# Cloud forecasting and ramp rates at Alpurrurulam's off-grid hybrid power system

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## 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 on how CPT helps manage system ramp rates with and without the support of a BESS at Lake Nash (Alpurrurulam), which is home to an off-grid hybrid power station located in the Northern Territory (NT).

Alpurrurulam is one of three communities included in the TKLN Solar project, which successfully integrated solar PV into off-grid diesel power stations, achieving high renewable power fractions (RPF). TKLN Solar Pty Ltd is wholly owned and operated by Epuron, where electricity is 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. Alpurrurulam's hybrid power station is located approximately 600km north-east of Alice Springs and is home to over 4,000 people [6].

Some of the approaches commonly used to manage intermittent PV generation on remote and isolated hybrid power systems include limiting PV connections, curtailing PV output, maintaining a larger spinning reserve of online thermal capacity, and/or relying on the support of alternative generator technologies (e.g., BESS). At Alpurrurulam, solar PV generation is curtailed to ensure output does not exceed the dynamic setpoint signal sent from the control system at the diesel power station. While these approaches, including those implemented at Alpurrurulam, serve a useful purpose, they also present significant barriers to achieving high renewable energy fractions (REF) [6]. The value proposition for integrating CPT in off-grid applications is often to enable achieving higher REFs in the absence of a battery energy storage system (BESS). However, each of the TKLN sites present a slightly unique value proposition since a BESS was already installed prior to integrating CPT.

During the design stage for TKLN, an insufficient amount of site-specific solar resource data was available, resulting in reference data sets being relied upon when determining what size battery inverters will be required to provide necessary smoothing capabilities. At the time, publicly available data from a test-site in Hawaii demonstrated solar PV ramp rates reaching approximately 40% (over one minute) of nameplate capacity. However, actual operational data from TKLN sites indicate this value to sit closer to 80% (over four seconds). The sizing selection of battery inverters at TKLN sites were based on assumptions that likely underestimated the rate and magnitude of solar variability. As a result, the originally installed lead-acid BESSs experienced high use & performance requirements. The intention for the CPT was to reduce the reliance upon the BESS and ultimately extend its operational lifespan.

[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. Originally from [21].**

A Fulcrum3D CloudCAM was installed and integrated into the real-time control systems as the BESS neared the end of its useful life. This study reports on how the CPT impacts overall system ramp rates at Alpurrurulam with and without the support of a BESS.

## The System

Alpurrurulam's hybrid power station includes the following technology:

1. A 272 kW solar PV system
2. 16 SMA 17,000TL Tripower string inverters
3. 6 x Selectronic Pro SPLC-1201-AU inverters
4. A 156 kW, 62.1 kWh Toshiba Lithium-ion BESS
5. A Fulcrum 3D CloudCAM
6. Diesel generators

The CloudCAM has been operational at the site for several years and assists in managing system ramp rates, which is a requirement under the PPA. The lead-acid BESSs were replaced by lithium-ion technology in August 2020. The diesel generators form the grid, and the site never operates in diesel-off mode.

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.

### Methodology

A list of data cleansing and filtering techniques were applied on raw operational datasets before estimating the impact the cloud camera is having on system ramp rates. One note-worthy cleansing technique is the one taken to smooth irradiance from a point-sensor reading. Modelling solar PV generation from point-sensor irradiance data tends to overestimate actual solar power ramping. Solar farms occupy larger areas than point sensors and therefore the irradiance reaching the solar farm is different to what a point sensor would measure. The irradiance has been smoothed by computing the spatial aggregation time series smoothing on clear sky index [7] values based on the Wavelet Variability Model [8]. The top axis in Figure 2 compares clear-sky [7], point-sensor, and smoothed irradiance, while the bottom axis compares raw, pre-processed, and smoothed clear-sky index values over one day. Measurement uncertainty during low irradiance conditions (e.g. early morning and late evening) causes asymptotic behaviour in the calculation of the clear-sky index, which can be seen by raw clearness index. To combat this, techniques used in [9] produce a pre-processed clearness index. Finally, a smoothed clearness index is generated using the Wavelet Variability Model, which is used to smooth the original point-sensor irradiance data.

