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Solar Hybrid Case Study & Optimisation

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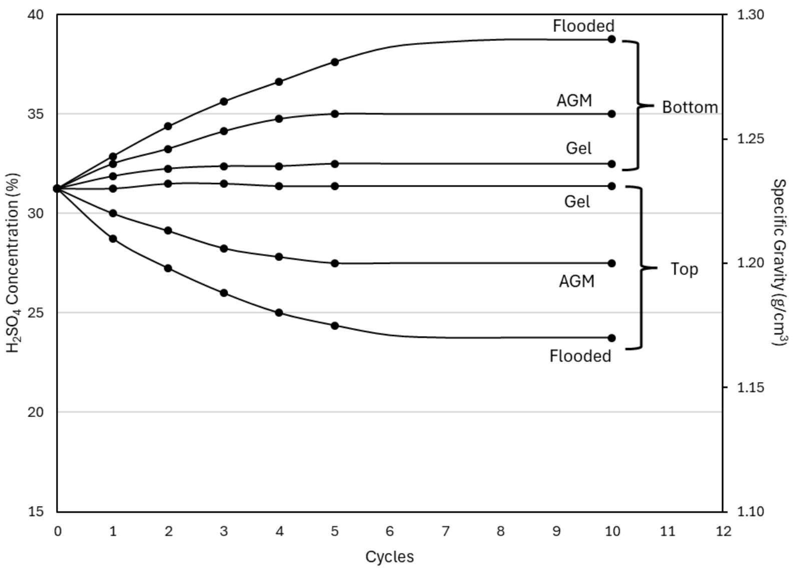
Battery Energy Introduction

- Battery Energy has been manufacturing gel lead acid batteries for ~30 years in Australia.
- We have a strong foothold in the domestic telecommunications and energy storage sectors.
- In 2017, we expanded to include system integration (8 years).
- Solar hybrid sites include batteries, power conversion, photovoltaics, generators and site controllers.

Battery Energy Gelled VRLA – 2SG1400

- The cell used in these solar hybrid sites is a 2SG1400.
- This gel cell uses flat plates formed in-jar.
- This is a large cell (680 mm long and 71 kg)
- Rated at 888 Ah at the 10 hr rate to 1.8 Vpc at 25°C.
- Thick positive grids (5.3 mm), and a high electrolyte volume 15 mL/Ah_{C10} enable high voltage equalisation for deep cycle applications (2.5 Vpc).
- The gel chemistry abates acid stratification for uniform plate utilisation.



Hans Tuphorn – Sonnenschein

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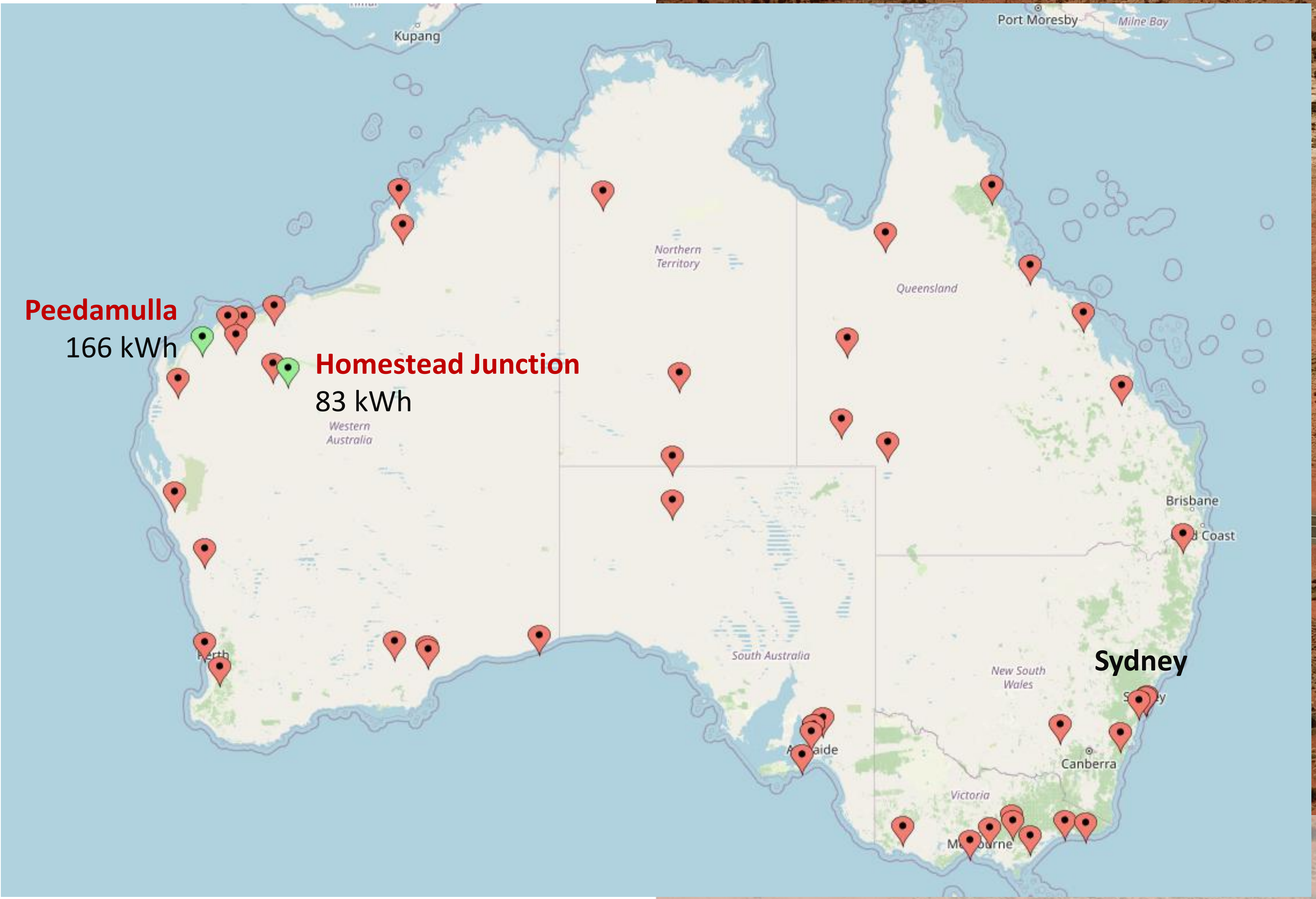
Site Locations

