DC-side storage for Grid Connected PV Systems

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School of Electrical Engineering and Robotics

1st September 2023

QUT the university for the real world

ACKNOWLEDGEMENT OF TRADITIONAL OWNERS

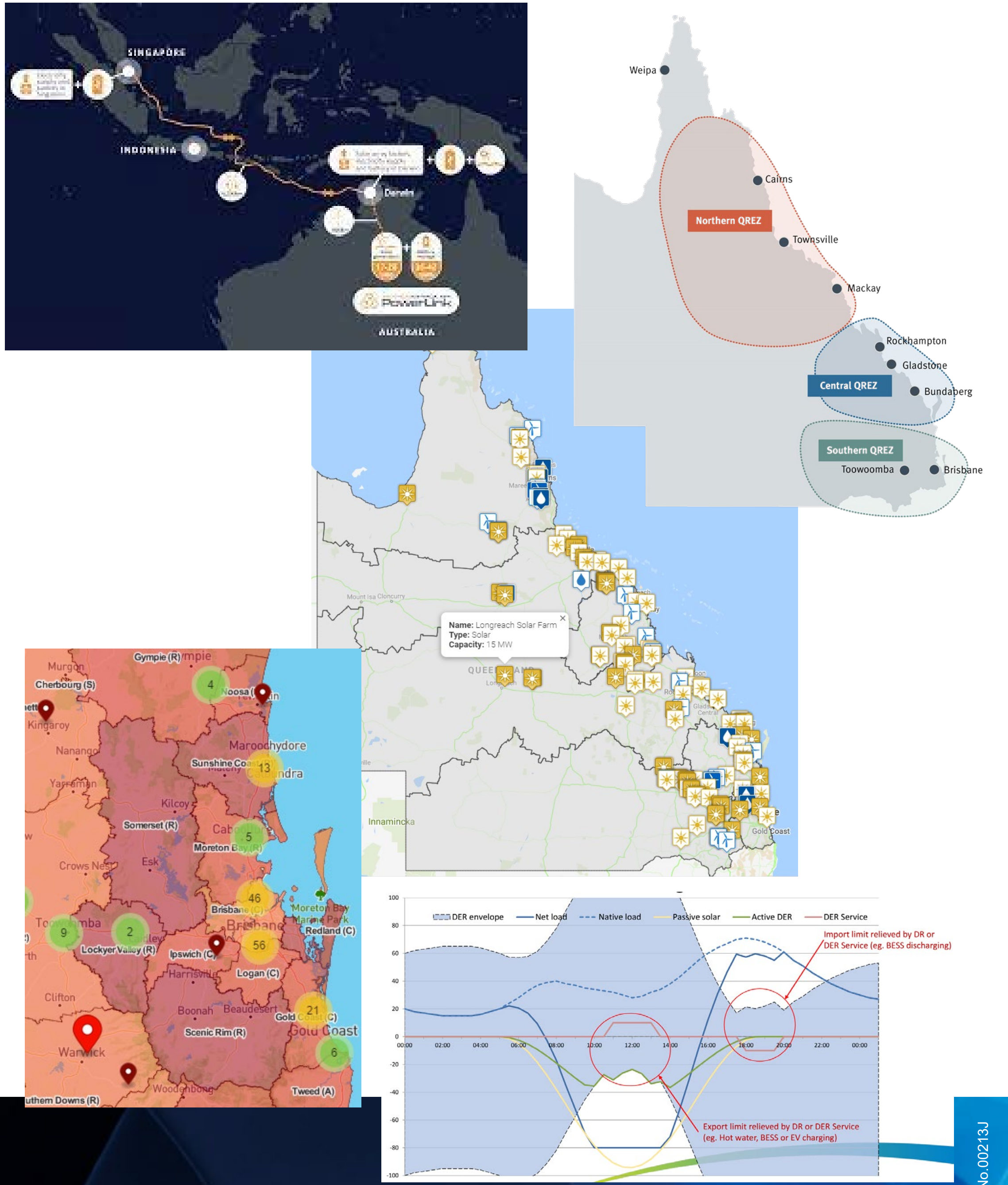
QUT acknowledges the Turrbal and Yugara, as the First Nations owners of the lands where QUT now stands. We pay respect to their Elders, lores, customs and creation spirits. We recognise that these lands have always been places of teaching, research and learning.

QUT acknowledges the important role Aboriginal and Torres Strait Islander people play within the QUT community.

Renewables keep growing!
How are networks responding?

Rough Agenda

- Battery projects are now happening
- Oversizing PV at the residential scale, …
- And then adding batteries on the DC side
- Solar farm scale PV projects, …
- And adding batteries on the DC side
- Novel ways to integrate batteries with PV and inverters – recent research



Battery projects now accelerating

Operational: (since) MW / MWh

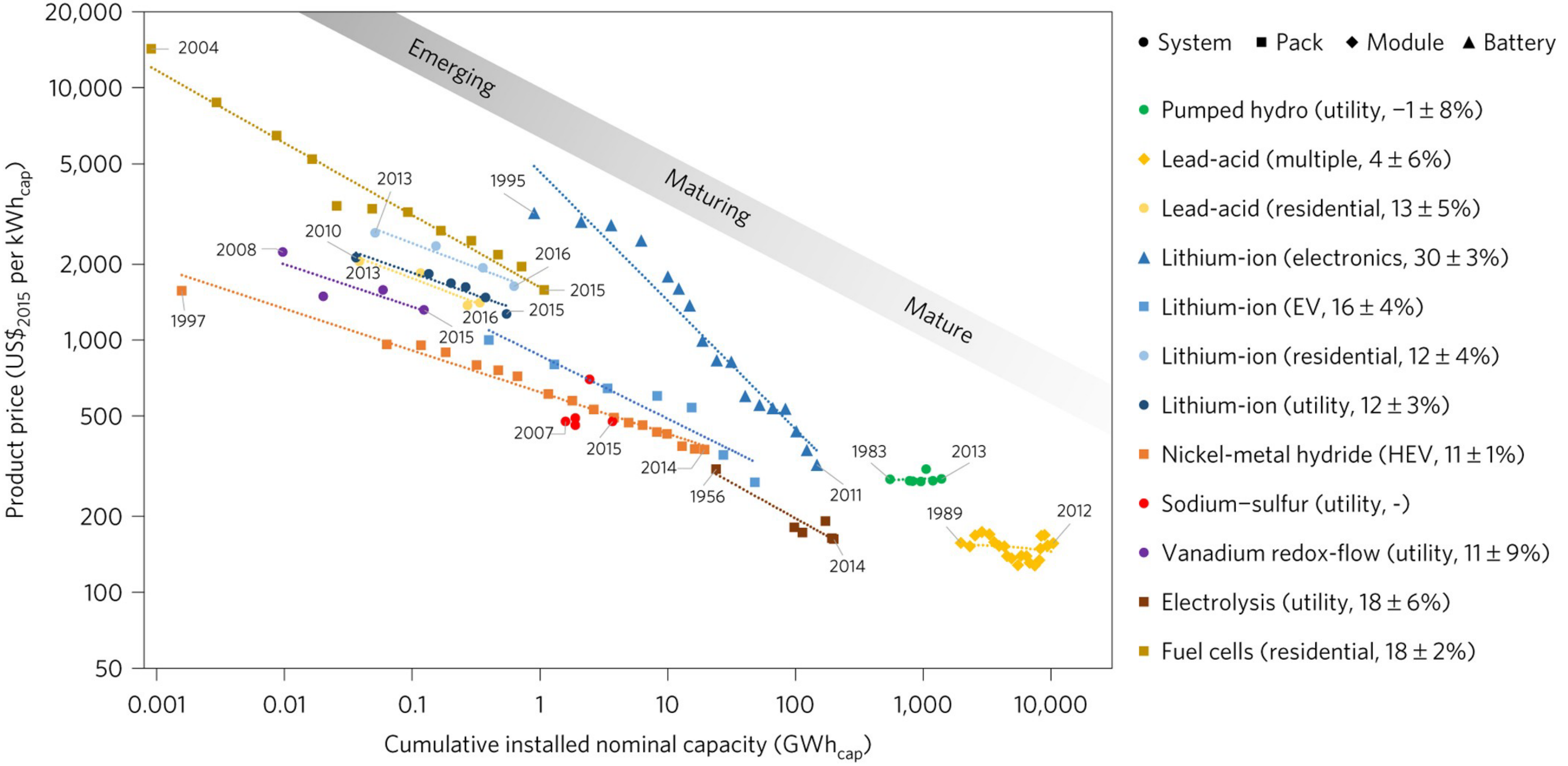
- Hornsdale (2017), 150 / 194
- Victoria Big Battery
  (near Moorabool) (2021), 300 / 450
- Wondoan South (2021), 100 / 150
- Wallgrove NSW (2022), 50 / 75
- Hazelwood (2023), 150 / 150
- Torrens Island (2023), 250 / 250
- Kwinana (2023), 100 / 200

Under Construction: (finish) MW / MWh

- Chinchilla (2023), 100, 200
- Western Downs (2024/25), 270 / 540
- Eraring (2025), 700, 2800
- Waratah super battery (2025), 850, 1680

Energy storage learning curves

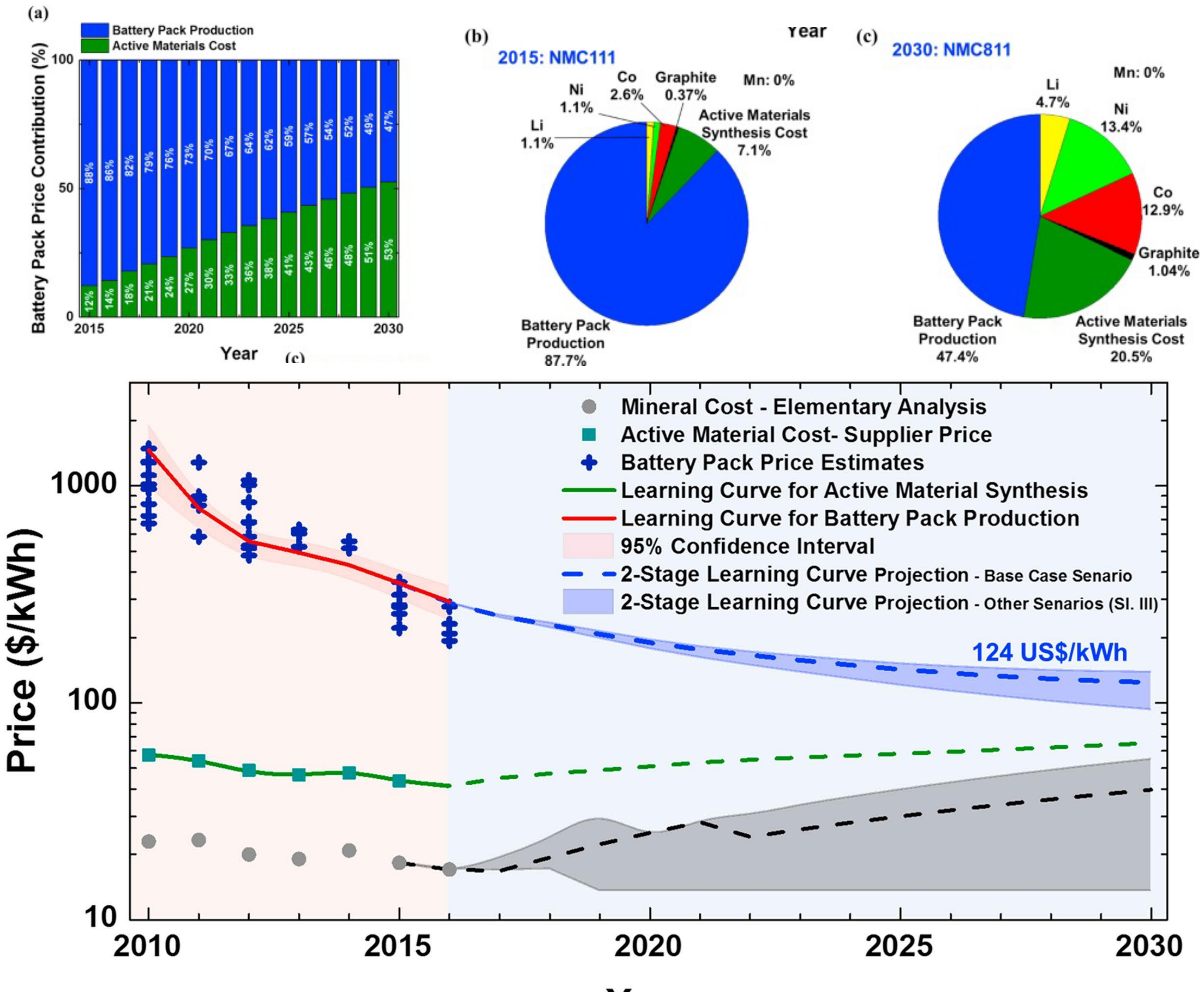
- Experience curves generated to project future prices for 11 electrical energy storage technologies.
- Once 1 TWh of capacity is installed for each technology, regardless of technology, capital costs are on a trajectory towards
  - US$340 ± 60 kWh^{-1} for installed stationary systems and
  - US$175 ± 25 kWh^{-1} for battery packs



- O. Schmidt et al., "The Future Cost of Electrical Energy Storage Based on Experience Rates," *Nature Energy* 2, no. 8 (July 10, 2017): 1–8, https://doi.org/10.1038/nenergy.2017.110.

Learning Only Buys You so Much: Practical Limits on Battery Price Reduction

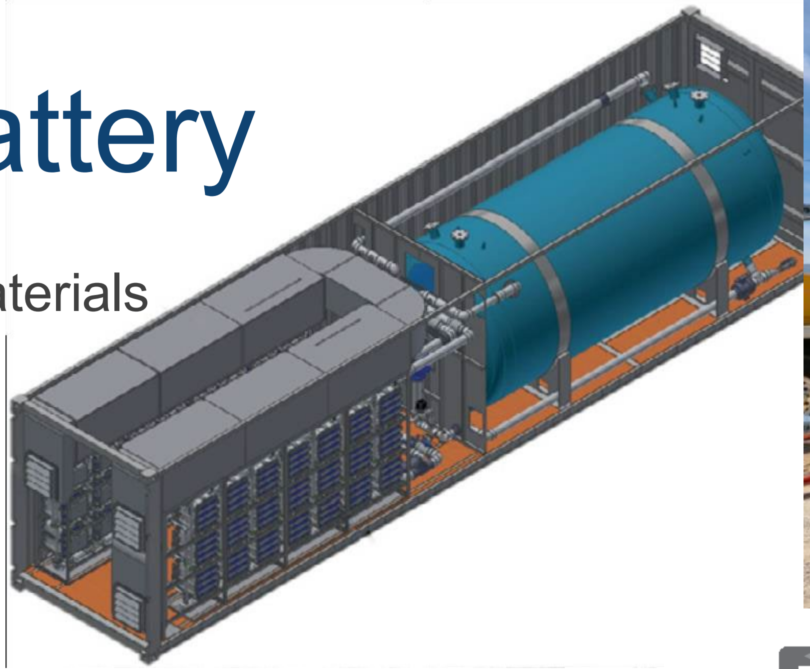
- Low battery prices would facilitate transition to electro mobility.
- Essential materials costs set lower limits on electric vehicle battery prices.
- Lithium-ion NMC battery is unlikely to reach the $100/kWh price target.
- New battery chemistry is required to lower the price floor imposed by materials.

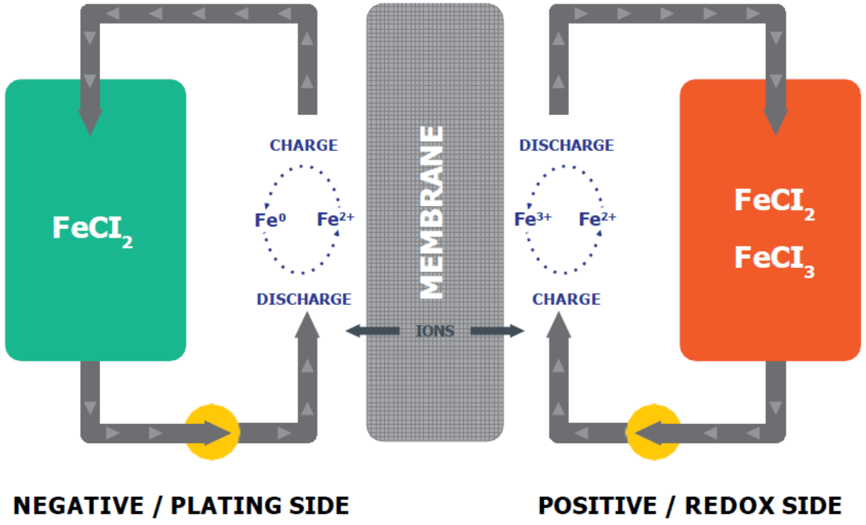


I-Yun Lisa Hsieh et al., “Learning Only Buys You so Much: Practical Limits on Battery Price Reduction,” Applied Energy 239 (April 1, 2019): 218–24, https://doi.org/10.1016/j.apenergy.2019.01.138

ESS Iron flow battery

- Low Cost, Abundant Electrolyte Materials
- Can ship dry, just add water
- Non toxic, non flammable
- 8 hours Nameplate Capacity,
- 25 Year Life
- No capacity loss with cycles, or time
- Lowest LCOS when Frequently Cycled
- DC/DC Round Trip Efficiency ~ 75%
- Fast Response Times for Grid Stability
- Full power in <1 second
- Current being tested at NBTC QUT Bayno
- Manufacturing plant being set up in Maryborough

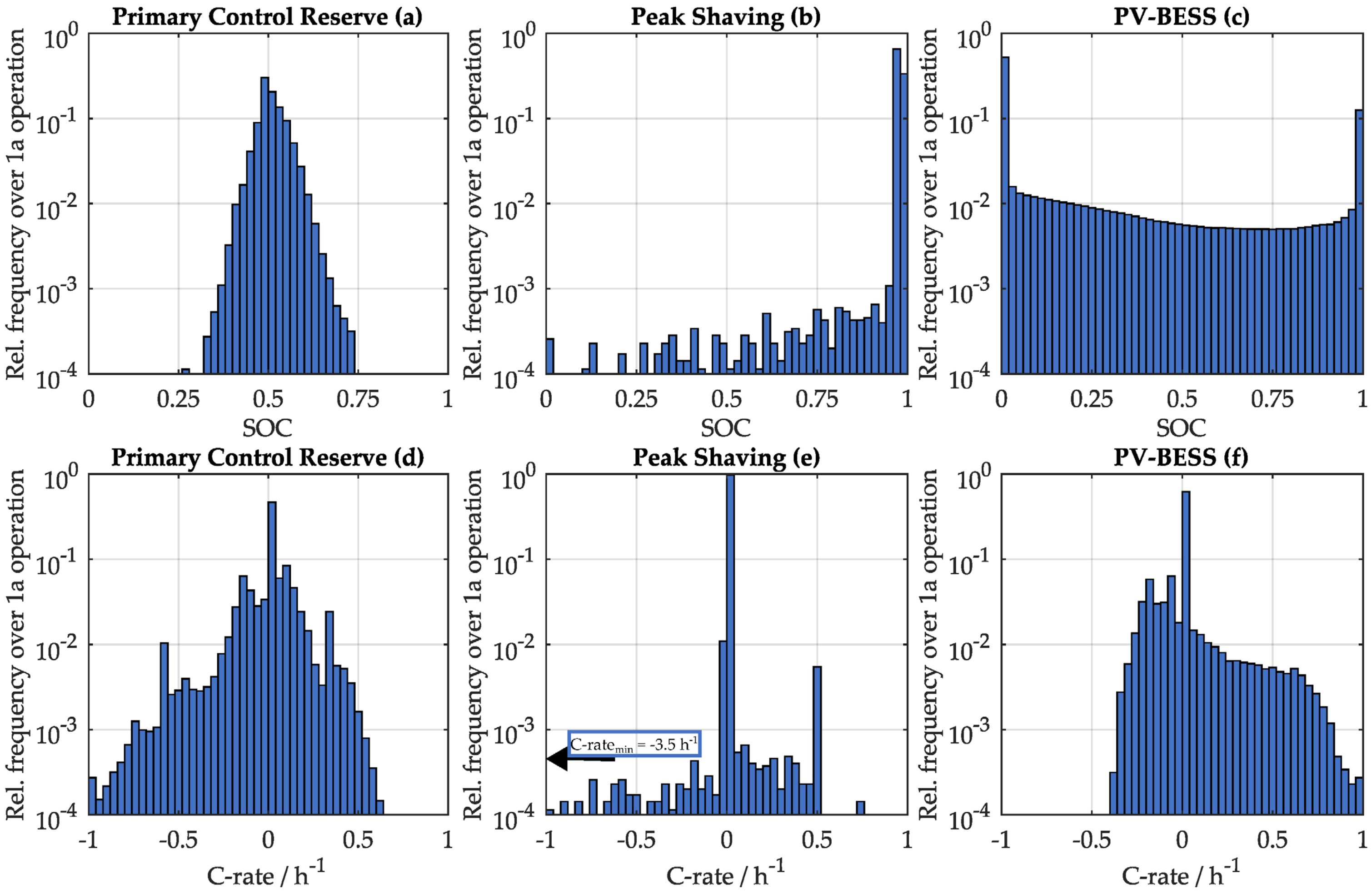




https://www.pv-magazine-australia.com/2022/12/14/iron-flow-battery-arrives-at-queensland-testing-centre-ahead-of-major-perfectly-suited-manufacturing-play/

Lithium-Ion grid storage

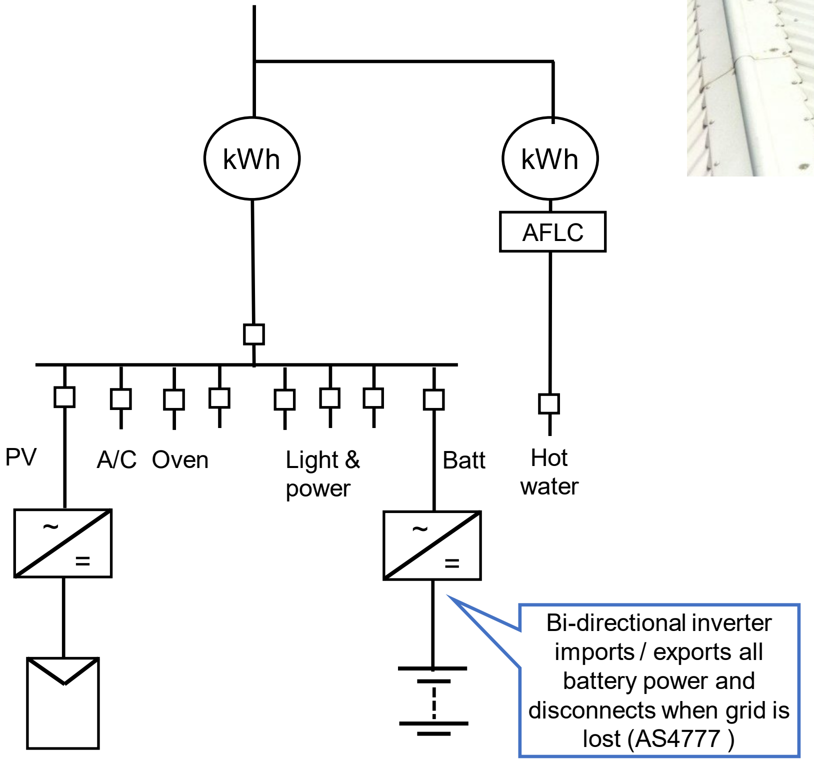
- Open access
- 208 references
- Coverage of all aspects of topic
- Example figure: Distribution of State of Charge (SOC) and C-rate for three exemplary storage simulations:
    - (a,d) BESS in frequency regulation (primary control reserve) application, data from [132];
    - (b,e) BESS in peak shaving application, data from [174];
    - (c,f) BESS in PV residential battery storage system application, data from [13].



