Key Learnings from the World's largest Testbed for Floating PV

Solar Energy Research Institute of Singapore

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EDB singapore

SERIS is a research institute at the National University of Singapore (NUS). SERIS is supported by the National University of Singapore (NUS), National Research Foundation Singapore (NRF) and the Singapore Economic Development Board (EDB).

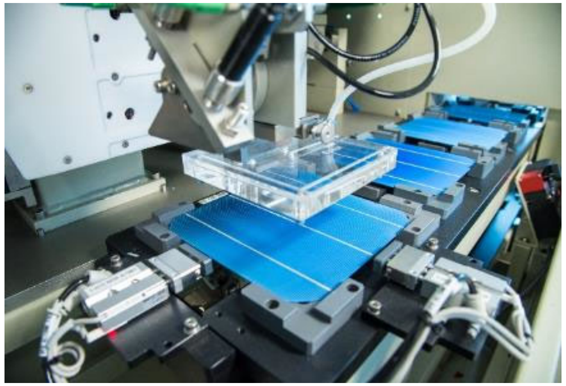
NUS National University of Singapore

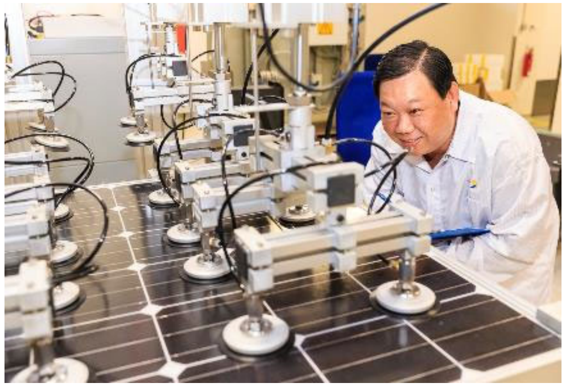
SERIS

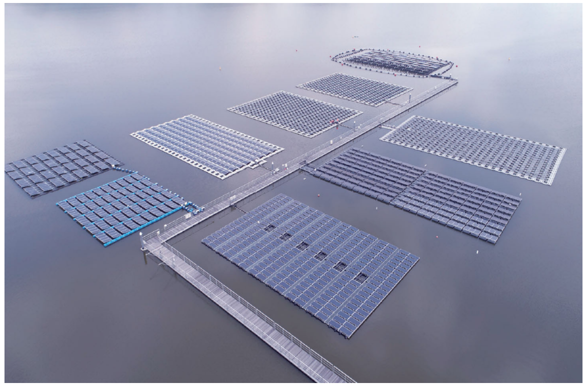
Solar Energy Research Institute of Singapore

- National Lab founded in 2008; supported by NRF, EDB and EMA
- Part of the National University of Singapore (NUS)
- Focuses on applied solar energy research (solar cells, PV modules, PV systems)
- More than 160 staff & adjunct researchers and > 6000 m^2 of space
- State-of-the-art laboratories
- Specialised in professional services for the PV industry
- ISO 9001 & ISO 17025* certified (* PV Module Testing and PV system Testing & Commissioning)

Main R&D areas of SERIS







Solar cells:

- Silicon solar cells (various cell architec-tures)
- Perovskite/silicon tandem solar cells
- Characterisation & simulation

PV modules:

