HORIZONTAL SINGLE AXIS TRACKER IN WEATHERING STEEL, A SOLUTION WITH A LOW IMPACT ON THE LCOE AND LCA INDEX

Giuseppe Demofonti, Andrea Ricci, Antonio La Mura, Antonio Timidei, Alessandro Mercurio
Convert - Valmont (Roma, Italy)
contact e-mail: alessandro.mercurio@valmont.com

ABSTRACT

Specific aim of the research activity described in this paper was to improve the existing know-how and to generate new knowledge in the design of Horizontal Single Axis Tracker (in a 2P configuration) made in Weathering Steel for bifacial PV panels. Solar Trackers should be characterized in giving a relevant contribution to reduce to both the Levelized Cost of Energy (LCOE) and the Life Cycle Assessment (LCA) of large PV plants.

Specific research actions have been carried out focused on:

- The use of Weathering Steel for solar tracker fabrication, as a cheaper steel-coating solution to be used in aggressive corrosive environment (both air and soil).
- The experimental evaluation of wind loads to take into account for solar tracker design, in order to assure a safe and economical design of the structure.
- The Wireless Control & Powering Systems integrated to new generation of monitoring SCADA A.I., in order to reduce cables and time for commissioning and, at the same time, assure a high reliability of the monitoring.

All the research activities have been supported by an integrated experimental and analytical approach, characterized by a large scale experimental tests program performed on full scale mock-up.

This activity presented has been carried out in the framework of a European project H2020, GOPV (Global Optimization of integrated PhotoVoltaic system for low electricity cost).

Keywords: PV system, Solar Tracker, Energy Production, Single-axis Tracker, Weathering Steel, LCA, LCOE

1 INTRODUCTION

World Energy transition will be mostly driven by solar photovoltaic technology. Around 190 GW of new photovoltaic capacity is expected to be commissioned in 2022, which is 25% higher than 2021's [1].
Main case of International Energy Agency (IEA) report shows the yearly solar photovoltaic capacity additions will be constantly over 160GW in 2021-2026, reaching almost 200 GW in 2026. Utility scale solar PV provides, in the majority of countries, the lowest cost of adding new electricity capacity, especially in the actual context of increasing natural gas prices. These large projects represent the 60% of new yearly installation. [1]
In order to increase energy production from PV system, solar tracker technology is more and more deployed. As shown in the diagram of figure 1, IHS Markit has predicted that starting since 2019 solar trackers will represent more than one third of all ground installations; in terms of capacity trackers will exceed 150 GW during 2019 – 2023. That said, trackers are now being used more widely overseas, and in some markets their penetration has already reached nearly 50% of total installations.

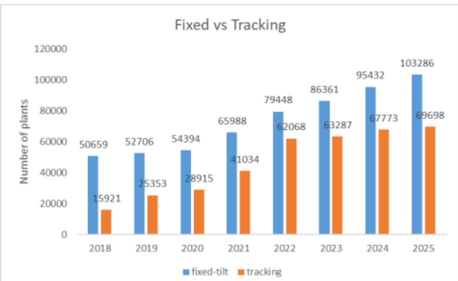

Figure 1 – Ground PV plants: in blue the fix-structure, in orange the trackers (one third of the total) – IHS Markit

Inside this scenario, the solar industry developed across the years two main key types of solar tracking systems: single-horizontal axis and dual-axis. The first, single horizontal rotational axis, moves the panels on one axis of movement, usually aligned with north and south: this means that the panels track the sun from east to west)as the sun rises and sets). The second, dual-axis tracker, allows panels to move on two axes, aligned both north-south and an east-west. In Figure 2 examples of horizontal single axis in tracker PV utility scale plants.

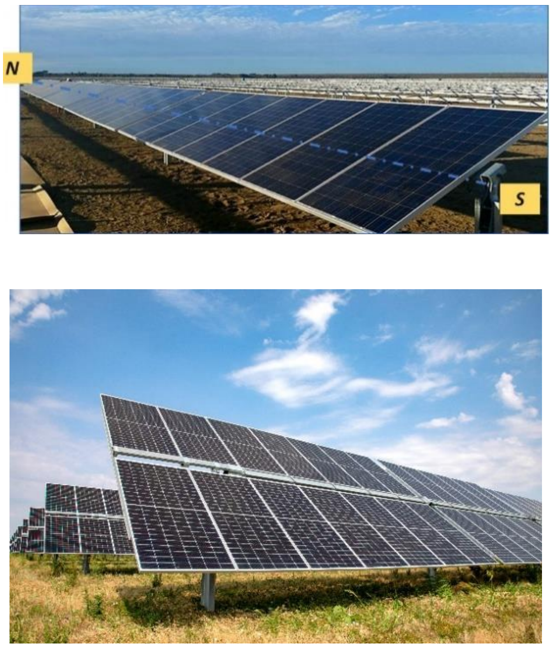

Figure 2 - Horizontal single axis tracker (1 and 2 modules) in PV utility scale plants

