Monitoring of floating PV system
Facts and Examples

Sara Golroodbari

An introduction about myself

Sara Golroodbari

Bachelor of Electronics Engineering, Isfahan University, Iran

Masters of Power Electronics, University Malaya, Malaysia

Doctor of philosophy in Solar Energy, Utrecht University, the Netherlands

Also, worked as researcher at
University of Melbourne
Delft Technical University
Tehran Polytechnic University

Several years of Industrial experience in four different countries.

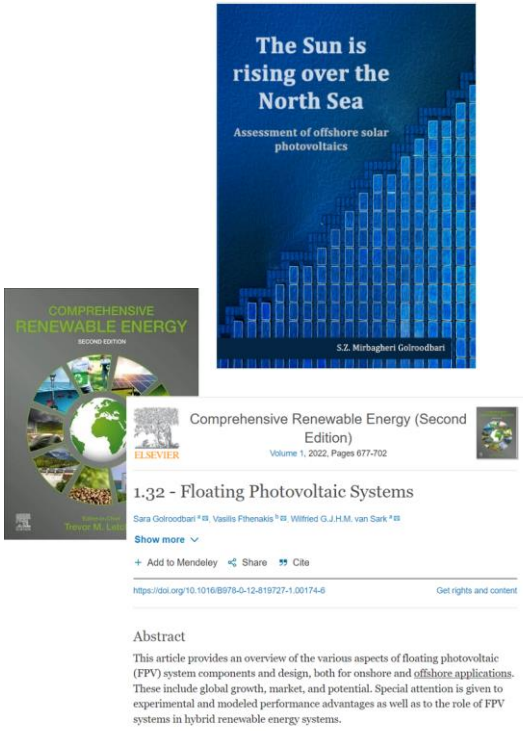
Quiz

The test time now:

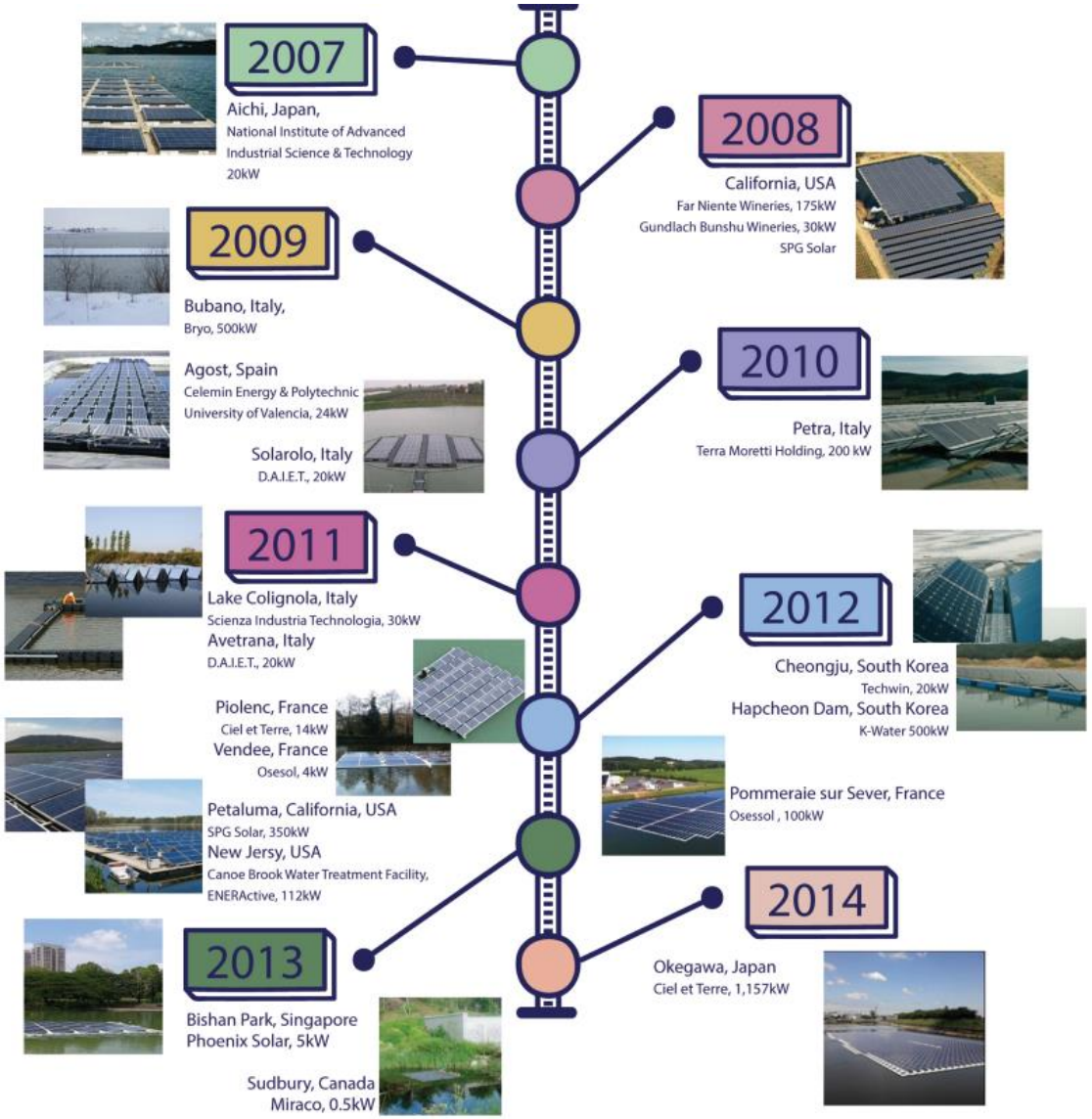
Through https://kahoot.it/

Based on the following references

- Sara Golroodbari , The Sun is rising over the North Sea. Assessment of offshore solar photovoltaics, PhD thesis, 2021, 175 pages, ISBN: 978-94-6416-590-6
- Sara Golroodbari, Vasilis Fthenakis, Wilfried G.J.H.M. van Sark, 1.32 - Floating Photovoltaic Systems, Editor(s): Trevor M. Letcher, Comprehensive Renewable Energy (Second Edition), Elsevier, 2022, Pages 677-702, ISBN 9780128197349
- Practical testings