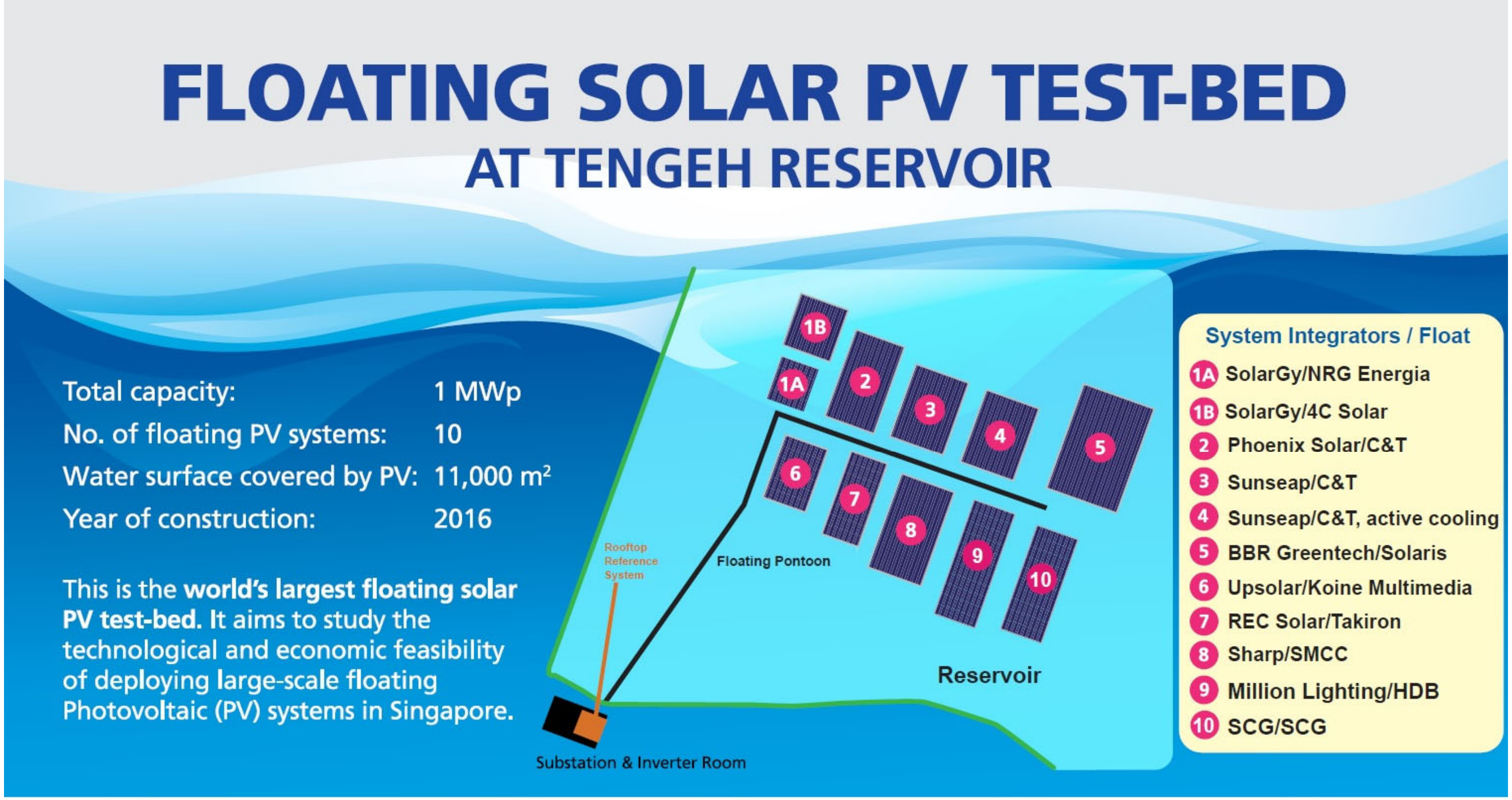
- Module development
- Module testing (indoor & outdoor)
- Characterisation & simulation
- Module reliability studies, failure root cause analysis
- Module recycling

Solar PV systems:

- System technologies, incl. **Floating solar**
- PV grid integration
- Solar potential & energy meteorology
- Urban Solar, incl. BIPV
- Quality assurance of PV systems

The Singapore floating PV Testbed

- Total capacity ~ 1 MWp



Project collaborators: PUB Singapore's National Water Agency, EDB Singapore, NUS National University of Singapore, SERIS Solar Energy Research Institute of Singapore

The Singapore floating PV Testbed

- Total capacity ~ 1 MWp

Testbed design and objectives

- 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

Research facilities

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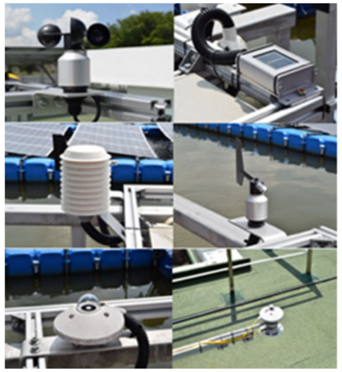
- Comprehensive monitoring infrastructure, with >500 parameters
  - Meteorological station (reservoir & rooftop)






  - PV System performance monitoring

DC (PV String)

AC (PV array)

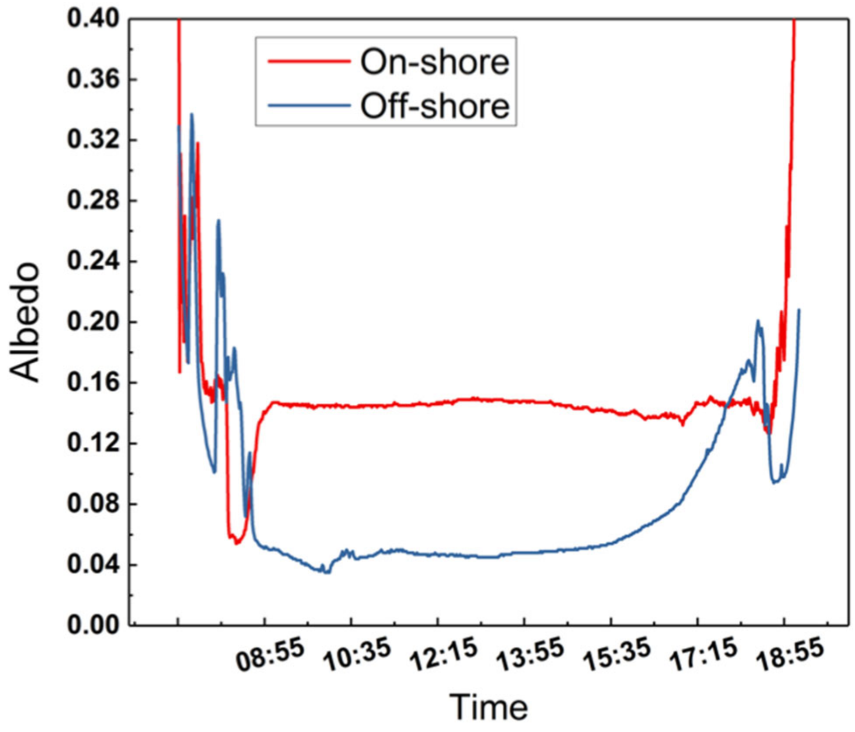
Motion sensor

Module Temp.