- Holger C. Hesse et al., "Lithium-Ion Battery Storage for the Grid—A Review of Stationary Battery Storage System Design Tailored for Applications in Modern Power Grids," *Energies* 10, no. 12 (December 2017): 2107, https://doi.org/10.3390/en10122107.

Residential grid connect PV and storage

- Residential Grid connected PV is widely adopted and so now (relatively) well understood.
- Reduces energy consumption,
- Reduces bills and had reasonable payback depending on tariff and ability to load shift
- But cannot generate without grid
- Residential battery storage is slowing growing,
- More self-consumption flexibility, but still long payback
- May provide additional reliability with the right configuration.



Battery storage: the possibilities for the ...

Customer

- The ability to maximise self-consumption or PV export to minimise bills / maximise income,
- Even energy arbitrage (buying cheap, selling peak),
- Larger PV capacity capability
- Blackout proofing (backup)
- Better voltage regulation

- Ultimately lower network charges?

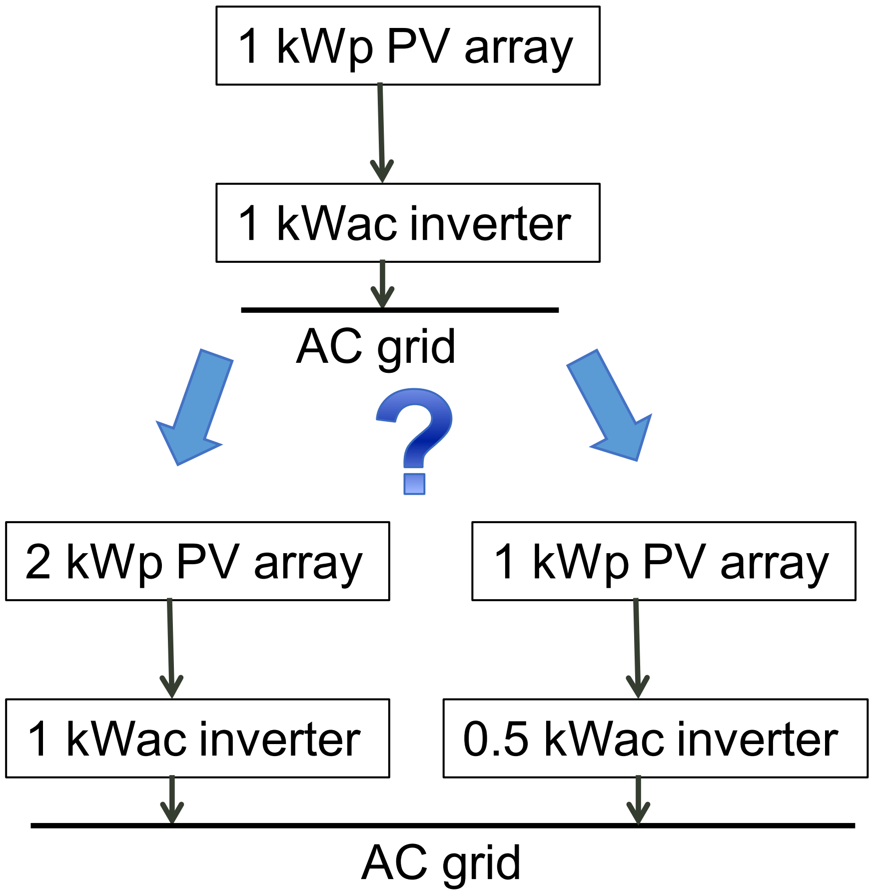
Network

- Flattened load curve due to peak clipping and valley filling
- Reduction in PV export (and associated issues) and more support at peak times
- Better SAIDI / SAIFI ??
- Better voltage regulation and power quality

- Ultimately network investment deferment?

Oversizing PV array for given inverter rating, The Premise …

- A typical PV array is matched with an inverter of identical rating (in 2011!)
- This usually means the inverter is underutilised / over specified
- How much energy would be forfeited (“spilled”) if the inverter were undersized, or alternatively, if the array were oversized? (less than you might imagine)
- For ease of comparison, the inverter and AC grid connection are assumed as the limiting factor and are set to 1 kWac.
- All sizes can be scaled in proportion without affecting the results



Case study – my 4 kW PV system

http://pvoutput.org/
http://pvoutput.org/list.jsp?id=2128&sid=1588

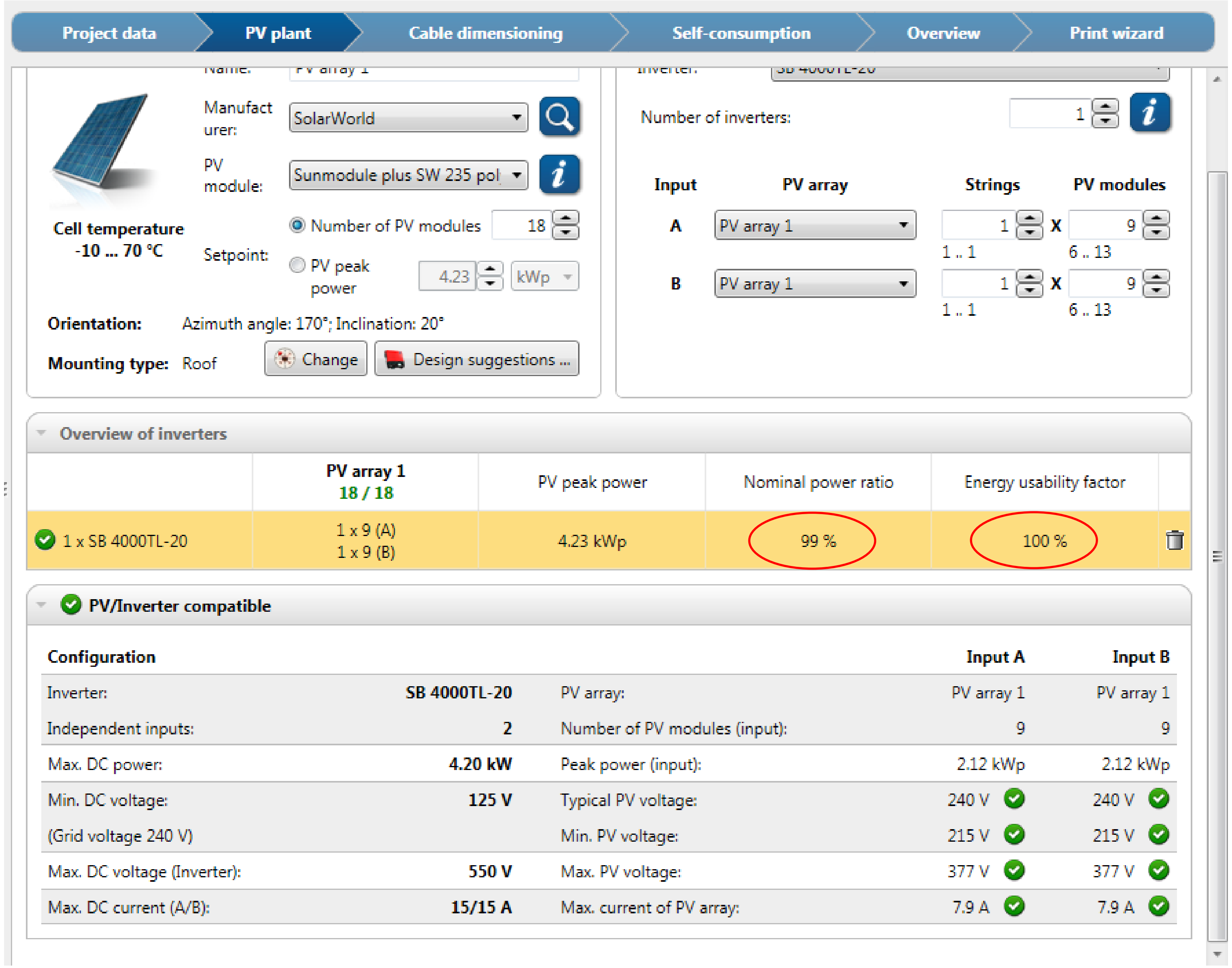
- Installed March 2011
- 4.23 kWp PV capacity
- 18 x 235 W PolySi modules
- 20° pitch roof, 10° West of North

- 4.0 kWac inverter
- SMA Sunnyboy SB4000TL

- 5 min data collected for first few years
- 78182 kWh generated as of Sept 2023
- Generation exceeds consumption
  - but is not time aligned and …
  - is not available at night.

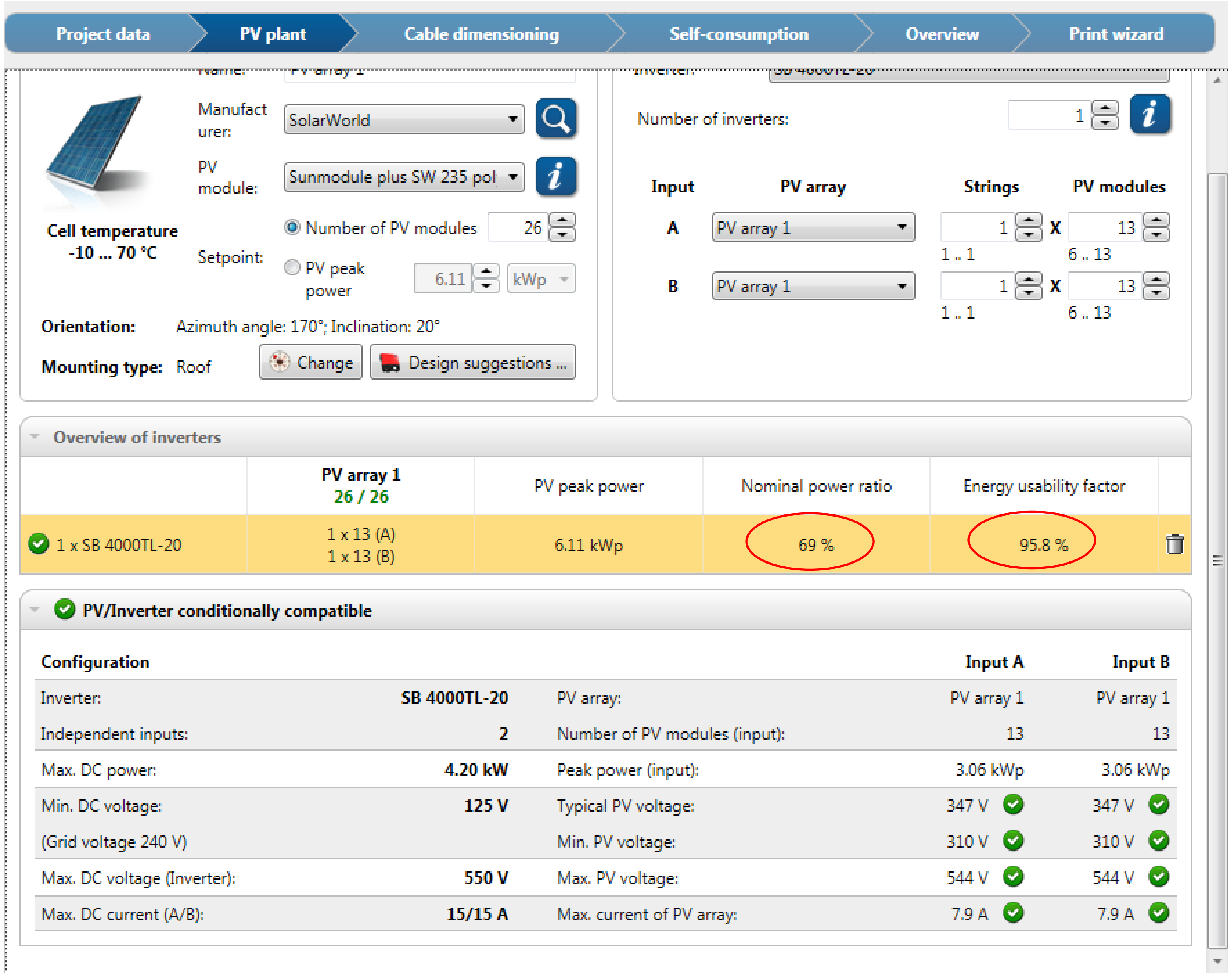
My PV array

SMA provided “Sunny design” system configuration tool shows my system arrangement is a perfect match of PV capacity to inverter capacity

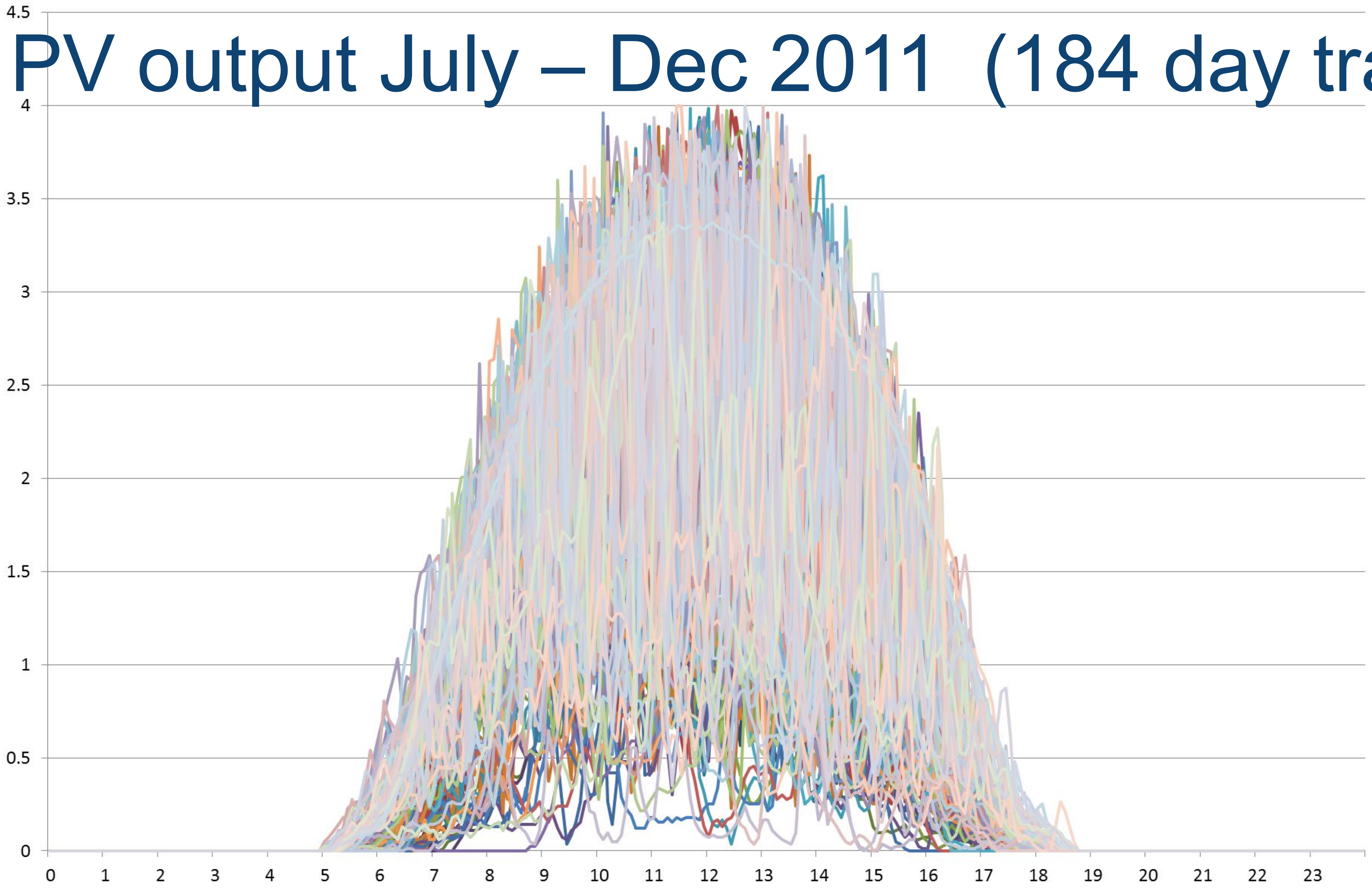


My future PV array?

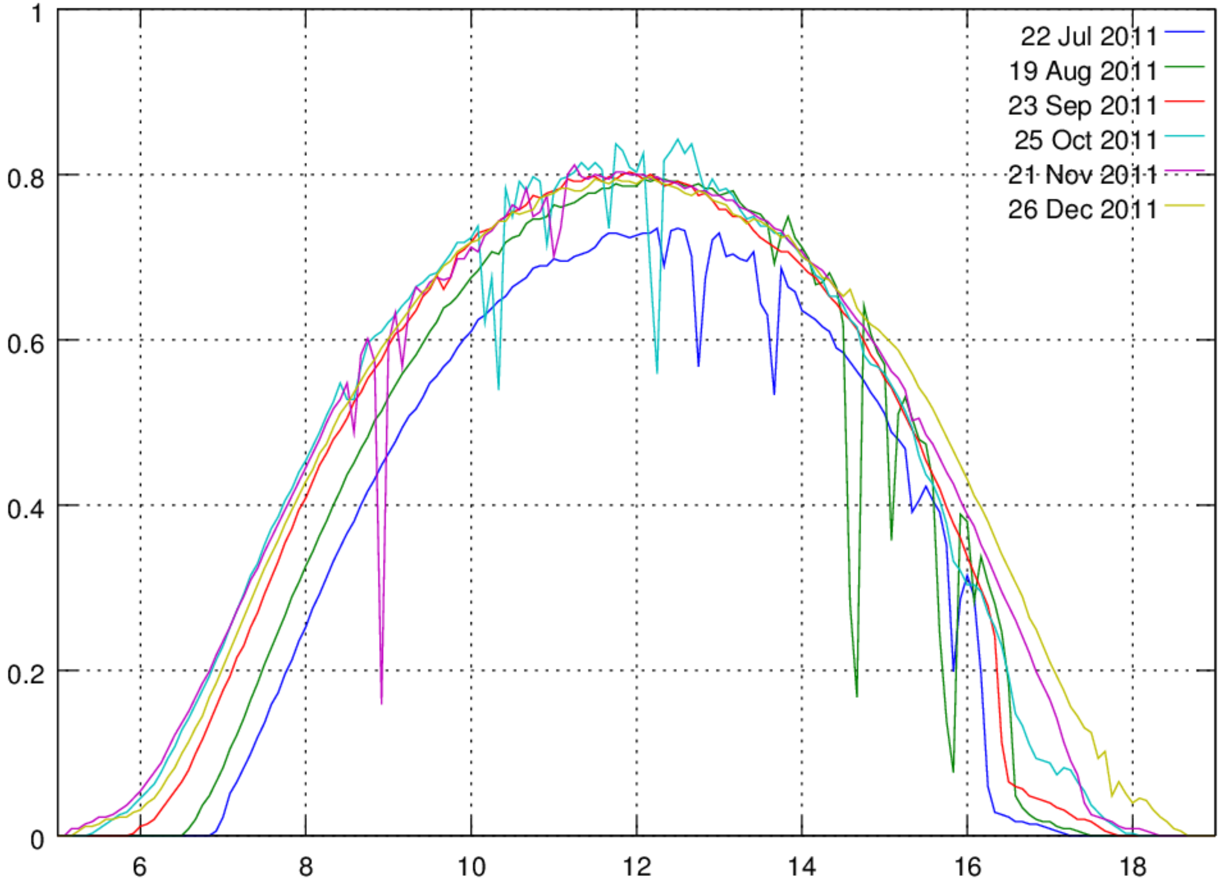
- SB4000 (4kW nominal) can accept 26 x 235 Wp PV modules = 6.11 kWp
- This is 26/18 or 144% of my existing PV system size
- SMA sizing tool suggests energy exported would still be 95.8% of energy generated.



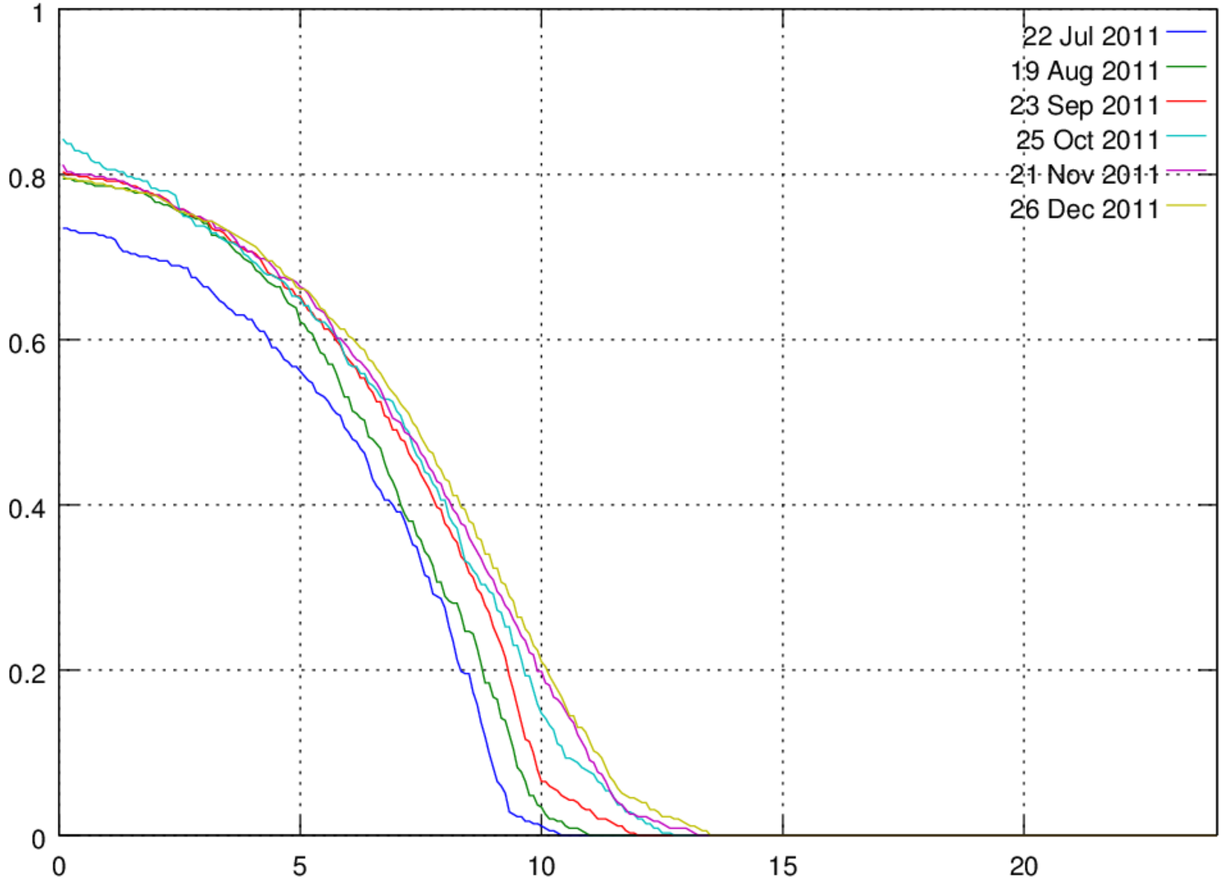
Daily PV output July – Dec 2011 (184 day traces)



