Cloud Forecasting at Alpurrurulam

The impact cloud forecasting has on system ramp rates at Alpurrurulam's off-grid hybrid power system

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1. Abstract

Sky-camera based forecasting systems for solar PV generation are now a commonly used technology, and the value proposition for this technology in the specific context of small microgrids has been made clear. However, that value remains unproven. We provide results from an off-grid hybrid system in which a sky-camera forecast system is integrated into a solar PV ramp-rate control system. The results and supporting analysis demonstrate that the skycamera was successfully able to predict almost all significant drops in solar resource, and its integration resulted in a significant reduction in the utilisation of co-located battery system used for ramp-rate control.

2. Introduction

The feasibility of integrating cloud-prediction technology (CPT) depends on the context in which it is applied. Lessons have been shared from applying CPT on large, interconnected systems (e.g. National Electricity Market and the South-West Interconnected System)[1], small to medium sized interconnected systems (e.g. North-West Interconnected System and the Northern Territory Energy Market)) [1] [2] [3] and within many off-grid environments [4] [5]. This study contributes new knowledge and lessons learned from the integration of a cloud-prediction technology solution into an off-grid hybrid power station at Lake Nash (Alpurrurulam), located in the Northern Territory (NT).

Epuron's TKLN Solar takes its name from an abbreviation of three Northern Territory communities – Ti Tree, Kalkarindji and Lake Nash (also known as Alpurrurulam) where three power stations have successfully integrated high penetration solar PV into off-grid diesel power stations. Alpurrurulam is located approximately 600km north-east of Alice Springs and is home to approximately 494 people [6] [7]. TKLN Solar Pty Ltd is wholly owned and operated by Epuron, and energy generation from the solar PV arrays are sold to Power and Water Corporation (PWC) under a Power Purchase Agreement (PPA) [6]. The location of each TKLN site is shown in Figure 1. At Alpurrurulam, the now-cast outputs from the CPT system are used by the solar PV local control system to help manage site export ramp rates and reduce reliance upon the battery energy storage system (BESS).

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[1] The Australian Renewable Energy Agency' Knowledge Bank is home to many reports discussing the lessons learned from the short-term forecasting round: https://arena.gov.au/knowledge-bank/

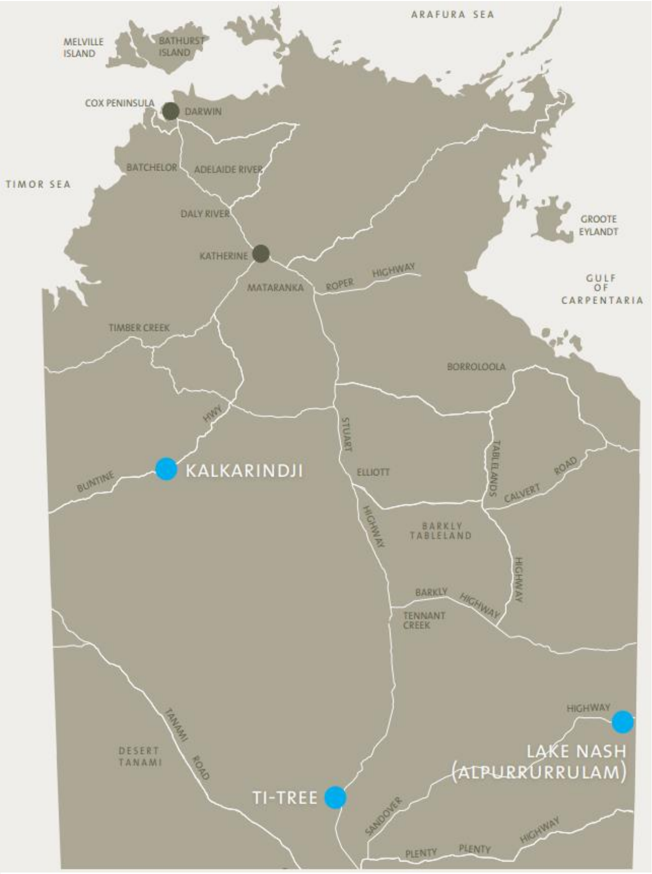

Figure 1. Map of the three TKLN sites. Figure originally from [6].