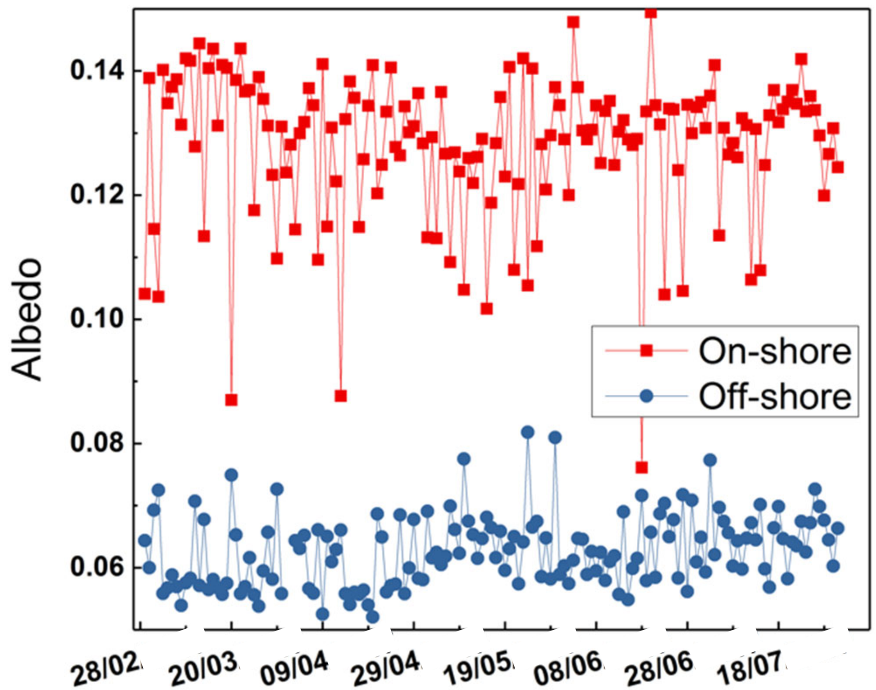
Testbed operating conditions

- Albedo
  - Albedo of water surface is rather small, 5~7% measured

Albedo for a day



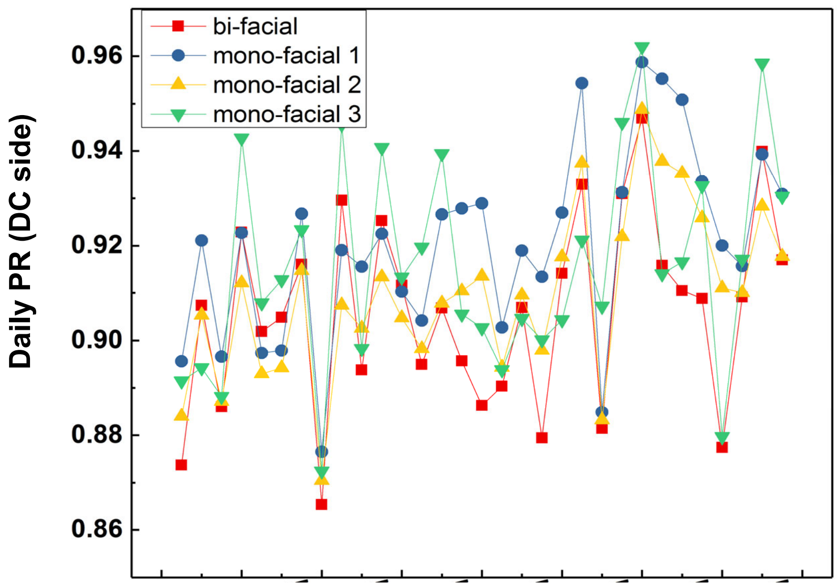
Daily average

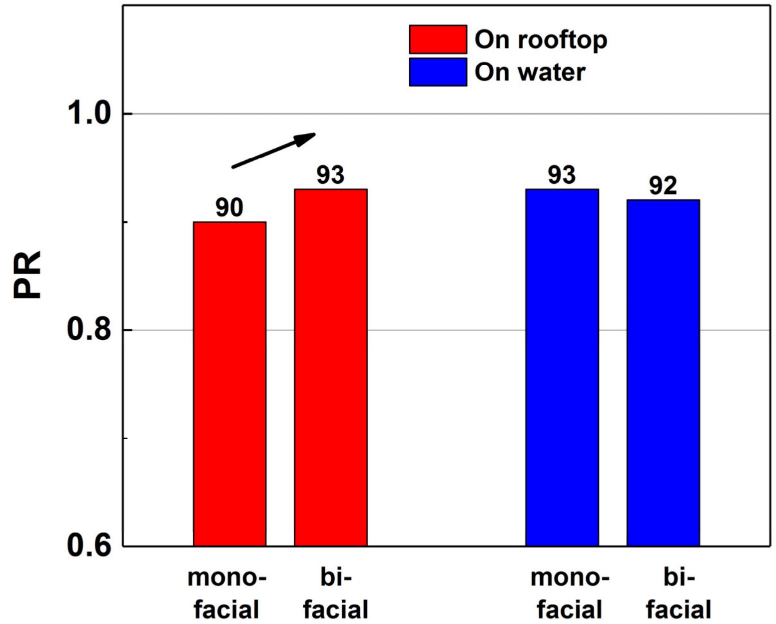