Single horizontal axis solar trackers provide significant advantages for renewable energy in terms of LCOE, in fact power output can be increased up to 30% (40% for dual axis tracker) [3], with a significantly lower cost increase compared to the two-axis solution. So, the deployment of single horizontal axis tracker for utility-scale PV plant is attracting the interest of several PV operators.

This paper describes the research activity carried out in the framework of a European project H2020, GOPV (Global Optimization of integrated PhotoVoltaic system for low electricity cost). [3] [4]

More in details the research activity performed by Convert – Valmont inside the GOPV project has been focused to improve the existing know-how, and also to generate new know-how, in the design of Horizontal Single Axis Tracker, for utility-scale PV plant optimized in terms of both Levelized Cost of Energy (LCOE) and Life Cycle Assessment (LCA) index. The technical approach followed, the most relevant experimental activities performed and the main results obtained are summarised in this paper.

2 APPROACH AND ACTIVITY

In order to achieve the above goals in terms of LCOE and LCA values, specific research actions have been carried out focused on:

- The use of Weathering Steel in the fabrication of tracker, as a cheaper steel-coating solution to use in aggressive corrosive environment, both for air and soil conditions. Solution with a lower environment impact.
- The experimental evaluation of wind loads to take into account in the tracker design, in order to assure a safe and economical design of the structure and in parallel to improve the existing international standards concerning the structural design of the tracker assuring also an optimization regarding the materials use,
- The develop of Wireless Control & Powering Systems integrated to new generation of monitoring SCADA A.I., in order to reduce cables and time for commissioning of PV plant and, at the same time, assure a high reliability of the monitoring

All the research activities have been supported by an integrated experimental and analytical approach, characterized by a large scale experimental tests program performed on full scale mock-up.

2.1 CORROSION RESISTANCE BASE MATERIAL / COATINGS

Solar Trackers are mainly fabricated in Hot Dip Galvanized (HDG) steel that has proven to be an excellent protection against corrosion and to provide service lifetime of 25 years, also in aggressive environments. Figure 3 shows HDG tracker structure, with its typical silver-grey color.
Nevertheless, HDG process is estimated to account about 20% - 25% of the cost of the tracker. Alternative materials should be explored to reduce costs, ensuring similar or higher mechanical and anticorrosion performances, and increase lifetime up to 35 years: Weathering Steel (W.S.) could be a technical and economical valid solution.

Figure 3 - HDG tracker structure, with the typical silver-grey colour.

It has been patented in 1933 by United States Steel Corporation, called *Cor-Ten,* as a low-alloy carbon steels with improved resistance to atmospheric corrosion on the time. In fact, the Weathering Steel in aggressive environments assure a self-protection from corrosion through the formation, on exposed surfaces, of a compacted layer of oxides (patina), obstructing oxygen diffusion. In general, the use of W.S. steels eliminates the galvanizing process (or other coating systems, e.g. painting) in the construction of the steel structure, with a significant effect on both LCOE and LCA.

Corrosion rate is estimated to be 4-5 times lower than traditional carbon steel, depending on the aggressiveness of environment and on the chemical composition of the steel. They are particularly indicated for atmospheres in categories C1, C2, C3 (ISO 9223 as reference). Moreover, changing its color from yellow to dark brown in the time made the W.S. very interesting structural steel for civil applications, so it has been used in many bridges, civil structures, guard rails, architectural buildings [5] [6]. Figure 4 shows typical applications of W.S. in the area of civil construction.

Figure 4- Typical applications of W.S. in the area of civil construction.

Nevertheless it was not used extensively in PV systems due to a lack of specific know-how dedicated to the design trackers for PV systems made in W.S., limit made more difficult to overcome due to the reduced thicknesses used in a tracker (2-4 mm) compared to those used in civil applications (>8 mm).

