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goPV

June 22

Mounting System and Tracker Device for PV plant

GLOBAL OPTIMIZATION OF INTEGRATED PHOTOVOLTAIC SYSTEM FOR LOW ELECTRICITY COST

co-organized with Università di Catania

Mounting System and Trackers for PV plant

Lecture objective:
To provide a comprehensive overview of **Mounting System /Tracker Device** currently used in utility scale PV plants, highlighting the issues and approaches currently followed to achieve an optimization between the *Needs of Reliability*, Capex & Opex *Values*, *Service Lifetime* of the plant.

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6. Failure modes and maintenance
7. New Challenges

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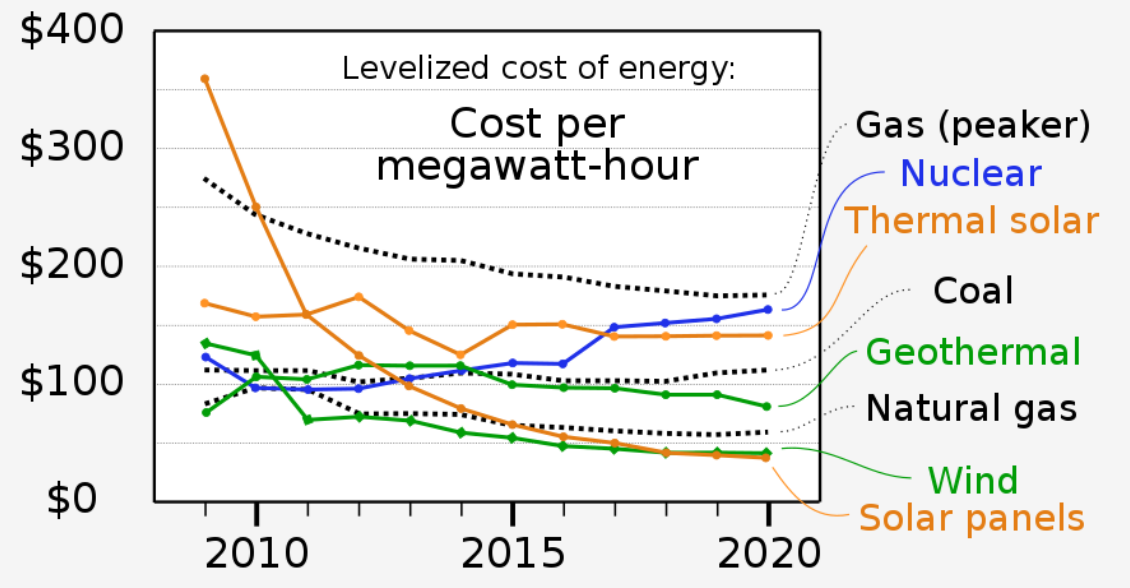
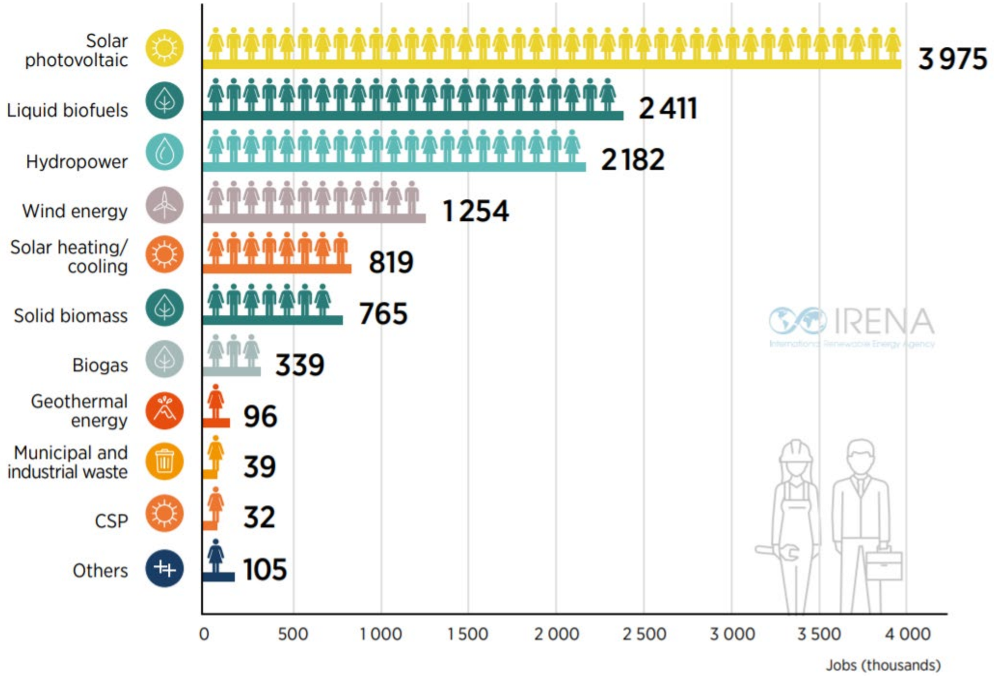
Photovoltaic: business approach





- Cheapest price for kWh from renewables tech
- It is more convenient to produces from renewables to maintain fixed prices and increasing gross margin

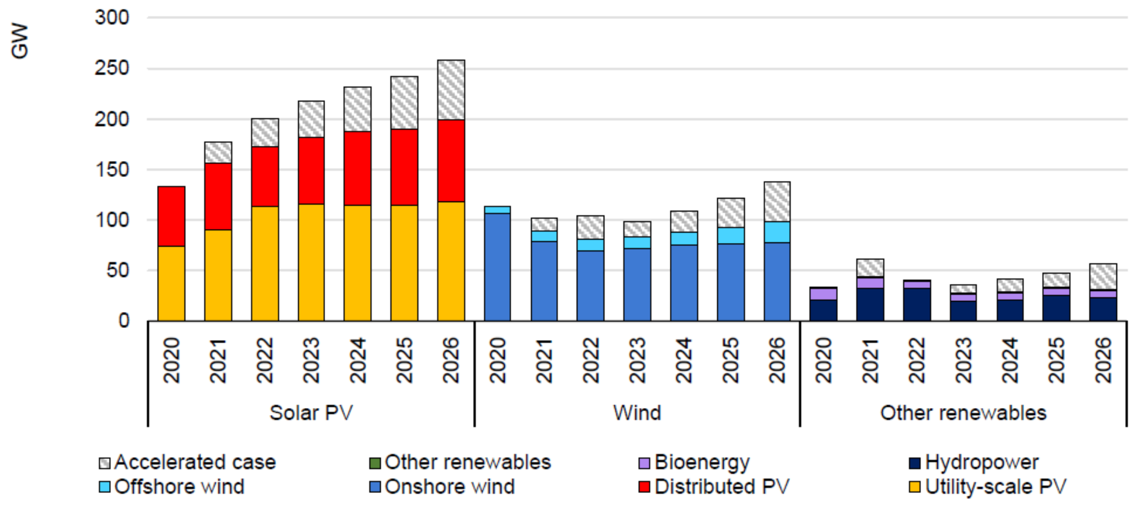
- Millions of jobs related with renewable technologies
- Solar will absorb most of them

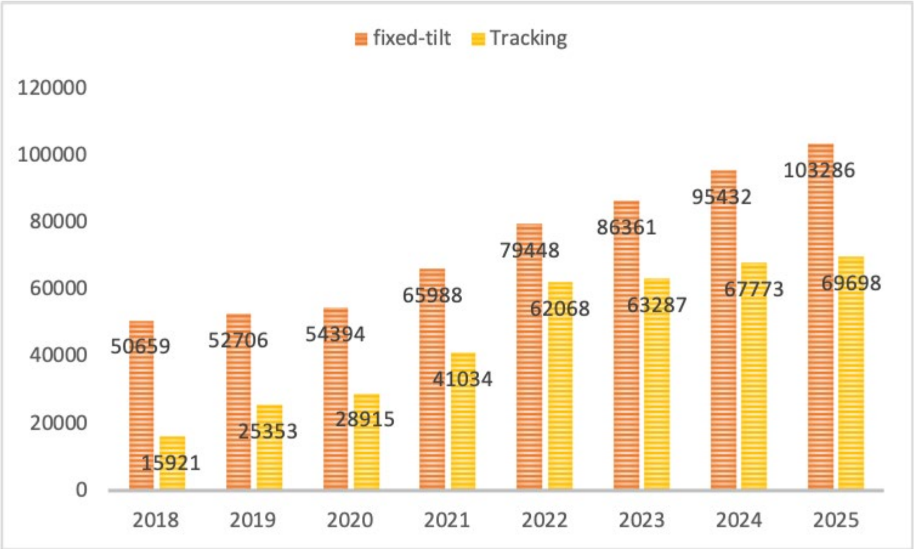
Gtm research, IEA, IRENA, IHS

PV Solar Capacity

World

843 GW of installed capacity (2021)
1010 TWh electricity
1200 working hours





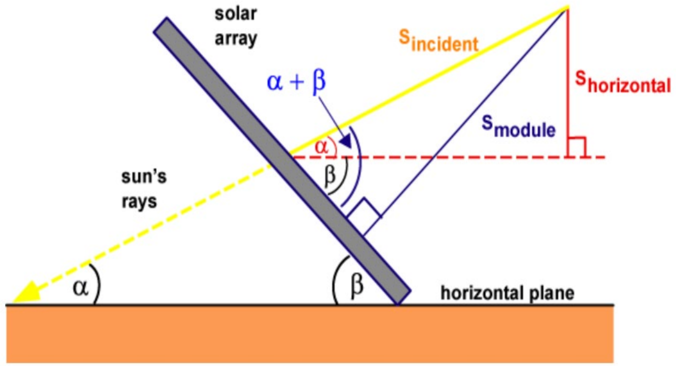
- Annual market to grow by 17% year-on-year
- Almost 160 GW in 2021
- PV accounts for almost 60% of all renewable capacity additions
- Utility scale PV gives lowest cost of adding new electricity capacity
- Utility-scale projects over 60% of all solar PV additions worldwide.

- 60% of Utility Scale installation will be with tracking systems

Gtm research, IEA, IRENA, IHS

Mounting System for PV plants

- Fixed-tilt: static system, fixed tilt angle
- Tracking: angle mechanically adjusted to maximize energy production



Fixed

Production: 100 kWh
Cost: 100 €

Single axis

Production: +30%
Cost: +15%

Azimuth

Production: +30%
Cost: +30%

Dual axis

Production: +35%
Cost: +40%

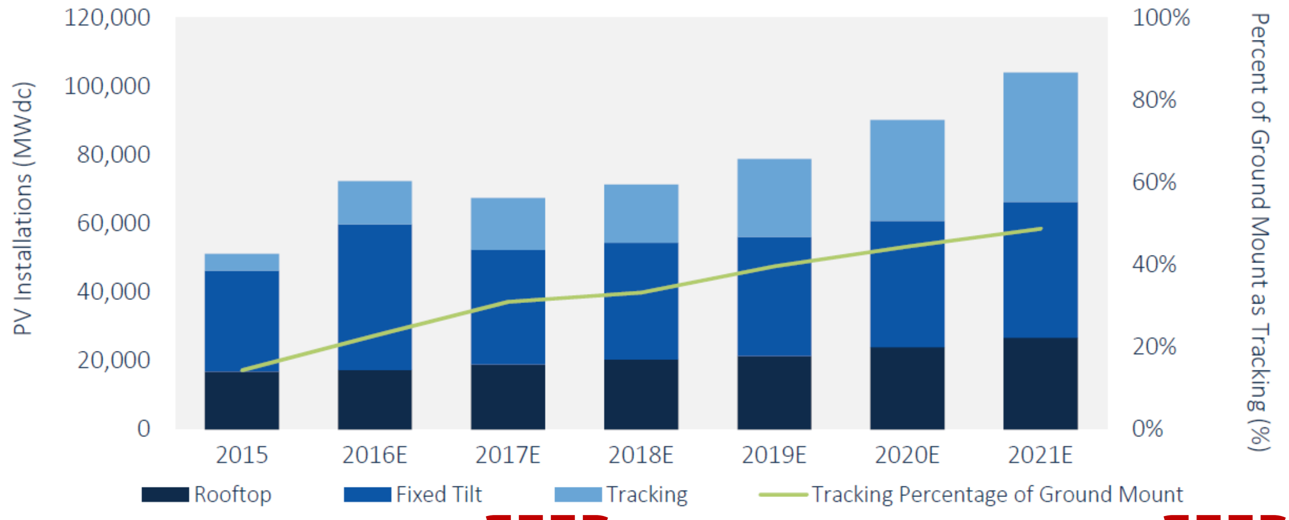
Gtm research

Single Axial Tracker

- The costs/benefits balance in large PV plants of standard PV modules identified the **horizontal single axis tracker as best compromise**: with a reasonable increase of CAPEX and OPEX costs, it allows to **increase productivity by 20-30%.**

- This potential is driving a growing interest for PV horizontal single axis trackers with strong and fast increase in market share over the coming years: **more of 50% of market in 2021**

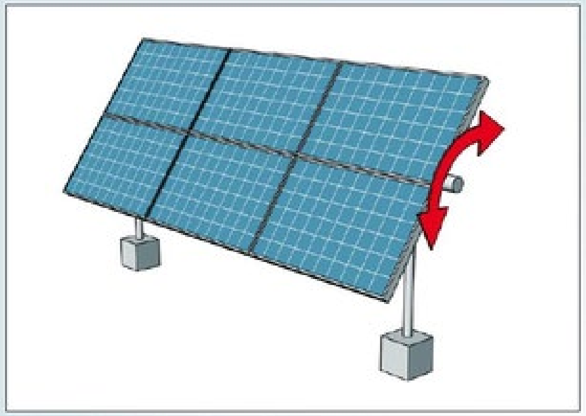
Global PV Mounting Systems Forecasts, 2015-2021E (MWdc)



Global Racking Type Forecast (MWdc)	2015	2016E	2017E	2018E	2019E	2020E	2021E
Fixed Tilt*	29,352	42,429	33,451	34,007	34,634	36,759	39,568
Tracking*	4,975	12,631	15,078	17,000	22,808	29,419	37,747
Total	51,230	72,412	67,487	71,411	78,895	90,216	104,087
Tracking Percentage of Ground Mount	14%	23%	31%	33%	40%	44%	49%

Source: GTM Research *Fixed tilt includes utility ground mount, commercial ground mount, and canopies; Rooftop includes both pitched and flat roofs

Single Axial Tracker



Horizontal single axis tracking:
Rows of modules are usually orientated in a north-south line rotating from east to west.

Single Axial Tracker

Centralized

Trackers with linked rows.
Two or more rows are powered by single actuator
Group of tracking angles

Push-pull

Rotary drive

Decentralized or indipendent

Each row indipendently powered
One actuator per each
Different tracking angles

Auxiliary module

Parasitic distributed

Tech Comparison

Centralized: push-pull

Centralized: Rotary drive

Decentralized: selfpower by auxiliary module

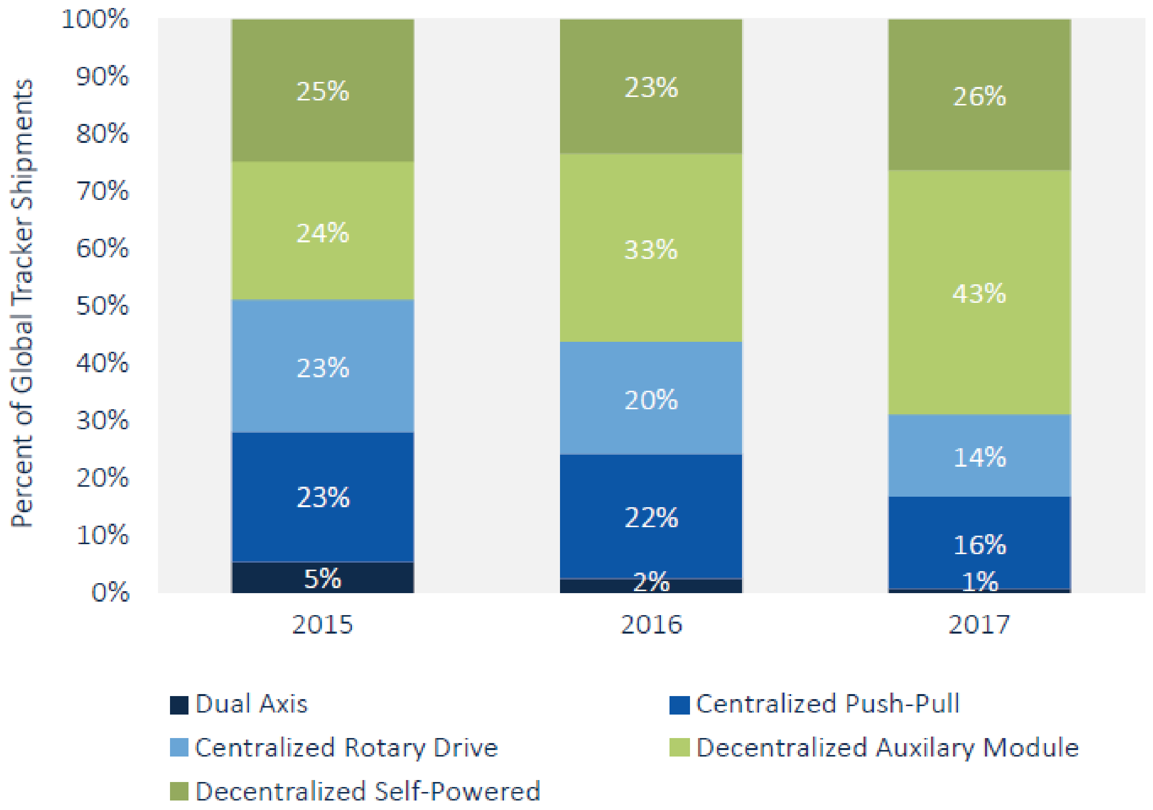
Decentralized: parasitic

	Centralized: push-pull	Centralized: Rotary drive	Decentralized: selfpower by auxiliary module	Decentralized: parasitic
Main Advantage	Largest block sizes, which amortizes the cost of the tracker and minimizing schedule maintenance	Same benefit of pushpull minimizing wind forces, fewer moving parts, smaller components	Design flexibility, lower grading, less cabling, small modules «off-the shelf» with high availability	Similar benefit to self-power. Energy taken from inverter or string is minimum, higher module density in each tracker
Main disadvantages	Larger actuator, large mechanical component. High grading for liner actuator. Limits with E-W slopes. If motor fails, all the block stops. Long trenches from inverter	Less flexibility with slope. Problems if one motor stops, long trenches from inverter	Cleaning of auxiliary module, battery needed as backup (increasing failure rate of the system), high maintenance	If powered from inverter, trenches needed. If powered by string, a transformer lowering the voltage from 1500V to the one of the actuator
Maintenance	Urgent maintenance if a block stops. Generally less components to be maintained but critical	Similar to centralized	Battery and modules increase the number of programmed and unprogrammed failures	In between of centralized e decentralized with modules.
Cost implications	Lowest cost in terms of product (few actuators) but high installation costs	Lowest cost in terms of product (few actuators) but high installation costs	Less civil work but more components.	Similar to auxiliary modules. If powered by inverter, costs increases for cabling