Bifacial module performance

- 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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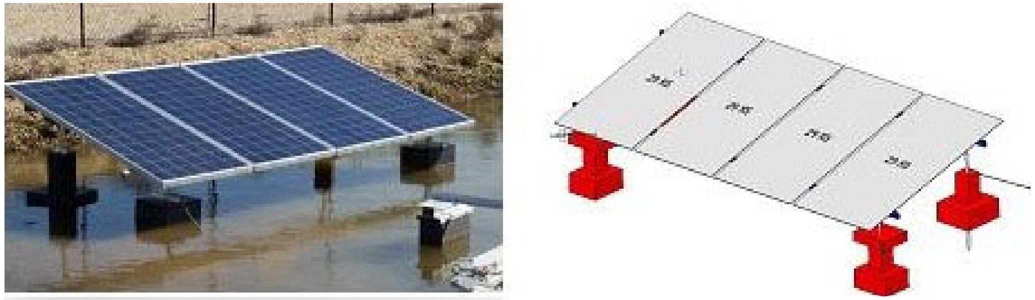
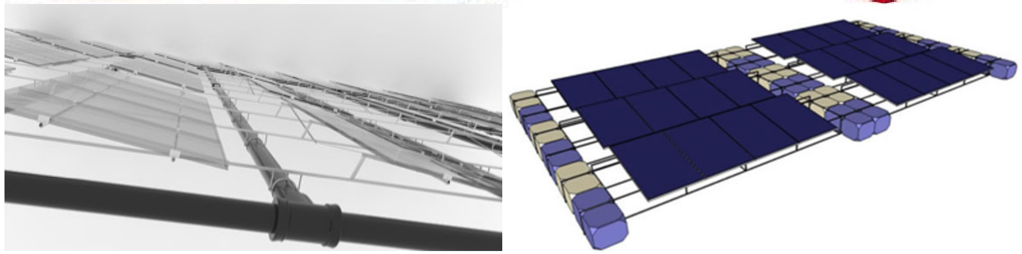
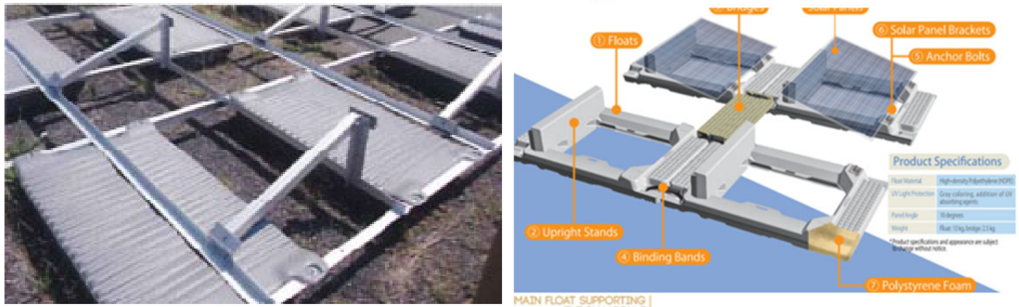
Cooling effect comparison

