Best Practices in Solar Operation & Maintenance
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Who we are?
We are the world's largest producer of renewable energy

Over 65 years of experience
Worldwide

More than 63,500 collaborators

30 countries
We speak from Spanish, Italian, English, Portuguese, Romanian, Greek and even Russian

+ 1,400 plants
You would need 4 whole years to visit each of them

2.1 million km of energy distribution
Able to turn the earth around 52 times

+42 GW
Generation capacity
EGP
INSTALLED CAPACITY

- 675 MW EOLIC ENERGY
- 52 MW HIDRO ENERGY
- 992 MW SOLAR ENERGY

4 PROYECTOS UNDER CONSTRUCTION
4 PROYECTOS UNDER EXECUTION
WILL ADD AN ADDITIONAL 1GW

MÉXICO
Enel Green Power
How we work today within O&M

Goal
Optimize O&M Solar strategy, processes and activities following solar significant growth at global scale, with large plants (>100 MW) in emerging solar markets for a total of 4.3 GW to be managed by 2Q 2018

Project work-streams
- Definition of optimized O&M Solar Strategy
- Operational Efficiency and Diagnostic Analysis improvement
- O&M Innovative Solutions & Practices scouting, analysis and implementation
- Training and professional growth for “solar” colleagues
- Dedicated IT Systems to optimize solar plant maintenance
- Communication to boost involvement of all EGP colleagues on Solar

Installed capacity growth (GW)

Dec 2016  |  1.5 GW  |  515 MW
Jun 2017  |  2 GW    |  179 MW
Dec 2017  |  3 GW    |  292 MW
April 2018|  4.3 GW  |  992 MW

Dec 2017  |  4.3 GW  |  34 MW
April 2018|  4.3 GW  |  275 MW

NEW

How we work today within O&M Enel Green Power
Maintenance strategy

**Preventive maintenance**
Preventive Maintenance activities are the core element of the maintenance services to a PV plant. It comprises regular visual and physical inspections, as well as verification activities conducted with specific frequencies. It is under the responsibility of the O&M contractor to prepare the task plan until the end of the contract.

**Corrective maintenance**
Corrective Maintenance covers the activities performed by the Maintenance team in order to restore a PV plant system, equipment or component to a status where it can perform the required function. Corrective Maintenance include:

- **Fault Diagnosis**: also called troubleshooting to identify fault cause and localization
- **Temporary Repair**: to restore the required function of a faulty item for a limited time, until a Repair is carried out
- **Repair**: to restore the required function permanently

**Extraordinary maintenance**
Extraordinary Maintenance actions are necessary when major unpredictable events take place in the plant site that require substantial activities and Works to restore the previous plant conditions or any maintenance activity generally not covered or excluded from the O&M Contract. Extraordinary Maintenance interventions are required for:

- Damages that are a consequence of a **Force Majeure event**
- Damages as a consequence of a theft of fire
- Modifications required by regulatory changes
- Other upgrade activities for performance improvement

**Predictive maintenance**
Predictive maintenance is a Condition-based maintenance carried out by evaluating typical patterns of significant parameters of plant components degradation. Predictive techniques help to determine the condition of in-service equipment in order to predict when and whether maintenance should be performed.

**2 main activities to trigger:**
1. DATA ANALYSIS ON MAIN EQUIPMENTS (Modules, Inverter, transformers)
2. TECHNICAL INSPECTIONS

Operational Efficiency and Diagnostic Analysis
Algorithms developed in house on SAS platform

✓ **References Power Curves for single MPPT**: created through fully in-house developed algorithms based on neural network approach and statistical analysis on historical data and updated on yearly bases.

✓ **Operational Efficiency Analysis** for each MPPT to monitor the performance until the day before. Lost Production estimation and classification thanks to the Alarm Logbook from SCADA and Manual Logbook compiled by Supervisors on field.

✓ **Smart Reporting** and **Iterative Analytic Tool** developed in-house and available on-line and on personal mobile: **ICARUS**
Operational Efficiency and Diagnostic Analysis
Examples Unavailability Events without an alarm

Tracker problems

Automatic Allarm Trigger
That consent to have a fast intervention on field in order to solve the problems.

Soiling Problems

- Daily acquisition of data from field and automatic processing;
- Evaluation of the Losses due to the dirty on panel;
- Cleaning optimization for the Country.
### Goals

**Predictive Maintenance & Monitoring**
- Preliminary Scouting and PoCs of Predictive Monitoring Solutions with INN
- Completion of onsite inspections within prototype project

**Innovative Cleaning**
- Testing of Anti Soiling Coating and data analysis in collaboration with INN
- PoC for dry-cleaning by Robots with INN

**Digitalization**
- Preliminary Gap analysis in Data Lake
- Gathering of signals database from LCR and WMR Cloud (Intellysync)

**Drones and Smart Glasses**
- Scouting of Drones suppliers with INN
- AR project with INN. Definition of the demo for Smart Glasses at PV plant in Europe