The History of FPV

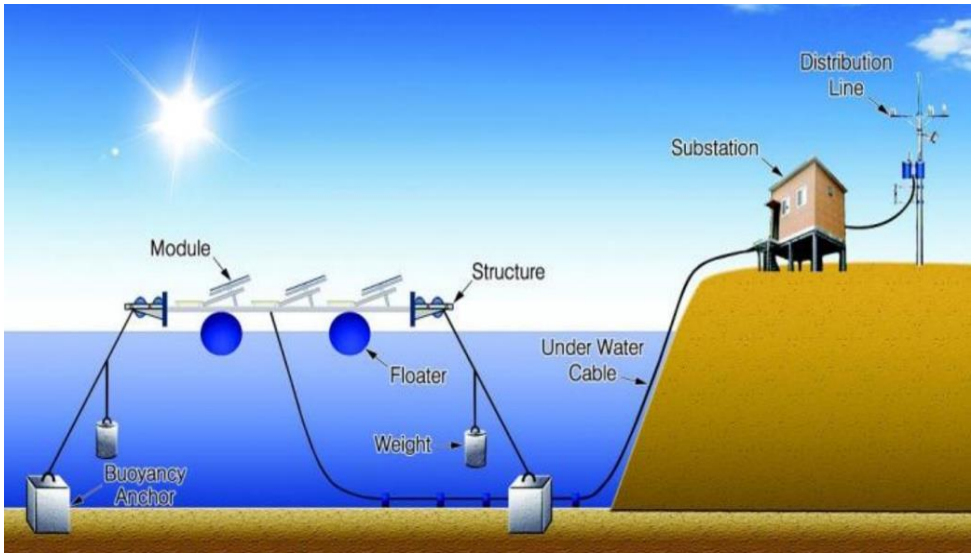


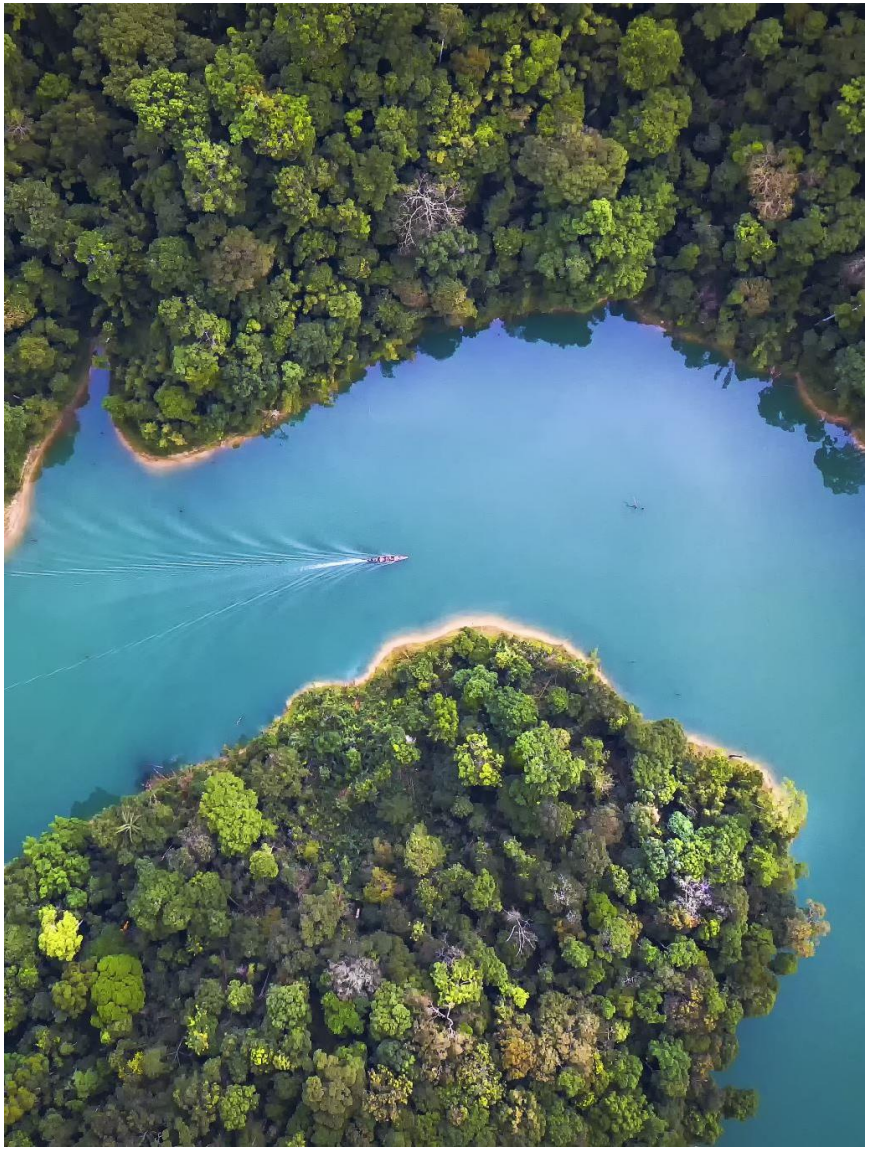
Advantages

- The environmental
  - Integration with aquaculture,
  - Water quality improvement,
  - Reduced water evaporation,
  - etc.
- Technical advantages
  - Higher energy yield,
  - Easier deployment,
  - Complementary operation for a hybrid energy resource such as with hydro power plants and (offshore) wind farms,
  - etc.

Structural design

- Floating platform: Raft, Pantoon
- Floats
- Mooring system
  - Ropes
  - Anchoring system
- Solar PV module and inverters
- Monitoring system
- Cables and connectors
- Energy storage (Optional)

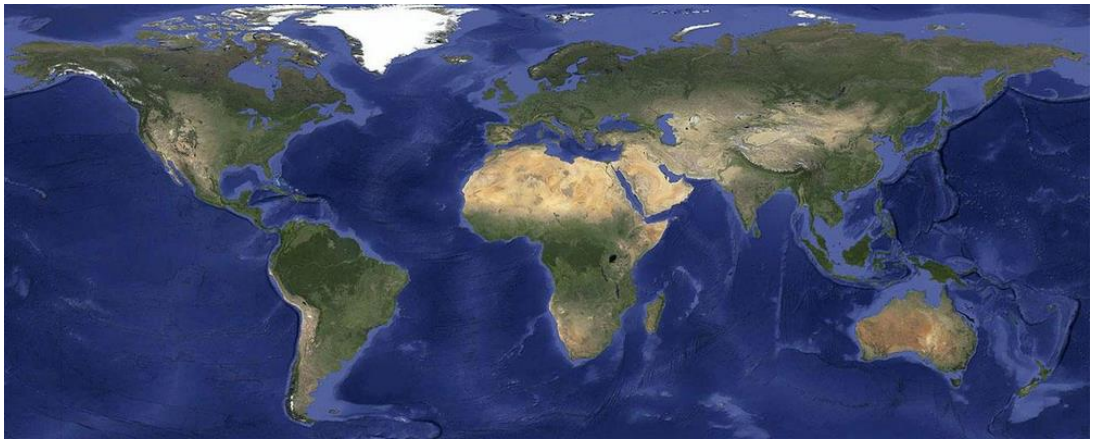




FPV system classification

- Canal top systems
- Reservoir/Lake based systems
- Offshore systems

Fresh water or Open water?! That is the problem!



There are two main challenges for FPV on open water:

- Salt corrosion
- Wave impact

Good news!

That challenges could be managed!

