CLIPPING AND CURTAILMENT: IMPACT ON MODULE TEMPERATURE AND DEGRADATION

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Introduction

- We investigated the impact of clipping and curtailment on module temperature and subsequent degradation, focusing on various operating points and mounting systems.
- A higher DC/AC ratio (≧1.3) of PV systems has been used to reduce the levelised cost of electricity (LCOE)
- The oversupply of electricity is also a rising issue, which is often controlled through curtailment. This is expected and economically efficient
- Clipping and curtailment reduces electrical power out, $\eta \downarrow$ therefore $T_{module} \uparrow$, temperature increases exceeding 5 degrees during peak summer hours.
- This increase is typically viewed as unimportant, given that the plant output is already limited. But what about module degradation?
- Increased temperature leads to accelerated module degradation, which includes thermal, UV, and light-induced degradation (LID).
- Comparative analysis reveals that single-axis tracking (SAT) systems may experience elevated temperatures compared to east-west mounting systems like MAVERICK from 5B (MAV)

Thermal Modelling

- Simulations were performed for Armidale (part of a renewable energy zone in NSW, Australia) and Bannerton Solar Farm (Victoria, Australia)
- Simulations were performed for SAT's and MAV's (10° tilt E-W system)
- We used a modified Faiman model, accounting for radiative transfer with the sky and transient effects[1,2]. As such the power into the module at any point in time is given by:

$$Q_{in} = POA \cdot \alpha(1 - \eta) + F \cdot \varepsilon \cdot q_{dr}$$

Of most interest to this work is the efficiency, η, representing the fraction of incident irradiance that is converted to electrical power

The results in Figure 1 below demonstrate the impact clipping and curtailment on the Armidale site, with increases up to 6°C due to full curtailment and 1-2°C due to clipping.

