SERIS
Solar Energy Research
Institute of Singapore

Key findings from Singapore Floating PV Testbed Project

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Solar Energy Research Institute of Singapore (SERIS)

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Outline

- Introduction to the Floating PV Testbed in Singapore
- Operation conditions and system performance analysis
- Field experience: issues encountered
- Conclusion

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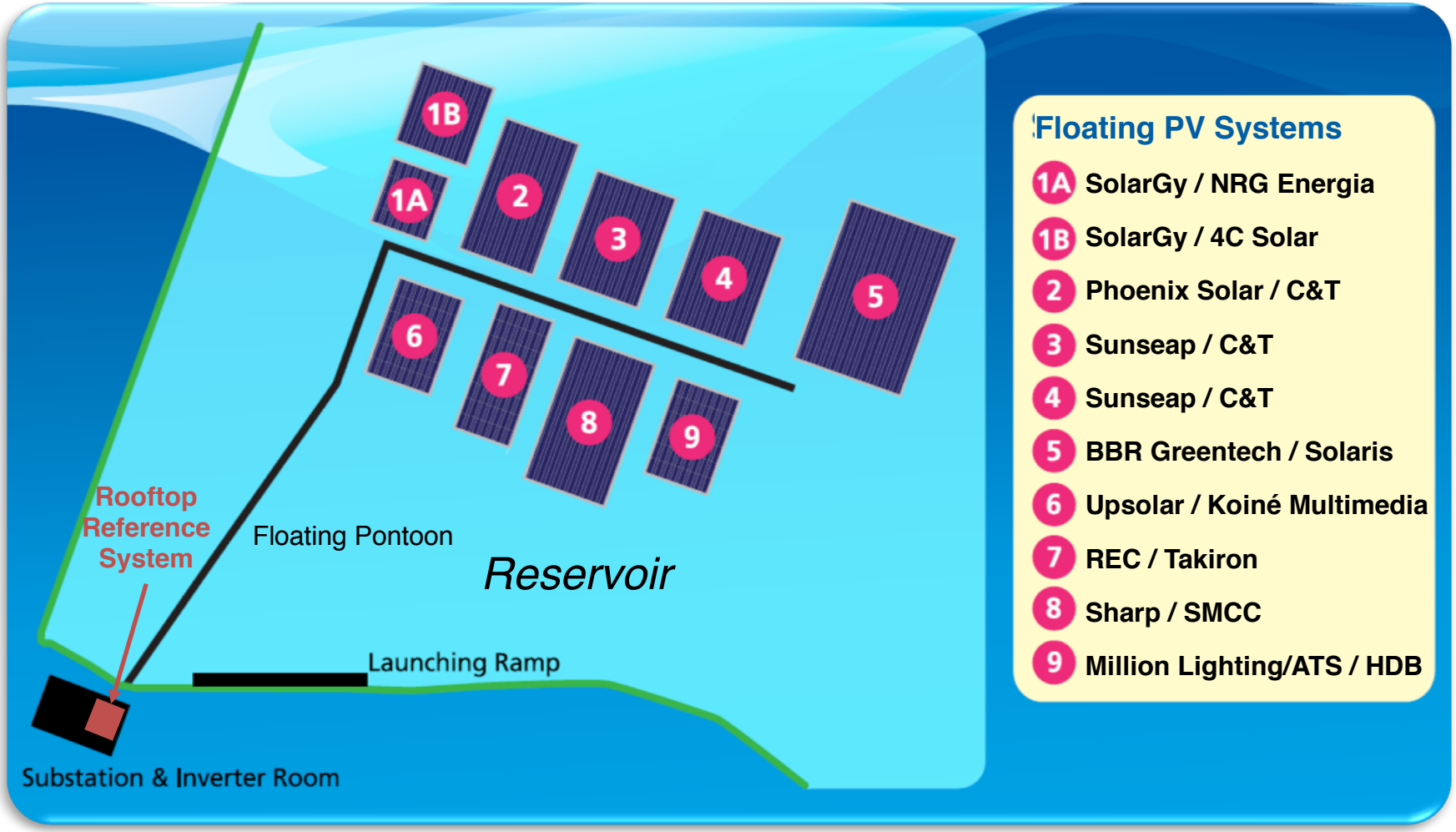
Floating PV Testbed (2)

- Project Site Plan



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Floating PV Testbed (3)

- Supporting Infrastructure Works

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Floating PV Testbed (4)

- Large scale FPV testbed
- Side-by-side comparison of major commercial FPV technologies
- Detailed monitoring
  - Environment
  - Energy yield
  - Module temperature
  - Bi-facial module
  - Active cooling
- Economics, LCOE

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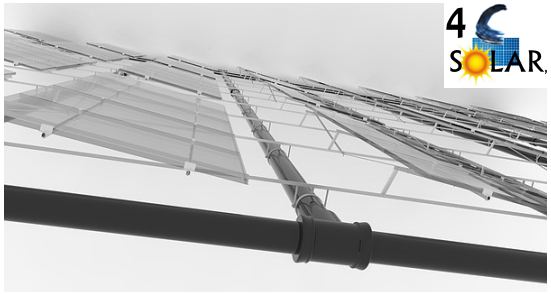
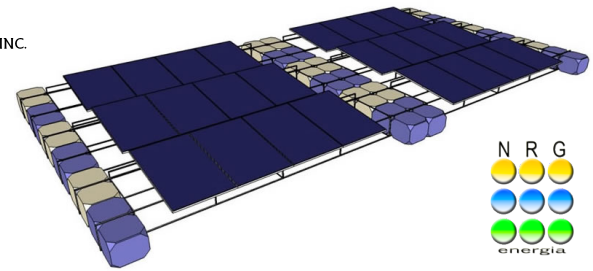
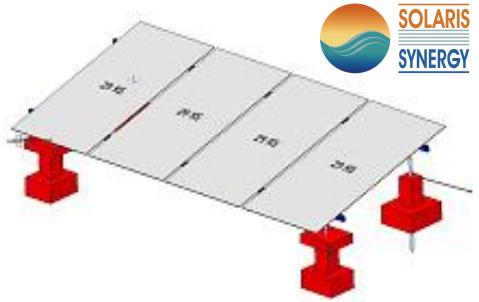
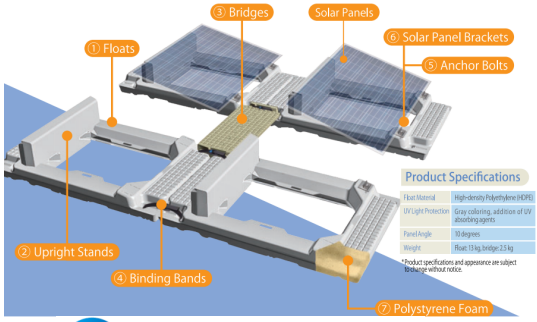
Floating PV Testbed (5)