Six clear sky days July to Dec 2011

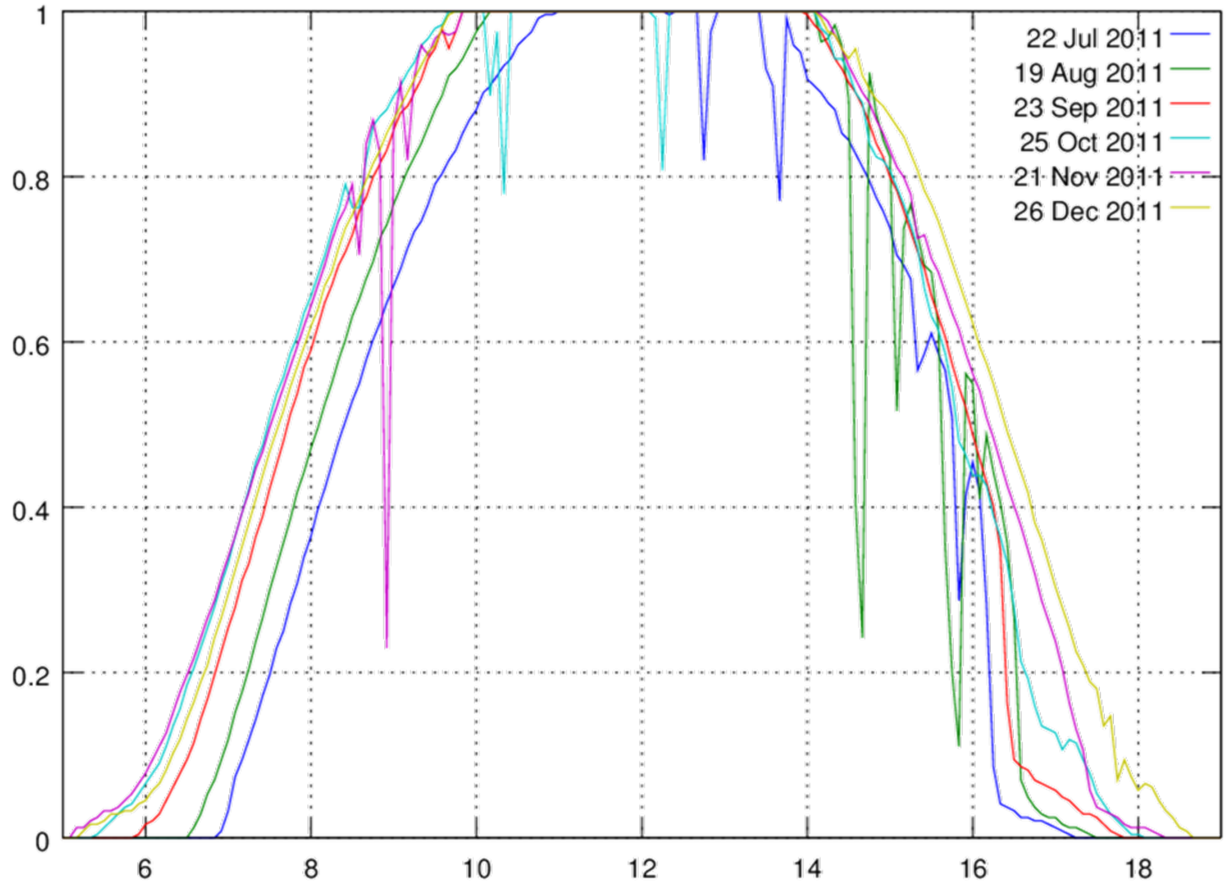


Normalised power output (kWac / kWp) vs hour of day for six clear sky days July to Dec 2011

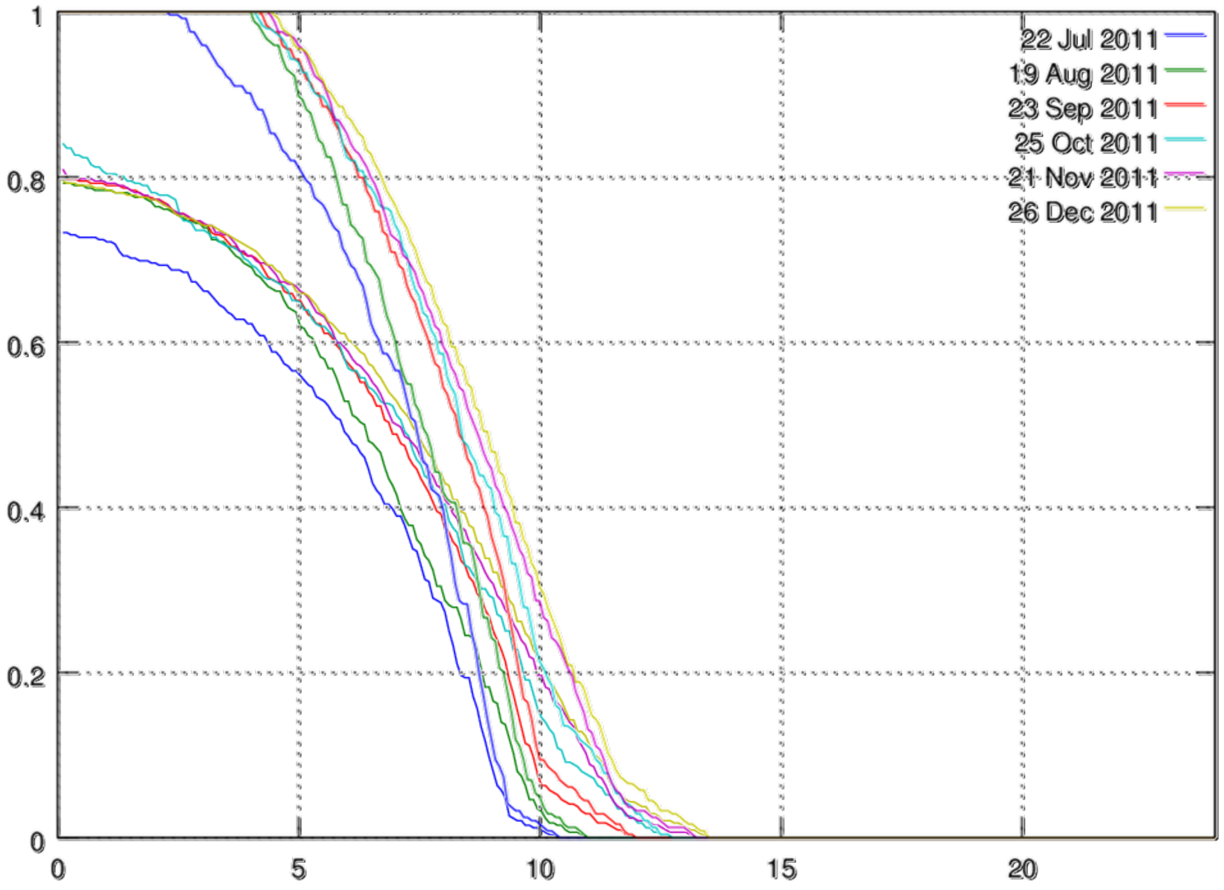


Daily Normalised power curves sorted by descending value vs duration

Six clear sky days July to Dec 2011, 144%

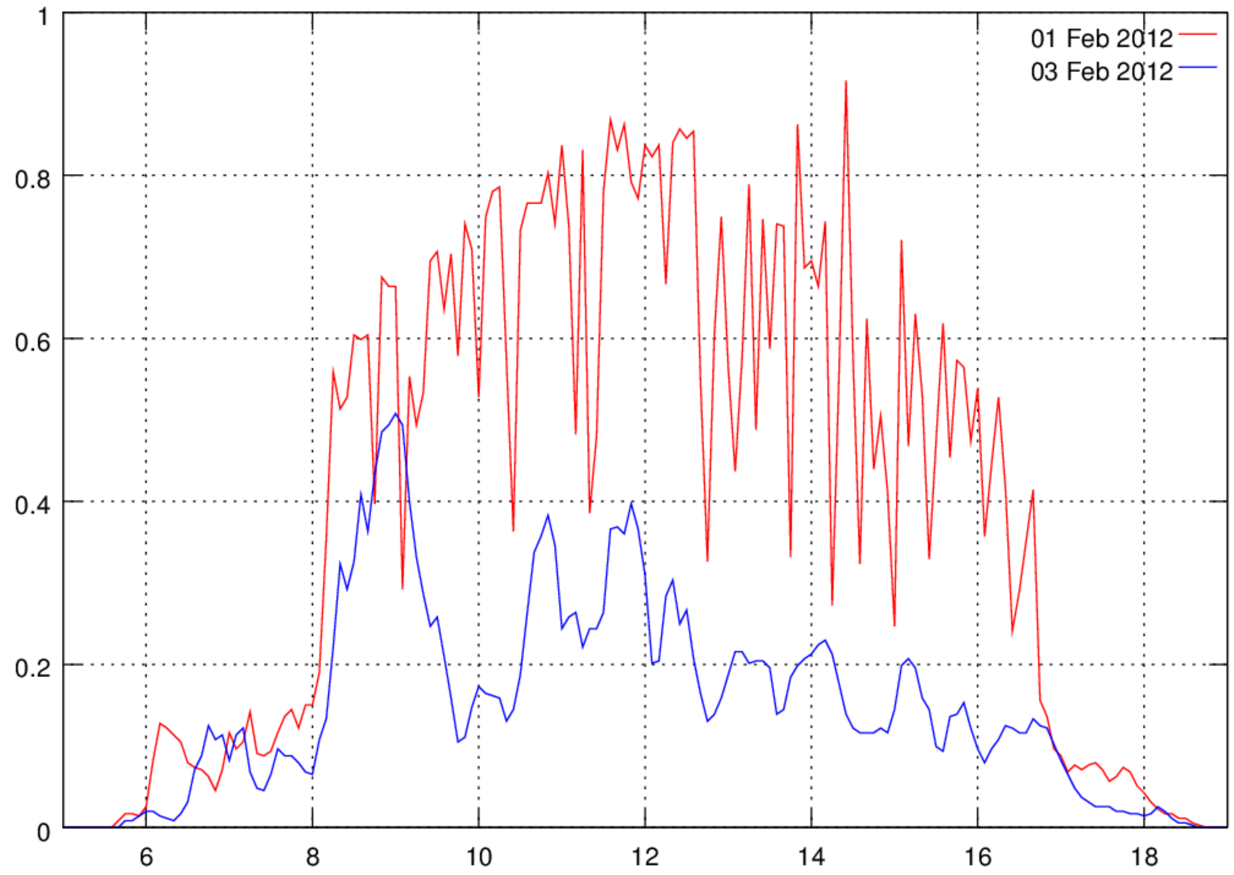


Normalised power output (kWac / kWp) vs hour of day for six clear sky days July to Dec 2011

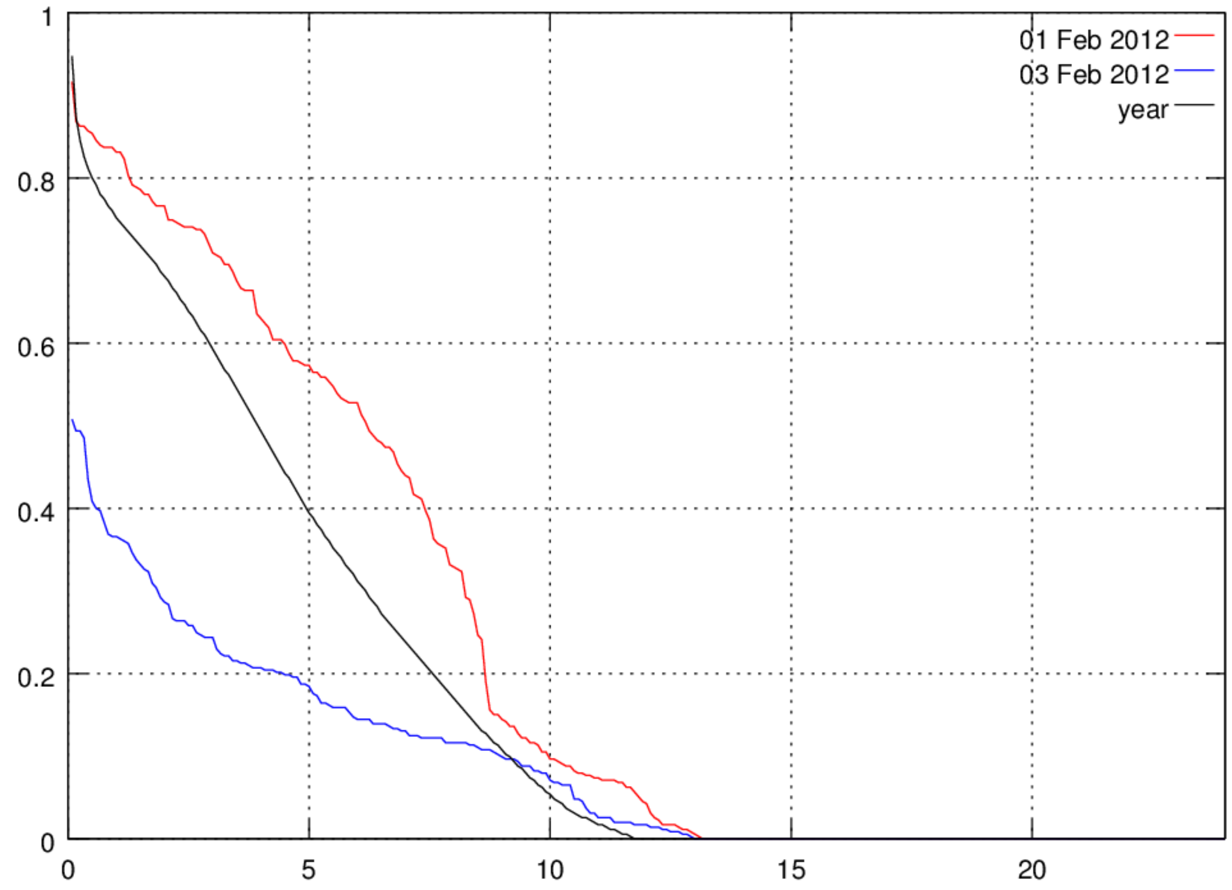


Daily Normalised power curves sorted by descending value vs duration

Two days in Feb 2012, and yearly average

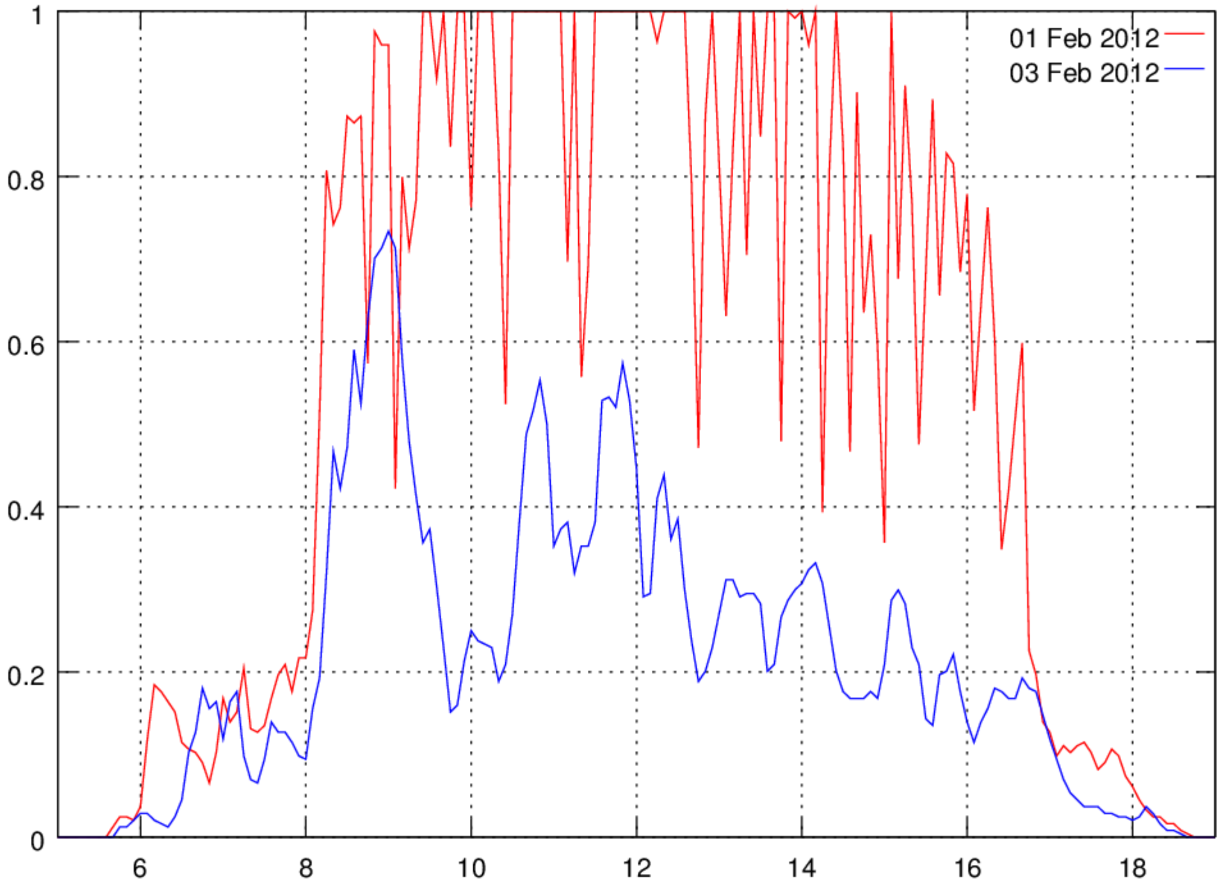


Normalised power output (kWac / kWp)
vs hour of day for two day in February 2012

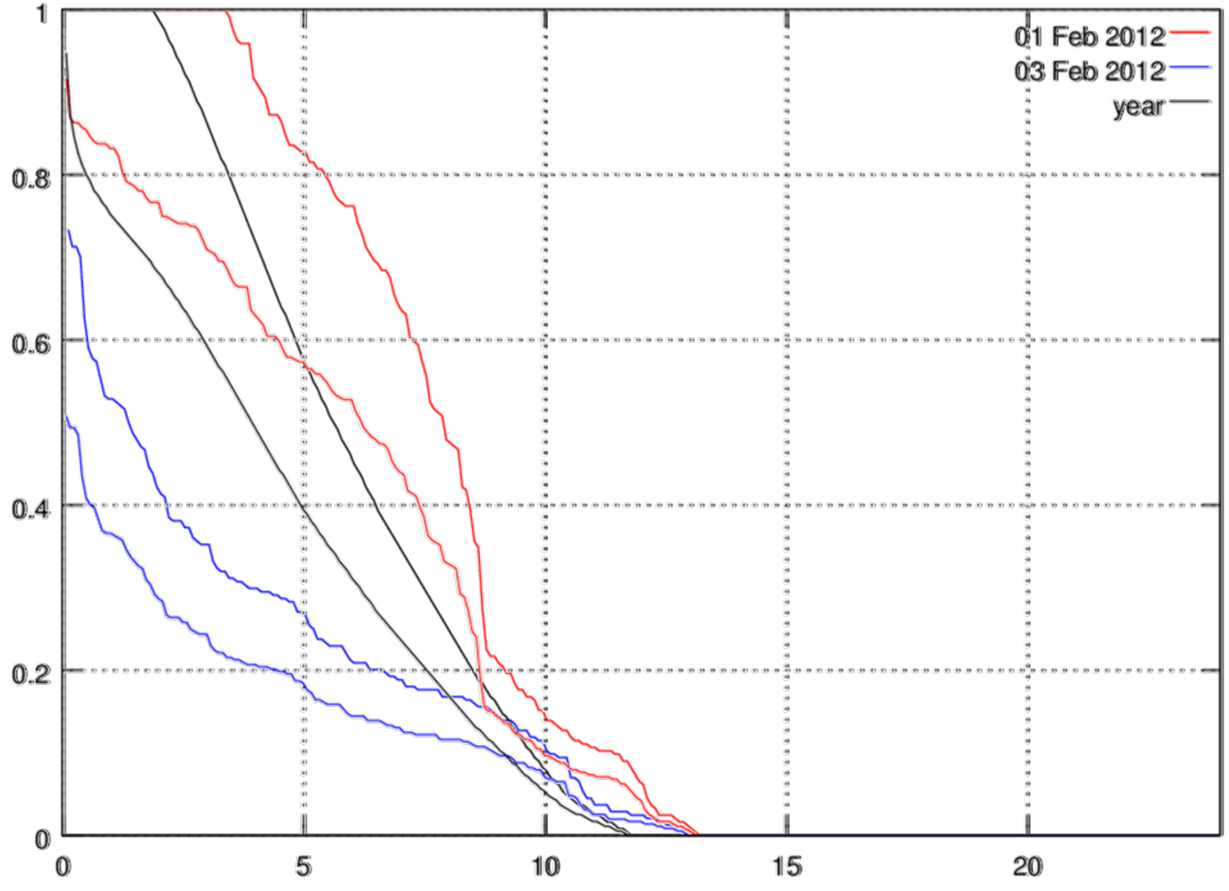


Daily Normalised power curves sorted by descending value vs duration, including yearly ave

Two days in Feb 2012 + yearly average x 144%



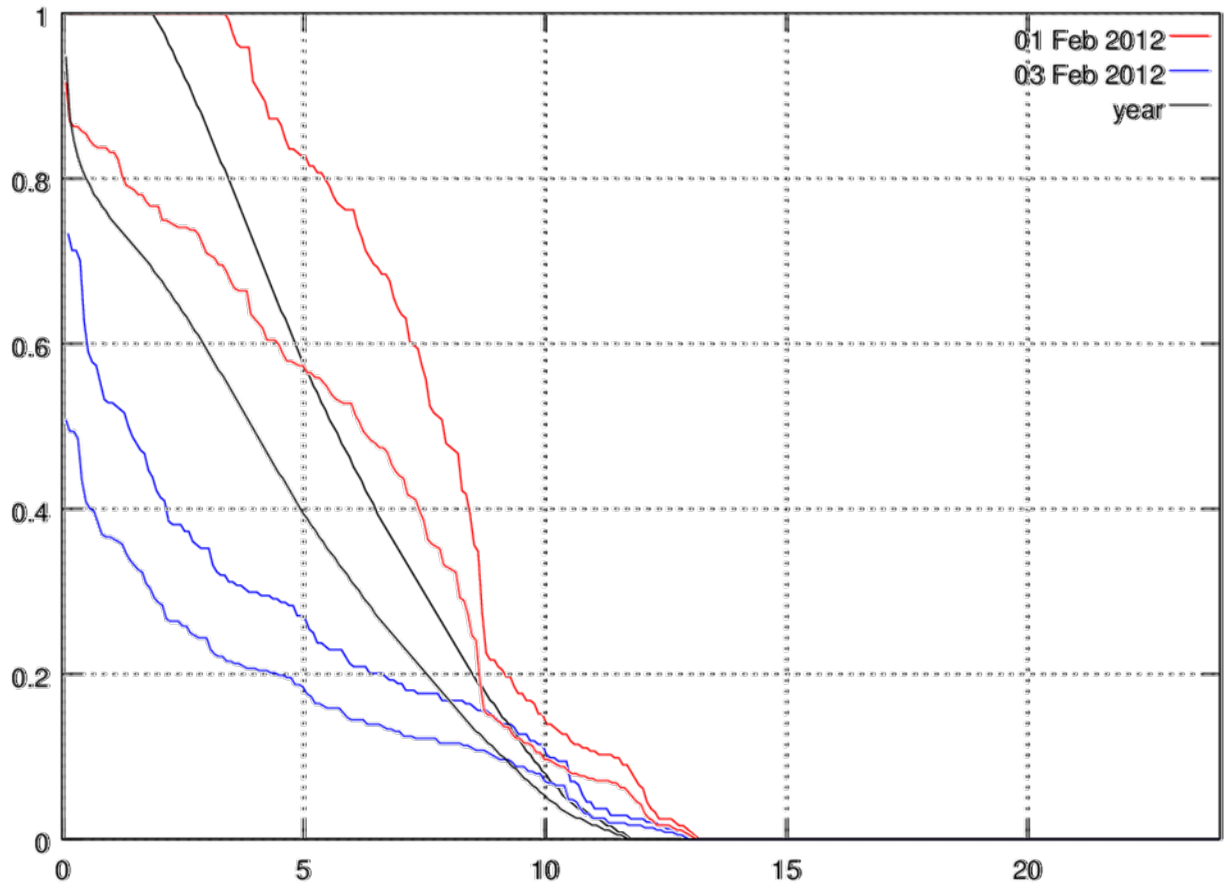
Normalised power output (kWac / kWp) vs hour of day for two day in Feb 2012, increased by 144%



Daily Normalised power curves sorted by descending value vs duration including yearly ave.

