AI4PV Final event

28th June 2023, online event

COMPETE 2020 PORTUGAL 2020 @CDTIoficial European Union European Regional Development Fund

Agenda

- AI4PV in a nutshell
- Diagnosing issues in large-scale Photovoltaic Plants using AI & Digital Twin technologies
- An introduction to digital twins of PV inverters & maintenance policy recommendations
- AI to optimize PV cleaning schedule

AI4PV in a nutshell

- Christian Verrecchia (R&D Engineer)

NEW by EDP & CTG

AI4PV in a nutshell

Christian Verrecchia – R&D Engineer at EDP NEW

The AI4PV project in a nutshell

3 Partners

NEW by EDP & CTG

INESCTEC

isotrol

Objectives

Specific objective 1 - Increasing PV Plant reliability

- Development of advanced and automated functions for data analysis for fault detection for critical elements of PV plant and its grid integration. Comparing real data with simulation, providing insights of problems at early stages.
- Provide improved plant reliability optimizing the O&M tasks and procedures through an AI based recommendation engine tasks based on the impact of failures or underperformance. KPI: number of maintenance actions at validation site

Specific objective 2 - Optimizing PV Plant generation performance

- Underperformance and degradation problems at PV plants can lead to a loss of production, but usually they don´t trigger an alarm so that the O&M or the Asset Management teams start a correction action. This way they are usually unnoticed until they get to a certain level, but meanwhile there has been loss of energy production during months. The objective is to detect this at early stages through advanced data analysis from Scada and sensor data.

AI4PV

COMPETE 2020 | PORTUGAL 2020 | CDTI @CDTIoficial | European Union European Regional Development Fund

AI4PV outcome and validation

Outcome and tools

Fault prediction and detection

- DT for normality analysis;
- AI for fault prediction and classification

Optimizing O&M policies

- RL for defining optimal policies and maximize RoI

Demonstration

Validation in a real PV park

More info at

ai4pv.eu
info@ai4pv.com

COMPETE 2020 PORTUGAL 2020 CDTI @CDTIoficial European Union European Regional Development Fund

Enjoy the webinar and….

Don’t forget to ask your question in the chat!

European Union
European Regional Development Fund

Diagnosing issues in large-scale Photovoltaic Plants using AI & Digital Twin technologies

-Jose Garcia-Franquelo (Head of Innovation)
-Miguel Ángel Delgado Molina (Data Analyst)

isotrol

Diagnosing Issues in Large-Scale Photovoltaic Pl ants Using AI and Digital Twin Technologies

Miguel Ángel Delgado Molina
José García Franquelo
ISOTROL

European Union
European Regional Development Fund
@CDTIoficial

Agenda

- Isotrol overview
- The need for advanced analytical solutions
- Success cases
- Takeaways

Agenda

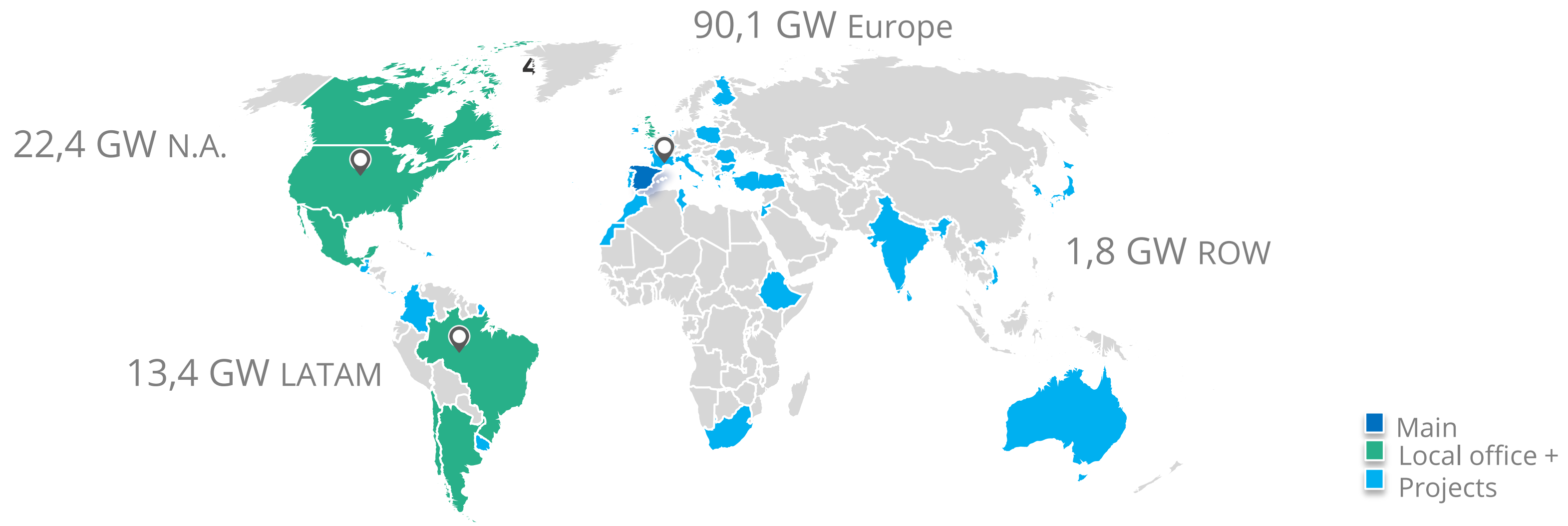
- Isotrol overview
- The need for advanced analytical solutions
- Success cases
- Takeaways

Isotrol overview

Covering the World with our Solutions

+120 GW and outstanding references in more than 40 countries

Renewable generation	**Monitoring, control and advanced performance management of renewable assets**
Energy Trading	**Solutions to optimize energy management in wholesale markets**



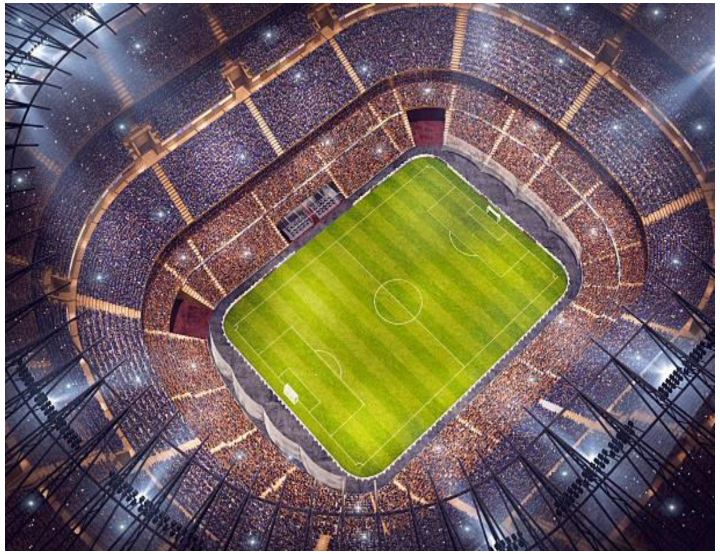
AI4PV isotrol

COMPETE 2020 PORTUGAL 2020 CDTI @CDTIoficial European Union European Regional Development Fund

Agenda

- Isotrol overview
- The need for advanced analytical solutions
- Success cases
- Takeaways

The need for advanced analytical solutions



I **Renewable portfolio management**

Large, complex and multi-technology

II **Data**

Big, with quality issues. Economic criterion at plant sensorization

III **SCADAs & Control centers**

Focused in operation, not in analytics: availability

So …. how to identify that there is a problem, where and why?

The need for advanced analytical solutions

What they are and what we can expect from them. Maturity model & added value

Digital Twin

Analytics based in models and AI

e.g. Datasheet compliance, Trackers misalignment, sensor fault, MPPT,…

Performance Diagnosis

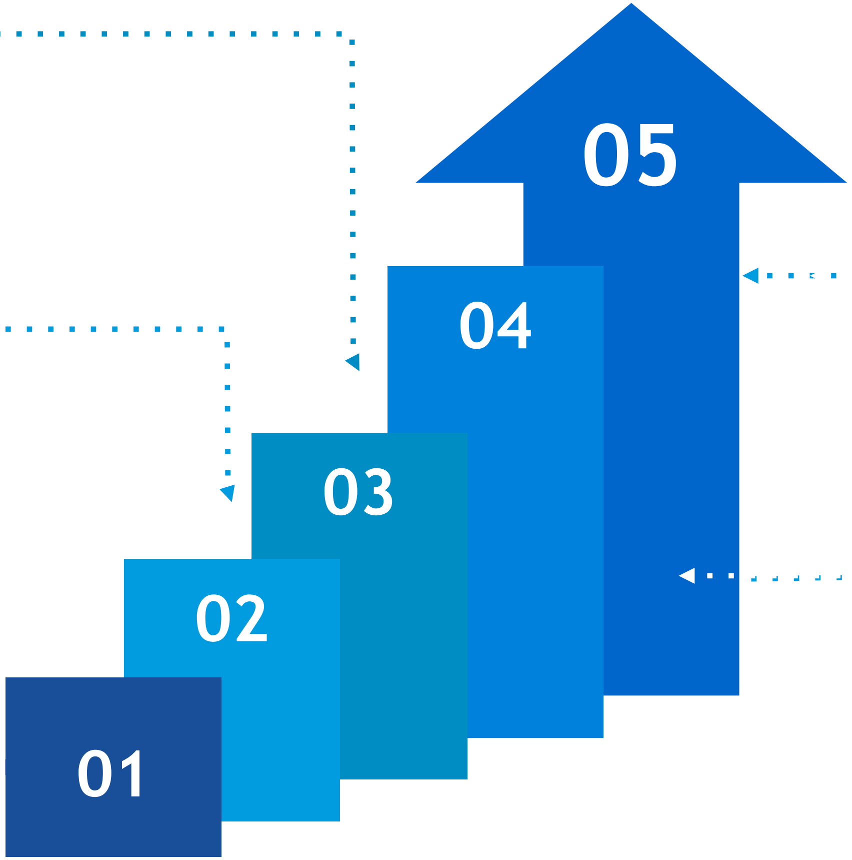
Time series based analytics with ML

e.g. and out-of-normality Trackers blocking, inverter problems,…

Performance Monitoring

Energy losses identification from theoretical yield

e.g. energy losses classification



Operational efficiency

Recommendation engine

e.g. scheduling optimal operations

Predictive analytics

Deep learning for failure and inefficiency prediction

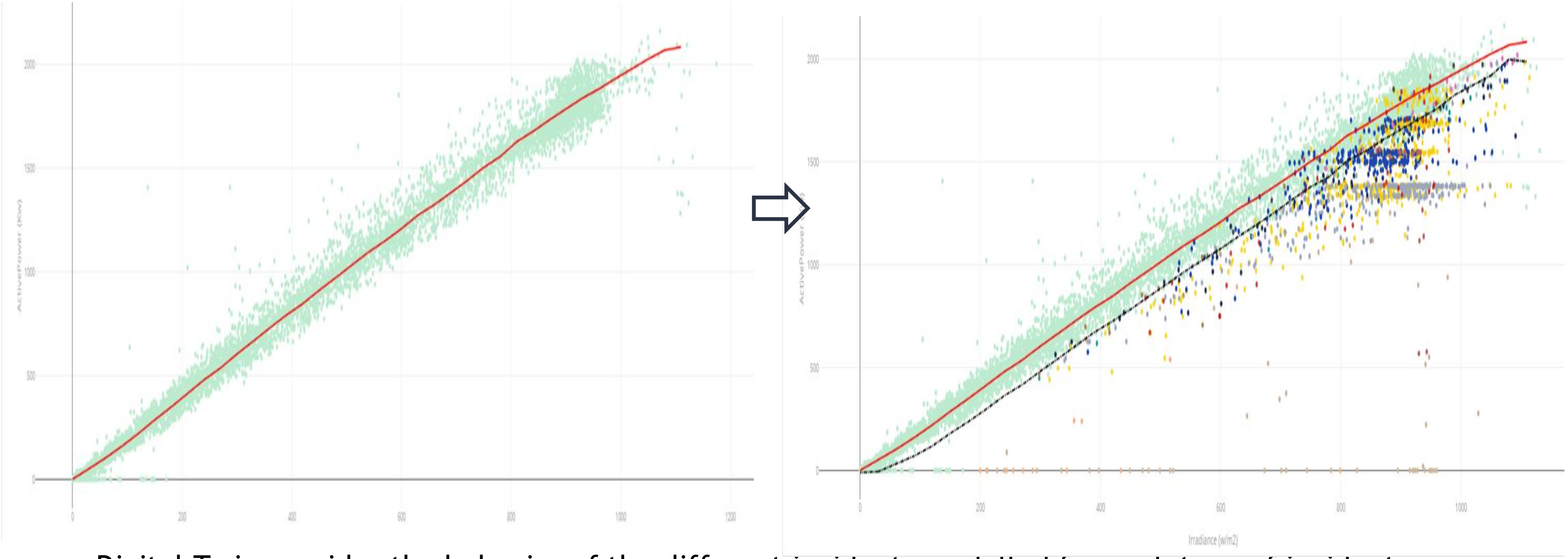
e.g. Inverters (overheating, isolation, fan,..)