3. Power system and integration

Alpurrurulam's hybrid power station includes the following technology:

1. Owned by Epuron within the solar compound
    a. A 272 kW solar PV system
    b. 16 SMA 17,000TL Tripower string inverters
    c. 6 x Selectronic Pro SPLC-1201-AU inverters
    d. A 156 kW, 62.1 kWh Toshiba Lithium-ion BESS
    e. A Fulcrum 3D CloudCAM with meteorological sensors.
2. Owned by PWC within the thermal power plant compound
    a. Diesel generators

The solar PV generation at Alpurrurulam is curtailed to ensure output does not exceed a dynamic setpoint signal sent from the control system at the diesel power station. The value of this set point is determined by operational factors, such as the maximum and minimum loading capability of committed diesel generators. This operating philosophy reflects an assumption that PV generation is volatile, and that operating reserves must be maintained to replace PV generation in the event of sudden cloud cover. In practice, this approach creates a significant barrier to achieving high renewable energy fractions [6].

In principle the level of operating reserve can be reduced if the PV generation is "firmed", i.e., measures are taken to reduce to volatility of the PV output. To this end, the PWC power purchasing agreements include specific restrictions upon the PV output power ramp rates. Penalties are paid by Epuron to PWC whenever the solar PV generation ramp rate exceeds pre-agreed limits. These penalties are applied for each 1-minute event. The size of the penalty is scaled to the size of the fall in output.

To satisfy the ramp-rate requirements of the PPA, each of the TKLN sites have installed battery energy storage systems (BESS) to provide ramp-rate control of the station output. When the PV generation is suddenly reduced due to cloud cover, the BESS compensates by discharging the battery so that the ramp rate of the net power does not exceed a fixed limit.

During the design stage for TKLN, insufficient site-specific solar resource data was available, resulting in reference data sets being relied upon when determining the sizing of battery inverters required to provide firming. Actual operational data from TKLN sites indicate that this sizing was based on assumptions that likely underestimated the rate and magnitude of solar variability. As a result, the originally installed lead-acid BESS experienced high-use and risked a severely shortened lifespan. In August 2020, the original lead-acid BESS at Alpurrurulam was replaced with Lithium-Ion technology.

The primary value proposition of the sky-camera system at Arparrurulam is to provide advance warning of cloud events and use this signal to direct the PV inverters to ramp down their generation at a controlled, acceptable rate, therefore reducing the reliance upon the BESS and ultimately extending its operational lifespan. When the sky-camera system predicts that a drop in irradiance is likely, the PV inverters are directed to ramp down their output via a set point signal. This results in less compensating power being required from the BESS when the cloud cover occurs.

The control system integration is demonstrated by example in Figure 2, which shows the simulated ramp-rate control system with and without the CPT forecast integration. The upper sub-plot shows the PV output power, which is curtailed to below 100 kW when the CPT system is enabled. The middle sub-plot shows the power output of the BESS system, which discharges to limit the downward ramp rate of the site output power, which is shown in the bottom sub-plot.

On the day shown, a significant cloud event occurred in the afternoon, causing large ramps in the available PV power. The cloud camera system's set point (dashed line) caused the PV system to be curtailed in advance of the cloud cover. The image demonstrates that the CPT system has allowed the ramp-rate control system to operate with significantly less utilisation of the battery system than the counterfactual simulation.