Solar Hybrid sites in connection with this project



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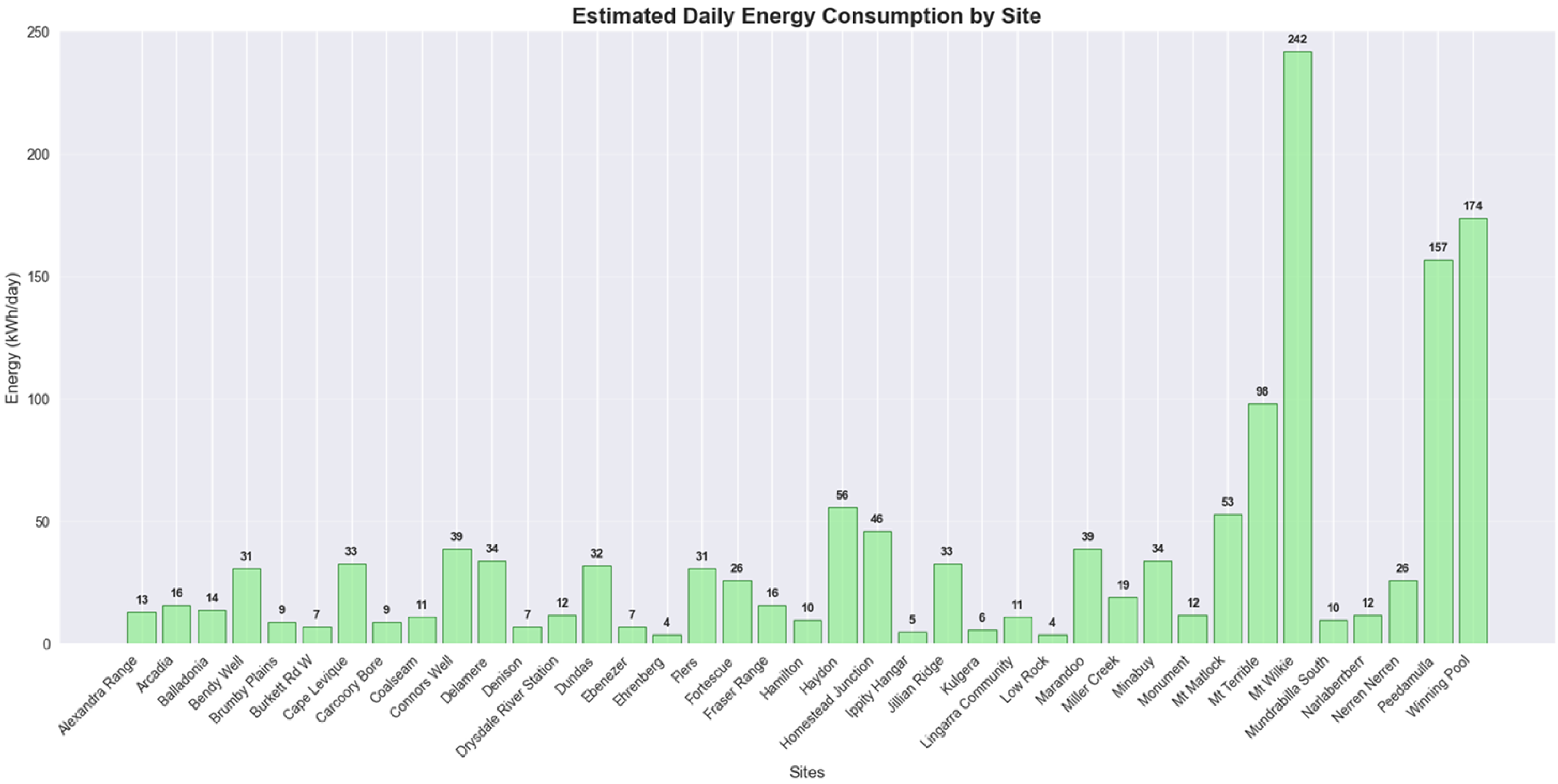
Site Energy Usage



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Site Topologies

Peedamulla

- 4 × strings of 2SG1400 cells.
- Storage (166 kWh_{C10}).
- Photovoltaics (14 kW).
- Generators (56 kW).

Homestead Junction

- 2 × strings of 2SG1400 cells.
- Storage (83 kWh_{C10}).
- Photovoltaics (12 kW).
- Generators (10 kW).