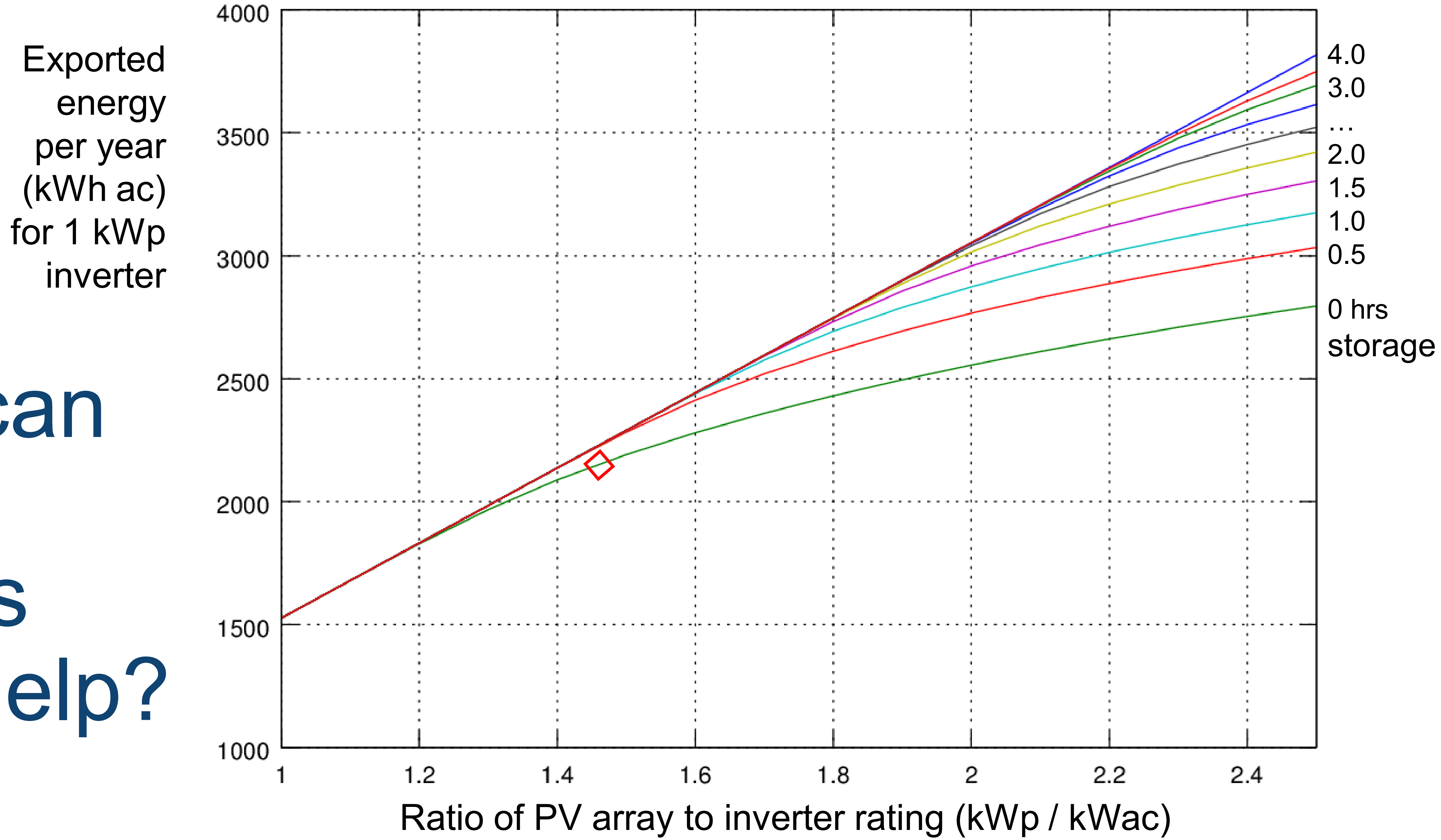
Two days in Feb 2012 + yearly average x 144%

- With 1kWp array and 1kW inverter,
  - Feb 1   5.56 kWh
  - Feb 3   2.12 kWh
  - Year total 1526 kWh
- With 1.44 kWp array and 1kW inverter,
  - Feb 1   7.59 kWh = 136% up, 94.5% of available
  - Feb 3   3.06 kWh = 144% up, all available exported
  - Year total 2136 kWh = 140% up, 96.9% of avail.
- Taking note of the following
  - 2011 was a poor solar year (about 5% low)
  - This is one case study based on one system
  - SMA solar design predicts 95.8%
  - Array is a fixed array.
    Tracking will definitely change the outcome.
  - Array has 20° tilt.
    An array with summer bias (eg 3° tilt) will do worse; an array with a winter bias may do better.



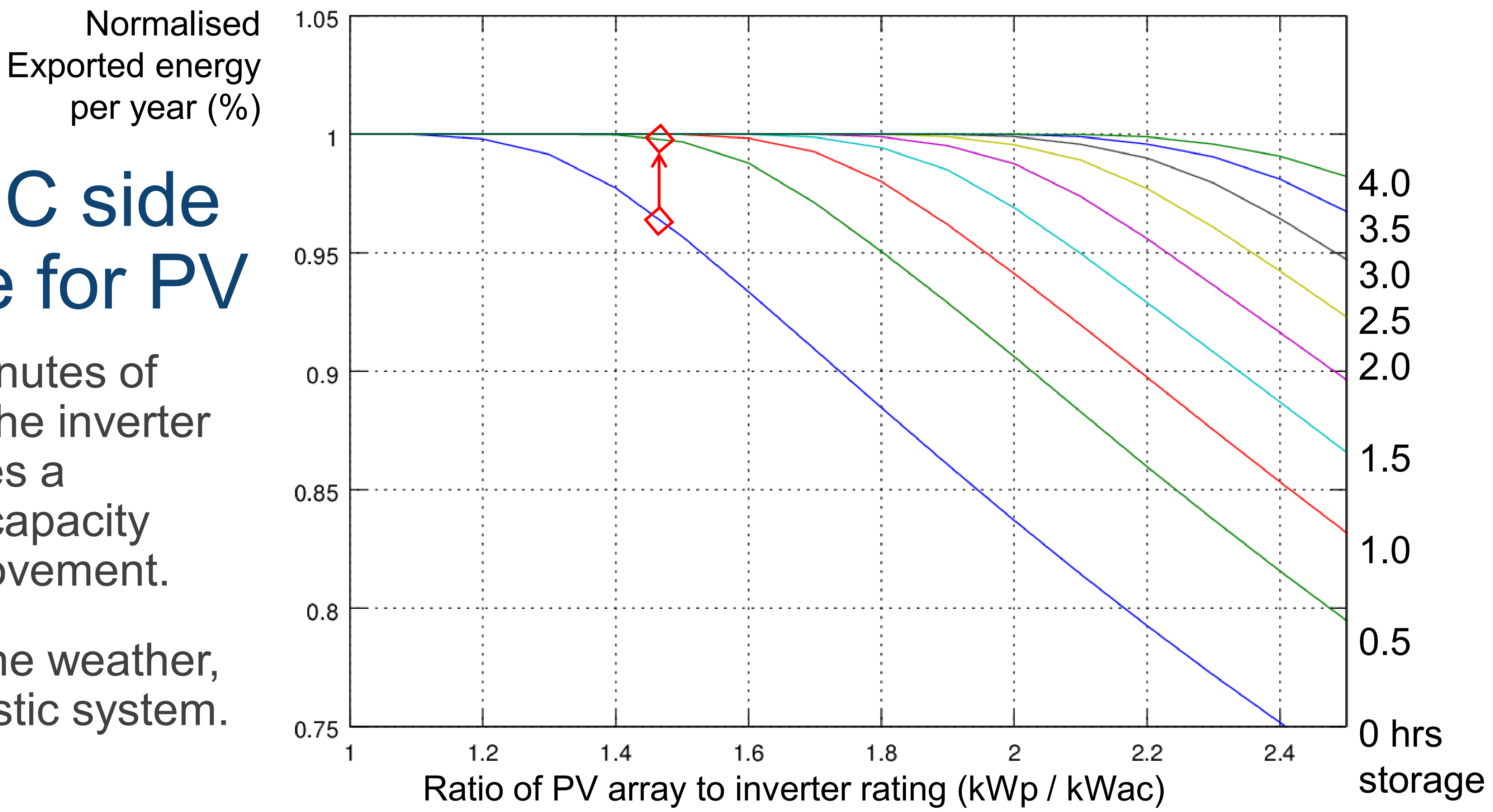
Daily Normalised power curves sorted by descending value vs duration including yearly ave.

How far can you go? How does storage help?



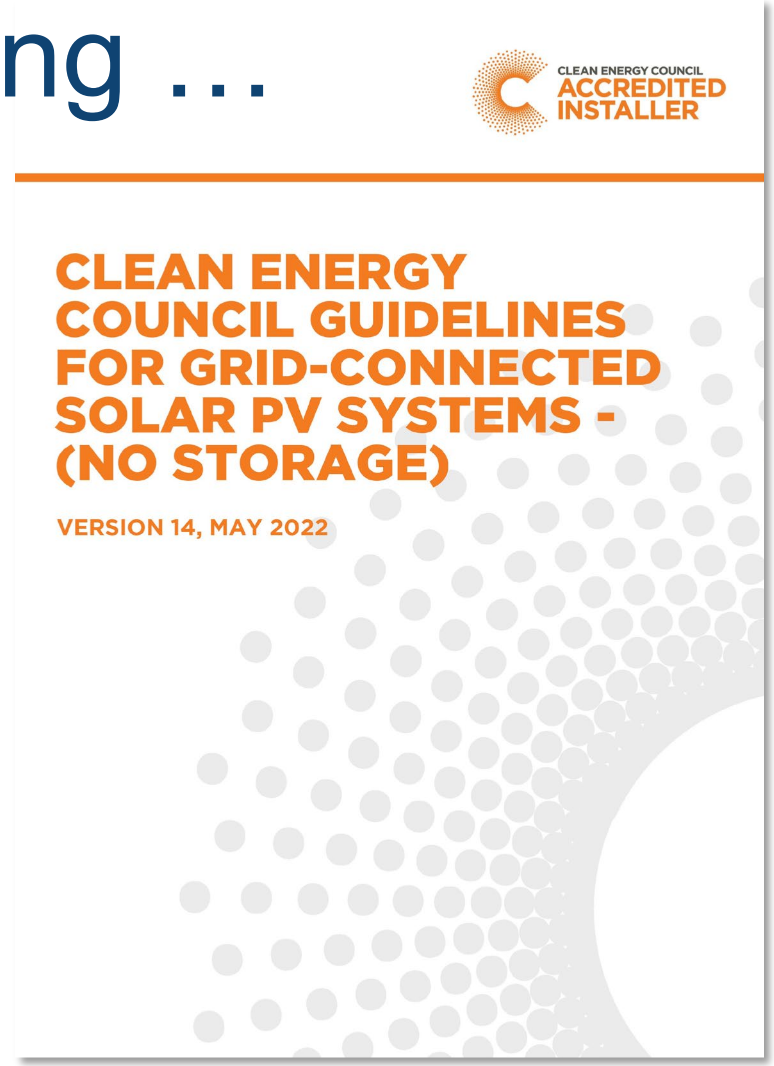
PV + DC side storage for PV

- Even 30 minutes of storage at the inverter rating makes a significant capacity factor improvement.
- NB: Brisbane weather, Domestic system.



The rules of (domestic) oversizing …

- For systems installed under the Small-scale Renewable Energy Scheme (SRES), these guidelines require:
  - 4.4.1 In order to facilitate the efficient design of PV systems, the inverter nominal AC power output cannot be less than 75 per cent of the array peak power and it shall not be outside the inverter manufacturer’s maximum allowable array size specifications
- This means PV kW / Inverter kW cannot exceed 133%
- Hence the typical 6.6 kWp PV system (with 5 kVA inverter)
- And if you have storage? Then it’s maybe OK … see
- https://www.solarquotes.com.au/blog/beat-solar-oversize-rule/


CLEAN ENERGY COUNCIL
ACCREDITED INSTALLER

CLEAN ENERGY COUNCIL GUIDELINES FOR GRID-CONNECTED SOLAR PV SYSTEMS - (NO STORAGE)

VERSION 14, MAY 2022

Solar farm current build approach

- Traditional fixed tilt – 1.5Ha per MW
- 5 MW block shown below 2 x 2.5 MW inverters

- Traditional single axis ≈2Ha per MW
- 5 MW block shown below 2 x 2.5 MW inverters

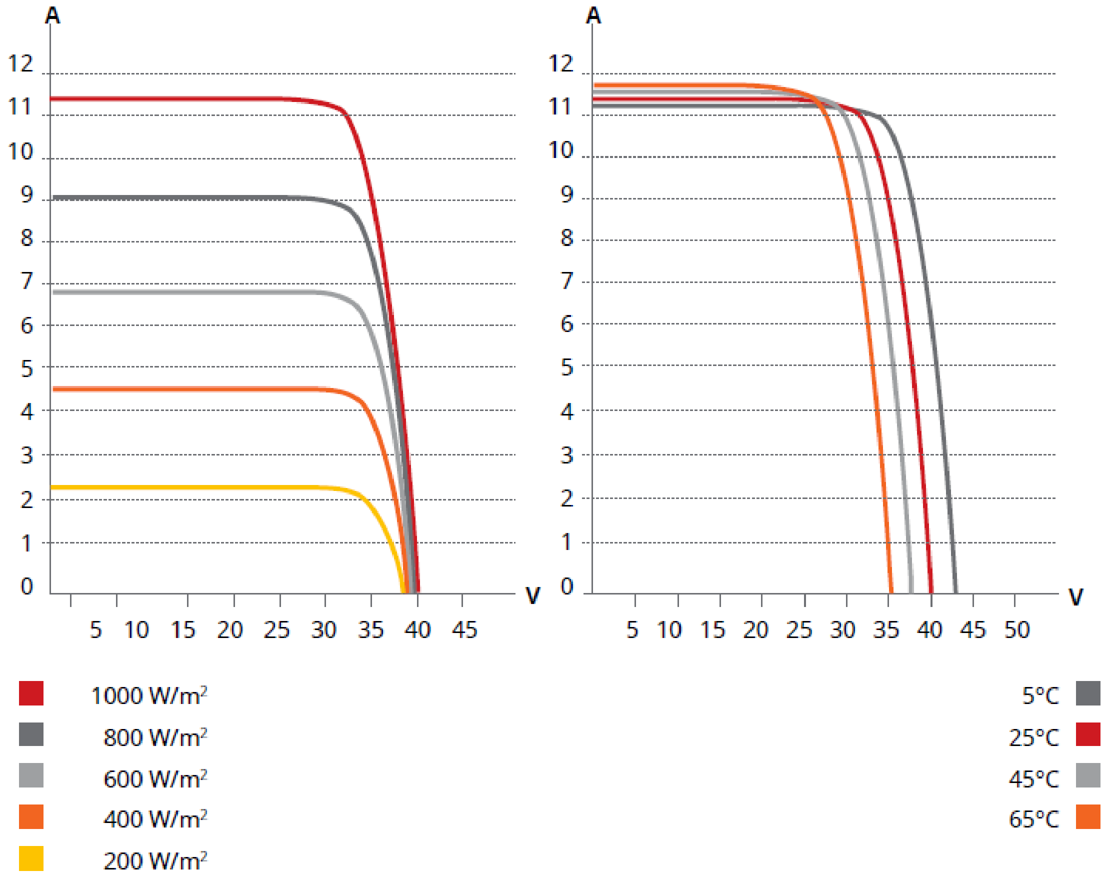
PV modules

- Example 360W PV module
- Double insulated, so can be put in series strings to 1500V

ELECTRICAL DATA | STC*

CS3L	350MS	355MS	360MS
Nominal Max. Power (Pmax)	350 W	355 W	360 W
Opt. Operating Voltage (Vmp)	32.7 V	32.9 V	33.1 V
Opt. Operating Current (Imp)	10.71 A	10.80 A	10.88 A
Open Circuit Voltage (Voc)	39.6 V	39.8 V	40.0 V
Short Circuit Current (Isc)	11.33 A	11.38 A	11.45 A
Module Efficiency	18.92%	19.19%	19.46%
Operating Temperature	-40°C ~ +85°C		
Max. System Voltage	1500V (IEC/UL) or 1000V (		

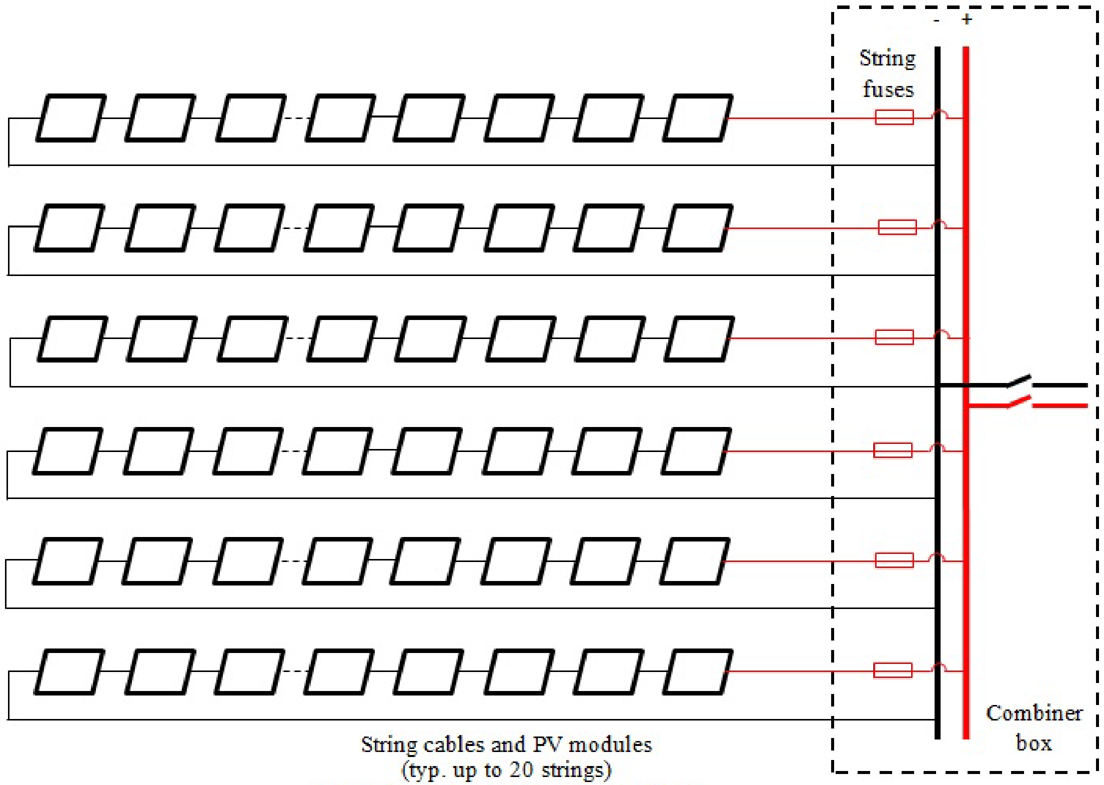
CS3L-360MS / I-V CURVES



PV Strings to combiner boxes

- Strings typically 29 to 31 series modules
- = 30 x 40V = 1200 Voc,
- = 30 x 33V = 1000 Vmpp
- = 30 x 300W = 9 kW per string
- 20 strings in parallel
- = 20 x 11.5A = 230 A short circuit,
- = 20 x 10.8A = 220 A operating

- Total power at combiner box approx. = 180 kW

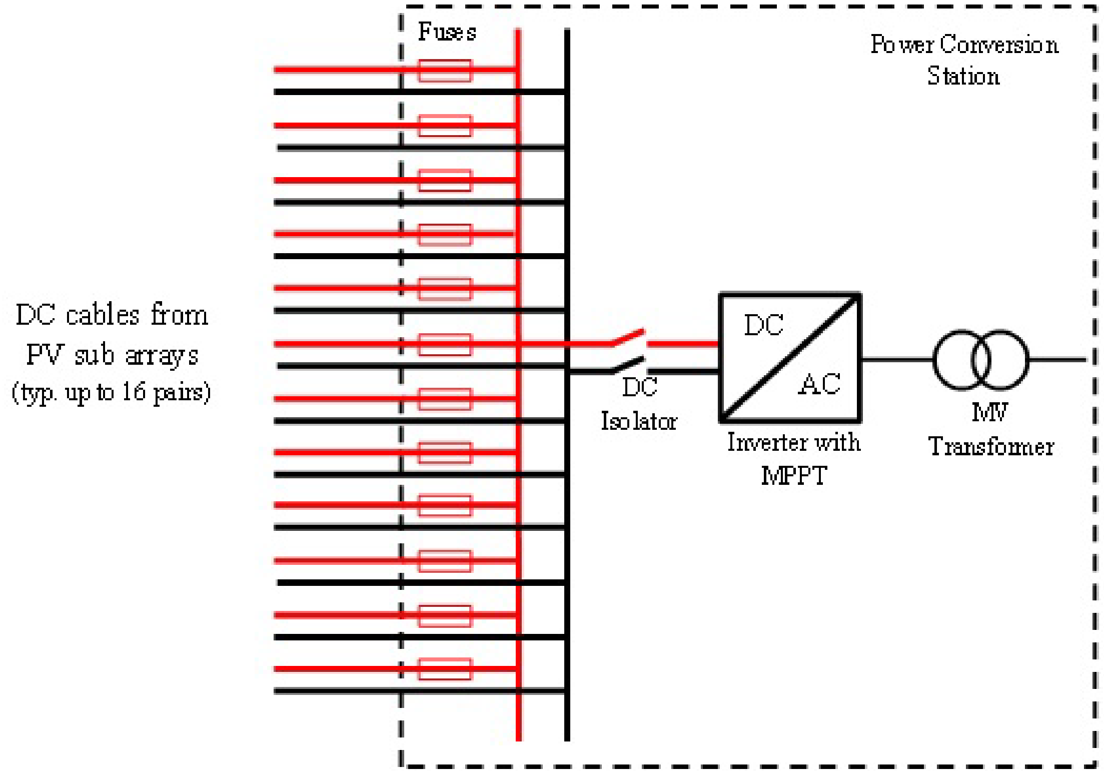


String cables and PV modules
(typ. up to 20 strings)
(each string typ. 29 to 31 modules long)

Combiner boxes to inverters

- Up to 16 parallel DC cables from PV sub arrays (combiner boxes)
- DC voltage still = 900V
- 20 strings in parallel
- = 16 x 220 A = 3500 A

- Total power at inverter
  = 16 x 180 kW = 2.88 MW



SMA central MV inverter example

- **Technical Data SC 4400 UP (NB: 4400 kVA, similar size to 2750 kVA pictured)**
- **DC side**
- MPP voltage range VDC (at 25 °C / at 50 °C) 962 to 1325 V / 1050 V
- Min. DC voltage VDC, min / Start voltage VDC, Start 934 V / 1112 V
- Max. DC voltage VDC, max 1500 V
- Max. DC current IDC, max 4750 A
- Max. short-circuit current IDC, SC 8400 A
- DC input: Busbar with 26 connections per terminal, 24 double pole fused or 32 single pole fused, or with optional DC coupled storage 18 double pole fused (36 single pole fused) for PV and 6 double pole fused for batteries
- Max. number of DC cables per DC input (for each polarity) 2 x 400 mm²
- Available PV fuse sizes (per input) 200 A, 250 A, 315 A, 350 A, 400 A, 450 A, 500 A
- Available battery fuse size (per input) 750 A
- **AC side**
- Nominal AC power at cos ϕ =1 (at 35°C / at 50°C) 4400 kVA / 3960 kVA
- Nominal AC active power at cos ϕ =0.8 (at 35°C / at 50°C) 3520 kW / 3168 kW
- Nominal AC current IAC, nom (at 35°C / at 50°C) 3850 A / 3465 A
- Max. total harmonic distortion < 3% at nominal power
- Nominal AC voltage / nominal AC voltage range1) 8) 660 V / 528 V to 759 V
- AC power frequency / range 50 Hz / 47 Hz to 53 Hz
- Min. short-circuit ratio at the AC terminals9) > 2
- Power factor 0.8 overexcited to 0.8 underexcited, 1.0 at rated power
- **Efficiency**
- Max. efficiency / European efficiency / CEC efficiency 98.8% / 98.7% / 98.5%