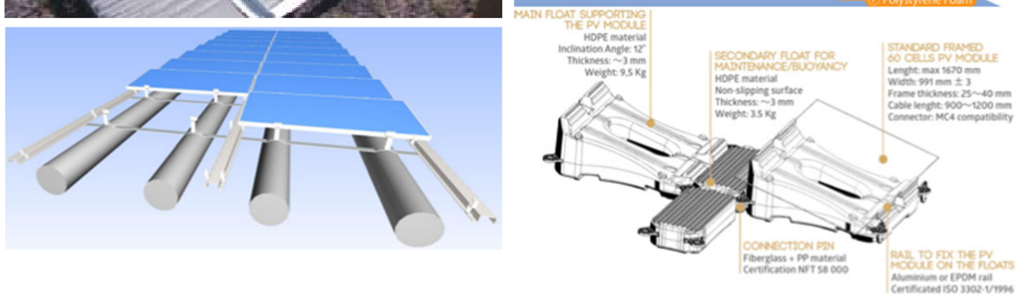


Free Standing
Minimal footprint on water, with very good convective cooling



Small Footprint on water, with good convective cooling

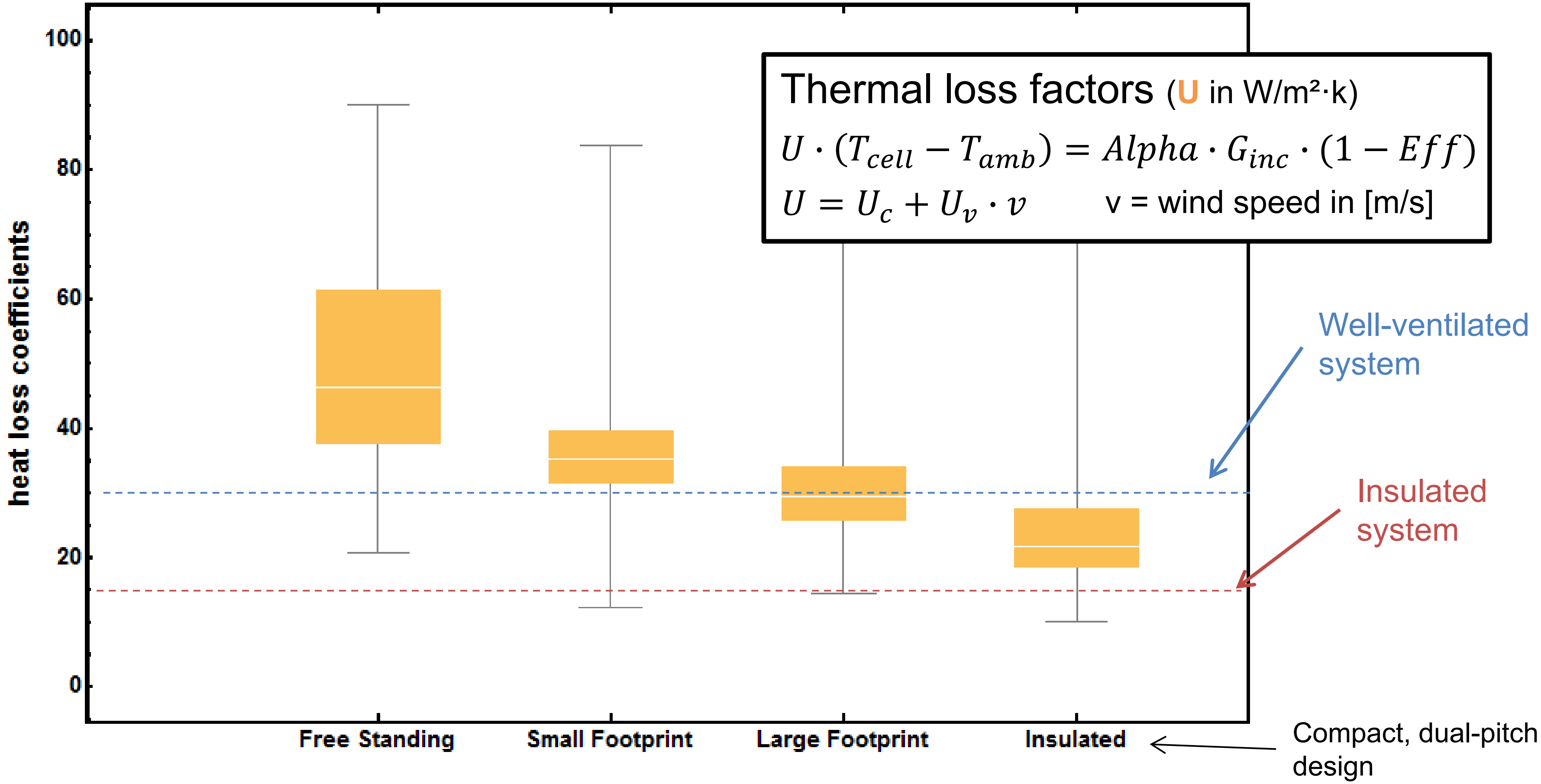




Large Footprint on water, with water surface partially blocked by the floats

Cooling effect comparison

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



Thermal loss factors (U in W/m²·k)

$$U \cdot (T_{cell} - T_{amb}) = Alpha \cdot G_{inc} \cdot (1 - Eff)$$

$$U = U_c + U_v \cdot v$$ v = wind speed in [m/s]

