The Cost of Battery Firming – AEMO's 2030 Plan and Beyond

Is a 100% VRE Grid Design Feasible?

James Taylor (Updated 12 January 2023[1])

Introduction

The Prime Minister and Energy Minister are certain that Australia needs 100% renewables by 2050. In fact the target is 82% by 2030 – close enough to 100%.

System Design Principle

Before we look at the details of how that might be achieved, it is critical to understand a key principle of system design which is:

"A high-reliability system design must be based on worst-case conditions and then incorporate a margin of safety on top to guard against possible degradation in the system capabilities."

This principle is almost entirely absent and ignored in reports produced by AEMO and CSIRO. Instead they tend to use average conditions, completely devoid from the realities of worst case and hope that everything will be OK.

In the real world of professional engineering, whether it is a commercial jetliner, a bridge or a building, lives depend on getting this right. And there are massive penalties for getting it wrong.

The question that must be asked: will more batteries save AEMO's disastrous 2030 Plan?

The basics are that the NEM delivers **power** to customers whereas batteries store **energy**, which is just power x time. In addition, the process of converting electricity to electrochemical energy then converting it back to grid power is 80-90% efficient, meaning up to 20% of input power is wasted as heat.

Grid batteries are characterised by two parameters; stored energy capacity (MWh) and maximum power output (MW) – usually over a 1 - 2 hour minimum discharge period. (Shorter discharges at higher power can damage the battery.) Batteries can supply lower power outputs over longer durations up to the limit of its stored energy.

What are the worst-case conditions? There are five.

1 The NEM must reliably deliver power to customers at maximum demand.

AEMO's ESOO (Aug 2022) states 2030 maximum power in terms of Probability of Exceedance (POE).

> At 41.1 GW, 50% POE means 50% of time it is higher! This is average max demand.
> At 44.8 GW, 10% POE means 36 days/year, it is higher! In this analysis I use 10% POE.

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[1] Updated to reflect discussions and improve worst-case definition

2 Grid demand varies over the day with peaks in early morning and early evening and can fall by up to 25% during night. But…..overnight EV charging – preferred by 95% in a recent survey – will greatly increase night time power demands in the future, as AEMO's ISP notes. Worst-case means max demand all day long.

3 Individual power generators and distribution systems are often unavailable due both to scheduled maintenance and repair. Therefore, a designed-in dispatchable reserve margin is always needed so that available power always exceeds grid demands. This has historically been about 20%, when the NEM was operating reliably to the required 99.998% standard.

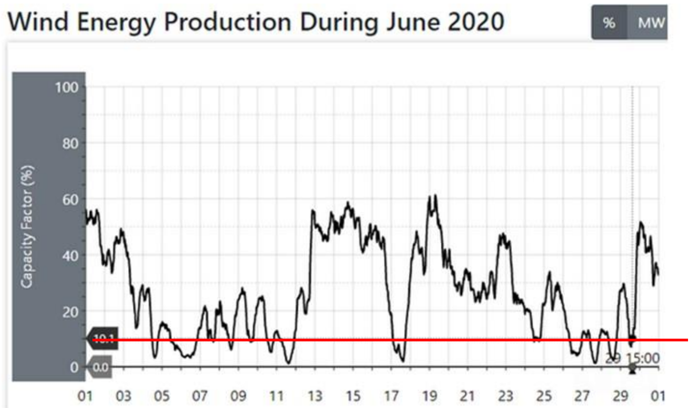

Figure 1 Craig Brooking, Michael Bowden Firming Wind Farms with Batteries December 2022

4 Variable renewable energy (VRE) generators, both wind and solar, produce power outputs averaging 25-30% of its installed power (its capacity factor). This varies during the daily 24 hour cycle, from day to day and also with the seasons. Figure 1, from a recent paper (Firming Wind Farms with Batteries December 2022) by Craig Brooking and Michael Bowden, shows a typical month of wind power across the NEM for June 2020. Clearly, in Dunkelflaute conditions (dark and still), it can frequently be less than 10% for periods of many hours and often multiple days.

5 It should be noted that solar power output is ZERO every day for 16 hours and simultaneously across the entire NEM. In Figure 1, notice how wind capacity factor drops below 10% nine times in the month; three times almost to zero; when this happens during non-daytime (16 hours per day) total VRE falls to ZERO. Recent UK and European experience shows VRE falling well below average for periods lasting weeks and even months. Figure 1 shows that during an eight day period, wind power seldom exceeded 20%. AEMO and CSIRO carefully avoid these facts.

Making the 2030 grid design workable

Battery firming was investigated using the same top-level system design approach as in our Reliability Assessment Report (29 November 2022), which showed 2030 AEMO grid design could not deliver reliable power due to inadequate baseload backup and energy storage.

The whole NEM is treated as a single perfectly integrated system with 100% interconnectivity. After all, the government has embarked on transmission system upgrades costing tens of billions of dollars.

The first step in system design is sizing the total grid with a top-level power budget over a 24 hour cycle using worst-case conditions. I use both zero percent and 6% VRE capacity factors to illustrate both worst-case and a slightly better case when wind and solar are still less than 10%. Keep in mind AEMO's plan for 2030 includes dispatchable power of coal (9.0 GW), gas (12.3 GW) and hydro (7.2 GW) which I assume are running at 90%. I have also allowed for 3% transmission losses.

