The Power of Far-flung Arrays: Yulara's Dispersed Design to Reduce System Variability

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INTRODUCTION

Renewable power generation systems often encounter a concern about variability in their performance. While the use of energy storage, smart control systems and hybrid approaches can pacify the outdated critique that renewables give ‘no power when the sun doesn’t shine and wind doesn’t blow’, a more pressing concern for power infrastructure and the grid is the ‘ups and downs’ of solar and wind resources on a less predictable basis, which is termed ‘variability’.

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Abrupt changes due to intermittent cloud movements, for example, put the onus on other generators, such as gas/diesel reciprocating engines and turbines, to cover loads while renewable resources fluctuate. Sometimes this occurs at start-up rates that are unfeasible to achieve by the standby generators or supporting systems that facilitate the response, potentially resulting in blackouts (cessation of power supply), brownouts (diminution of power supply) or instability of the broader electricity grid depending on its inherent inertia and ability to cope with the fluctuation. Variability is a genuine concern that has impeded the uptake and extent of renewable energy in many power systems.

A design strategy that requires no special or complex infrastructure and equipment, but conscious attention to the physical system layout, can be explored. This much overlooked concept is geographic dispersion: the wide spacing of sections of a renewable power installation so that climate conditions affect different areas of the system at different times, resulting in a net output that has greater power continuity than that of a centralised system.

This vignette examines one solar PV plant in the Northern Territory that embraced this concept from design to operation, comprising five distributed installations in a 1.8 MW$_P$ plant located near Uluru (Ayers Rock). While the following discussion focuses on solar PV, its principles also apply to wind energy and other renewable power systems.

Figure 1: The Desert Gardens hotel 1 MW$_P$ array, the largest in Yulara’s 1.8 MW$_P$ PV system near Uluru

ABOUT THE YULARA PROJECT

Owned and operated by Voyages Indigenous Tourism (Voyages), Yulara Resort is based at Australia's iconic landmark and sacred site Uluru. The township associated with Uluru is called Yulara, while Mutitjulu is the Aboriginal community in the area.

The 1.8 MW_p PV system at Yulara was installed in 2016 across five locations at distances ranging from around 500 m to 5.5 km apart. The arrays are identified by their settings: Desert Gardens (1060 kW_p), Laundry (328 kW_p), Service Station (227 kW_p), Sails in the Desert (107 kW_p) and Connellan Airport (106 kW_p) as shown in Figure 2. Owned by Voyages, the PV system delivers its power to the local distribution grid operated by the NT's main utility, Power and Water Corporation, while Territory Generation operates the main gas-fired power station supported by diesel. Compressed natural gas (CNG) is transported 450 km by road train each day from Alice Springs. The largest array of Yulara's PV system, the Desert Gardens array can be curtailed to ensure stability of the grid and responds to signals from the central power station.

Insolation at Yulara is generally strong, with daily values ranging from 3.2 to 8.6 kWh/m^2 and frequent clear-sky days. Nonetheless, like most places, it is not immune to passing clouds and the resultant shading of arrays and PV power generation variability.

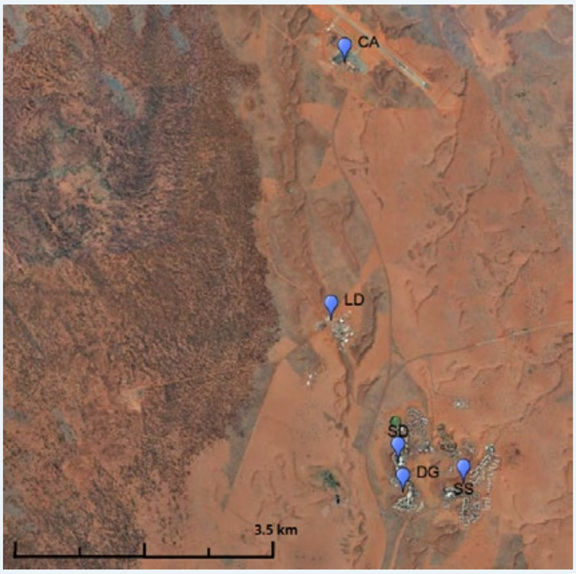

Figure 2: Geographical distribution of the PV arrays in the 1.8 MW_p Yulara system, where CA = Connellan Airport (106 kW_p), LD = Laundry (328 kW_p), SD = Sails in the Desert (107 kW_p), DG = Desert Gardens (1060 kW_p) and SS = Service Station (227 kW_p)