SANTOS Port Bonython 2.12 MW PV array

https://www.iceengineering.net.au/case-studies/santos-port-bonython-2-12-mw-solar-array/

5B Port Bonython 2.12 MW PV array

- 62 x 5B Mavericks, each with
  - 18 x 5 = 90 East-West PV modules.
  - = 5580 x 380 Wp modules
  - Area = 13000 m^2
  - Each Maverick = 34.2 kWp
- Over 25 km DC cable, and
- 1.3 km of HV 240 mm^2 XLPE cable
- all on cable ladder
- Inverter station made in Melbourne
- $800k, completed July 2019

Happy Valley SA 12.8 MWp PV array

375 Mavs, 4 inverters

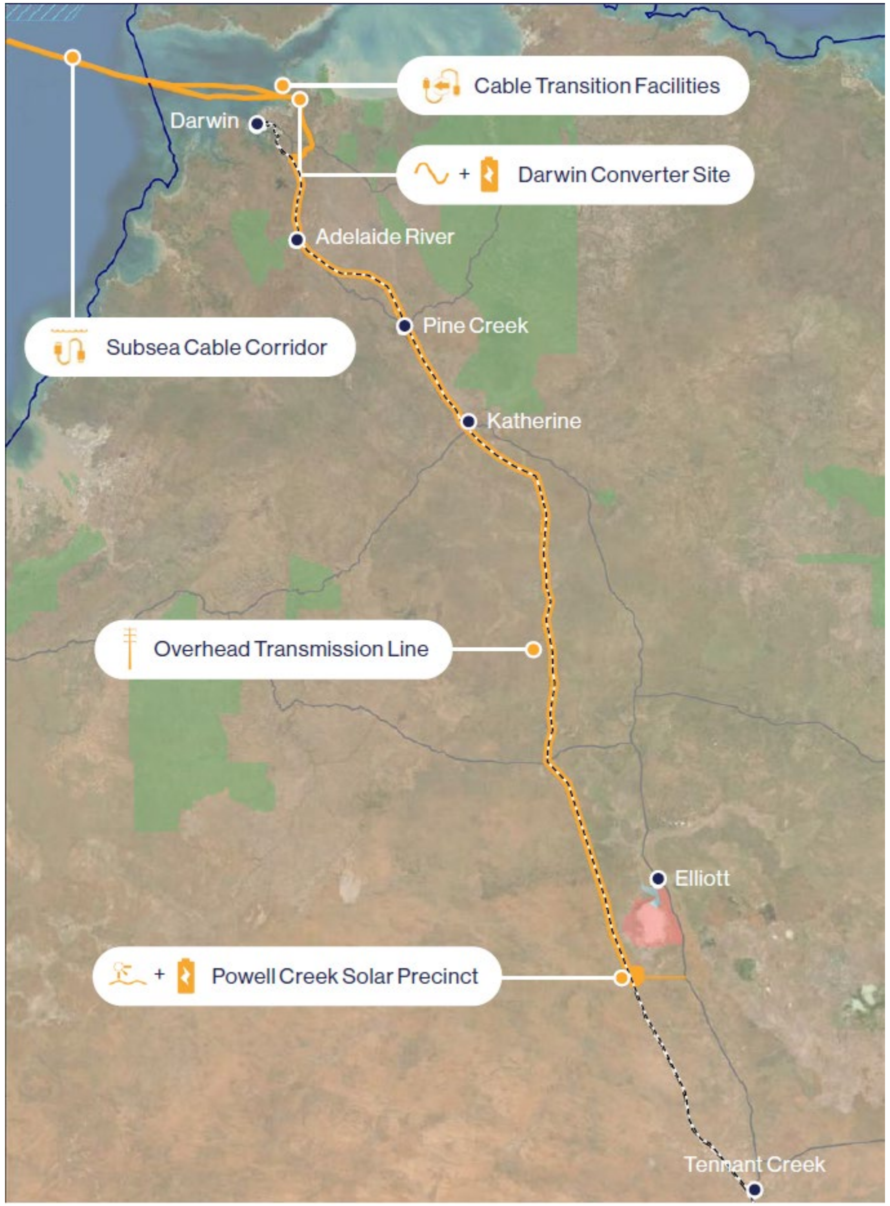
https://5b.co/projects

Happy Valley SA 12.8 MWp PV array

- 375 x 5B Mavericks, each with
  - 18 x 5 = 90 East-West PV modules.
  - = 33750 x 380 Wp modules
  - Each Maverick = 34.2 kWp
- Four inverters, so 3.2 MWp per inverter
- Up to 21 Mavs per 3 combiner boxes, normally 6 or 7 Mavs per combiner box.
- Three strings of 30 PVs per Mav.
- Thus 205 to 240 kWp per combiner box, 18 – 21 strings per combiner box.

Sun Cable Progress (2021)

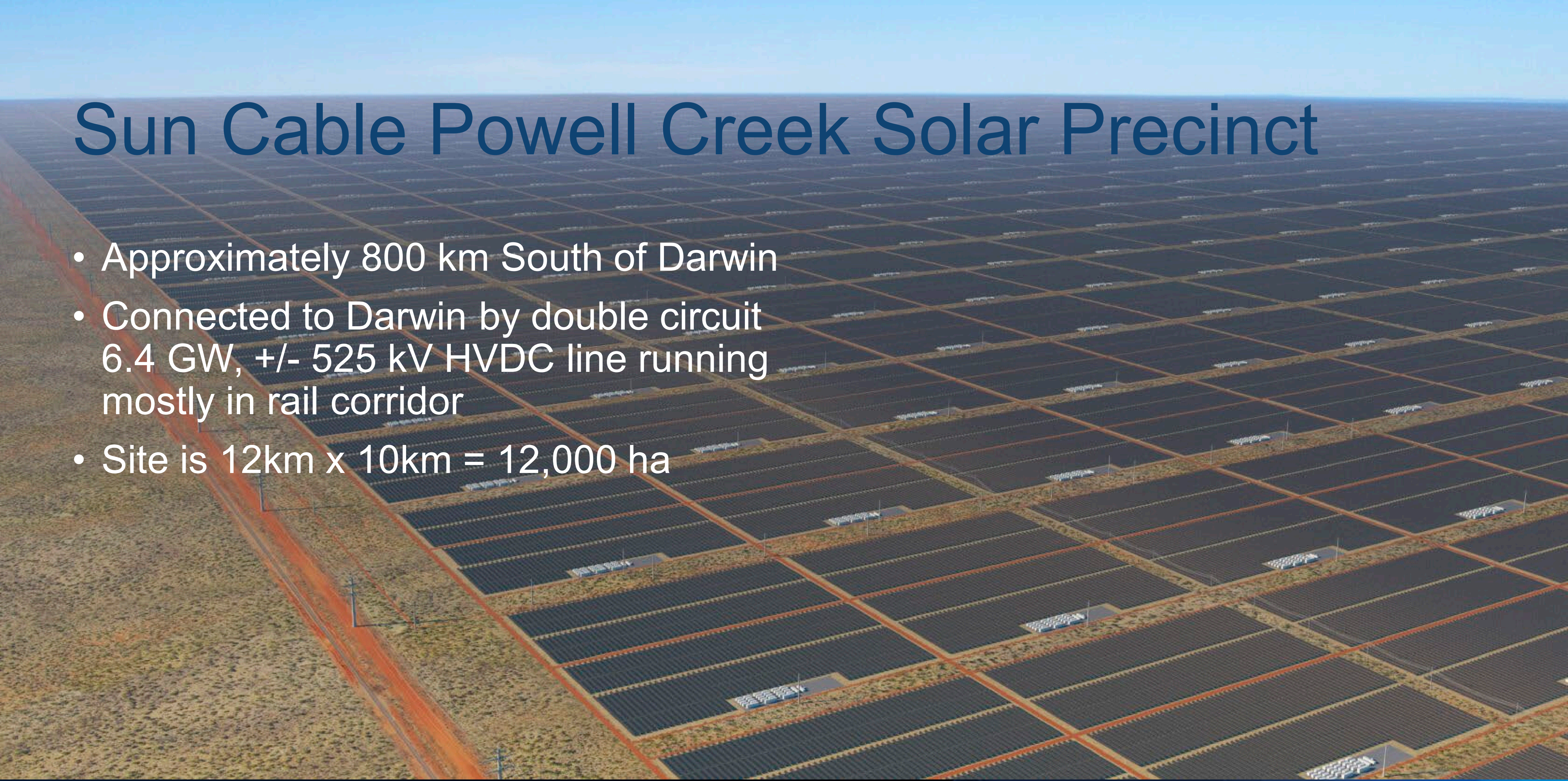
- 24 Sept: Sun Cable has secured a subsea survey permit from the Indonesian government
- 20 Oct: Integrated Project Delivery Team (IPDT) announced:
  - Bechtel (Project Delivery),
  - Hatch (HVDC Transmission),
  - Marsh (Risk Management),
  - PwC Australia (Project Advisory),
  - SMEC (Solar Generation System)
- 25 Oct: Singapore Government's announcement today that it will import up to 4 GW of electricity by 2035 and will run a competitive market process. Sun Cable announces that it is open to expressions of interest from customers in Singapore who desire dispatchable zero emission electricity
- Almost double in size: 17-20 GWp solar farm and approx. 36-42 GWh battery, on 12,000 ha at the Powell Creek Solar Precinct, 70 km sw of Elliott, adjacent to the Darwin-Adelaide rail-line.
- A +/- 525 to +/- 600 kV HVDC connection,
  - 3.2 GW HVDC OHTL runs 800 km to Darwin mainly in the rail corridor, then
  - 2.2 GW HVDC undersea cable, 4200 km to Singapore via Indonesia.
  - A Voltage Source Converter (VSC) station at Darwin to connect the Darwin-Katherine AC network.



- https://suncable.sg/newsroom/ >> 23 Sept 2021 Current fact sheet for Australia-Asia PowerLink

Sun Cable Powell Creek Solar Precinct

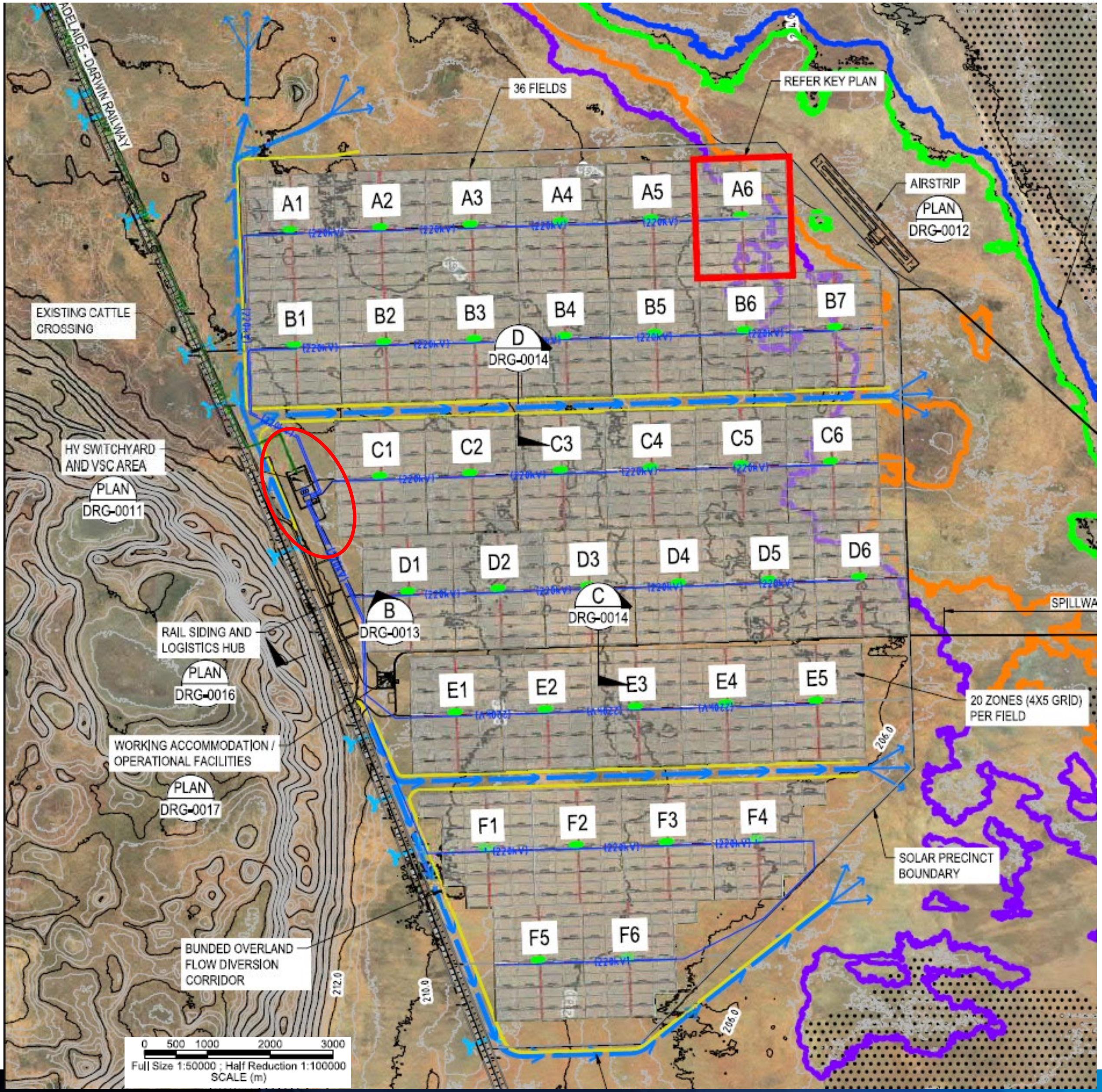
- Approximately 800 km South of Darwin
- Connected to Darwin by double circuit 6.4 GW, +/- 525 kV HVDC line running mostly in rail corridor
- Site is 12km x 10km = 12,000 ha



March 2022 EIS documents available at:
https://ntepa.nt.gov.au/your-business/public-registers/environmental-impact-assessments-register/assessments-in-progress-register/australia-asia-powerlink-project

Sun Cable Powell Creek Solar Precinct

- 6.4 GW HVDC VSC converter station and HV switch yard
- Consists of 36 Solar Fields; each one has
  - 400 – 560 MWp DC PV
  - 1.2 GWh of storage
  - 180 MW substation with 220 kV OHTL to HV switch yard.



March 2022 EIS documents available at: https://ntepa.nt.gov.au/your-business/public-registers/environmental-impact-assessments-register/assessments-in-progress-register/australia-asia-powerlink-project

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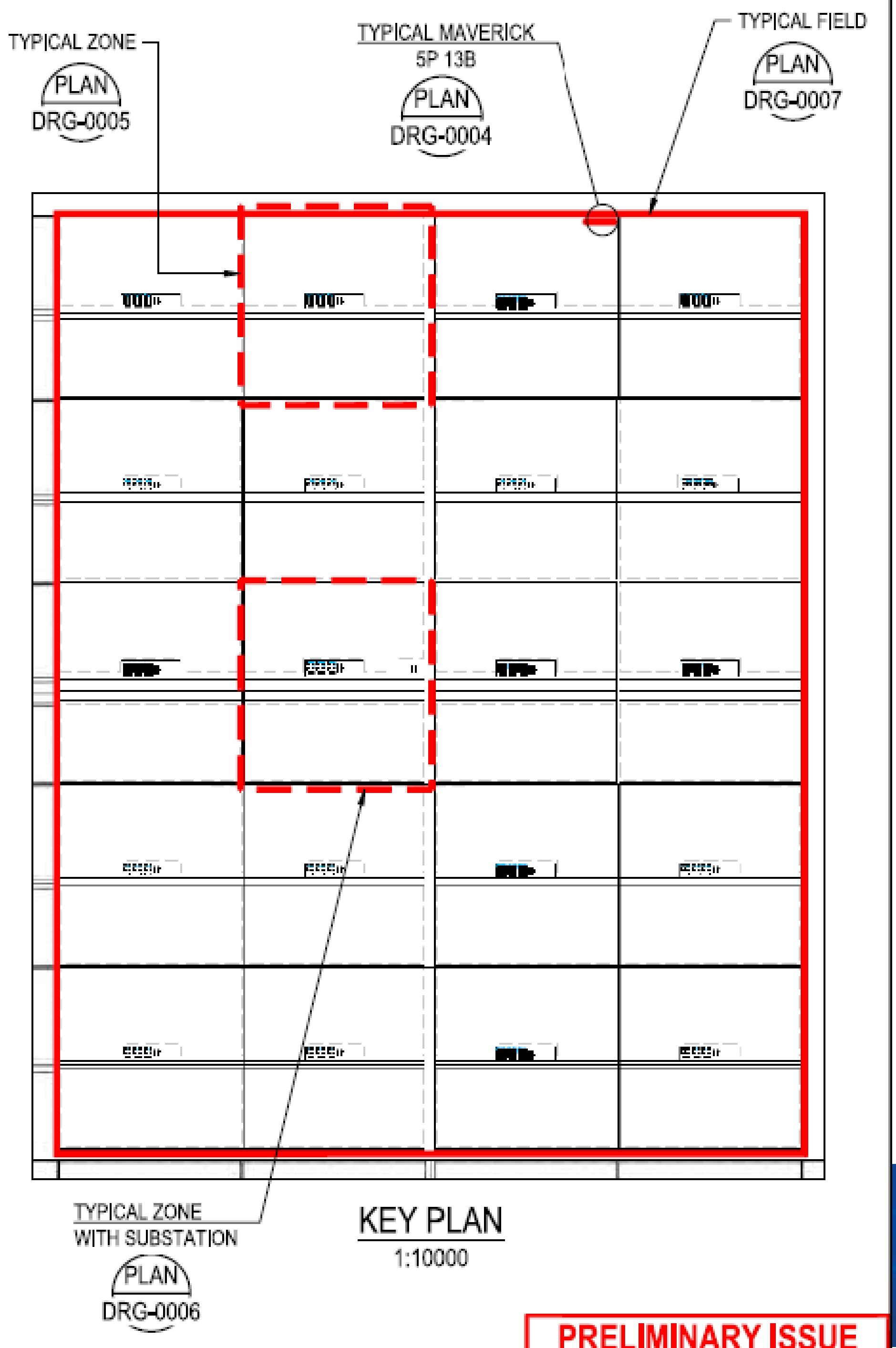
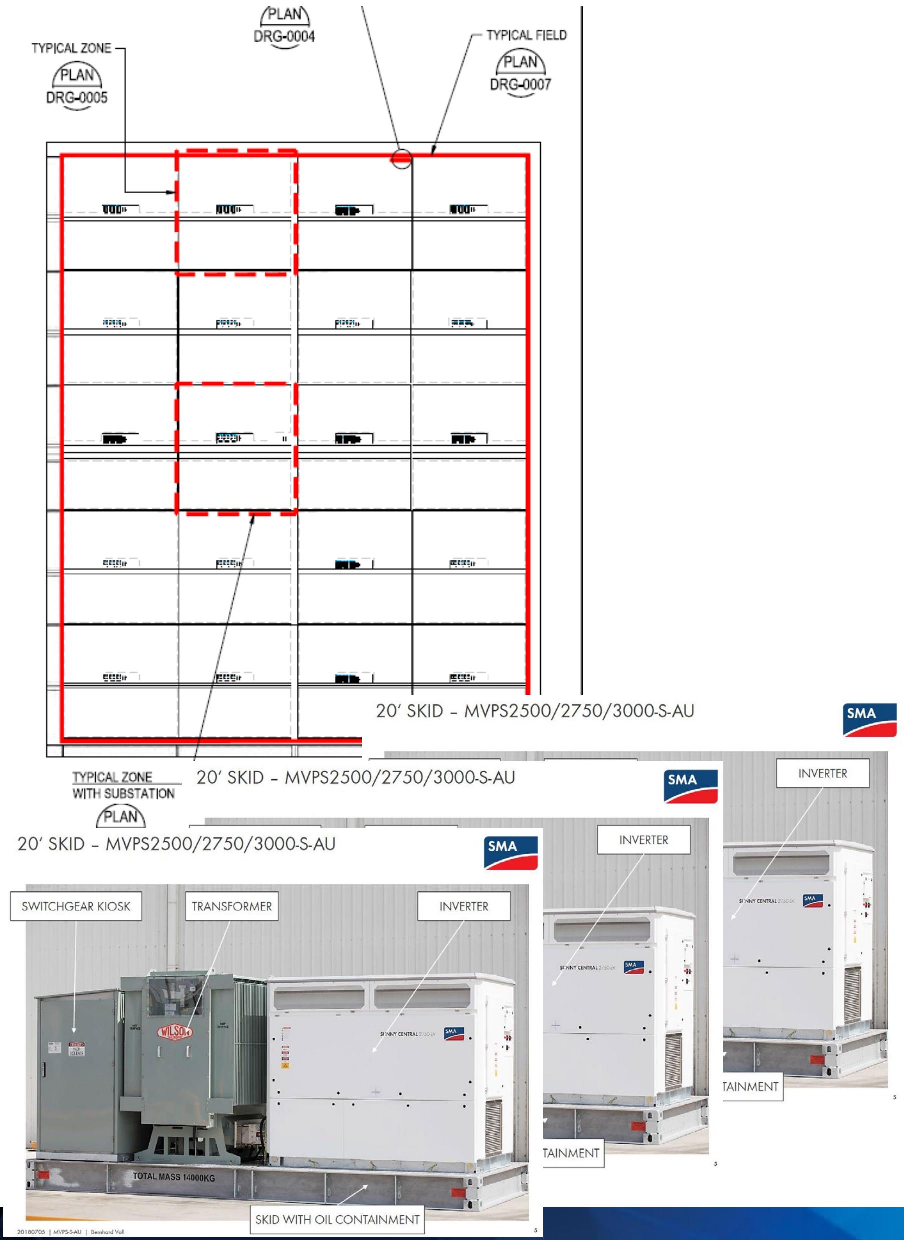
- Consists of 36 Solar Fields; each one has
  - 400 – 560 MWp DC PV
  - 1.2 GWh of storage
  - 180 MW substation with 220 kV OHTL to HV switch yard.
- Each Solar field has 20 Solar Zones,
  - 23 to 28 MWp DC capacity
  - 60 MWh of storage
  - Approx 9 MW inverter(s) and step up transformer(s).
  - DC collection at 1500 V from 5B Mavericks