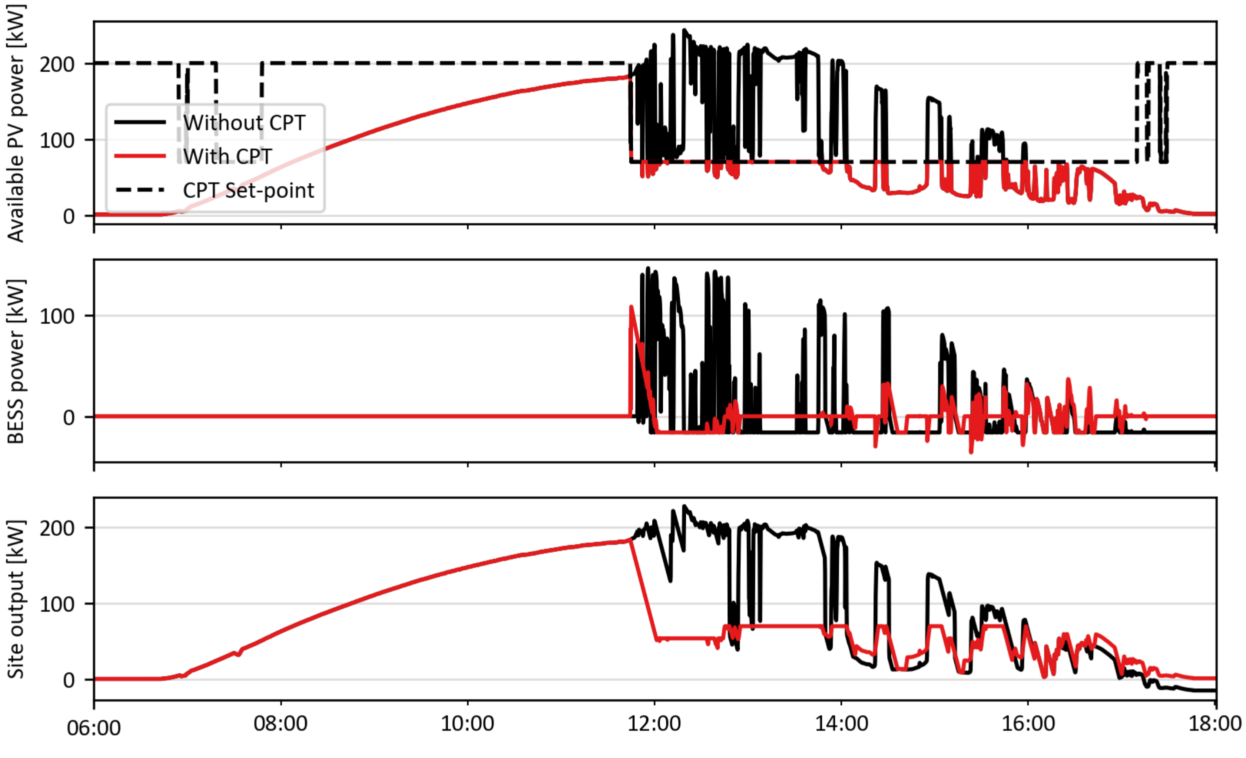

Figure 2. Simulated ramp rate control system, using measured weather and CPT set-point data from the Alpurrurulam system. The plot demonstrates that significantly less energy and power is required from the BESS when the CPT system is integrated.

4. Data

1-second resolution data was obtained from the site data logger as well as the Fulcrum 3D weather station. Periods of missing or spurious data were filtered. Data points used in the subsequent analysis are described in Table 1.

Table 1. Data points used in analysis.

Source	***Description***	***Units***
Weather station	Global Horizontal Irradiance	kW/m^2
	Ambient Temperature	°C
Site data logger	Active power from BESS	kW
	Active power from PV inverters	kW
	Active power at connection point	kW
	PWC set-point signal	kW
	Fulcrum3D set-point signal	kW

The overlapping periods of the obtained data sources spanned from 16/04/2020 to 12/12/2020, with significant periods of unavailability in the data obtained from the site data logger. Overall data availability is summarised by Figure 3.

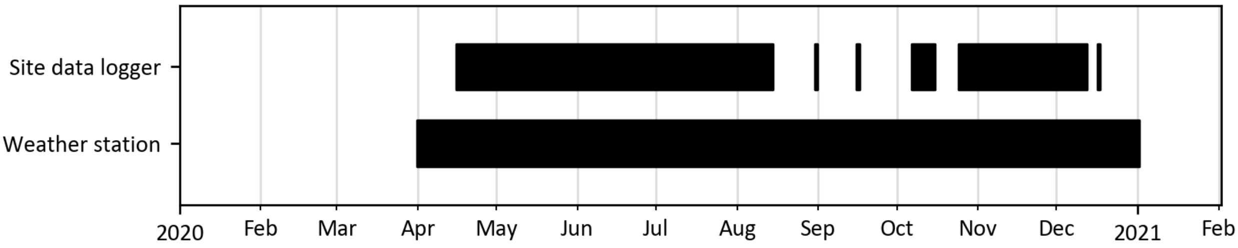

Figure 3. Summary of availability periods for data used in this study.

5. Aim and approach to analysis

At the outset of this study, we sought to provide analysis of the data in terms of:

a) The accuracy of the CPT system as a short-term predicter of changes to available PV power.
b) The impact of the CPT system upon the utilisation of the BESS.
c) The ability of the local control system to effectively limit the export ramp rate.

An initial exploratory analysis of the data revealed that the energy demand at Alpurrurulam had decreased significantly since the power station and solar array were designed, likely due to population shift, and that this had resulted in unexpected levels of curtailment of the PV array (Figure 4). One outcome of this curtailment is that a direct assessment of the ramp rate control system (item c above) could not be made, since the output of the site was too frequently limited by the external set point.