AI4PV isotrol COMPETE 2020 PORTUGAL 2020 CDTI @CDTIoficial
European Union
European Regional Development Fund

The need for advanced analytical solutions

Why use a digital twin for diagnosing PV Plant Issues

A model capable of replicating the behaviour of plant



Digital Twin provides the behavior of the different incidents modelled for each type of incident (dirt, ageing, tracker mismatch, string disconnections, partial shadows)

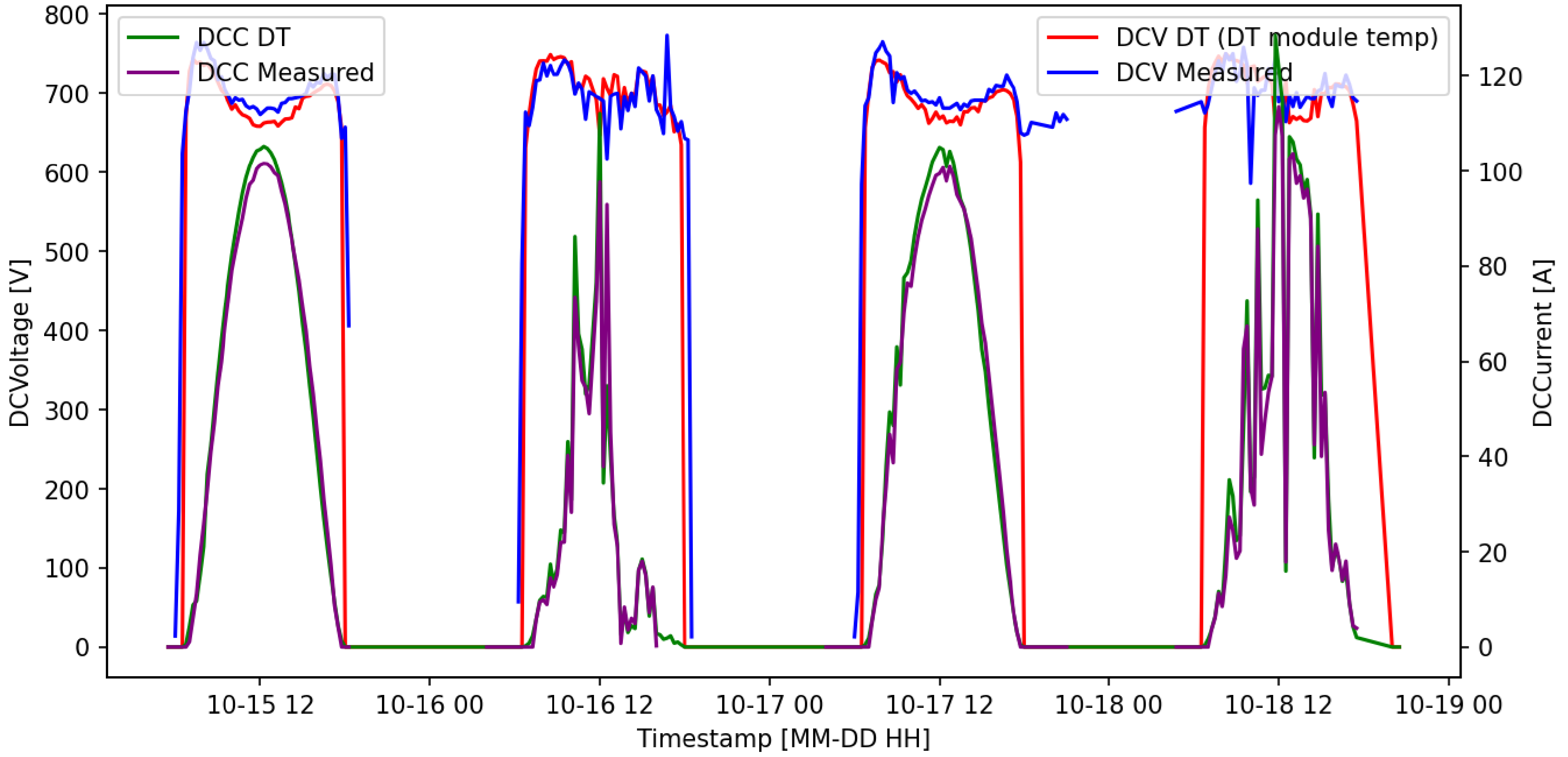
AI4PV
isotrol
COMPETE 2020
PORTUGAL 2020
CDTI @CDTIoficial
European Union
European Regional Development Fund

Agenda

- Isotrol overview
- The need for advanced analytical solutions
- Success cases
- Takeaways

Success cases

Asset simulation: Replicate the real world



isotrol

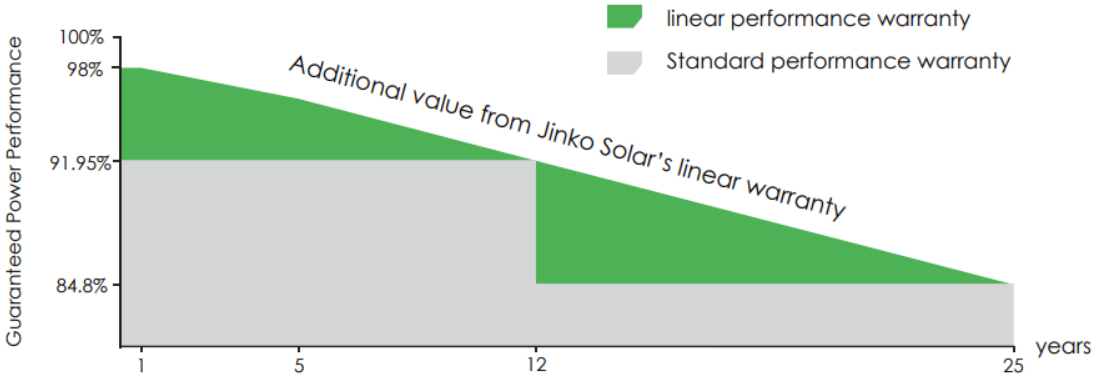
COMPETE 2020 PORTUGAL 2020 CDTI @CDTIoficial European Union European Regional Development Fund

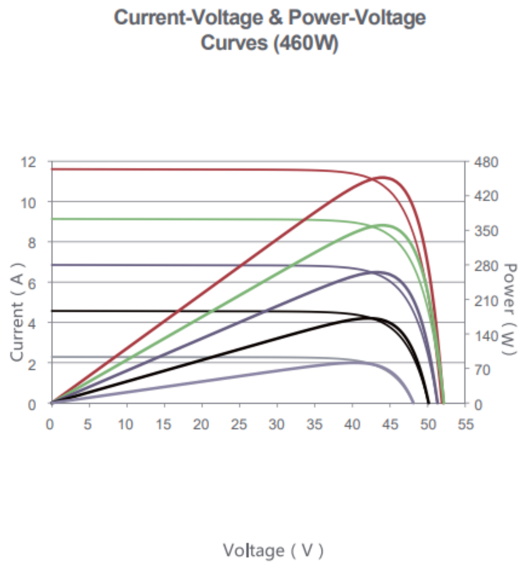
Success cases

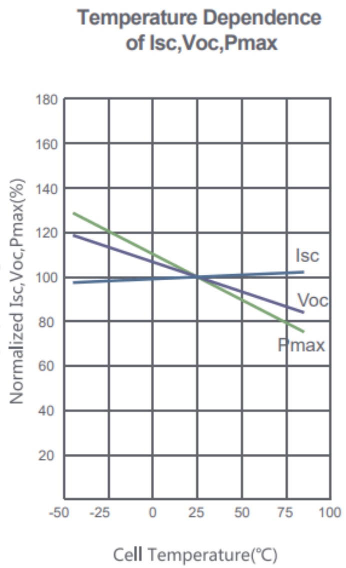
Problem 1: Datasheet compliance validation

SPECIFICATIONS

Module Type	JKM455M-7RL3 JKM455M-7RL3-V		JKM460M-7RL3 JKM460M-7RL3-V		JKM465M-7RL3 JKM465M-7RL3-V	
	STC	NOCT	STC	NOCT	STC	NOCT
Maximum Power (Pmax)	455Wp	339Wp	460Wp	342Wp	465Wp	346Wp
Maximum Power Voltage (Vmp)	42.97V	39.32V	43.08V	39.43V	43.18V	39.58V
Maximum Power Current (Imp)	10.59A	8.61A	10.68A	8.68A	10.77A	8.74A
Open-circuit Voltage (Voc)	51.60V	48.70V	51.70V	48.80V	51.92V	49.01V
Short-circuit Current (Isc)	11.41A	9.22A	11.50A	9.29A	11.59A	9.36A
Module Efficiency STC (%)	20.26%		20.49%		20.71%	
Operating Temperature(℃)					-40℃~+85℃	
Maximum system voltage					1000/1500VDC (IEC)	
Maximum series fuse rating					20A	
Power tolerance					0~+3%	
Temperature coefficients of Pmax					-0.35%/℃	
Temperature coefficients of Voc					-0.28%/℃	
Temperature coefficients of Isc					0.048%/℃	
Nominal operating cell temperature (NOCT)					45±2℃	





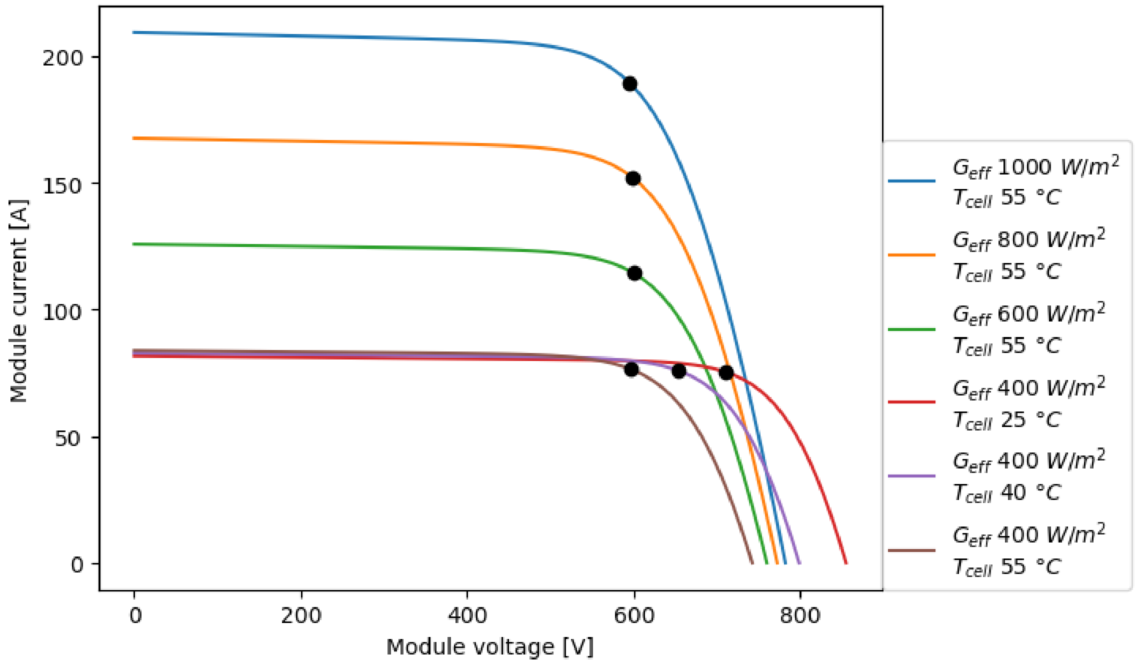


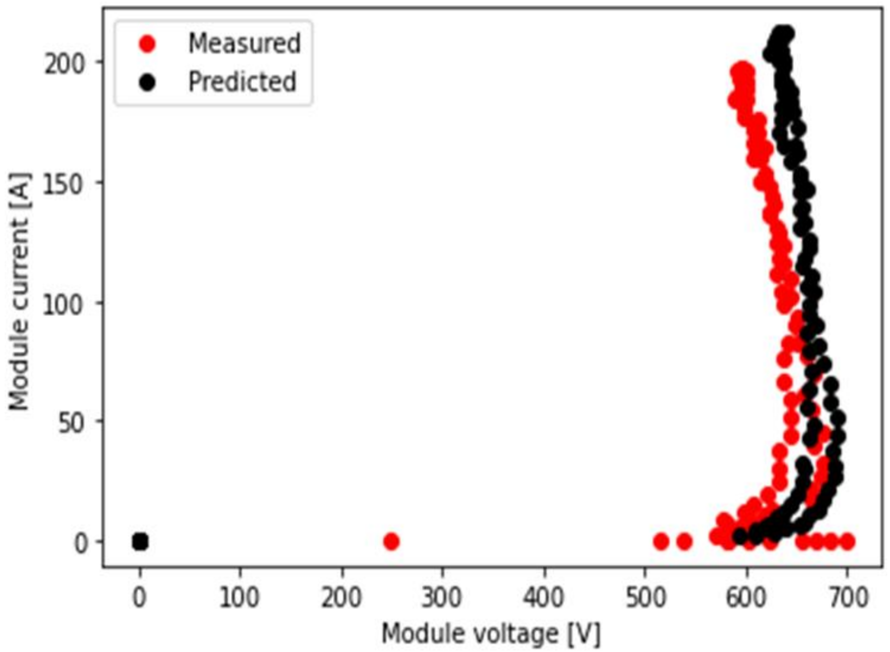
AI4PV isotrol

COMPETE 2020 PORTUGAL 2020 CDTI @CDTIoficial European Union European Regional Development Fund

Success cases

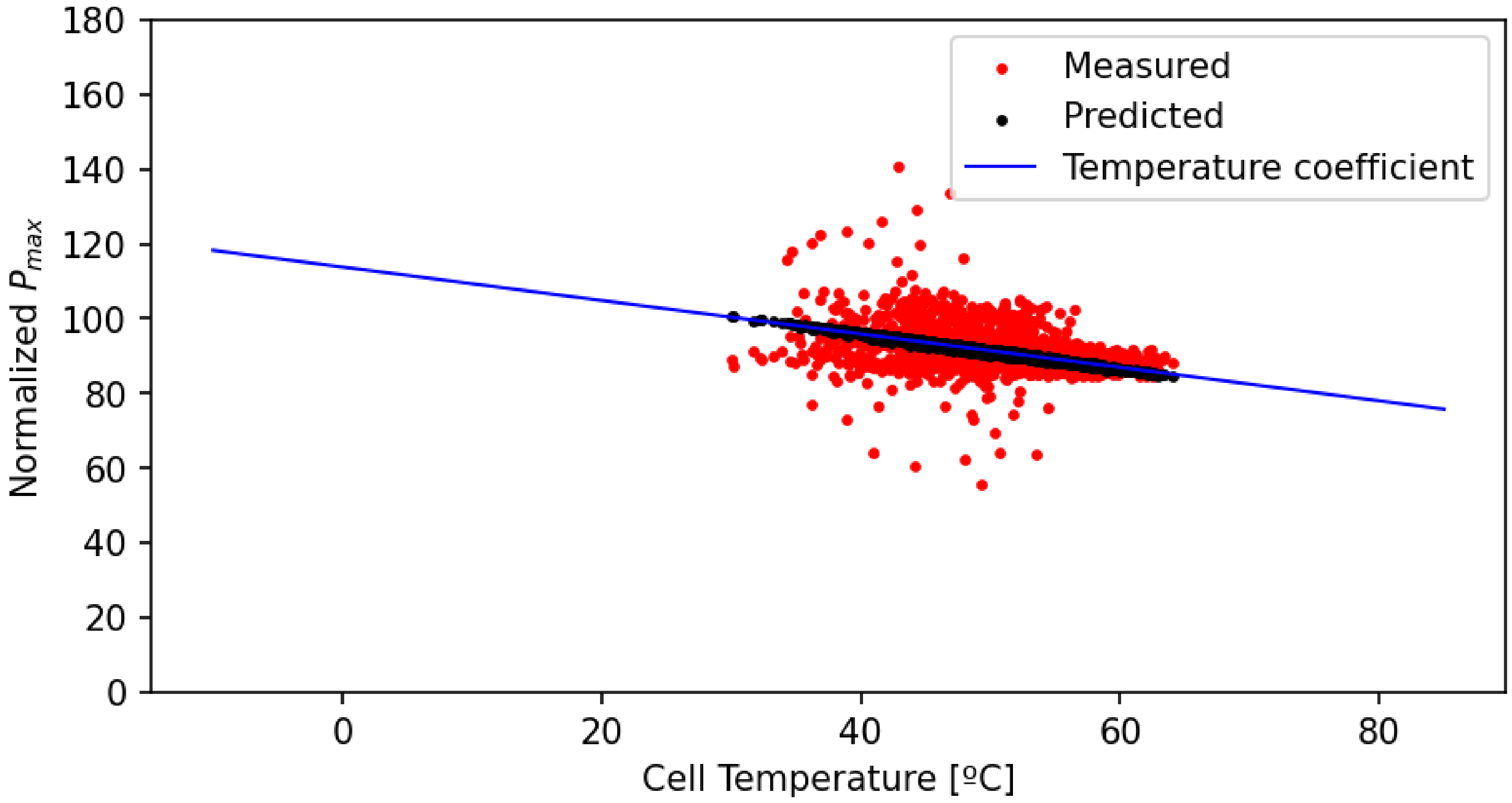
Problem 1: Datasheet compliance validation – MPPT point