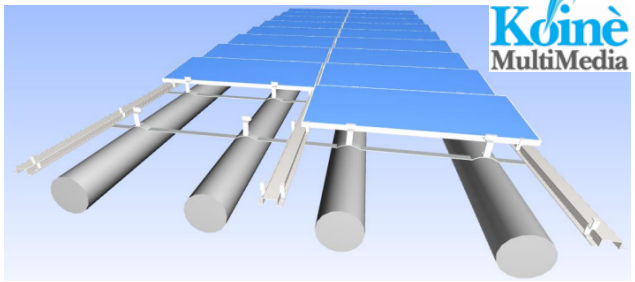
- Floating platform technologies in the testbed





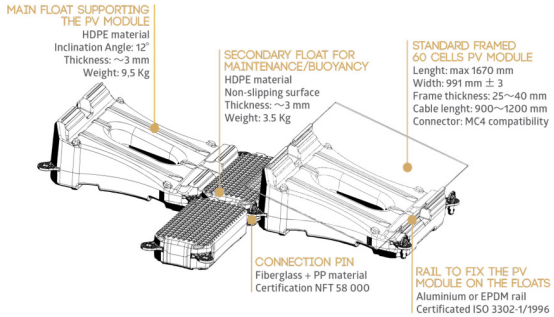




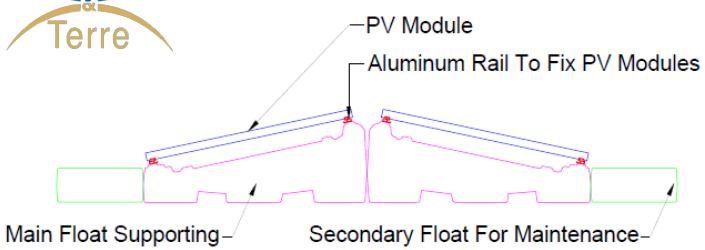


SUMITOMO MITSUI CONSTRUCTION CO.,LTD.

TAKIRON



Ciel et Terre



Floating PV Testbed (6)

- Comprehensive monitoring infrastructure, with >500 parameters
  - Meteorological station (reservoir & rooftop)




  - PV System performance monitoring




DC (PV String) AC (PV array) Motion sensor Module Temp.

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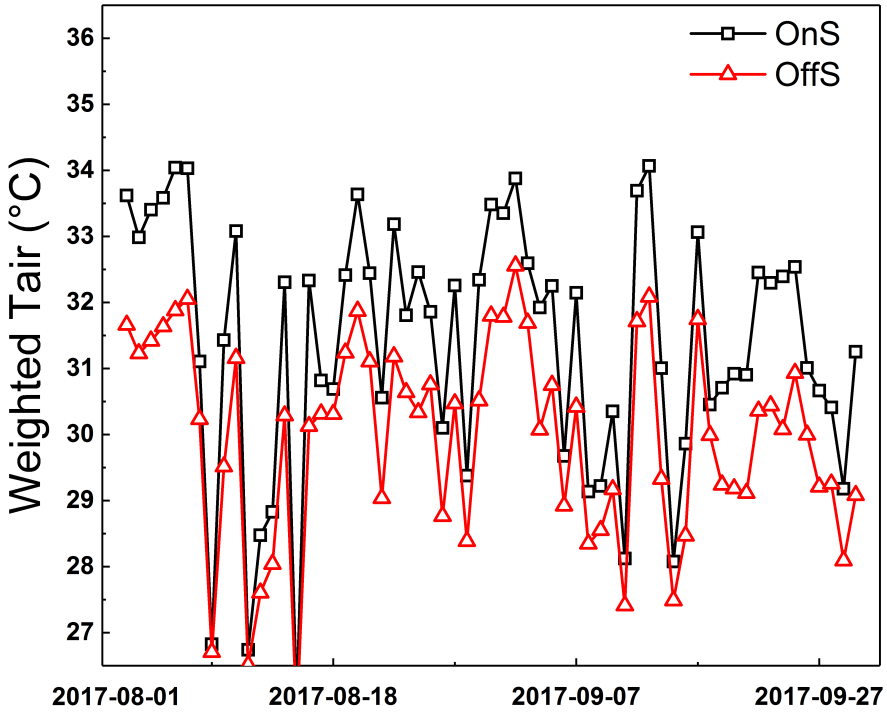
Testbed operating conditions (1)