Gtm research

Single Axial Tracker Market

Global PV Tracker Shipments by Technology Type 2015-2017

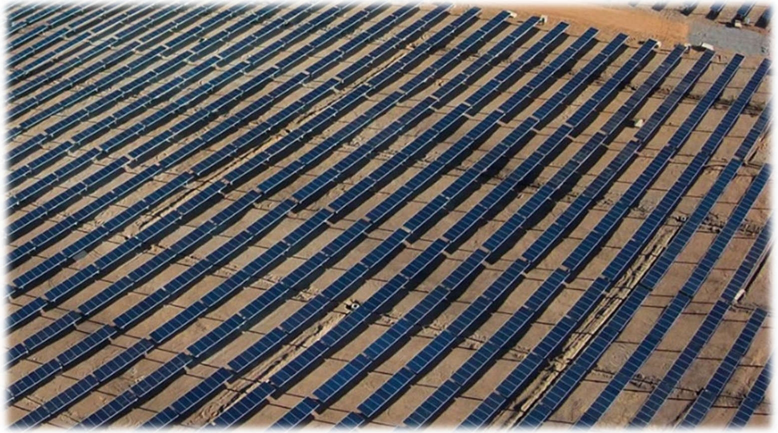


Source: GTM Research

- Decentralized with auxiliary module is leading the trend
- Decentralized trackers trend push up also the parasitic
- No Technology dominating: many producer propose both solution in their portfolio
- Dual Axis tracker market share is decreasing

Utility Scale Projects

SAO GONÇALO – Brazil (255 MW)



JUAZEIRO - Brazil (155 MW)

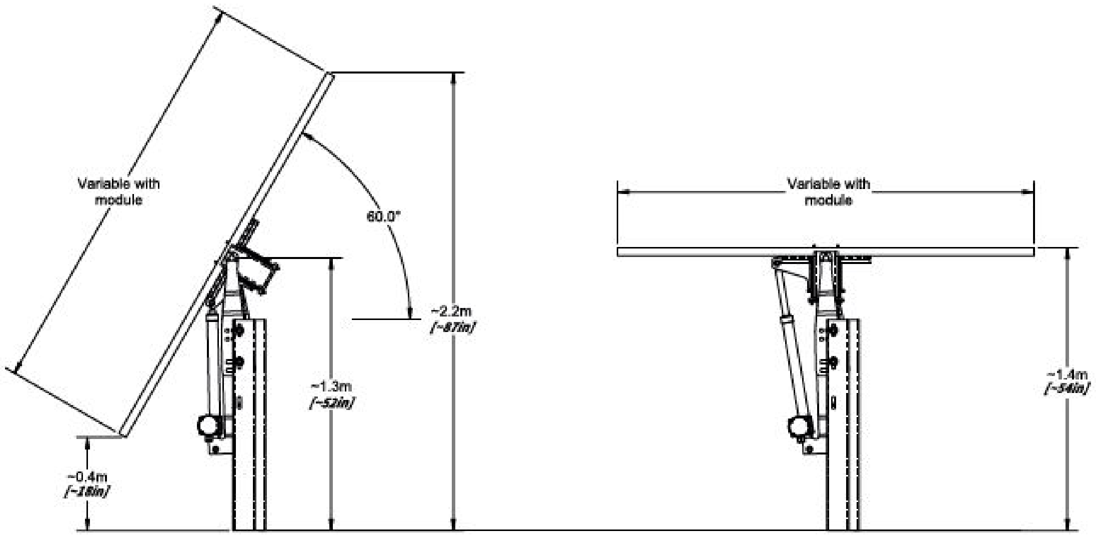
Campos del Sol – Chile (375 MW)

CAFAYATE – Argentina (100 MW)

Single Axis Tracker type

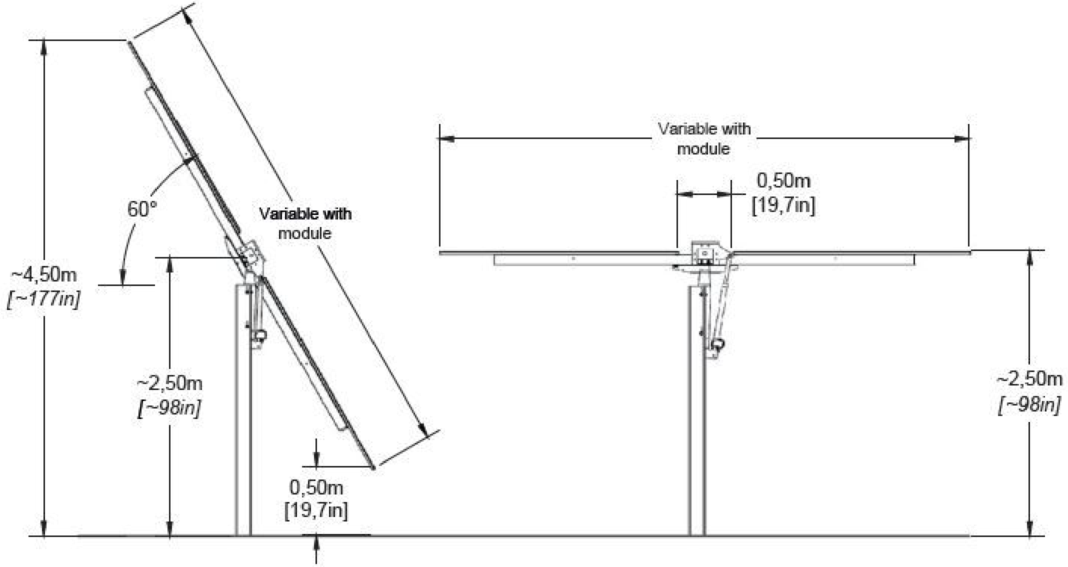
1 Portrait (1P)

- Optimized for Distributed Generation
- Minimal back side module shading
- Lowest installation labor costs
- Ideals for areas with high wind loads (minimum wind shear)



2 Portrait (2P)

- Born for bifacial modules
- Eliminates back side module shading
- Targeted for Utility Scale projects
- Increased module density
- Fewer posts / MW

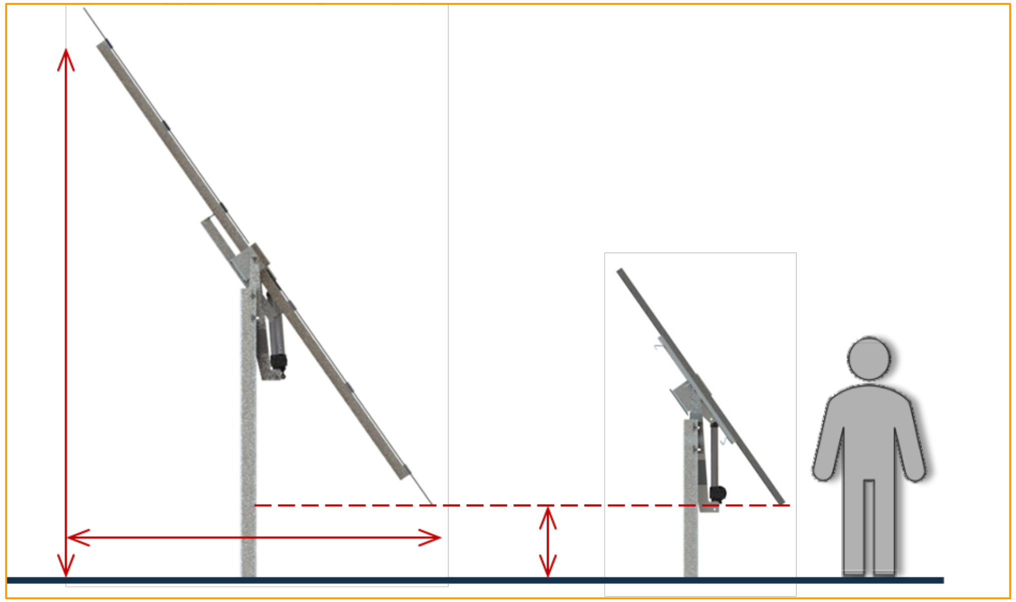


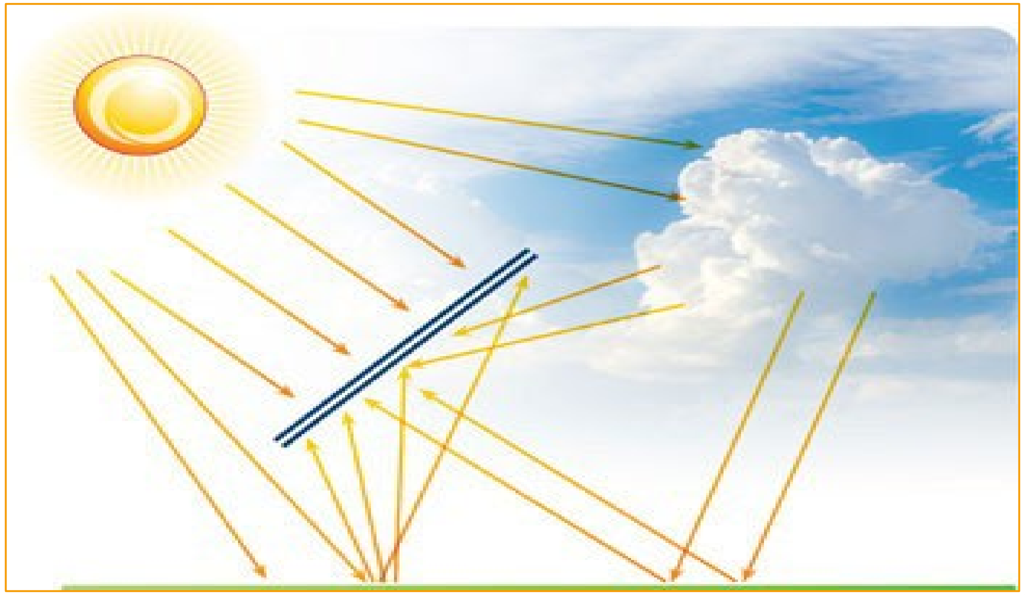
Tracker for bifacial modules

The new horizontal single axis tracker for bifacial modules should **ensure a significant contribution of reflected light** on the back of the PV module.

A new architecture of the tracker is needed: from single module to double module in portrait configuration

The **overall height of the tracker is more than doubled**, with consequent **greater effect of external loads** on the stability of the tracker, in particular wind loads.





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Tracker

Guideline for structural design

Good reliability in relation to the hazards from the environment for all design life of PV plant

vs

Low LCOE

Hazards from the environment :

- **External loads**: wind, snow,….
- **Ground movements**: landslide, earthquake, ….
- **Weather events**: lightning strikes, storms,….
- **Time:** aging, gear wear of driving devices, …
- **Aggressive environment**: corrosion,….

Appropriate Design:

- **Use of consolidate knowhow** about the steel structure design;
- **Use of available international standard** and certification codes,
- **Accurate models for loads- tracker interaction**:
  - Computational Fluid Dynamics (CFD) Analysis
  - Finite element stress-strain analysis of tracker steel critical components.
- **Full and Mid-scale lab test:**
  - Wind-tunnel test
  - Tests in climatic chambers on electronic /electromechanical components,
- **Appropriate use of available field experiences**

Available Codes

- A dedicated design code focused on tracker do not exist.
- Two main international standards approaches which dedicated to steel structure and building are used: **Eurocode 1-4** & **ASCE 7-16**
- The main differences between the two codes:
  - ✓ loads and load combinations,
  - ✓ return time of each characteristic variables loads (50 years vs 100 years),
  - ✓ difference between the "Service Limits" and "Ultimate Limits".
- Tracker must be designed according to the local regulations (considered as civil structures)
- Additional requirements coming from the customer must be met.
- Assumptions too conservative could make a project no-economically good
- A comprehensive regulation focus on mono-axial tracker is being developed in the IEC–WG9: at the moment, it is under development a regulation on "people safety"

New development

- ✓ New design
- ✓ More accurate models for wind loads: Wind tunnel tests and CFD simulation.

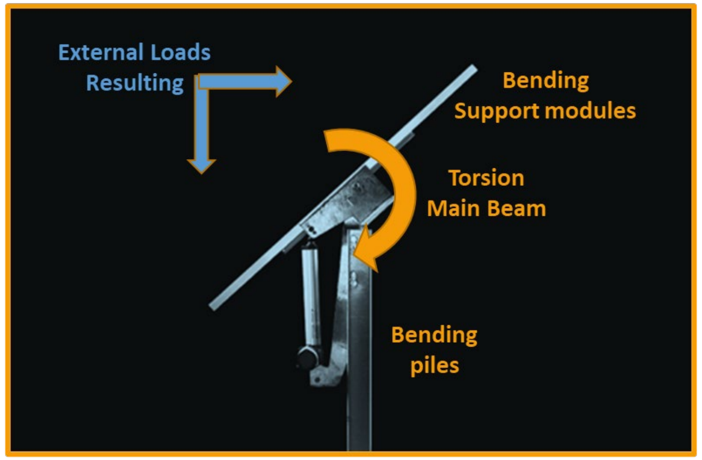
Technical requirements for Solar Tracker

Permanent Loads

1. Structure weight (≈40% of total masses),
2. Modules weight (≈60% of total masses).

Variable Loads

1. Snow Load,
2. **Wind Load** *(Static pressure and dynamic effect)*
3. Thermal Load,
4. Seismic Load.



→ Except for particular cases, in common applications **Wind Loads govern the tracker design**.

Specific restriction

Main resistance and deflection evaluation

All components must be adequately designed to avoid local instability problems (local buckling)

- ✓ Bending and Torsional section resistance and deflection for the **main beam** (tube),
- ✓ Bending section resistance and deflection for module **rails**,
- ✓ Bending and twisting section resistance for the **piles**.

Aiming error

In all service ranges no plastic deformations are permitted:

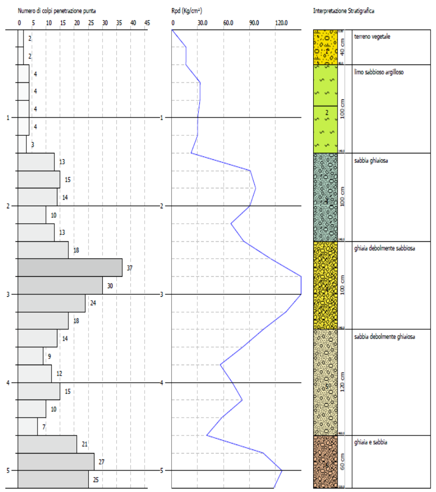
- Tracking accuracy must be guaranteed in the range of a few degrees (usually around 1° or 2°) of error throughout the expected life of the project

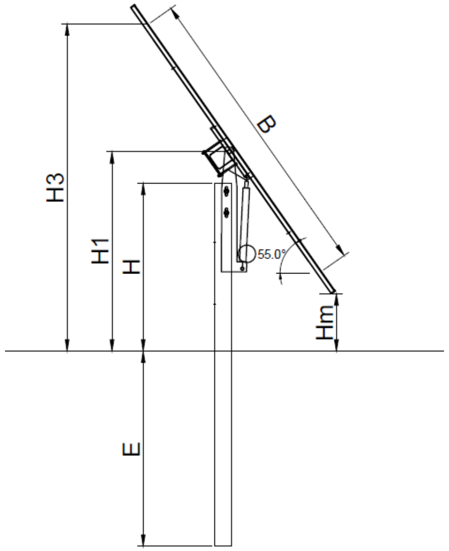
Module Deflection

- PV-Modules have to be considered as independent elements, which do not produce any structural resistance improvement and which may have their own rotations/displacements.
- Commonly it is considered the ***L/150 limit*** as a deflection restriction prescribe to prevent failures among the connection's points (bolts, rivet, clamps, etc).

Foundations

- One of the most variable elements in tracker designing: it is affected by all soil-mechanical-characteristics
- Detailed models for embedded length calculation are requested and confirmed with pull-out tests.
- Geological and PoT are a consolidated for the soil properties definition on large sites.
- Omega (Ω) sections maximize the contact surface with the soil, reducing embedment lengths.
- Concrete foundations in general are not used.