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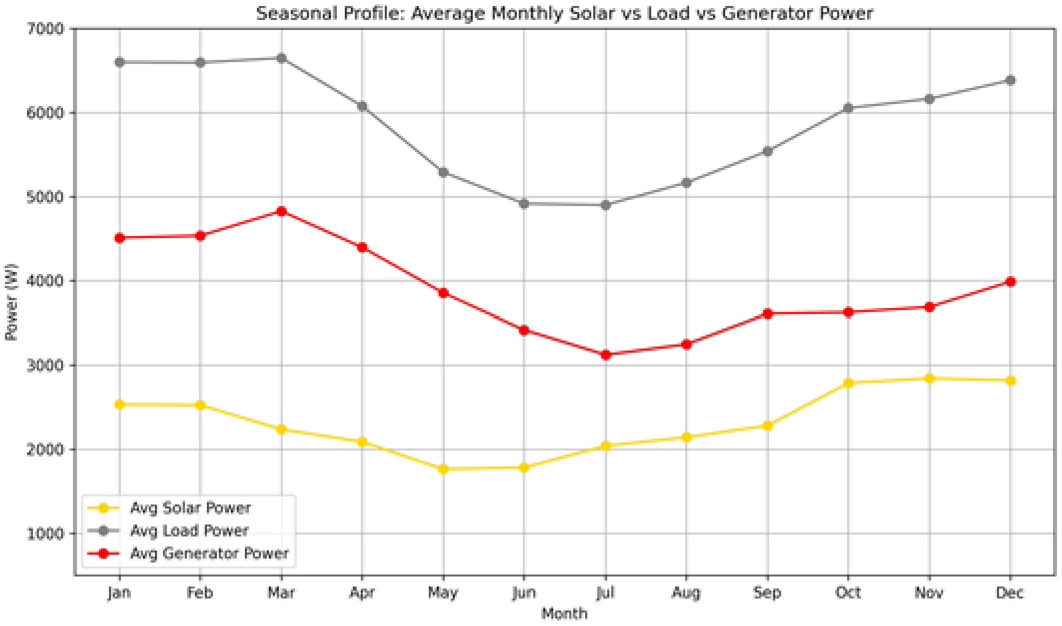
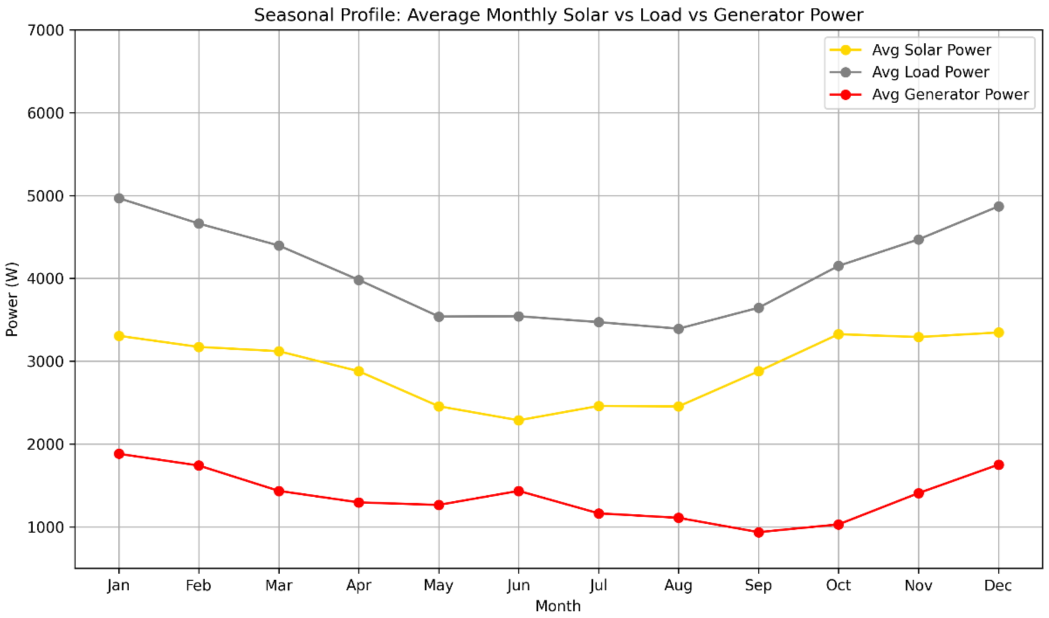
Site Comparison

Peedamulla



Homestead Junction



- Loads are higher during summer due to air conditioning (Dec-Feb).
- Peedamulla has a higher loads than Homestead Junction.
- Solar power was comparable between the sites.
- Peedamulla showed heavy generator usage.

State-of-Health

- How to estimate Battery state-of-health (SoH)?
- SoH is calculated as capacity/rated capacity.
- To perform a capacity test, a full charge and discharge is required.
- Both sites operate over ad hoc profiles (no full charge and discharge).
- Therefore, partial discharges were used to estimate battery capacity and SoH.
- The available data included bank current, bus voltage and battery temperature.

	Peedamulla			Homesteaed Junction		
Parameter	Maximum	Minimum	Mean	Maximum	Minimum	Mean
Voltage/ Vpc	2.06 - 2.14	1.97 - 2.04	-	2.06 - 2.15	1.94 - 2.05	-
String Current/ A	43	21	33	31	11	18
Temperature/ °C	35	16	25	32	23	29
Depth-of-Discharge/ %	74%	30%	49%	86%	31%	47%

