Performance of Floating PV Systems

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Contents

• Introduction
• Floating PV Potential
• Pros and Cons
• Performance comparison
• Conclusion and outlook
Introduction

• Deployment of solar PV
  • in the built environment (roofs, facades)
  • as large field installations

• Both require land: competition with other types of land usage (agriculture, etc.)

• Surface of the Earth consists for 71% of water (mostly oceans), and half of population lives within 100 km from oceanic shores

→ large potential for floating PV structures
Floating PV potential

- Identified as >5 TWp global potential [Rosa-Clot, Tina, 2020]
- 100%RE scenario requires 35 TWp, all onshore [EWG, LUT, 2019]
- What if the offshore option is added?

<table>
<thead>
<tr>
<th>TABLE 1.2</th>
<th>Technical Photovoltaic Potential for Climate Zones.</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Surfaces, km²</td>
</tr>
<tr>
<td>Tropical zone</td>
<td>1,448,031</td>
</tr>
<tr>
<td>Temperate zone</td>
<td>1,386,202</td>
</tr>
<tr>
<td>Cold zone</td>
<td>1,611,663</td>
</tr>
<tr>
<td>Total</td>
<td>4,445,896</td>
</tr>
</tbody>
</table>
Example off-shore PV potential: the Netherlands

Enormous potential:
100,000 km², ~1% PV: 237 GWp
off-shore: 45 GWp

- Agriculture, forest, nature, recreational
- Built environment
- Infrastructure (roads)
- Water, off-shore >50%
- Part of area covered with PV

Folkerts et al., Roadmap PV systemen en toepassingen, 2017
Pros and cons

- **Pros**
  - Massive potential
  - Better performance due to cooling of water body
  - How much?

- **Cons**
  - Ecological
  - Wind load
  - Cost (infrastructure)

Note:
- on-shore: sweet water, low winds
- off-shore: salty water, high winds

Performance

• Water body provides cooling and thus increases efficiency
  • Submerged PV panels (4 cm) [Rosa-Clot, Tina, 2018]
    • Efficiency gain: 5-15%
    • Energy yield gain: up to 15%
    • Due to cooling and less variation in panel temperatures

• Hapcheon dam water reservoir, South Korea (100 and 500 kWp)
  • Annual yields [Suh, 2020]:
    • 1297 [2012], 1364 [2013], 1260 [2015] kWh/kWp
    • 13.5% higher yield compared to land-based system
Performance test site Singapore

Aerial photograph and details of the Singapore Tengeh Reservoir test-bed with different Floating PV technologies [Reindl, 2018]
Performance ratio comparison

PR 10-15% higher than typical rooftop PV systems in Singapore (with PR of 75 ~ 80%) [Reindl, 2018]

Frequent inverter fault, significant downtime

Typical rooftop system PR in Sg

High PR for ref system:
- Good ventilation
- Bi-facial modules
- Low mismatch loss

This reference system is much better than typical rooftop systems in Singapore.
Bifacial performance comparison

Bifacial modules have similar PR for offshore and onshore conditions, due to low albedo [Reindl, 2018]
Performance modeling

- Case study simulation
  North Sea, the Netherlands

- Floating pontoons with horizontally located solar panels
  (design: Oceans of Energy, NL)

- Performance modeling using irradiance and wind at sea
  - module temperature
  - varying tilt

[Golroodbari, 2020]
• Wind induces waves which affect tilt
• Using data of wind speed variation tilt variation is calculated

Tilt angles per day
- variation between 0 and 20 degrees
- mostly calm
- except Aug 3

[Goiroodbari, 2020]
Tilt variation, monthly averages

- Variation limited, larger in Jan, Feb (note: 2016)
Average module temperatures

• Module temperature offshore PV is lower than on land
Yield advantage

- 13% higher annual yield, with monthly dependence
Performance ratio advantage

• Higher yield and higher irradiance: higher PR?

Annual average PR
FPV: 85%
Land: 82%
Summary of performance

• Higher performance due to cooling effect of water body

• Beneficial effect differs per geographical location
  • +13% higher yield in the Netherlands, 4% PR advantage
  • +15% in Singapore, 10-15% PR advantage

• Comparing tropics with NL:
  • Higher irradiance and higher ambient temperature lead to higher panel temperature
  • Also, higher temperature of cooling water body
  • Are cooling effects similar?
Summary of performance

• Is there a link with KG classification?
  • NO (see poster 6CV.2.34, Ayyad et al.)

• But correlation is found between latitude, temperature and clear-sky differences for offshore and onshore sites (preliminary work)

• Offshore advantage variation up to 30%
Conclusion

• Floating PV performance is better than on land, due to cooling
  • Positive effect depends on geographical location
  • Verification and further R&D necessary

• Application potential
  • Integration of floating PV with other renewables
    • Hydro reservoirs
    • Offshore wind parks: allows for cable pooling, more often constant power
Thank you

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