In off-grid contexts, the importance of reducing power generation variability is pronounced as these fluctuations can strongly influence the grid's voltage and power factor. In Yulara, the small size of the local grid makes it resemble an off-grid scenario; the impact of supply variability on power quality is important enough to warrant attention. This also owes to the high contribution fraction of PV towards Yulara's consumption mix: approximately 30% of peak power and 15% of electricity demand on average. Being reasonably sensitive to the characteristics of PV generation and planned in a wide configuration makes Yulara's power system apt for studying the possibilities of geographic dispersion.

1 A peer study compared PV array pairs representing high and low correlation conditions. These were spaced at 11 m and 168 m respectively, validating the Yulara system's interpretation as a well-dispersed setup [1].

GEOGRAPHIC DISPERSION

Mitigating Variability by Dispersion

While high-resolution power generation data at the resolution needed to analyse variability in an accurate manner from the 1.8 MW_p Yulara PV system is not available for study purposes, the data does permit evaluation of variability. Figure 3 illustrates the need for high resolution data by comparing an irradiance dataset recorded at 5-second intervals to an aggregated set based on 30-minute averages over the same period. While the 30-minute data may capture the total resource over the day with sufficient accuracy for most purposes, information about the short-term step changes is lost in the averaging process. Therefore, the lower resolution dataset fails to reveal a true picture of fluctuating resource conditions which is crucial for proper variability analysis.

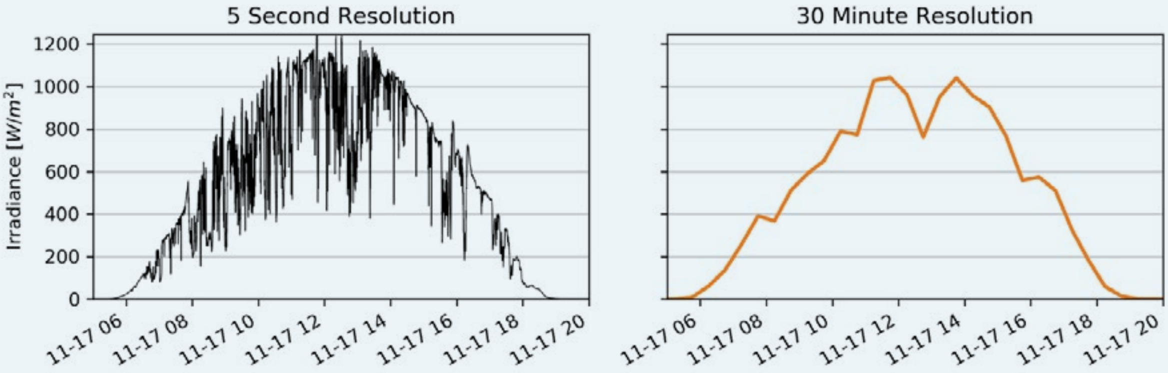

Figure 3: A single, cloudy day of irradiance data captured at both high and low resolution

To better highlight the impact of geographical dispersion on PV output variability at Yulara, the plant has been simulated using high resolution irradiance data from five Alice Springs weather stations (these were installed for a prior variability study in Alice Springs [1]). A model compares this simulated Yulara system to one with an equivalent capacity but arranged in centralised fashion (recall Yulara's five arrays are positioned up to 5.5 km from each other, with a minimum distance of around 500 m, as per Figure 2).

Figure 4 affirms the principle that geographically distributing the arrays reduces the range between minimum and maximum values of power produced by the overall system. The dispersed configuration shown in red has a reduced variability than the centralised array in black, with the separation of the arrays in the dispersed configuration resulting in smaller changes from moment to moment: it has lower peaks (maxima) and higher troughs (minima) than the centralised system.