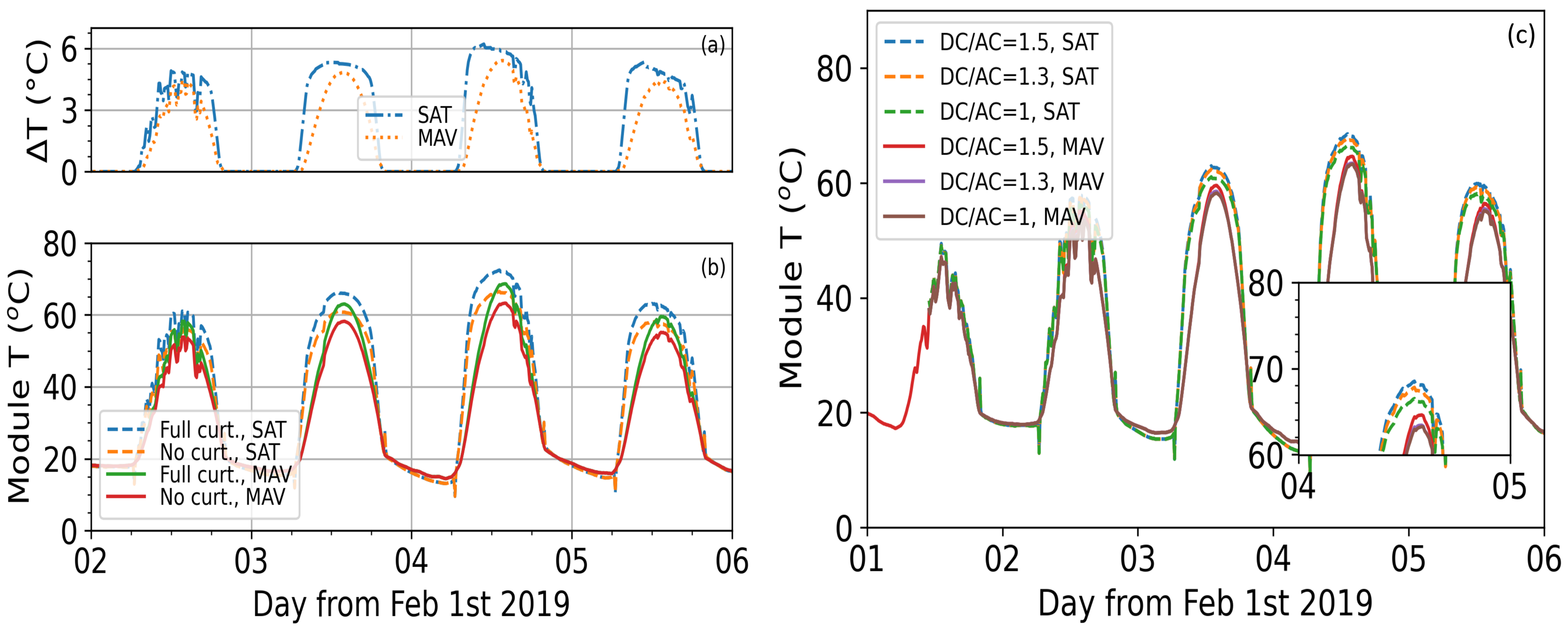


Figure 1: Simulated cell temperatures for SAT and MAV systems in Armidale, NSW, for different DC:AC ratios and under full curtailment.

Thermal Degradation

- Thermal degradation at each timestep was calculated assuming an activation energy E_A of 1 eV:

$$R_{deg} = Ae^{\frac{E_A}{kT}}$$

- The cumulative sum over the year is presented in Figure 2. As expected, the simulated degradation was fastest during the summer months.
- SAT systems were simulated to have higher degradation generally, as well as a greater increase due to clipping/curtailment.
- The extent of the difference was heavily dependent on activation energy

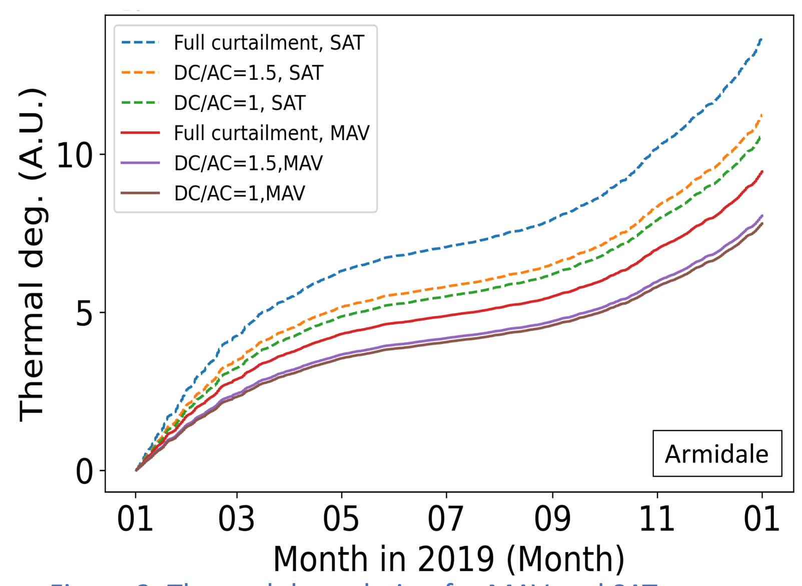


Figure 2: Thermal degradation for MAV and SAT systems over a year for different operating conditions