### Activities carried out

**Predictive Maintenance & Monitoring**
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### Main results

**Predictive Maintenance & Monitoring**
- Preliminary examples of Predictive Platforms (i-EM, M2D)
- Risk analysis and Catalogue of main PV modules Failures
- Webinar on PV Failures Detection. Involvement of EGP Solar Community

**Innovative Cleaning**
- Cleaning Business cases shared within E&C Revolution Cleaning work stream
- Testing of Robots in ITUVERAVA

**Digitalization**
- Check of signals in Cloud per Inverter Manufacturer
- Preliminary analysis of signals from MV system, trackers, DC section from LCR

**Drones and Smart Glasses**
- Business case for drones usage and Smart Glasses case shared within E&C Revolution dedicated work stream
- Release of O&M Guideline for Drones inspections

### Next step

1. **Strengthening the synergies with GRE Digital Hub** for internalisation of Predictive mathematical models
2. Defining the Amendment of Contract for next tasks in 2018-2019

1. Identification of Fully Automatic Cleaning solution for O&M (if applicable, depending on specific site environments and PV plant design i.e. trackers)

1. Strengthening the synergies with GRE Digital Hub for unified Digital systems to be used in O&M activities

1. Identification of solutions feasible to be applied in current Operation activities
O&M Innovative Solutions
Innovative PV Cleaning: use cases

Assessing the best innovative solutions for PV modules’ cleaning to be applied in EGP PV Plants by using customized cleaning robots.

Project objective

KPIs

✓ Self-Powered
✓ Being automatic or semi-automatic (operated with some, or totally without human intervention)
✓ Suitable to be mounted on solar tracking structures
✓ Without (or with very short) water usage for cleaning
✓ Suitable to guarantee a soiling recovery (dust, sand) ≥ 95%
✓ Deployed with a target price according to EGP economical requirements (e.g.

Highlights

• Technology reliability assessment performed by 2 different suppliers - operating tests performed in Europe for 2 plants on 5 robot per technology
• Ituverava (Chile) on field test.
O&M Innovative solutions

Solar cells optimizers

Smart modules replace the bypass diodes in the module with the optimizer chip in order to push the MPPT function deep into the PV system. Cell string optimizers allow to produce the **most energy possible** regardless of shading issues and mismatch, without the complexity of DC Optimizers and with simplified system design, improving also the reliability of the modules.

**Advantages**

1. **Increase energy yield** (each cell string delivers maximum power at the best current)
2. **Increase ground coverage and improve land utilization** (allows 10%-20% tighter row pitch at the same energy production per panel)
3. **Higher reliability**: Minimize power degradation over the panel and eliminate hot spots
4. **No additional BOS** (control unit, network cabling, network configuration)

**Results of La Silla project do not show significant values of energy increase**
The PID - Potential Induced Degradation - is a specific Failure Mode occurring at PV Modules and leading to a Performance Degradation. The combination of several environmental stressors, quality of PV materials and exposure to a negative voltage potential is responsible for its occurrence.

When PID affect our PV plant, a lower yearly revenue will be obtained with a direct impact on our total financial profit. The impact of PID could be so strong to invalidate the investment.

**PID effect**

Yearly Energy Production and Revenue reduction

PV Plant Profit Loss

**PID = NET PROFIT LOSS**

PID Recovery has to be considered as a corrective action in order to restore profitability of PV Plant investment.
O&M Innovative Solutions
PID Solution

Stroussi PV Plant
Nominal Power [MWp] 6.43
Yearly Energy prod [MWh] 9570
Yearly Energy Prod [MWh/ MWp] 1488

COD 24-01-2013
Operating LifeTime 27 years (30-35 years is typical value for EGP plants)

4.45 MWp (JA Solar JAP6230-235 crystalline modules) identified as impacted by reversible PID.

After 1 year operation actual PR lower (>5%) than theoretical one.

On going activities

Three different PID recovery technical solutions are under evaluation:
• Grounding Kit by constructor Installed in January 2016
• Two differentes PID Commercial Device in December 2017/April 2018

PID recovery benefits

PID Recovery loss of yearly Energy Prod (x MWp) = 5%
PID recovery Time (months) = 6
Drones for O&M

- Aircrafts that can be remotely controlled or fly semi-autonomously through software-controlled flight plans, working in conjunction with global positioning system (GPS).

- Utilized in multiple industries, driven by a growing need to improve productivity and efficiency via automation. Global market revenue is estimated to reach $6.66 bln by 2020.

- Able to perform a variety of tasks, most often involving imaging or payload-bearing capabilities, leveraging on precision robotics, computer vision, and artificial intelligence technologies.

New and innovative technique to reduce costs and timing of operation, maintenance and construction activities.

Substitute human workers during inspections, reducing risks related to people operating at height and confined areas.