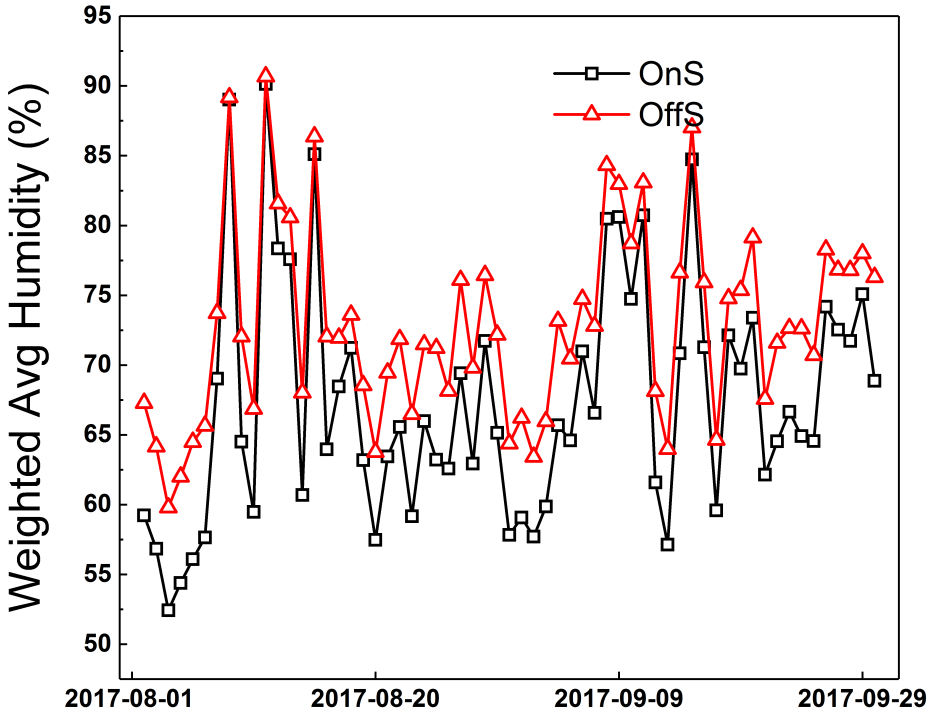
❑ Ambient temperatures

- ➢ $T_{ambient}$ on water (vs. rooftop) is consistently lower

❑ Humidity

- ➢ Humidity on water is generally higher





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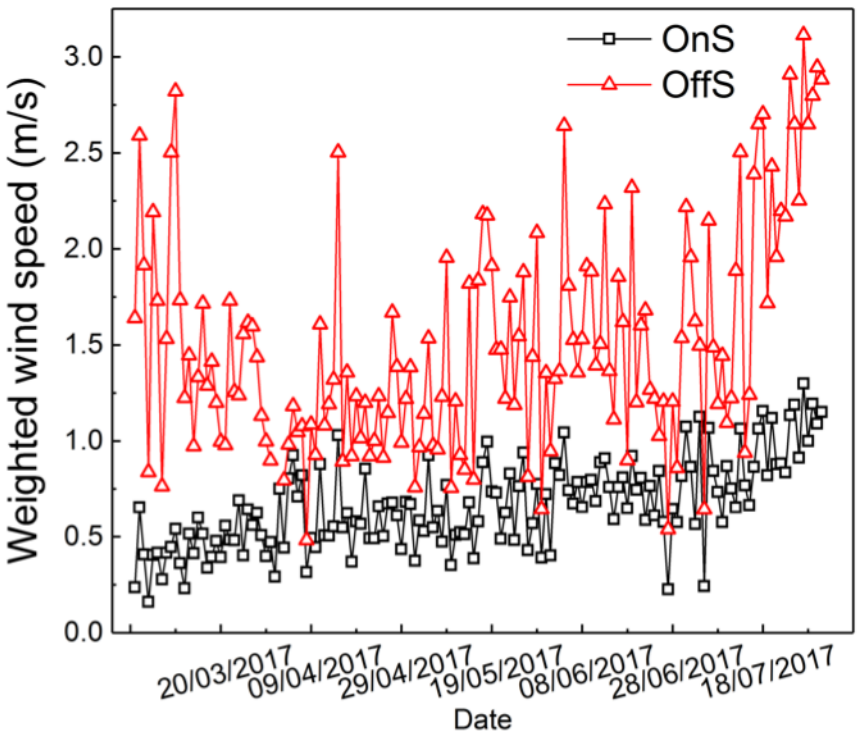
Testbed operating conditions (1)

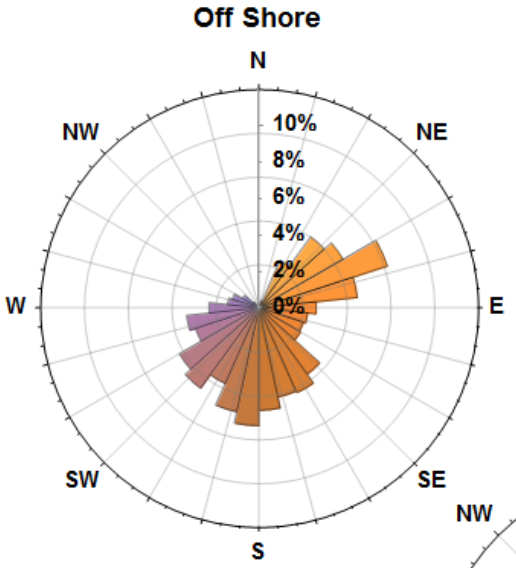
❑ Wind Speed

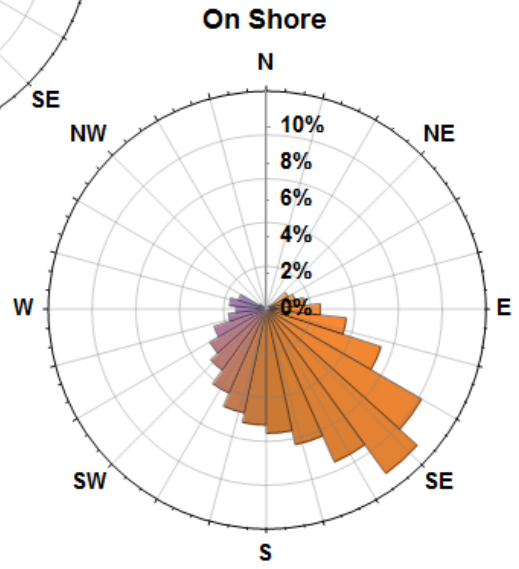
- ➢ Wind speed on water (vs. rooftop) is generally higher



❑ Wind Direction

- ➢ Less obstruction on water





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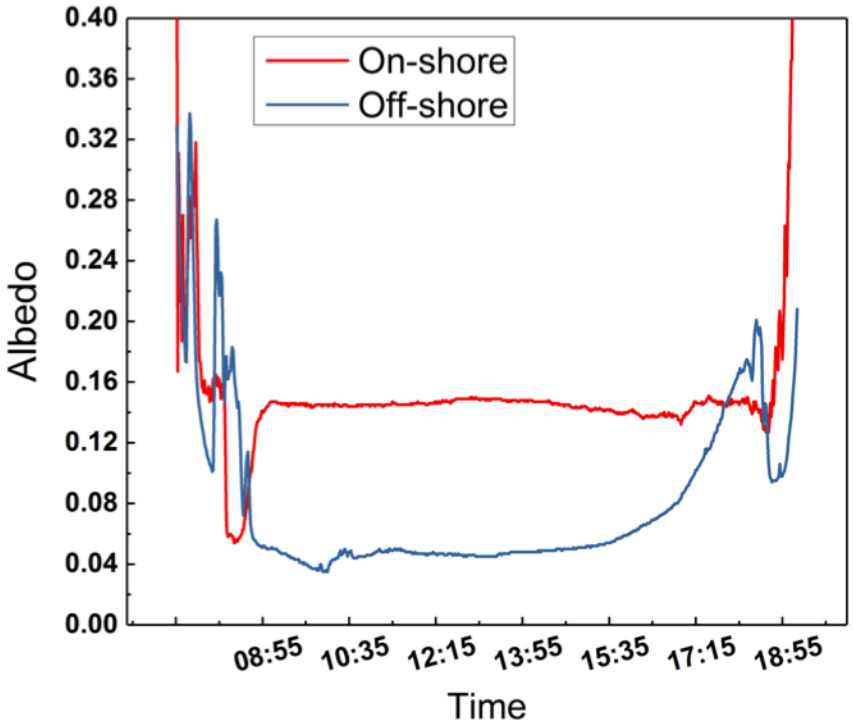
Testbed operating conditions (2)