Starting from the basis of both the knowledge available in the literature and the international standards, we followed analytical procedures to easy classify the environment aggressiveness (atmosphere and soil) and to evaluate the sacrificial extra-thickness for tracker cross sections when weathering steel is used, in particular for this specific activity W.S. grade S235 ÷ S355, EN-10025, have been used.

A relevant improvement of the available know-how about the corrosion behavior of Weathering Steel in aggressive environment has been achieved through an out-door long term corrosion experimental test program on small specimens (three test-sites with different environmental conditions and more of two years of exposition) and specific laboratory analyses. Specific topics of this study were:

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

In parallel, the monitoring of a tracker exposed in the environment of Tuscania (VT, Italy) allowed to collect knowledge about the transferability of data obtained on laboratory test specimens to real structures. Figure 5 shows the prototype in Weathering Steel tested in Tuscania.

Figure 5 - Tuscania, Italy: Horizontal Single Axis Tracker made in Weathering Steel

After one year of soil and air exposure, the 2P tracker and laboratory samples were analyzed. The same deep analysis has been repeated after about 2,5 years.

Results lead to the following indications/conclusions:

- Availability of validated analytical models for both evaluation of sacrificial extra-thickness for W.S. application and also an easy classification of the environment aggressiveness to use in the design regarding the lifetime of tracker.

- There is a full compatibility between W.S. components and hot-dip galvanized bolts to be used for structure and modules fixation, in figure 6 details of connection W.S. and hot-dip galvanized bolts are shown.

- No particular grounding issues occurred due to passivated connections. in particular no electric grounding issues due to passivation of connections has been detected. The experimental values shown a R-Earth bellow of the maximum accepted values of resistivity R-Earth ≤ 1 Ohm, indicated by standard.

- Passivated layer in W.S. can be measured by Coating Thickness US Gauge with successful, as direct measurements of coating thickness on metallographic sections confirmed.

- No trouble on the embedded part of pile, for medium aggressive soil, has been detected after approximately 2.5 years of burying; figure 7 shows a phase of the survey performed in Tuscania on the tracker piles.

Figure 6 - Details regarding the W.S. components and hot-dip galvanized bolts

Figure 7 - A phase of the survey performed in Tuscania on the tracker piles

2.2 WIND STATIC AND DYNAMIC LOADS

Regarding the evaluation of wind loads effect on the strength and stability of the tracker, an integrated numerical-experimental approach has been developed and tested inside the GOPV project, with the final goal to evaluate the wind loads to use in the tracker design, in order to assure a safe and economical dimensioning of all tracker structural components and also its stability at

higher wind values.
Moreover, this was carried out to validate the CFD approach in order to use it as an analytical tool to perform sensitivity analyses, and so to be able to apply the wind tunnel results in scenarios differing from the one assumed in the testing.
Wind Tunnel (W.T.) tests has been performed considering in-scale GOPV tracker, and was carried out at the Polytechnic of Milan (POLIMI) [7]; On the other hand, the numerical CFD analysis has been carried out using the ANSYS code.
The Wind Tunnel test focused on three specific topics:

- Evaluation of wind pressure on single tracker vs wind speed (wind coefficients), for different tilting angle of tracker.
- Influence of the tracker position within the field layout in terms of wind coefficients (Internal rows vs External rows).
- Definition of wind conditions/tilting angle that may determine the instability of tracker, in terms of both Static Torsional instability (Divergence) and Dynamic Torsional Instability (Flutter/Galloping).

Figure 8 shows pictures of the tests lay-out, both to detect the static pressure load coefficients and to quantify the aerodynamic instability of tracker developed.

Figure 8 - Pictures of the tests lay-out inside the POLIMI Wind Tunnel Laboratory.

The W.T. results allow 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 an important cost reduction. In particular has been estimated that inner rows suffer around 40% less pressure and torque reduction in stowing/safety position, and 50% less pressure and torque reduction in service positions. These experimental indications were also confirmed by CFD simulations performed using ANSYS code (figure 9).

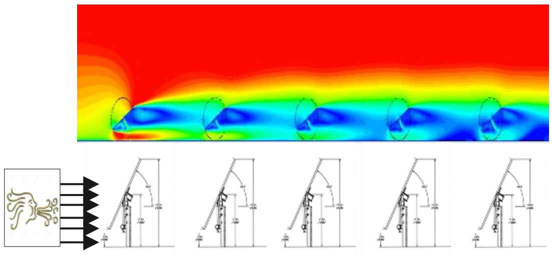

Figure 9 – CFD with Ansys software

Regarding the aeroelastic instability phenomena on the developed 2P tracker, the key results can be summarized as following:

- Torsional stability – Diverge: the phenomenon can born only in Stow position (0° +/-2°), with wind speed above 40 m/s
- Dynamic Instability Flutter: All other Service positions – stable up to 40 m/s
- Not Galloping in the same range of wind velocity

Values valid for a wind speed velocity referred to 10 minutes averaged values measured at 10m height above ground, to scale at gust factor can been used a multiplier of 1,46.

