NT SETuP:
A first look at the integration of PV and Diesel Power Stations in remote communities

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ARENA

INTRODUCTION

Each year Power and Water Corporation's (Power and Water) subsidiary Indigenous Essential Services (IES) supplies more than 100 GWh of energy to 72 indigenous communities spread throughout some of the most remote regions of the Northern Territory. According to the Australian Bureau of Statistics, these are classified as being Remote Australia or Very Remote Australia, highlighting the distance to reach major population centres in the country.

Due to their small scale and extreme distances from existing transmission networks, these communities are serviced by autonomous diesel generator power stations, and the reliance on diesel fuel makes delivery of reliable, sustainable, and affordable electricity especially challenging. One of the most remote (in terms of distance) of these communities is Kaltukatjara (Docker River), located in the far South-Western corner of the Northern Territory, home to between 300 and 400 Anangu. To supply power at Kaltukatjara, 60,000 litres of diesel fuel is transported every eight weeks from Darwin, over more than 2,000 kilometres of highways and dirt tracks.

While the potential to displace fuel usage by integrating solar PV installations in these communities is well understood, historically such installations have been limited to annual Renewable Energy Fractions (REFs) of less than 5%, due to the relatively high cost of PV at the time and limited industry experience with ensuring a reliable supply during cloud events.

The Northern Territory Solar Energy Transformation Program (NT SETuP), funded by the Northern Territory Government, with the support of Australian Renewable Energy Agency (ARENA), seeks to overcome some of these challenges, and push the frontier of possibilities towards significantly higher REFs.

The program is a staged installation of 10 MW of solar photovoltaic systems (PV) across twenty-five sites, servicing 27 communities. Of these, twenty-four sites aim to achieve approximately 15% total diesel fuel displacement, while the remaining community, Daly River, is the subject of a high penetration pilot project, and is achieving up to 50% diesel fuel displacement through the use of a grid forming battery installation. The overall project will lead to lower operational costs (especially the purchase of diesel fuel), a reduced exposure to diesel market price risk, and a lower frequency of diesel refuelling trips, which is an important consideration for many top-end communities which can become inaccessible for months at a time during the wet season.

Beyond the immediate benefits of diesel fuel displacement at the twenty-five sites, the NT SETuP project aims to bring about transformational changes to Power and Water's approach to remote power station design and operation through new integration and control techniques, workforce reskilling, supply chain development for PV components and the generation of a wealth of data and other learnings about the operation of remote hybrid systems. The transformational aspects of NT SETuP are significant, which includes upskilling of Essential Services Operators (ESOs) who perform the day-to-day maintenance of the diesel power stations and now also perform maintenance on the PV systems.

