areas where infrastructure such as concrete batching, licensed craneage and building materials may not be available. Even when local skills and capabilities are available, transport of containers to the site is likely to cost less than transporting building materials to the site.

The price per square metre of bespoke shipping containers such as those used by Hydro Tasmania has been found to be similar to constructing permanent buildings in remote locations. Due to the containers being far more compact than an equivalent permanent building, the total capital cost of a containerised piece of equipment will generally be significantly less than the same piece of equipment installed in a permanent building.

Time on site and the intrusiveness of installing containerised equipment at any existing power station or power system facility will be significantly quicker, less intrusive and lower risk than building a permanent building at the same location and installing equipment in it.

In the event of major equipment failure, the containerised equipment can be shipped as a unit to a repair facility. This ability is also useful at end of life when the equipment needs to be removed from site. This is especially useful at temporary or short-term sites such as disaster relief or at a short-duration mine site.

Disadvantages

Shipping containers have a strictly defined and quite small space and height, which constrains the choice of equipment that can be installed in a container. The principal constraint that this imposes on equipment is the choice of voltage for switchgear. Standard distribution voltages such as 11 kV or 22 kV typically result in sizeable circuit breaker cubicles with additional access space requirements e.g. to rack out circuit breakers. Hydro Tasmania has standardised on 690 V for enabling equipment apart from the dynamic resistor which operates at 415 V. The lower voltages increase cable sizes and

require connection transformers; however the low-voltage switchgear can be safely fitted in a 20 foot shipping container at relatively low cost.

The small space available in shipping containers also means that careful consideration needs to be given to access for operations and maintenance (O&M) activities. The container designs produced and used by Hydro Tasmania allow all except the most major O&M activities to be carried out within the enclosure, mitigating the issue, but only after careful consideration during the design stage.

Careful consideration of surface preparation and paint finishes should be given to containers to be used as long-term equipment housings, especially in a marine environment. The use of Corten steel in containers limits the amount of corrosion that will be experienced during the service life; however, this operates by forming a protective oxide coating which may look unsightly unless the paint covering is kept in good condition. Permanent buildings would also require maintenance; however it has not been possible to compare the maintenance costs of a permanent building with a shipping container solution.

Other considerations

Standard shipping containers are readily available at very low prices; however, users need to be aware that a comprehensive set of international regulations covers certification of containers for transport, shipping and handling.

Containers are fitted with a compliance plate under the international Container Safety Convention (CSC). The compliance plate can be invalidated if a standard container is altered in any way, such as by having additional access doors or cable entry points fitted.

The containers used by Hydro Tasmania on its projects have been designed by an experienced designer to be compliant with CSC regulations and have been inspected by a Lloyd's Register inspector. Due to the cost, the containers have not been load tested to ensure compliance and so do not have a CSC plate fitted; however, they do have a transport plate fitted after a structural engineer certified the designs as suitable for lifting and handling by a number of different methods including crane and forklift.

Although altered standard shipping containers are readily and cheaply available, care needs to be taken that any alterations have been checked by a licensed container surveyor to certify that the container meets transport requirements. Failure to do this would mean that transport and lifting regulations are being breached and could result in reputable transport companies refusing to transport altered containers.

Implications for future projects

The benefits of a suite of standard containerised designs for enabling technologies have already been demonstrated on the ARENA-funded Coober Pedy renewable hybrid project.

Two containerised diesel-UPS (D-UPS) units, a containerised dynamic resistor and containerised low-voltage switchgear were supplied to the Coober Pedy project following successful factory testing of each unit as well as all the units connected together. The successful off-site testing led to a reduced time on site for commissioning and site testing, saving the customer (Energy Developments Ltd) and Hydro Tasmania time and money.

As further projects are delivered, further cost savings and particularly time reductions can be expected. The team is investigating further modular units including a smaller capacity D-UPS and other enabler units, as well as having control cabinets for PLC (programmable logic controller) power system and solar farm control systems prefabricated and tested prior to shipment to save time and reduce technical risk.