The remaining analysis of the forecast accuracy and the impact of the integration upon the BESS utilisation, both draw heavily upon simulation of the PV and BESS generation, utilising the measured weather and sky-camera data. These aspects of the analysis were not impacted by the curtailment.

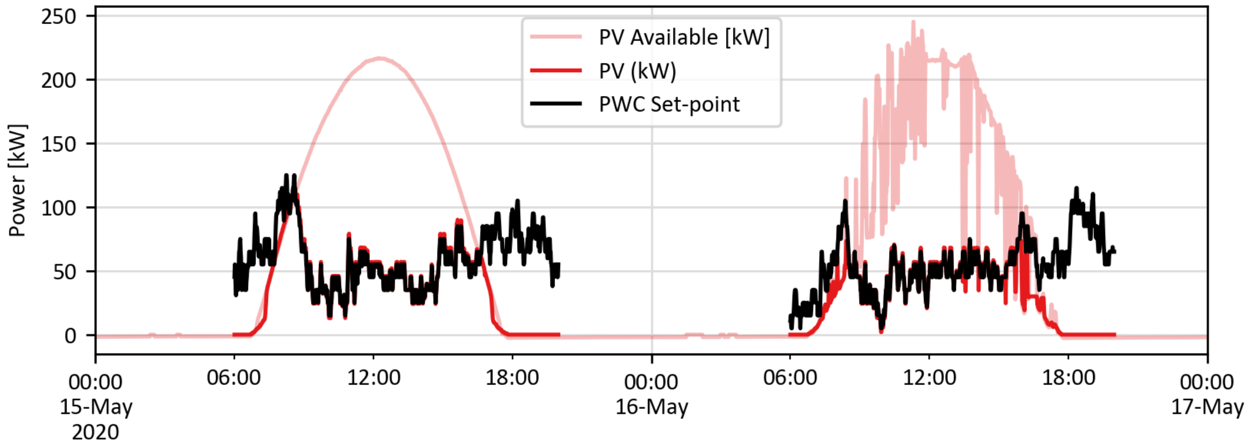

Figure 4. Demonstration of extreme PV curtailment over two days. On the second day, the ramp-rate control system is mostly unutilised despite intermittent cloud cover; the impact of the solar resource volatility is already mitigated by the curtailment.

6. Forecast accuracy assessment

6.1 Methodology

Our previous work [4] established an approach for assessing the efficacy of CPT systems in the off-grid context. This methodology defines a “significant drop” in available PV output power to be any instance in which the difference in available PV power over a short time interval exceeds a fixed threshold. These significant drops form the subject of evaluation of the CPT forecast’s performance as a binary classifier.

Importantly, over periods of sustained cloudy weather there may be several measured significant drops over a short period of time. In this case a fixed exclusion window is used to ensure that only the first such drop is considered for evaluation.

The presence of heavy curtailment of the solar farm for much of the assessment period meant that a calculation of the available PV power was not directly measurable. To estimate the available PV power, we have employed a simulation of the PV using the PVLib software package [8]. Direct beam irradiance was estimated from global horizontal using the DISC model [9], and plane of array transposition was achieved using the Hottel and Woertz model [10]. To account for the smoothing effect due to the geographical dispersion of PV modules within the solar array, spatial aggregation smoothing on clear sky index [9] values has been computed using the Wavelet Variability Model [11].

Two scores are produced that establish the CPT’s receiver operating characteristic:

- A reliability score – which quantifies the percentage of evaluation events that were successfully predicted by the CPT system. This metric fills the role of a true positive score.
- An efficiency score - which quantifies the amount of energy lost due to curtailment during clear-sky weather periods. This metric fills the role of a true negative score.

In the case of Lake Nash, the CPT’s output is not a binary predictor, but a variable set-point of the PV output set point (as described Section 4). For evaluation purposes we consider all times during which this set point is set below 200 kW to be a prediction of imminent cloud cover.