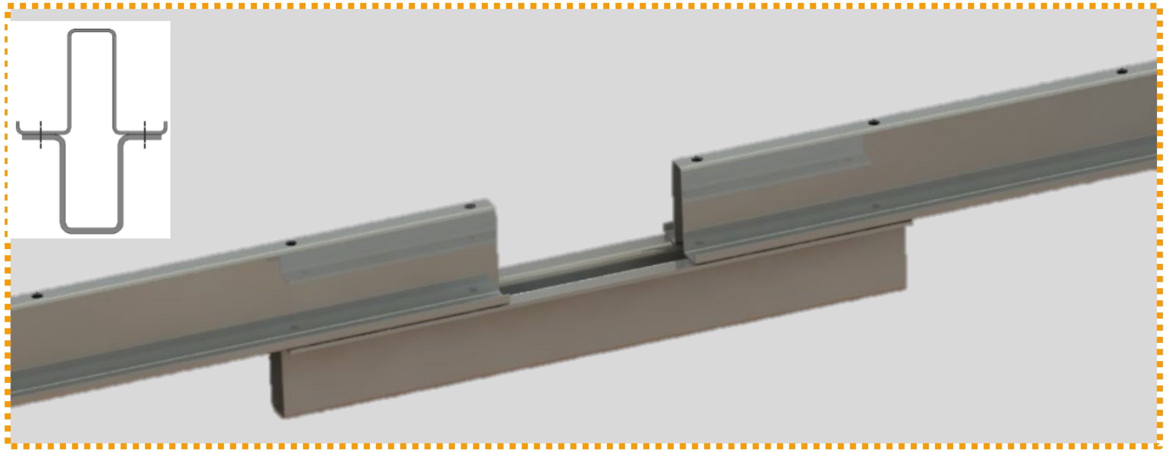




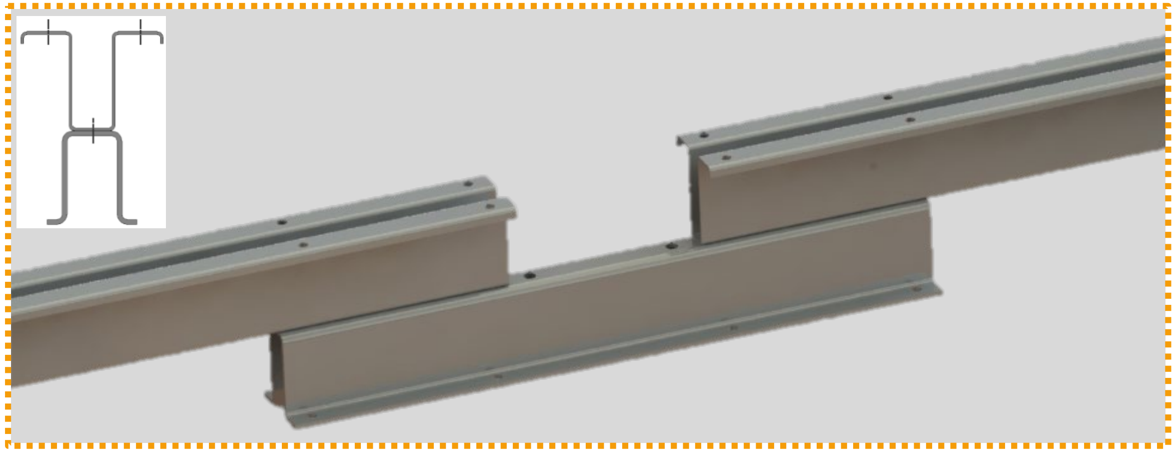
Design for Standardization of processes

- One of the main standard components scope is to be **easily manufactured** worldwide and **easily adaptable** to different situations.
- Module rails have been developed to be suitable in both configurations: frame and frameless module installation (currently both available in the market).

Frameless configuration *(GOPV Project)*



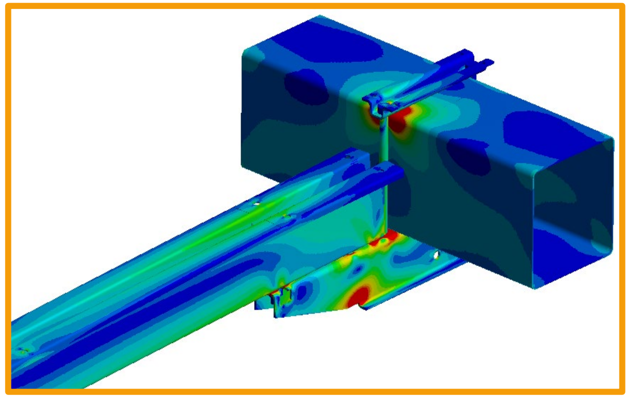
With frame configuration

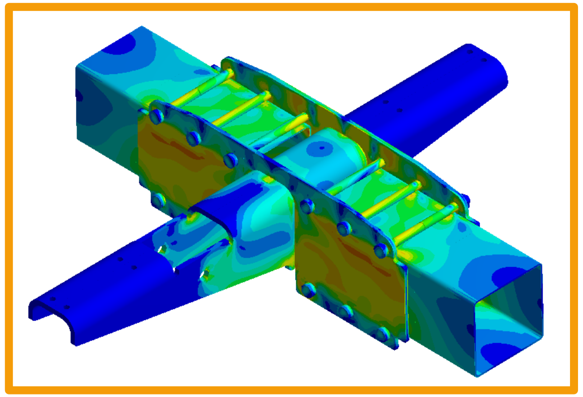


→ *Same omega shape profiles for both configurations*

Modeling and prototyping

- Due to their complexity (geometrical and in terms of loading condition), many times finite element analysis and lab testing are required to make reliable calculation and a cost-effective design.
- All mechanical elements (KIT) needs a specific design, mainly based on:
    - ✓ the load inputs coming from standard component design (defined by the codes),
    - ✓ Installation and maintenance requirements
    - ✓ Movement and mechanical performances granted along the project life.





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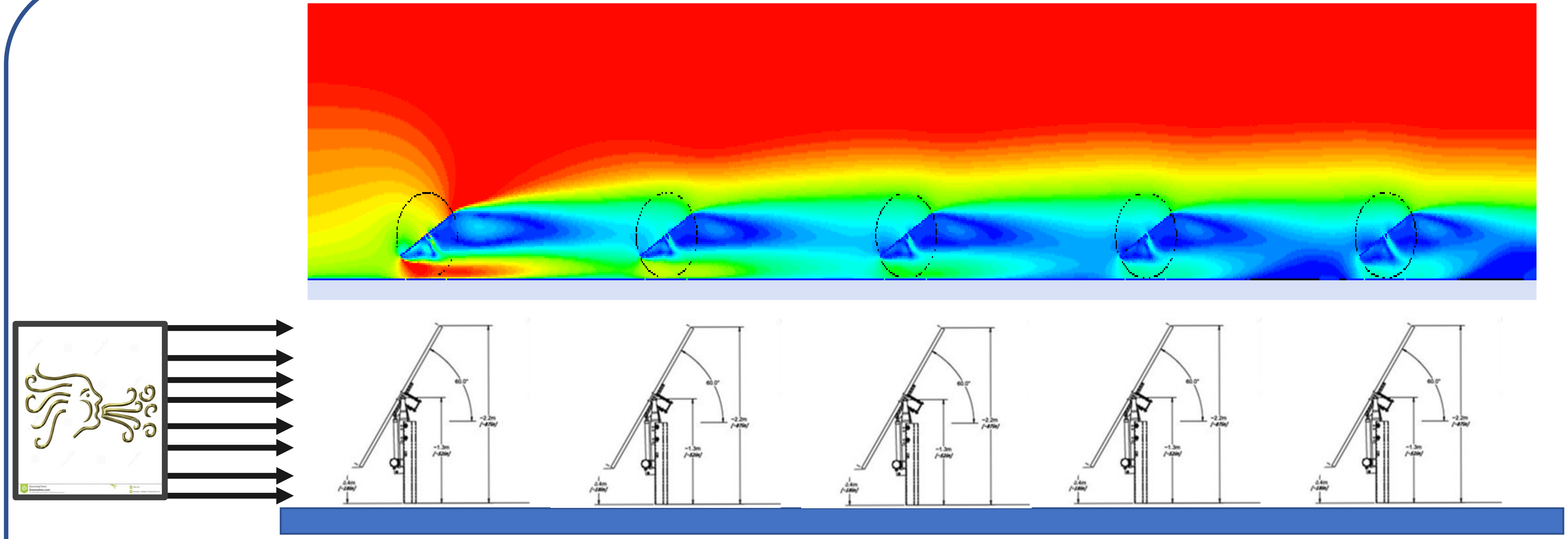
Wind Load: base knowledge



Wind Static Loads:
Static strength

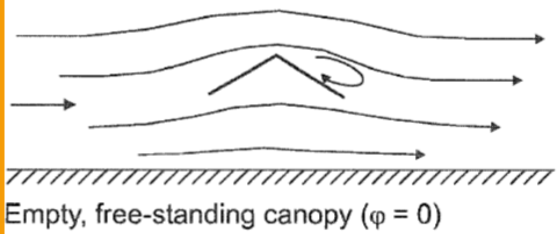
Aero-elastic Phenomenon:
Dynamic Instability

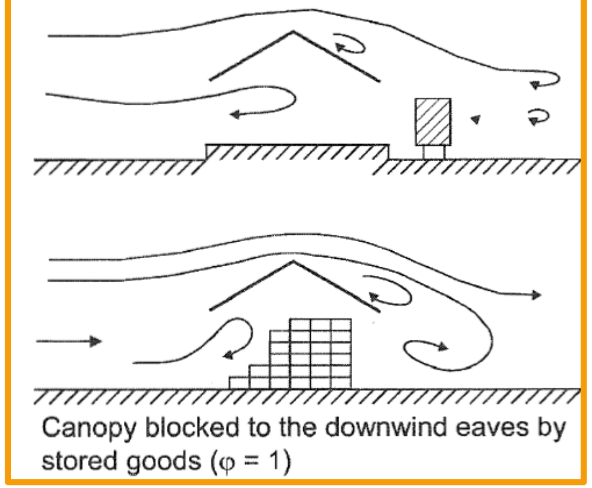
Wind Load: main codes approach

Issues connected with codes are:

- ✓ the **absence of a specific standard** for tracker design, only building codes could be considered;
- ✓ trackers are manly ***design as a generic single canopy roof***,
- ✓ no information about internal and external structure is generally taken into account.

- ➢ A code procedure does not adequately describe the wind interaction among tracker and air flow and represents a **conservative approach**;
- ➢ **CFD** and **Wind Tunnel** tests are the only way to "fill this gap of knowledge".





Wind Load: needs & approaches

WIND LOADS

Structural design
(Thicknesses)

Tracker shape
(Geometry)

Aero-elastic phenomenon
- Bigger surface exposed to wind,
- Lighter structures,
- Installation in climatological hard sites.

Wind pressure coefficient (Cp)
- Depending on national codes,
- Lack of a specific tracker design code,
- Need to reduce nominal wind loads/security coefficients.

Definition between one or two canopies analysis
- Gap between modules rows definition

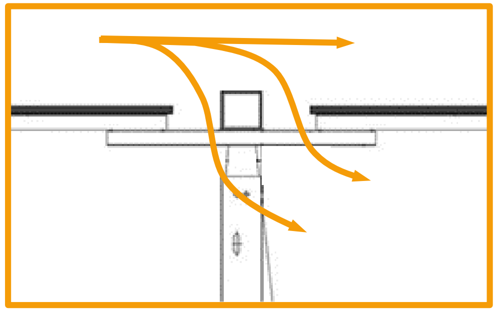
WIND TUNNEL TESTS

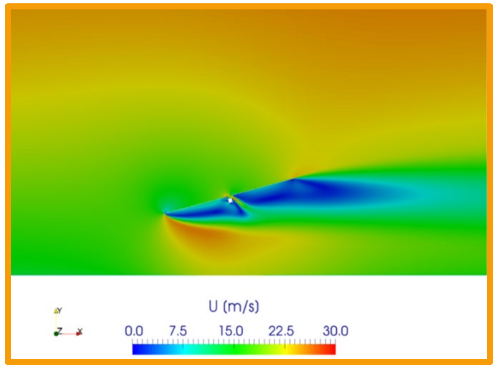
CFD Simulations

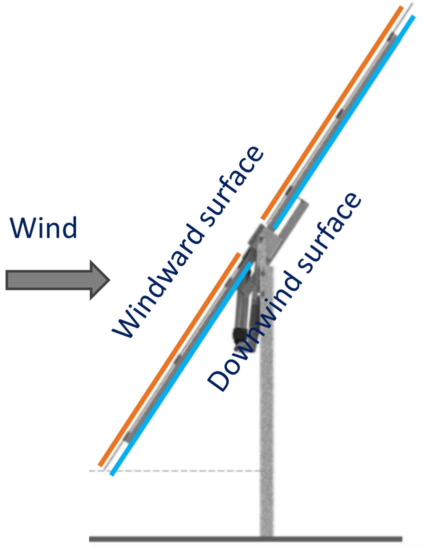
Wind loads: gaps effects

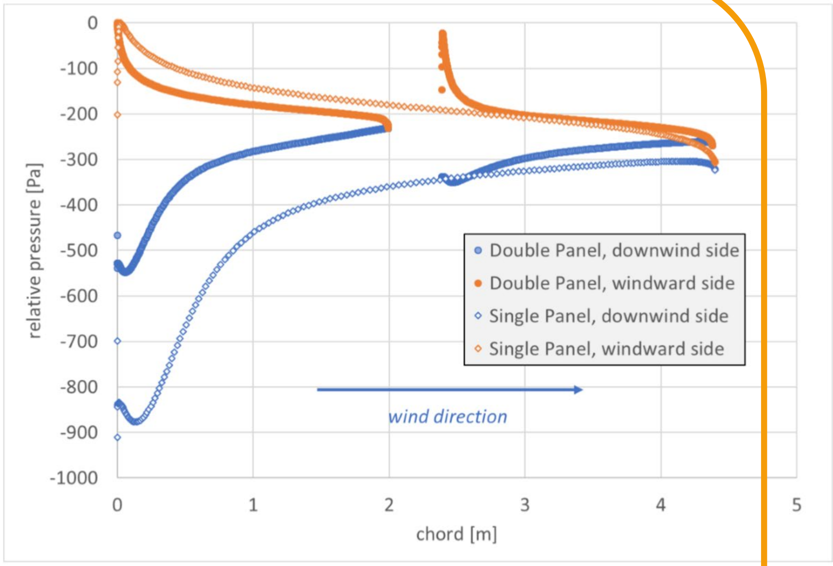
The University of Rome “*La Sapienza*” and *Enginesoft* were involved to support Convert in the develop CDF studies concerning wind-tracker interaction, especially focused on:

- ✓ the role of the gap on a two-portrait-modules tracker has on wind loads actions,
- ✓ how to the wind loads acting on surfaces may **change due to for to different angles of attack**.







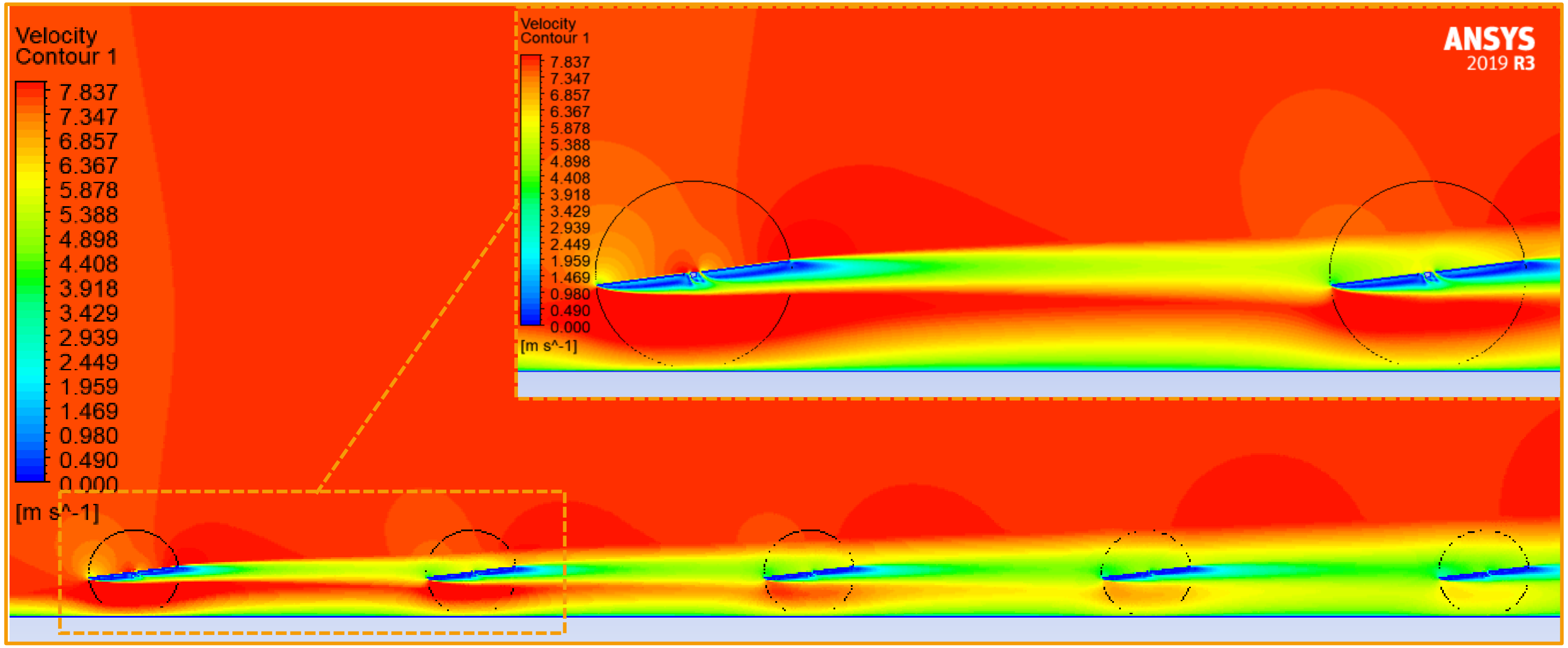


For example in a 5° tilt position the gap produce around 50% of load reduction on the tracker