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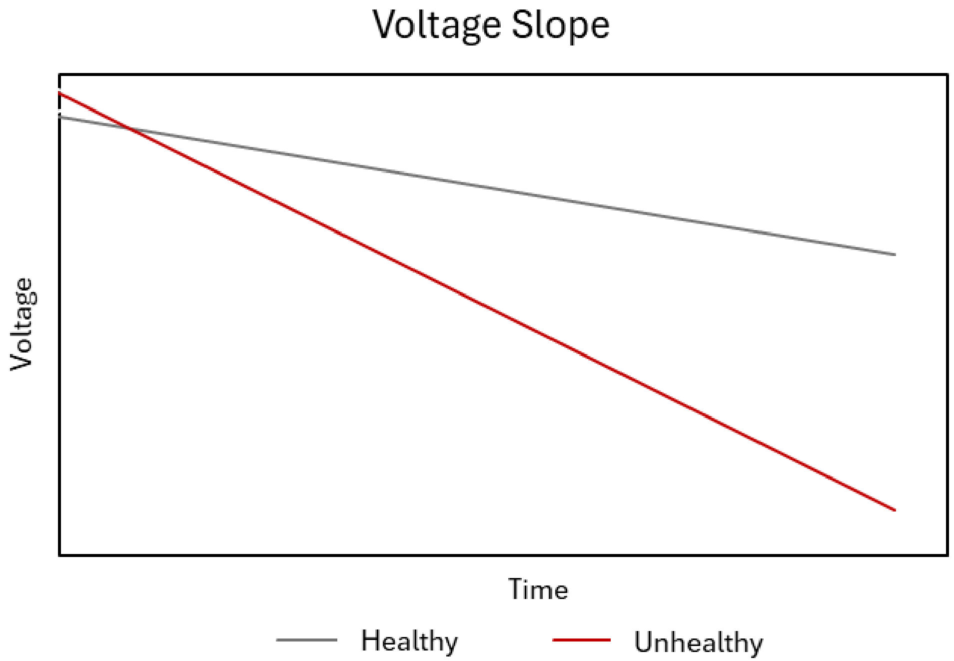
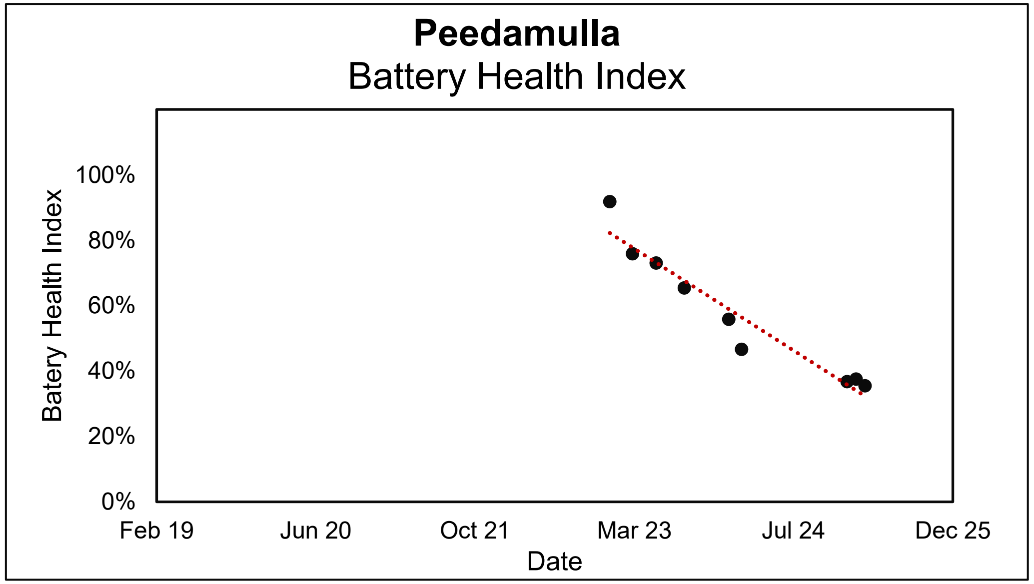
Voltage Slope

- A line was fitted to discharge data (voltage vs time).
- The slope of the line was calculated.
- A gentle slope indicates a healthy battery.
- The reciprocal of the slope was then calculated (1/slope).
- A high reciprocal indicates a healthy battery.
- Discharge events over several years were compared.
- The data was then normalised (the highest reciprocal was set as 100%).
- A Battery Health Index was then generated.

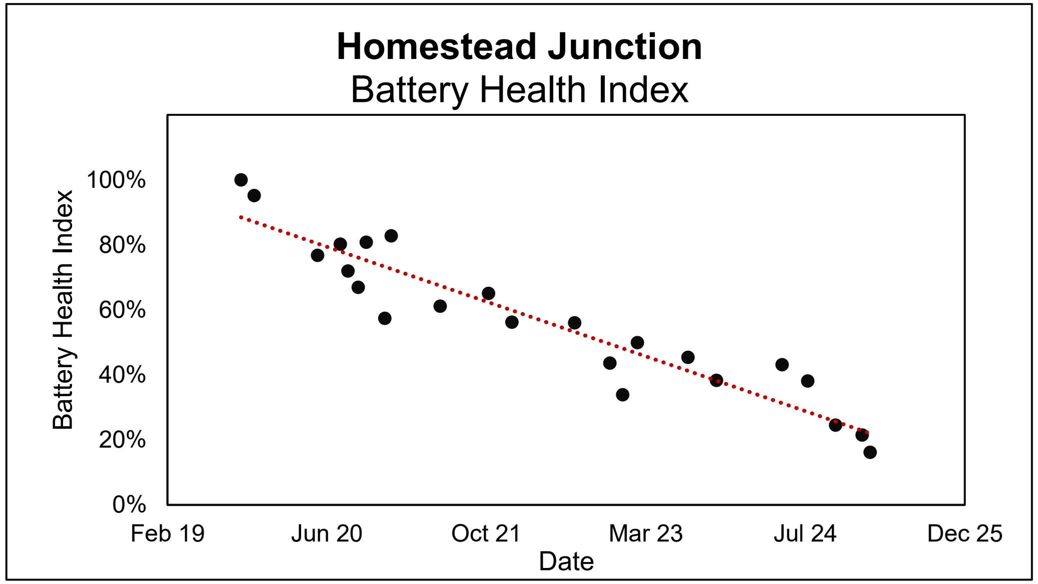


Battery Health Index (Voltage Slope)

- Battery Health Index decreases over time for both sites, as expected.
- Peedamulla demonstrated more facile aging compared to Homestead Junction.