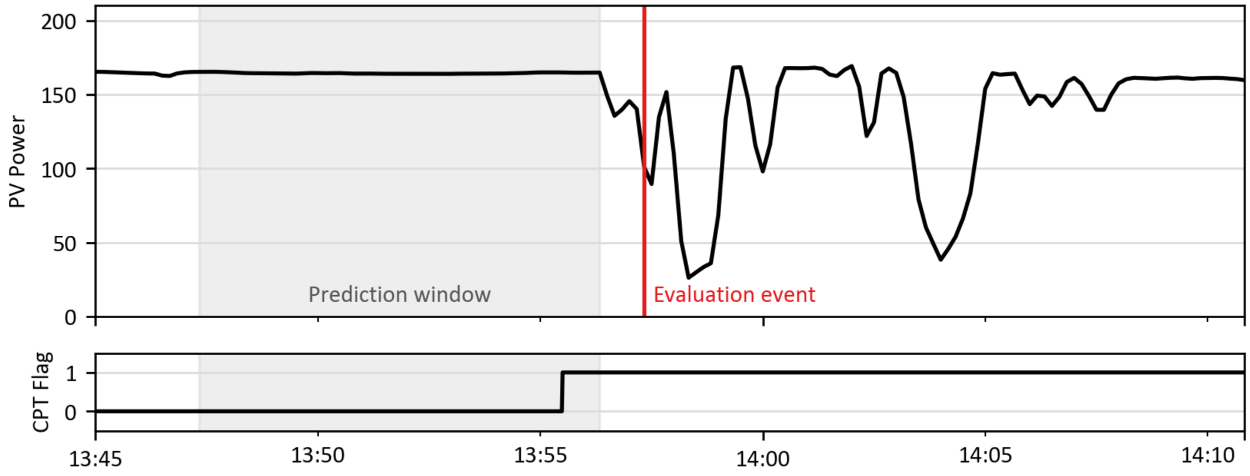

Figure 5. Demonstrating the evaluation methodology for a successful prediction of a drop in available PV power. The CPT setpoint signal has been converted to a binary flag, with 1 indicating a prediction of imminant cloudcover. In this example, the flag is set to 1 within the prediction window, indicating a positive prediction.

6.2 Results

The analysis found that the CPT system was able to predict almost all significant drops in available PV power, with very little energy lost due to curtailment during clear weather periods. These results are summarised in Table 2.

Table 2. Results of forecast accuracy analysis.

Reliability	Evaluation events Total number of observed drops in available PV power	244
	True positives Successfully predicted significant drop	232
	False negatives Failed to predict significant drop	12
	Reliability score	**94.7 %**
Efficiency	Evaluation Hours Total observed hours of clear weather.	1398
	Available PV Energy [MWh]	180.2
	Curtailed PV Energy [MWh]	5.4
	Efficiency score	**97.1 %**

7. Ramp-rate control simulation

7.1 Methodology

To determine the impact of the CPT system upon the utilisation of the BESS, we have relied upon simulation of the ramp-rate control system in place at Lake Nash. This simulated control system was then used to provide firming of a) the total available PV power, and b) the PV power after curtailment by the CPT system. Various metrics of the BESS utilisation, such as the total number of cycles, and the number of hours spent at near peak power, are compared across the two simulations scenarios.

The control system simulation operates under three modes:

1. If the ramp rate of the available PV power is less than ΔP_{min} the BESS is discharged to compensate so that the ramp rate of the net site output power is exactly ΔP_{min}.
2. If the ramp rate of the available PV power is greater than ΔP_{max} the BESS is charged or, if the BESS is fully charged, the PV is curtailed, so that the net site output power is exactly ΔP_{max}.
3. If the ramp rate of the available PV power is between ΔP_{min} and ΔP_{max}, then state of charge control is employed to target 95% state of charge.

The specific parameters (e.g., ΔP_{min} and ΔP_{max}) used in the simulation were tuned to the true behaviour by comparison with logged data from the station. Figure 6 demonstrates the simulated values over a cloudy period, along with the measured values for the same period.