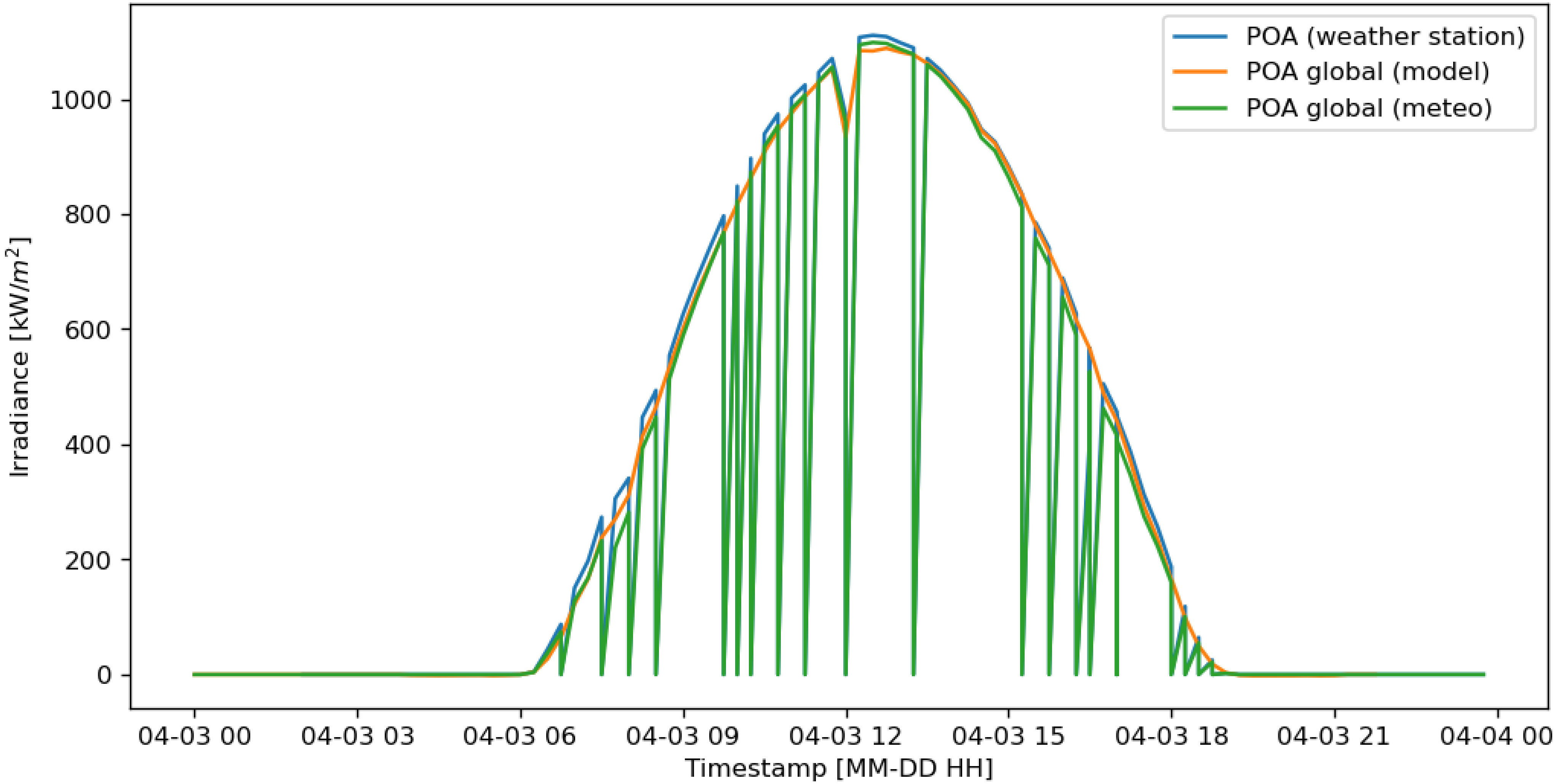
Success cases

Problem 1: Datasheet compliance validation – Temperature coefficient



Success cases

Problem 2: Sensor malfunction detection & data correction



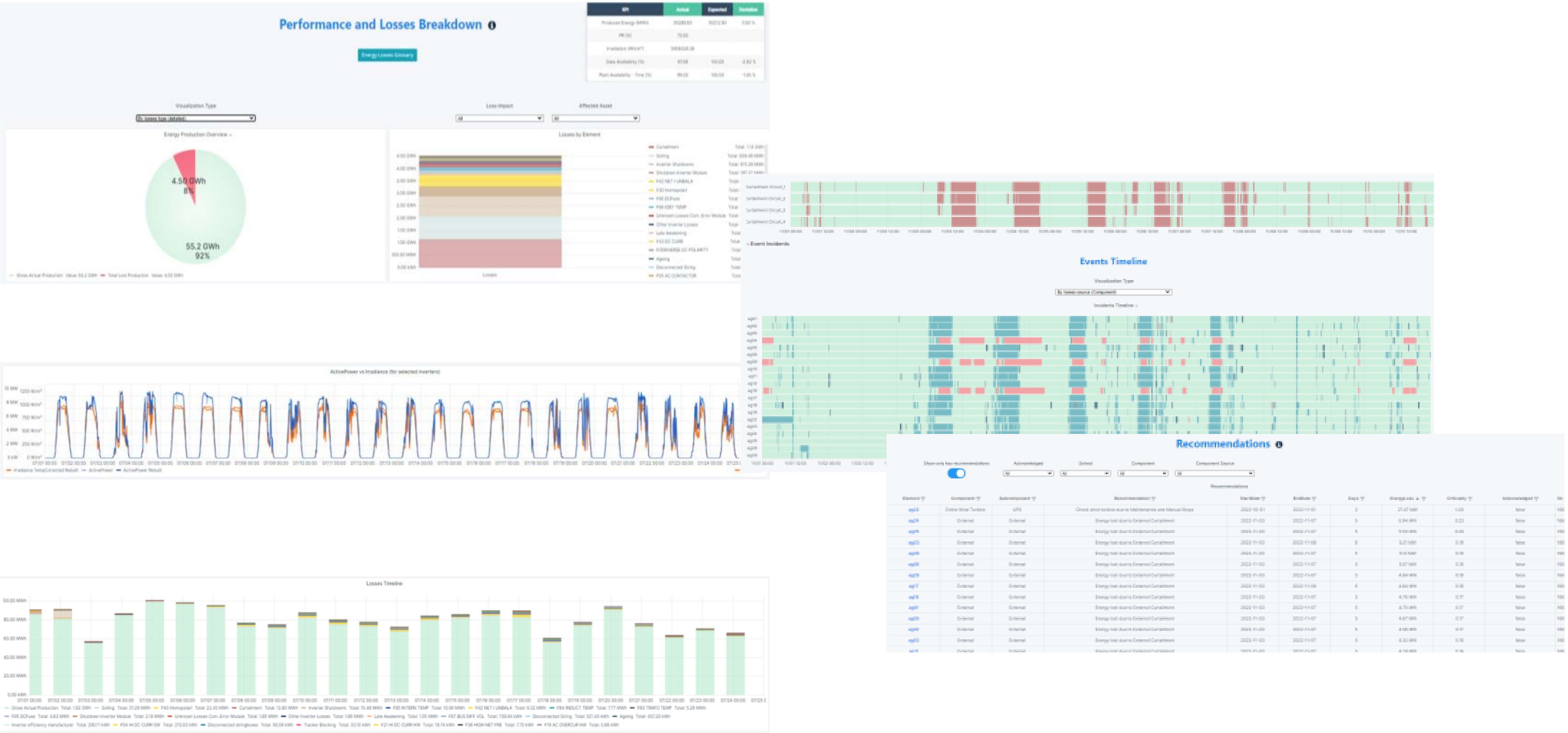
European Union
European Regional Development Fund

Agenda

- Isotrol overview
- The need for advanced analytical solutions
- Success cases
- Takeaways

Takeaways

Integrating the results in a easy to use tool for AM and O&M teams



European Union
European Regional Development Fund
@CDTIoficial

Takeaways

Detecting issues with Digital Twin

01 DT and AI provides better accuracy than time-series ML analysis

02 Better and quicker insights of issues

03 Faster adaptation to different plant typologies

04 Increasing the yield and profitability of PV plants

Thanks for your attention!

Don’t forget to ask your question in the chat…

COMPETE 2020
PORTUGAL 2020
CDTI @CDTIoficial
European Union
European Regional Development Fund

An introduction to digital twins of PV inverters & maintenance policy recommendations

- Louelson Costa (Assistant Researcher)
- Flávia Barbosa (Senior Researcher)

INESCTEC

An Introduction to Digital Twins of PV Inverters and Maintenance Policy Recommendations

Louelson Costa (INESCTEC)
Flávia Barbosa (INESCTEC)

European Union
European Regional Development Fund
@CDTIoficial

Agenda

- INESC TEC
- Digital Twin of PV Inverters
  - Introduction
  - Definition
  - Simulation and validation
  - Fault classification
  - Conclusion
- Maintenance Policy Recommendations
- References

Agenda

- INESC TEC
- Digital Twin of PV Inverters
  - Introduction
  - Definition
  - Simulation and validation
  - Fault classification
  - Conclusion
- Maintenance Policy Recommendations
- References

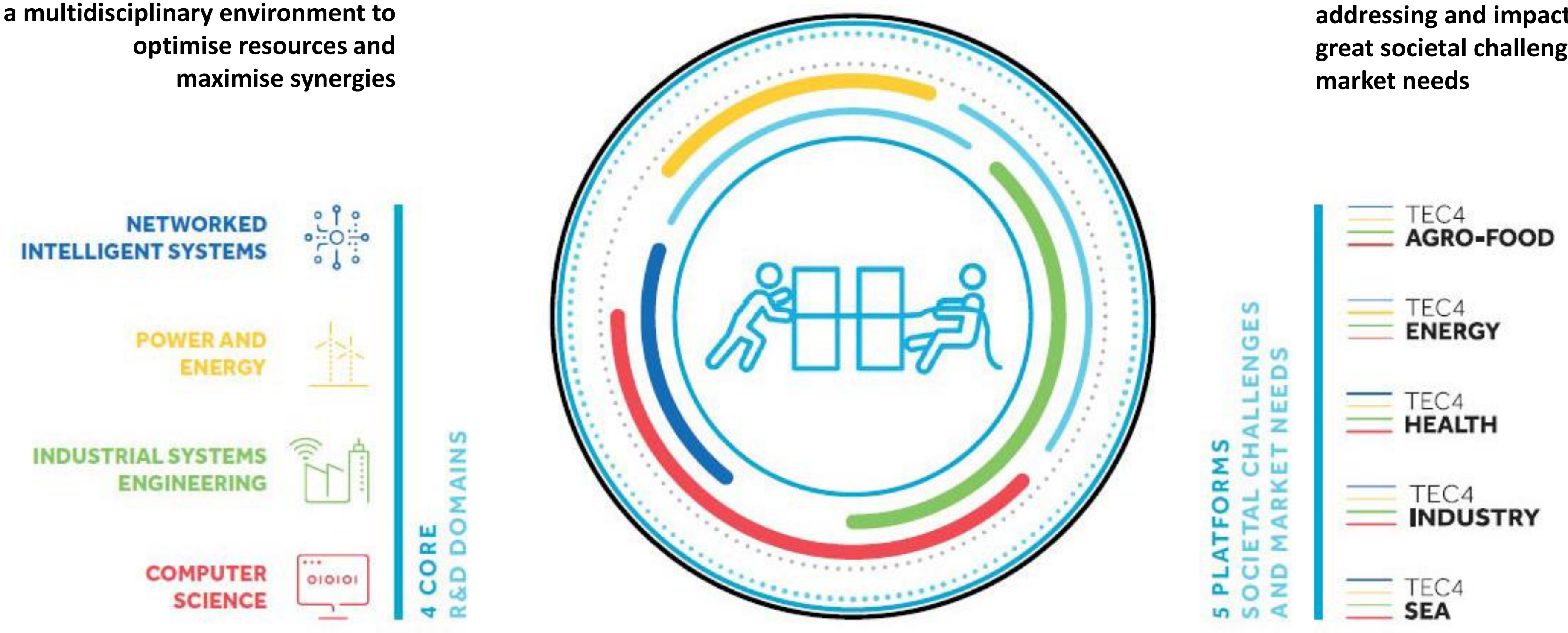
INESC TEC
35 YEARS LEADING R&D IN ENGINEERING
TURNING SCIENCE INTO ECONOMIC VALUE

RESEARCH
CLUSTERS BEHIND SCIENCE PUSH

Clusters of research centres build a multidisciplinary environment to optimise resources and maximise synergies