2.3 CONTROL & POWERING SYSTEMS

A new compact electronic control board and powering system for a performance large scale PV plant should satisfy the following general requirements, in order to achieve a redaction of LCOE:

- The new electronic device functioning in a “distributed inverters scenario” and with the possibility also to be powered directly by the inverter output.
- The new electronic device and powering system should assure a reduction of cables to install and consequently a decrease of commissioning time.
- The new monitoring and tracking should be based on a full new Centralized Tracker Wireless Control System.
- The dimension of these new electronic control boards/systems (and its switchboard/box) should be smaller of the existing one, in order to reduce shadowing on the rear side of modules.
- The Actuator – Motor device should ensure adequate values of both actuator force and stroke, in order to ensure the designed tracking operations.

In order to meet these requirements described above, and more generally to ensure an optimum cost/performance ratio of the system applicable in photovoltaic fields of different sizes, a new electronic control and powering system have been developed inside the GOPV project and tested in agreement with the EN-IEC-62817.
This system referred to as “Control & Power 100M” is integrated to a new Tracker Wireless Control System (SCADA A.I). It is based on a "Master - Slave" configuration, where a single “Master” board, controls and power a series of “Slave” boards of very reduced dimensions that are positioned inside each actuator.

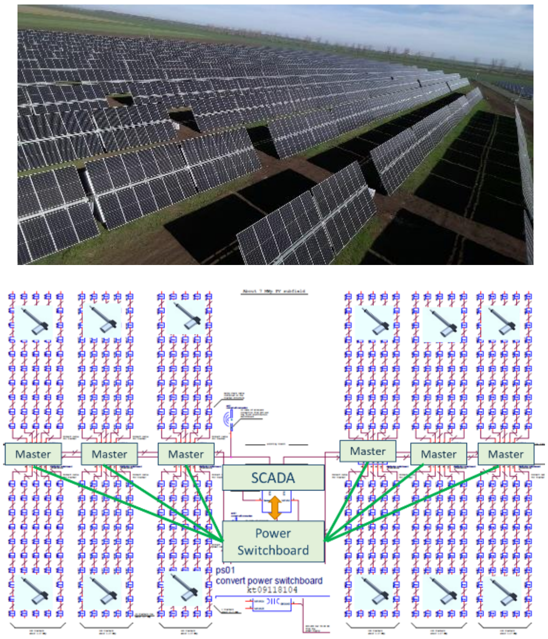

Figure 10 – A real application of 100M and its schematic configuration

The developed "Control & Power 100M" system can connect up to 100 Actuator – Motor device, with a reduced number of cables to install, with a consequently reduction commissioning time. The evaluation made show that technical/economic benefit increases with the plant size. In addition to the development of the "Control & Power 100M" system, a full new Centralized Tracker Wireless Control System, a has been developed: the SCADA A.I. In figure 10 a real application inside an utility scale PV plant of 100 M configuration is shown.

Finally figure 11 and 12 show Control System, SCADA A.I. and Driving Device components under testing at low and high service temperature (-30° and +85°C) inside a testing climatic chamber.

Figure 11 – Climatic chamber for testing

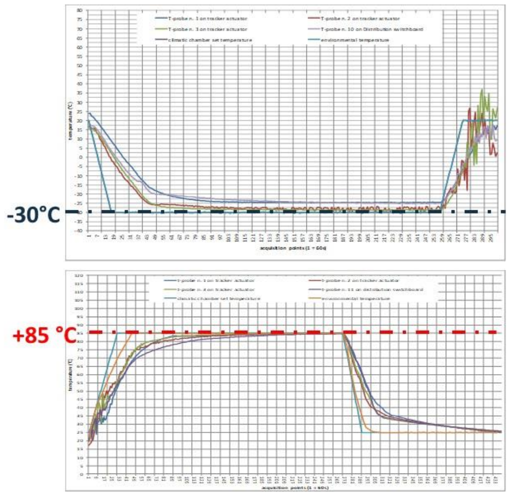

Figure 12 - Control System, SCADAA.I. and Driving Device components under testing at low and high service temperature, data record.