UV Degradation

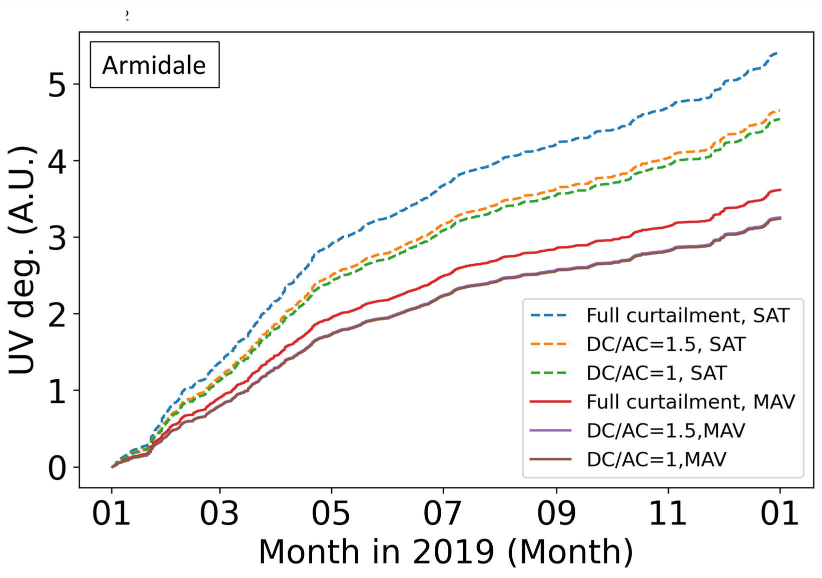


Figure 3: UV degradation for MAV and SAT systems over a year under different operating conditions

- UVA and UVB radiation was calculated from irradiance and sun position using the model of Wald *et al.* [3].
- The UV diffuse faction was then derived using the modified Erbs method[4,5].
- Finally, the UV transposition factor was determined for the module tilt at each timestep.