INNOVATION
TEC4 BEHIND MARKET PULL

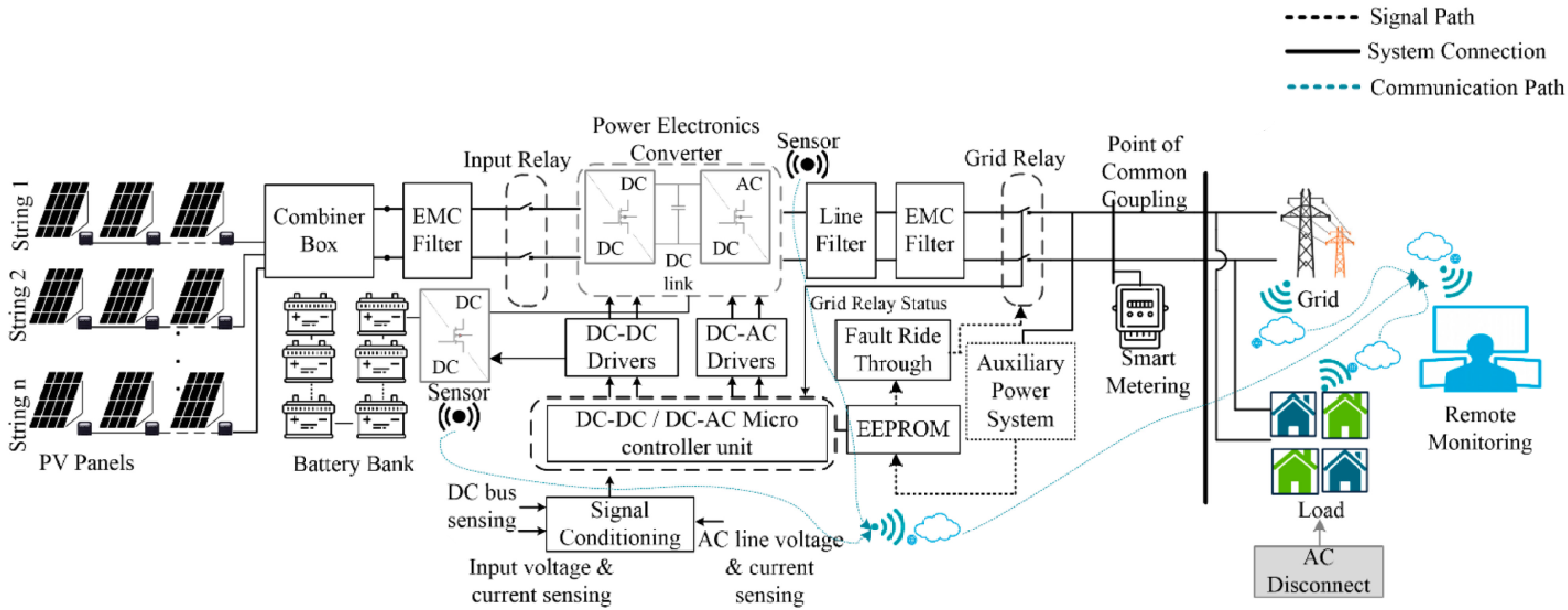
Strategy-driven platforms addressing and impacting great societal challenges and market needs



Agenda

- INESC TEC
- Digital Twin of PV Inverters
  - Introduction
  - Definition
  - Simulation and validation
  - Fault classification
  - Conclusion
- Maintenance Policy Recommendations
- References

The PVPP and the problems [1]

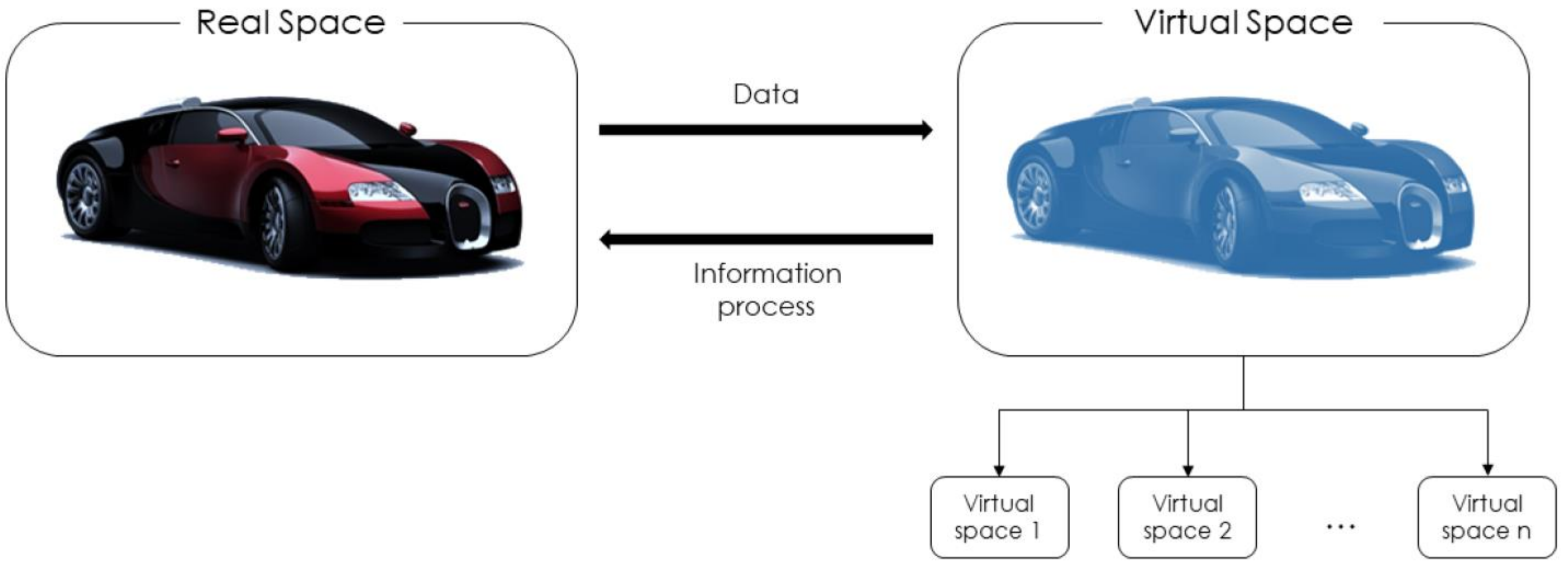


Agenda

- INESC TEC
- Digital Twin of PV Inverters
  - Introduction
  - Definition
  - Simulation and validation
  - Fault classification
  - Conclusion
- Maintenance Policy Recommendations
- References

What is a digital twin after all [2, 3]?

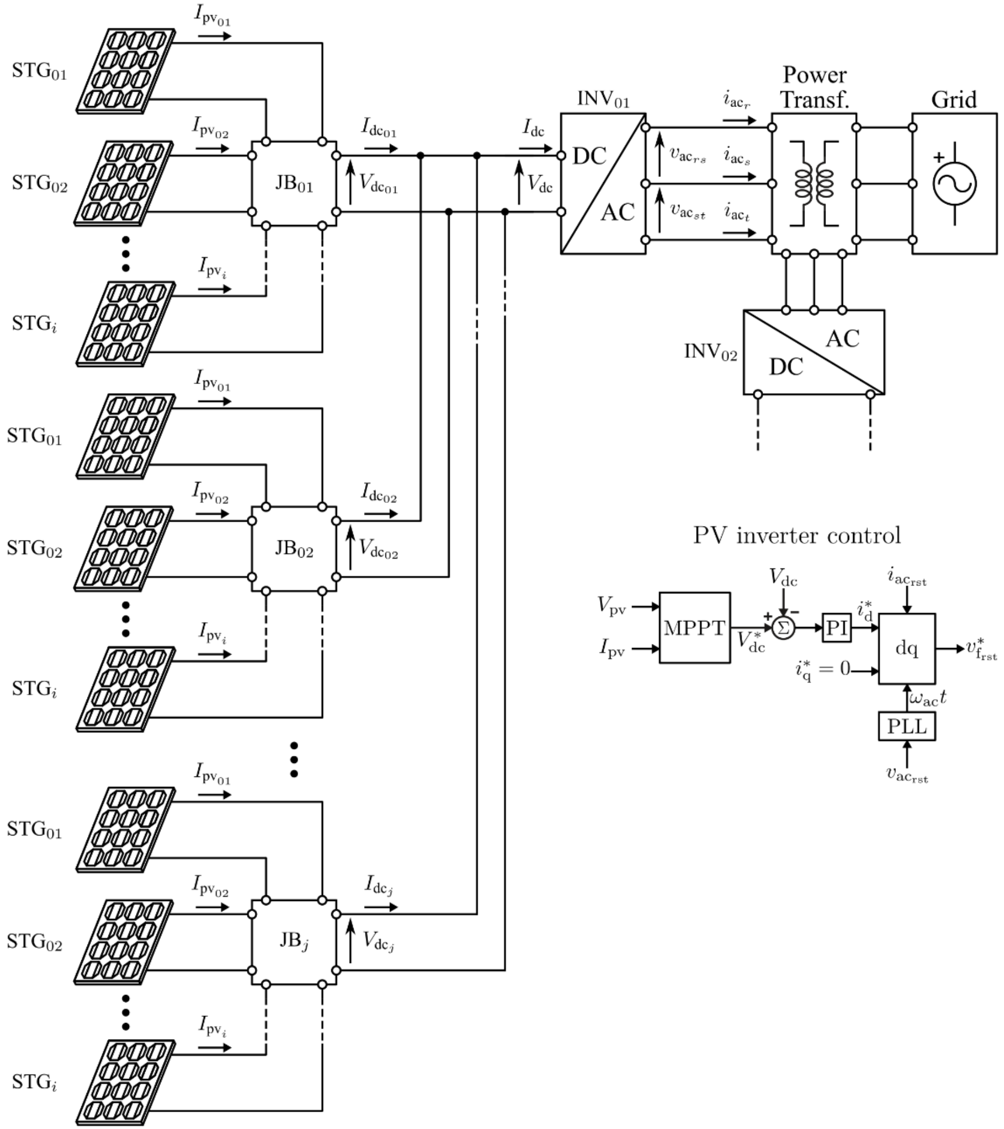
- First introduced in 2002 by Michael Grieves:
  - "Virtual representation of real-world entities and processes, synchronized at a specified frequency and fidelity."
- DT must have three basic elements:
  - A real space containing a physical object
  - A virtual space containing a virtual object
  - A link for data flow from virtual to real space and vice-versa



European Union
European Regional Development Fund

From a power electronics point of view

- Physical object:
  - PVPP, considering the PV modules, JBs, PV inverters, transformer and gri
- Virtual object:
  - MATLAB/Simulink simulation containing:
    - PV strings, junction boxes, PV inverter, power transformer, grid
- A link for data flow:
  - Usage of API to download the daily meteorological and SCADA data, and to upload daily fault and failure report, maintenance recommendation, etc.

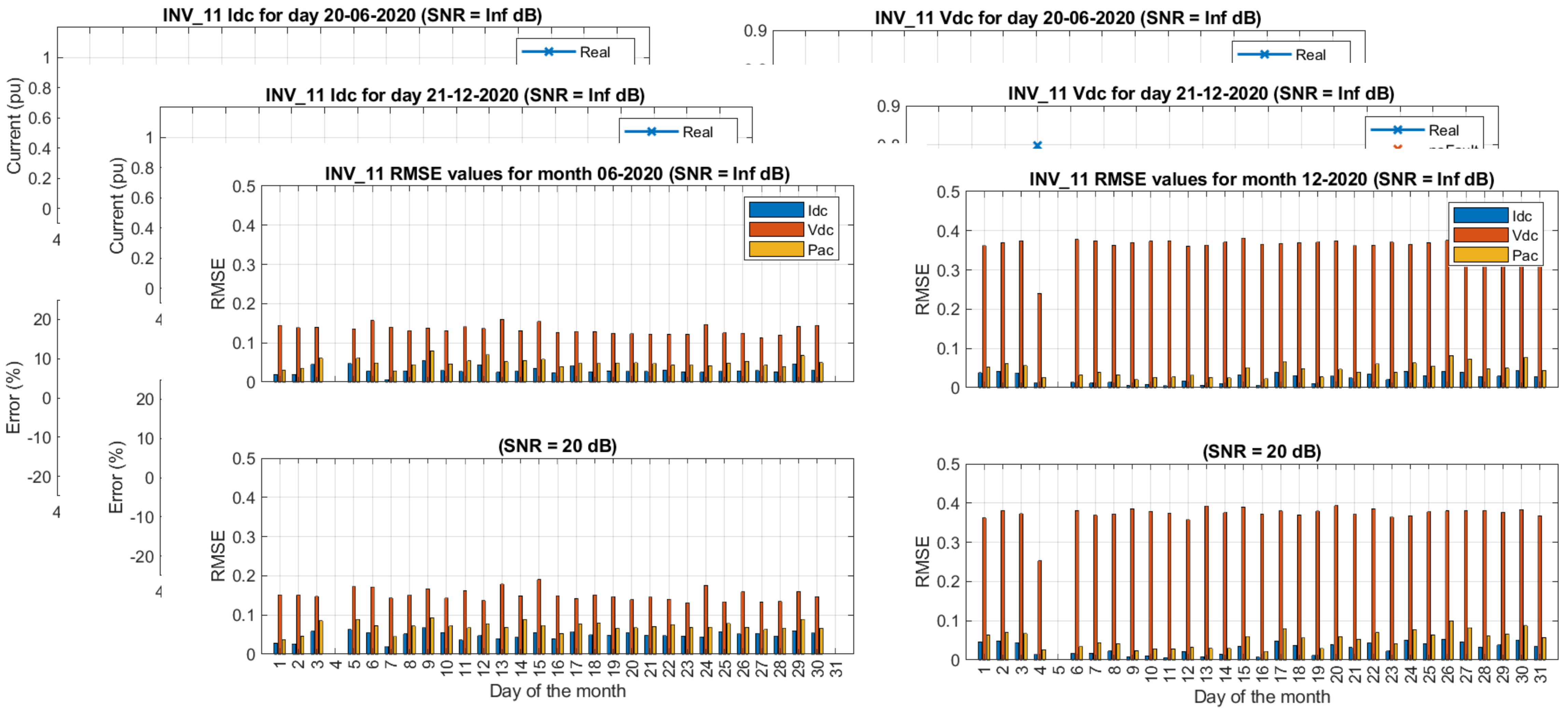


an Union
Regional
nt Fund

Agenda

- INESC TEC
- Digital Twin of PV Inverters
  - Introduction
  - Definition
  - Simulation and validation
  - Fault classification
  - Conclusion
- Maintenance Policy Recommendations
- References

How to validate our model [5]?