22% decline per year



12% decline per year

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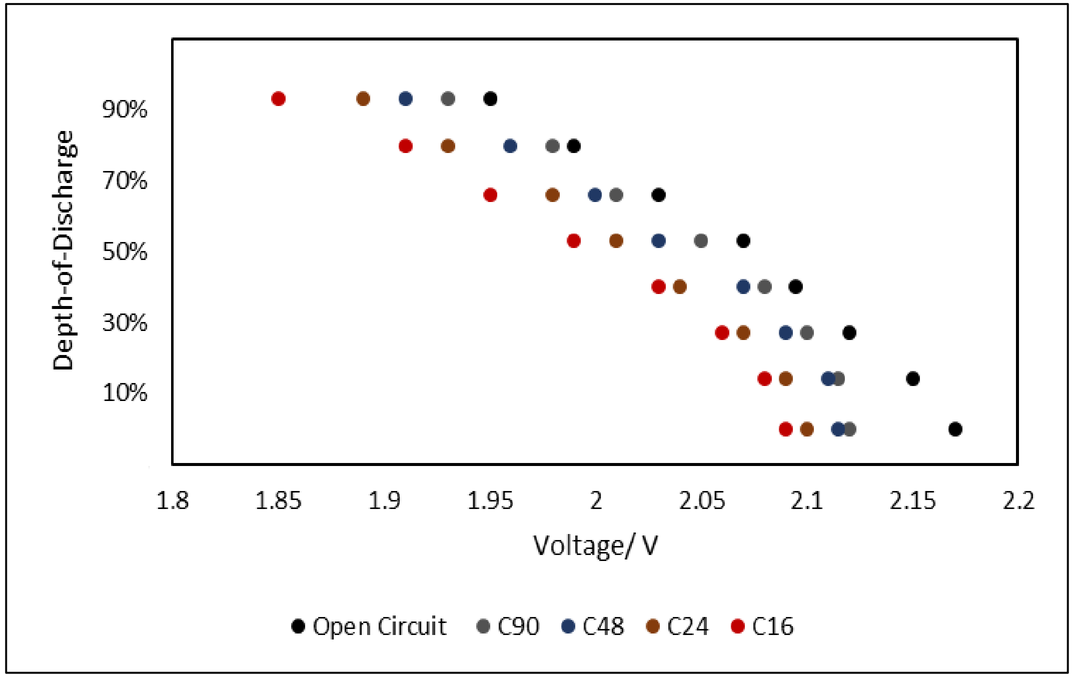
Ampere-hour Counting

- The same discharge events were analysed using ampere-hour counting to estimate Battery Health Index.
- Discharge ampere-hours were calculated ($Q = \int_{t_f}^{t_i} idt$).
- Discharge ampere-hours were then divided by depth-of-discharge (DoD).
- This was done to compare partial discharges to an equivalent full discharge.
- The DoD was estimated from the end-of-discharge voltage (EoDV) under load.
- Temperature compensation was applied from the battery standards (IEC 60896-2 Section 5.1.8).
- Corrected capacity = capacity/1+0.006×(test temperature-25°C).



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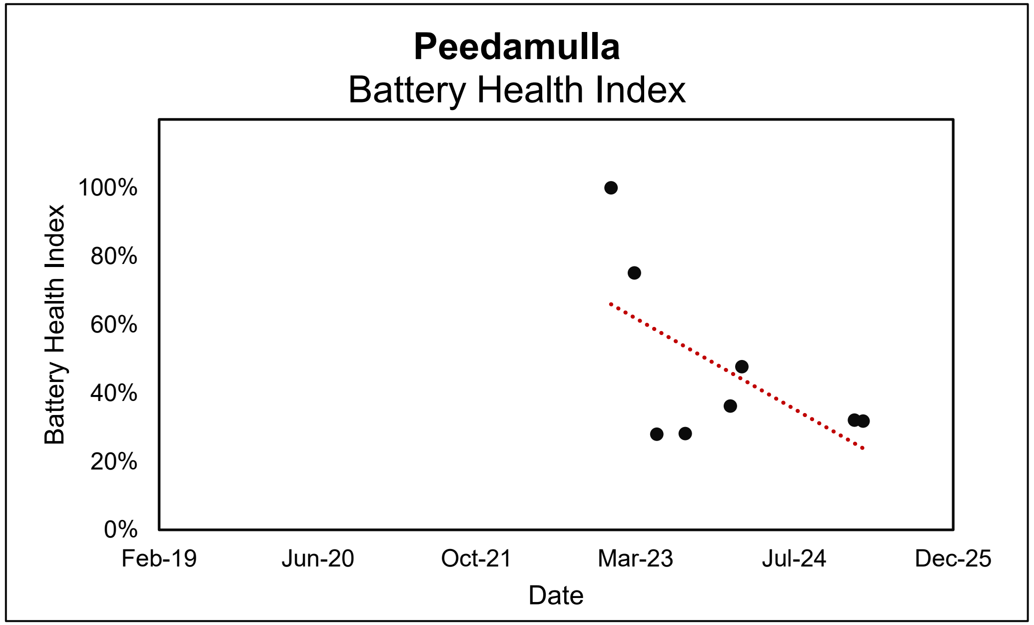

