The Benefits and Risks of Photovoltaic Hybrid Mini-grid Systems for Rural Electrification in Northern Territory, Australia

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Introduction

Photovoltaic Hybrid Mini-grid Systems (PVHMS) present an attractive solution to providing electricity to the remote communities of Australia that do not have access to centralised networks. PVHMS can help to address some of the shortcomings of both diesel-only mini-grids and stand-alone photovoltaic (PV) systems, and are often the lowest cost option, particularly given rising fuel prices and the additional cost and difficulty of fuel transportation to remote areas [1]–[3]. However, PVHMS inherently add some novel complexities to system design, implementation and operation beyond those of their underlying parent technologies. A particular challenge is adapting standard control systems in order to achieve and maintain optimal operation with a highly variable and somewhat unpredictable solar resource [4]. As such, there are risks associated with the technology's use that may be quite different to those understood for standalone PV or diesel-only mini-grids. PVHMS are also a relatively new technology in the Asia/Pacific region and although system numbers are increasing, the benefits and risks associated with these technologies, and the extent to which these are understood and managed by stakeholders, will be fundamental to their ultimate future success or failure [5], [6].

In the Australian Northern Territory, Power & Water Corporation (PWC) through its Indigenous Essential Services (IES), own, operate and maintain 52 isolated electrical mini-grids totaling 76MW of generation capacity [7]. The energy source mix for PWC's mini-grids is dominated by diesel (contributed 88% in 2009). In 2013 Epuron[1] commissioned the integration of three PV systems in a novel Power Purchasing Agreement (PPA). These systems were designed, built, owned and operated by TKLN Solar[2], and consisted of almost 1MW of PV retrofit into existing diesel mini-grids, allow PV to contribute up to 80% of load in peak sun hours.

This paper begins with a short background into the development of the TKLN projects and the intended benefits that drove the project. The paper goes on to present some

[1] Epuron is a privately owned renewable energy company which develops wind farms and solar power stations and which owns the 1MW Uterne Solar Plant near Alice Springs
[2] TKLN Solar is a wholly owned subsidiary of Epuron

of the risks encountered, explains how these were mitigated and provides some recommendations for future projects.

Data analysis from one year of operation for the Ti Tree site is presented to describe the operation of the system. This dataset is used to quantify some of the benefits provided by the system, along with the results from baseline simulations using modelling software developed by PWC and the technology consultancy Radical Systems with support by the Australian Renewable Energy Agency.

Background on TKLN Projects

State funding was awarded to PWC to undertake these projects and TKLN Solar secured federal grant funding under the former Renewable Remote Power Generation Program (RRPGP) program. Consultant CAT Projects was subcontracted by the Northern Territory Government (NTG) to undertake an EOI and tender process. The three communities were selected due to their large size and recent load growth[3]. To ensure the most economic result, the request for tender (RFT) did not specify the system configuration or even choice of generation/storage technology, so a variety of solutions were presented to the vendor.

The tender was awarded to Epuron, who nominated a conventional fixed tilt PV array with a short term storage device to smooth PV output, referred to as the Grid Stability System (GSS). A 20 year PPA was agreed upon with a site specific annual minimum (take-or-pay) obligation in kWh. The final PPA also included methods for accounting for system performance failures.

The total renewable energy plant capacity installed across TKLN communities exceeds 1MWp, consisting of 992kWp of PV (Kalkarindgi 402kWp, Ti Tree 324kWp and Lake Nash 266kWp) and a further 45kWp of wind turbines at Lake Nash. The works also coincided with a replacement of existing diesel power station at Lake Nash which had reached end of life, along with communications upgrades for remote monitoring at all sites. The projects reached final completion on the 1st January 2013.

Drivers for the Project

From PWC's perspective, the primary project driver was to minimise diesel fuel consumption, thus reducing long term electricity generation costs and exposure to possible future fuel price increases [8]. Supplementary drivers identified from discussion with PWC staff included improving security of electricity supply, achieving greater alignment with environmental objectives of the Northern Territory Government, reducing the runtime of larger gensets, and the development of in-house skills and expertise for future projects. It is worth noting that a number of related projects have since been undertaken by PWC, including a detailed feasibility

[3] Two sites had also experienced fuel supply issues due to inclement weather.

study for hybridisation at another site (Daly River), production of a handbook on PV/Diesel integration [8] and the development of an open source modelling tool that allows detailed time-step analysis (1sec) of generator/PV scheduling and control for PVHMS. Further information on ASIM is below and the package is available for download via the PWC website (www.powerwater.com.au).

