Cloud-based decision support system for operation and maintenance in photovoltaic systems

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1C4PV One intelligent cloud for PV Assets Diagnosis and Maintenance

INTRODUCTION

- A key enabling factor for the **future uptake** of the **photovoltaic (PV)** technological value chain is the **reduction** of the **levelized cost of electricity (LCoE)**
- This can be achieved by **improving lifetime PV performance** and **reducing operation and maintenance (O&M) costs**

$$\downarrow LCoE(€/MWh) = \frac{(CapEx) + O\&M \downarrow}{(Energy\ yield) \uparrow}$$

BACKGROUND & OBJECTIVE

Problem statement

- Performance losses and failures can occur during the operational lifetime of PV systems due to different factors
- Such faults decrease the output power of the system and also degrade the PV module properties
- The average **recoverable energy** of a PV plant is **5.27%** [1]
- **Recoverable income** for a typical 16.1MW plant is **€160000/year** [1]

Motivation

- Early detection of faults and performance problems
- Quantification of energy losses
- Suggestion of field actions and optimization of O&M activities

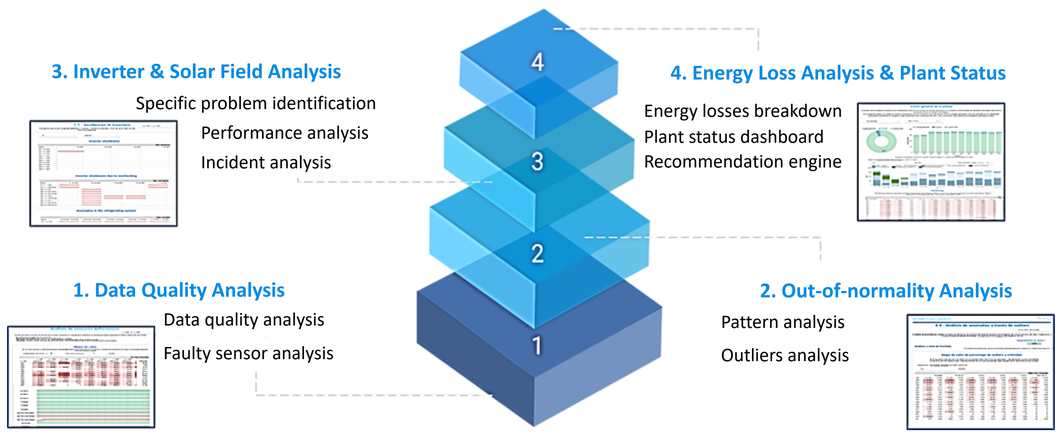
SOLUTION

Scope

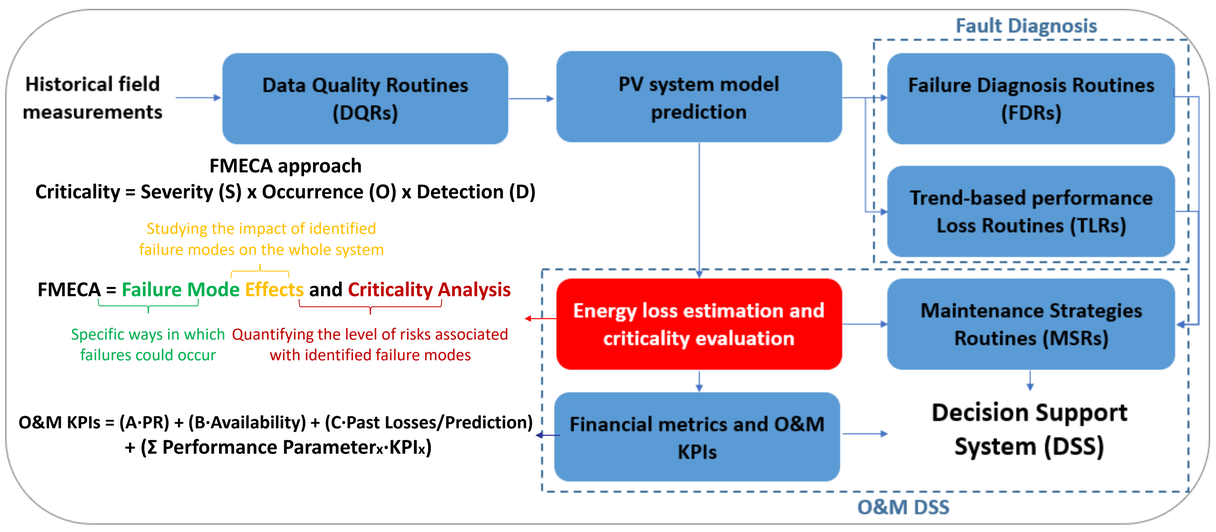
- Development of a **Decision Support Systems (DSS)** for **PV assets diagnosis** and **maintenance**

Approach

- Modularized architecture for autonomous operation
- Statistical, machine learning (ML) and artificial intelligence (AI) algorithms for data cleansing (Module 1), outliers' analysis (Module 2), PV system modeling and problem detection (Module 3), energy loss analysis and plant status (Module 4)



- Cloud-based solution that provides recommendations of actionable decisions to resolve detected underperformance issues

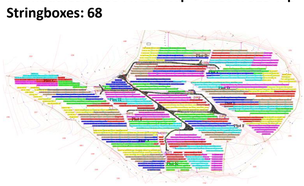


[1] A. Livera, M. Theristis, L. Micheli, E. F. Fernández, J. S. Stein and G. E. Georghiou, "Operation and Maintenance Decision Support System for Photovoltaic Systems," in IEEE Access, vol. 10, pp. 42481-42496, 2022, doi: 10.1109/ACCESS.2022.3168140