Wind loads evaluation: CFD - tracker array

Study of a multiple tracker array configuration by the CFD analysis:

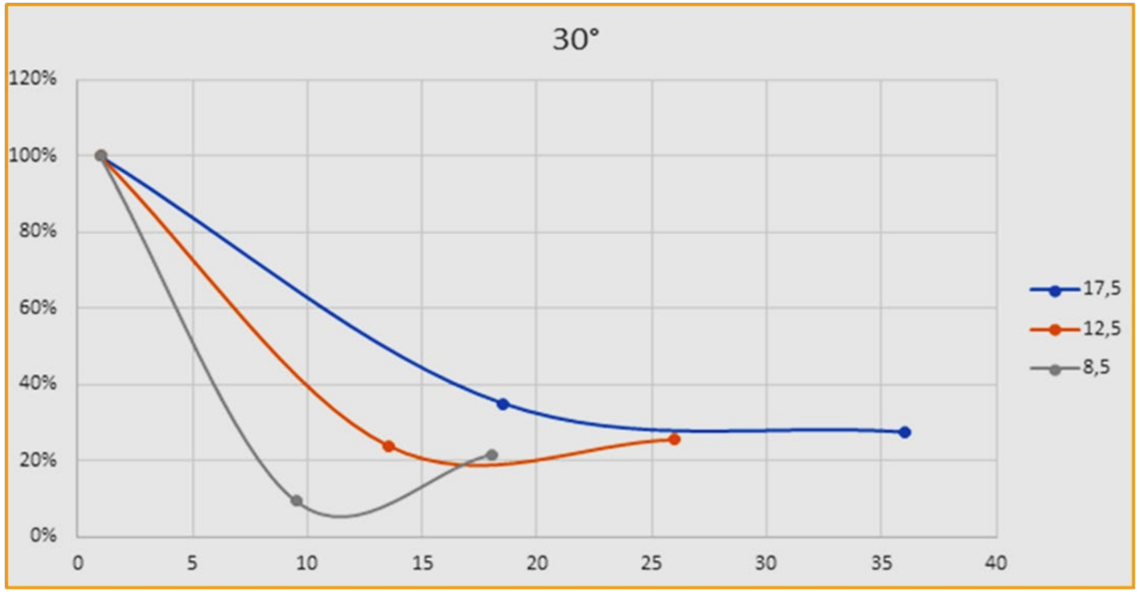
shielding effect of the windward rows on the following ones in terms of pressure acting on modules

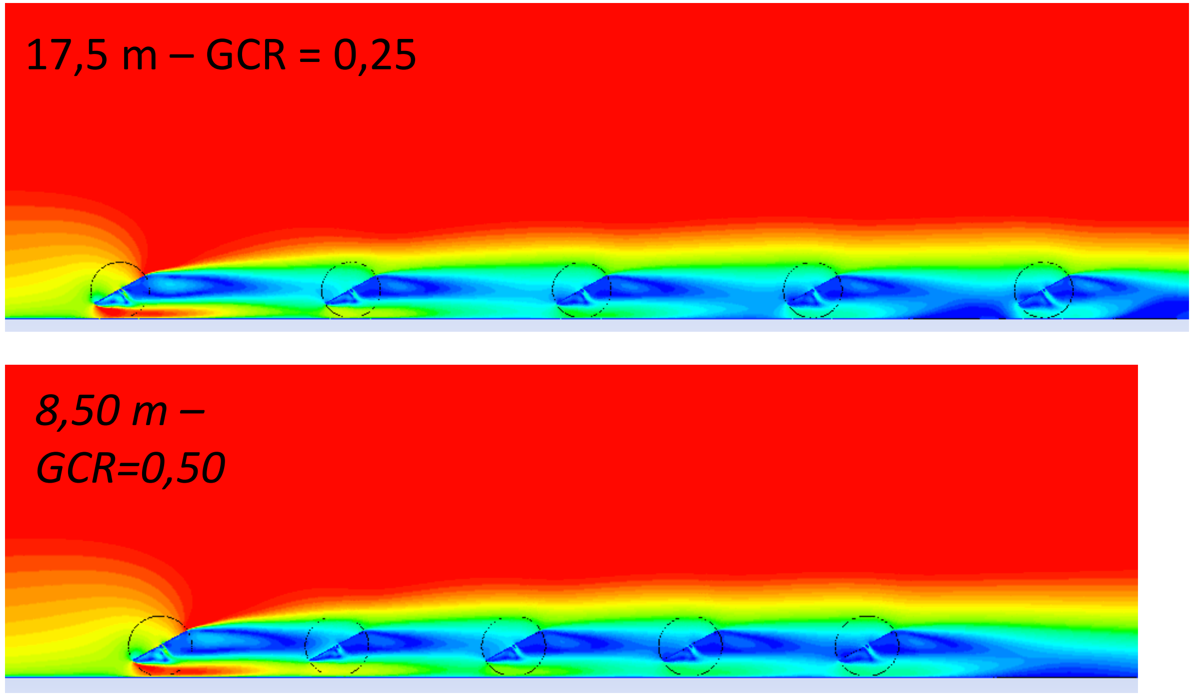


The wind pressure reduction is around 35% starting from the third row

Wind loads evaluation:
CFD - tracker array

- The influence of a tracker arrays on internal structures it is affected by the GCR (Ground Cover Ratio)
- Lower is the row spacing higher is the sheltering effect: *positive effect on the pressure on modules*

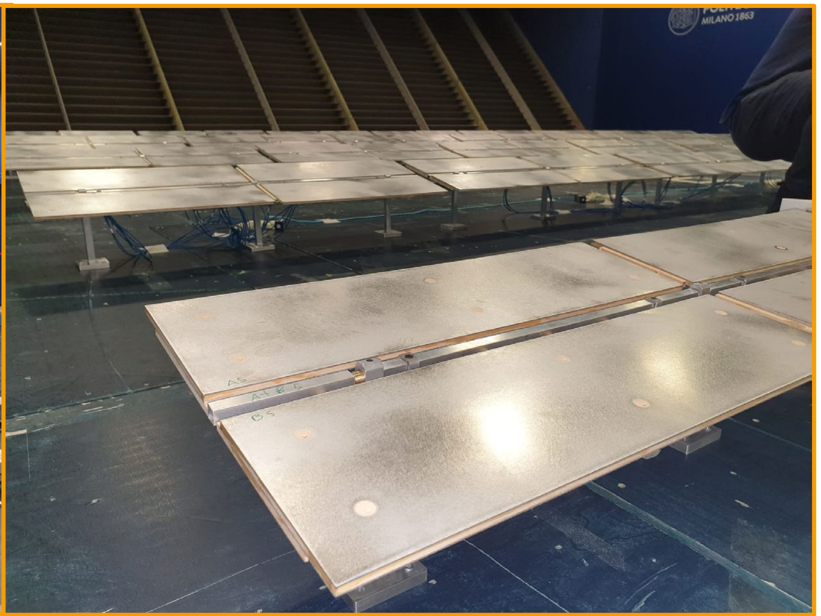




Wind Tunnel Test: Wind static loads

Main Reason of Wind tunnel tests:

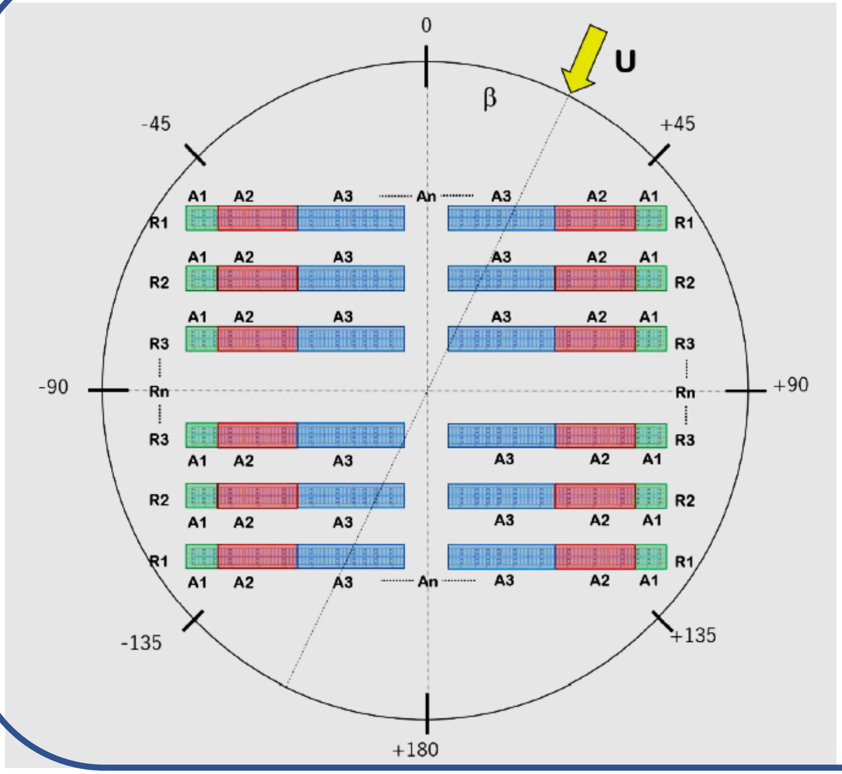
- To give a experimental support to the CFD analysis: *on the gap between two panels and on the shielding effects,*
- Obtain reliable data for wind coefficients in different plant positions,
- Correctly and safely derogate codes,



Aim to a more appropriate and cost-effective design

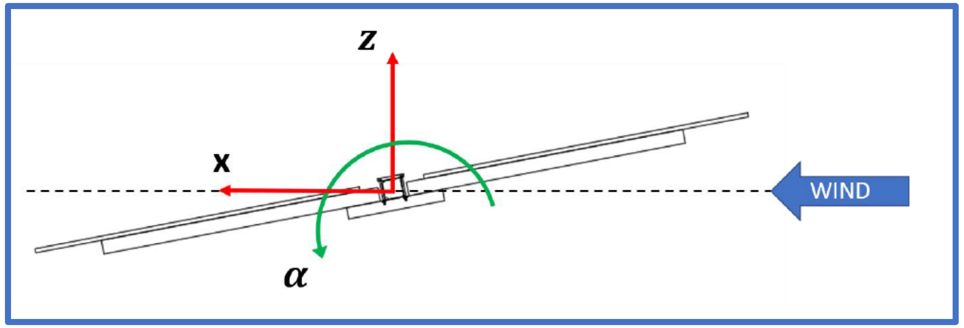
Wind Tunnel Test: Wind static load

Wind tunnel laboratory can provides wind pressure coefficients, distinguish among different tracker position, for different tilt angles and for different wind directions.



Measured parameters

- ✓ Pressure and moment coefficient vs orientation of modules α,
- ✓ Sensitivity of wind loads if changing the <u>distance among modules</u>,
- ✓ Sensitivity of wind loads reduction due to shielding effects of windward structures



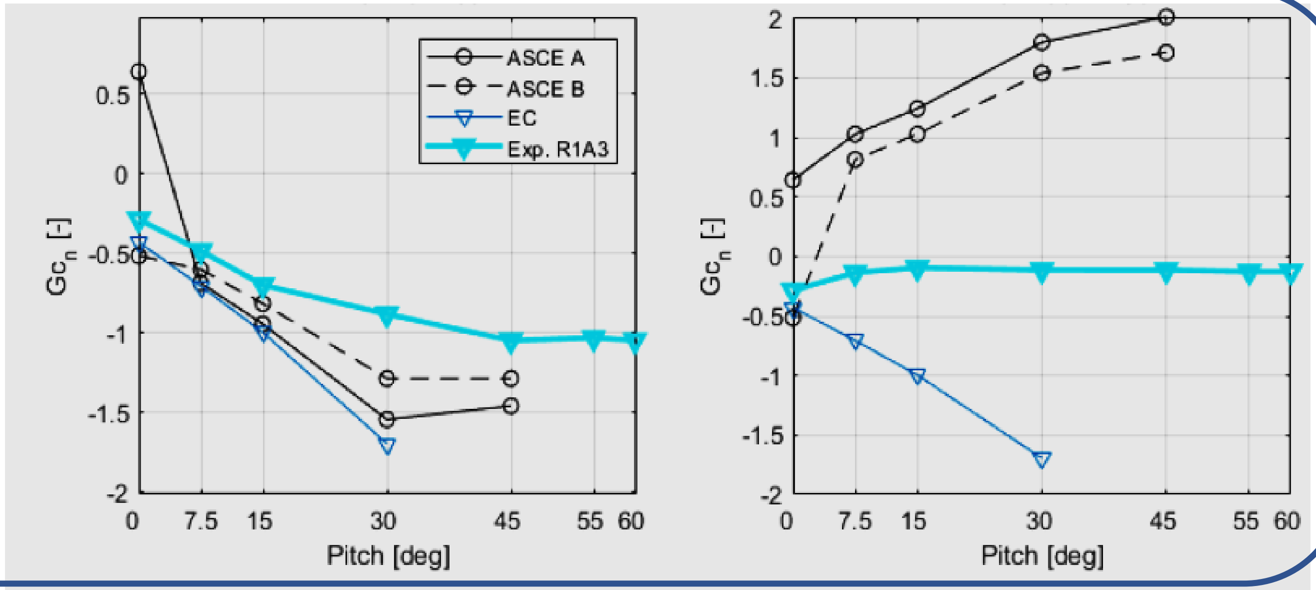
Wind Tunnel Test: single axis tracker

Results

- The WT result is allowing a more accurate plant design, distinguishing among internal and external rows.
- Internal rows are around 80 - 85% of the overall structures: the optimization of their design assure a cost reduction.

Roughly, the inner rows suffer:

- ≈ - **40%** pressure and torque reduction in stowing/safety position,
- ≈ - **50%** pressure and torque reduction in service positions.

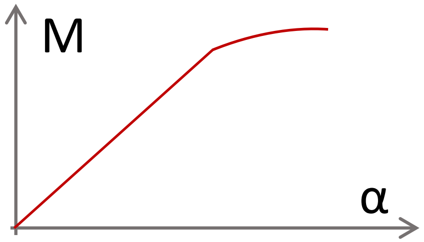


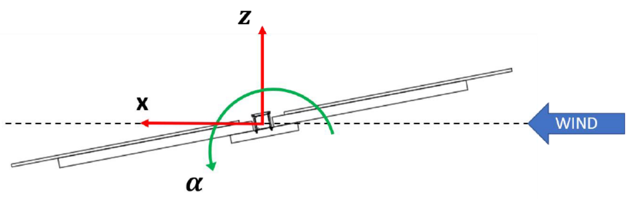
Wind Tunnel Test: Aeroelastic instability

- Nowadays tracker design is heavily focused on aerodynamic instability, especially for the windward rows.
- This turns to be the main and more restrictive design issue.

Tracker instability

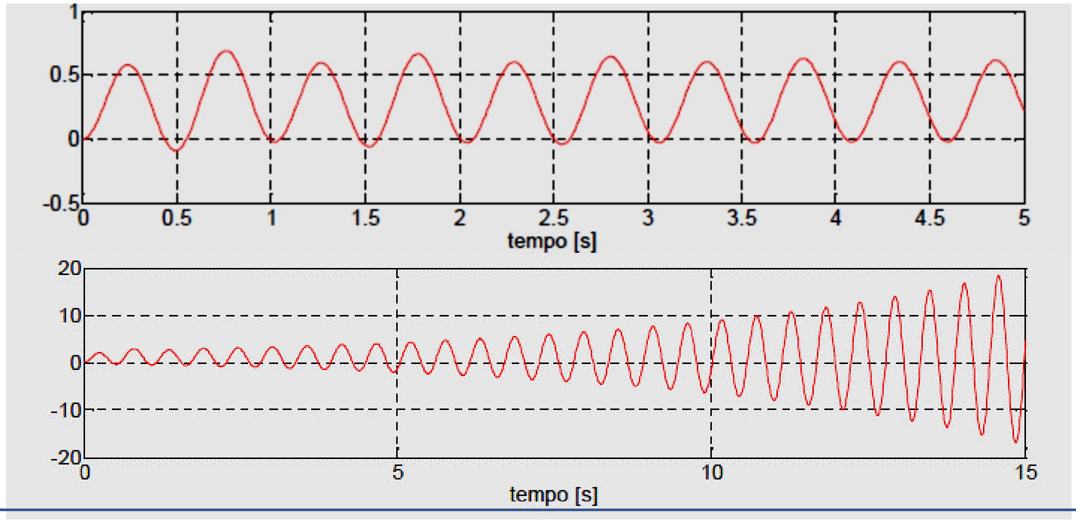
Torsional static instability: *Divergence*