Specific yield and Performance Ratio

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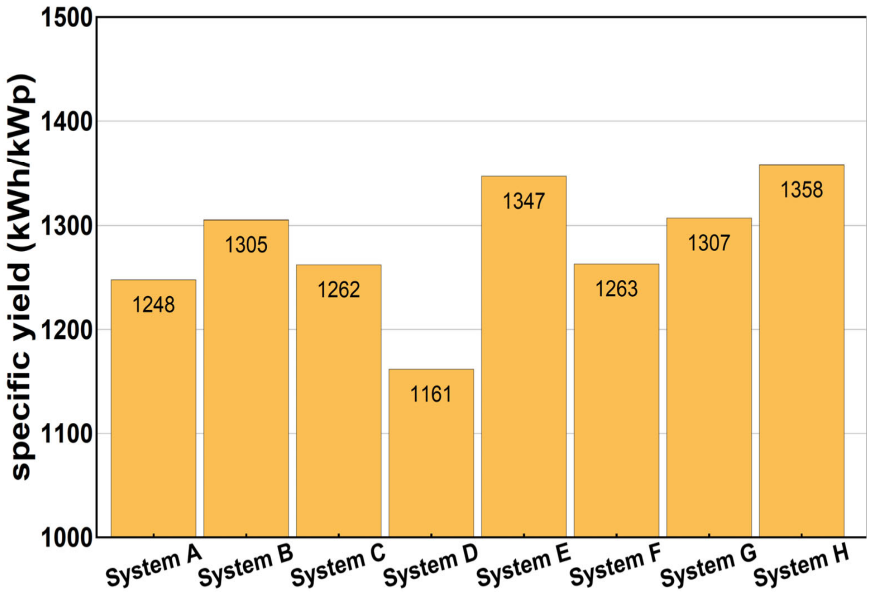
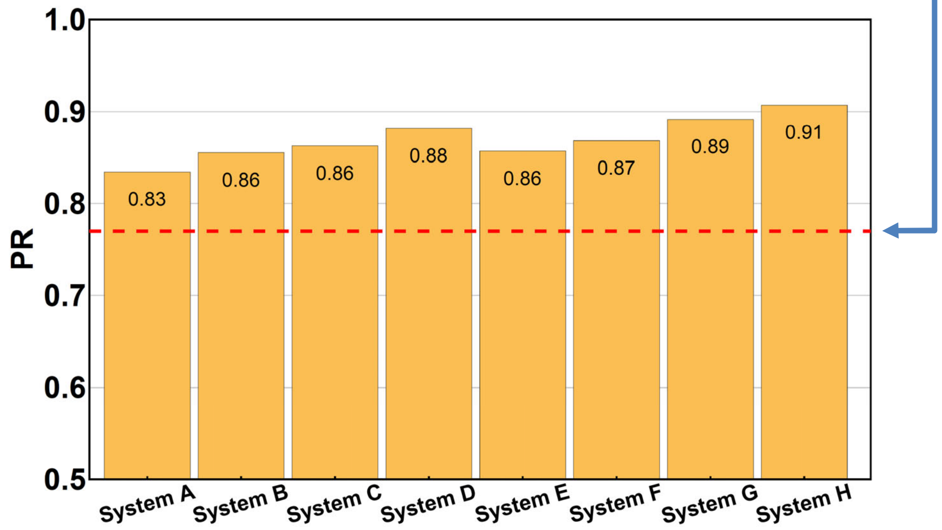
For the first year