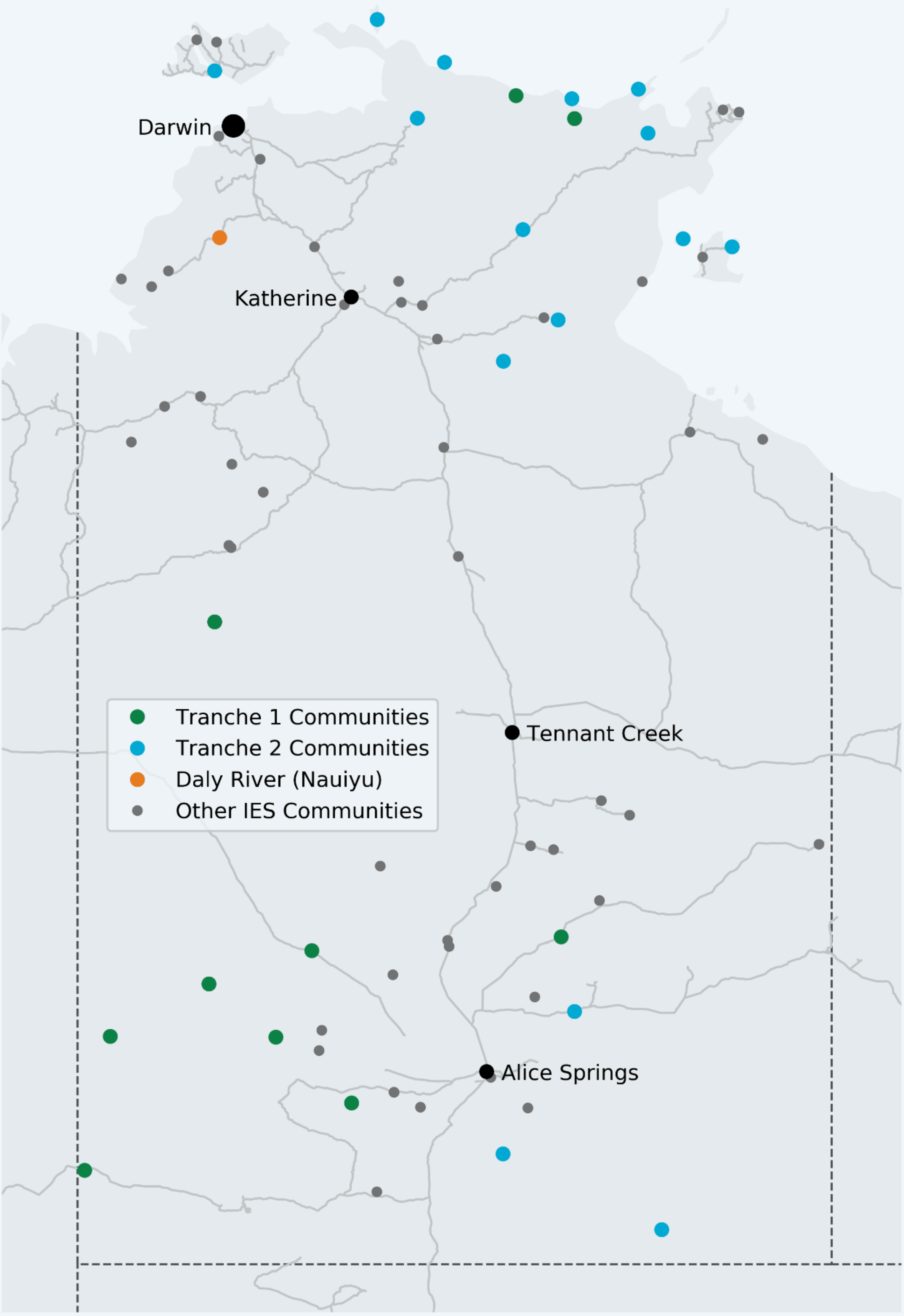

Figure 1. Map of all major communities serviced by IES, with SETuP installation sites color-coded by tranche.

The NT SETuP roll-out has been staged in two tranches which have gone out to tender, with ten "Tranche One" communities being completed over 2017, and the remaining 15 to be installed by the end of 2018. The high renewable energy fraction pilot project at Daly River was completed in early 2018.

SOLAR – DIESEL POWER STATION DESIGN AND OPERATION

Power and Water's power stations are designed to provide reliable and autonomous supply for the large variations in demand typical of small, remote communities, while also minimising the need for expensive maintenance works. To meet these constraints, each power station uses several generators of varying capacity which are automatically dispatched in response to fluctuating demand. Under normal operations, this control strategy requires only a single generator to be online at any instant to minimise the overall accumulation of wear on the fleet. As the community's total usage changes throughout the day, the station control software automatically selects the most appropriate generator for the current power level.

Introducing grid-following PV generation into these systems can be difficult, since PV generation is susceptible to variations caused by the weather, particularly with cloud movements. The PV must be integrated in a way that ensures the diesel generators are able to maintain supply as the PV varies over the course of the day.

When clouds pass over a PV array the output is reduced and the shortfall in power must be met by the diesel generators. In the event of rapid changes in the PV power, the station control system may be unable to switch to the appropriate generator fast enough, since diesel generators require time to turn on and warm up. In such cases a generator may be forced to operate below its recommended minimum power level, potentially causing increased wear, or may exceed its maximum rating, which can result in a network blackout.

A guiding principle in the design of the SETuP hybrid stations was to make as few changes as possible to the existing diesel control system, and dynamically adjust the maximum PV power in response to the constraints of the currently selected generator. While the technique of curtailing the output power of a PV system is common in hybrid power systems, it is typically employed at a fixed power level, or at a fixed percentage of the overall demand. By selecting the engine that would run, if PV were not available (or present), and then curtailing the PV to the engine's allowable minimum loading, the SETuP power stations are able to maximise the utilisation of PV power for the existing pattern of generator usage, while still providing strong system security guarantees.