Golven tot 13 meter hoog

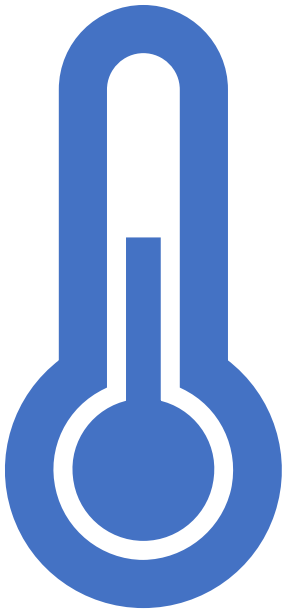
Op papier kan het systeem golven tot wel 13 meter hoog doorstaan. Toekomstig onderzoek moet uitwijzen of drijvende zonneparken die veel groter zijn ook zulke golven kunnen weerstaan.

Het platform heeft 56 zonnepanelen en een vermogen van 17.5 kilowatt. Het Nederlandse bedrijf Oceans of Energy is verantwoordelijk voor het project. Later dit jaar wordt het vermogen uitgebreid naar 50 kilowatt.

General Monitoring System Design for FPV

- FPV System monitoring
  - PV performance
    - Ambient variables:
      - Irradiation
      - Temperature
      - Wind speed
      - Relative humidity
      - Salinity
  - Storage
  - Related equipment, e.g. water pump
- Environmental Monitoring system
  - Water quality
  - Water temperature

Cooling effect

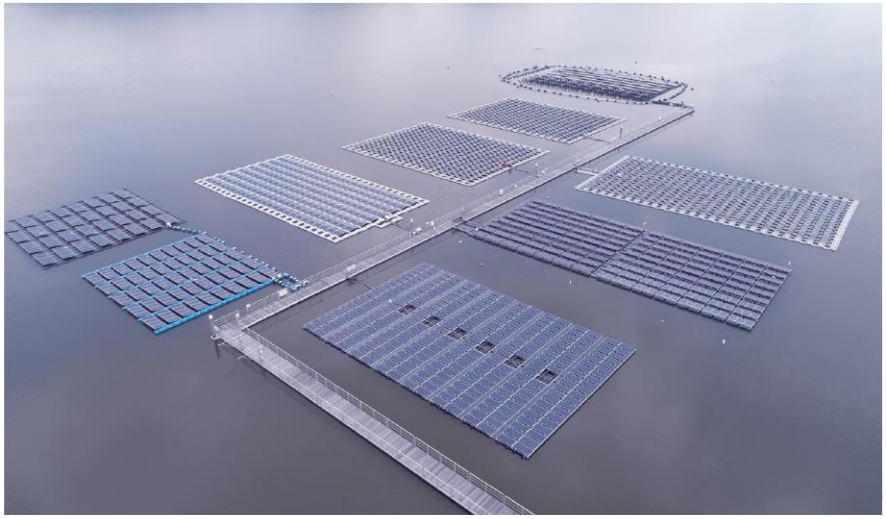


Tengeh reservoir, Singapore

Nine different commercial FPV technologies have been installed, and monitoring has been performed to study the potential cooling effect depending on the specific technology.

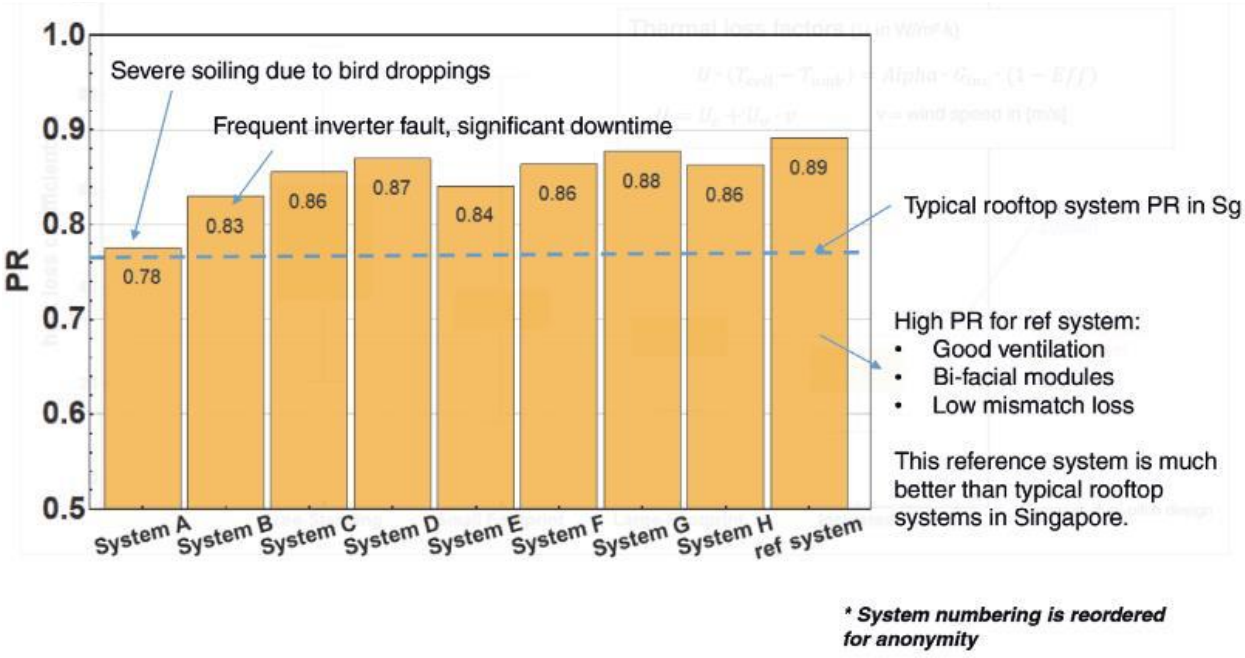
Monitoring the environment showed:

- The ambient temperatures over water typically are 2-3°C lower than on land,
- The wind speed on water is generally higher
- The humidity above water is higher
- The albedo on water is considerably lower



Tengeh reservoir, Singapore

- The module temperatures are about 5°C to 10°C lower than similar modules mounted on rooftops.
- The annual performance ratios are 10-15% larger than typical *PR* (75 – 80%) of rooftop systems in Singapore.



Wave effect

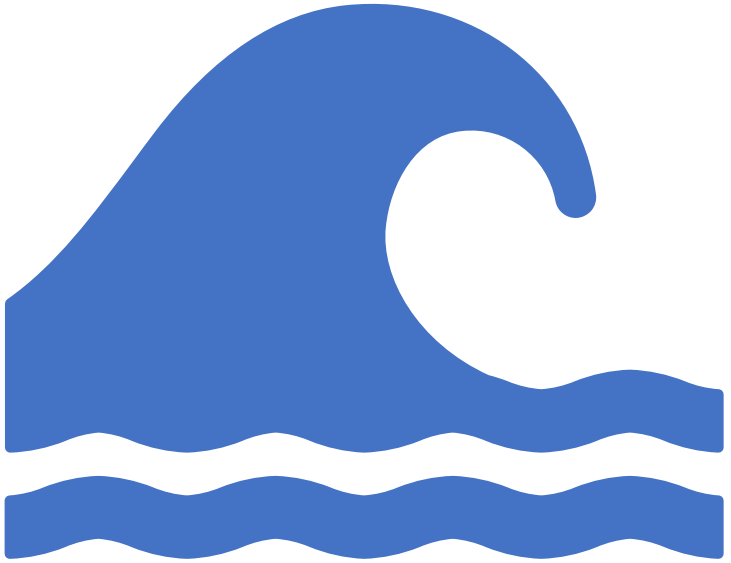
Wind effect and dynamic tilt

What happened if we have a wind speed of 8m/s?