Yet more critically, the geographically dispersed scenario results in a reduction in ramp rates. As shown in the lower graph of Figure 4, taking 21 November as an example, the dispersed system experienced fluctuations of little greater than 28% (500 kW) change in power output per 5 seconds, compared to the centralised system experiencing up to around 44% (800 kW) change per 5 seconds.

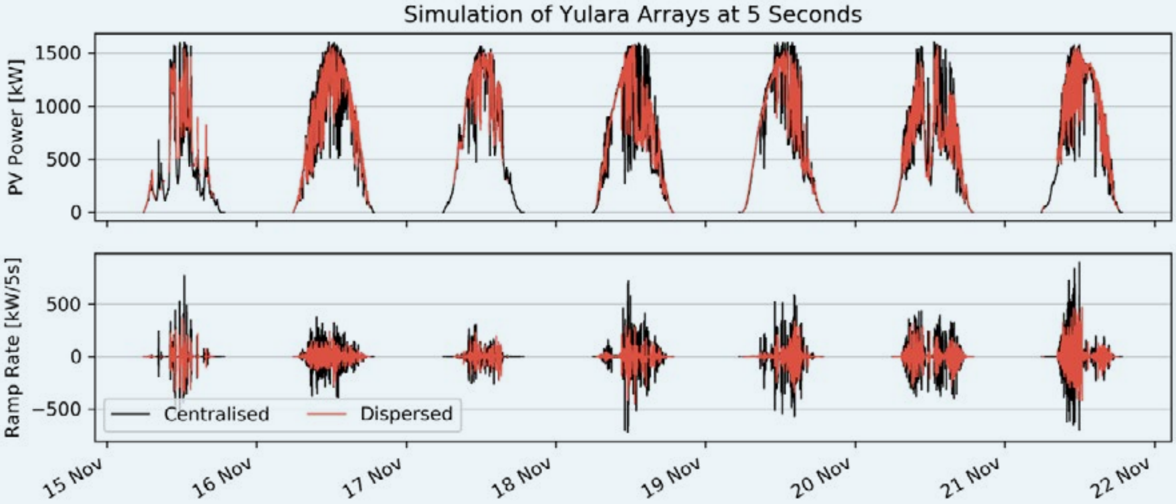

Figure 4: Comparison of the variability in modelled power output of a geographically dispersed system (red) to a centralised system (black) based on the 1.8 MWP Yulara PV plant, simulating data at a 5-second timescale

The histogram in Figure 5 demonstrates this further. In the centralised scenario, fluctuation magnitudes are seen to reach nearly 70% (1,200 kW) of nameplate power while the dispersed scenario sees no greater change than 40% (700 kW). This can be intuitively understood as dispersed arrays will have clouds passing over them at different times, whereas a centralised array will be more strongly affected when clouds appear.