The engine selection thus guarantees that a sudden loss of PV power (a complete disconnect, or partial loss of power from cloud movements) can be absorbed by the engine, while the PV curtailment is aimed at preventing reverse[1] power through the selected engine. This guarantees that the reduction of PV power caused by cloud activity is kept within acceptable limits. The use of PV curtailment is shown in Figure 2, which demonstrates the available and curtailed PV power, and the effect of each on diesel generator loading at Maningrida, a SETuP Tranche One community in Arnhem Land, in the North-East of the Northern Territory. As can be observed, the curtailment of the PV reduces the size of load changes as seen by the generator, compared to what would have happened in the uncurtailed situation. The further benefit is that the diesel generator loading is kept above its minimum and thus does not result in increased wear and tear.

1 A generator is designed to have power flow in one direction, from the generator to the load. Having power flow from the "load" to the generator due to an excess of PV power (thus having the generator operating as a motor) can result in very serious consequences for the equipment.

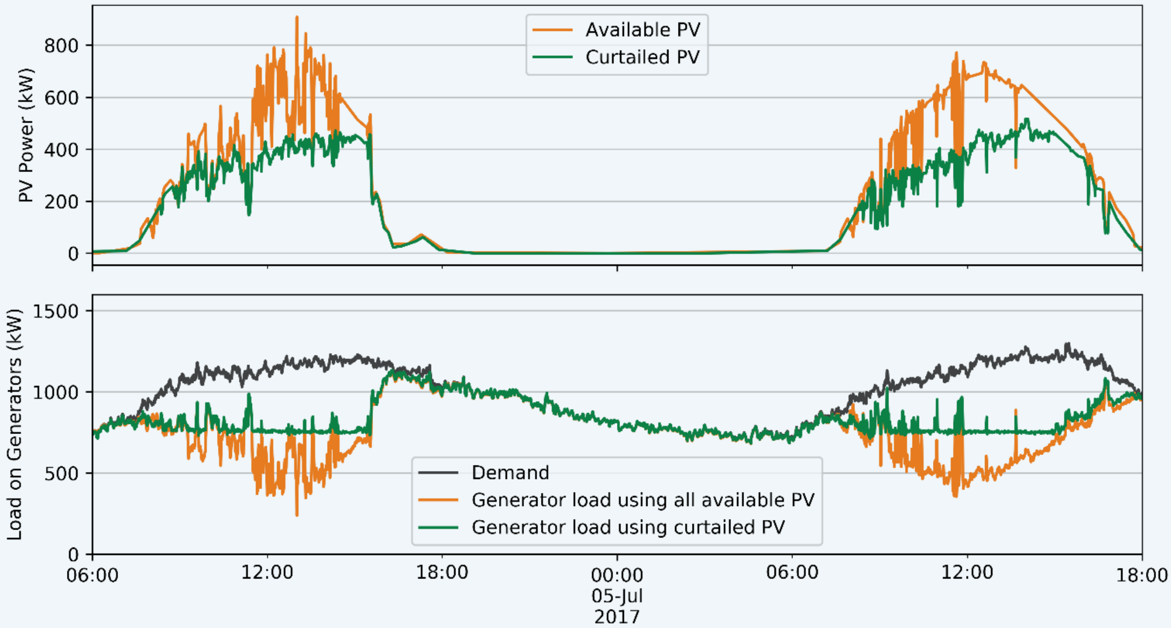

Figure 2: Available and curtailed PV power (top) and the resulting load on the diesel generators at Maningrida (bottom).

Figure 3 further demonstrates the use of curtailment at Ramingining, another Arnhem Land community. The diesel generators are selected in response to the overall level of demand, and the level of PV curtailment is dependent on which generator is currently in use. This can be seen clearly as the demand reaches high threshold near midday on March 27th, causing Gen 3 to come online (which has a higher minimum loading setting than Gen 2) and the PV to be curtailed in response. From a PV operator's perspective, such a curtailment is undesirable as it reduces the total energy produced by the system. However, as Power and Water owns and operates both the PV and the diesel generation, the decision to curtail the PV fits within a broader framework of system stability and risk mitigation, and a cost-benefit (or benefit-risk) evaluation: how much is the extra risk to system stability and the risk to higher engine maintenance costs worth, compared to the extra diesel fuel savings?