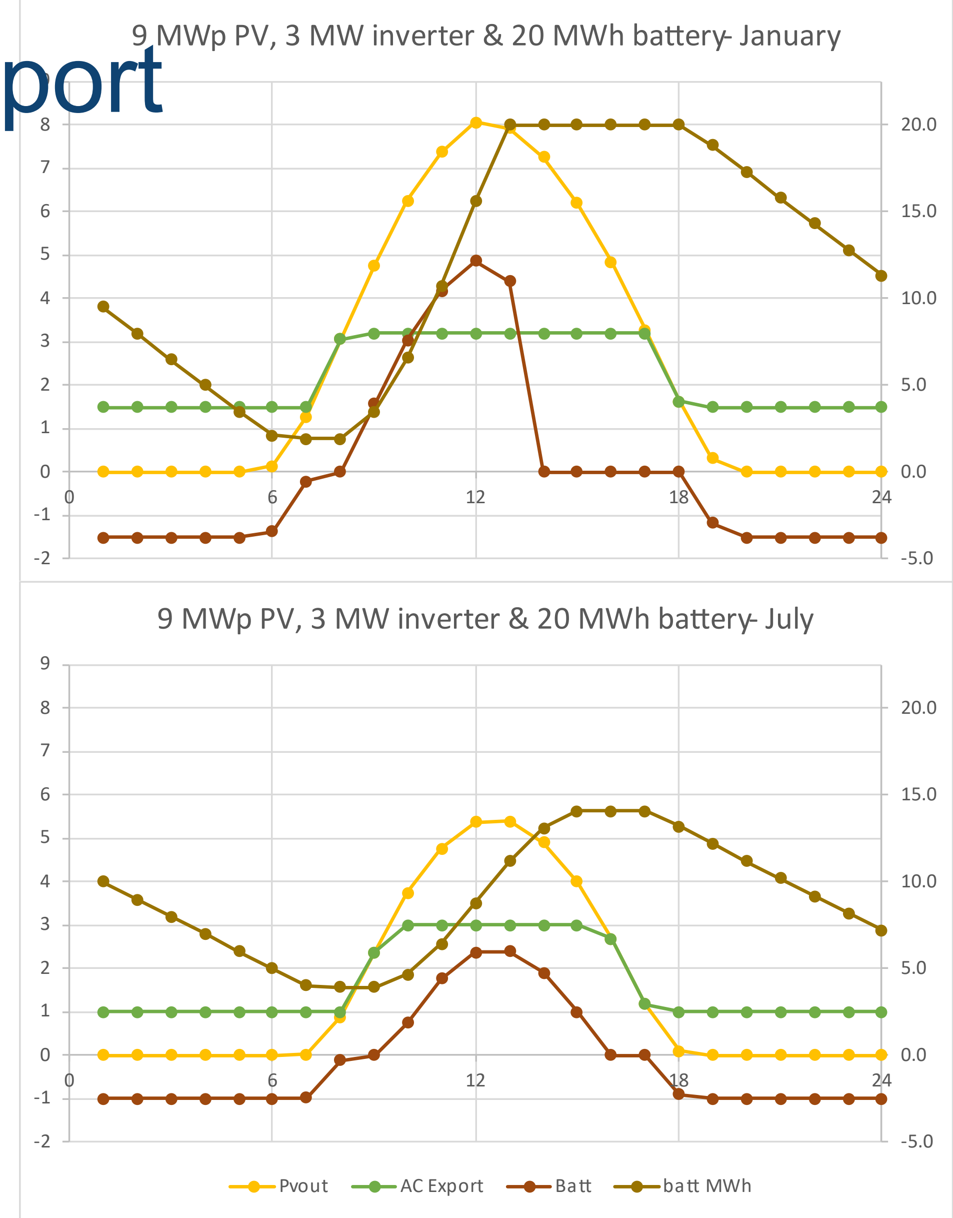
Sun Cable – 720 Solar Zones

- 36 Solar fields x 20 Solar Zones = 720 zones,
- Each Solar Zone
  - Approx 9 MW inverter(s) and step up transformer(s)
    - 3 x 3 MW inverters?
  - 23 to 28 MWp DC capacity   (Assuming 27 MWp…)
    - 9 MWp DC PV capacity per 3 MW inverter?
  - 60 MWh of storage
    - 20 MWh DC storage per 3 MW inverter =
    - 10 hrs at 2 MW discharge?
    - 16 hrs at 1.25 MW discharge? (8 hrs charge)
  - DC collection at 1500 V from 5B Mavericks



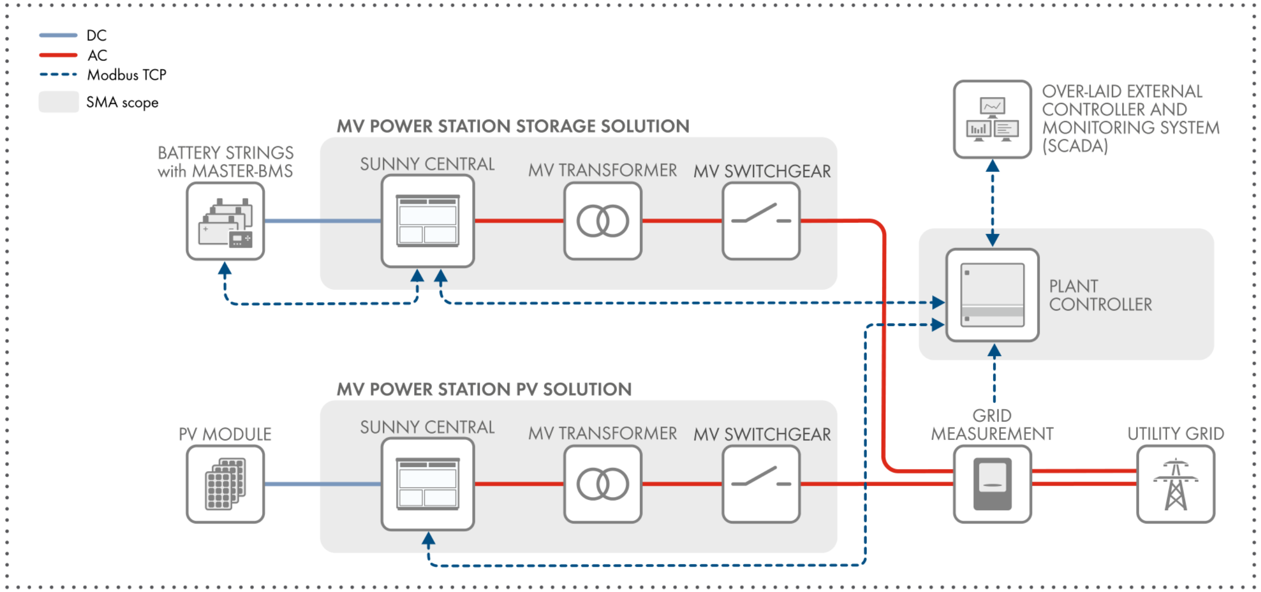
Sun Cable – MWh of PV, Batt, export

- Analysis of one PV inverter and battery assuming
  - 3.2 MW inverter
  - 9 MWp PV delivering 8.1 MWac at 1 Sun
  - 20 MWh DC storage
  - Alice Springs PV data – Monthly average hourly Global Horizontal plane Irradiation (GHI).
- January, PV peaks at 1.0 Sun at noon, 7.7 PSH
  - 3.2 MW exported for 10 hours,
  - 1.5 MW exported for 14 hours, 53 MWh total
  - Battery full by 1pm. (capacity factor = 69%)
- July, PV peaks at 0.67 Suns at noon, 4.4 PSH
  - 3.0 MW exported for approx. 8 hours,
  - 1.0 MW exported for 16 hours, 39 MWh total
  - Battery never fills, 10.2 MWh of capacity used.

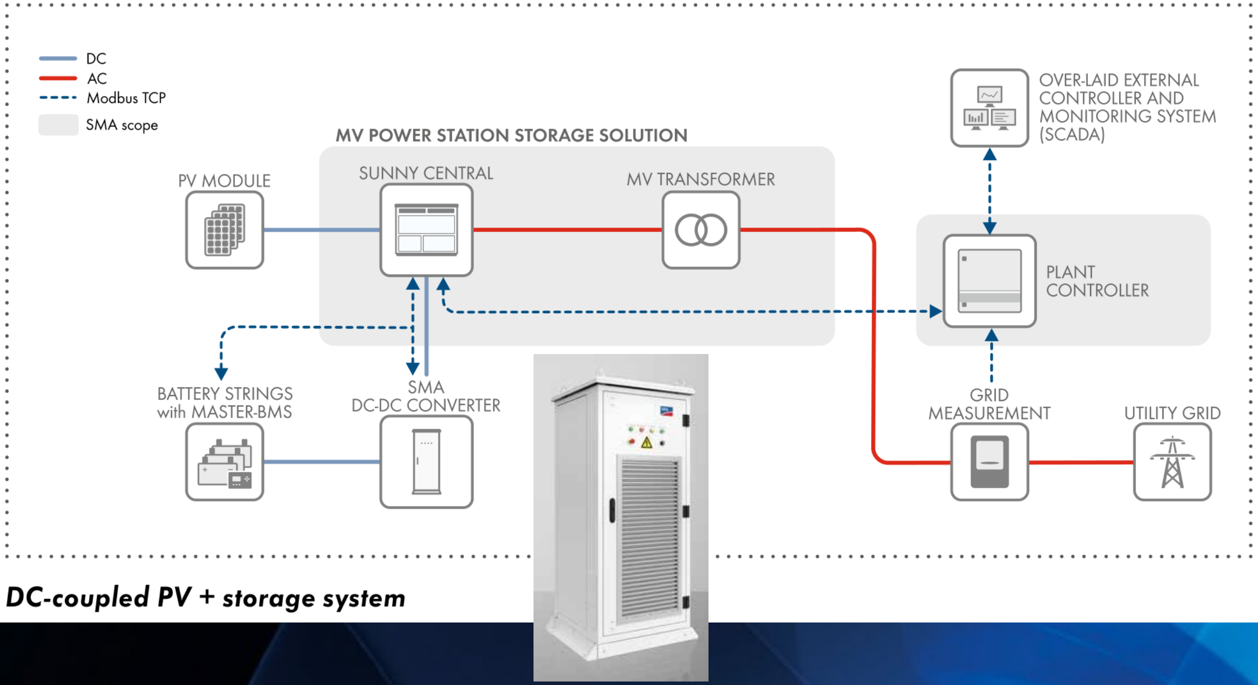


SMA DC coupled storage solution

- SMA has a “new” DC coupled storage solution for adding battery strings to their Sunny Central PV inverters in parallel with PV strings.
- No further information included.
- For a Sun Cable like system, the DC-DC converter would need a MW rating equal or possibly greater than the AC converter rating.
- Storage system energy flows through the DC-DC converter twice, so efficiency loss is compounded.

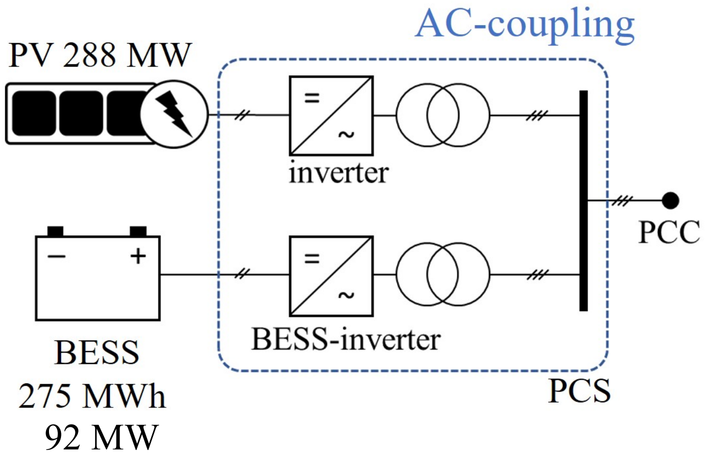


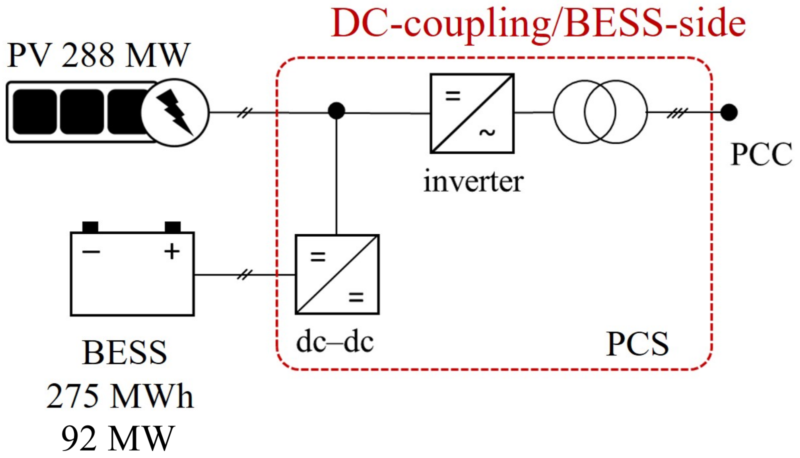
AC-coupled PV + storage system

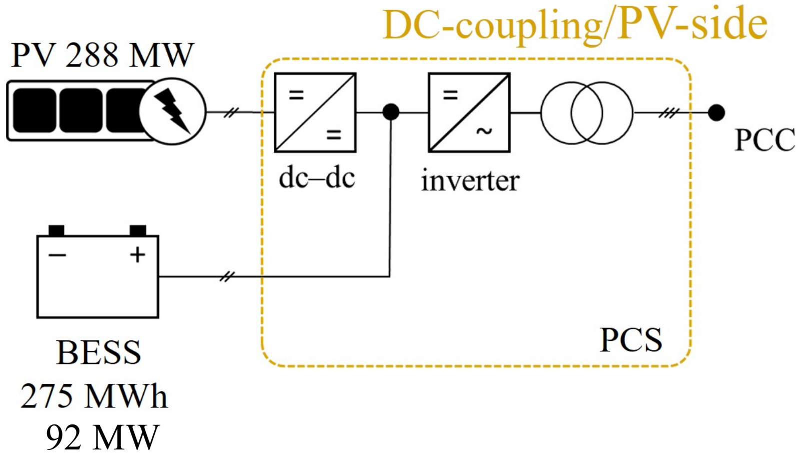


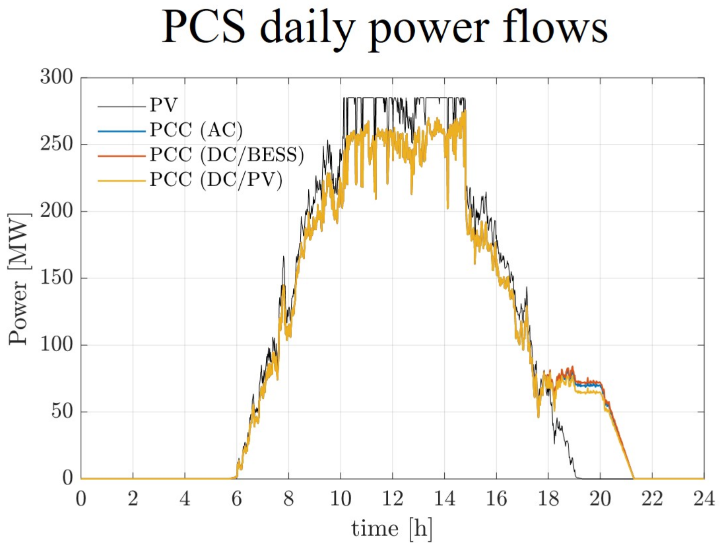
DC-coupled PV + storage system

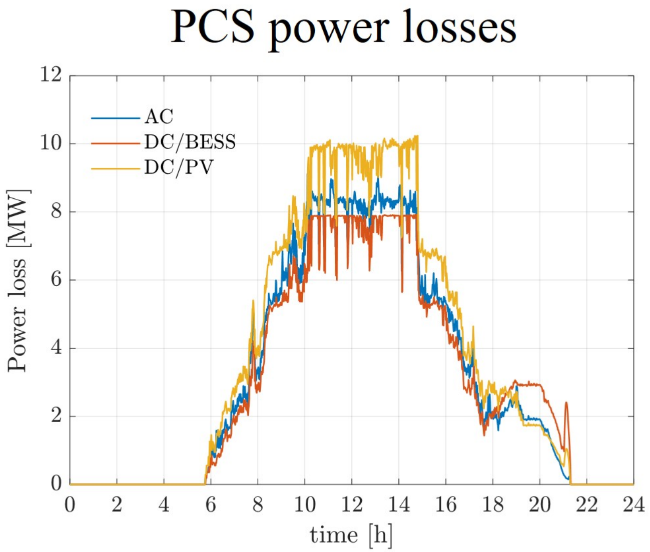
“Graphical abstract” – DC coupled BESS is most efficient

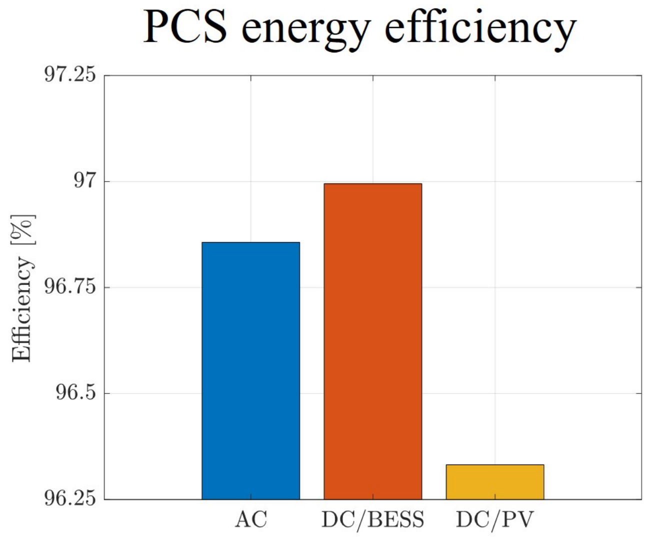






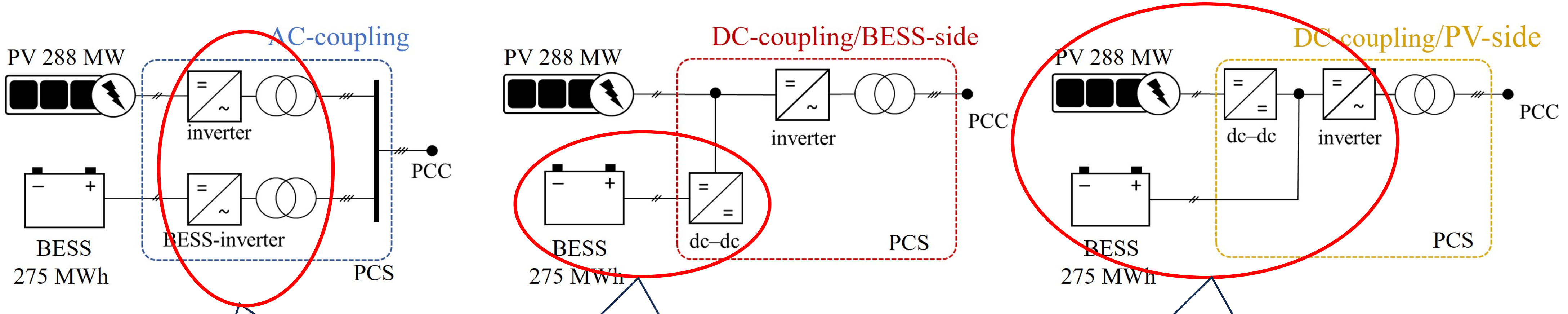






Lo Franco, F.; Morandi, A.; Raboni, P.; Grandi, G. Efficiency Comparison of DC and AC Coupling Solutions for Large-Scale PV+BESS Power Plants. Energies 2021, 14, 4823. https://doi.org/10.3390/en14164823

Future (technical) presentation:
PV and Battery integrated converters …

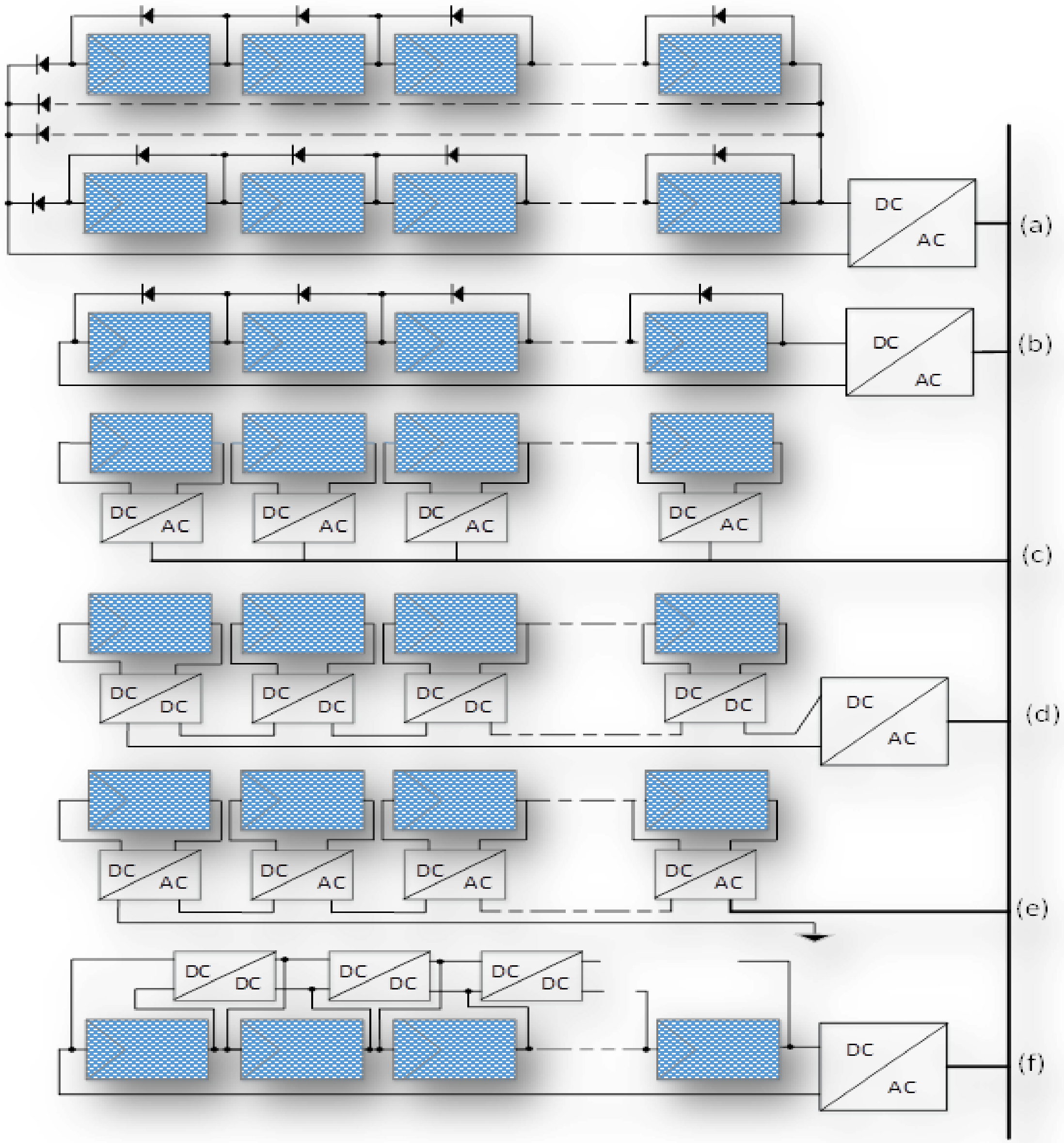


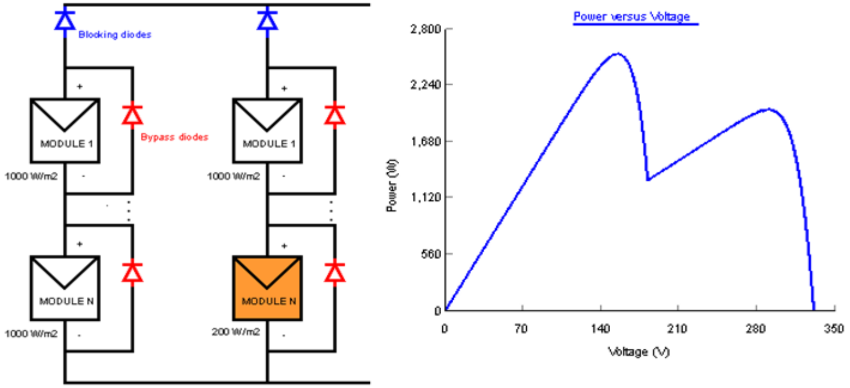
It works, It's well understood, but it misses so many opportunities!