Galloping

Flutter



Wind Tunnel Test: Aeroelastic instability

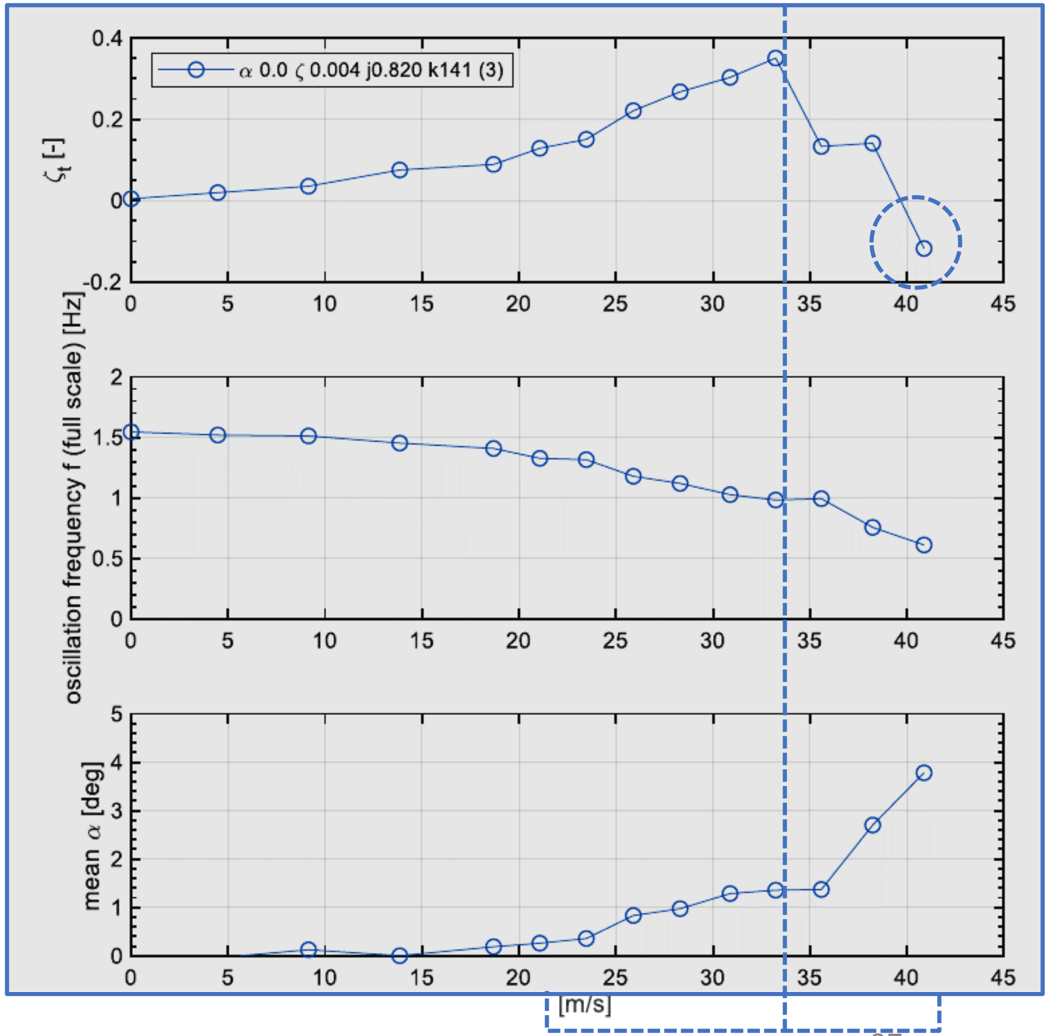
Analyzed ***Aeroelastic instability*** phenomena on GOPV tracker:

- ✓ *Torsional stability – Divergence,*
- ✓ *Flutter,*
- ✓ *Galloping,*

Wind Tunnel Test: Aeroelastic instability

Results:

- As long as the tracker-flow ensemble can have an overall damping higher than the forcing in play, the system is in equilibrium.
- As the wind speed increases, the total damping increases up to a peak value, beyond which there is a sharp variation. The full system in no more able to damp forces as before: Vibrations starts.
- Up to the total damping remains as positive value, vibration amplitude remain "constant" without being destructive,
- Once the total damping become a negative value, the tracker-flow interaction increase up to a destructive event.



Aerodynamic Design of GOPV 2-P tracker

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Aeroelastic instability phenomena:

- ***Torsional stability – Divergence:***

  *In **Stow** position (0° +/-2°) – stable up to **30 m/s (*)***

- **Dynamic Instability Flutter:**

  *All other **Service** positions – stable up to 23 m/s (*)*

  ***Not Galloping** in the same range of wind velocity*

***(*) Note**: velocity are referred to 10minutes averaged values measured at 10m height above ground.*

To scale at gust factor use a multiplier x 1,46

Mounting System and Trackers for PV plant

Lecture objective:
To provide a comprehensive overview of **Mounting System /Tracker Device** currently used in utility scale PV plants, highlighting the issues and approaches currently followed to achieve an optimization between the *Needs of Reliability*, Capex & Opex *Values*, *Service Lifetime* of the plant.

Agenda

1. General concepts about Solar Trackers
2. Guideline for Structural Design
3. Wind Loads and aerodynamic effects
4. Criteria for the evaluation of corrosion resistant of steel tracker structure operating in aggressive environment
5. Electronic control board
6. Failure modes and maintenance
7. New Challenges

Evaluation of corrosion resistant of tracker operating in aggressive environment

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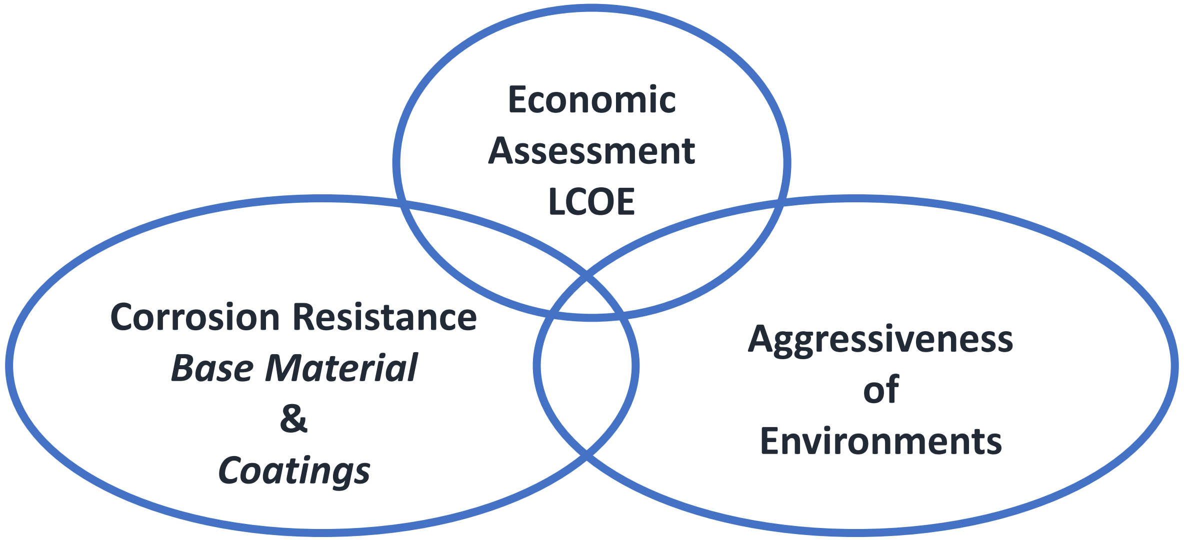

The input data:

- The "corrosivity class" of the atmosphere and soil: *chemical and physical investigation/study of PV plant area*
- Selection of steel and coating to use: *chemical analysis, performances, availability on the market and cost;*
- The useful life of the tracker.

Evaluation of corrosion resistant of tracker: Base material & Coating

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Base Material of tracker : Low-alloy carbon steels, grade S235 ÷ S355, *EN 10025*

External Coating made using zinc or zinc alloys:

- Each components of tracker are **Hot Dip Galvanized** .
- Use of pre-hot galvanized strips (**SENDZIMIR**) to produce tracker componets

Base Material of tracker : Low-alloy patinable carbon steels, Weathering Steel (Cor-Ten) grade S235 ÷ S355, *EN 10025*

Use of patinable low carbon structural steels, weathering steel: External coating generated by a compact/non-porous oxide layer due to the corrosion process of steel

Evaluation of corrosion resistant of tracker: Base Steel & Coating

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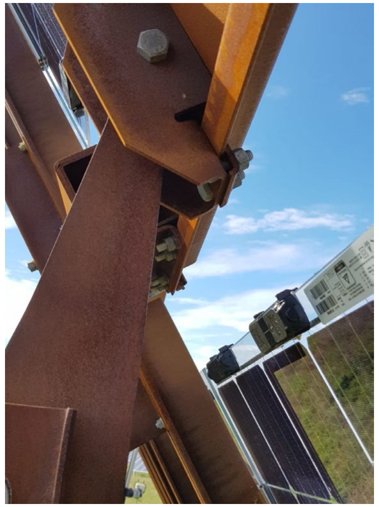
Low-alloy carbon steels +
Hot Dip Galvanized
HDGS

Patinable carbon steels
Weathering Steel
W.S.



Evaluation of corrosion resistant of tracker: Base material & Coating

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Mechanism of coating protection

Passive Protection:

A physical barrier (coating) that separates the surface of the steel from the aggressive environment. *Zinc, W.S.*

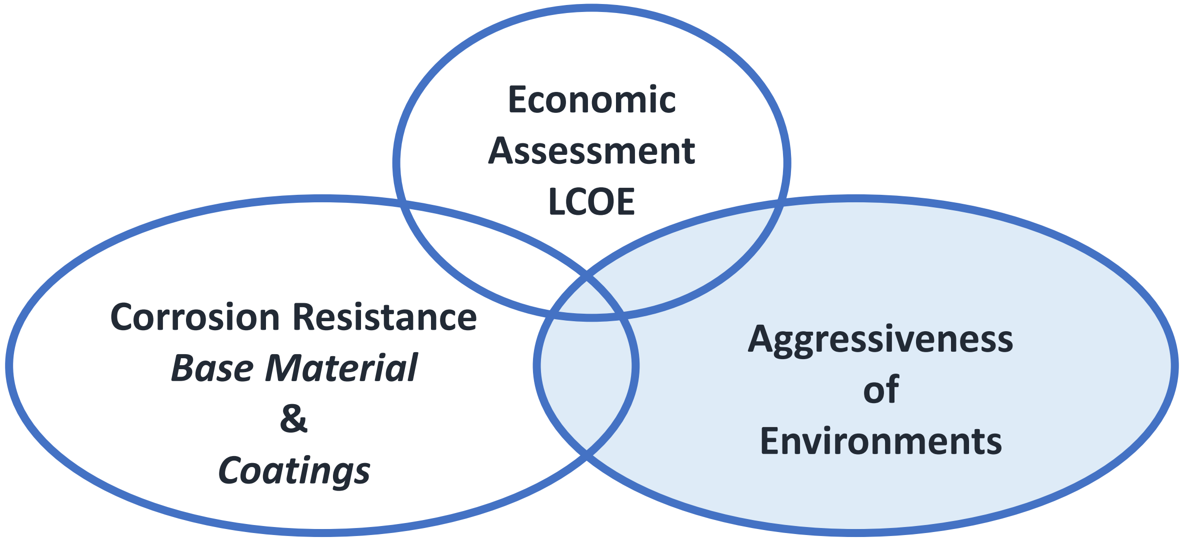
Active Protection:

the coating protects the steel due to its electrochemical characteristics between base steel and coating: ***Cathodic Protection- Sacrificial Zinc***.

Cathodic Protection – Sacrificial Zinc

Zinc is anodic to steel; therefore, the galvanized coating will provide cathodic protection to exposed steel. When zinc and steel are connected in the presence of the electrolyte, the zinc is slowly consumed while the steel is protected. ***The zinc's sacrificial action also offers protection where small areas of steel may be exposed due to cut edges, drill holes, scratches, or as the result of severe surface abrasion during rough handling or job site erection****. Cathodic protection of the steel from corrosion continues until all the zinc is consumed.*

Evaluation of corrosion resistant of tracker operating in aggressive environment



The input data:

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Factors influencing corrosion atmosphere aggressiveness

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- **Relative Humidity**: it has a negative effect when it leads to the formation of dew and condensation, as it produces the formation of the liquid film that gives rise to corrosion.
- **Precipitation:** exposure to rainwater has a generally beneficial effect, as the surface is washed from pollutants and salts.
- **Temperature:** generally an increase in temperature produces an increase in the rate of corrosion.
- **Pollutants:** the presence of pollutants (eg SO2, NOx, ...) and hygroscopic salts promote the formation of condensation on surfaces, even above the dew point. Furthermore, pollutants can acidify the water layer.
- **Aerosol particles:** composition, concentration and particle size are dependent on location, time, weather conditions, local sources, ... strongly aggressive is marine aerosols
- **Wind:** has a direct influence on corrosion as they affect the transport of particles (in particular, sand and dust, has an erosive action on the material, which produces an increase in the exposed surface, which leads to an increase in corrosion).

Atmospheric corrosivity categories: class C1, C2, C3, C4, C5, Cx

Corrosively category of the atmosphere:
ISO 9223

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CORROSIVITY CATEGORY			CORROSION RATES OF METALS for the first year of exposure – r_{corr}				
Class	Corrosivity	Outdoor – Typical examples	Unit	Carbon steel	Zinc	Copper	Alluminium
C1	Very low	Dry or cold zone, atmospheric environment with very low pollution and time of wetness, e.g. **certain deserts, Central Arctic/Antarctica**	g/(m² y) µm/y	$r_{corr} \le 10$ $r_{corr} \le 1.3$	$r_{corr} \le 0.7$ $r_{corr} \le 0.1$	$r_{corr} \le 0.9$ $r_{corr} \le 0.1$	--- ---
C2	Low	Temperate zone, atmospheric environment with low pollution (SO_2 < 5 µg/m³), e.g. **rural areas, small towns dry or cold zone, atmospheric environment with short time of wetness**, e.g. deserts, subarctic area	g/(m² y) µm/y	$10 < r_{corr} \le 200$ $1.3 < r_{corr} \le 25$	$0.7 < r_{corr} \le 5$ $0.1 < r_{corr} \le 0.7$	$0.9 < r_{corr} \le 5$ $0.1 < r_{corr} \le 0.6$	$r_{corr} \le 0.6$ ---
C3	Medium	Temperate zone, atmospheric environment with medium pollution (SO_2: 5 µg/m³ to 30 µg/m³) or some effect of chlorides, e.g. **urban areas**, coastal areas with low deposition of chlorides, Subtropical and tropical zone, **atmosphere with low pollution**	g/(m² y) µm/y	$200 < r_{corr} \le 400$ $25 < r_{corr} \le 50$	$5 < r_{corr} \le 15$ $0.7 < r_{corr} \le 2.1$	$5 < r_{corr} \le 12$ $0.6 < r_{corr} \le 1.3$	$0.6 < r_{corr} \le 2$ ---
C4	High	Temperate zone, atmospheric environment with high pollution (SO_2: 30 µg/m³ to 90 µg/m³) or substantial effect of chlorides, e.g. **polluted urban areas, industrial areas, coastal areas without spray of salt water** or, exposure to strong effect of de-icing salts. Subtropical and tropical zone, atmosphere with medium pollution.	g/(m² y) µm/y	$400 < r_{corr} \le 650$ $50 < r_{corr} \le 80$	$15 < r_{corr} \le 30$ $2.1 < r_{corr} \le 4.2$	$12 < r_{corr} \le 25$ $1.3 < r_{corr} \le 2.8$	$2 < r_{corr} \le 5$ ---
C5	Very high	Temperate and subtropical zone, atmospheric environment with very high pollution (SO_2: 90 µg/m³ to 250 µg/m³) and/or significant effect of chlorides, e.g. **industrial areas, coastal areas, sheltered positions on coastline**	g/(m² y) µm/y	$650 < r_{corr} \le 1500$ $80 < r_{corr} \le 200$	$30 < r_{corr} \le 60$ $4.2 < r_{corr} \le 8.4$	$25 < r_{corr} \le 50$ $2.8 < r_{corr} \le 5.6$	$5 < r_{corr} \le 10$ ---
CX	Extreme	Subtropical and tropical zone (very high time of wetness), atmospheric environment with very high SO_2 pollution (higher than 250 µg/m³) including accompanying and production factors and/or strong effect of chlorides, e. g. **extreme industrial areas, coastal and offshore areas, occasional contact with salt spray**	g/(m² y) µm/y	$1500 < r_{corr} \le 5500$ $200 < r_{corr} \le 700$	$60 < r_{corr} \le 180$ $8.4 < r_{corr} \le 25$	$50 < r_{corr} \le 90$ $5.6 < r_{corr} \le 10$	$r_{corr} > 100$ ---

Factors influencing corrosion soil aggressiveness

- **Condition of soils**: *undisturbed soils* (little oxygen, not very corrosive), *disturbed* (rich in oxygen, more corrosive), *recomposed* (similar to those undisturbed).
- **Grain size:** determines the ability to drain water, which decreases with decreasing particle size.
- **Electrical resistance**: gives indications on the soil's ability to make current flow and is a joint measure of water content and salinity. The soil resistivity is inversely proportional to the corrosion rate.
- **Redox Potential**: allows the identification of anaerobic soils, in which sulphate-reducing bacteria could be present
- **Presence or absence of corrosive substances**: ***chlorides*** are particularly dangerous, and ***sulphates***, which, although potentially harmless, can become highly corrosive in the presence of sulphate-reducing bacteria.
- **Soil pH**: acid soils are corrosive.

Soil corrosivity categories *:* class I, II, III, IV,…V

Methodologies for classifying soil aggression:

- ***DIN 50929 – PART 3 Approach***
- ***Eurocode 3, EN 1993-5 Approach***

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Eurocode 3, EN 1993-5 Approach

Proposes a qualitative classification of the soil, focusing on corrosion loss, once the type of soil is known. Soils are classified into 5 categories, for which the amount of thickness loss with time is given.

Required design working life	5 years	25 years	50 years	75 years	100 years
Undisturbed natural soils (sand, slit, clay, schist, …)	0,00	0,30	0,60	0,90	1,20
Polluted natural soils and industrial sites	0,15	0,75	1,50	2,25	3,00
Aggressive natural soils (swamp, marsh, peat, …)	0,20	1,00	1,75	2,50	3,25
Non-compacted and non-aggressive fills (clay, schist, sand, slit..	0,18	0,70	1,20	1,70	2,20
Non-compacted and aggressive fills (ashes, slag, …)	0,50	2,00	3,25	4,50	5,75

Notes:

1) Corrosion rates in compacted fills are lower than those in non-compacted ones. In compacted fills the figures in the table should be divided into two.
2) The values given for 5 and 25 years are based on measurements, whereas the other values are extrapolated.