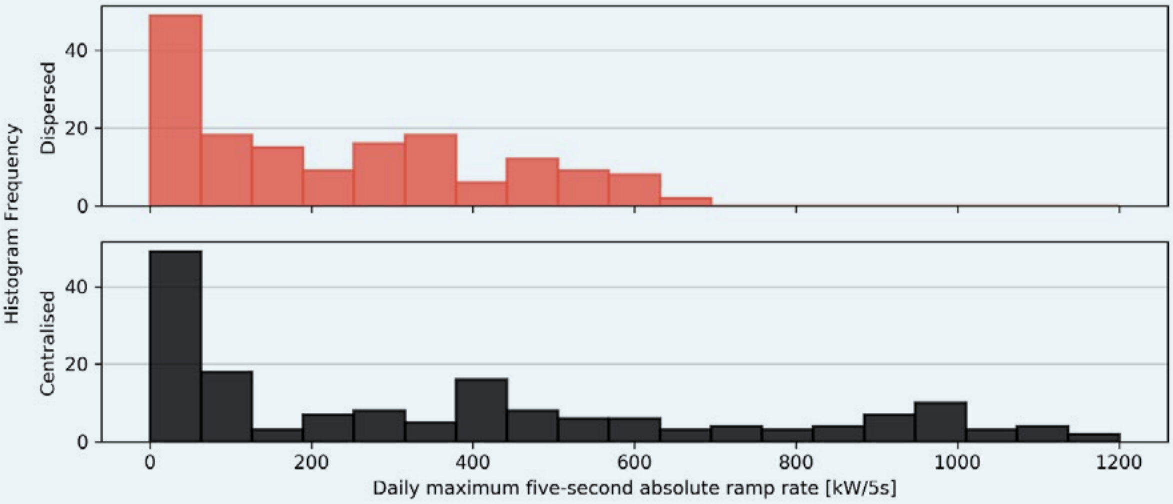

Figure 5: Simulated power variations encountered by dispersed (red) and centralised (black) array layouts. Each histogram bin shows the number of days over a 10-month period in which a particular maximum absolute ramp rate was observed.

The *counterintuitive* aspect is that distributed arrays are more likely to see fluctuations than a centralised system, as there are more places where clouds can affect the arrays. On a system-wide level though, dispersed arrays result in significantly less high-power ramp rate events, which are the most difficult to deal with.

Economic Implications of Dispersion

In the Yulara system's distributed layout, PV generation is roughly co-located with load centres; the five sites are not simply spaced to take advantage of different climate conditions but to deliver an amount of power roughly suitable to the needs of respective areas. Compared to a centralised system – say, for the whole township – this allows electrical distribution losses to be reduced and avoids the need for additional cabling investments.

While potentially reducing costs of distribution infrastructure, a geographically dispersed array is likely to encounter different geographies concomitant to the pursuit of different climate conditions – not to mention encounter a mix of different site-specific conditions among the candidates. This can increase installation costs, as site selection is no longer a matter maximising use of the most ideal location. The chosen sites may also have a range of geographic profiles and locational characteristics, some more difficult to host PV arrays than others, and in that sense, the cost of installation cannot always be optimised when dispersion is the primary intent.

As well as the sites occupying different levels of installation ease and efficiency, the fact that multiple sites are used can, itself, come at a cost. PV systems necessarily include margins and other concessions such as fencing around or within the field of modules for safety, compliance and operation and maintenance access purposes. Splitting a system into multiple sites can increase the physical 'overheads' of each sub-system, reducing the packing efficiency of the array design and occupying a greater total footprint. The added disadvantage is that some scale benefits are lost, as multiple sites need to be scoped, prepared and have equipment mobilised to these.

Similarly, land acquisition costs are less apt to leverage the benefits of scaling when multiple locations are used. Negotiation requirements with site owners may also be compounded in sheer quantity, let alone complexity, if a site is less optimal for locating PV than its alternatives.

Dispersion or Simply Diversity?

A parallel concept to spacing individual arrays widely is to orient them in a variety of ways. This, too, uses the principle of exposing different parts to different conditions at different times, avoiding single climate conditions dictating performance of the entire array. Indeed, studies have shown power output correlation between arrays decreasing when they face various directions [1], which is desirable when net smoothing is sought, but the drawback is that optimal orientation of all arrays together is compromised. Note that smoothing in this case pertains to power output over the day, not from moment to moment; it addresses variation of sun position during a daily trajectory instead of the variability of cloud movements. The latter issue is the one prioritised in this vignette because of its unpredictability and problematic effect on power systems via short, sharp changes. Variation in the sun's position tends not to cause technical issues, and tracking systems, hybrid approaches, load-matching and peak-shifting via storage offer solutions to this predictable natural phenomenon.

Taking advantage of the different climate conditions accessible through multi-siting and multi-direction approaches can also be attained by expanding the area of a single system or designing its shape to span a large distance in one direction, that is, create a widely spaced or long array. However, land may not always accommodate and there is a natural limit on maximum distances achievable by a single array as costs increase (e.g. the need for longer cables), which may or may not be enough to diminish correlation and capitalise on the dispersion advantage.