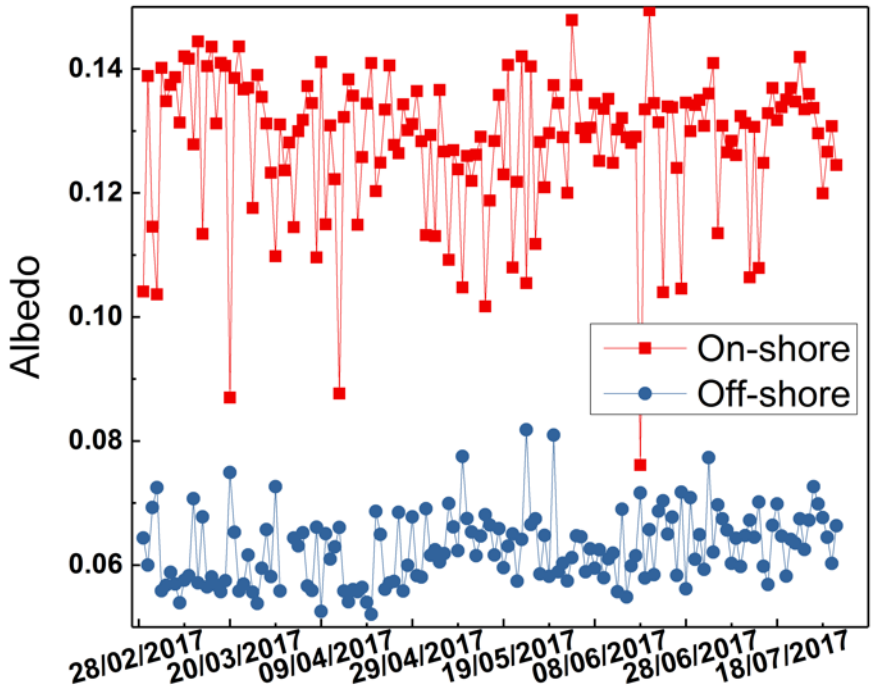
❑ Albedo

- ➢ Albedo of water surface is rather small, 5~6% measured

Albedo for 15 Mar 2017

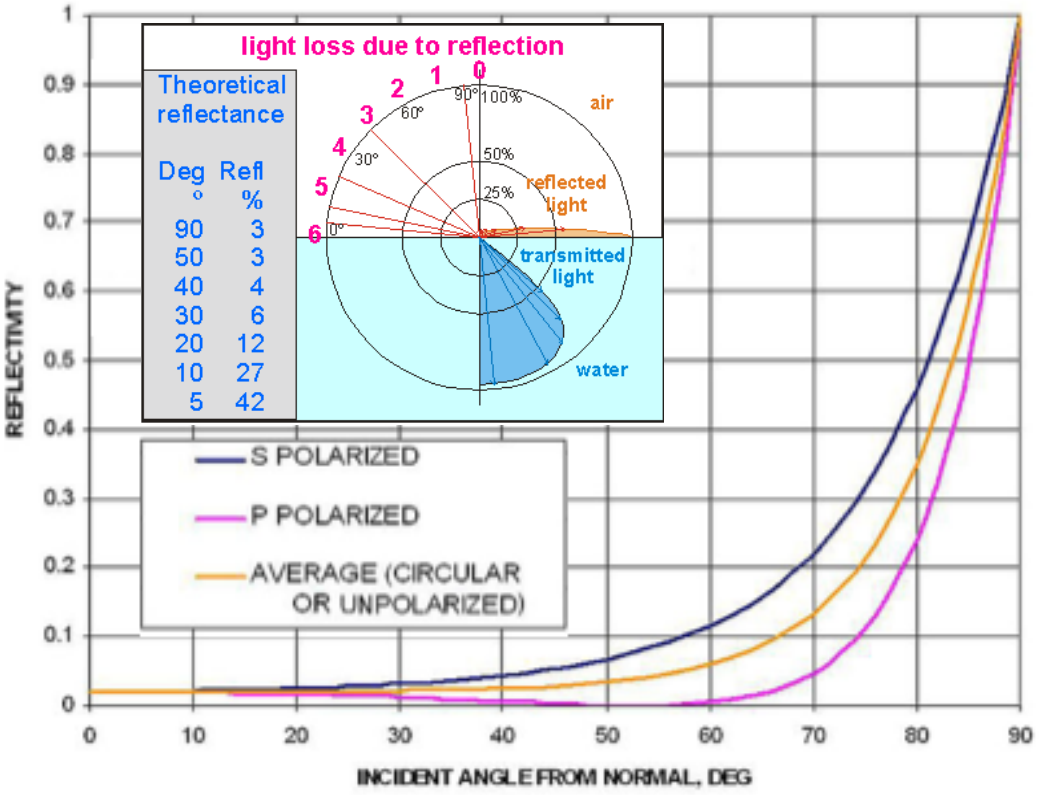


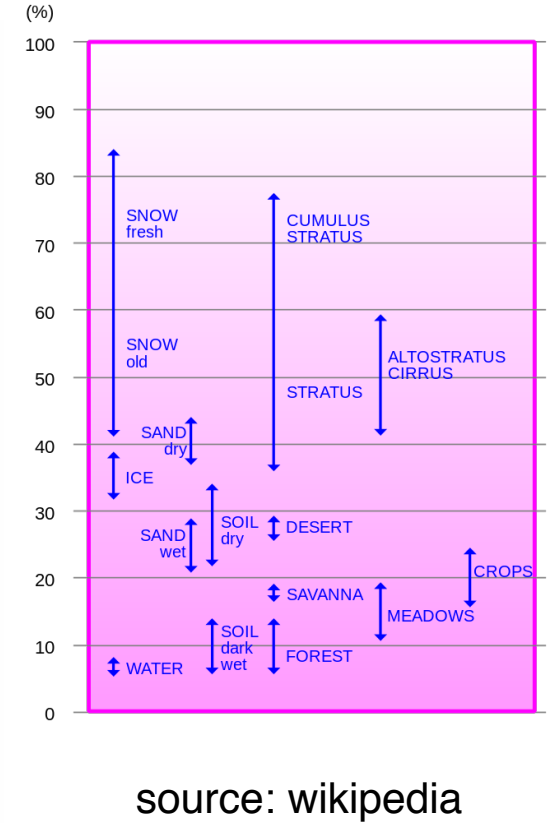
Daily average



Testbed operating conditions (2)