Yearly insolation=1601 kWh/m²

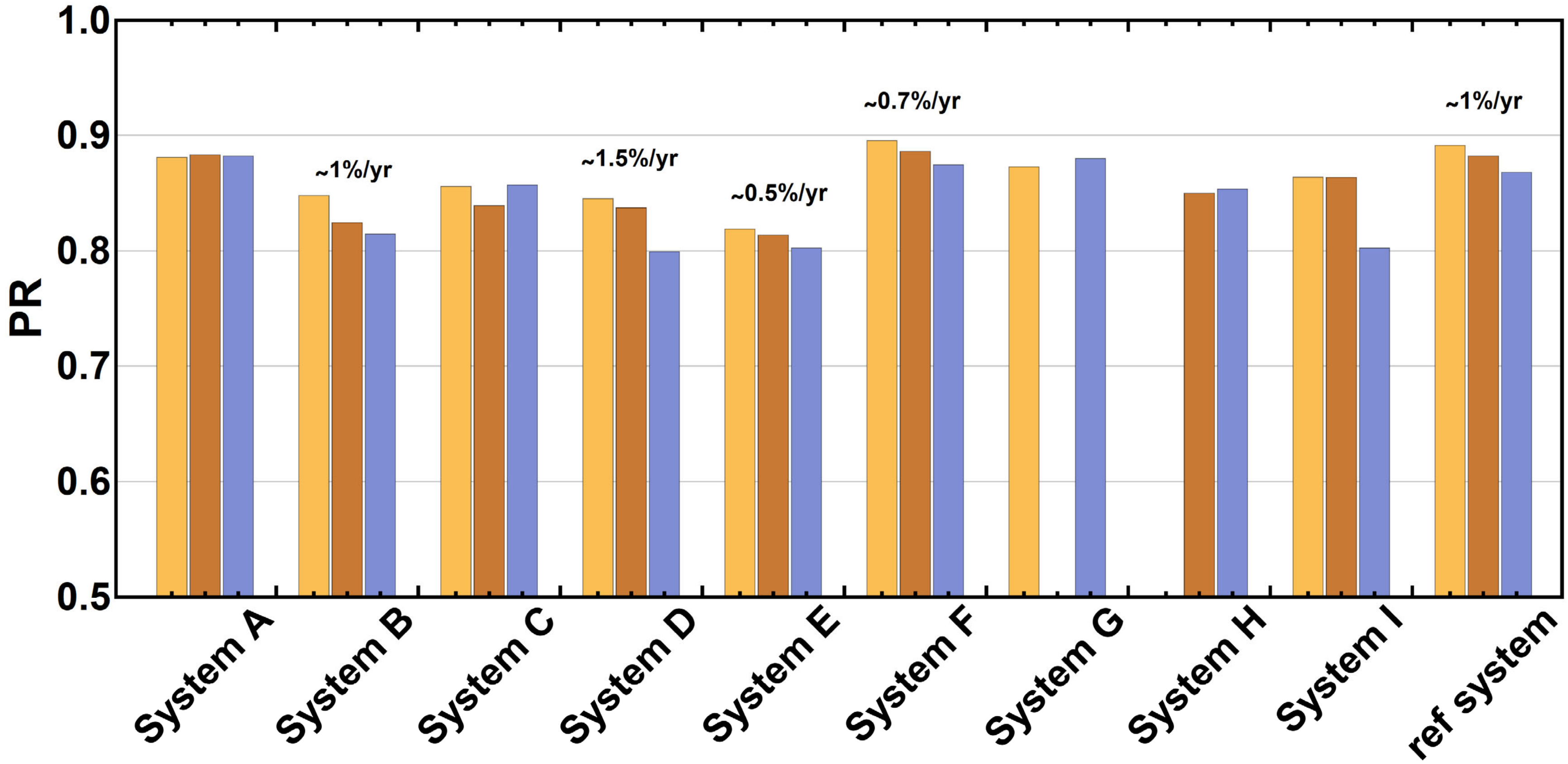


Average rooftop system in Singapore



Excluding major downtime

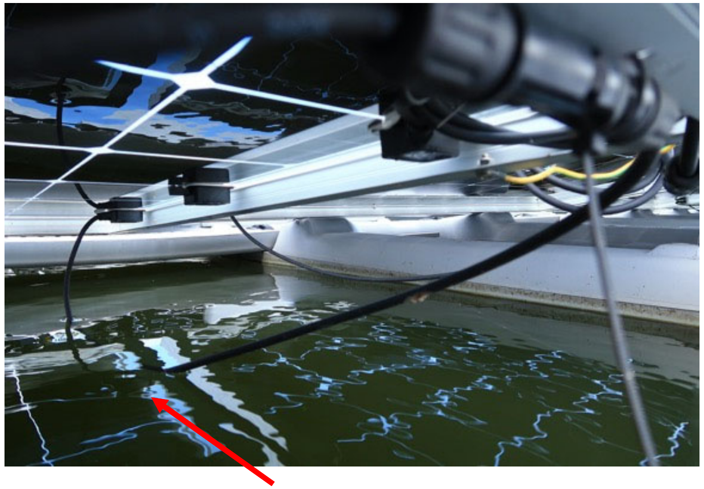
Performance Ratio (PR), initial trends



- ~0.5%/year to ~1.5%/year degradation rate observed. However depends on the design and component used and few system shows stable performance.

Cables or connectors touching water

- Causes
  - Low clearance from water surface as well as mismatch in module cable length and floats dimension.
  - Waves due to wind or boat
- Consequences
  - Leakage and low insulation resistance
  - Degradation (corrosion) of cables