European Union
European Regional Development Fund

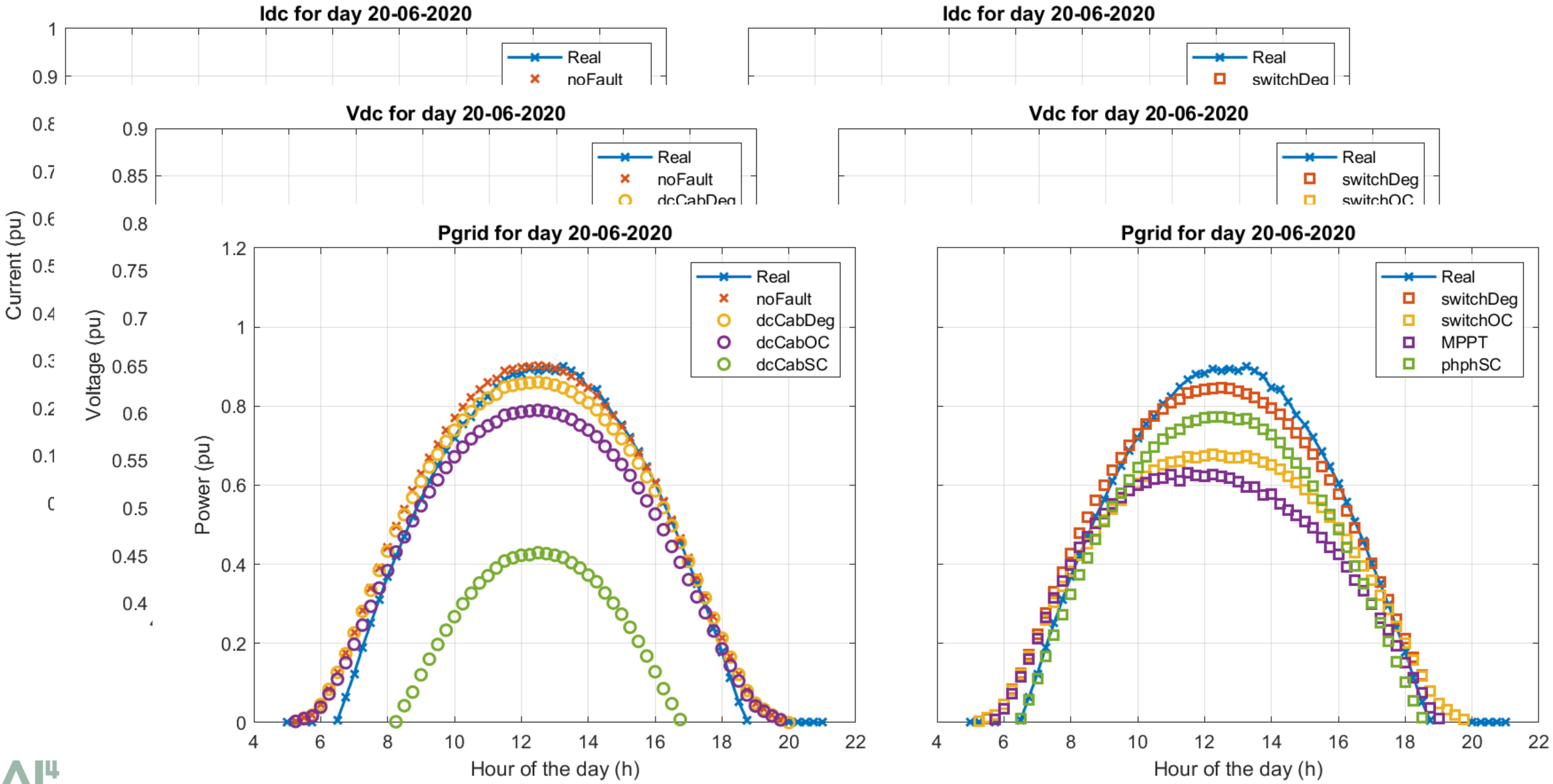
How to generate the faults [6, 7]?

- Functions to control the current simulation **condition** of the inverter
  - **Randomly** selected of fault of the day, fault starting time, fault location, inverter under fault
  - Daily, weekly or monthly **periodicity**
- Degradation **evolution** of dcCabDeg included

faultType	Condition	What happens?
00	noFault	Nothing really
01	dcCabDeg	Series resistance
02	dcCabOC	Cabe disconnection
03	switchDeg	Ron resistance
04	switchOC	Switch always open
05	dcCabSC	Short resistance between + and -
06	phphSC	Short resistance between phases
07	MPPT	Reference voltage campling (VdcMax)

European Union
European Regional Development Fund
@CDTIoficial

Fault-free and faulty data



2020
European Regional Development Fund
@CDTIoficial

Agenda

- INESC TEC
- Digital Twin of PV Inverters
  - Introduction
  - Definition
  - Simulation and data flow
  - Fault classification
  - Conclusion
- Maintenance Policy Recommendations
- References

AI4PV particular case

Datasets

Raw variables

Inverter Measurements	Current, Voltage, Power, etc.
Weather Measurements	Temperature, pyranometer measurements

Feature Engineering

Calendar Variables	Extracted from timeseries timestamps
Daily sky type *(reference: Clear Sky Model)*	Clear/ cloudy/ partly cloudy
***Lagged* Measurements**	Inverter and JB data at *t*-*15* and *t*-*30*
Statistical data *(variance, mean)*	Applied to pyranometers' measurements

Classifier

Model Creation Pipeline

Train-Test Split
(80% Train / 20% Test)

↓

Pick ML Technique
(Random Forest, LightGBM, XGBoost, Logistic Regression*)

↓

Feature Selection +
Hyperparameter Tuning
(using K-fold Cross Validation)

↓

Test on out-of-sample set
& compare with validation scores

Output

Multi-Class Classification

Output Classes:

1. No fault
2. DC cable degradation
3. DC cable open circuit
4. Switch degradation
5. Switch open circuit

Classification provided per sample, with 15 min. time-resolution

* **Note:** For Logistic Regression, the one-vs-rest approach was used to create the multi-class classification

@CDTIoficial

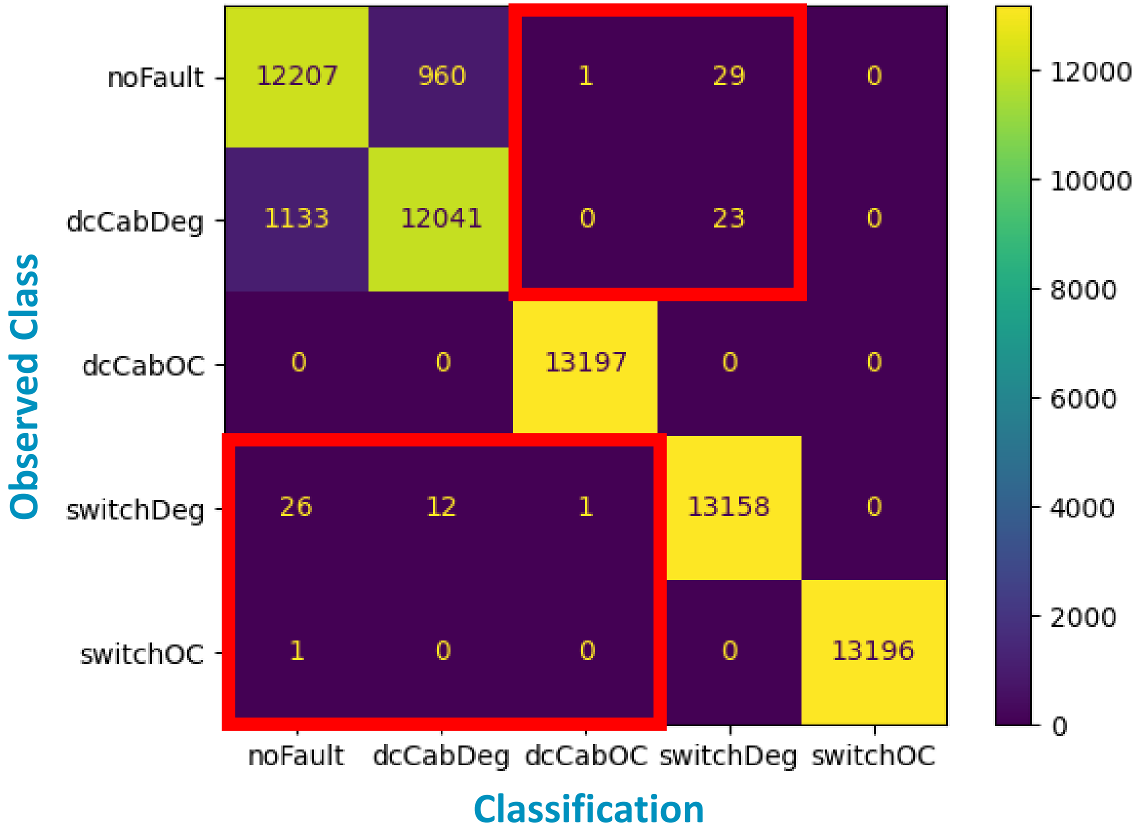
European Union
European Regional Development Fund

The best model: LightGBM

Preliminary model

inputs: calendar, weather, inverter, sky type

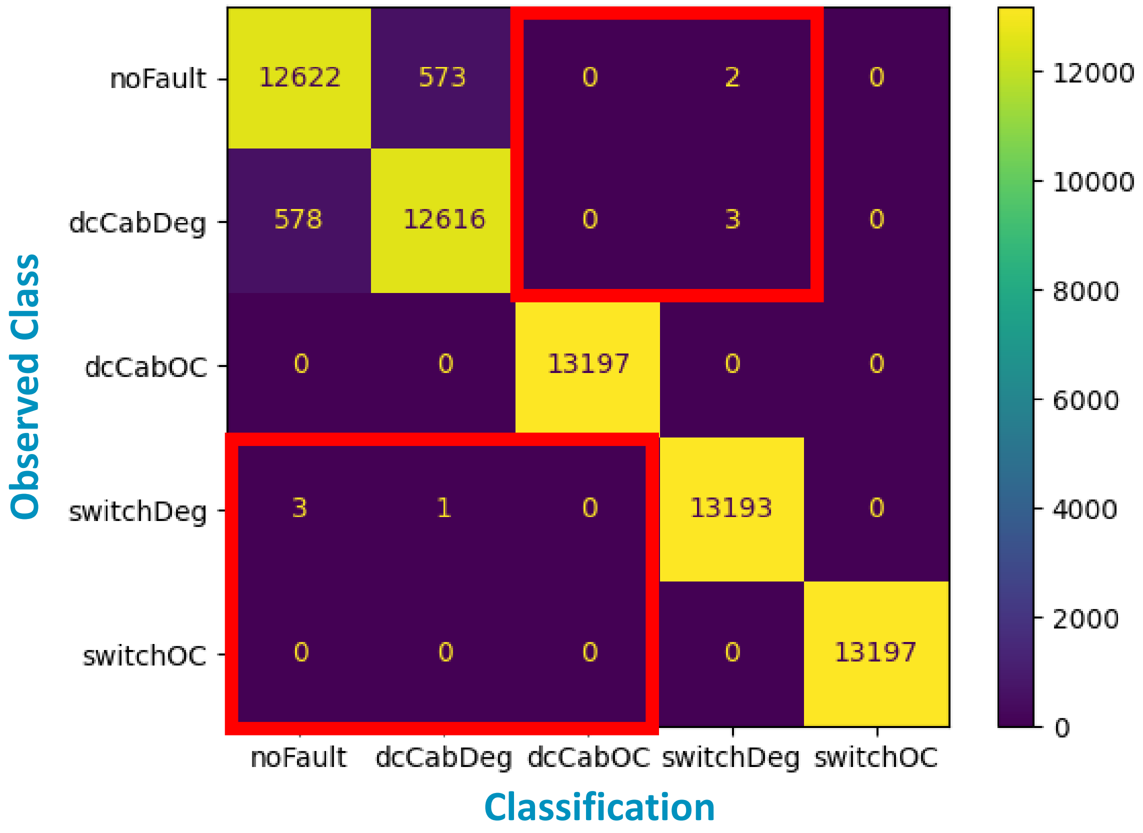
(Acc.: 96.7%; F1 macro: 0.967)



Best model

inputs: calendar, weather, inverter, sky type, **time, lags, statistics**

(Acc.: 98.2%; F1 macro: 0.982)

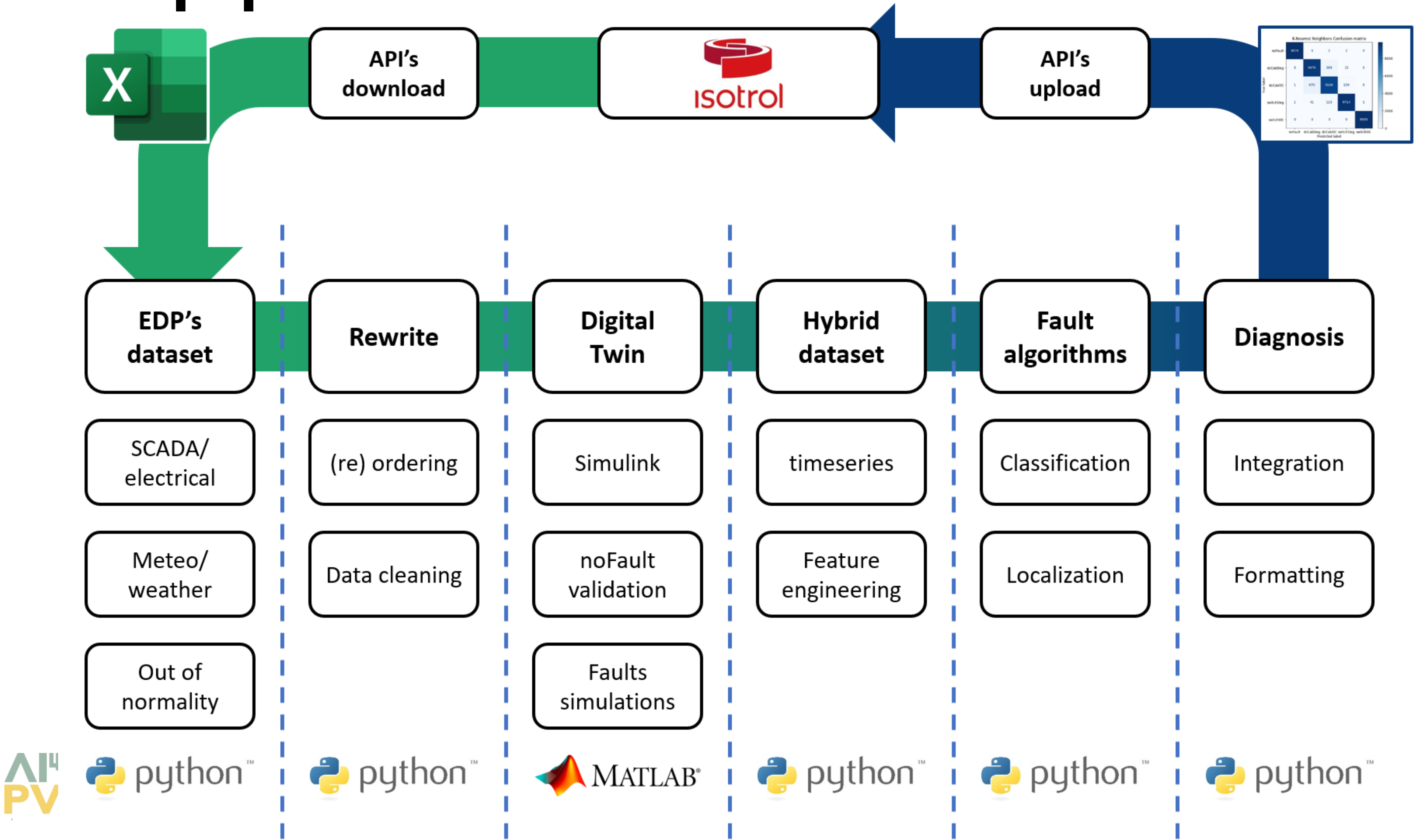


COMPETE 2020 PORTUGAL 2020 CDTI @CDTIoficial European Union European Regional Development Fund