This is much better, but there are some clever ways to integrate the converters with the batteries

There are also clever techniques to integrate the PV into the system as well

The Concept of Module Integration in PV





a) Centralized in

b) String inverters

C MICs

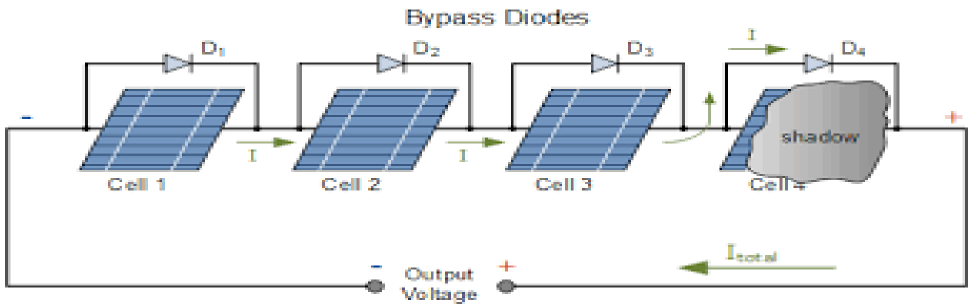
d) Cascaded dc-dc MICs

e) Cascaded dc-ac

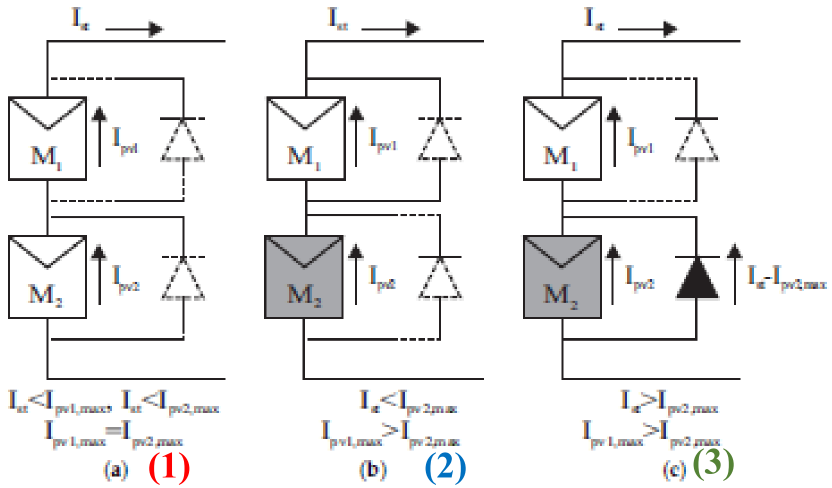
f) Bypass dc-dc MICs

- Series / parallel PV strings can suffer from mismatch and lower performance.
- Multiple smaller converters can solve this issue

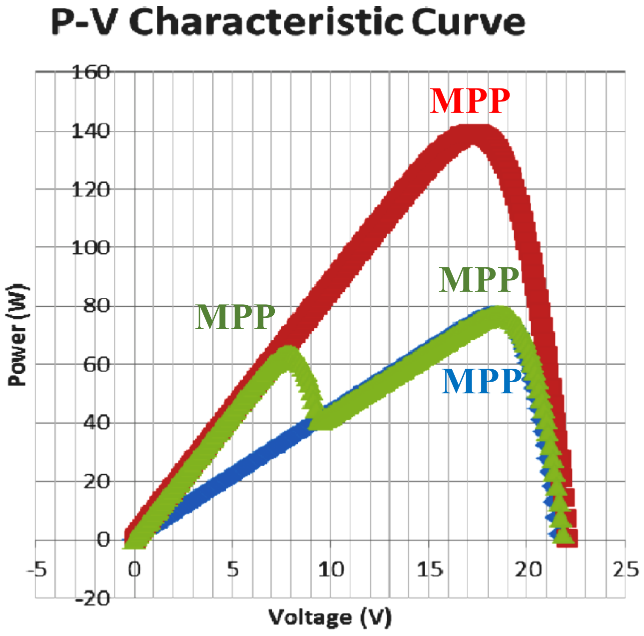
The Concept of Module Integration in PV Applications



Series connected PV modules with bypass diodes [5]

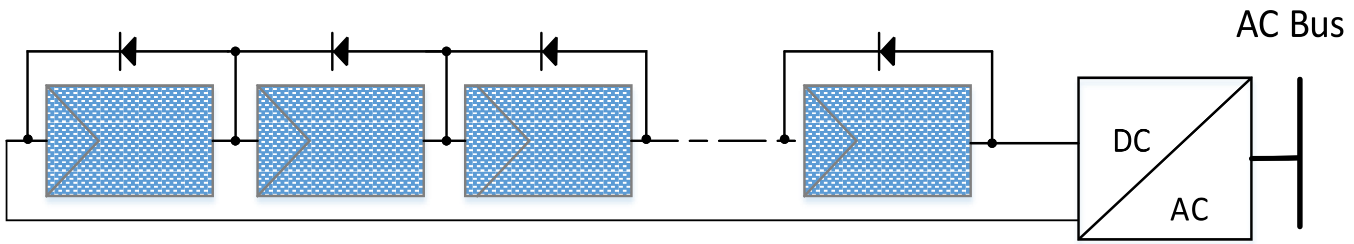


Series-connected PV modules with bypass diodes under uniform and mismatching conditions. (**a**) Uniform conditions: $I_{pv1,max} = I_{pv2,max}$; (**b**) Mismatching conditions: $I_{st} < I_{pv2,max}$; (**c**) mismatching conditions: $I_{st} > I_{pv2,max}$. [6]

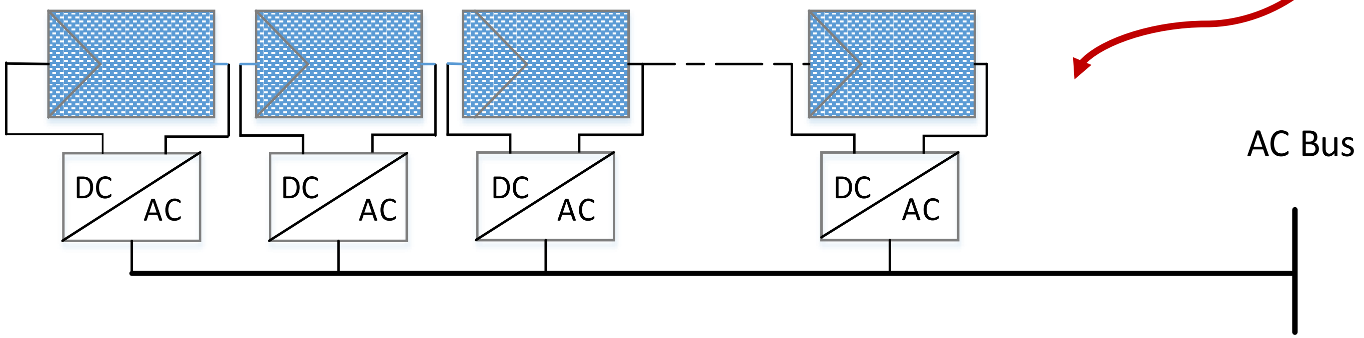


P-V Characteristic curves of 3 different conditions [7]

The Concept of Module Integration in PV Applications

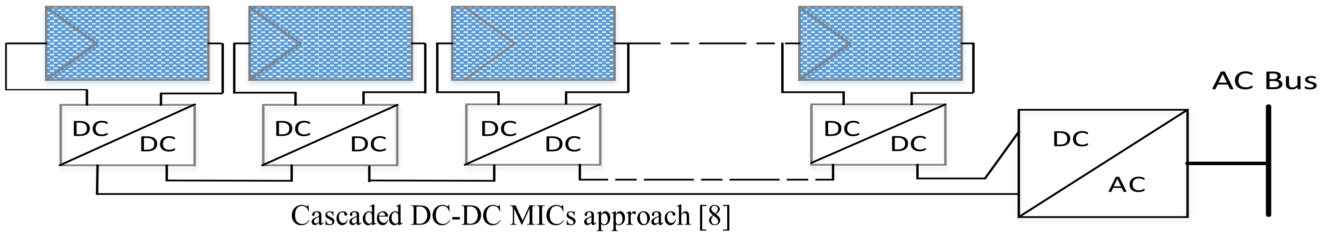


string inverters approach [8]

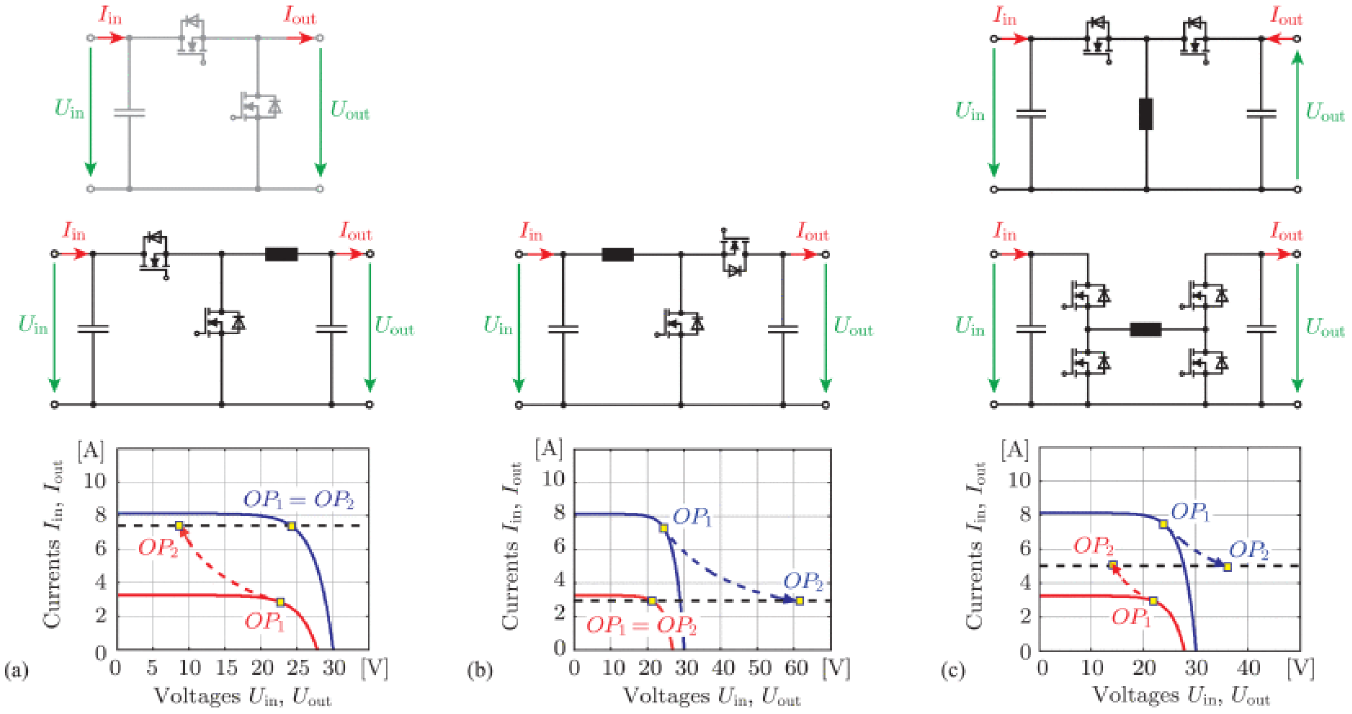


Module Integrated Converters (MICs) approach [8]

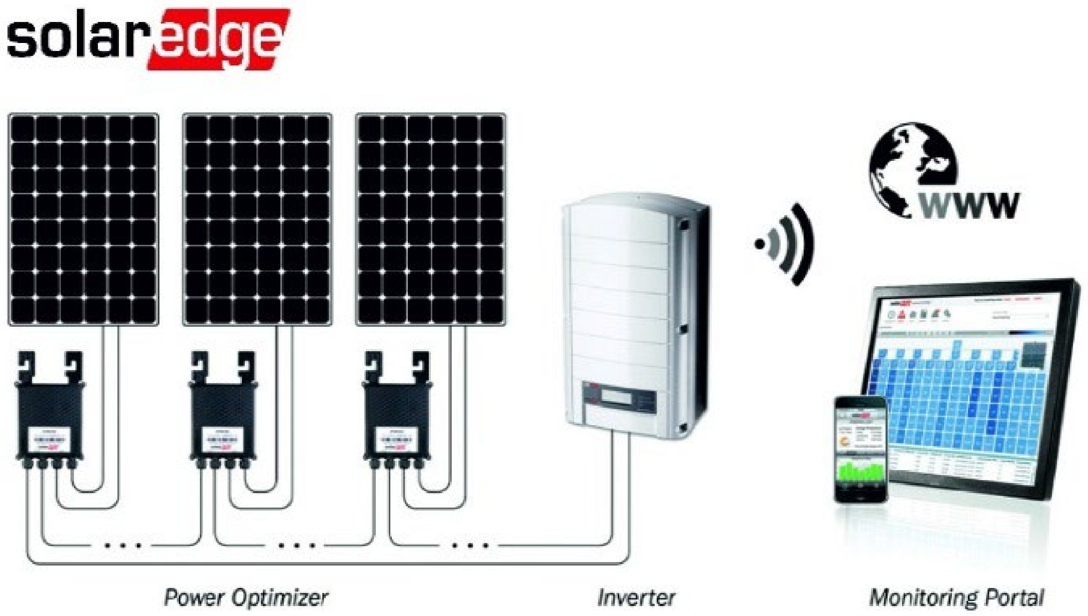
The Concept of Module Integration in PV Applications



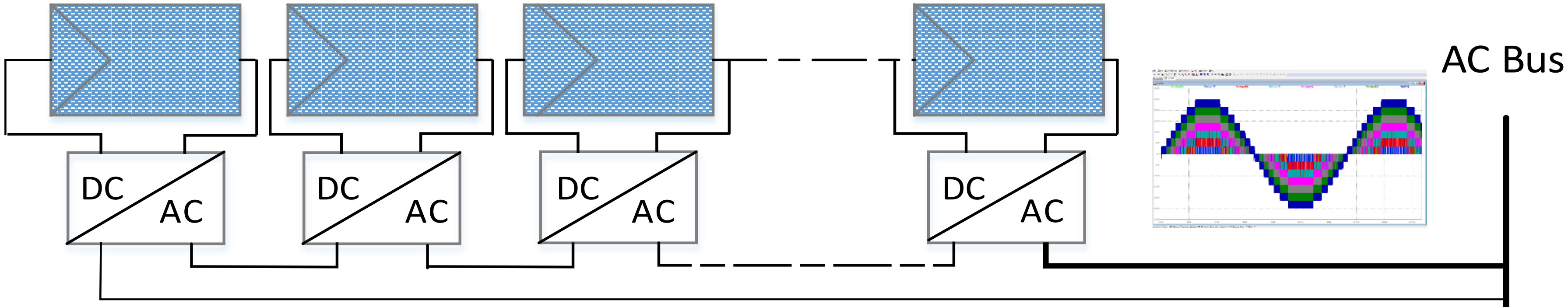
Cascaded DC-DC MICs approach [8]



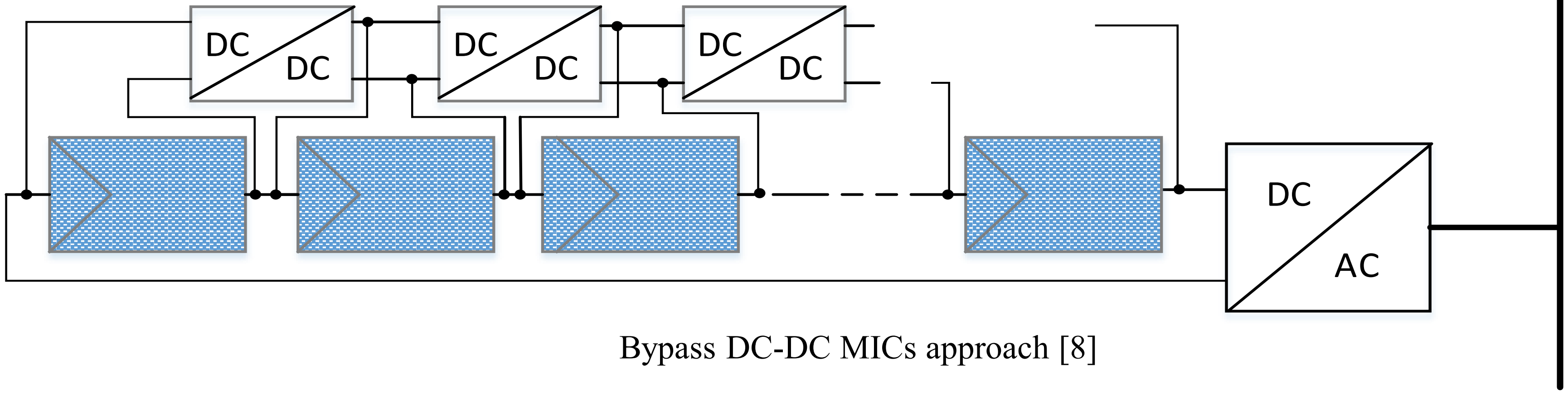
Working principles of full-power converters for series connection of shaded (red) and unshaded (blue) panels: (a) buck converter, (b) boost converter, and (c) buck–boost converter [9]



The Concept of Module Integration in PV Applications



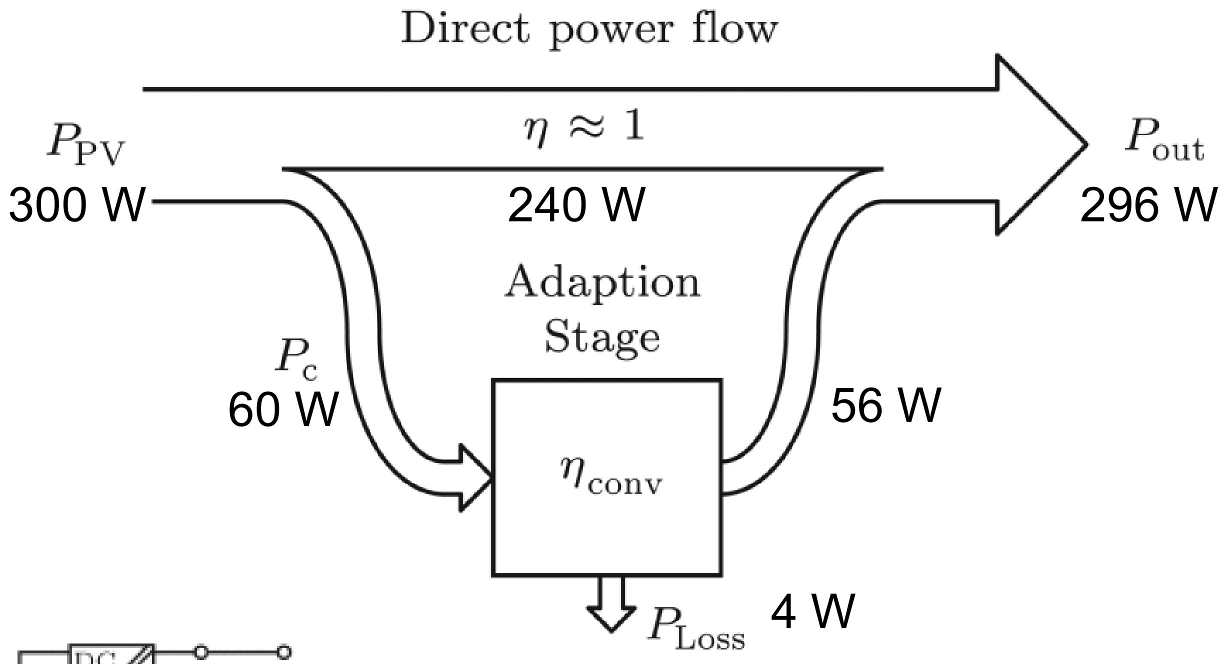
Cascaded DC-AC MICs approach [8]

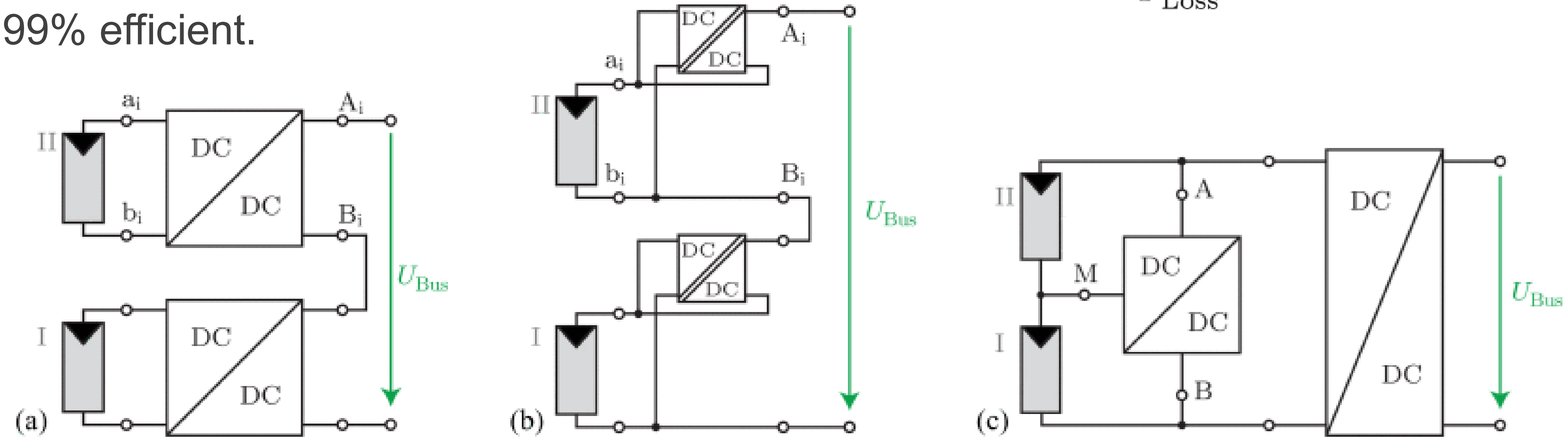


Bypass DC-DC MICs approach [8]

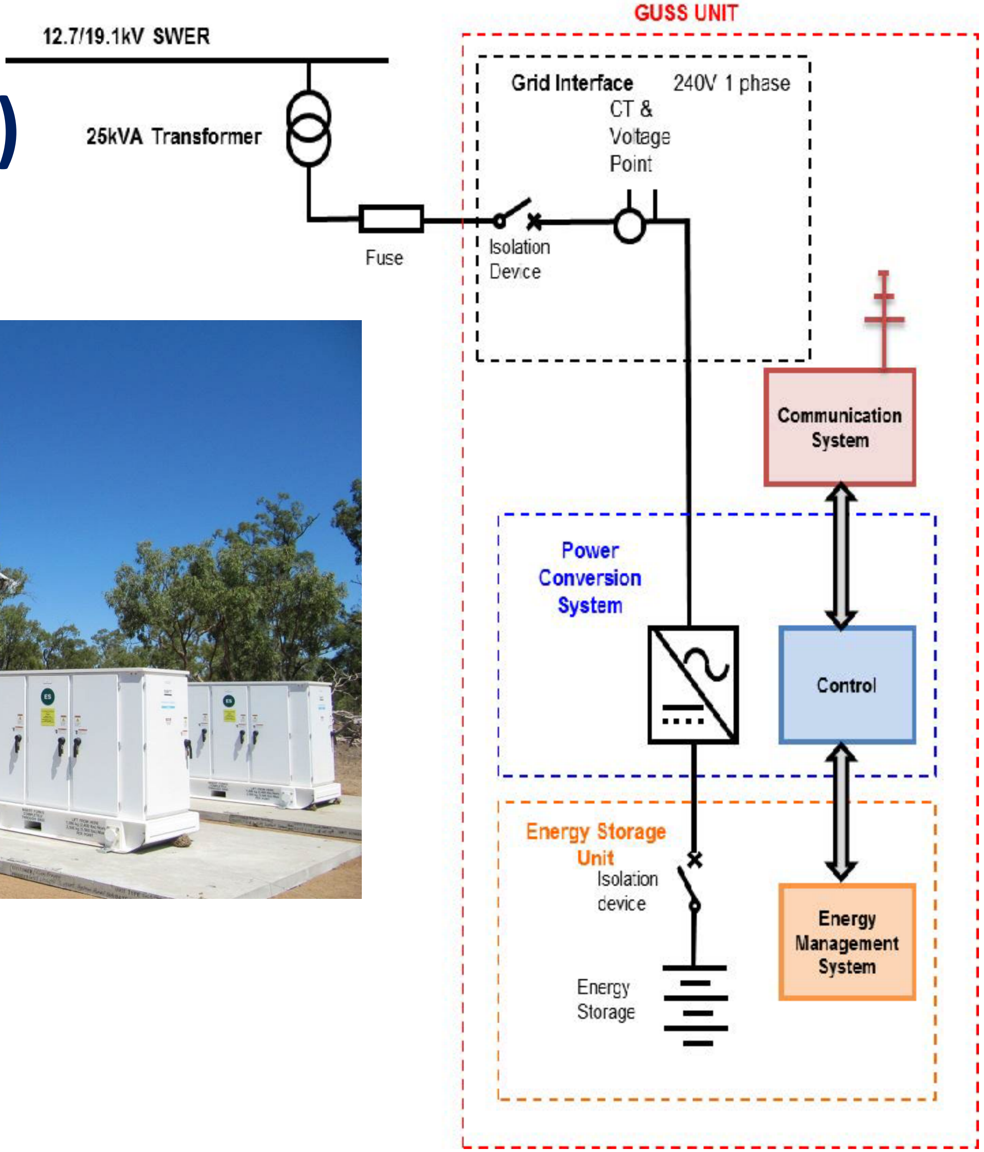
Partial Power Processing

- Example …
- PV 30V x 10A = 300W (ai, bi)
- DC-DC only 93% efficient
- 30Vx2A = 60W in, 7Vx8A = 56W out
- Output 37V x 8A = 296W (Ai, Bi)
- Overall almost 99% efficient.