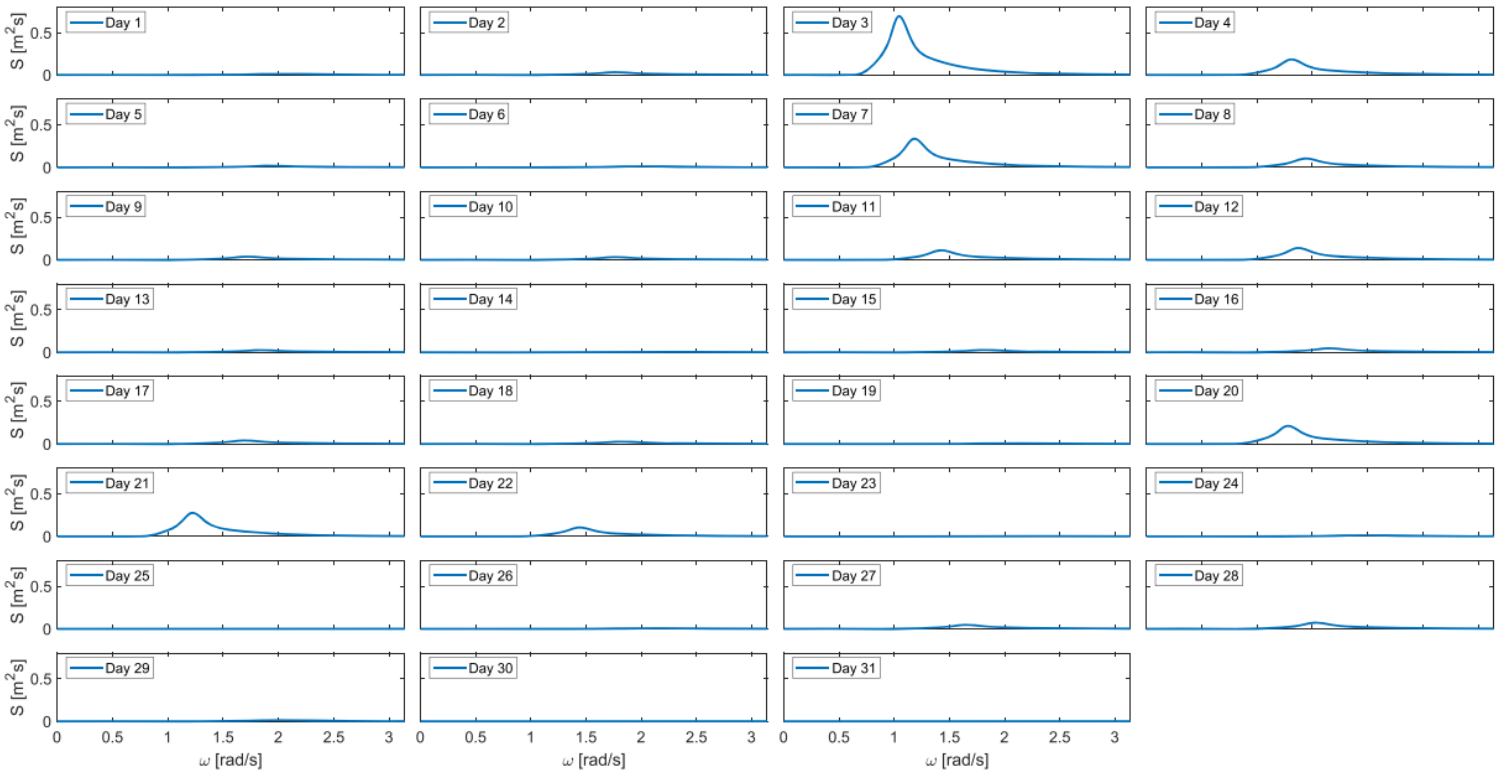
- **Step 1:** produces small waves with wavelengths of a few centimeters.

- **Step 2:** Wind blowing over the wave produces pressure differences along the wave profile causing the wave to grow exponentially.

- **Step 3:** Finally, the waves begin to interact among themselves to produce longer waves leading to waves going faster than the wind,(noted by Pierson and Moskowitz)