Lessons Learnt Report 4: Wind turbine connection on a customer feeder

Project Name: Flinders Island Hybrid Energy Hub project

Knowledge category:	Technical
Knowledge type:	Network connections
Technology type:	Wind
State/territory:	Tasmania

Key learnings

The project made significant budget savings by making use of the existing 11 kV feeder to connect the wind turbine to the power station. Although physical augmentation of the existing 11 kV feeder (wood poles and single circuit conductor in a horizontal arrangement) was required, this was considerably less costly than the cost to build a new feeder or add a second circuit to the existing feeder. There were two other major benefits:

- the works could be done by our local distribution team
- there was less visual impact for the community along the main road on Flinders Island.

However, embedded generation of a significant size within a small distribution network introduced complications into the system, such as:

- Faults on the customer feeder downstream of the embedded generation asset may take the generation offline. The following actions were required to address this group of issues:
 - o Physical works were undertaken to reduce number of faults due to line clashing, such as reducing spans between poles and increasing horizontal separation.
 - o Additional protection equipment was required to ensure protection schemes work regarding fault detection to isolate the impact of any outages.
- Load-shedding schemes needed amending as this feeder is now a net generation feeder not a customer feeder (dropping this feeder at the breaker may not reduce overall system demand if generation is greater than feeder customer load).
 - o The protection device downstream of the wind turbine connection point was also used as a circuit breaker (across fibre-optic cable) in the load -hedding scheme.
- Special protection schemes need to address anti-islanding to ensure customer safety for other uses on a feeder with a large embedded generator.

To support a solution to these problems, optional equipment was purchased for installation within the wind turbine generator (in addition to the network protection equipment). While not such an issue with solar due to its modular nature, including additional functionality within third-party proprietary equipment, such as wind turbines, can be unnecessarily complicated to retrofit.

When making decisions on supporting infrastructure, all eventualities need to be considered to ensure there is flexibility into the future to meet any system requirements as they may arise (i.e. optic fibre to provide rapid and reliable communications to any sensitive points in the network).

Finally, embedded generation in hybrid systems also creates issues around metering in terms of payment for power generation and for earning RECs. Additional metering and calculation arrangements were needed to support the existing power purchase agreement (PPA) with a third-party wind turbine as well as for earning RECs. More generally, PPAs need to be fit for purpose for application in small systems with the potential for constraints and/or storage or other enablers.

When designing these systems, metering decisions need to be made looking at all requirements including PPAs, RECs, and equipment and system operational requirements.

Key learnings are:

Equipment selection

1. Ensure that all potentially required electrical functionality (i.e. the ability to trip the generator) is included as a requirement in the placement of an order up front to provide flexibility to best address current or future eventualities so that the equipment supplier can address this during production.
2. Where practicable, install fibre to any critical points within the electricity network to ensure that any communication requirements can be met now or in the future.

Metering and regulatory arrangements

3. Commercial arrangements for embedded generators should consider all eventualities in regard to placing or lifting constraints and the preferred outcome for each one or simply committing to a negotiation in those circumstances. These arrangements should provide ability for the system operator to control and/or constrain the embedded generation, amongst other technical requirements that are part of a power purchase agreement (PPA) and connection agreement. This applies to both large-scale and small-scale networks and grids.

Implications for future projects

In addition to the key learnings, moving forwards, there will be significantly more embedded generation in networks both large and small. The application of these learnings for larger networks is around small or nodal constraints and the application within the network. For example, if a battery is installed at a local substation that lifts an existing constraint on a nearby intermittent renewable generator (or a capacitor bank is installed to control voltage), then the commercial arrangements need to allow for these scenarios. Essentially paying a generator for production at a non-commercial rate should be avoided as this inefficiently lifts the costs of generation in a system.

Virtual power plants or battery systems are concepts that are being considered in the on-grid space. Be that at a household or commercial level, solar and batteries are being aggregated to larger blocks for better treatment. However, system impacts still need to be treated and costed appropriately or the utility or system operator bears those costs and passes them onto the consumer through a regulated asset base (or some other underlying function). Again, this has the potential to create inefficiency in the system.

Knowledge gaps

System operators around Australia are rapidly transitioning from a business-as-usual operation to a rapidly changing market with many technical, commercial and regulatory issues to solve. Dealing with embedded generators is one such issue.