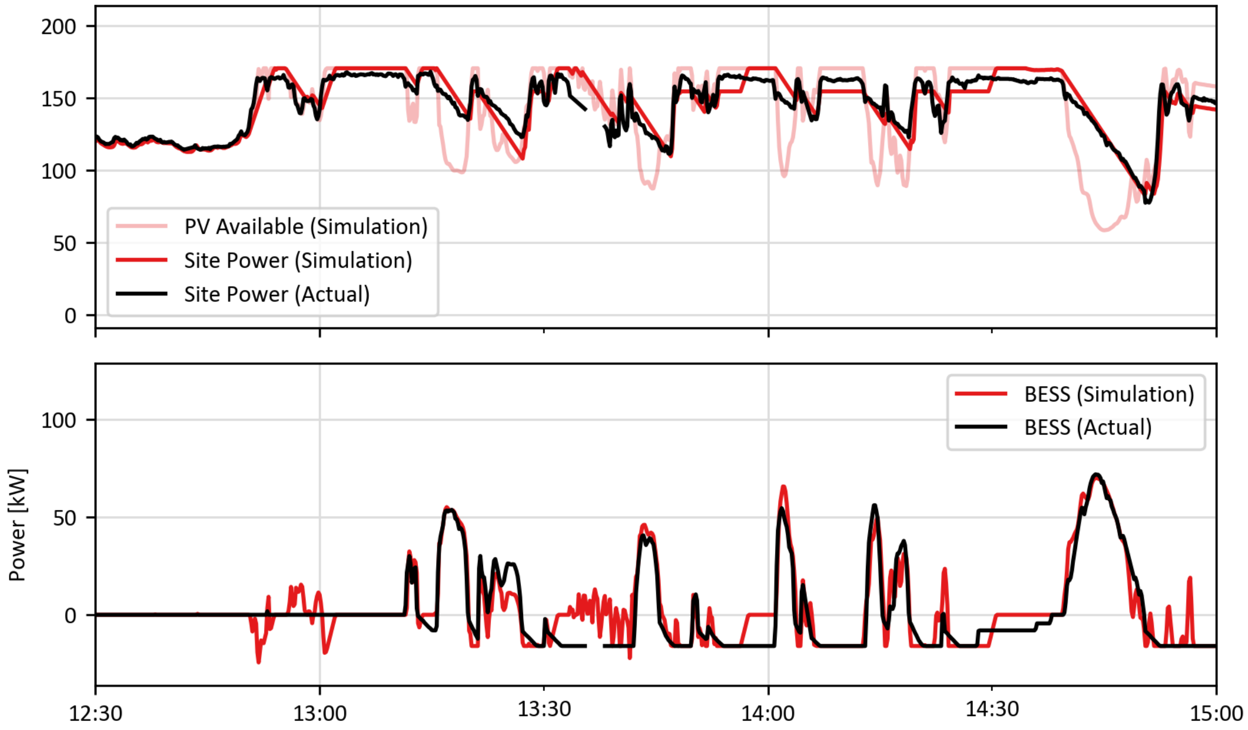

Figure 6. Example of BESS ramp rate control simulation, along with actual site output power.

7.2 Results

After data cleansing and filtering, simulations were conducted over 182 full days. For each day, two distinct simulations were conducted: first, the ramp rate control system was simulated using the direct “PV available” estimate (see Figure 6), and second, the same simulation was conducted after first limiting the PV available estimate according to the CPT set point.

Some key metrics of performance for the two simulations are shown in Table 3.

These results show that the use of the CPT system resulted in a small decrease (5.4%) in the total exported energy, but in doing so was able to significantly reduce the utilisation of the BESS.

Table 3. Results of BESS ramp-rate control simulation over 182 days of real data, with and without the cloud prediction system.

	Without CPT System	With CPT System	% Difference
Total BESS Cycles	45.6	34.4	-24.6 %
Energy Exported [MWh]	228.1 MWh	215.8 MWh	-5.4 %

Time with BESS discharging at greater than 90% of rated power [h]	0.57	0.06	-90.3 %
Time in exceedance of target ramp rate [h]	2.13	1.13	-47.2 %
Number of days minimum state of charge reached.	13	3	-76.9 %

8. Summary

The results and supporting analysis demonstrate that the CPT was successfully able to predict almost all (94.7%) significant drops in solar resource, with very little (5.4%) energy lost due to curtailment during clear weather periods. PWC have reported an average diesel fleet efficiency figure of 0.274 litres / kWh [12]. Using this assumption for diesel consumption, the energy lost due to curtailment equates to approximately 3,370 litres of diesel being consumed. However, this figure will be partially offset as the CPT's integration of CPT resulted in a significant reduction in the utilisation of co-located battery system used for ramp-rate control, thereby reducing the inefficiencies associated with round trip losses. The benefits to the operation of the co-located battery through the integration of the CPT are:

1. 25% less cycles
2. 90% less time discharging more than 90% of rated power
3. 77% less days where minimum state of charge is reached

Without integration of CPT, across the analysis period, the site would have exceeded the target ramp rate by an additional 47% of the time.

A direct assessment of the ramp rate control system could not be made as Alpurrurulam's demand has decreased significantly since the power station was designed, resulting in unexpected levels of solar PV curtailment.

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