3 APPLICATION OF GOPV KNOW-HOW FOR NEW DEVELOPMENT

Results of the GOPV research projects gives an important know-how for new applications which are following the last trends in Photovoltaics, such as Agrophotovoltaic applications. Convert-Valmont has developed the first prototype of horizontal axis tracker for AgopPV plants, integrating fruit trees (citrus). This prototype has been made in cooperation with EF Solare Italia and Le Greenhouse for the Scalea Plant (south of Italy), figure 12.

This solution used all three topics developed and already presented. More in detail:

- Thanks to W.S. it has a lower cost steel-coating solution to use for aggressive corrosive environment (close to the see and environment with pesticides). It has also lower visual impact than standard steel structures, thanks to the brownish colour of the patina. This gives a positive feedback in term of acceptance (considering that visual impact is always a critical topic regarding the acceptability of a new PV plants).
- Thanks to experimental evaluation of wind loads it was possible to ensure a safe and economical design of the structure, considering its height and an important increase of static and dynamic effect of wind on structure.
- The Wireless Control & Powering Systems integrated to new generation of monitoring SCADA A.I., in order to reduce cables and time for commissioning and, at the same time, assure a high reliability of the monitoring. SCADA A.I. has been design to assure the monitoring and control also of agro-parameters .

Figure 12 - AgroPV structure, Scalea

4 CONCLUSIONS

The research activity performed inside the GOPV H2020 project and the obtained technical data have a key role in the optimization of the Technical- Economical design of tracker for large scale PV-Plant and in the reduction of both LCOE and LCA. These decreases could be summarized as follows:

The Use of Weathering Steel (W.S.) as a lower cost structural steel/coating:

- It has been confirmed for class of environment C1, C2, C3 and length of life 25 years; moreover, the W.S. solution can be used to design a tracker with a lifetime above 25 years.
- Allows to eliminate the HDG coating with a reduction of tracker cost of about 10% - 20% (with a redaction of LCOE) and in parallel a relevant redaction of CO2 related to the tracker fabrication process. With a good influence on LCA of PV plant.

The new experimental Wind Loads to take into account in the tracker design:

- The improvement of tracker design (in comparison of existing international code/guideline) can be made using the Wind Tunnel tests results and CFD analysis, reducing the total weight of steel to use in PV utility scale plant of 10% - 20%, in relation of dimension/layout of plant and severity of site.
- Regarding the Aeroelastic instability phenomena, the results showed that the tracker developed inside GOPV project is stable: up to a wind speed of 40 m/s (144 km/h) in relation with the Static Torsional Stability - Divergence; in relation to the Dynamic Instability- Flatter the tracker is stable at all service positions up to 40 m/s (108 km/h); finally no Galloping phenomenon was not observed in the same wind speed range.

New Wireless Control & Powering Systems integrated to SCADA A.I.:

- Reduction of length/weight of cables and trenches of 10%÷60% is possible, in relation of the dimension/layout of plant. In parallel also time for commissioning can be reduced;
- A higher reliability in the monitoring is possible using the new SCADA A.I., integrated also with new PV plant configuration, as AgroPV.

All these tracker design optimizations that lead to a reduction in the amount of steel/materials used to manufacture the tracker and its electronic control, while maintaining high performance and reliability. Reduction which results in a positive effect on LCOE and LCA. Values.

5 REFERENCES

[1] Renewable Energy Market Update Outlook for 2022 and 2023– IEA[2]https://ihsmarkit.com/products/solar-intelligence-service-premium.html

[3] Grant Agreement number: 792059 — GOPV — H2020-LCE-2016-2017/H2020-LCE-2017-RES-IA

[4] https://www.gopvproject.eu/project/

[5] European design guide for the use of weathering steel in bridge construction Nº143, 2nd Edition, 2021 Published by: ECCS – European Convention for Constructional Steelwork publications@steelconstruct.com

[6]https://www.promozioneacciaio.it/cms/it5537-acciaio-corten-un-materiale-per-tante-soluzioni.asp

[7] https://www.windtunnel.polimi.it/

ACKNOWLEDGMENTS

This paper is supported by European Union’s Horizon 2020 research and innovation programme under grant agreement No 792059., project GOPV (Global Optimization Of Integrated Photovoltaic System For Low Electricity Cost).