Background

Process undertaken

Initially, the wind turbine on Flinders Island was intended to connect into the power station through a dedicated feeder. It is typical practice to isolate generation assets from customers for a number of

reasons, and this is particularly applicable where all generation assets are physically located near the power station. This is done to minimise the number of overall system outages that are required, to protect equipment and personnel, and for flexibility in system operation.

On Flinders Island, there were already a number of existing generation assets around the island:

- small wind turbines on ends of feeders (now decommissioned)
- household and commercial solar around the network
- solar installation at the airport
- third-party-owned 300 kW wind turbine on one of the three feeders
- diesel generation at the power station.

This project introduced additional generation assets to the system:

- wind turbine generator (900 kW)
- solar generation (175 kW)
- diesel-UPS (580 kW)
- battery (500/750 kW).

All new assets are located at the power station on a single dedicated feeder, with the exception of the wind turbine, which is located adjacent to the existing third-party wind turbine.

The initial design was to connect the new 900 kW wind turbine generator to the main switchboard of the power station on a dedicated feeder as per the other generation assets.

Due to overall cost pressures on the project, and higher-than-expected feeder construction costs, the project team revised its design to connect the wind turbine directly into the customer feeder instead (as per the arrangements for the existing 300 kW wind turbine).

However, due to its size, this meant that a number of other actions were required.

- The physical works on the 3 km of existing feeder connecting the new 900 kW wind turbine to the power station. This was a significantly cheaper solution that also minimised the visual impact along the main road between the two town centres on Flinders Island.
- A number of other studies were required looking at protection, power quality and other system-related issues. These studies showed that there needed to be a change to the protection settings in existing protection equipment, that new protection equipment was required, and that we needed the ability to externally trip the wind turbine.

Specifically, the metering arrangements needed to be reviewed to support the commercial terms for purchasing power from the third-party 300 kW wind turbine, as well as the RECs accreditation arrangements of all of the renewable assets on the system.

Typically, RECs calculations are based on generation from new renewables that are registered and accredited with the Clean Energy Regulator (CER) under the large-scale scheme. This typically can be captured by one metering point.

For hybrid systems where not all the energy generated is provided to customers, but is consumed by enablers or charged and discharged by batteries, the RECs calculation needs to rely on multiple metering points. Or, at worst, there needs to be a time-series approach through a series of logic steps. This may add additional complexity for the CER as well as for the project proponent. This is complicated further if there is multiple ownership of the different assets in the system.

The same applies for tariffs and power purchase agreements (PPAs). Any PPAs that are put in place for embedded generators need to consider whether there will be any system constraints, how those constraints may be lifted, and the commercial arrangements on these issues.

Lessons Learnt Report 5: Internet security re third-party remote support

Project name: Flinders Island Hybrid Energy Hub project

Knowledge category:	Technical
Knowledge type:	Risk Management
Technology type:	
State/territory:	Tasmania

Key learning

For utilities and other large-scale customers across industry but particularly in essential services, significant changes are required on IT network security management that will significantly impact or even prevent original equipment manufacturers (OEMs) and specialist service providers from remotely supporting equipment within customer networks.

Currently, large players in Australia's critical infrastructure sector (and particularly transmission network service providers and key generators) are being given time to improve their practices in this area with several federal government initiatives in place to work with industry to bring about this change. Onerous mandatory requirements may come into place if insufficient action occurs at the same time as these requirements may be expanded to other industry players. Many countries around the world already have more stringent requirements than Australia.

The practice of providing separate connections into equipment through a modem/router (be that 3G, NBN or otherwise) and gateway or other device to provide security is no longer acceptable. No common solutions are available in industry as yet. However, many suppliers are starting to consider how best to tailor their solutions to these internet connection arrangements. Any developer or operator needs to consider how they will access support in light of these federal government best-practice requirements.

Implications for future projects

The federal government is targeting essential services providers and large-scale infrastructure operators initially. However, these requirements will likely flow rapidly through to most utilities in the near future with best-practice guidelines currently in development that will apply to all of industry. Developers cannot rely solely on remote support service providers having direct access to equipment in future.