To estimate costs, two Australian examples of installed battery cost factors are the Hornsdale battery, which costs $0.83 billion/GWh (Ref. Brookings and Bowden) and the ARENA announcement for eight large batteries, which are to cost $0.643/GWh. The lower figure is used to estimate installed battery system costs.

Table 1 AEMO's 2030 Grid Top Level Power Budget – One Day – Worst-Case Conditions

Period	4 hr Peak	12 hr night	8 hr daytime
	GW	GW	GW
Grid Demand			
10% POE Max Demand	44.8	44.8	44.8
With 20% Reserve	53.8	53.8	53.8
Power Sources (allowing for 3% transmission losses)			
Coal, gas & hydro 90%	24.9	24.9	24.9
Snowy 2.0 (7 days)	1.9	1.9	1.9
Wind 0% CF	0.0	0.0	0.0
Solar 0% CF	0.0	0.0	0.0
Total supply	26.8	26.8	26.8
Required Battery Firming Power			
Battery Power	26.9	26.9	26.9
Discharge period	4 hrs	12 hrs	8 hrs
Energy required	107.8 GWh	323.3 GWh	215.5 GWh

Total Battery Capacity and Cost for one day: **646 GWh and $415 Billion**

Table 1 – using AEMO's own data for demand and power sources – shows the 2030 grid design fails under worst-case conditions (when VRE falls to zero) to produce sufficient power at any time during a 24 hour cycle. Yet this condition is entirely plausible at night when wind falls close to zero output across the entire NEM and solar is zero every night.

AEMO's ISP has only 53 GWh of energy storage (in addition to Snowy 2.0). It will claim that geographic diversity will always ensure that some wind power will be available in the grid at all times during nights and interconnectors will deliver it to where it is needed. AEMO has never provided the analysis of wind statistics to prove this assertion.

Nevertheless, if it is assumed that VRE capacity factors are never less than 6% for the 24 hour period, the 2030 grid still fails to meet maximum demand at any time, requires **525 GWh** of storage (ten times the ISP) at an installed cost of **$337 Billion** and still has no recharge capability within the 24 hour period.

To resolve the lack of recharge capability, AEMO has two options:

1. Wait until Dunkelflaute conditions disappear and VRE outputs rise to a level during daytime, sufficient to fully recharge the battery and Snowy 2 storages in one day.
2. Add more VRE power capacity to recharge the one day batteries within the next day assuming VRE capacity factors are near average.

Option 1 using the ISP VRE design and a one-day 646.5 GWh battery, requires 6.4 days at 101 GW per day to subsequently recharge the batteries during 8 daytime hours when wind and solar are both at 25% capacity factor. But what happens during the next 16 hr non-daytime period even if wind outputs remain at 25%? The batteries are required to supply 434 GWh the second night but have only recharged to 101 GWh. If the wind falls off again, the situation is even worse. Hence, once again AEMO's 2030 grid design fails. Significantly more VRE is needed.

Option 2 would add enough extra VRE so that a one day recharge would be feasible during the next daytime period. Using 25% capacity factors for wind and solar during the next daytime period following 24 hours of Dunkelflaute, when VRE is zero (worst-case conditions), it requires tripling the installed VRE to accomplish an 8 hour battery recharge (including Snowy 2.0).

Cost estimates for wind and solar power generators are taken from the CSIRO GenCost2022 report. Solar is $1046/kW and wind is the average between land and offshore wind turbine costs at $3112.5/kW. The ratio between wind and solar is kept at 0.72 as for the ISP in 2030. With these cost factors the additional VRE cost is $670 Billion. When added to the one-day battery cost of $415 Billion, it will require $1.08 trillion to make the ISP work for 2030.

Keep in mind that this option depends on wind and solar returning to no less than 25% capacity factors after a 24 hour Dunkelflaute. And the area of land required for solar and wind farms increases from 10 million hectares to about 30 million hectares – more than the entire area of Victoria! And also keep in mind that the batteries require replacement after just 10 years while the lifetime of VRE facilities is 20-25 years.

Given these estimates, system design considerations may wish to have larger batteries which can extend capacity to multiple days. A 7 day battery capacity would drive total additional costs to $3.6 trillion.

Conclusions

1. The viability of the AEMO ISP for 2030 grid design is once again called into question. Expanding the battery capacity by thirteen times is required to handle worst-case demand over a 24 hour period. But there is insufficient power to recharge the batteries in one day if wind and solar immediately return to 25% capacity factors the

following day. Hence the AEMO ISP is non-viable by just adding additional battery capacity.

2. Adding more wind and solar renewables to the 2030 grid design is necessary to provide additional recharging capacity after a 24 hour Dunkelflaute episode. To achieve this in one day would require tripling the VRE in the grid assuming 25% capacity factors and cost $1.1 trillion.
3. Given that Dunkelflaute conditions can last for multiple days, adding additional battery capacity up to 7 days would cost a total of $3.6 Trillion.

The costs required to make the AEMO ISP design for the NEM viable are clearly unaffordable and would elevate costs to consumers and the nation to completely unacceptable limits.

Thus the entire AEMO approach is an exercise in magical thinking, to use a phrase from Mark Mills from the Manhattan Institute. An alternative way using reliable baseload power generation is absolutely necessary.

Note: This study only looks at incremental capital costs. No estimates have been made for maintenance and repairs, financing, management and waste disposal for vast quantities of VRE materials for which recycling technologies are not yet available at affordable costs.