- Albedo
  - Water surface reflectivity is usually less than 10% at high incident angles (around 3 ~ 6% according to most reported measurements).





source: wikipedia

Reflectivity of smooth water at 20 °C (refractive index=1.333)

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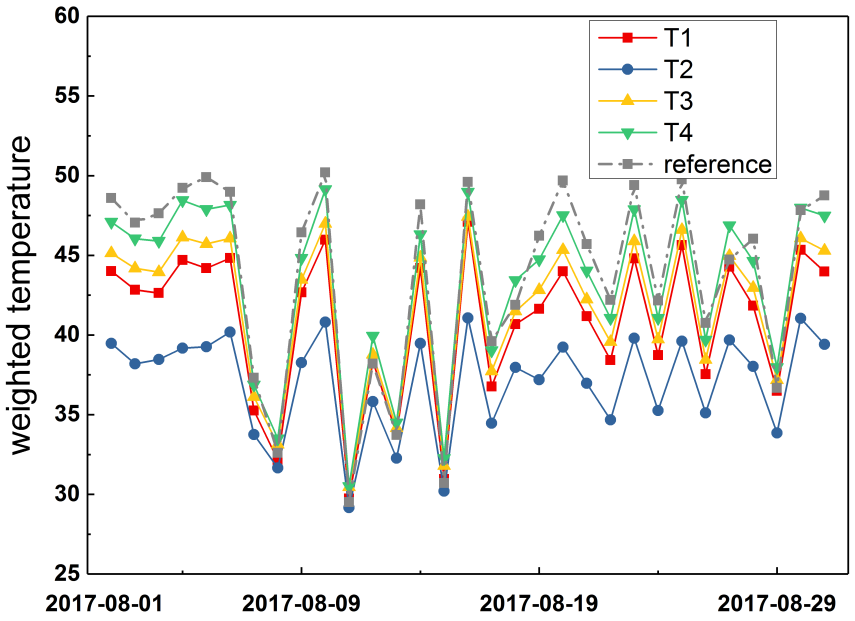
Comparison of operating conditions (3)

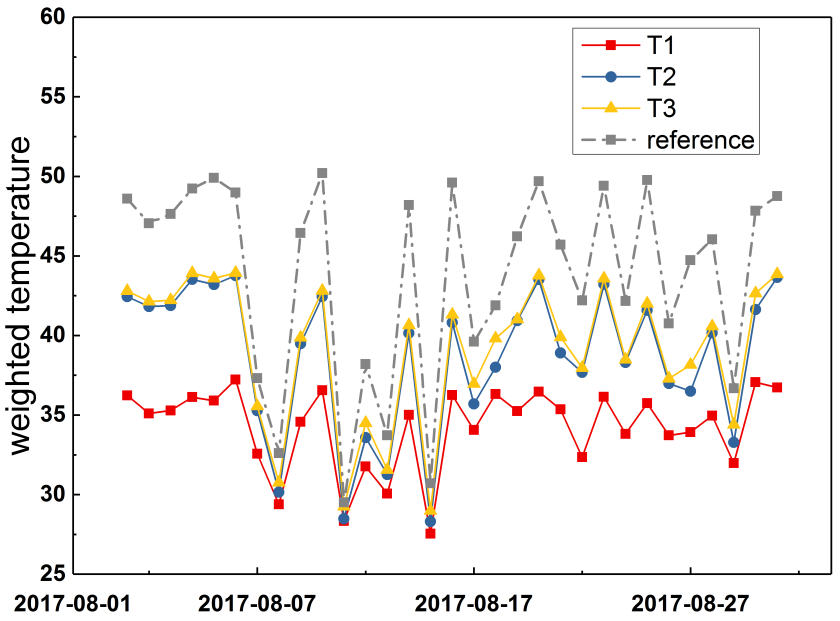
On-shore and off-shore module temperatures

- Module temperatures depend on floating structures as well as location within the floats.
- FPV modules have cooler operating temperatures (by ~5° C).

Float structure A



Float structure B



Daily weighted average module temperatures

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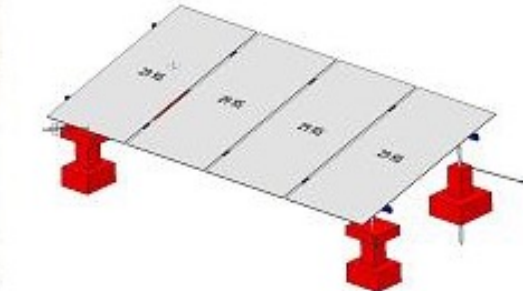
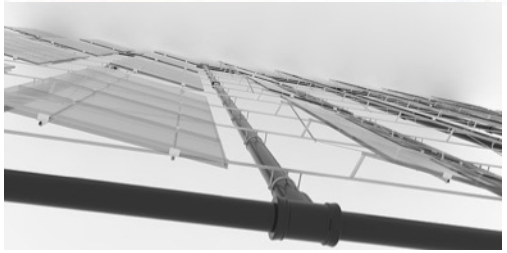
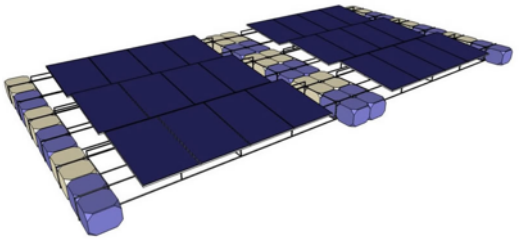
Cooling effect on PV module Temp