Knowledge gap

Across many industries, customers require specialised support from the original equipment manufacturer (OEM). In order to provide the support, the OEM typically requires remote real-time access to the equipment and its control system.

To date, the method of accessing the equipment has been for the customer to provide a separate internet connection directly to the equipment. This would typically be a 3G modem and router allowing some sort of secure connection (such as a VPN connection) supported with some additional physical security by a gateway or other device. With security now a global issue, there has recently been an increased focus on network security for utilities and other infrastructure companies (and essential services more generally). Amongst a raft of measures, the approach of creating multiple

internet connections into a corporate network and maintaining and monitoring all those different access points is no longer acceptable.

Along with a whole range of technical recommendation, the applicable guideline to this situation is to ensure there is a single secure connection point to the internet, managed corporately, and more specifically, ensuring that all back doors are removed. This basic structure sets up how an internal corporate network should look to the outside world, and gives the customer a fighting chance of safeguarding its operational technology (OT)/information technology (IT) networks. Of course, all hardware and software still needs to be managed and updated, and, even so, this only reduces the likelihood of hackers breaking into networks.

From the OEM's perspective, however, their systems are often not set up to function through a provided tunnel inside a third party's internet systems. And this requirement or change in approach to accessing equipment will likely create issues re standardising their systems. If an OEM has many customers and each customer provides this access in a slightly different format, they will need a different solution (or at least a set of solutions) to access their equipment. This may increase costs and complexity, which the OEMs would need to pass on to their customers, who may not be willing to bear these costs.

In some cases, this arrangement is a problem during commissioning as well as operation. An OEM's standard commissioning procedure will include setting up external internet communications and downloading and installing latest software and settings for their equipment.

To date, no standard approach is in place in industry to address this problem either during operation or commissioning. However, some OEMs have a mature understanding of this issue and are looking to offer solutions to their clients. It is certainly an issue to address upfront with service providers, particularly where there is a choice of supplier.

As of end of calendar year 2017, industry in Australia has been given an opportunity to participate in government roundtables regarding setting expectations on IT security requirements and making changes immediately. However, if industry does not improve its practices to the satisfaction of its federal government stakeholders, then onerous mandatory regulations may be put in place.

Lessons Learnt Report 6: Impacts of increasing behind-the-meter solar installation in large and small grids

Project Name: Flinders Island Hybrid Energy Hub project

Knowledge category:	Technical	
Knowledge type:	Community Engagement	Network connections
Technology type:	Solar PV	Storage
State/territory:	Tasmania	

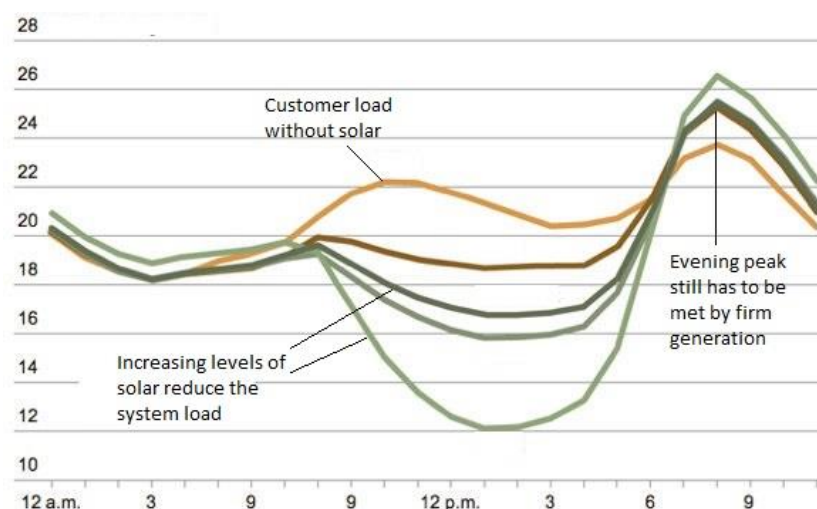
Key learning

Alongside deliberate incentive-based schemes, tariff settings may also inadvertently encourage significant take up of behind-the-meter solar (and battery) installations. In both large and small systems, these rapid changes can result in (a) significant technical issues for the utility to manage, and (b) a negative impact on utilities' balance of cost and revenue.