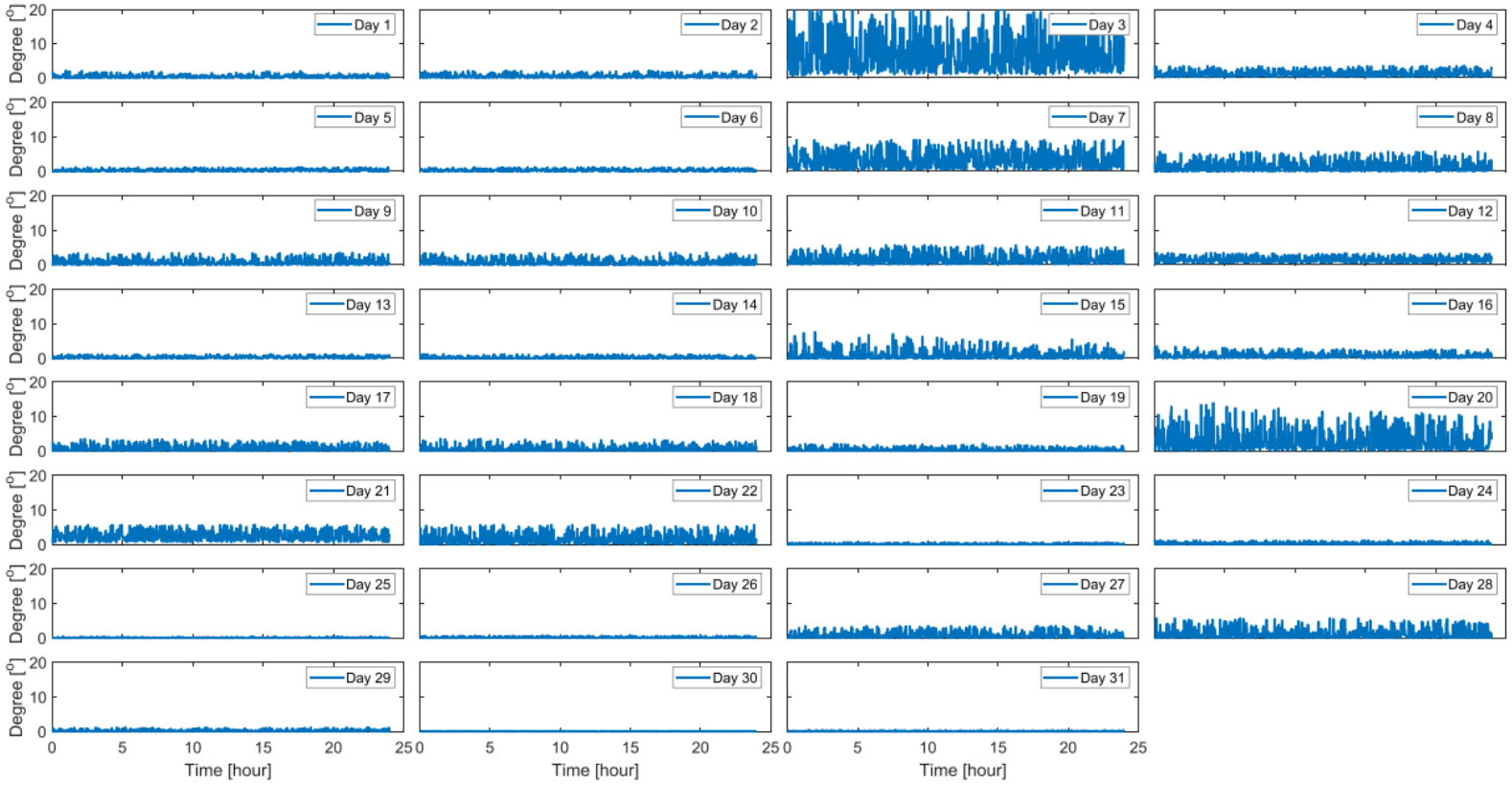


Example of one month Wave spectrum and tilt angle on the North Sea



Joint North Sea Wave Project (JONSWAP) spectrum (JS) for all days of August 2016

Example of one month Wave spectrum and tilt angle on the North Sea



The tilt angle of the pontoon for all days of August 2016

Corrosion

An Example: 58.5 MW project in northeastern Thailand

Sungrow supplied

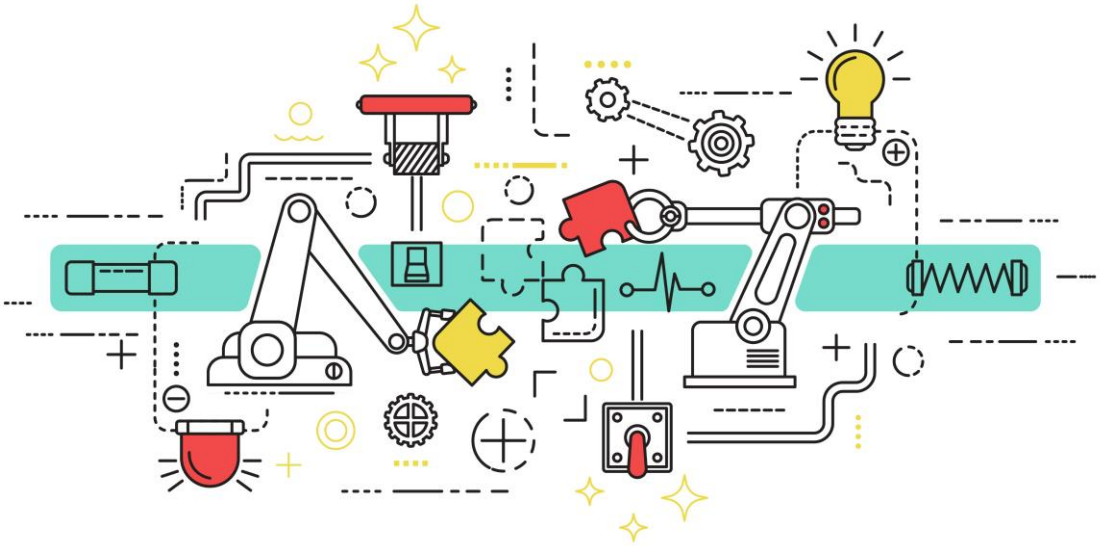
- the SG3400HV PV inverter solution which reaches a level C5 of anti-corrosion.
- Coming together with the combining box of protection level IP67, the solution proves resilient in the harsh reservoir conditions.

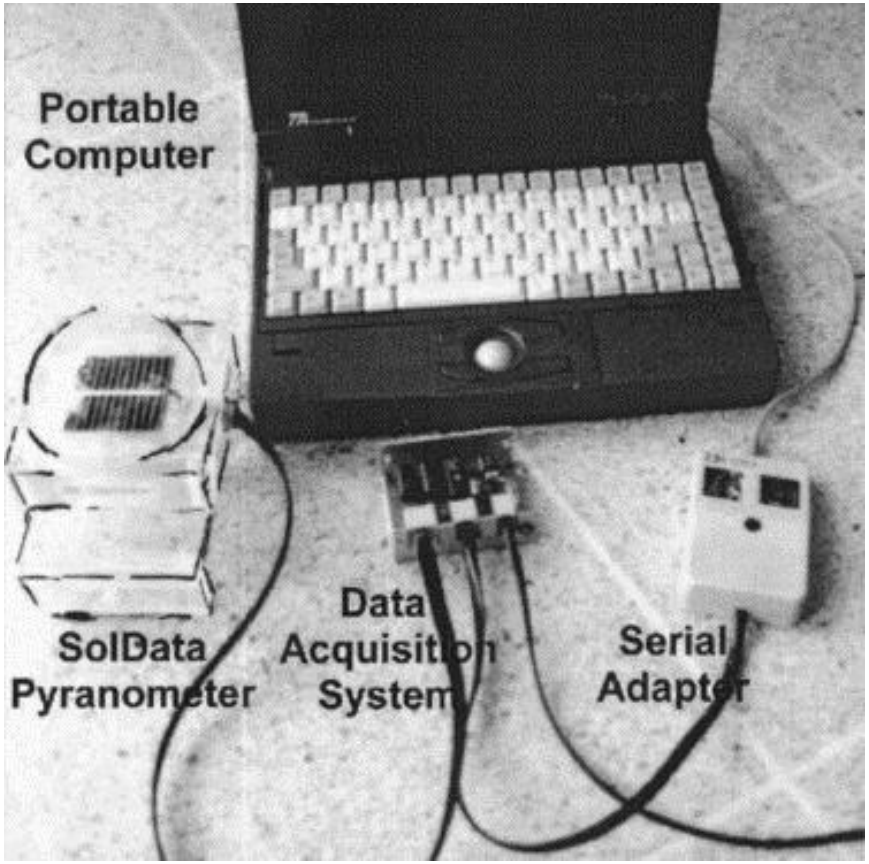
IP Code and Corrosion classes

Code letters	First characteristic numeral: Solid particle protection	Second digit: Liquid ingress protection	Third digit: Mechanical impact resistance	Additional letter: Other protections	Supplementary letter: Other protections
IP (Ingress Protection)	Single numeral: 0–6 or letter X	Single numeral: 0–8 or letter X	Single numeral: 0–9	Single letter	Single letter
Mandatory	Mandatory	Mandatory	No longer used	Optional	Optional

ISO 12944	Impact	Interior	Exterior
C1	Very low	Heated buildings with clean air, such as offices, shops, schools, hotels, etc.	None
C2	Low	Buildings not heated, where condensation may occur, such as warehouses and sports halls.	Atmosphere with low pollution. For example in the country.
C3	Middle	Buildings for production with high atmospheric humidity and some air pollution such as food manufacturers, breweries, dairies and laundries.	Urban and industrial areas, moderate sulphur dioxide pollution. Coastal areas with low salt content.
C4	High	Chemical manufacturers, swimming baths and ship- and boatyards by the sea.	Industrial areas and coastal areas with moderate salt impact.
C5-I	Very high - Industry	Buildings or areas with almost permanent condensation and with high pollution.	Industrial areas with high humidity and aggressive atmosphere.
C5-M	Very high	Buildings or areas with almost permanent condensation and with high pollution.	Coast and offshore areas with high salt content.