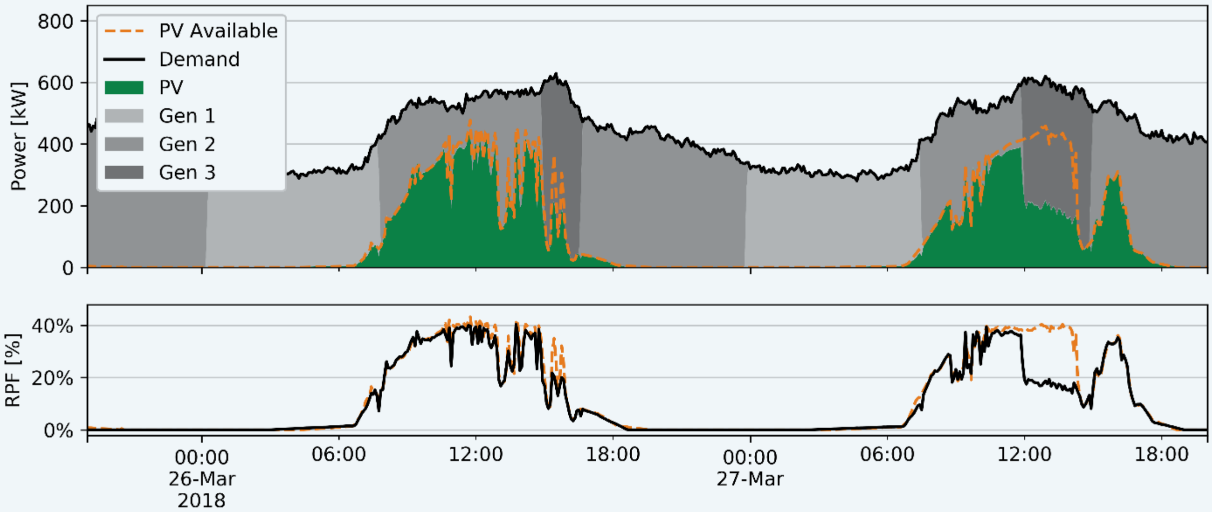

Figure 3: Monitoring data for Ramingining power station, showing the total contribution of the curtailed PV system and the three diesel generators, along with the available (uncurtailed) PV for comparison.

Learnings such as these indicate the need to better understand and communicate that a variable renewable technology such as wind or PV operates within the space provided by the other generators on the grid, and the demand: a change in either the demand or the generators can result in the need to curtail the renewable generation, to ensure that the diesel generators continue to operate within their operational boundaries.

While systems like Ramingining's and others are testing the limits of simple PV-Diesel integration, even higher renewable power and energy fractions can be achieved through the inclusion of "enabling technologies", such as cloud forecasting, low-load diesel generators, dynamic resistors, modern grid-forming inverters (standard PV inverters cannot independently form a grid – they need to synchronise to an existing grid), and batteries or other forms of energy storage systems.

The most ambitious of the NT SETuP projects, at Nauiyu (Daly River), is successfully demonstrating several of these technologies, including the installation of a 1 MW PV array with a 2 MWh Lithium-ion battery. Here, the battery takes over the task of maintaining the grid during the day while it has sufficient energy stored and is charged and discharged as the PV power output changes. Unused PV power is used to charge the battery, which discharges to the grid if the PV drops below the demand. At the end of the day, the remaining stored energy in the battery is used, thus leaving the battery ready to absorb excess PV energy on the next day. Once the battery has reached its minimum state of charge, the diesel generators meet all of the load until next day when the PV array starts to produce power. In this way, the system operates as a PV-battery (-diesel) station during the day and as a typical diesel power station at night.

As can be seen from the two days of operational data plotted in Figure 4 below, the system at Nauiyu is able to achieve 100% RPF during daylight hours, resulting in an overall reduction in diesel fuel use of up to 50%. Compared to the other NT SETuP stations, Nauiyu has both a larger PV array and a large battery in place, which permits it to reach significantly higher Renewable Power Fractions and then Renewable Energy Fractions over the year (Nauiyu reaches RPF values of up to 100%, versus typical values of up to 50-60% for the other communities).