Agenda

- INESC TEC
- Digital Twin of PV Inverters
  - Introduction
  - Definition
  - Simulation and validation
  - Fault classification
  - Conclusion
- Maintenance Policy Recommendations
- References

The pipeline



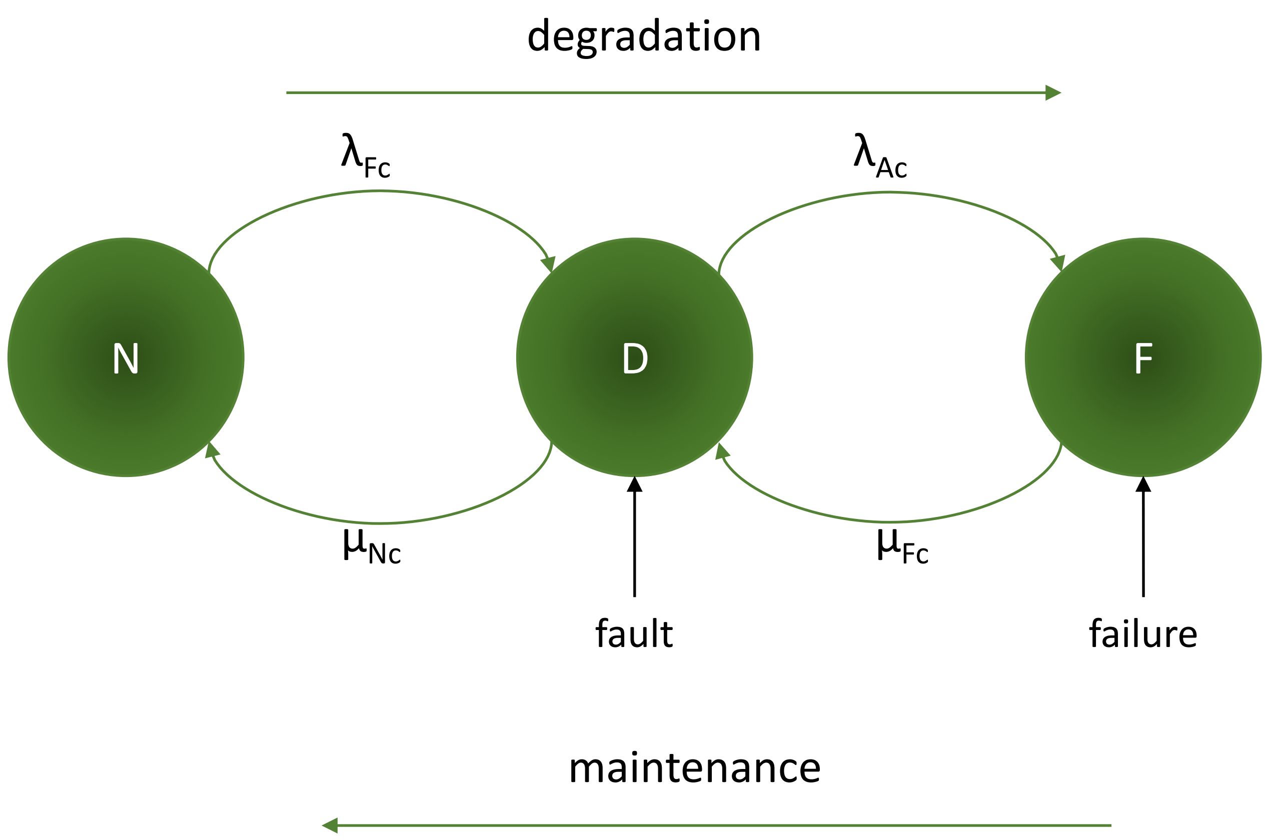
an Union
Regional
nt Fund

Agenda

- INESC TEC
- Digital Twin of PV Inverters
  - Introduction
  - Definition
  - Simulation and validation
  - Fault classification
  - Conclusion
- Maintenance Policy Recommendations
- References

Inverters Maintenance Recomendation

Markov Decision Process



Set of states:

- N: new equipment
- D: equipment with degradation
- F: equipment breakdown

Set of actions:

- No action
- Minor maintenance
- Major maintenance

Rewards:

- Irradiance
- Efficiency
- Maintenance costs

Failure Probability

Mean time between failures - MTBF:

$$MTBF = \frac{\sum total\ operational\ time}{number\ of\ failires}$$

Failure rate λ during day d:

$$\lambda(d) = \frac{1}{MTBF}$$

Failure occurrence: a non-homogeneous Poisson process with arrival rate $\lambda(d)$:

$$p_F(t_k) = 1 - e^{\lambda(d)\cdot\Delta t}$$

Reliability, the probability of the equipment working in perfect condition in the following t_k days.

Transition probabilities:

$p_k(s_j|s_i, a = 0) = p_F(t_k)$ (no maintenance action)

$p_k(s_j|s_i, a = \ ) = p^F(t_k)1_{/\sigma}$ (maintenance action level σ)

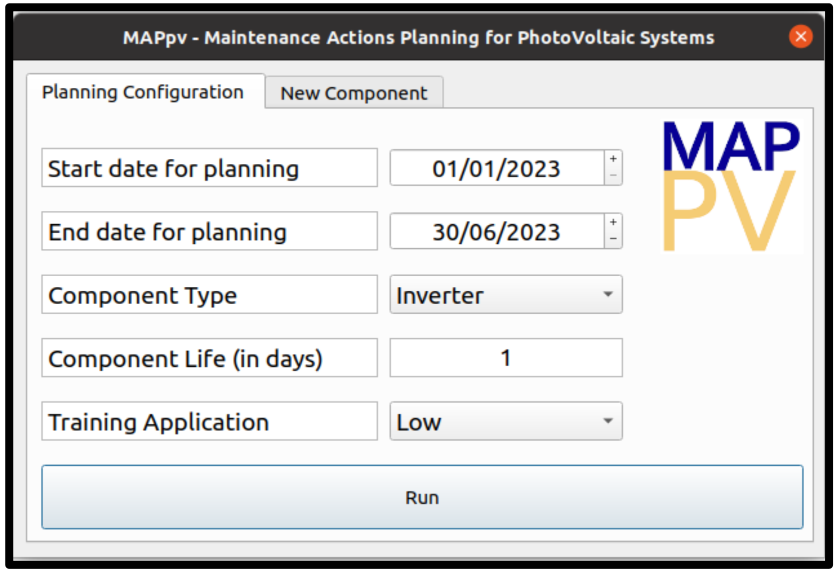
Reward:

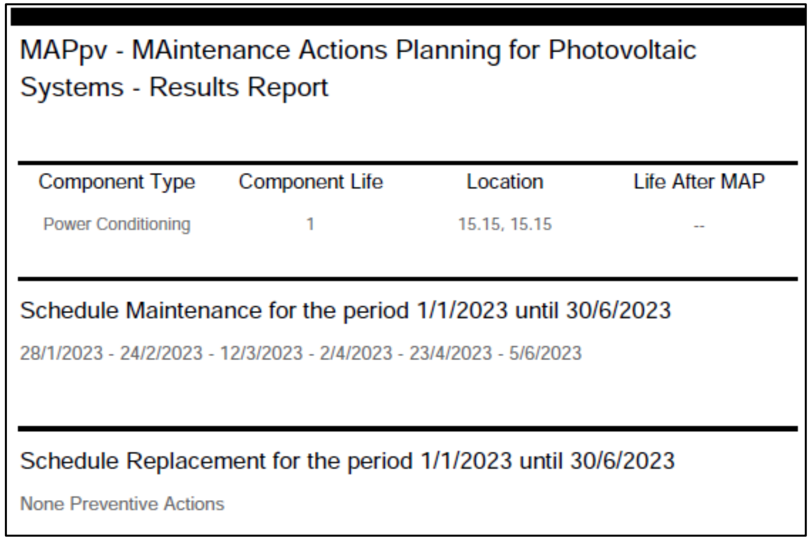
$$max\ Z = \sum_{t \in T} R(I^t|a_n^t) + \sum_{k \in K} E(s_k^t) - C(a_n^t)$$

Maintenance recomendations

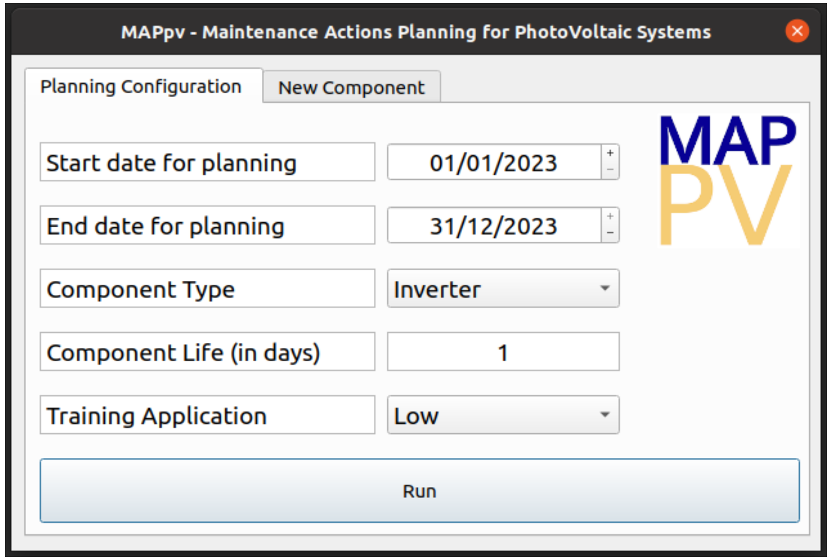
New component

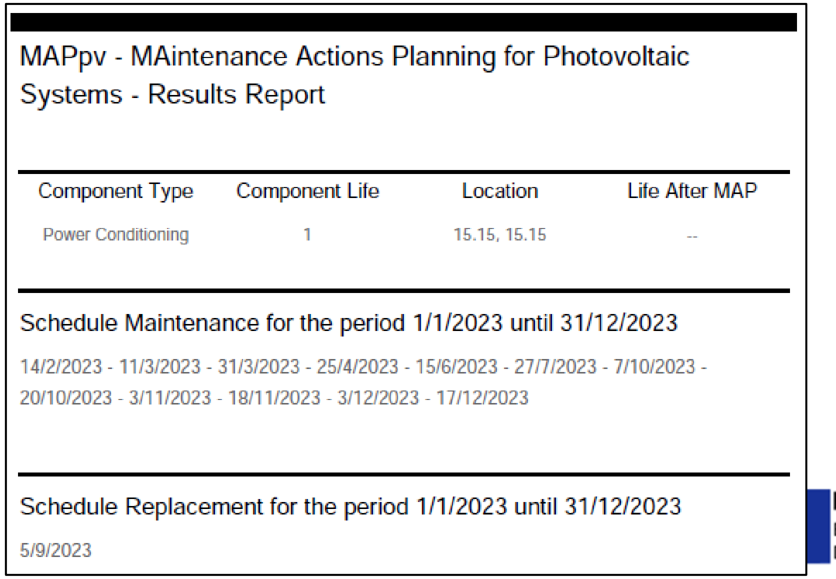
6 months planning





1 year planning



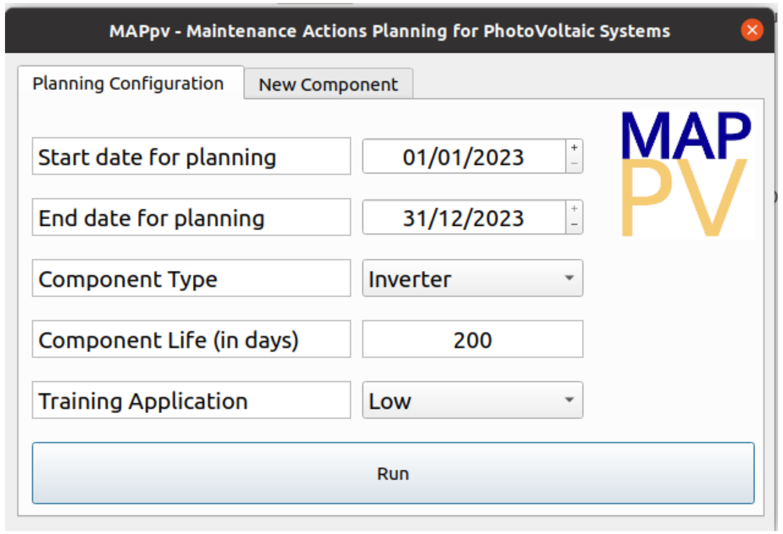


European Union
European Regional Development Fund

Maintenance recomendations

1 year planning

200 days old



MAPpv - MAintenance Actions Planning for Photovoltaic Systems - Results Report

Component Type	Component Life	Location	Life After MAP
Power Conditioning	200	15.15, 15.15	--

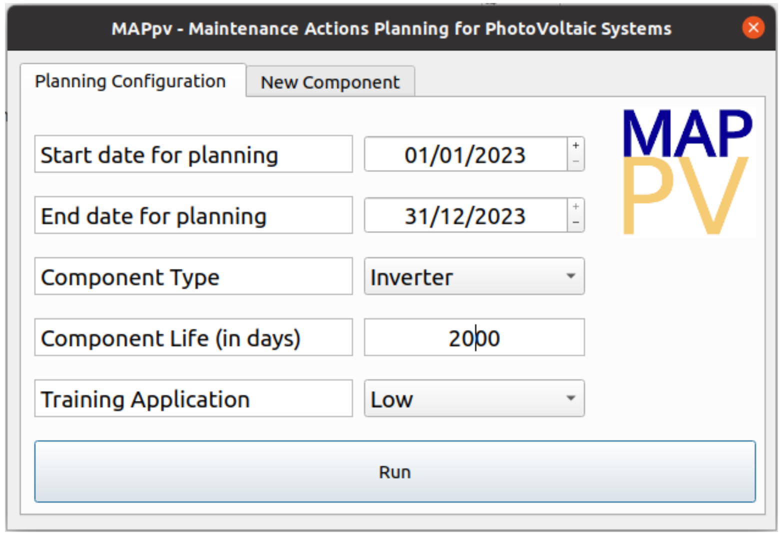
Schedule Maintenance for the period 1/1/2023 until 31/12/2023