PROJECT COMPLEXITIES

Examined on its own, the design of Yulara's system to space PV arrays and avoid a coincidence of climate conditions and power fluctuations is validated by performance modelling. However, as with all power plants, project-specific commercial constraints can influence the effectiveness of a theoretically optimised design or design strategy.

In the case of Yulara, an important constraint is the regulated curtailment mandated by the incumbent power station operator, which is applied to the Desert Gardens array and calculated in proportion to the load in real time. This has two implications, one positive and one less so. First and less desirably, the system's output is curtailed resulting in losses from curtailment that consume much of the added benefit of improved yields from the strategic dispersion of the arrays. The spilled PV energy reaches approximately 28% on an annual basis, with up to 800 kW – nearly half the installed PV capacity of the full array – curtailed in the highest instances.

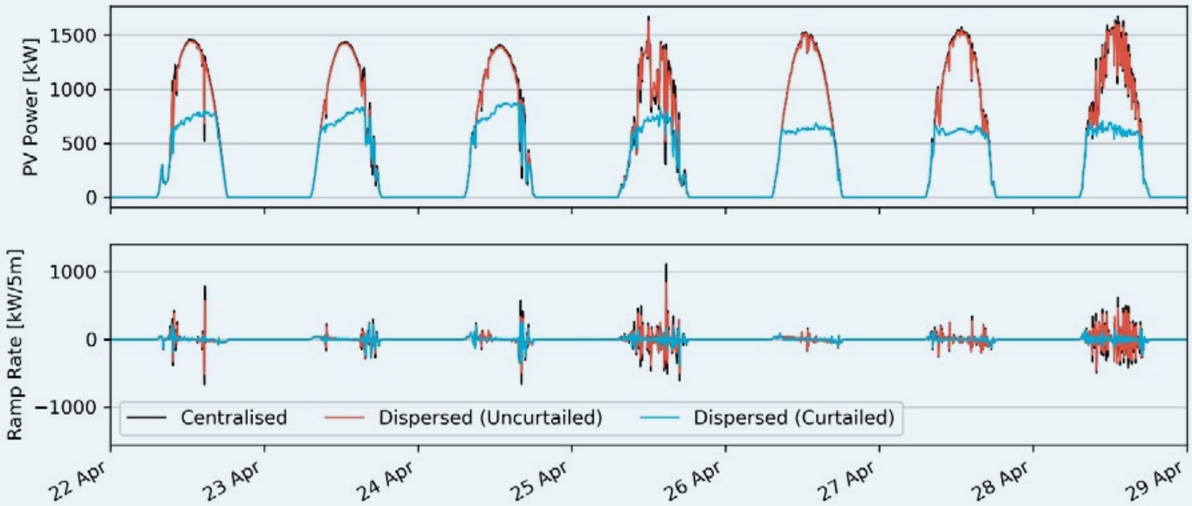

Figure 6: Comparison of the operation of the Yulara array (blue is actual operation: Dispersed with curtailment), compared to uncurtailed dispersed (red) and uncurtailed centralised (black) operation.

Secondly and more desirably, curtailment itself reduces the effect of the variability encountered and, in this sense, complements the effort of the geographically dispersed design to protect the system from high ramp rates. Curtailment offers a benefit in this case, but as a variability-mitigation method it is a crude tool. This is particularly undesirable on clear-sky days, when it means lost energy without the advantage of reducing variability. These effects are visible in Figure 6, where 26 and 27 April were nearly perfect clear-sky days. On the other hand, the benefits of curtailment are particularly pronounced on 25 and 28 April. In all of the days shown, the benefit of a dispersed array is that it reduces the size of the largest step change in power, and speaks to the benefit of the design decision for Yulara. Figure 7 illustrates how the frequency of high-power ramp rates decreases from a centralised array, to Yulara's dispersed array without curtailment, to the actual operation of Yulara's dispersed array with curtailment.