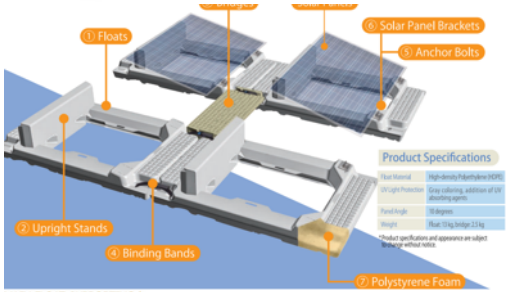


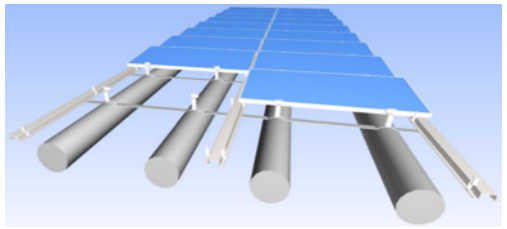
Free Standing
Minimized Footprint on water
Very Good convective cooling

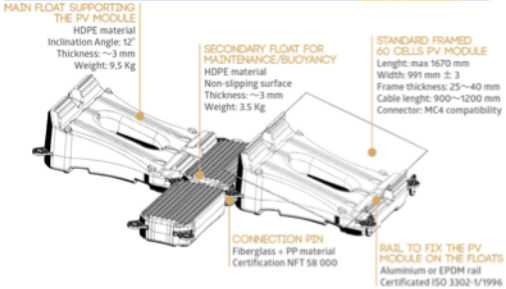




Small Footprint on water
Good convective cooling







Large Footprint on water
Water surface partially blocked

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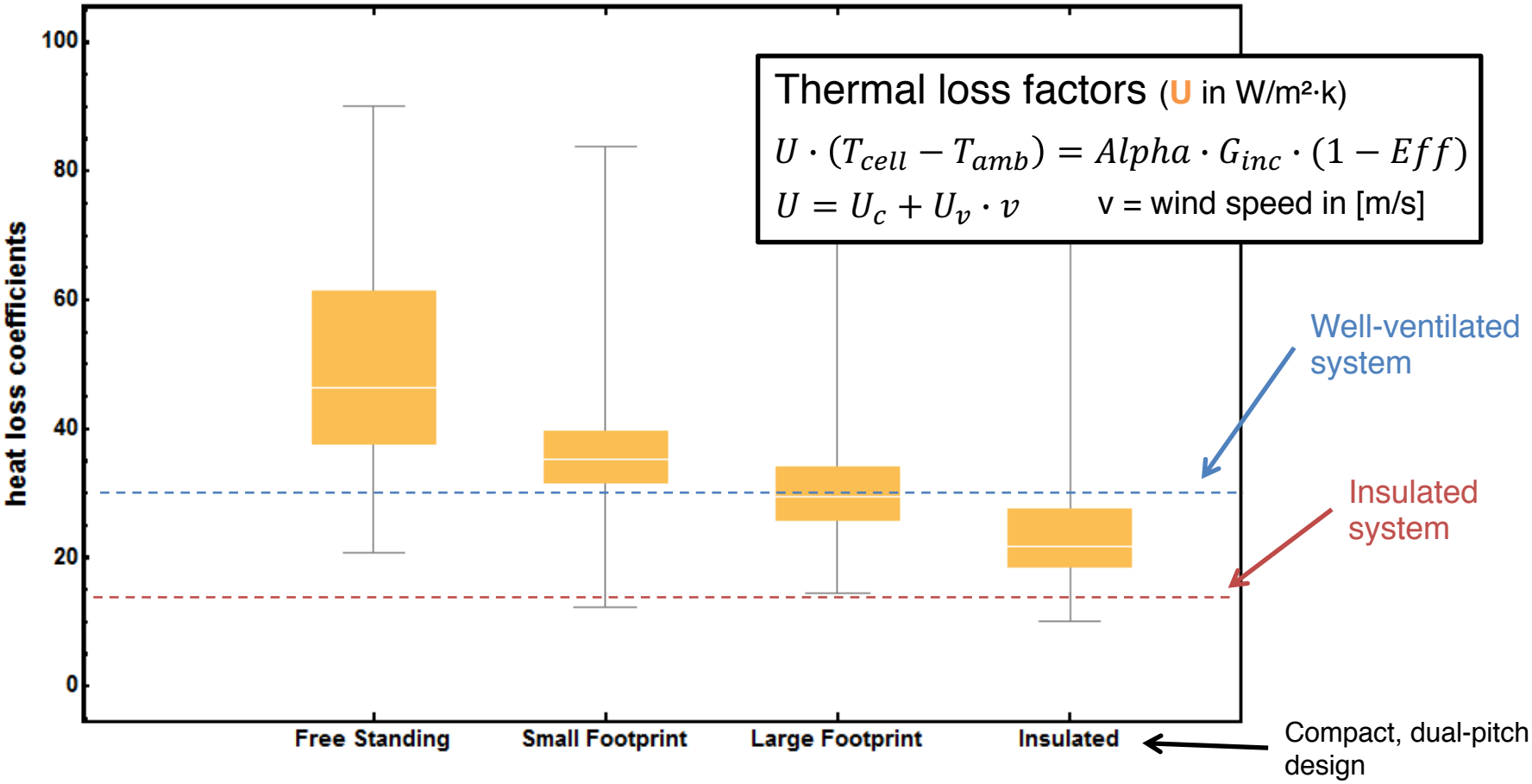
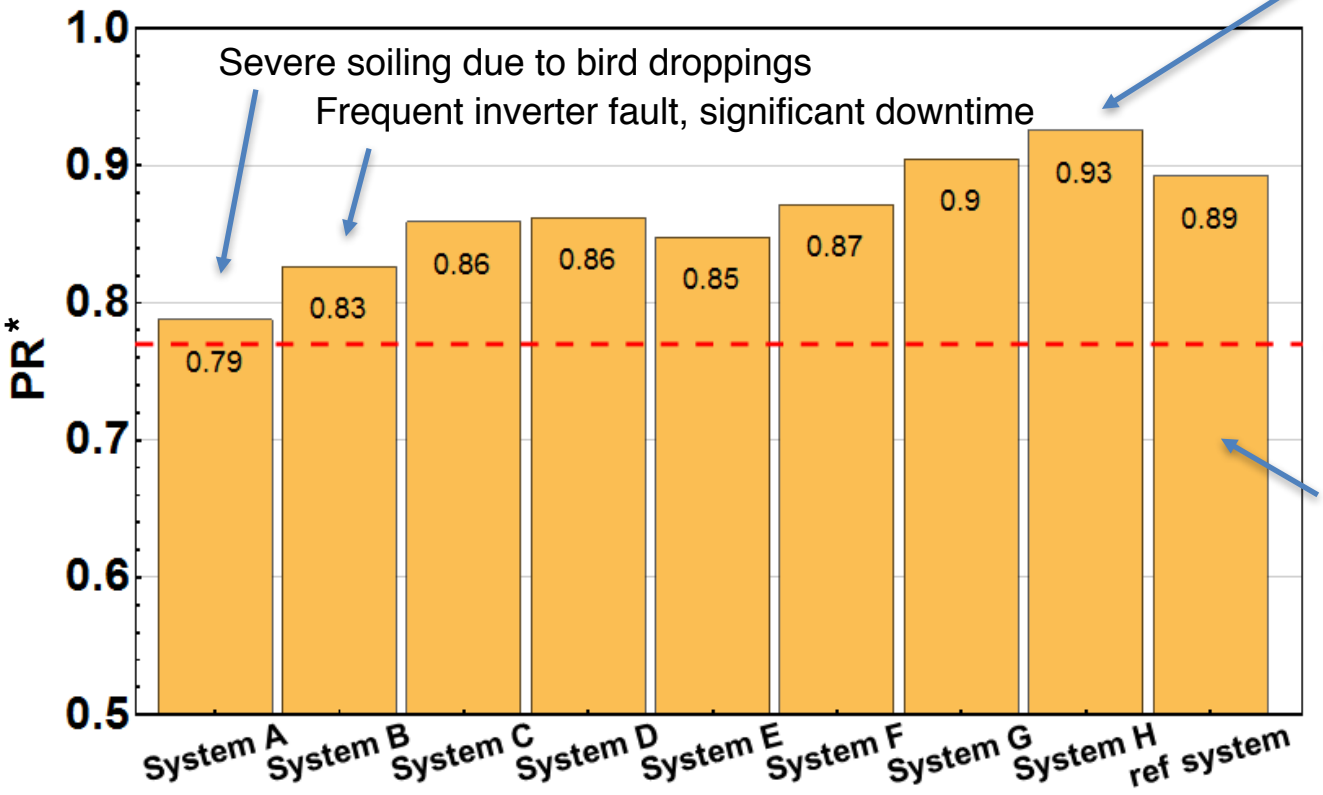
Module cooling