Let us roll up our sleeves for a little bit of Engineering





Example from old versions of monitoring system: Photograph of the SIMBADAS measurement system.

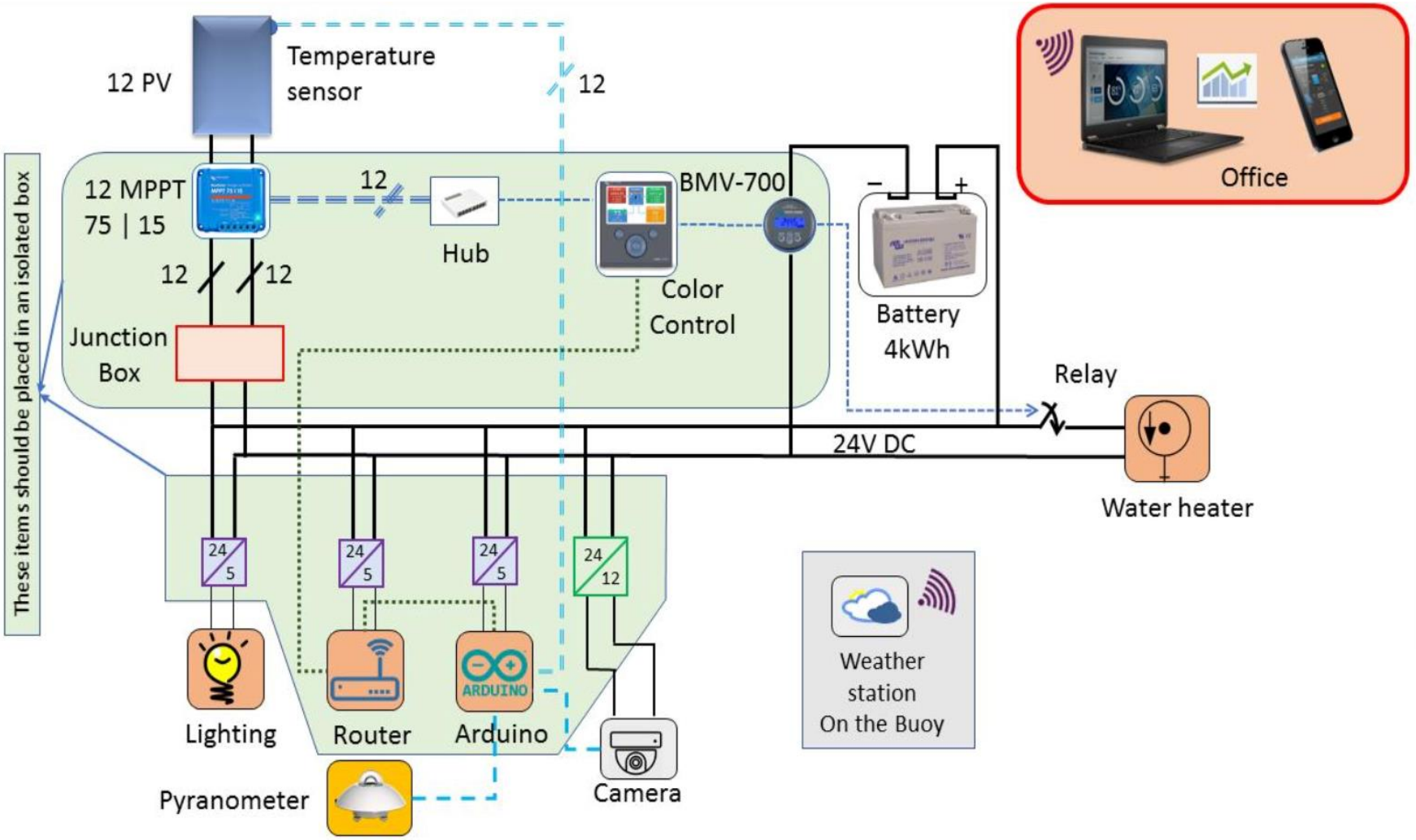
A Microcontroller-Based Data Acquisition System for Solar Radiation and Environmental Monitoring

- Raphael Mukaro and Xavier Francis Carelse
- IEEE TRANSACTIONS ON INSTRUMENTATION AND MEASUREMENT, VOL. 48, NO. 6, DECEMBER 1999

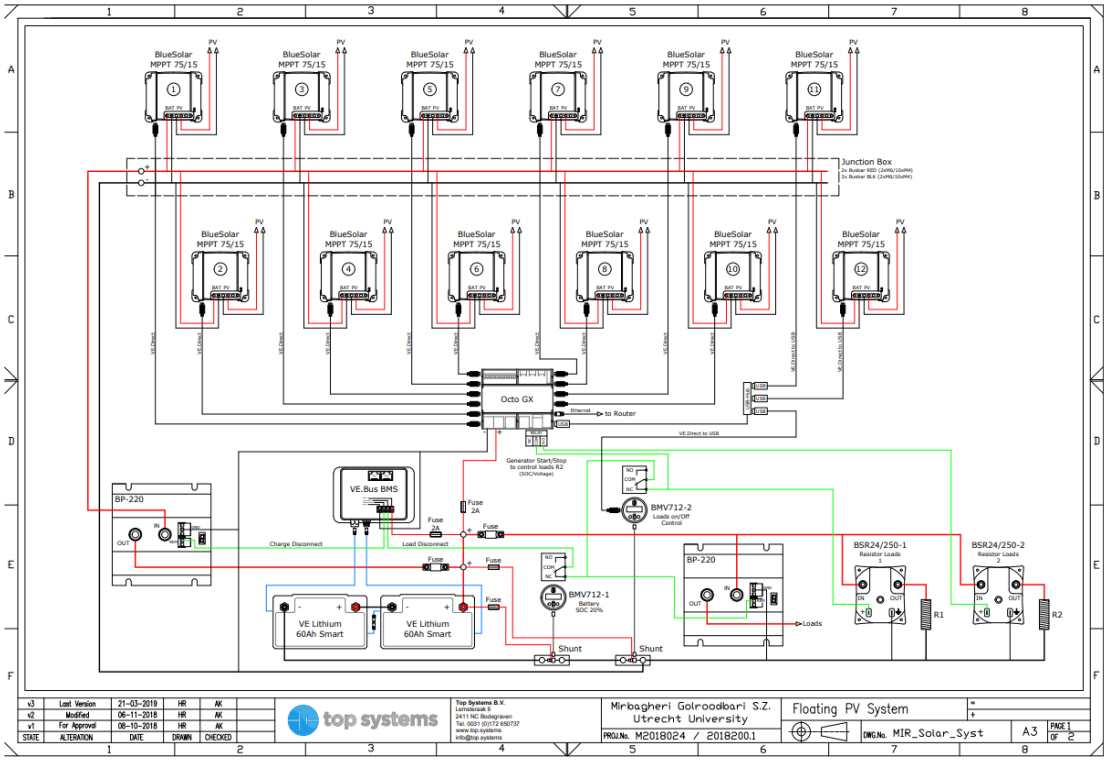
Let us start to design our standalone, research-based system