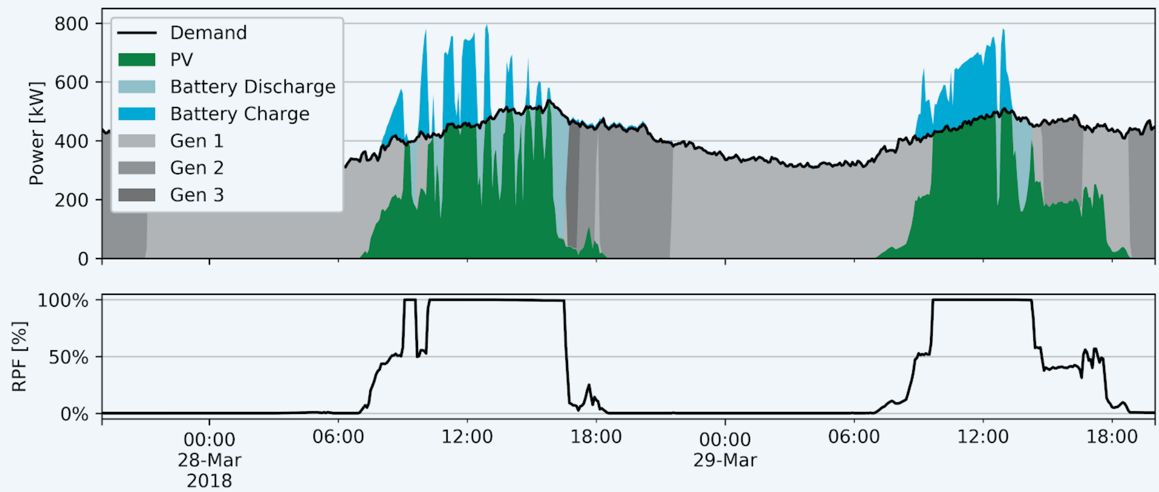

Figure 4: Monitoring data from the Nauiyu power station, showing the contribution from PV, diesel generators, and the battery energy storage system. The figure demonstrates the use of the battery for smoothing and grid forming, which enables 100% Renewable Power Fraction (RPF) by turning off the diesel generator.

2 Grid-connected PV inverters have anti-islanding protection requirements: in the event of a failure on the grid (e.g. a blackout), they must disconnect from the grid within a set amount of time.

Since conception of the project, some NT SETuP communities have benefited from additional diesel generator replacements, where traditional diesel generators (which have a limit of around 60% RPF) which were at the end of life were replaced by low load diesel generators, which can tolerate up to 90% RPF.

In terms of evaluating the expected versus actual performance of NT SETuP, complicating factors are the replacement of diesel generators since the project design (for example, the need to replace a generator by one of a different capacity), the actual versus modelled solar resource and weather observed by the communities, changes in demand in the communities, and the modelling of the combined performance of diesel generators with PV (both the software and the assumptions used at the time).

SUMMARY

This vignette reports on some of the early operational experience from the Tranche One projects of the NT SETuP program and illustrates the ability of the diesel generators to accommodate the PV generation without using additional enabling technologies, achieving Renewable Energy Fractions of approximately 15%, and having peak Renewable Power Fractions of up to 60%. Some communities have benefited from the deployment of low-load diesel generators, which increase the diesel savings without significantly increasing the risk profile for those grids. Nevertheless, the achieved Renewable Power Fractions are higher than what was previously considered to be possible without batteries or other forms of enabling technologies.

In the case of Daly River (Nauiyu), the presence of the suitably-sized battery and grid-forming inverter increases the operational envelope of PV and permits the power station to operate at RPFs of 100% for long periods throughout the day. These results are among many learnings that the NT SETuP program will generate, which can be applied for similar power stations and systems which can be both on-grid and off-grid.

The performance of the NT SETuP projects will be evaluated, with the learnings valuable not only within Australia for similar grids (e.g. the remainder of the Power and Water-supplied communities), but also for other systems worldwide, both on-grid and off-grid.

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