- UV degradation was then given by:

$$R_{deg} = A \cdot UV_{POA}^{0.63} \cdot \left(1 - RH_{eff}^{1.8}\right) \cdot e^{\frac{-0.45}{kT}}$$

Where UV_{POA} is the UV power in the plane of array and RH_{eff} is the relative humidity on the module surface
- Due to the low activation energy there was a lower increase in degradation due to curtailment

Carrier Induced Degradation

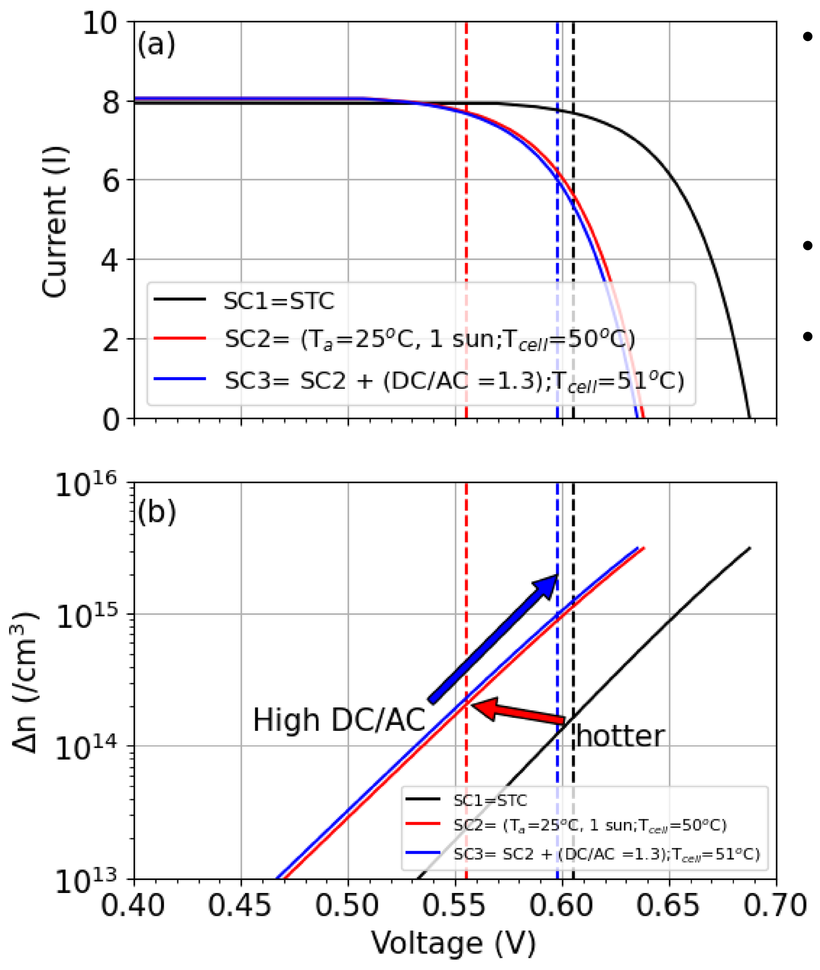
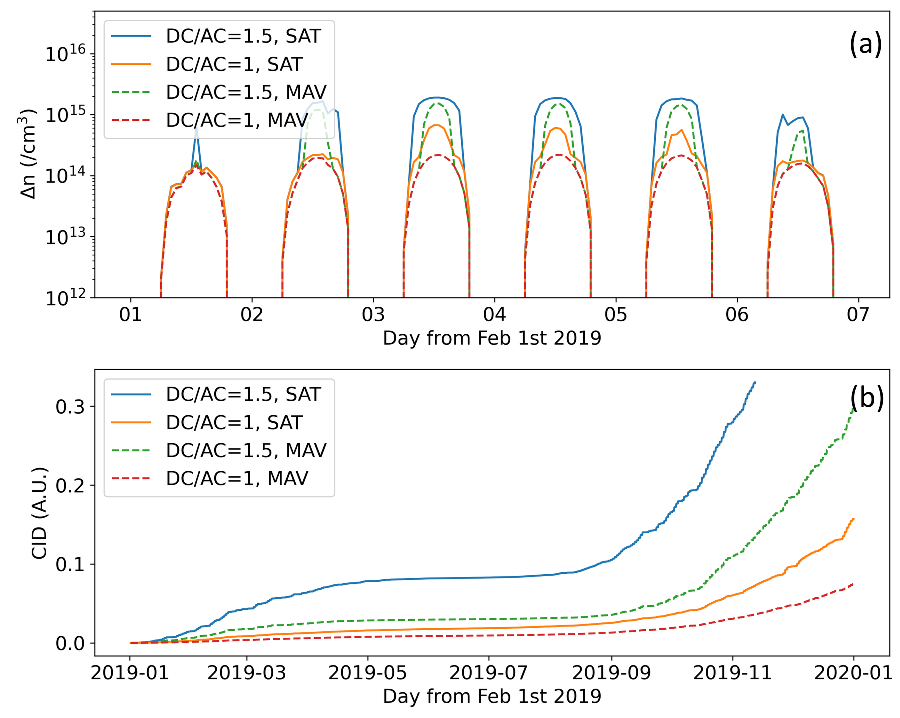