Methodologies for classifying soil aggression:

- ***DIN 50929 – PART 3 Approach***
- ***Eurocode 3, EN 1993-5 Approach***

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DIN 50929 – PART 3 Approach

- DIN standard provides a methodology for classifying soil aggression: soils are classified descriptively into 4 categories.
- The method is based on a quantitative analysis of the parameters that determine soil corrosion, to which a weight Zi is associated.

	EVALUATION OF SOIL SAMPLES	weight
1	TYPE OF SOIL	Z1
2	SOIL SPECIFIC RESISTANCE	Z2
3	WATER CONTENT	Z3
4	PH VALUE	Z4
5	BUFFER CAPACITY	Z5
6	SULFIDES (S^{2-})	Z6
7	NEUTRAL SALT $c(Cl^-)+2\,c(SO_4^{2-})$	Z7
8	SULFATES (SO_4^{2-})	Z6

	ON-SITE EVALUATION	weight
9	LOCATION OF GROUNDWATER	Z9
10	SOIL HOMOGENEITY, HORIZONTAL	Z10
11	SOIL HOMOGENEITY, VERTICAL	Z11
12	Potential between object and soil	Z12

VALUE OF RANGE B_0 E B_1	CLASS OF SOIL	SOIL AGGRESSIVENESS	UNIFORM CORROSION RATE 100 years mm/a		UNIFORM CORROSION RATE (30 years mm/a	
			Average	Range	Average	Range
≥ 0	Ia	No aggressive	0.005	0.0025–0.01	0.03	0.015 – 0.06
-1 a -4	Ib	weakly aggressive	0.01	0.005 – 0.02	0.05	0.03 – 0.12
-5 a -10	II	aggressive	0.02	0.01 – 0.04	0.2	0.1 – 0.4
< -10	III	Very aggressive	0.06	0.03 – 0.12	0.4	0.2 – 0.8

Index for homogeneous soils: $B_0 = Z_1 + Z_2 + Z_3 + Z_4 + Z_5 + Z_6 + Z_7 + Z_8 +$

Index for non-homogeneous soils: $B_1 = B_0 + Z_{10} + Z_{11}$

Evaluation of corrosion resistant of tracker operating in aggressive environment

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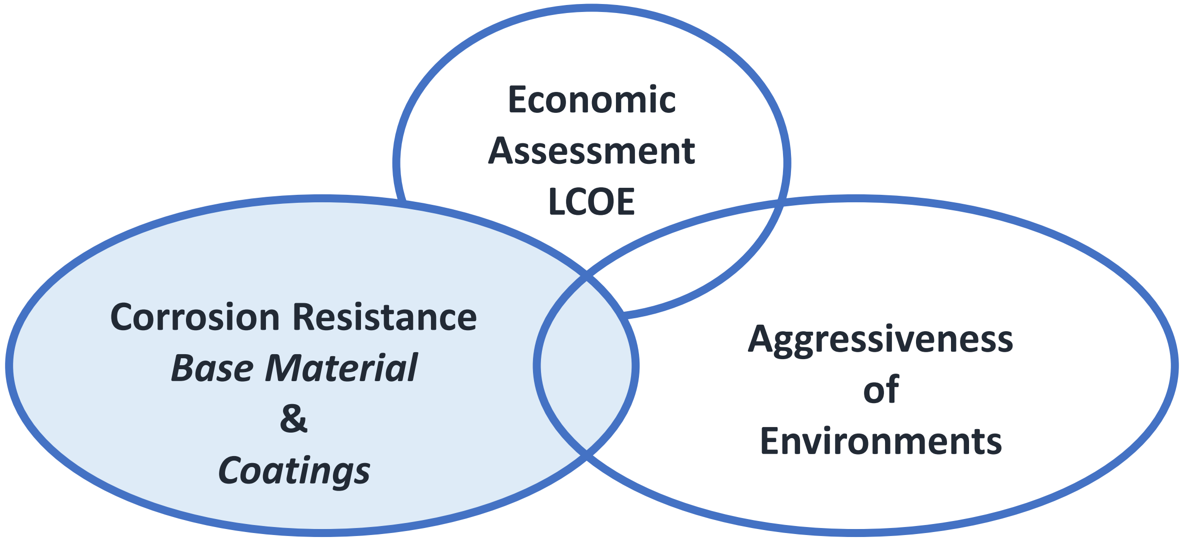

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- The "corrosivity class" of the atmosphere and soil: *chemical and physical investigation/study of PV plant area*
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- The useful life of the tracker.

Corrosion Resistance
Base Material / Coatings for Tracker

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STATE OF ART

Trackers are mainly fabricated from **Hot Dip Galvanized (HDG) steel** that has proven to present an excellent protection against corrosion and a service lifetime of 25 years.

HDG STEEL

- HDG process represents about **20% of the cost of the tracker.**
- The Hot Dip Galvanization method does **not allow to chose the specific quantity of zinc** required to protect the structure during its lifetime: the quantity of zinc cannot be less than a minimum.
- Frequently the **zinc amount is over-dimensioned** respect to the corrosion resistance required by the environment classification and the planned service-life.

pre-hot galvanized strips **SENDZIMIR**

- The **SENDZIMIR method does allow to have the specific quantity of zinc required** to protect the structure up to during its lifetime up to about 40 µm,
- SENDZIMIR coated steel could be a good acceptable solution when the aggressively of environment is: C1, C2, C3 low.
- **Areas of steel may be exposed due to cut edges**

NEW PROPOSAL: ***Weathering Steel***

Alternative materials should be explored to **reduce costs**, maintaining similar or higher performance levels, and **increase lifetime up to 35 years**.

The Weathering Steel an be a technically and economical possible and   promising solution

Corrosion Resistance: **Weatering Steel**

DEFINITION

- Low-alloy carbon steels with improved resistance to atmospheric corrosion on the time
- Typical alloy elements: Cu, Cr, Ni, P, Si < 3-5% wt

PROPERTIES

- Self protection from corrosion through the formation, on exposed surfaces, of a compacted layer of oxides (patina), obstructing oxygen diffusion.
- Corroson rate 4-5 times lower than traditional carbon steel.
- Color of the patina changes with exposure time.
- Corrosion rate dependent on the aggressiveness of environment and on the chemical composition of the steel.
- Particularly indicated for atmospheres in categories C1, C2, C3 (ISO 9223).

Weatering Steel: History and fields of application

- **First** weathering steel patented in 1933 by United States Steel Corporation, as Cor-Ten **-Ten**
- **Distribution:** first applications in the USA in ‘30, but in ’60 they start to be used all over the world.
- **Main uses:** civil structures such as bridges, guard rails, architectural scopes.
- **Availability on the market:** nowadays provided by all the main steel suppliers.

Only recently W.S. is used for fabrication of PV trackers

An “Old" steel for a “New" application

Corrosion in atmosphere:

- Thickness of hot galvanizing coating
- Sacrificial thickness of W.S.

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ISO 9224

First 20 years of exposure a trend

$$D = r_{corr} \cdot t^{b}$$ *[ISO 9224 – (2)]*

After the 20 years of exposure linear trend

$$D(t>20) = r_{corr} [20^{b} + b (20^{b-1}) (t-20)]$$ *[ISO 9224 – (3)]*

t	*[y]*	exposure time (years)
D	*[µm or mg / m2]*	mass lost due to corrosion at time t
r_{corr}	***[µm/y or mg/(m2 y)]***	corrosion rate of the first year function of corrosivity class of the atmosphere, *ISO 9223*
b		is the metal-environment-specific time exponent, usually less than 1.

b metal-environment-specific time exponent

Steel

$$b = 0.569 + \Sigma b_i w_i$$ *ISO 9224 – (C.1)]*

b_i multiplicative coefficient for the alloy element *i*

w_i [%] fraction of the alloy element *i*

Zinc

b = 0,813 ÷0,873

Corrosion in Soil: Sacrificial thickness of W.S.

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Prediction of the corrosion rate of WS in soil:

- Evaluation of class of soil corrosion under examination by DIN 50929,
- Evaluation of average corrosion rate of W.S. It can be evaluated by DIN 50929 (integrated by EN 1993-5 for a life of structure < 30 years), using the specifications given for low carbon structural steels (*conservative approach*) .

INDEX OF SOIL B_0 , B_1	CLASS OF SOIL	SOIL AGGRESSIVENESS	UNIFORM CORROSION RATE 100 years mm/y		LOCALIZED CORROSION RATE 30 years mm/y	
			Average	Range	Average	Range
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Index of soil

Corrosion in Soil: Thickness of hot galvanizing coating

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Prediction of the corrosion rate of hot galvanizing coatings in soil:

- Evaluation of class of soil corrosion under examination by DIN 50929,
- Evaluation of average corrosion rate of Zinc in soil can be evaluated on the base of **existing available technical know**. .

INDEX OF SOIL B_0 , B_1	CLASS OF SOIL	SOIL AGGRESSIVENESS	UNIFORM CORROSION RATE µm/year
			Average
≥ 0	Ia	No aggressive	0,6
-1 a -4	Ib	Weakly aggressive	1,25
-5 a -10	II	Medium aggressive aggressive	2,4 ÷ 3,2
< -10	III	Very aggressive	5,0

Aim and Activity in GOPV Project: New Know-How

Aim

Aim:
*Improving existing know how for predict the corrosion behavior of **Weathering Steel** in specific environment, in order to reduction of the LCOE of the PV plant by decreasing tracker cost and extending its service lifetime up to 35 years.*

Activity

On the basis of both the knowledge available in the literature and the international standards , **analytical procedures for W.S. application** have been developed , in order to achieve:

- an **easy classification of the environment aggressiveness** (atmosphere and soil),
- a reliable **evaluation of sacrificial extra-thickness** for tracker cross sections when weathering steel is used

A **long-term corrosion test program** is in progress to improve the corrosion assessment procedures on weathering steel structures:

- Mechanical connections and bolts and possible use of hot galvanized bolts,
- Prediction of the corrosion rate of Weathering Steel in soil,
- Connection between Weathering Steel and Hot galvanized steel

Testing in progress in "Tuscania Lab"

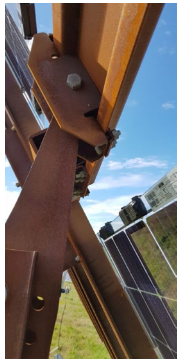
Corrosion resistant: WS tracker components

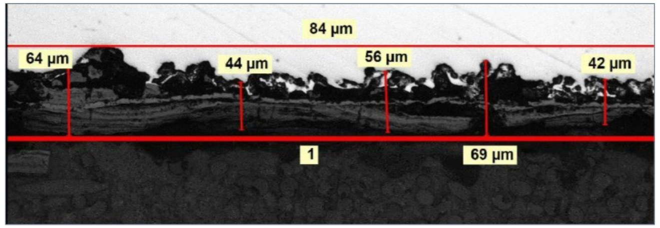
GOPV Issues & Results

Availability of validated analytical models for:
- *Evaluation of Sacrificial Extra-Thickness for W.S. Application*
- *Easy Classification of the environment aggressiveness*

Compatibility between WS components and hot-dip galvanised bolts

- ***Measurements of passivated layer in WS by Coating Thickness US Gauge***
- ***No electric grounding issues*** *due to passivation of connections.*





Results obtained in Lab. and by the analysis of the full 2P Tracker after one year of exposure

Corrosion resistant: WS tracker components

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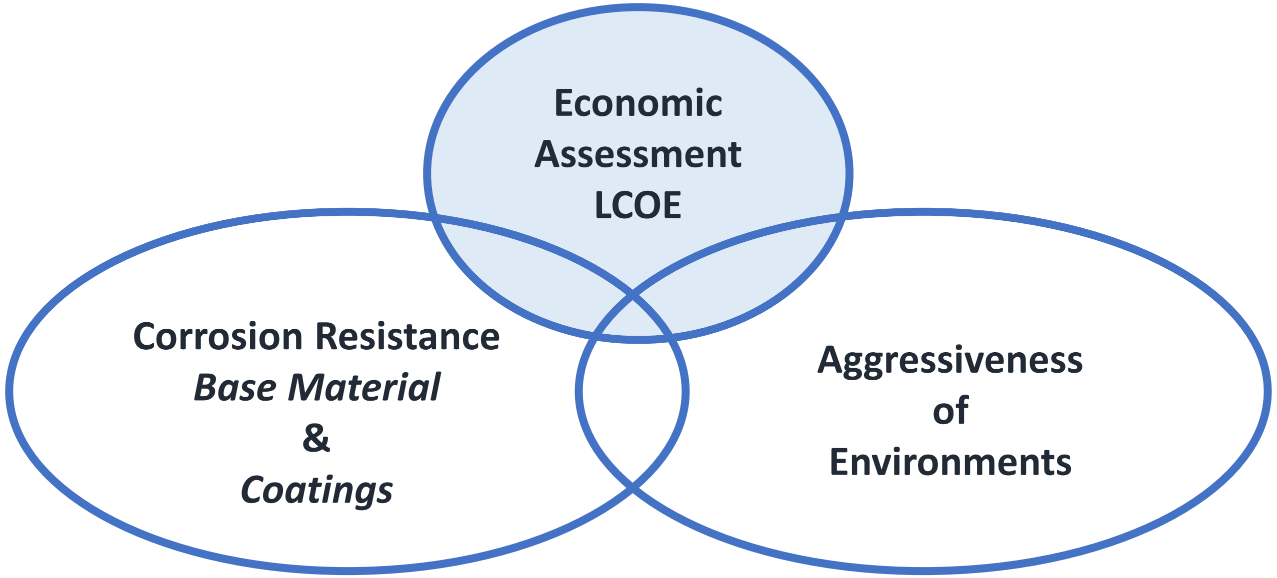
- ***No trouble on the embedded part of pile,*** *for medium aggressive soil*
- ***Possibility of galvanising the embedded part of the pile very aggressive***

Conclusions



Optimization is possible through:

- **An "accurate" and "realistic" quantification of the "corrosion class" of the atmosphere and soil,**
- **Careful selection of the steel and coating to be used**, in relation to the aggressively class of the environment.
- **Improving the available know-how and predictive models on the corrosion behavior of steels** and steel coatings

Mounting System and Trackers for PV plant

Lecture objective:
To provide a comprehensive overview of **Mounting System /Tracker Device** currently used in utility scale PV plants, highlighting the issues and approaches currently followed to achieve an optimization between the *Needs of Reliability*, Capex & Opex *Values*, *Service Lifetime* of the plant.

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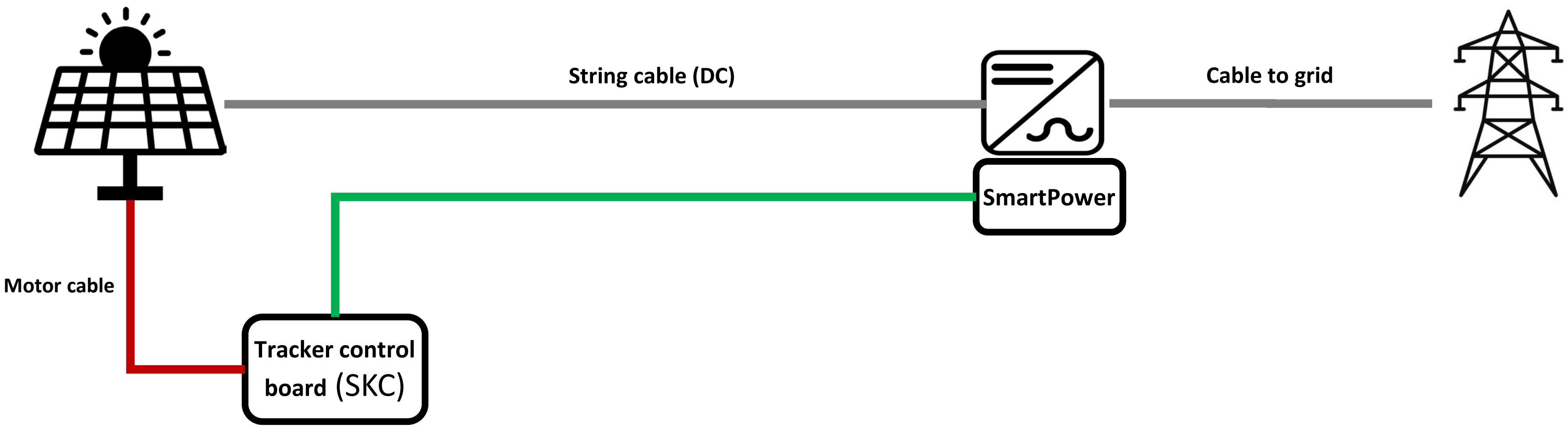
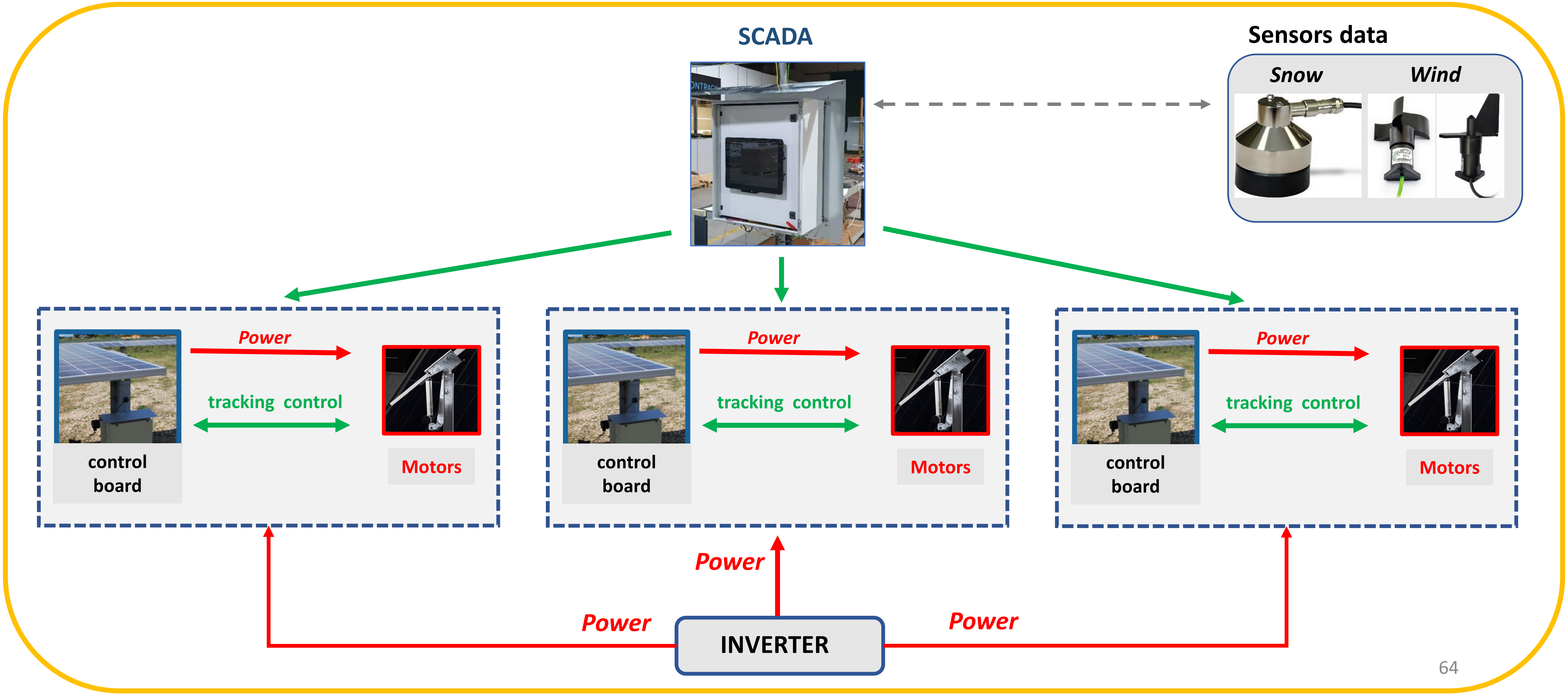
Control and power