- Cooling effect (indicated by heat loss coefficient) is dependent on floating structure.



Testbed system performance (1)

- FPV system performance ratio (from Apr till Sep 2017)
  - Up to about 15% higher than typical rooftop PV systems in Singapore (with PR of 75 ~ 80%)



Very good ventilation (slightly overestimated due to reduced module tilt)

Typical rooftop system PR in Singapore

Note: This reference system is much better than typical rooftop systems in Singapore.
- Good ventilation
- Bi-facial modules

**** PR values are corrected for DC cabling loss***

System numbering is reordered for anonymity

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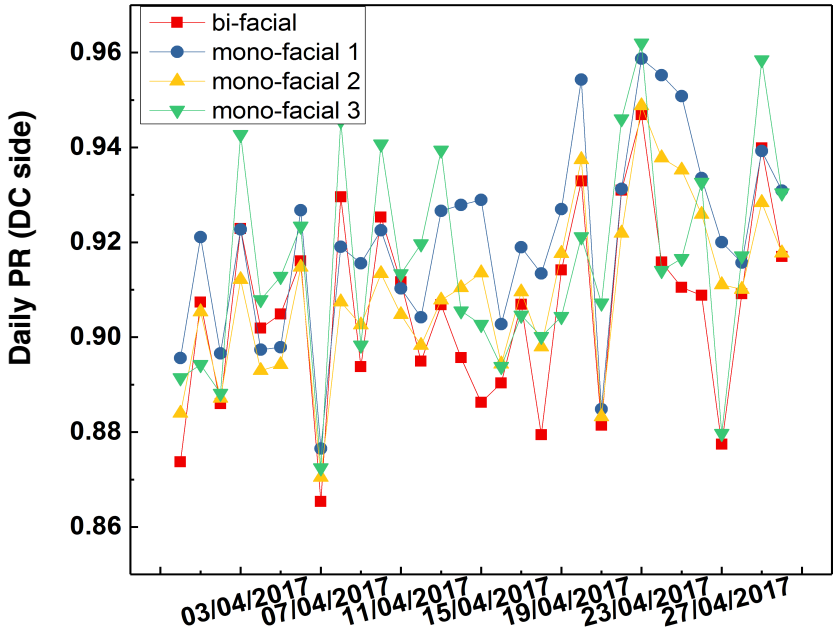
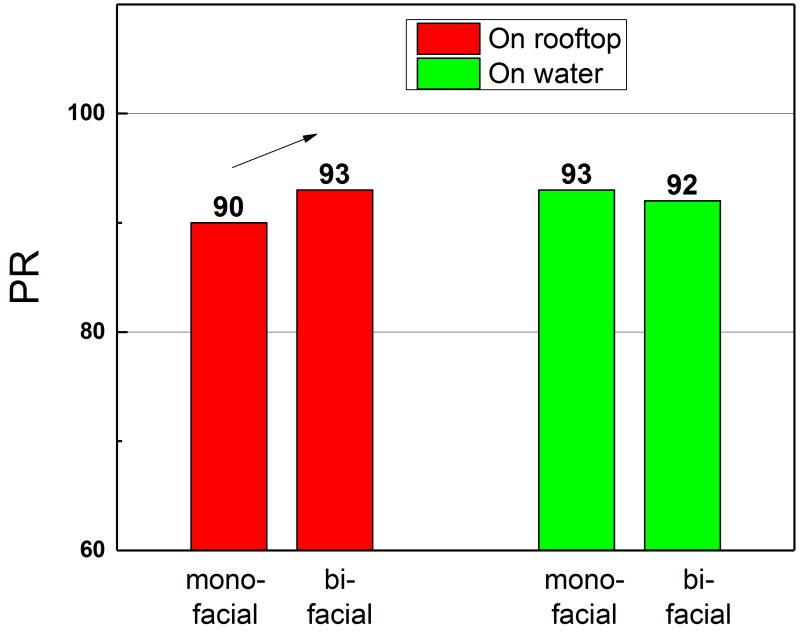
Testbed system performance (2)

- Bifacial modules
  - On rooftop, bi-facial string outperforms mono-facial strings
  - On water, bi-facial string does not seem to outperform mono-facial strings, due to low albedo on water
  - However, bi-facial might have benefit in the long term (dual glass, slower moisture ingress)

Bifacial string vs. mono-facial strings





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Issues encountered (1)