Risks, Mitigations and Recommendations

PWC and Epuron shared a collaborative working relationship, which was crucial to help overcome unforeseeable risks, and work through issues that arose outside of the scope of tender and PPA. A number of the most significant risks identified by project stakeholders [8], [9] are listed below:

- *Limitations of Tender and PPA to detail and translate technical requirements*. The tender and PPA in this case could have benefited from more technical detail, such as diesel operating principles and specification of the technical limitations of a mini-grid. While not specified in the tender, it was agreed to by all parties that factory and user acceptance testing were necessary for risk mitigation. The project proponents recommend that a detailed list of performance requirements and commissioning tests be agreed once the tender is awarded.
- *Reliance on monitoring equipment for contractual purposes.* PPA calculations and good asset management practice depend on the information provided by monitoring equipment, which may not always be a priority in project design and commissioning. Those involved in TKLN stressed the need for accurate and reliable method to measure irradiance. It was recommended that the PPA should specify the monitoring solution, accuracy requirements and testing protocols. Deriving the expected system output from irradiance also involves some error and this should be tolerated by both parties.
- *Short Term Variability of Solar resource:* The only available solar variability dataset at the time of system design was from a larger, international solar farm, and showed worst case variability to be 40% of output in 60 seconds. The actual variability worst case was found to be much higher: 80% in 6 seconds. This issue was worked around by partially limiting maximum solar output to manage the risk, with minimal impact on solar contribution (<0.5%) expected.
- *Equipment interface and control system limitations:* To dampen short term solar variability, the ability to regulate or reduce solar output was necessary. The device used regulates inverter output from 0-100% defined by 16 discrete steps (see impact in frequency distribution graph below). In the initial control configuration this, combined with the need to avoid under loading the diesel and response latency in the system, resulted in the accrual of solar reductions, which in turn had unforeseen PPA implications. Realigned control signal timing reduced the impact

of the issue. Those involved note that detailed modelling at earlier stages may have avoided this. The use of inverters capable of continuous power curtailment would avoid the losses associated with the discrete output levels.

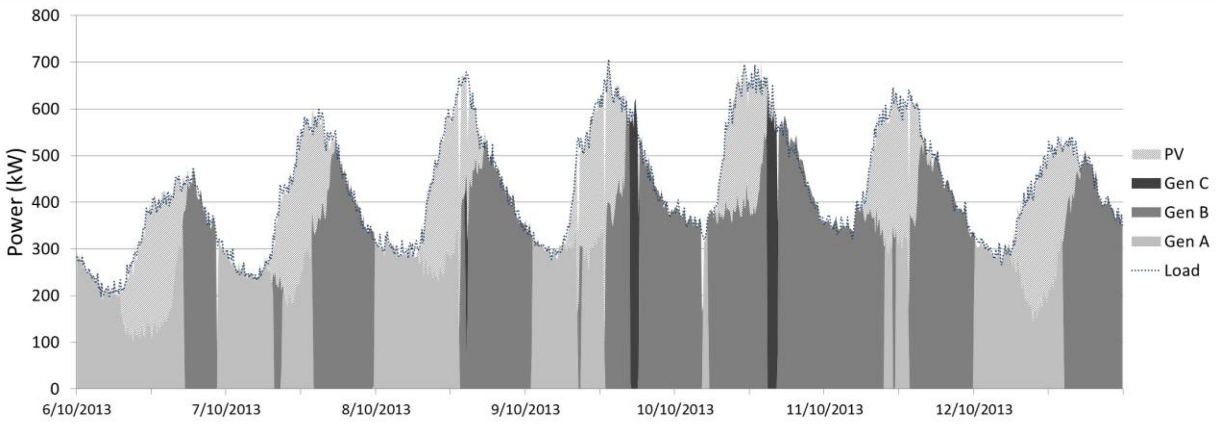
- *Equipment supply risk:* at the time of project development, the majority of lead acid battery factories in China were shut down due to environmental concerns, which resulted in a delay of six weeks. One strategy recommended is to order long lead time equipment as far in advance as possible – arranging storage until needed is a low cost insurance to avoid project delays.

Ti Tree System Operational Analysis

Ti Tree is a small roadside community north of Alice Springs with a population of 170 people. The power station configuration includes 3 diesel generators (450kW Gen A, 520kW Gen B and 700kW Gen C[4]), along with up to 324kW of PV. In 2013 the PV system contributed approximately 542MWh during the year, equivalent to 18% of the annual energy demand. The peak instantaneous PV output as a percentage of load achieved to date is 77%. The PV capacity factor was 19% across 2013, which is relatively high, and attributable to the favourable climate as well the fact the plant is slightly over built (i.e. there is more PV than there is Inverter capacity).

The time series below illustrates the week encompassing the highest demand for the year. Note generators are sized such that they rarely operate simultaneously except for start-up. This shows the PV contribution significantly reducing the run time of the two larger generators; this is quantified in the ASIM modelling to follow.