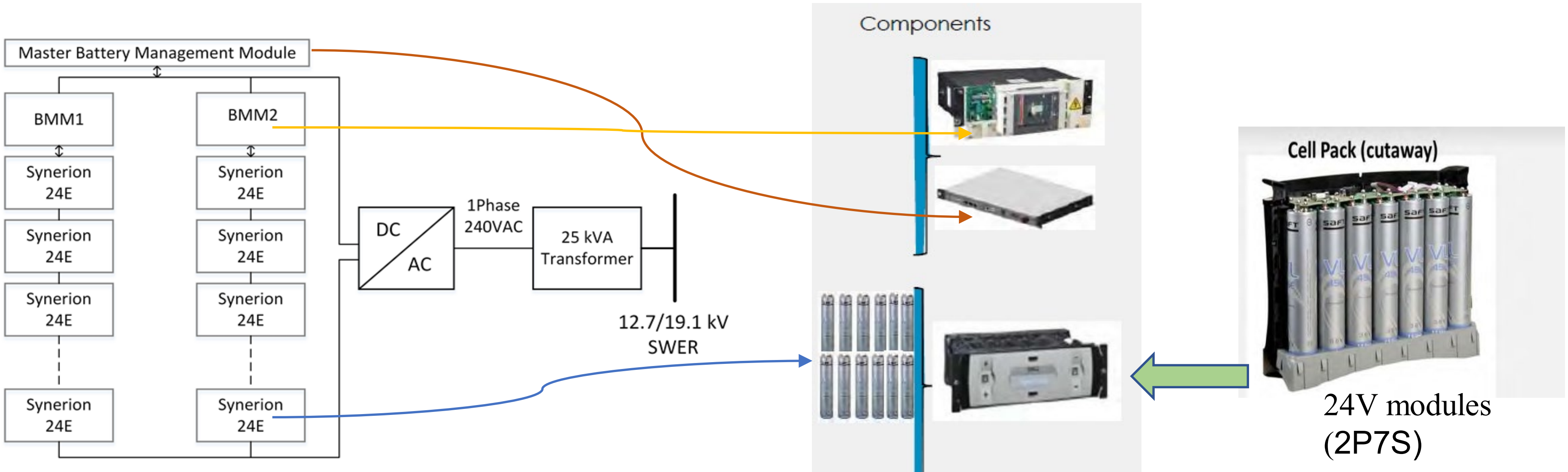


Ergon Grid Utility Storage System (GUSS)



- ✓ 120 kWh of Lithium Ion batteries (to meet a 5 hour load at 25 kVA).
- ✓ 25 kVA four quadrant single phase inverter
- ✓ Connects to the SWER line via a 240 V, 25 kVA pole mounted transformer (not shown in photo)

https://www.tdworld.com/distribution/storage-has-vital-role



Basic GUSS system (2P28S Synerion 24V modules)

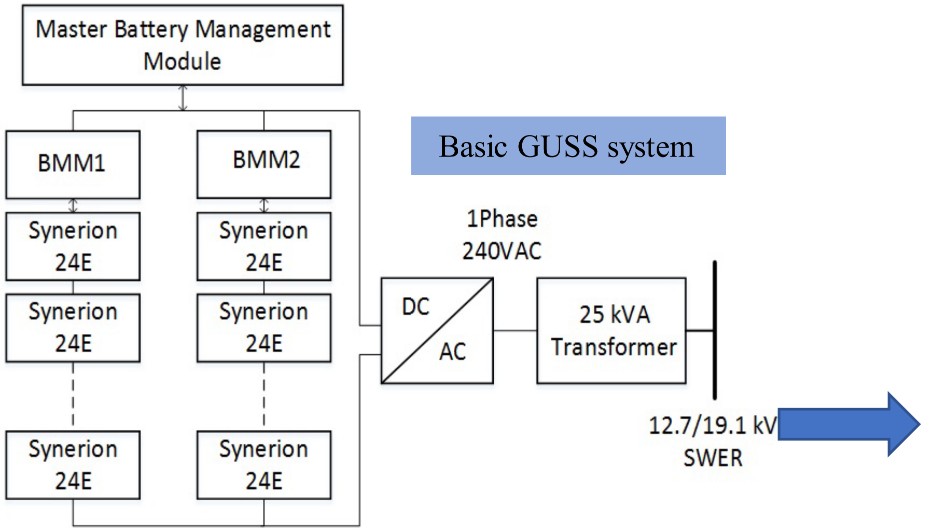
GUSS(Saft Intensium Mini system)

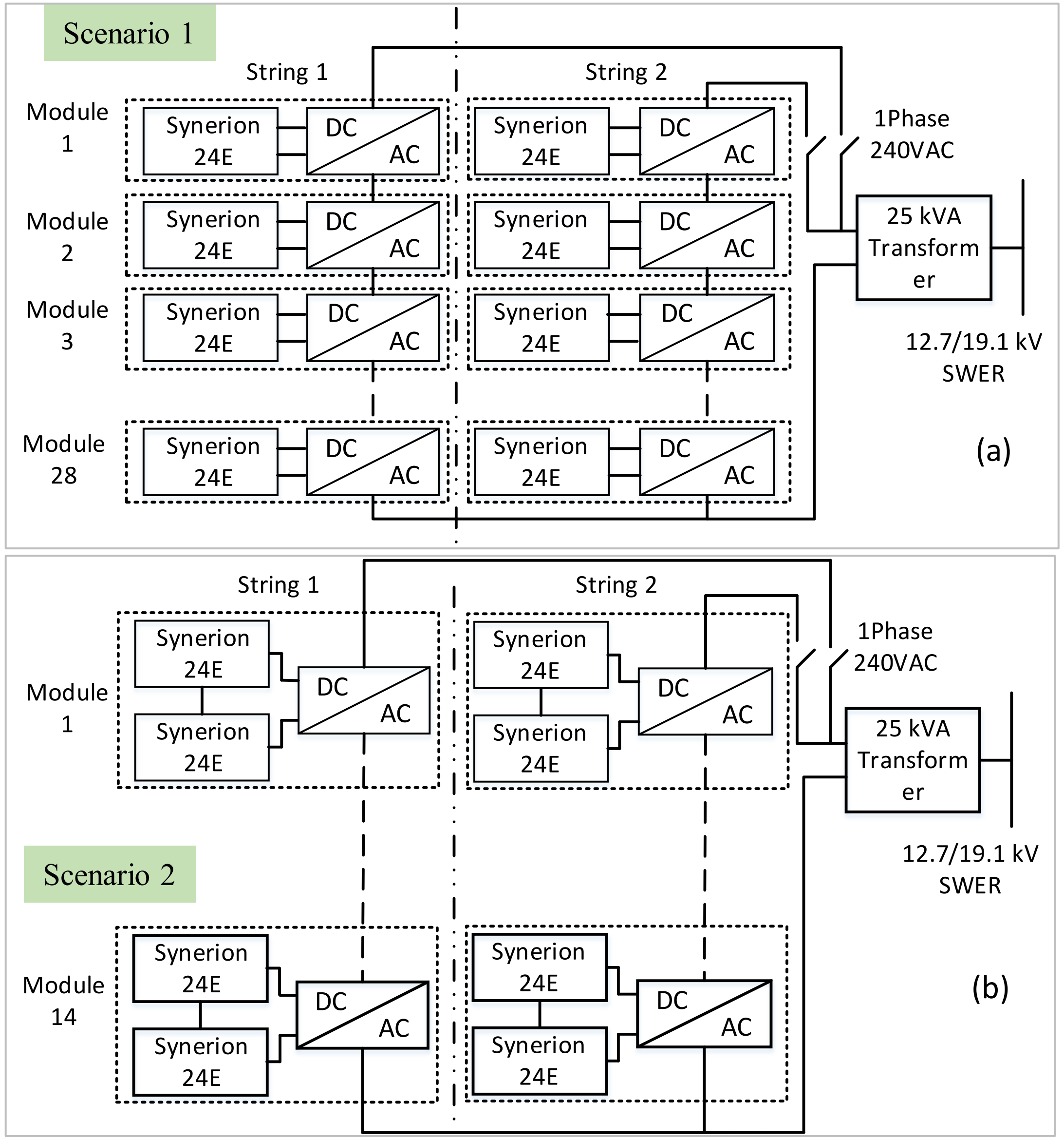
Electrical characteristics at +25°C	E
Nominal Voltage (V)	700
Minimum Voltage (V)	588
Maximum Voltage (V)	790
Capacity (C/5)(Ah)	174
Energy (C/5) (kWh)	120
Continuous discharge power (kW)	220
Continuous charge power (kW)	61
Maximum continuous discharge current (A)	360
Maximum continuous charge current (A)	90
Insulation resistance (1000 V – OC)	>100 MΩ
Dielectric isolator	3 kV rms

The GUSS components:

- ✓ 25 kVA four quadrant inverter
- ✓ 120 kWh of Lithium Ion batteries (to meet a 5 hour load at 25 kVA).
- ✓ one Master Battery Management Module (MBMM)
- ✓ 2 Battery Management Modules (BMM) per Intensium® Mini

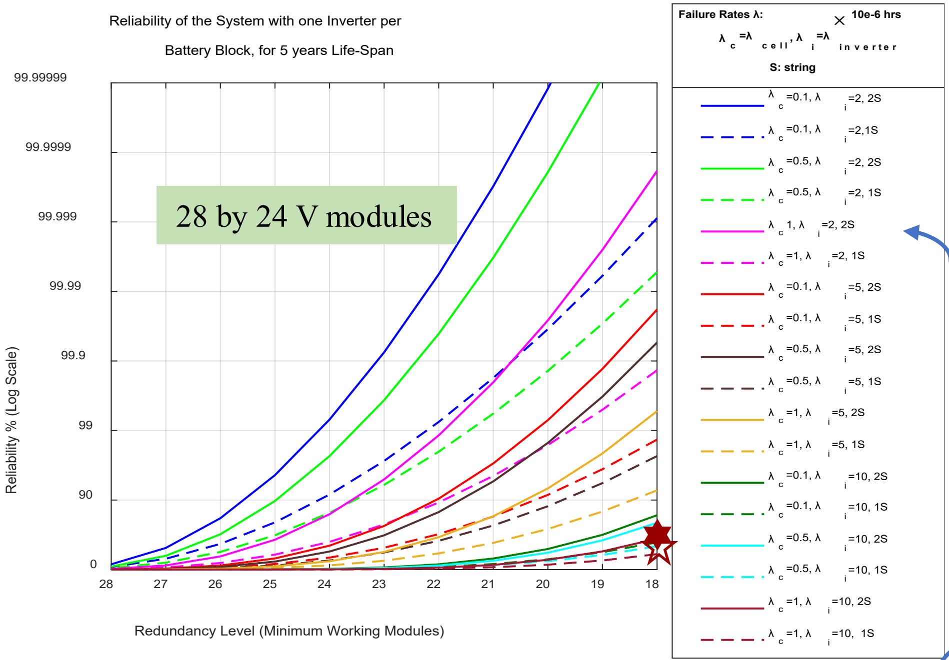
Battery-Integrated-Converter for GUSS Application

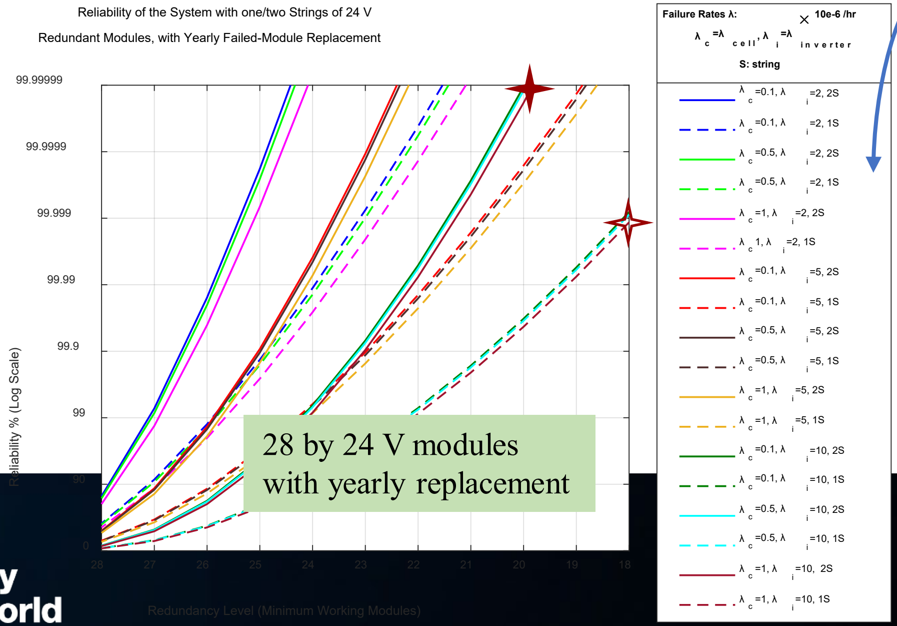




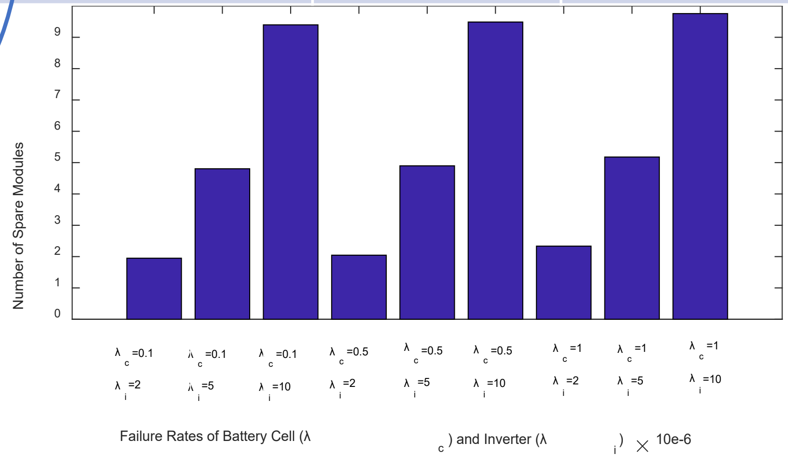
- Scenario 1: Nominal 24 V modules (21 V at 3V cell minimum), up to 18-out-of-28 redundancy
- Scenario 2: Nominal 48 V modules (42 V at 3V cell minimum), up to 9-out-of-14 redundancy

Results – Yearly failed module replacement – 24V modules



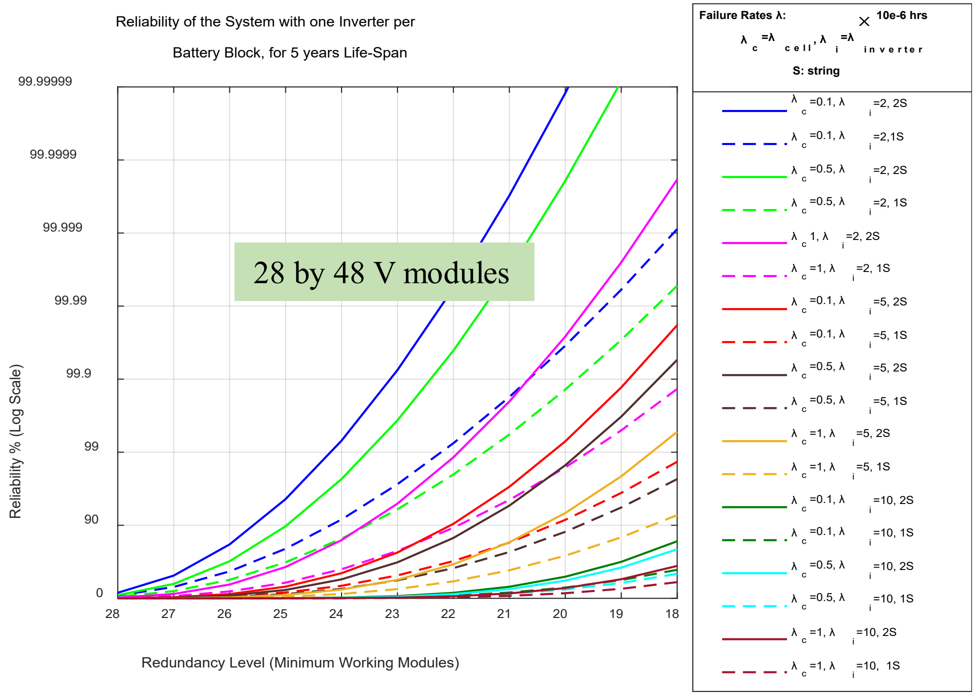


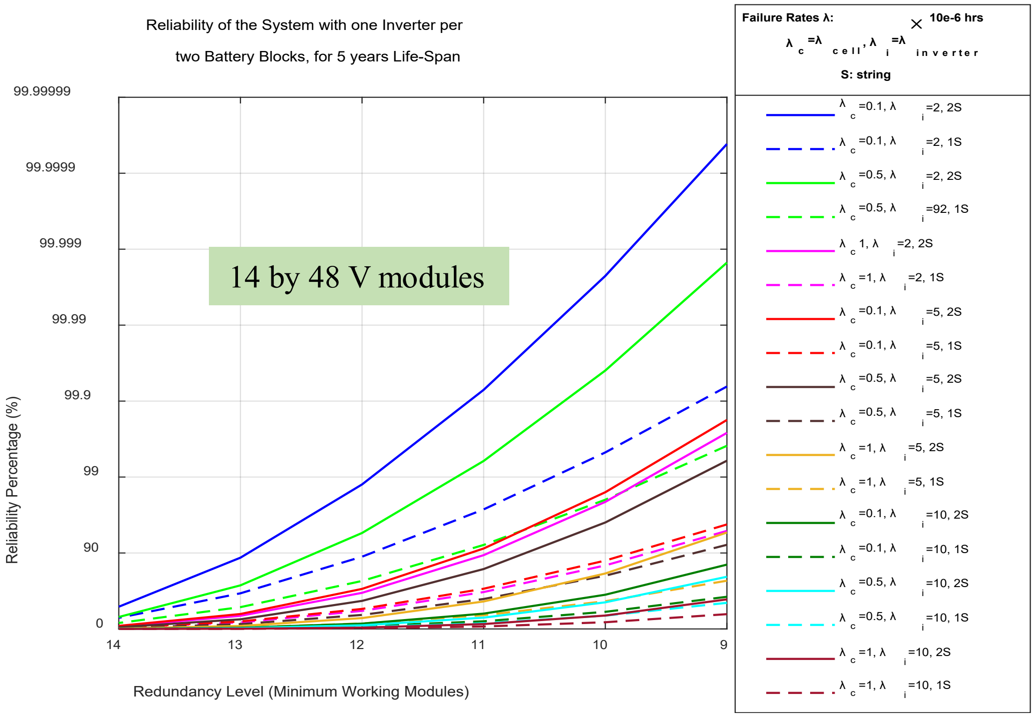
The battery-integrated-inverter system	$\lambda_{inverter}$ = 10e-6 /hr (the worst failure rate)	
	One string	Two string
28 by 24V modules	> 39.99 %	> 63.99 %
28 by 24V modules with yearly replacement	> 99.99885 %	> 99.99998% > six-sigma (99.99966)



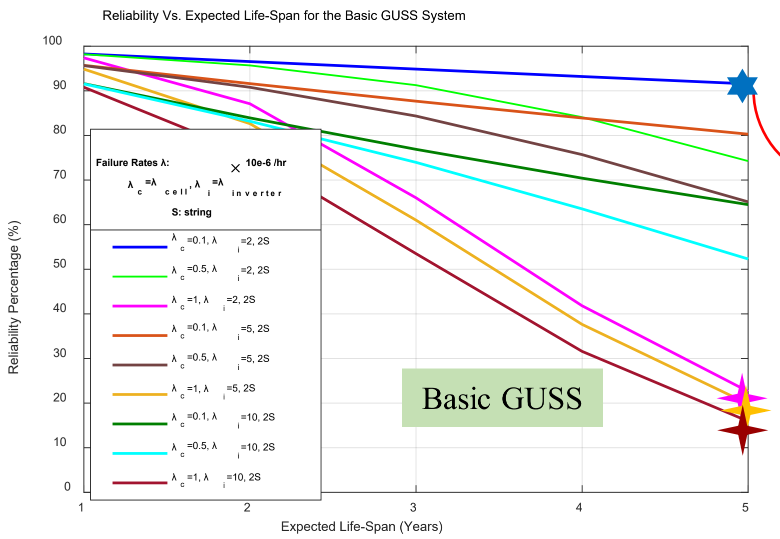
Number of the spare modules for the system with one-string of 24 V redundant modules to ensure > 99.99885 % reliability, with yearly failed-module replacement for 5 years

Results – Five year reliability – 18 combinations (refer to paper)





- the system with 14 by 48 V redundant modules is less reliable than the system with 28 by 24 V modules.
- This is because of the higher number of the series connected battery cells per module, which affects the module reliability.
- However the fewer number of inverters may decrease the cost and weight of the system as well.

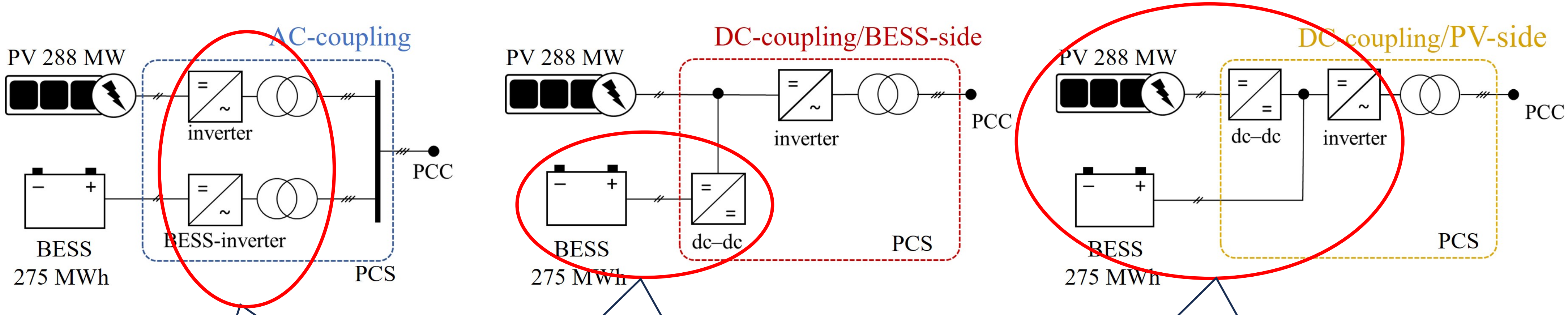


Results and Discussion

Basic GUSS System: total 2P 28S of modules (each module: 2P 7S cells) + single inverter

- At the best condition of the failure rates assumption (λ_{cell} = 0.1e-6 /hr, $\lambda_{inverter}$ = 2e-6 /hr) the system is 91.55 % reliable over a five year timespan.
- **NB:** reliability of ***actual*** GUSS systems, based on 25 units deployed for five + years, is much higher …

Future (technical) presentation: PV and Battery integrated converters …



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