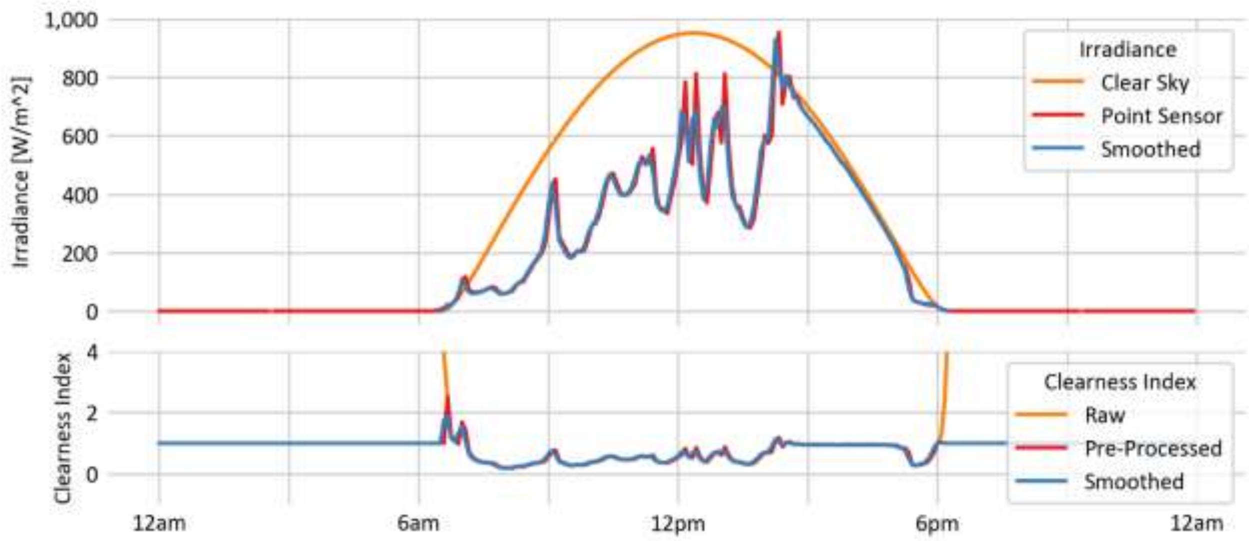


**Figure 2. Smoothing irradiance from point-sensor readings**

There are two main constraints that, when active, curtail solar PV output and need to be excluded from certain analysis. These constraints include:

1. PWC setpoint: Signal from PWC diesel generator, the maximum value that the solar power station is allowed to export. There is only one diesel generator online at a time and this value represents the diesel generator's minimum load. The solar PV generation is curtailed to not exceed this value.
2. CloudCAM ceiling: Calculated value using Fulcrum 3D's CloudCAM NowCast inputs & BESS prospective power inputs. Solar PV generation is curtailed to not exceed this value to ensure generation persists within the ramp rate boundary conditions of the PPA. Generally, a working BESS and periods of clear sky enable this value to be higher, ultimately reducing curtailment.

To understand how the CPT is impacting system ramp rates, it needs to be understood what system ramp rates would have been experienced where no constraints were active. No signal identified whether a constraint was active or not. Upon examination of the data, it seemed reasonable to assume that the solar PV was being curtailed if either the PWC setpoint or CloudCAM ceiling was within 10% of the solar PV output. This approximation does not capture all periods of active constraints, and this was evident when witnessing irregular spikes in the solar PV performance ratio (PR)[2]. An additional filtering step removed periods where the PR fell below 50%. The operational data could then be separated into periods where a:

1. PWC setpoint constraint was active, or
2. A CloudCAM ceiling constraint was active, or
3. Neither constraint was active (i.e., solar PV generation impacted only by weather).

To understand what system ramp rates would have occurred had there been no constraints, solar PV generation was estimated using ordinary least-squares linear regression, with plane-of-array (POA) irradiance and ambient temperature regressors. The POA irradiance data was estimated from on-site global horizontal irradiance (GHI) data using an isotropic transposition [10] model though the pvlib [11] module for Python. The model coefficients were fitted against observed data for periods without any active constraints. Ramp rates were then calculated and compared for a system that is subject to PWC setpoint constraints only, to CloudCAM ceiling constraints only, to both constraints, and to no constraints.

**Analysis**

To be reported on in full paper

**Conclusion**

To be reported on in full paper

**Future work**

To be reported on in full paper

[2] The ratio of the energy generated by the solar farm with respect to the energy that would have been generated if the system was continuously operated at the rated efficiency of the modules at nominal standard test conditions (STC).

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