27/1/2023 - 25/2/2023 - 16/3/2023 - 10/4/2023 - 30/5/2023 - 10/7/2023 - 21/8/2023 - 5/9/2023 - 25/9/2023 - 6/10/2023 - 20/10/2023 - 3/11/2023 - 18/11/2023 - 3/12/2023 - 18/12/2023

Schedule Replacement for the period 1/1/2023 until 31/12/2023

None Preventive Actions

2000 days old



MAPpv - MAintenance Actions Planning for Photovoltaic Systems - Results Report

Component Type	Component Life	Location	Life After MAP
Power Conditioning	2000	15.15, 15.15	--

Schedule Maintenance for the period 1/1/2023 until 31/12/2023

14/2/2023 - 10/3/2023 - 3/4/2023 - 24/4/2023 - 15/6/2023 - 26/7/2023 - 7/10/2023 - 20/10/2023 - 3/11/2023 - 18/11/2023 - 2/12/2023 - 17/12/2023

Schedule Replacement for the period 1/1/2023 until 31/12/2023

1/1/2023 - 5/9/2023

Agenda

- INESC TEC
- Digital Twin of PV Inverters
  - Introduction
  - Definition
  - Simulation and validation
  - Fault classification
  - Conclusion
- Maintenance Policy Recommendations
- References

References

[1] V. S. B. Kurukuru, A. Haque, M. A. Khan, S. Sahoo, A. Malik, and F. Blaabjerg, “A Review on Artificial Intelligence Applications for Grid-Connected Solar Photovoltaic Systems,” Energies, vol. 14, no. 15, p. 4690, Aug. 2021, doi: 10.3390/en14154690.
[2] M. Grieves, “Virtually intelligent product systems: Digital and physical twins,” American Institute of Aeronautics and Astronautic. Complex Systems Engineering: Theory and Practice, pp. 175-200, 2019.
[3] Barbara Rita Barricelli, Elena Casiraghi, Daniela Fogli, “A Survey on Digital Twin: Definitions, Characteristics, Applications, and Design Implications,” IEEE Access, no. 7, pp. 167653-167671, 2019.
[4] R. Isermann, Fault-Diagnosis Applications: Model-Based Condition Monitoring Actuators, Drives, Machinery, Plants, Sensors, and Fault-Tolerant Systems, 1st ed. Springer Publishing Company, Incorporated, 2011.
[5] A. E. Lazzaretti, C. H. d. Costa, M. P. Rodrigues, G. D. Yamada, G. Lexinoski, G. L. Moritz, E. Oroski, R. E. d. Goes, R. R. Linhares, P. C. Stadzisz, J. S. Omori, and R. B. d. Santos, “A monitoring system for online fault detection and classification in photovoltaic plants,” Sensors, vol. 20, no. 17, 2020.
[6] G. D. Lorenzo, R. Araneo, M. Mitolo, A. Niccolai, and F. Grimaccia, “Review of O&M practices in pv plants: Failures, solutions, remote control, and monitoring tools,” IEEE Journal of Photovoltaics, vol. 10, no. 4, pp. 914–926, 2020.
[7] P. Jain, J. Poon, J. P. Singh, C. Spanos, S. R. Sanders, and S. K. Panda, “A digital twin approach for fault diagnosis in distributed photovoltaic systems,” IEEE Transactions on Power Electronics, vol. 35, no. 1, pp. 940–956, 2020.

Thanks for your attention!

Don’t forget to ask your question in the chat…

COMPETE 2020
PORTUGAL 2020
@CDTIoficial
European Union
European Regional Development Fund

AI to optimize PV cleaning schedule

- Christian Verrecchia (R&D Engineer)

by EDP & CTG

AI to optimize PV cleaning schedule

Christian Verrecchia – R&D Engineer at EDP NEW

COMPETE 2020 PORTUGAL 2020 CDTI @CDTIoficial European Union European Regional Development Fund

Agenda

- Introducing EDP NEW
- AI4PV Cleaning module
- Results

COMPETE 2020 PORTUGAL 2020 CDTI @CDTIoficial European Union European Regional Development Fund

Agenda

- Introducing EDP NEW
- AI4PV Cleaning module
- Results

EDP NEW, leading applied R&D in the energy sector

Working every day to invent the future of energy and contribute to a carbon-free society

Our Mission Design the energy future, today

Our Vision A strong purpose and the best team to lead energy R&D

Where we started → ...our path so far... → Where we are

Small, lean, agile → Growing, widening, maturing... → Accelerating, delivering

Since 2015...creating a reputation in EU Energy R&D scene

R&D provides visibility for the future... and helps carve a leading path

36 Ongoing projects

35 M€ Secured Grant for EDP

20+ Pilots in EDP assets

#1 For-profit company in Portugal in EU R&D funding

251 Submitted Proposals

10 Consultancy projects

23% Hit rate in applications (vs 12% market)

15+ Collaborations with China

R&D@ EDP... Why?

R&D = anticipation

- R&D and public money = insightful look at future trends
- Opportunity to partner with academia, industrial & tech

Low-cost options

Public-funded projects have larger and more diffuse implementation timelines but offer an inexpensive stream of applied R&D

Future Talent

NEW enables technical-oriented training, providing highly skilled and talented people in leading-edge areas

Next step: Impact

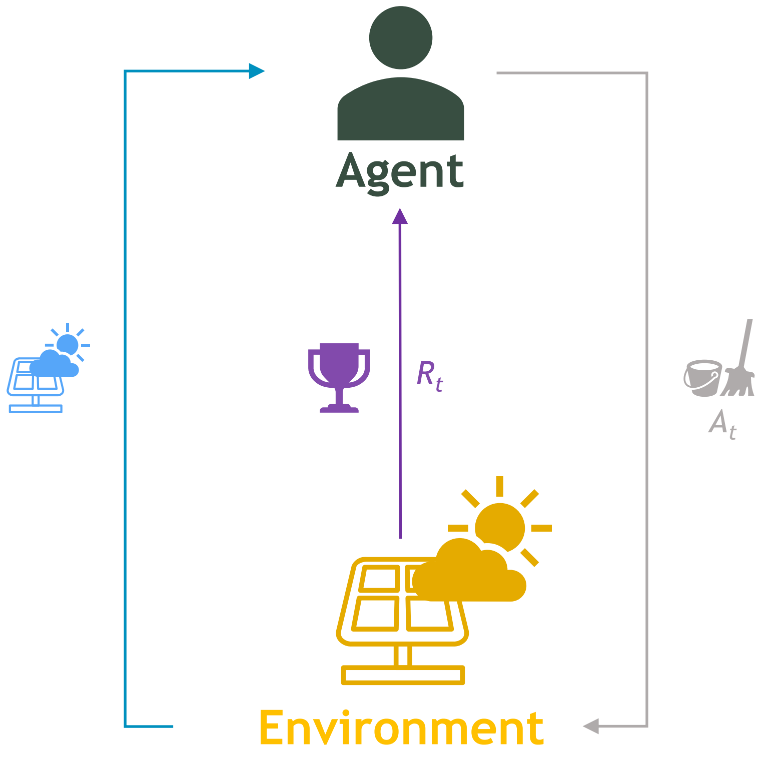
- Next step: create impactful solutions
- Liaising with EDP Innovation and DGU to productize and roll out tools to EDP's BUs

Agenda

- Introducing EDP NEW
- AI4PV Cleaning module
- Results

AI4PV's cleaning module: a dive into a Markov Decision Process

An MDP is a mathematical framework used for modelling decision-making problems where the outcomes are partly random and partly controllable.

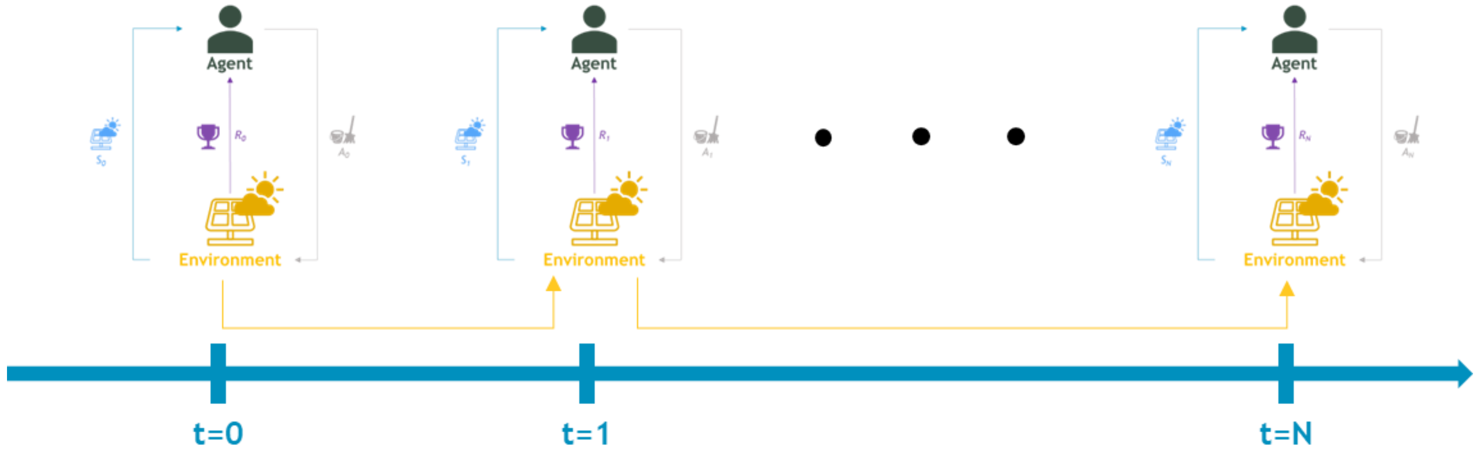


It can be defined as a tuple *(**S**, **A**, **T**, **R**, **γ**)*, where:

- ***S*** is a set of states,
- ***A*** is a set of actions,
- ***T*** is a transition function describing the probability of moving from one state to another after performing a certain action,
- ***R*** is a reward function assigning a scalar value to each state-action pair,
- ***γ*** is a discount factor controlling the trade-off between immediate and future rewards.

COMPETE 2020 PORTUGAL 2020 @CDTIoficial European Union European Regional Development Fund

AI4PV's cleaning module: States and Actions



The environment can be described as **Finite Horizon MDP** of length N simulating the whole lifetime of the PV park.

The **State** represent the level of the **Performance Ratio** (or **Soiling Rate**)

The **Actions** the agent can take is either to **Clean** (1) or **Not To Clean** the PV panels (0)

AI4PV's cleaning module: Transition probabilities

The dynamics of soiling loss are described by a **non-homogenous Markov chain** whose transition probabilities describe, for each time step, the likelihood of transitioning from one state to another, given a certain action.

These probabilities are **influenced by cleaning decisions** and two natural phenomena: **deposition of dust** on the panels **and rain events.**

In absence of cleaning, the transition probabilities can be written as:

$$p_k(SR_j|SR_i, a = 0) = p_R(t_k)p_{SR}(SR_j|SR_i, rain) + [1 - p_R(t_k)]p_{SR}(SR_j|SR_i, no\, rain)$$

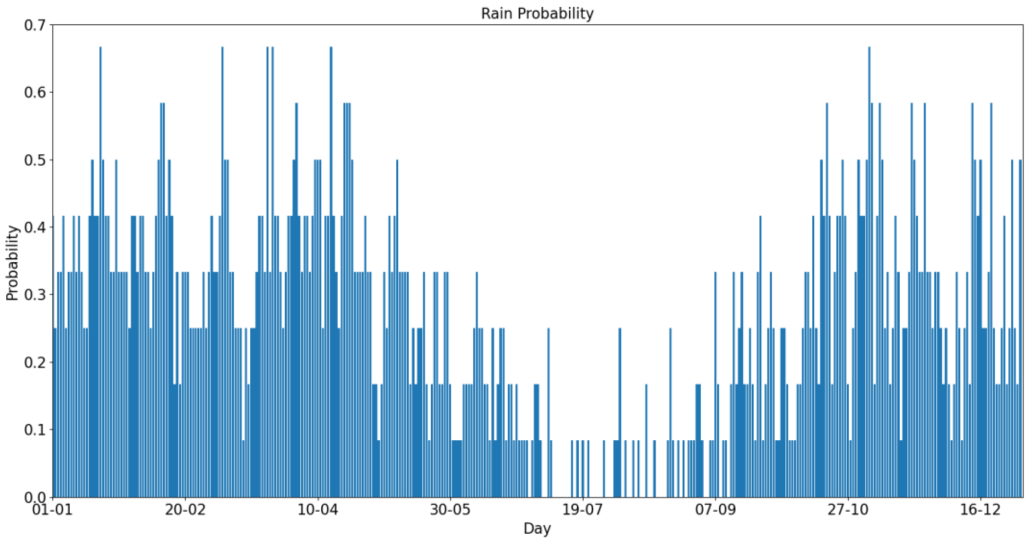
In the case of cleaning, we assume a perfect cleaning that results in the SR being set to zero. The transition probabilities of the SR when the action is to clean are given by:

$$p_k(SR_j|SR_i, a = 1) = \begin{cases} 1 & SR_j = 0 \\ 0 & SR_j \neq 0 \end{cases}$$

COMPETE 2020 PORTUGAL 2020 @CDTIoficial European Union European Regional Development Fund

AI4PV's cleaning module: Transition probabilities - no cleaning terms (rain event)

$p_R(t_k)$ It is the probability of rain in epoch k. Computed from historical weather data of the site at stake. A rain event is defined as such when the precipitation is above a certain threshold.



$p_{SR}(SR_j|SR_i, rain)$

Describes the cleaning effect of rain events. Computed on historical operational data of the PV park at stake.