Support security activities through automatic anti-intrusion inspections.
The Aim of the project is the development of **Fully automated System for PV Inspections and data acquisition & reporting allowing to**

- **OPTIMIZE STANDARD PV INSPECTION** (up to 4MW/day of 4 hours covered with drone flight, 30’ battery VS. 2%/plant only with manual inspection)
- **REDUCE COSTS** of PV Manual Inspections

**Use case description**

- Permanent robotic system that includes drones that are *autonomous*;
- Exploits *satellite imagery* to locate the building site of a new plant;
- Monitor the status of the plant while it is under *construction*;
- Totally *automatic and radiometric images analysis* of the PV field;
- Verify the potential value for EGP using *Big Data approach* and define KPI parameters of interest that can both drive action planning by means of Actions to Solve (e.g. Decision Support System).
- *Hotspot failure* detection.
O&M Innovative Solutions and Practices

Business Case: USA

Drones are a catalyst for digital workflows
O&M Innovative Solutions and Practices

Business Case: USA

- Machine learning (ML) analytics for PV installations is a launched product
- Previously built drone-mounted and fixedmount thermal ML systems with onboard computing
  Already working with EGP-NA partners in the field

Combine these 2 capabilities for Innovate Mass

- Restore 1.5% of lost capacity. Equivalent to removing 35,000 cars from the road per GW of installed solar.
- Lower O&M cost for PV systems, making solar more competitive.
O&M Innovative Solutions

Digitalization

➢ Solar Digitization…What for?
  ▪ Reducing the Technical Risks
  ▪ Increasing Efficiency, Safety and Sustainability
  ▪ Reduction of Operational Costs
  ▪ Increasing of Solar Assets Lifetime

➢ Solar Digitization...How?
  1. **Cloud Big Data Computing** with using Industrial Connectivity Data Platforms and Predictive Patterns-components specific to manage Plant Data and reduce emergency and periodic site visits
  2. **Remote Sensor & Control**. IoT, 5G and wireless communications, embedded test electronics and data analysis can help diagnose faults remotely
  3. **Digital Field Workers** using mobile and AR/VR technologies such as Smartphones and Smart Glasses to assist effectively O&M activities in a safer way;
  4. **Autonomous Drones** equipped with on-board data analytics to visual imaging modules and status of other PV components and IR imaging monitoring and transfer those images to Big Data Cloud;
  5. **Satellite Forecasting** service is the best practice for irradiance measurements and remote sensing to allow better-timed maintenance and also monitoring soiling accumulation for optimization of cleaning activities
  6. **3D Printing** to reduce spares in storage and theirs management cost and decreasing lead times

Source: Solar Power Europe Guideline, 2017
O&M Innovative Solutions and Practices
Digitalization: Proactive strategy

DRONES SWARMS:
Self-organized devices that autonomously detect failed modules and plant components

AUTOMATIZED O&M INTERVENTION
Exploiting plant robotized solutions for automatic maintenance work
O&M Innovative Solutions and Practices
Digitalization

Plant documentation archived on CSK (Company Knowledge System) in cloud and available globally to all users O&M

**Objectives**

- Create a unique document management and collaboration platform cross countries and functions
- Recuperate, store and digitalize all critical plant documents - currently stored in local files systems, facilities and power plants - to guarantee access, improved archiving and retrieval of missing documentation.
- Integration with other core systems (i.e SAP, Archibus, MDM)

**Benefits**

- Global access to a unique system in cloud (web application)
- All O&M Power plant documentation available and well organized following IO 117
- Collaboration instrument aimed at facilitating communication, project and knowledge management.
- Lever for cross-functional & cross-country business process integration & optimization

**PLANT**

- Handover and as-built documentation
- Legal permissions, concessions and restrictions
- Property document
- Contracts and warranties
- Manufacturer technical manuals

**Documentation Management System (DMS)**

Solar PV plant documentation is crucial for an in-depth understanding of design, configuration and technical details thereof. It is Asset Owner’s responsibility to provide those documents and if not available, they should, as best practice, be recreated at the Asset Owner’s cost. There are two important aspects related to the management of this information:

✓ Information type and depth of detail
✓ Management and control

Complete the implementation of the Quality Check-list process for the EGP Perimeter by 1H 2018
Complete the upload of Latam documentation and implementation of the Quality Check-list process by 2Q 2018
Completion of documents upload process with further ~200,000 documents by 2Q 2018
The models approaches for the generation and monitoring of predictive warnings at inverter level have been investigated:

- **Event Detection** to predict inverter deviations from nominal behavior
- **Automatic Fault Recognition** to predict a specific class of faults (e.g. ground fault): automatic report generation
- **Short term prediction** based on Cloud detection systems
- **Mid term prediction** based on BigData analysis and recognized faults

**Event notification & decision for action**

- **Inverter signals**
- **Cloud**
- **Input inverter signals & predictive models**
- **Case Prahova1**
- **Operator Dashboard**
- **Predictive Alert mail**

Events Predictability > 80%
~3 days in advance