Depending on PV-plant dimensions and specifications, in order to reduce LCOE, there is an optimal solution for each of possible configurations:

- Wired or Wireless configuration for the communication system,
- Distributed or centralized inverter for the energy production/supply,
- Centralized and/or distributed control system
- Tracking based on astronomical clock or solar pointing tool device



Base layout


SCADA
Sensors data
Snow
Wind
Power
tracking control
control board
Motors
Power
tracking control
control board
Motors
Power
tracking control
control board
Motors
Power
Power
Power
INVERTER

Sensors

Wind strategy

- Wind speed and direction sensors are placed in strategic positions of the PV plant
- The SCADA monitors them and if safety thresholds are exceeded, the trackers are moved in planned Safety Position for the Wind

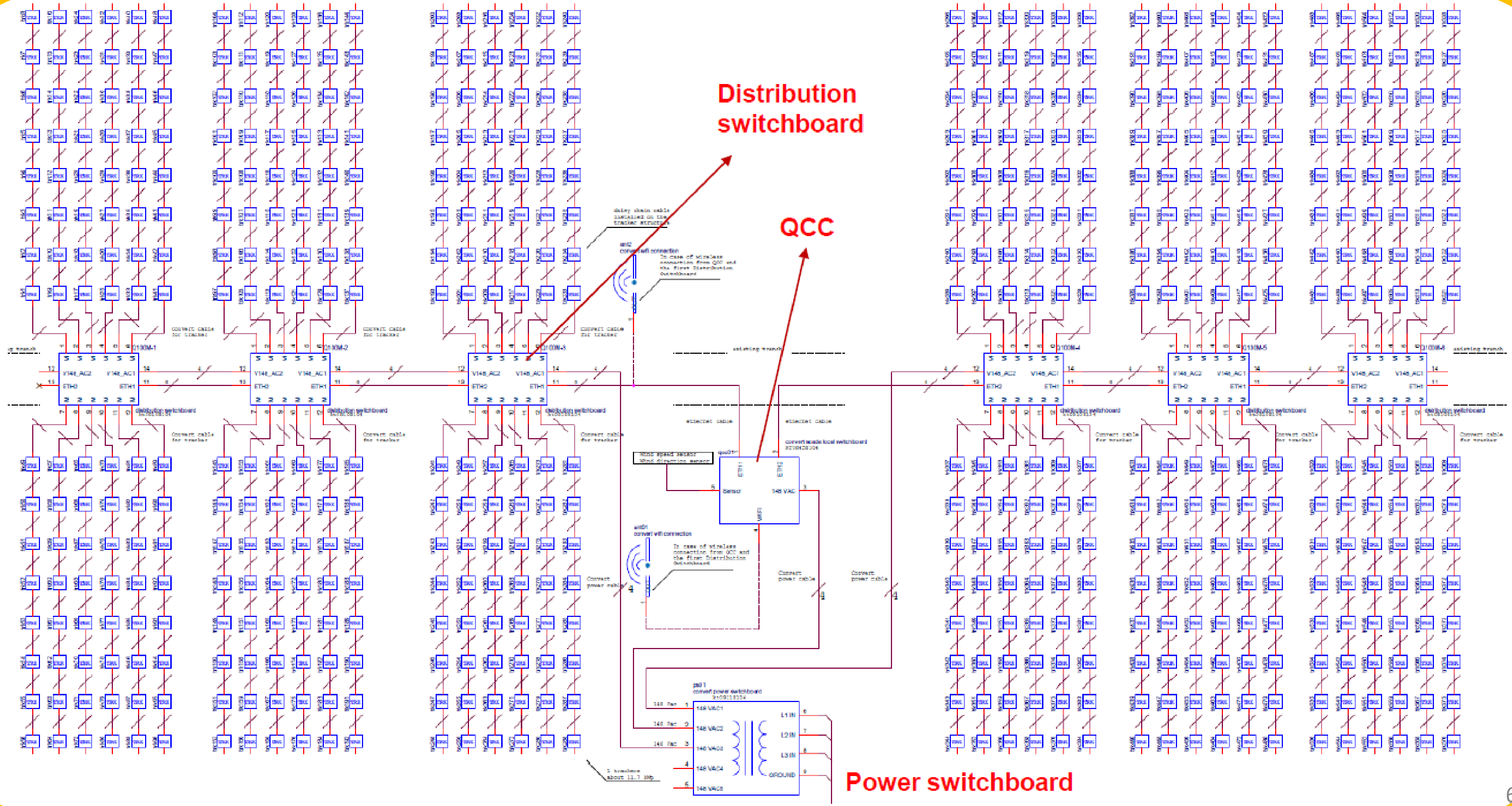
Snow strategy

- Snow accumulation is measured using sensor placed at strategic positions of PV plant
- The SCADA monitors it and if safety thresholds are exceeded, the trackers are moved in planned Safety Position for the Snow

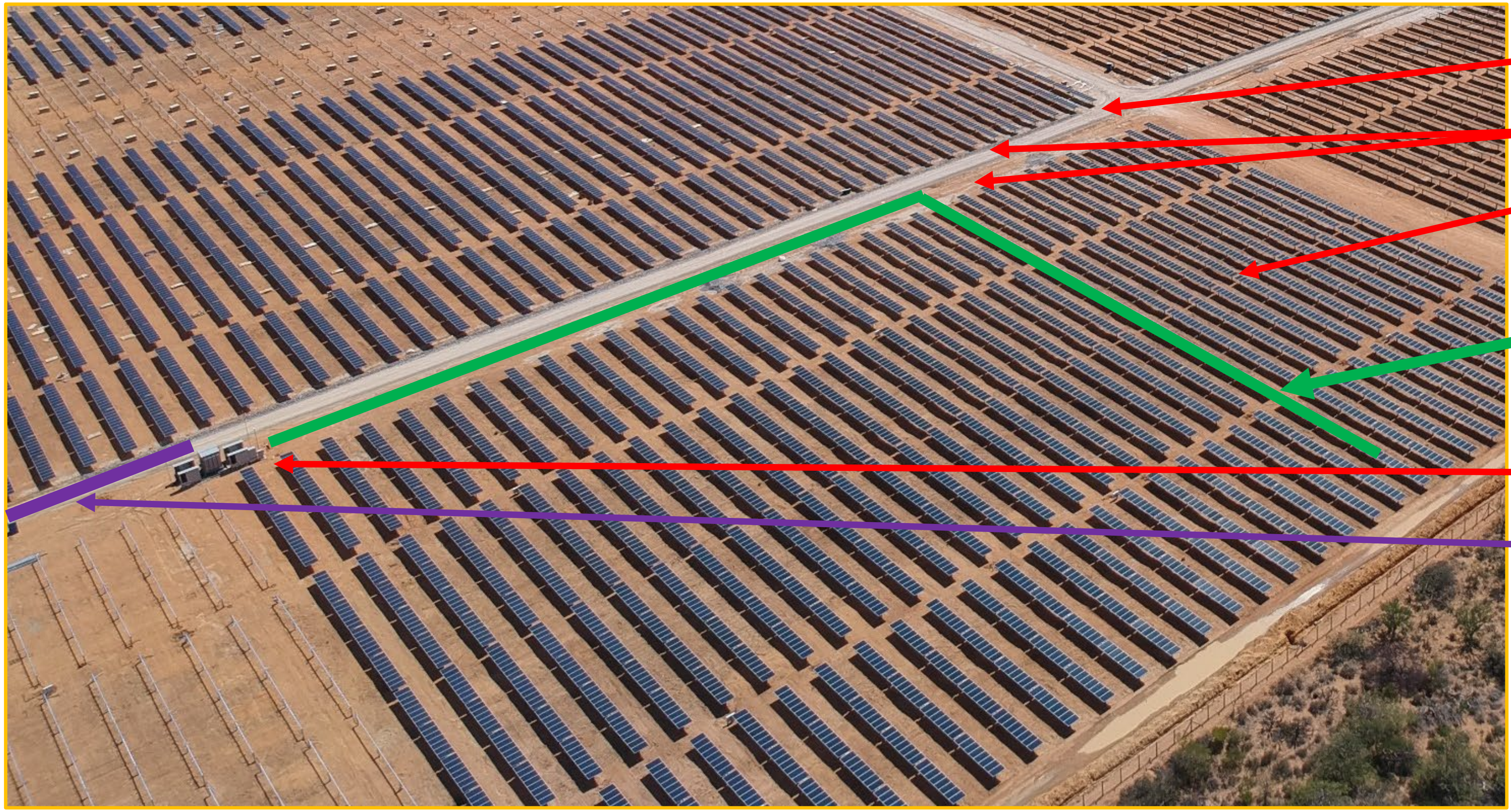
Plant design

- Each PV-plant can be subdivided into subfields
- Each subfield has his own wind zone, different thresholds between the zones are allowed as well
- One snow zone for each plant are allowed

Schematic layout



Real layout



Service road

Trenches

No threnches available here

Cable and power path

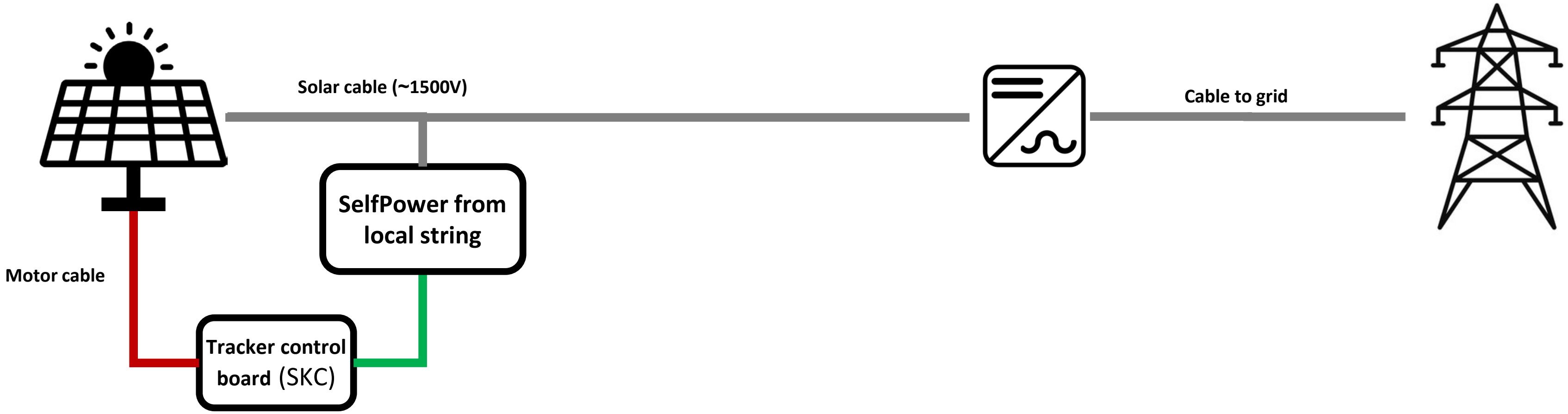
Inverter cabin

MV high power line

Tracker Powering System: Self Power Devise

The Self Power:

- It is a power convert that transforms the DC voltage input from the PV plant (500V ÷ 1500V) in an AC voltage (220V - 50Hz) to supply the tracker system
- The self power system allows to power supply the solar tracker without additional power cables inside PV plants.
- This system helps to reduce the PV plants costs.



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Main Tracker Failures

	Potential causes	Effect	Duration	detection	Repair time	Probability	Severity
Structural components	Wind speed higher of design limit. Catastrophic events related to climate change	PV string can be not aligned with the optimized orientation of tracker. In catastrophic case full structural resistance of tracker may be damaged	Temporary, during extreme wind conditions persistence	Immediate	From few hour to days. (Depending on the severity of the failure and how many trackers are involved)	Low probability if the wind hazard assessment has been correctly carried out.	For not catastrophic event there is a lower current/power generation than expected, minor for bifacial PV modules.
Driving devices: electric motor, Mechanical components, bearings.	Incorrect electric or mechanical assembly of actuator. Accidental stress. Early "infant mortality" failure	Single tracker is failure. Reduction of production is associated to nominal peak power of a tracker.	Maintenance procedure: components failure replacement	Immediate by SCADA	One hour, starting from availability of new actuator and maintenance structure.	1% for year. **GOPV project**: 1 failure /MW/year . Maximum average value for first five years of work.	Lower current/power generation than expected, minor for bifacial PV modules.
Electronic control boards and connection cables.	Wrong electric or mechanical assembly of electronic box Wrong service conditions electronic box. Early "infant mortality" failure	Max ten trackers could be involved in the failure. Maxima reduction of production is associated to the peak power of ten trackers,	Maintenance procedure: electronic control board replacement	Immediate by SCADA	One hour, starting from availability of new components for maintenance	0,4% for year: 0,4 failure for MW/year. Maximum average value for first five years of work.	Lower current/power generation than expected, minor for bifacial PV modules
Corrosion of steel structural components	Change over time of the corrosive aggressiveness of environment. External accidental damage	Not immediate effect in the short to medium period. Possible effect on the total lifetime of the tracker	Persistent until the repair of the coating	During periodic inspection	From few hour to days. Depending on the severity of the failure and how many trackers are involved.	Low probability if corrosive aggressiveness of environment has been correctly carried out.	Not reduction of current/power generation than expected, in the short to medium period

Unexpected Tracker Failures

Missile strike destroys solar plant in Ukraine

Two Russian missiles have hit a ground-mounted solar plant near Kharkiv, Ukraine. According to the manager of the plant, the missile attacks produced holes at the site that measured 6 meters deep and 11 meters in diameter.

MAY 30, 2022 EMILIANO BELLINI

UTILITY SCALE PV UKRAINE

Image: Screenshot from YouTube account of Suspilnie Kharkiv (Суспільне Харків)

- Destroyed on 28th May
- 60% of the plant back in operation after 5 days (2nd June)

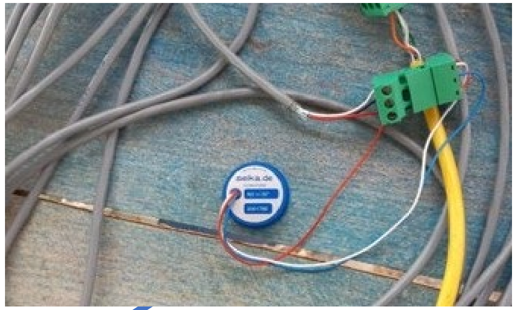
Qualification procedures to evaluate the tracker performances

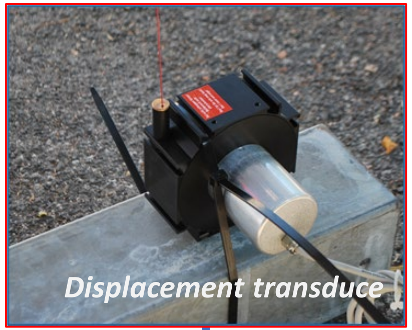
Outdoor testing

ISO EN 62817, Photovoltaic systems - Design qualification of solar trackers

- **Structural tests and analysis of deformation** of the structure during the load application.
- **Accelerated mechanical cycling**: to induce failures or infant mortality associated with design that may occur as a result of accelerated cycling on the drive system, control board and wiring
- **Accuracy of the tracker pointing**
- **Functional of tracker validation tests** to assure the functionality of tracker in the range of service loads fixed in the design of tracker: *Tracking limits verification; Automatic sun tracking after power outage; Emergency stop; Wind Stow*

Out Door Tests in Tuscania





Measuring sensors:

- ***Displacement transduce***
- ***Inclinometer***

Qualification procedures to evaluate the tracker performances

Indoor testing

ISO EN 62817: ***Environmental testing of fully functional drive train.***

Scope: to induce failures associated with design that may occur as a result of an accelerated environmental cycling of the **drive system**, **control system**, and **associated wiring** in a wide range of environmental conditions.