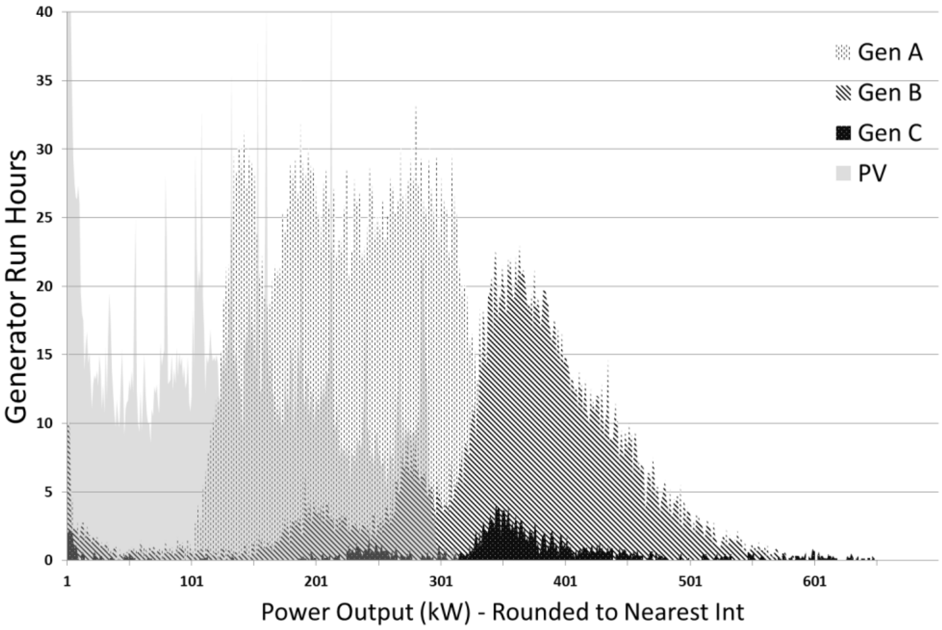
Figure 1 Operation of Ti Tree Power Station for 1 Week



The frequency distribution in Figure 2 gives a quick snapshot of annual contributions for each generator and the power range in which they operate. A higher occurrence (y value) indicates a longer time spent at that operating output (x axis). It can be seen that the PV and the smallest Gen A are the most regular input sources.

[4] Note generator names were changed from original to limit confusion, as naming order was not indicative of size.

Figure 2 - Distribution of Operating Ranges by Run Hours during 2013[5]



ASIM Modelling

PWC developed an open source modelling tool, ASIM, to allow highly customisable and variable time step analysis (down to 1 second steps) of generator, PV and battery operation. Comprising an Excel interface and C# power system modelling, ASIM is designed to be complementary to the widely used Homer tool from NREL, allowing more detailed input data (e.g. generator call up sequencing) to refine control strategies and allow more detailed economic analysis.

ASIM was utilised in this study to simulate how the power station would have run without PV to allow the evaluation of benefits from the integration of PV. Two commonly cited benefits of PVHMS are reduced fuel consumption and reduced maintenance requirements [6]. Using the detailed operational data and accurate modelling of what the alternative case may be, these benefits can now be assessed.

Fuel consumption is a modelled output of the ASIM model. A calculation series from actual 2013 Power data and efficiency curves against ASIM simulation expect a diesel fuel saving of 85kL (14%). In dollar terms, the fuel savings thus far have been greater than expected, largely due to higher than expected increase in fuel prices.

Since the diesel gensets are used to establish the grid frequency, a single generator will always be running. This then leads to the conclusion that in this case at least, overall generator run hours will be the same, and as this is a main determinant of maintenance requirements, there is unlikely to be any reduced maintenance costs with PV retrofitted sites. However, benefits may instead be realised as a reduction in run hours of the larger more expensive generators (Table 1).

Table 1: Generator Run Times with and without PV at Ti Tree

Scenario	Annual Run hour % Gen A (450kW)	Gen B (520kW)	Gen C (700kW)
Actual Performance with PV *From measured 2013 data*	65%	35%	4%
ASIM Reference case *Using actual PV and Load as inputs, to verify the accuracy of the model. (Ideally this would be close to recorded data.)*	68%	31%	2%
ASIM model of system without PV *Using the load profile for 2013, but without any PV/battery contribution/input*	52%	46%	6%

With the integration of PV, modelling indicates that runtime on the smallest generator would have been 25% higher for the year, while the two larger generators B and C would have runtime reduced by 23% and 50% respectively[6].

Conclusion

The TKLN projects were a highly innovative undertaking from both a technical and organizational perspective, and their success will pave the way for future PV projects in the Northern Territory. This paper has outlined some of the contractual and technical risks and consequent mitigation strategies that arose during the project implementation. The paper also uses ASIM simulation to provide some quantitative evidence in relation to the frequently cited benefits of fuel savings and reduced generator runtimes from PVHMS. Detailed risk benefit analysis is fundamental to good decision making. It is hoped that the findings of this case study can be used to assist project developers, policy makers and engineers to improve PVHMS project design, and therefore help to realize the potential of the technology.

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[5] Note: the spikes in PV output are understood to be caused by the power reducer control steps.
[6] Note that these figures are based on 10 minute data rather than 1 sec data required for detail control major outages (>1 day) were factored into the model, there are still smaller outage events that add up during the year and are not accounted for.