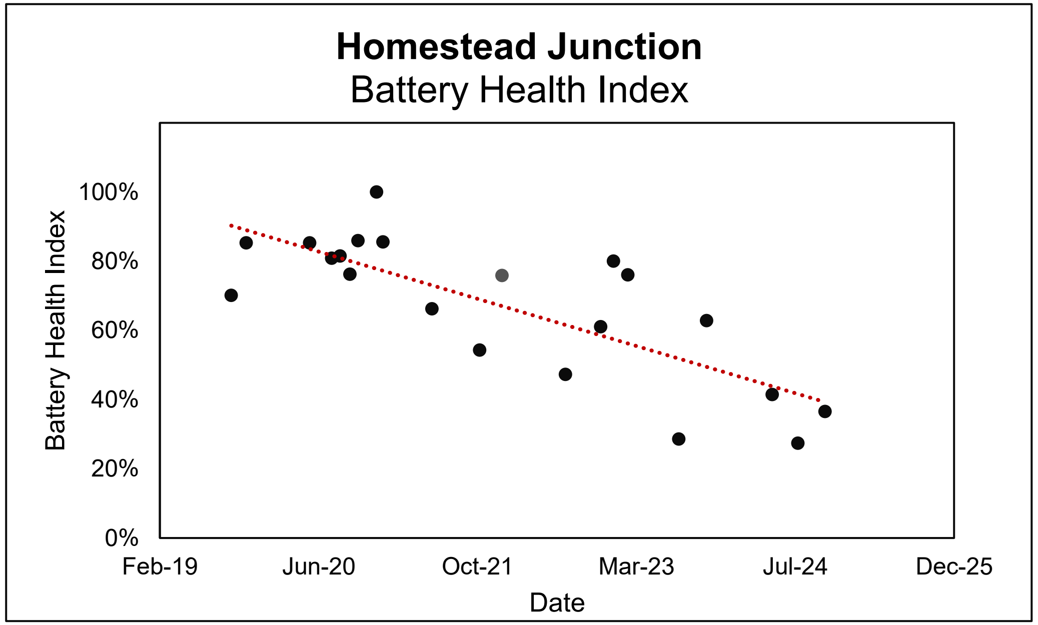

19% decline per year

10% decline per year

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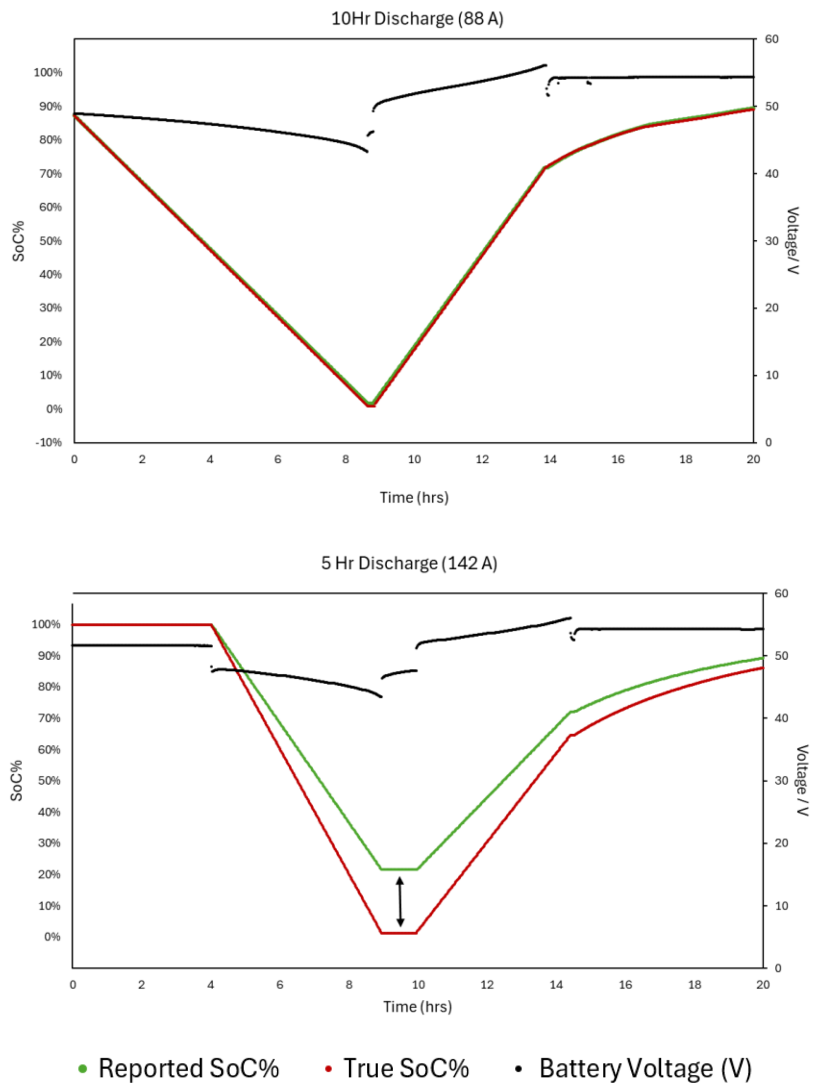
Battery Analysis

- Two methods and two sites were compared.
- Both methods show that Battery Health Index decreases over time.
- The voltage slope method is simple to calculate and does not require rated battery capacity or number of strings.
- Ampere-hour counting is closer to the true method of SoH verification (capacity/rated capacity).
- Homestead Junction performed better than Peedamulla.
- Generators were heavily relied upon to support higher loads at Peedamulla.
- State-of-charge informed the generator start signal.