- Recommendation: better cable routing, matching module & float dimensions

Cables snapped or sheath damaged

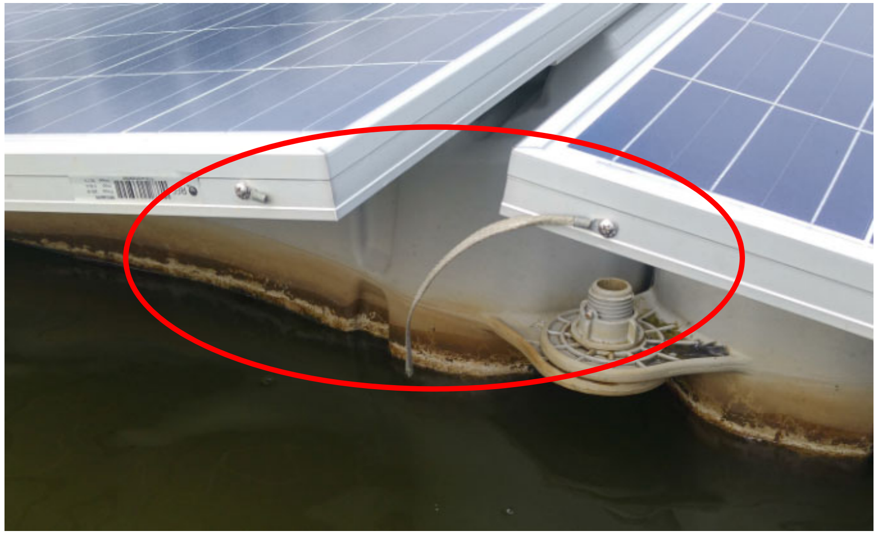
Snapped cables

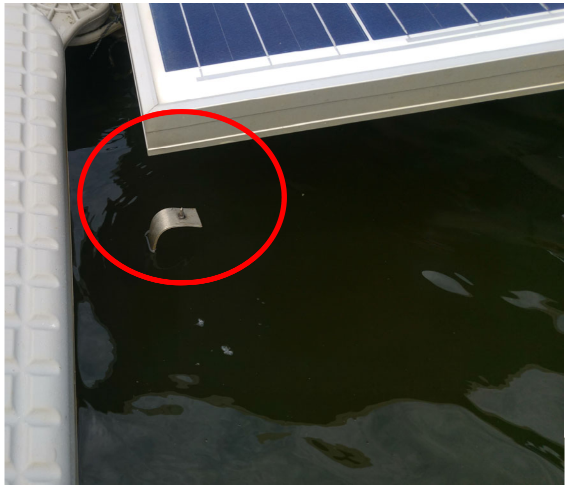
Damaged sheath

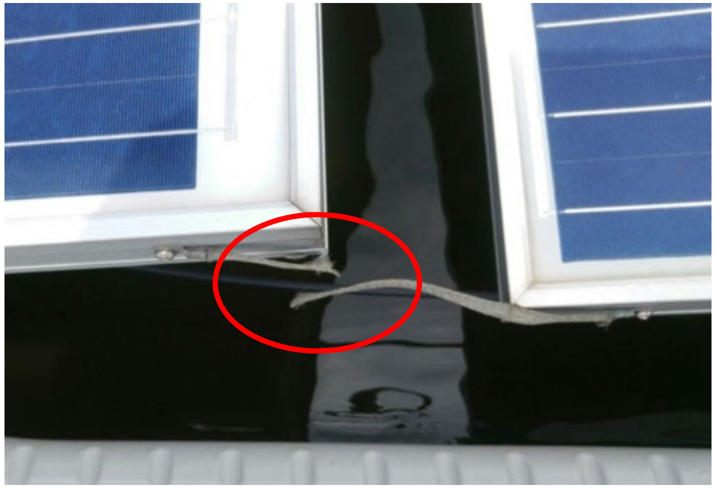
- ❑ Recommendation
  - ➢ Proper cable routing and calculation
  - ➢ Proper bank fixation: e.g. "L" shaped brackets

Breakage of connecting parts

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



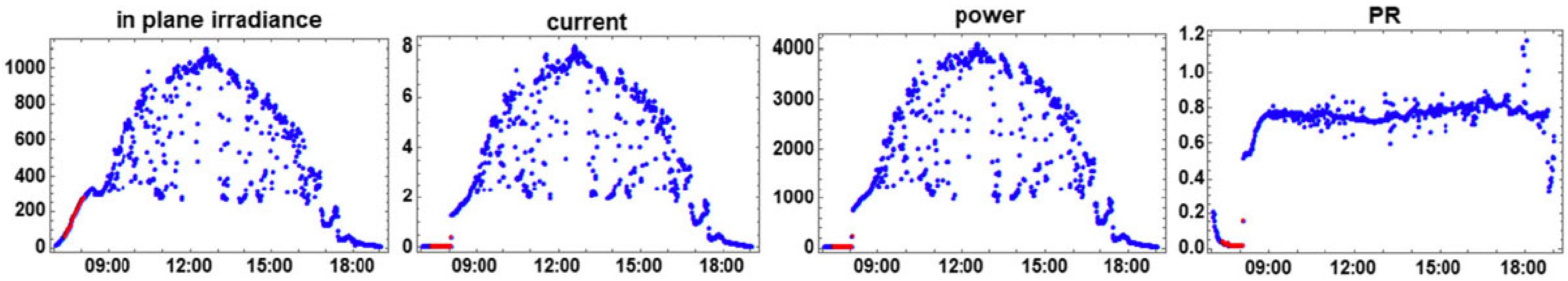




Insulation resistance issues

Inverters starting late

- Insulation faults observed for some systems
  - The insulation resistance (R_{iso}) is low for some floating PV strings.
  - Inverters measure R_{iso}. When R_{iso} does not meet the preset threshold, inverters do not start.
  - Result: inverters start late (till the R_{iso} limit is passed) and thus loss of energy.



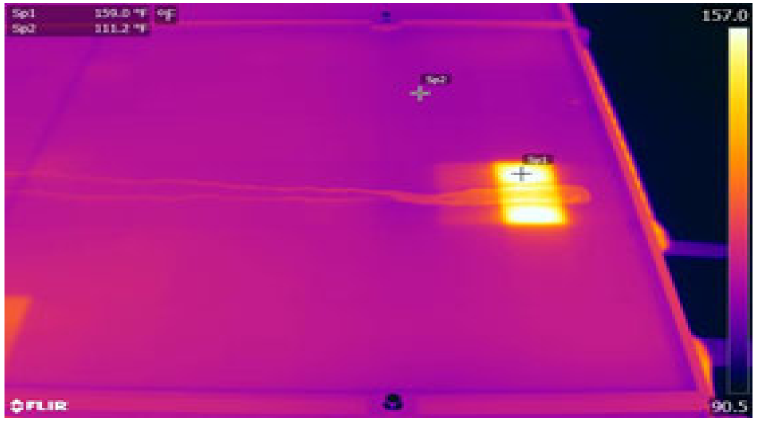
Animal visits

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



Hotspot created by the bird droppings

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 shall lead to new technical standards for Floating PV (via IEC TC 82)***

Next frontier: Off-shore Floating PV

Singapore is deploying a 5 MWp FPV system in marine conditions

- Likely world's largest off-shore floating PV system, size of 5 football fields
- Testing of more sever marine conditions:
  - Tides
  - Waves
  - Corrosive environment
  - Biofouling

Perceivable: Multiple purpose FPV

Example: Smart Floating Farms (SFF) with fish farming and crops

Source (picture): Smart Solar Farms

THE FOURTH

INTERNATIONAL FLOATING SOLAR SYMPOSIUM

28 Oct – 30 Oct 2020

Marina Bay Sands Convention Centre, Singapore

26 Oct 2020

SERIS (Solar Energy Research Institute of Singapore)
Workshops, lab tour and visit to the world's largest Floating PV testbed

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