- What we need?
  - PV performance per panel
  - Temperature per panel
  - Water temperature
  - Irradiation components
  - Camera
  - Battery monitoring system
  - Load control system

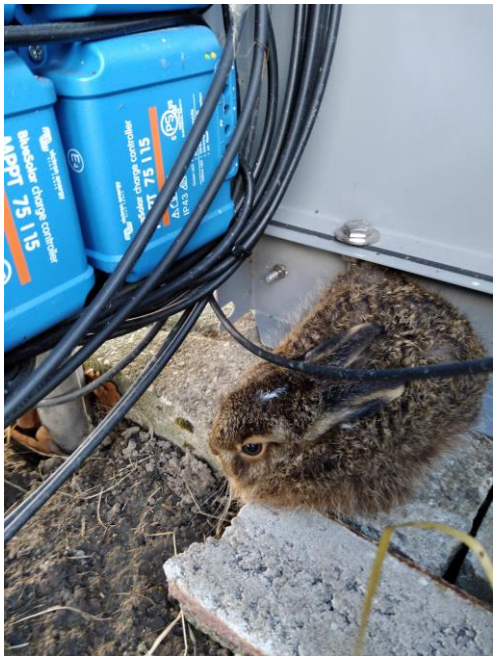
Schematic of an Example

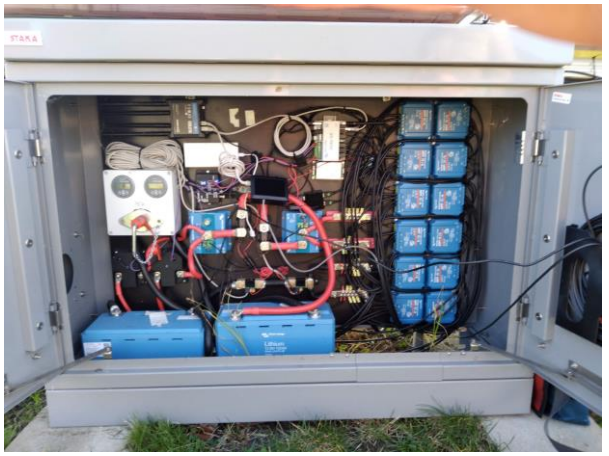


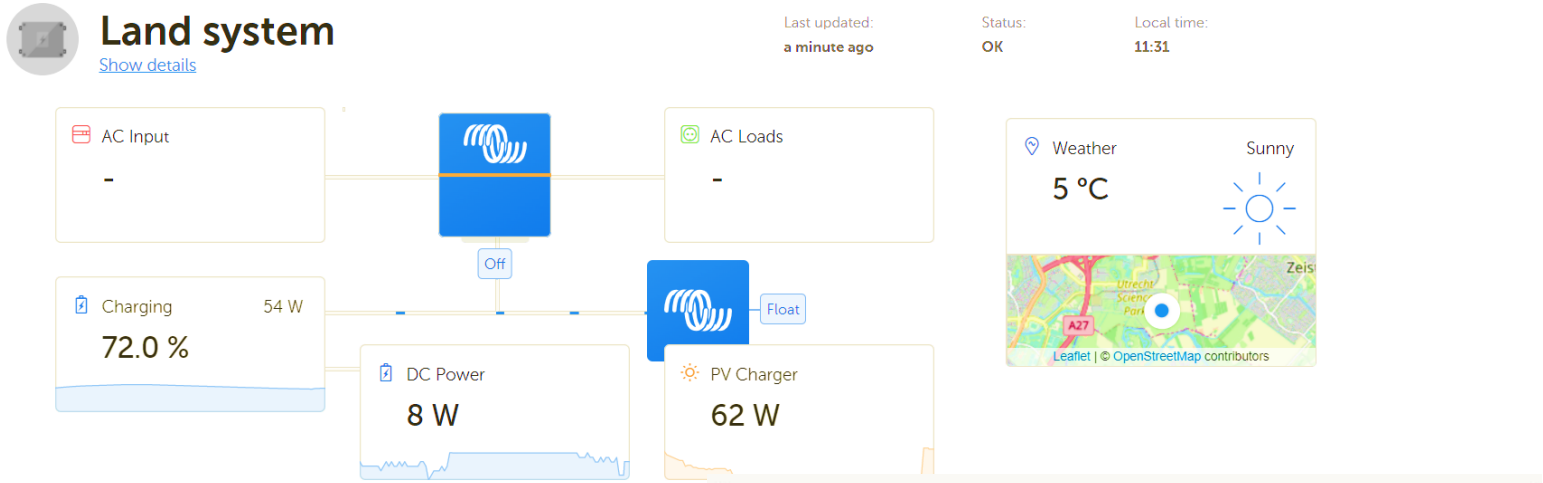
How is the engineering of such a system?