Site	Voltage Slope (%/Yr)	Amphour Counting (%/Yr)
Peedamulla	22%	19%
Homestead Junction	12%	10%

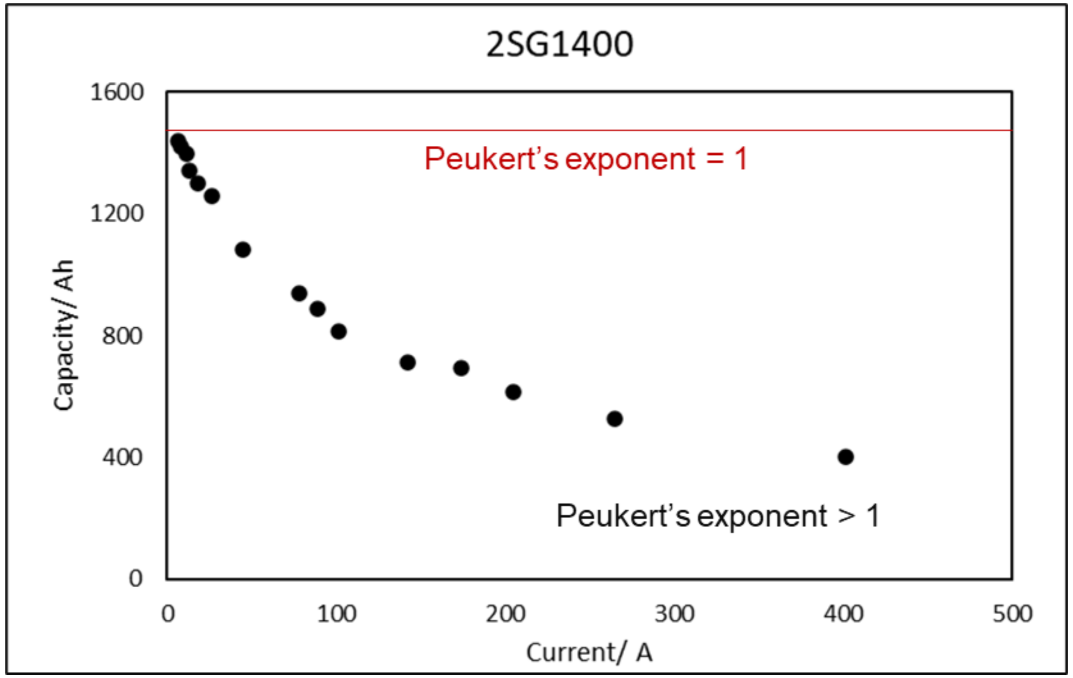
SoC Verification Test

- Laboratory discharge tests were performed on a string (24 cells) at both the 10 hr and 5 hr rate to verify how the controller estimates battery capacity at different discharge currents
- The controller estimated correctly at the 10 hr rate (888 Ah).
- However, at the 5 hr rate (712 Ah), the controller estimated the incorrect capacity (888 Ah).
- The controller estimates the 10 hr capacity irrespective of discharge current.
- The controller also estimates the 10 hr capacity on charge (888 Ah charging from 0-100% SoC).



Peukert's Exponent

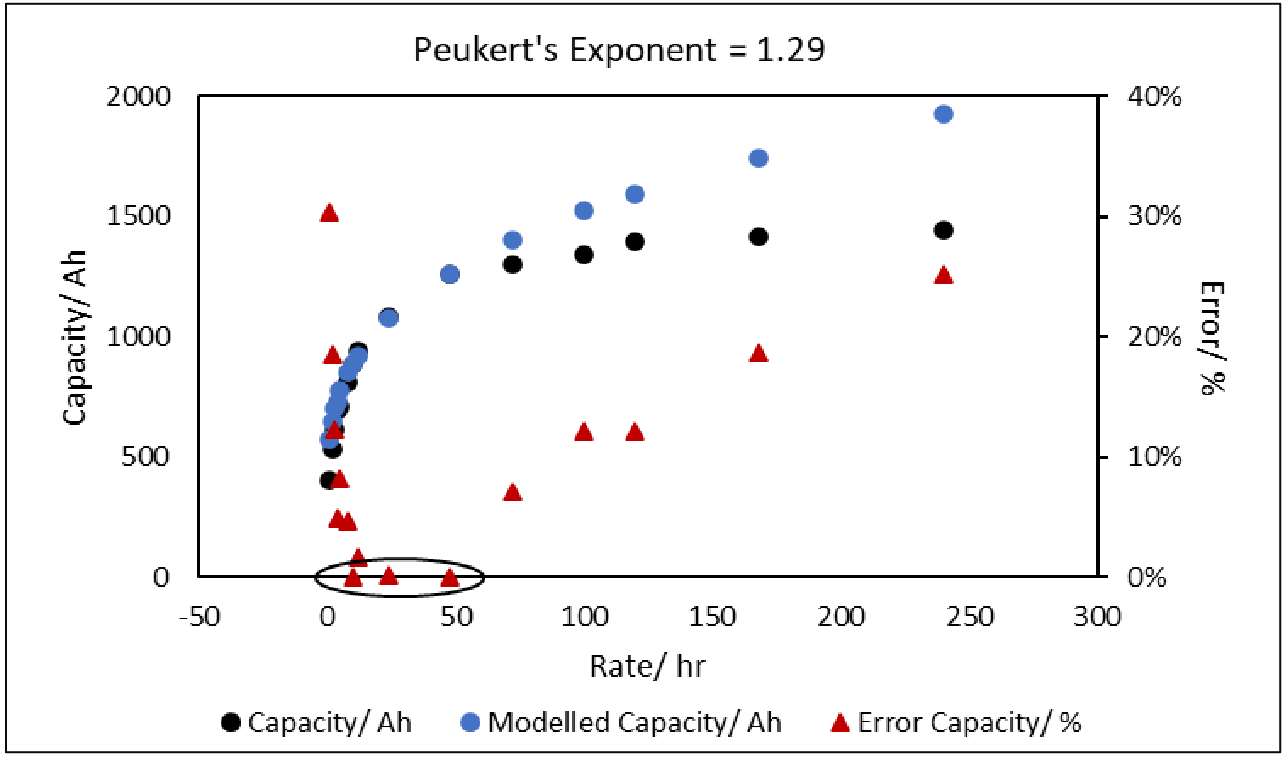
- Battery capacity is affected by discharge current.
- For ad hoc profiles, an accurate SoC algorithm must be able to adjust based upon discharge current.
- Peukert's exponent can be used to calculate battery capacity over a range of discharge currents.
- Peukert's exponent is also used as an indication of how much battery capacity is reduced for long duration discharge.
- For example, Peukert's exponent of unity (1) shows that there is no decrease in battery capacity over long duration discharge.