Soiling – from bird droppings

- Bird droppings observed on floating PV modules
  - Partial shading
  - Reduced performance, less energy yield
  - Cell reserve biased, hot spots, => can lead to accelerated module degradation

Singapore floating PV Testbed

- Possible solutions
  - Part of the O&M routine (i.e. immediate actions / cleaning)
  - Barrier methods
  - Non-barrier methods
    - Ultrasonic, Sonic Repeller
    - Visual Scare Device

Queen Elizabeth II reservoir, UK

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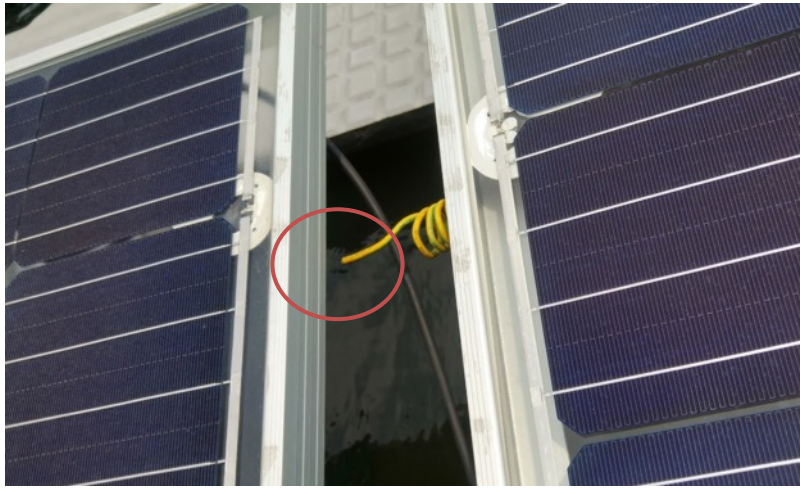
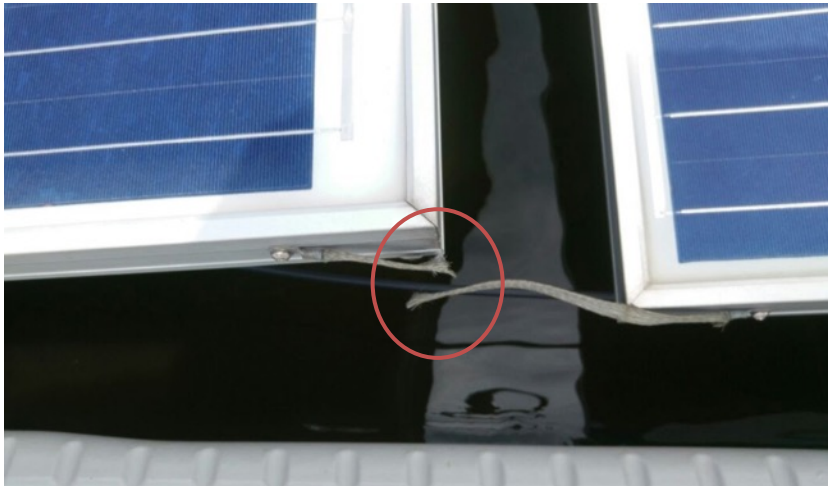
Issues encountered (2)

Constant movement of floating platform

- Mechanical stress
  - At the joints of rigid structures
  - On equipotential bonding tape/wire
  - At the earthing tape connection for grounding





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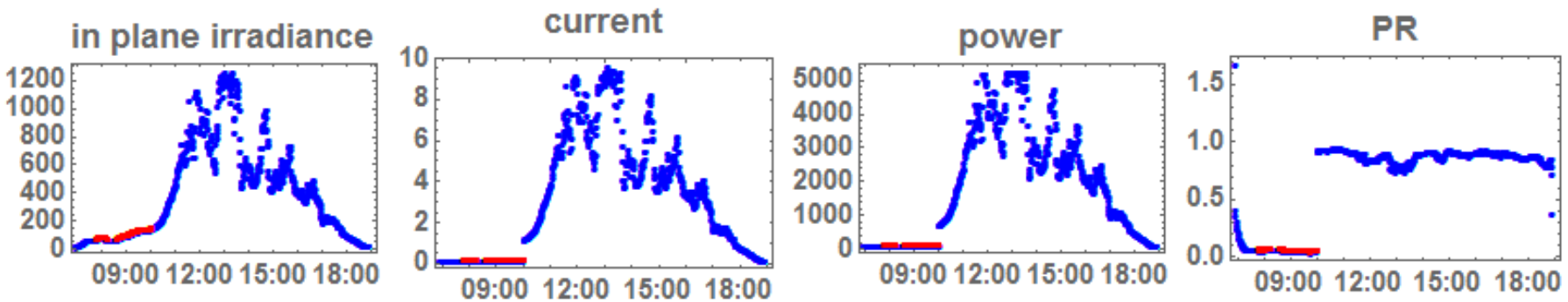
Issues encountered (3)

Insulation faults

- Insulation test failure for inverters
  - The insulation resistance (R_{iso}) dropped over time for floating PV strings
  - Inverters measure R_{iso}. When R_{iso} does not meet the preset threshold inverters do not start.
  - Common result: inverters start late (till the R_{iso} limit is passed).



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Other potential issues

Due to proximity to water, high humidity

- Potential Induced Degradation (PID)
  - Anti-PID modules preferred
- Corrosions (more aggravated for off-shore environments)
  - Combiner boxes
  - Inverters
  - Metal supporting structures
- Risk of solar cables submerged in water
  - Electrical safety, earth leakage
  - Performance drop, system downtime
- Structural
  - Anchoring / mooring needs to be carefully assessed during feasibility study

⇒ ***Highly valuable results from this testbed will potentially lead to new technical standards for Floating PV (via IEC TC 82)***

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Conclusion

- Floating PV market is taking off:
  - Large potential globally, with enormous opportunities in Asia: China, Japan, Taiwan, India, Pakistan, Sri Lanka, ASEAN
  - Hybrid operation of Hydropower and Floating PV has numerous advantages and huge deployment potential

- FPV system performance in the Singapore testbed
  - FPV PR ranges 79% ~ 93%
    Up to 15% higher than typical rooftop system in Singapore
  - FPV modules generally cooler. Cooling effect of FPV modules depends on floating structures and weather conditions
  - Bifacial modules does not seem to outperform mono-facial modules on water
  - Initial technical issues identified, but no major obstacle

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