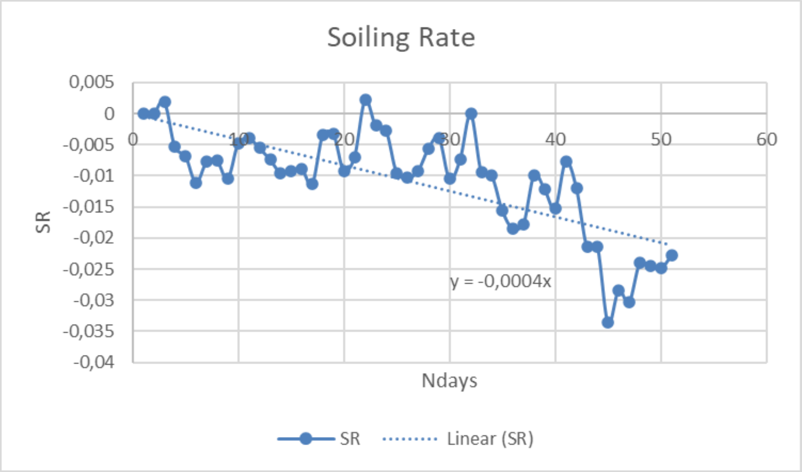
AI4PV's cleaning module: Transition probabilities - no cleaning terms (no rain event)

$$p_{SR}(SR_j|SR_i, no\ rain)$$

Describes the degradation of Performance ratio due to soiling.

Soiling was modelled using the **Gamma Process**, a commonly used distribution to describe degradation processes. The Gamma degradation process is characterized by a **shape parameter** (α), and a **scale parameter** (β), which determine the shape of the degradation curve and the rate at which the degradation occurs, respectively. **Average daily degradation was computed from historical data.**

$$f(x, \alpha, \beta, t) = \frac{\beta^{\alpha t} x^{\alpha t - 1} e^{-\beta x}}{\Gamma(\alpha t)}$$

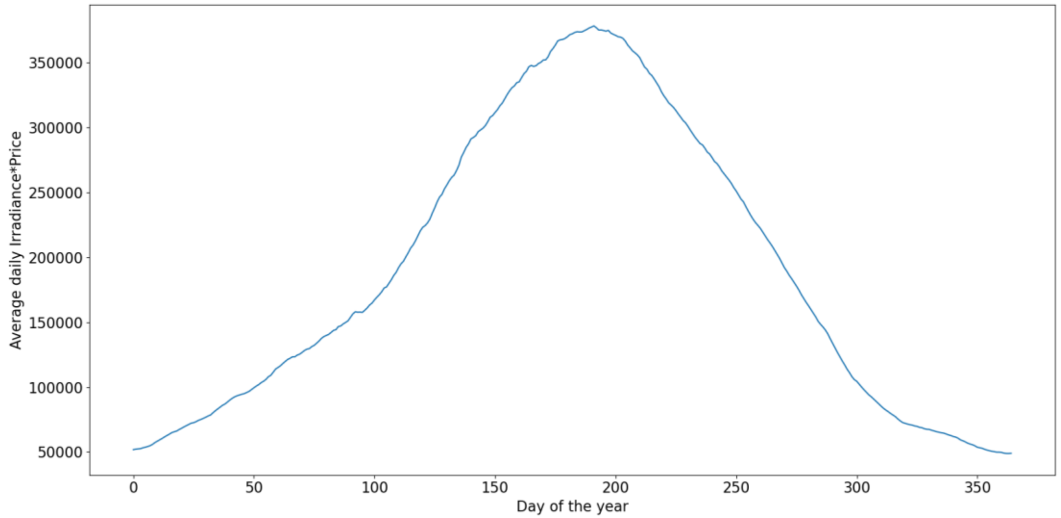


AI4PV's cleaning module: Reward

The reward is what the agent receives when taking a certain action At at time t, under the current state St. In the case of not cleaning the PV panels, the reward depends only on the current PR and the revenue associated with that.

$$r_k(SR_j|SR_i, a = 0) = -Area_{cell} \cdot Efficiency \cdot SR_i \cdot N \cdot E(DNI(t_k), price(t_k)))$$

To capture the interdependence between price and DNI, instead of sampling DNI and price separately, a set of hourly products of DNI and price, are described by the PD-day distribution, retrieved from historical values.



When cleaning the reward is:

$$r_k(SR_j|SR_i, a = 1) = -cost_{cleaning}$$

AI4PV's cleaning module: Optimal policy

The aim of this tool is to **find a cleaning policy that minimizes the total loss** (which consider both the cost of maintenance (cleaning) and revenue losses due to soiling.

However, this cost is subject to a number of stochastic phenomena: soiling rates vary with weather conditions, rain occurrences are random with seasonally-varying statistical properties, and the effectiveness of cleaning operations (particularly rain) may not be deterministic. All these phenomena were modelled using the probabilities introduced before.

Thus, the objective function is:

$$\min_{\pi} \sum_{k=0}^{N} R_k(S_k^d, \mu_{k-1}(\ S_{k-1}^d))$$

where the cleaning policy is denoted as $\pi = (\mu_0, \mu_1, \ldots . \mu_N)$ which is a sequence of actions the agent must take to minimize the revenue losses.

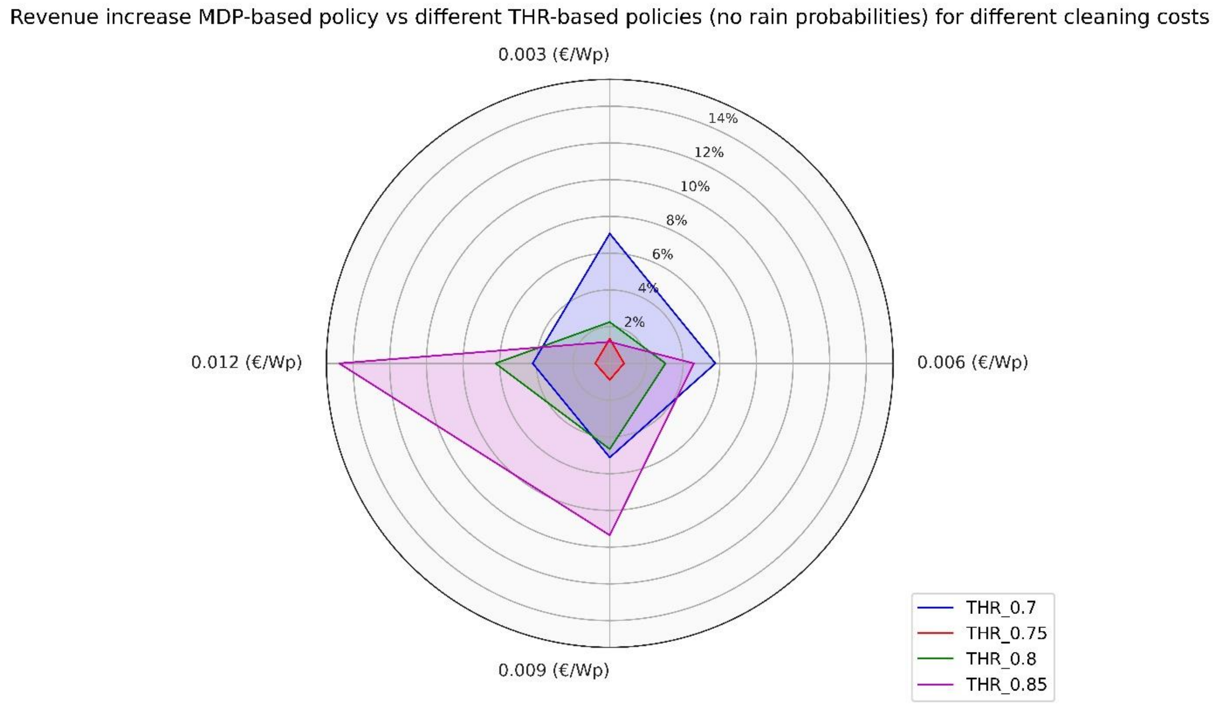
AI4PV
COMPETE 2020 PORTUGAL 2020 CDTI @CDTIoficial European Union European Regional Development Fund

Agenda

- Introducing EDP NEW
- AI4PV Cleaning module
- Results

CBA AI4PV cleaning policy vs Traditional methods

We compared our method (not considering rain probabilities) against threshold-based (on the PR) cleaning policy for different values of cleaning costs and thresholds.



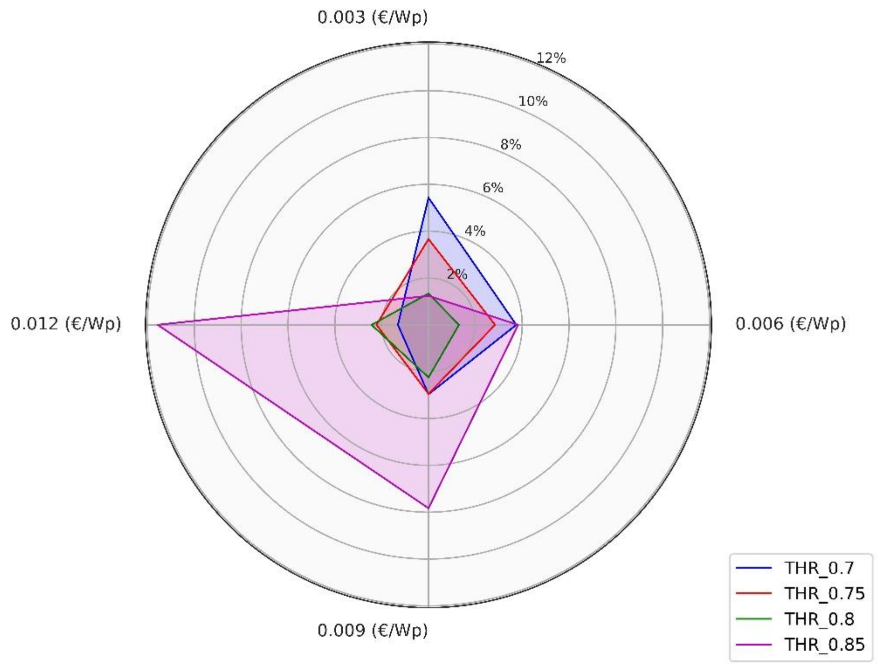
i.e. for a cleaning cost of 0.003€/Wp, the proposed method is:

- **7% more profitable** than the THR-based with **THR=0.7**;
- **2% more profitable** than the THR-based with THR=0.75;
- **1% more profitable** than the THR-based with THR=0.8;
- **1% more profitable** than the THR-based with **THR=0.85**;

AI4PV

CBA AI4PV cleaning policy vs Traditional methods

We compared our method (considering rain probabilities) against threshold-based (on the PR) cleaning policy for different values of cleaning costs and thresholds.

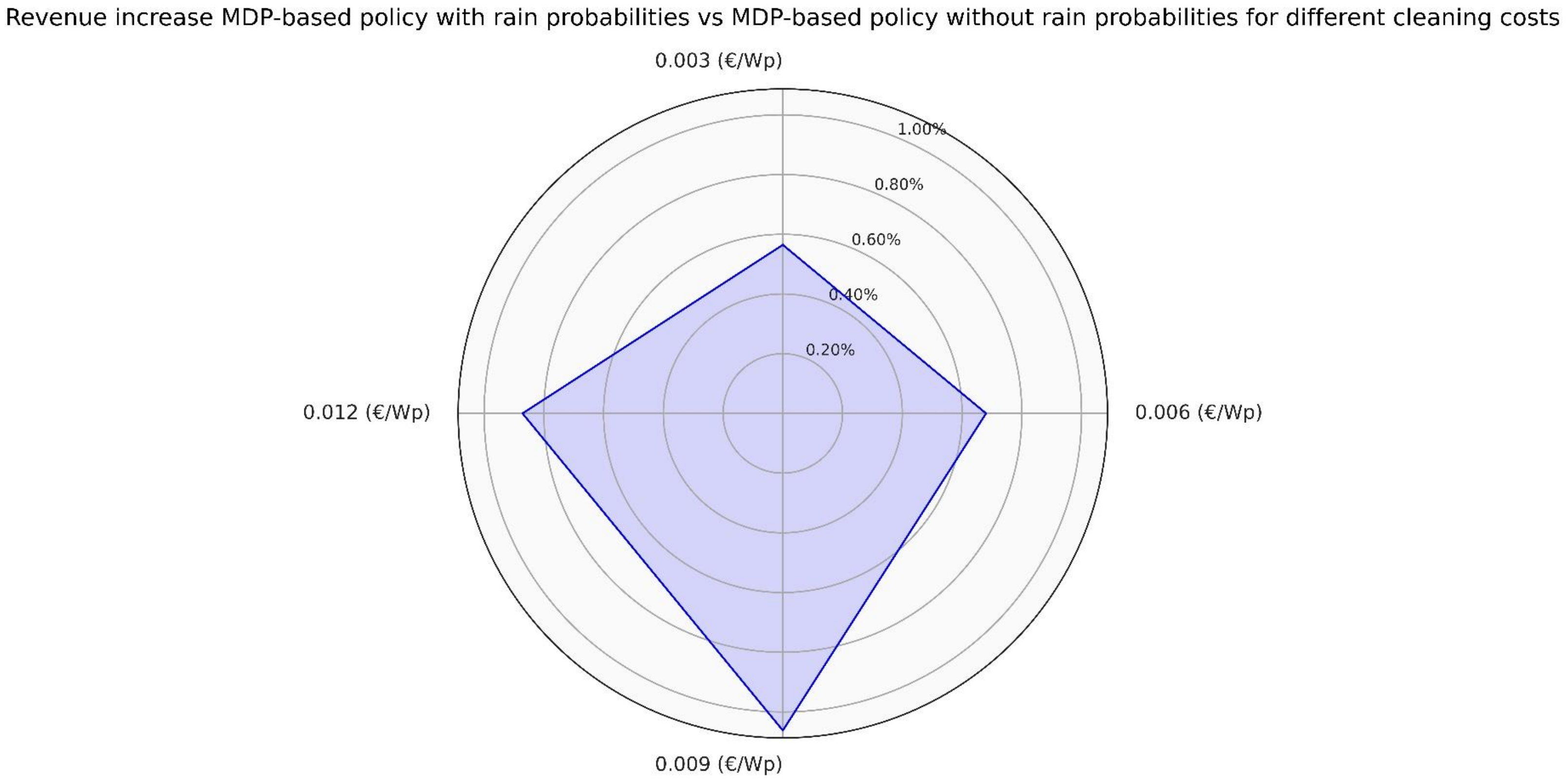


i.e. for a cleaning cost of 0.003€/Wp, the proposed method is:

- **4% more profitable** than the THR-based with **THR=0.7**;
- **4% more profitable** than the THR-based with THR=0.75;
- **2.5% more profitable** than the THR-based with THR=0.8;
- **1% more profitable** than the THR-based with **THR=0.85**;

CBA MDP-based cleaning

Considering rain probabilities into the model can bring additional revenues to plant owners, which from a minimum of 0.6% to a maximum of 1% depending on the cost of cleaning.



Thanks for your attention!

Don’t forget to ask your question in the chat…

COMPETE 2020 | PORTUGAL 2020 | CDTI @CDTIoficial | European Union European Regional Development Fund