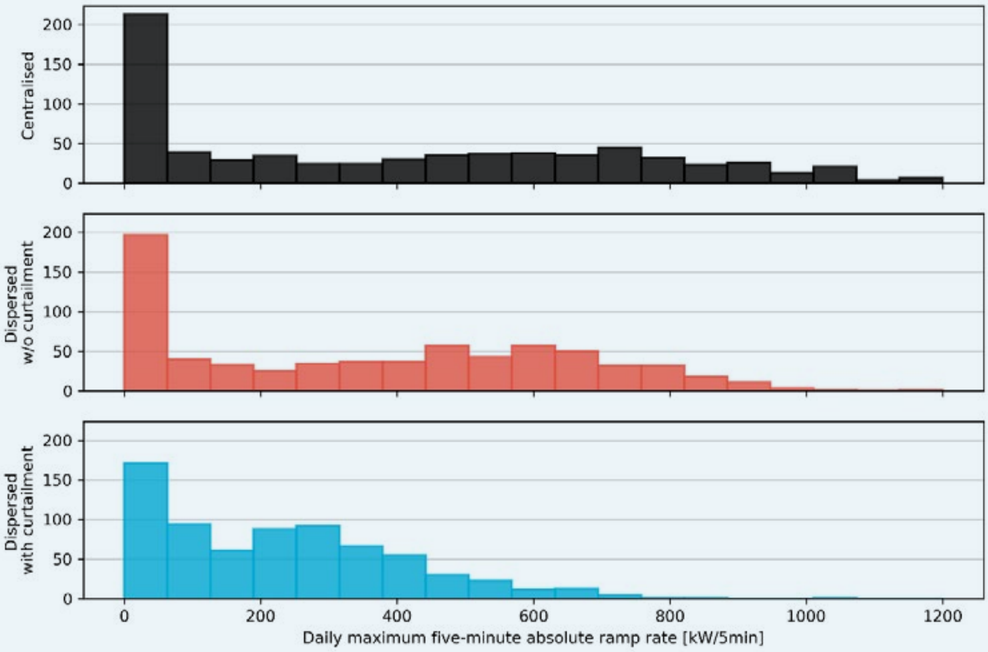

Figure 7: Histogram of the daily maximum 5-minute ramp rates at Yulara's PV power station based on measured and calculated data, observing the impact of dispersion and curtailment.

From an operational standpoint, it is possible to change the curtailment set point using data from a sky camera or other irradiance forecasting source, in which case more PV may be allowed on the network without increasing the ramp rate risk. Other alternatives that come to mind are batteries or flywheels for PV smoothing, although these were cost-prohibitive at the time that the Yulara PV project was being designed and financed. Such enabling technologies do come with a cost, and this cost needs to be weighed against the value of the amount of spilled PV energy that can be used.

CONCLUSION

Variability is an issue that can stem from both load variations and resource fluctuations, affecting not only renewable but also non-renewable power systems. With the potential to damage equipment, reduce power quality, create power supply shortfalls and waste energy, its effects are controlled by all parts of a power system – control infrastructure, generators, storage systems and other enabling technologies – with varying degrees of effectiveness as they step in to provide continuous power to a site, riding through large or high-frequency variable conditions.

Geographically distributing parts of a renewable power plant at Yulara as a strategy to reduce variability in the power system and spare its subjection to unviable ramp rates or extremes of high/low generation has worked, aided by the added curtailment put in place. Adding to the swathe of studies internationally and nationally, the Yulara project in Central Australia is an example of the opportunities enabled by this design approach. Equally, the complexities of its context are acknowledged to sit beside and beyond the advantages of this simple effect.

'Strength in diversity' is the core of effective, resilient power generation. The geographic dispersion method for renewable project planning, while not suggested as a substitute for other approaches to dealing with variability such as storage and fast-responding power electronics, may be invoked alongside those or in cases where they are not economically feasible. Just as its fundamental principle is that of diversity to create a net output more robust and consistently productive than otherwise achievable, so should diverse strategies and technologies be considered when planning power systems – which are, ultimately, at the mercy of human behaviour (as consumers) and the environment, with all the variability and unpredictability that come with each of these.

More information on the Yulara project is available at https://arena.gov.au/projects/yulara-solar-project/ (project details) and http://dkasolarcentre.com.au/locations/yulara (system performance).

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