- $\eta = \frac{log_{10}t_2 - log_{10}t_1}{log_{10}I_1 - log_{10}I_2}$
- $C_m = C/\left(\frac{I}{\frac{C}{R}}\right)^n \times \left(\frac{R}{C}\right) \times I$
- η = Peukert's Exponent
- C_m = Modelled Capacity
- I = Discharge Current
- C = Battery Capacity
- R = C Rate
- t = Time

SoC Optimisation

- Typical discharge currents onsite are ~30 A (40 hr rate).
- Could we improve the SoC estimation by using a Peukert's exponent calculated from rate data that matches the way the batteries are used (10 hr & 48 hr rate)?
- The revised calculation showed a significant improvement.

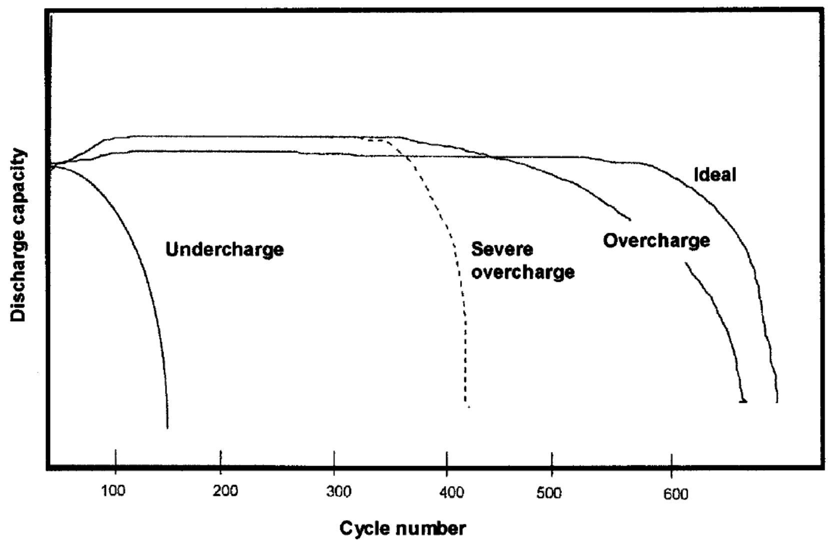


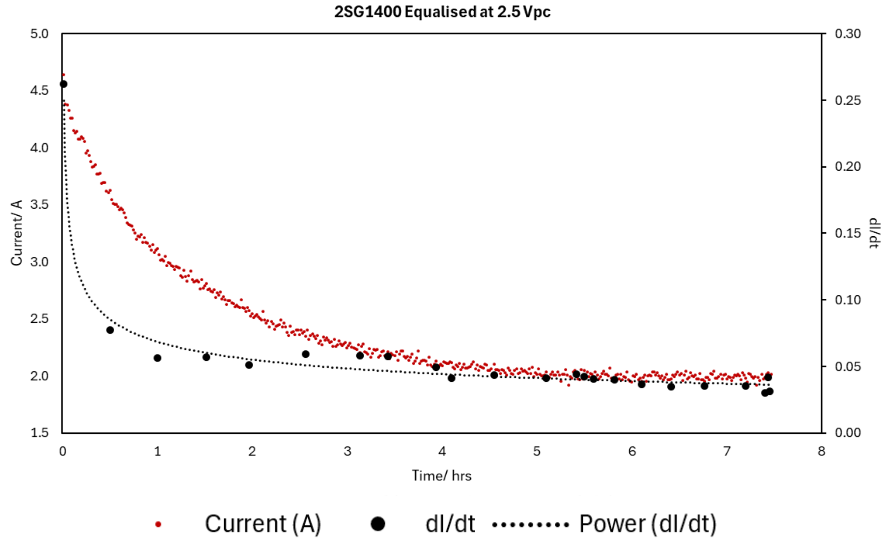
2SGU1400 30 A Discharge (1212 Ah)			
Model	Peukert's Exponent	Estimated Capacity/ Ah	Error
Fixed 10 hr Capacity	NA	888	27%
Peukert's Exponent 5 hr & 10 hr rates	1.47	1475	18%
Peukert's Exponent 10 hr & 48 hr rates	1.29	1213	0%

Equalisation

- For batteries that are discharged in operation, equalisation is essential to maintain battery performance and longevity.
- The literature shows that undercharging is concomitant with premature capacity fade (Nelson 2004).
- In deep cycle applications (≥50% DoD) our batteries perform best when equalised at 2.5 Vpc with temperature compensation (+7 mV/°C below 25°C and -4 mV/°C above 25°C).
- Thick positive grids (5.3 mm), and a high electrolyte volume 15 mL/Ah_{C10} enable high voltage equalisation 2.5 Vpc.
- Finishing current can be used to reset SoC to 100% (voltage ≥ 2.5 Vpc & current ≤2.5 A or dI/dt ≤0.05 A/min).

Nelson 2004





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Conclusion

Conclusions

- Trends in site metrics were analysed (load, solar, generator).
- Methods were developed to track battery aging from ad hoc data (bank current, bus voltage and battery temperature).
- High generator reliance was found to be concomitant with poor performance.

Future Work

- Battery Health Index to be compared to true SoH by performing capacity tests (full change and full discharge).
- Improve SoC estimation by using a Peukert's exponent calculated from rate data that matches the usage profile.
- Equalise batteries correctly and use this as a trigger to reset SoC to 100%.

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