Figure 4: (a) Simulated I-V curves and operating points for modules under different temperatures and DC:AC ratios (b) Resulting excess carrier densities as a function of voltage

- Carrier-induced degradation (CID) depends on both temperature and the excess carrier density (Δn) in the cells:

$$R_{deg} = A \cdot \Delta n \cdot e^{\frac{-E_A}{kT}}$$

- The output limit due to C&C is typically achieved by increasing the voltage above MPP.
- As shown in Figure 4 higher voltage results in an increase in Δn, hence more CID.



- The resulting difference in degradation is much more pronounced as shown in Figure 5.

Figure 5: (a) Simulated excess carrier densities for MAV and SAT systems as a result of different DC:AC ratios. (b) Simulated Carrier induced degradation for MAV and SAT systems

Bannerton Example

- Figure 6 presents results for the Bannerton solar farm, based on dispatch and curtailment data from 2023
- We do not have direct access to the site data so simulations were performed using SolarGIS weather data and a generic SAT system with a DC:AC ratio of 1.3.
- Plots present simulation results where the temperature is either 1) calculated assuming there is no clipping, 2) with clipping due to DC:AC ratio and where the 3) curtailed output is used.
- At this site the curtailment is simulated to increase thermal degradation by 20%

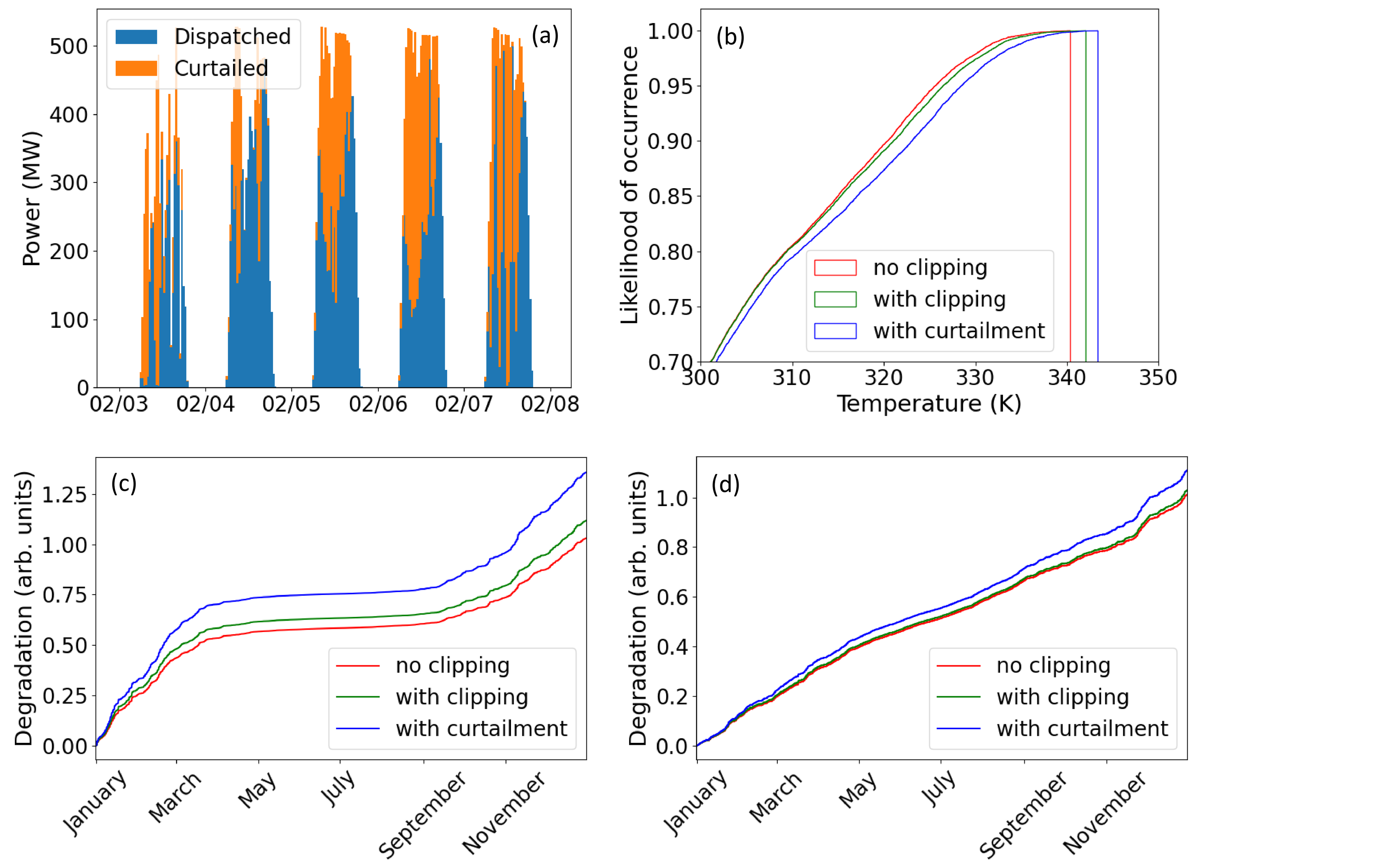


Figure 5: A) Dispatched and curtailed power from Bannerton Solar Farm, B) Simulated cumulative distribution function for cell temperature over 2023 as a result of clipping and curtailment, C) Simulated thermal degradation, D) Simulated UV degradation

Conclusions

This work investigates the impact of clipping and curtailment on module lifetime.
- We simulate that full curtailment can increase the peak operating temperature by over 5 degrees. Higher DC/AC ratios also leads to higher peak operating temperatures.
- Comparing different mounting systems, simulations show SAT systems are more susceptible than MAV to excess degradation.
- While a higher DC/AC ratio promises lower LCOE due to the reduced capital cost of the inverter, the additional degradation due to clipping should be incorporated into system and financial simulations.

Acknowledgements

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ARENA
Australian Government
Australian Renewable Energy Agency

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