One of the primary drivers for behind-the-meter installations are the tariff structures themselves in regard to usage, time of day, max volume charges, transmission and distribution service fees, and other fixed fee charges. The relative fees that consumers pay against these charges may not necessarily align with the true costs incurred by a utility in providing a connection and the ability to use power. Utilities have relied heavily on usage tariffs to earn revenue on a volume basis; however, there are significant fixed costs associated with generation and network infrastructure which typically need to be recouped regardless of tariff structure.

If utilities choose to provide a customer with the ability to net meter (household consumption less any solar generation exported to the grid) or to offer a customer a 'high' export tariff for behind-the-meter generation, falling energy prices of domestic solar and solar/battery systems, tariffs and connection charges can act to incentivise rapid uptake of embedded equipment.

Embedded generation results in lower net energy import and hence lower volume-based revenue for the utility. This is reflected in the concept of the 'duck curve' (a typical example is shown below). The peak load still has to be met by network infrastructure and firm generation capacity, but there is less system volume-based revenue to pay for those facilities.



Source: CallSO

The lack of control of small distributed generation also causes technical issues for the ability of the utility to limit the amount of generation being provided into the grid. This is a problem particularly for older installations where the older inverter technology may not have the ability to constrain PV export to the grid or set a zero net export limit. This is important because either on a whole network perspective or on localised areas of the grids, electricity networks only provide useful power supply when voltage and frequency are maintained within safe limits. This is achieved by the network operator balancing demand and supply, which can only be done if they have control over generation and/or load. Behind-the-meter solar generation and storage installations are typically not directly controllable by the network operator. Too much generation being injected into a small or localised system will see voltage and frequency increase in the absence of any controllable load banks or central storage. In severe cases, when there is excess distributed PV generation for example, this may cause central generation (such as diesel generators) to run into reverse power or below safe operating limits and trip off, likely resulting in a system outage.

System developers need to recognise that utilities and regulators, and perhaps even more importantly, other government institutions and governments themselves may not have a full depth of understanding of these issues.

It is important to define objectives and communicate community value that an electricity network provides to the whole community (i.e. 'a social good'). Once these goals are set, then relative actions can be considered to meet these goals over appropriate timescales to phase in any changes – noting that this may mean some negative commercial impacts for some individuals or segments of the community, and potentially also the utility itself. Again, these potential negative impacts need to be recognised but considered in the context of whether there is an overall benefit to the community. It is likely that in many communities there will be individuals who are not willing to pay to provide that 'social good' to the community.

The lowest overall cost of generation within a network might include only a limited amount of behind-the-meter solar generation due to any number of factors, such as poor siting, shading, orientation, maintenance or equipment failure.

Implications for future projects

As is prudent for any long-term infrastructure investment, system developers should design new electricity projects for the future requirements of the community. It will be an inefficient allocation of capital for projects to be built that focus on short-term gains under non-cost-reflective tariff structures, as these assets will only further increase the total cost of providing power to the community in the future.

And so for all systems, large or small, there may be a trade-off between enabling choices for all network participants (be they consumers or providers), security of supply, power quality and overall cost of providing that service.

As technology changes, both in terms of electrical network equipment (be that generation, storage, distribution protection, metering or distributed control) and also in terms of electricity usage (rural electrification in third world and developing countries, through to electric vehicles and automation in houses in developed economies), there will be significant shifts in these markets.

This is largely a social and economic policy issue both in terms of tariffs, but also in terms of service provision, small business sustainability, and overall outcomes for communities. These issues need to be considered on a case-by-case basis taking into account the local issues.

Knowledge gap

Electricity prices play a huge part in the lives of individuals from cost of living, industry competitiveness, small business, environmental concerns, security, innovation, standard of living and health. Even so, there is a lack of complete information and education materials about how electricity systems operate now and may operate into the future – certainly in terms of sustainable technical and economic operation into the future.