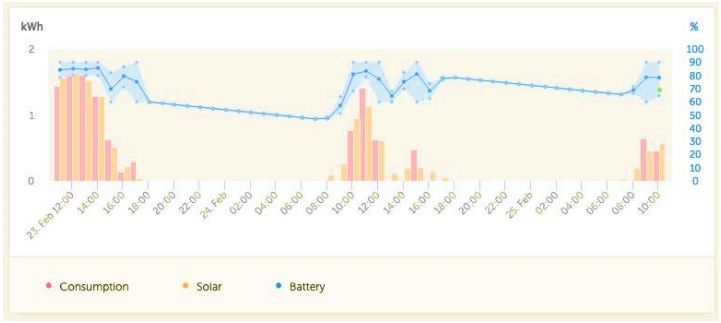


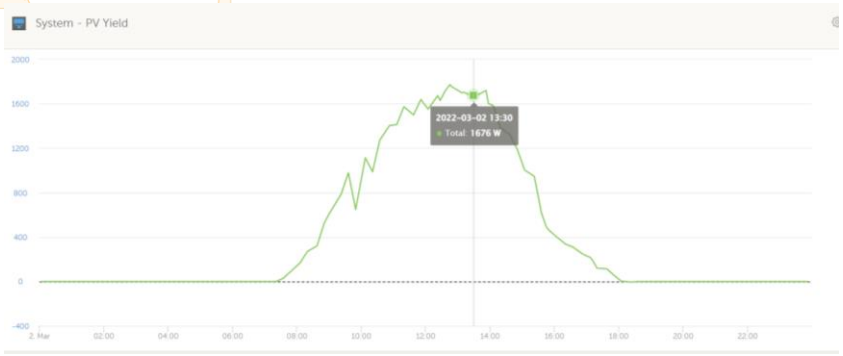
Land-based system





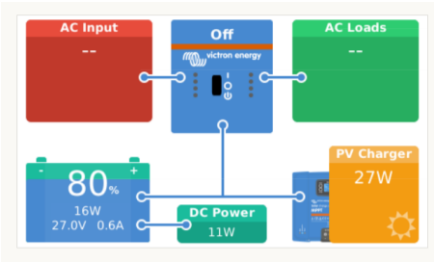




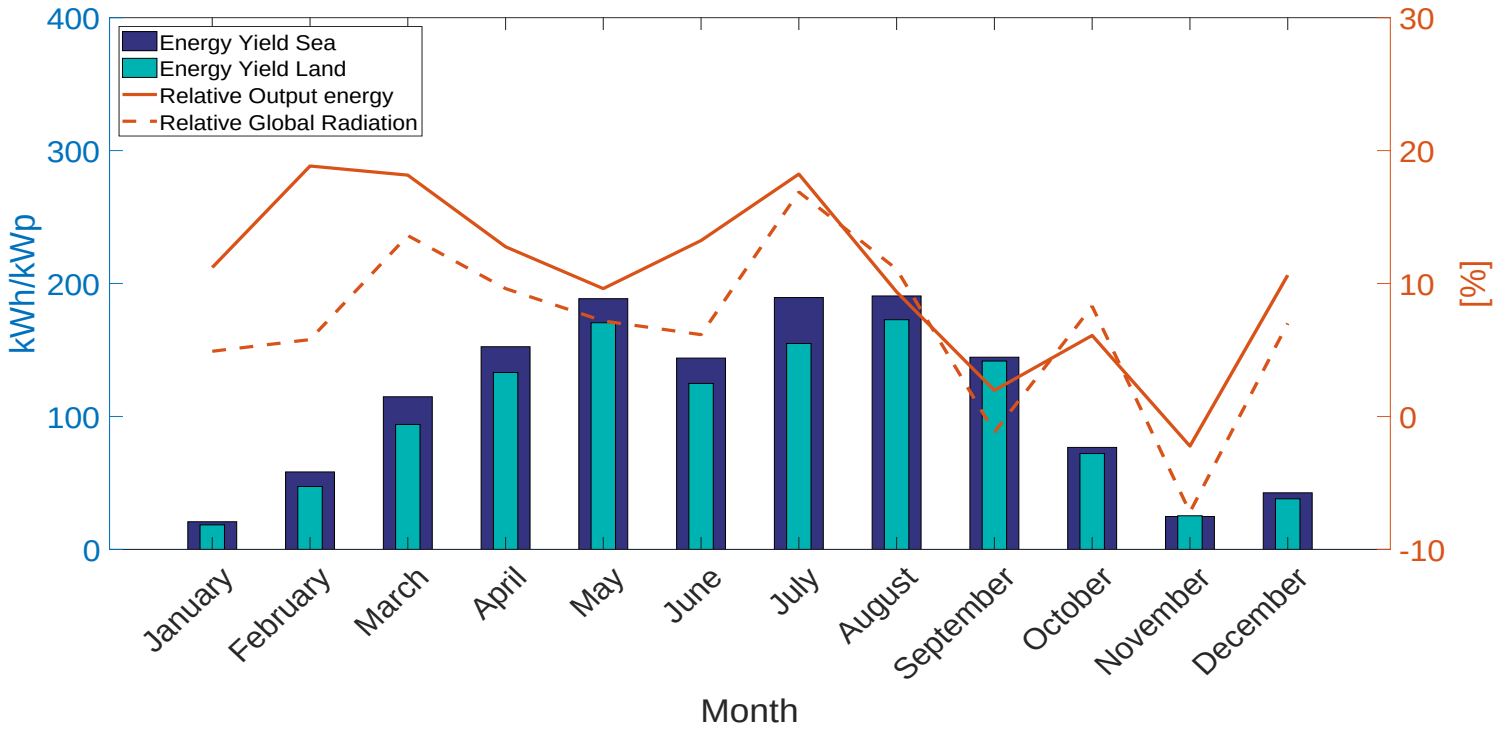


How a GUI look like?

[Land-based system]

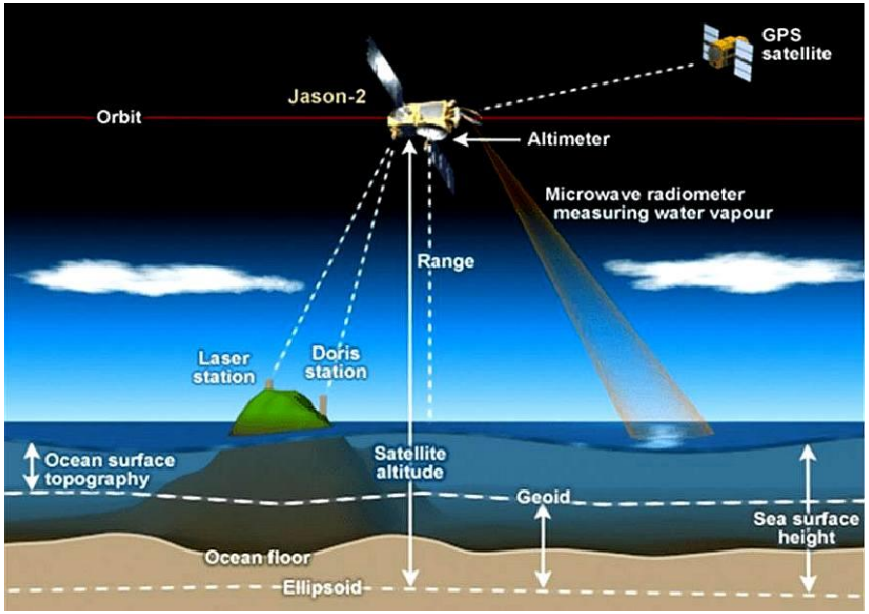


Land-based and floating comparison



Normalized energy yield in kWh/kWp for the offshore FPV and LBPV systems (right axis), and relative output difference (left axis)

Satellite monitoring

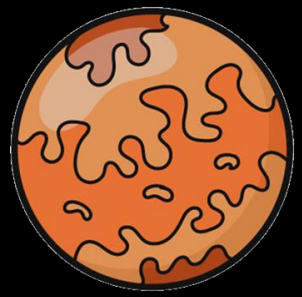


A new generation for monitoring system!

- Ambient temperature,
- Irradiation components,
- Wind speed,
- Relative humidity,
- Sediment transport pathways,
- Chlorophyll concentrations,
- Salinity
- Temperature ranges

Please find one the FPV systems on Google Earth

Keep the Time for a photon journey from Sun to Mercury



Examples for FPV from Google Earth

- Sirindhorn reservoir

The 45 MW hydro-floating solar hybrid at Sirindhorn Dam

Video

- Guqiaozhen

150 MWp deployed by Sungrow

- Centrale photovoltaïque flottante de Piolenc

17 megawatts-peak, on its time that was the largest in Europe

- Selangor Province

13 MWp with LCOE $0.051/kWh

Discussion and Questions!