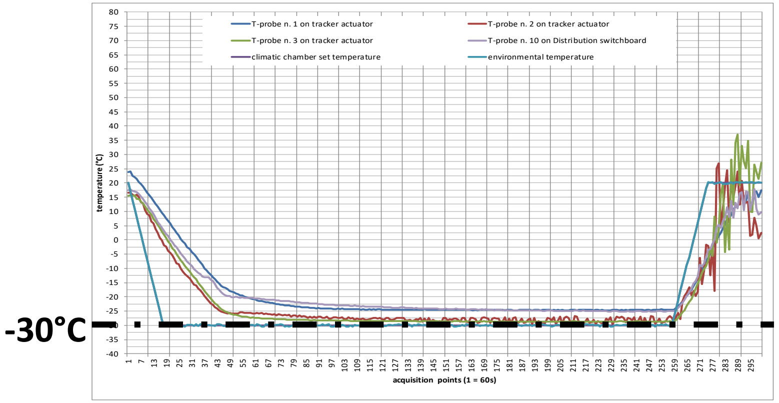
Procedure:

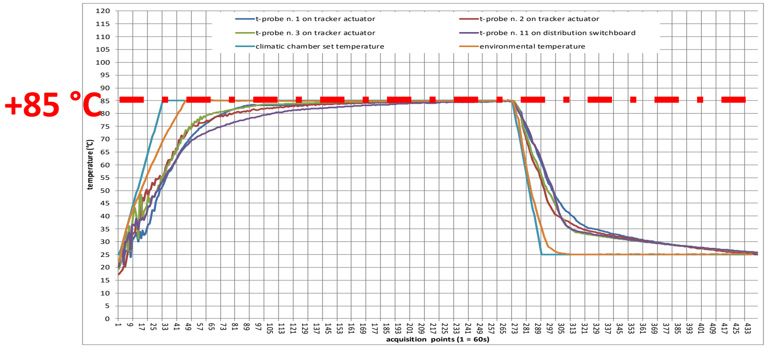
- fully functional drive train shall be mounted for operation in an **environmental chamber**.
- a **typical duty cycle shall be repeatedly applied to the drive train** while under environmental cycling and with in the manufacturer-specified operational temperature range.

Qualification procedures to evaluate the tracker performances

Indoor testing

Correct behaviour of Control System, Scada and Driving Device components at low and high service temperature

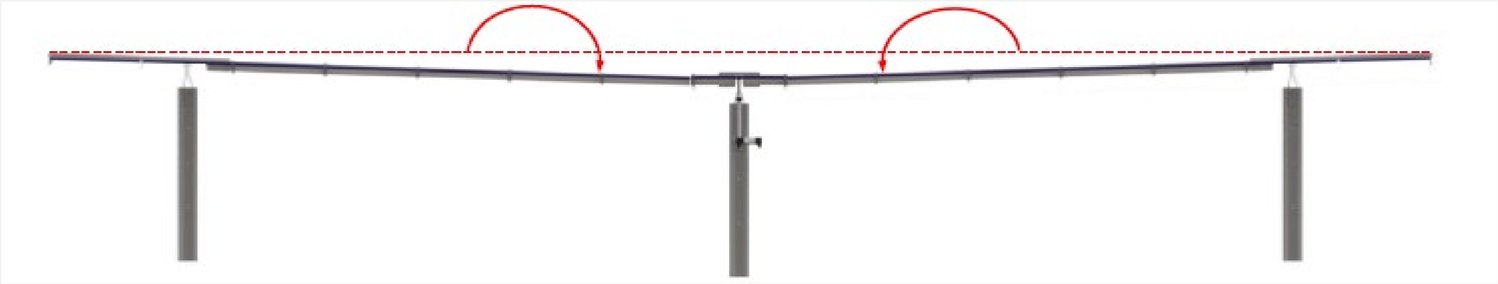




Maintenance actions

Mechanical structures/components:

- **Corrosion issues**: Inspection of all steel parts to identify any possible signs of corrosion, due to impacts, metal slags or other pollutants *(depending on site aggressiveness scheduled at different times);*
- **Bolts tightening:** Control that at least the main bolts connections are all well tighten *(scheduled every 1-2 years)*,
- **Tracker alignment:** through a visual inspection, verify the tracker correct alignment. The non-aligned point could be in correspondence of each pile due to bolt loosing tight and/or posts/foundation “failure” *(scheduled every year*)



Maintenance actions

Maintenance of Electrical Connections

To perform **every year**:

- ✓ **Checking the electrical boxes:** covers closure, structural integrity of box and cable glands
- ✓ **Checking the grounding system** of the tracker structure (central foundation pile)

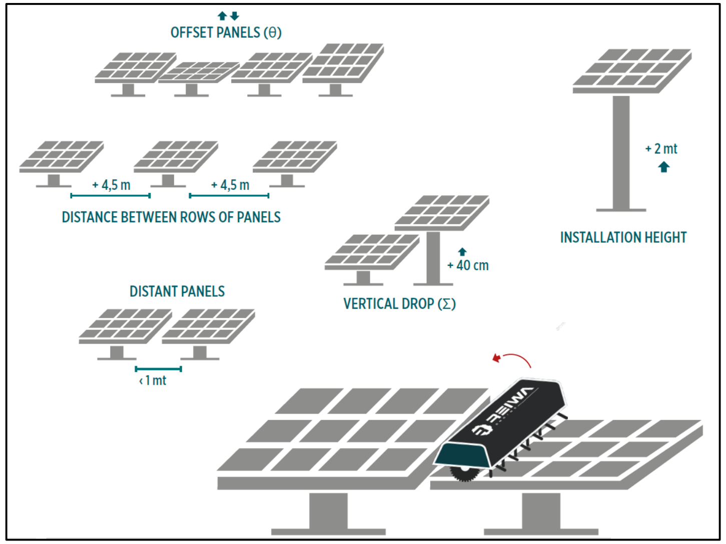
To perform every **2 years**:

- ✓ Checking the **tightening of the connector** screws of the control board,
- ✓ Checking the correct **position of the connectors** (*the weight of the cables must not load connectors*).

Cleaning

Modules cleaning for improving performances

- ✓ Completely self-powered (through a solar panel).
- ✓ Low maintenance costs (non-wear components)
- ✓ Dry-cleaning (no use of water)
- ✓ 70% less of economic loss (due to dust/sand)



Mounting System and Trackers for PV plant

Lecture objective:
To provide a comprehensive overview of **Mounting System /Tracker Device** currently used in utility scale PV plants, highlighting the issues and approaches currently followed to achieve an optimization between the *Needs of Reliability*, Capex & Opex *Values*, *Service Lifetime* of the plant.

Agenda

1. General concepts about Solar Trackers
2. Guideline for Structural Design
3. Wind Loads and aerodynamic effects
4. Criteria for the evaluation of corrosion resistant of steel tracker structure operating in aggressive environment
5. Electronic control board
6. Failure modes and maintenance
7. New Challenges

Agrivoltaic

Agrivoltaic (or Agrovoltaics or Agrophotovoltaic), is a new technology approach which has the goal of enhancing the synergy between photovoltaic production and agriculture

First technology has been conceived around 1981. Now is becoming more and more popular thanks to new photovoltaic technology and efficiency

The main Idea is that photovoltaic structures coexist in the same portion of land of the crops (or other cultivation)

Italian Decree-law (LEGGE 29 luglio 2021, n. 108) Agrivoltaic are those plants that:

*“that adopt **innovative & integrated** solutions with modules raised from the ground, eventually with solar trackers, which do not affect the continuity of agricultural and farming activities, and which allow the application of digital and precision agricultural control tools”*

Different approaches

Dynamic shades Agri-PV system, viticulture.

Agri-PV greenhouse

Beekeeping

Breeding

Agrivoltaics with solar tracking system in France.

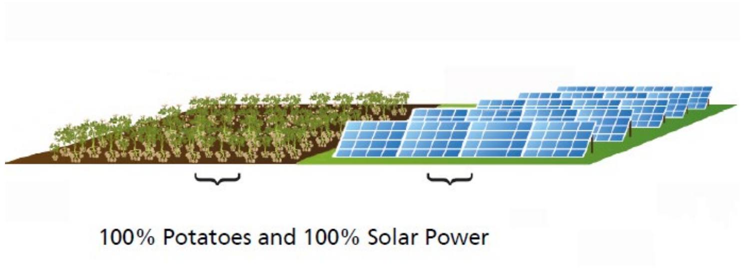
Vertically oriented bifacial modules in the Eppelborn-Dirmingen solar park,

Source: “Agrivoltaics opportunities for agriculture and the energy transition” - Fraunhofer ISE – October 2020

Benefits of Agrivoltaic

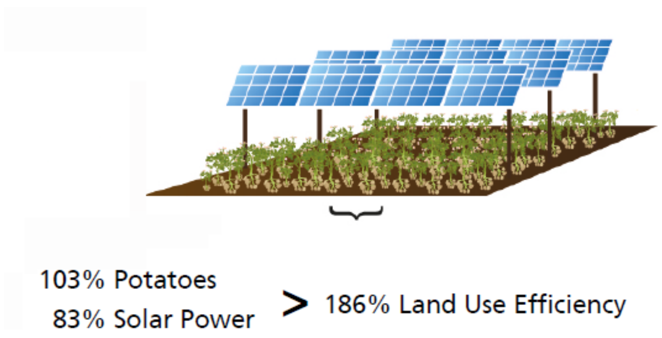
Benefit

- ✓ Modules protect crops from high temperature, water scarcity, soil stress and so on
- ✓ Lowering the water needs by shielding crops reducing evapotranspiration
- ✓ Stimulate new opportunities for agricultural and PV sectors in rural communities
- ✓ Enable a dual-use of land, reducing land take
- ✓ Oppose the land abandonment, increasing the productivity of land used.
- ✓ Optimize operational costs for PV plant.



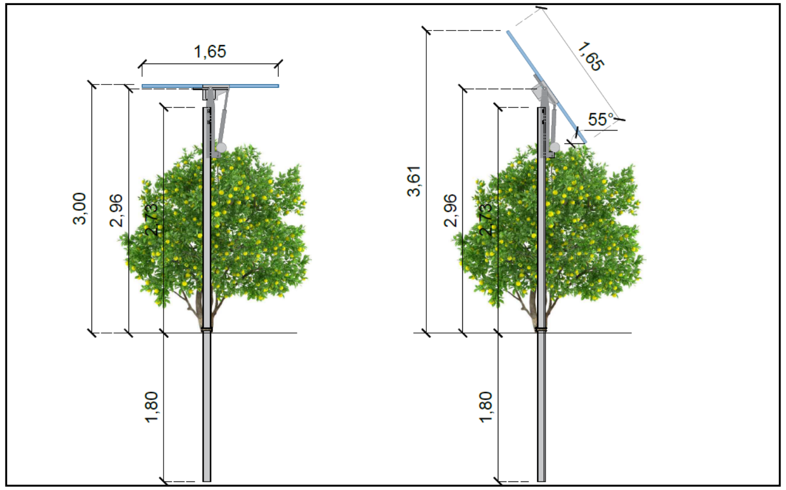
Technical aspects to analyze

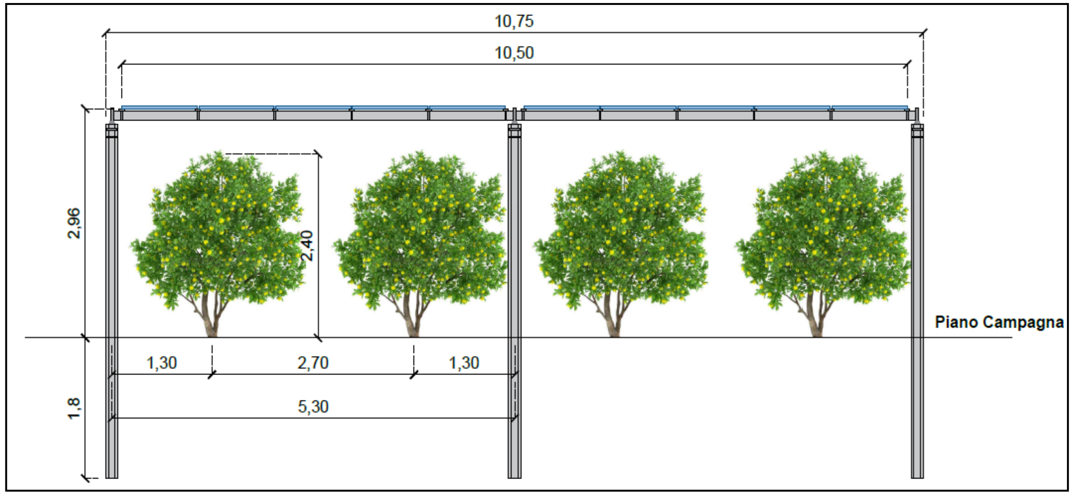
- ✓ To choose the best crop for the land is fundamental.
- ✓ The height of Agri-PV system have to be chosen according to crops. (>2 m above the field)
- ✓ Study the light management is important for the crops.
- ✓ CAPEX can vary considerably (fixed, tracking, greenhouse…)
- ✓ OPEX lower than ground- mounted PV, thanks to the saving in some O&M activities.
- ✓ Integrated analysis of the agriculture business model and the PV business model is fundamental.



Source: Italia Solare

Go-PV know how



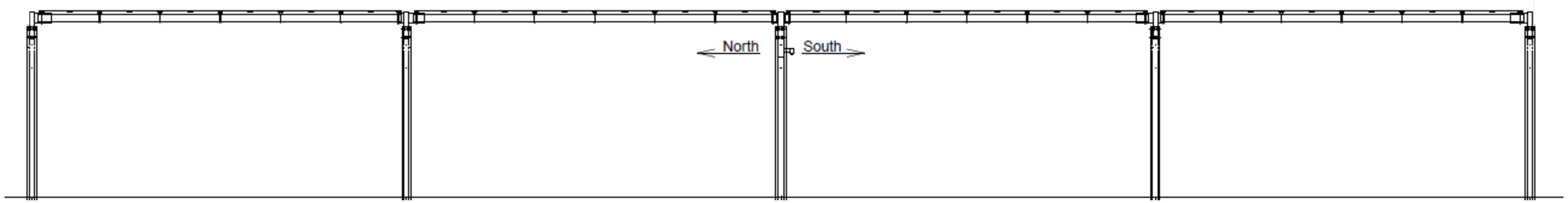


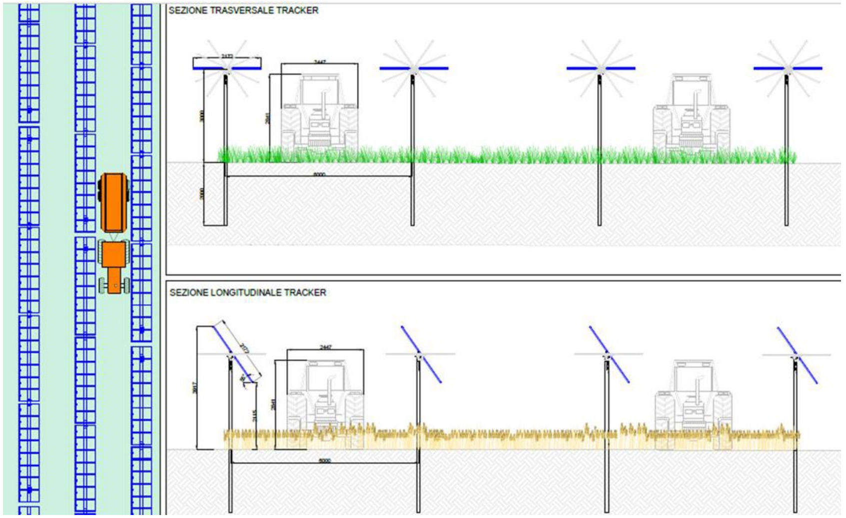
Know-how GOPV used:

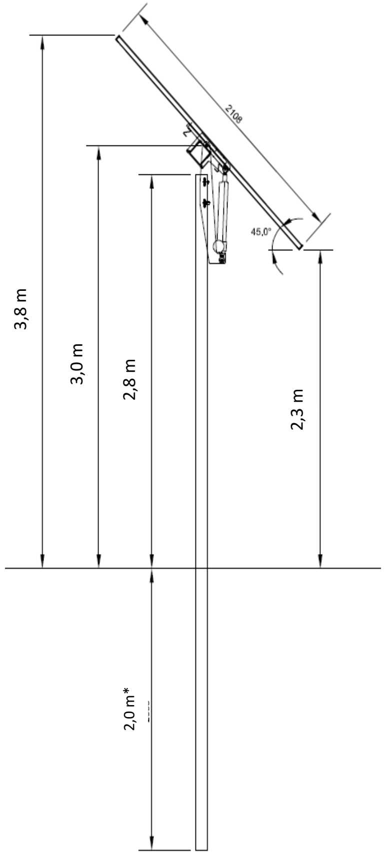
- **Base material W.S.**: *to reduce the have a low visual impact (brown structure)*
- **"Control & Power 100M":** *to reduce the number of cables*
- **SCADA A.I.:** *to assure the monitoring and control also of agro parameters.*
- **New Wind Loads and Aerodynamic coefficients**: *to optimize the weight and reliability of the structure*

Source: Italia Solare

Prototyping







Prototyping

Next Steps

1. Clear definition of Agri-PV regulatory framework and simplification of authorization procedures are necessary to support the increase of Agri-PV systems.

2. Stronger support and promotion of Agri-PV reality is essential in order to increase the interest and the acceptance of the population.

3. The involvement of the agricultural sector in the planning process is fundamental for the successful result of all the projects.

GLOBAL OPTIMIZATION OF INTEGRATED PHOTOVOLTAIC SYSTEM FOR LOW ELECTRICITY COST

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 792059

Thank you for your attention!

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