BENCHMARKING

- Historical field measurements over a 1-year period (January 2021 - December 2021) from a 10 MWp test PV plant installed in the Mediterranean region

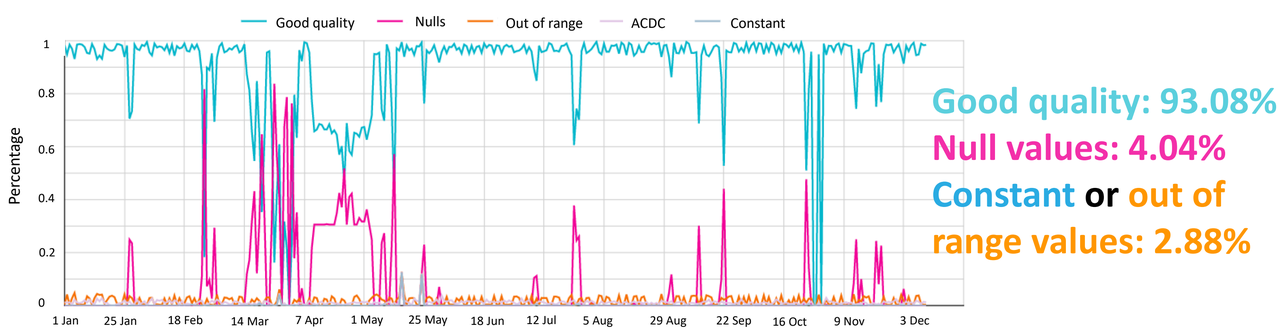
Nominal Power: 10.09 MWp
Inverters: 9 x 1000 kW + 1 x 630kW
PV modules: 36064 x 260 Wp + 2280 x 315 Wp
Stringboxes: 68



RESULTS

Data quality

- The most important data related issues took place in March-April

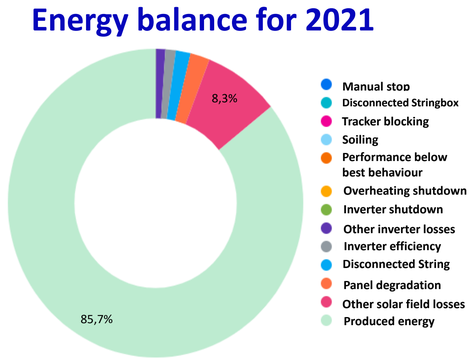


Good quality: 93.08%
Null values: 4.04%
Constant or out of range values: 2.88%

Energy loss analysis

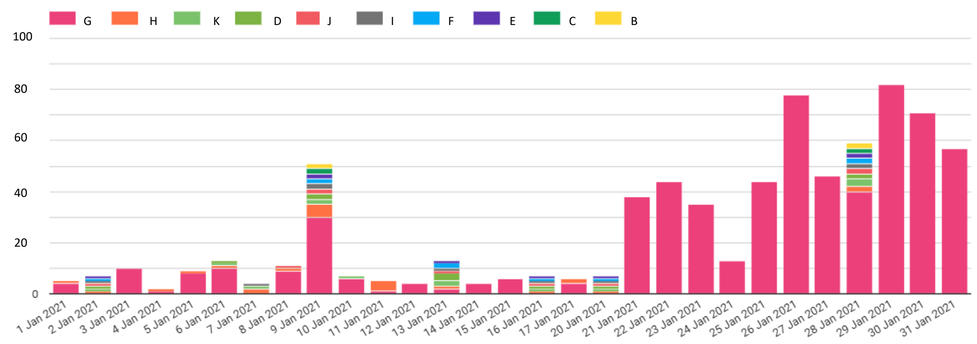
- Produced energy: 12586 MWh • Lost energy: 2100 MWh (14.30%)

Inverter & solar field analysis

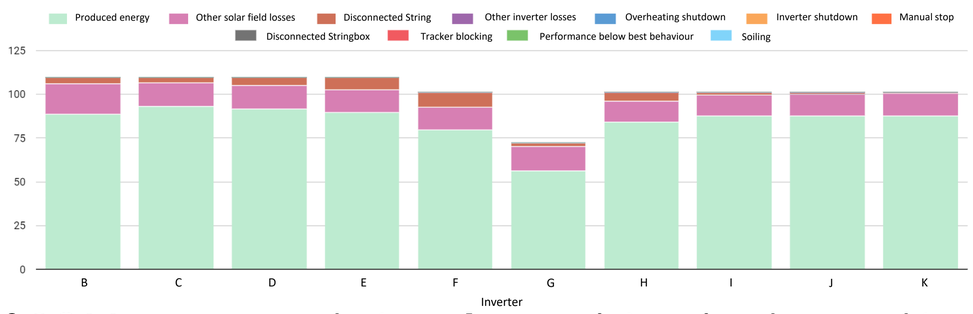


Group	Location	Type of losses	Losses (MWh)	Percentage
Total theoretical energy			14686	100%
Produced Energy			12586	85.70%
Nominal losses	Inverter	Inverter efficiency	167	1.14%
	Solar field	Panel degradation	313	2.13%
Underperformance losses	Inverter	Other performance inverter	147	1.00%
	Solar field	Performance below best behaviour	0.4	0%
		Other performance solar field	1226	8.34%
Incidences	Inverter	Shutdowns	6.5	0.05%
		Manual stop	0	0%
		Overheating	0.5	0%
		Curtailment temperatura	0	0%
	Solar field	Stringbox disconnections	0	0%
		String disconnections	238	1.62%
		Soiling	0	0%
		Tracker blocking	0	0%

- Most alarms at Inverter G, which was the worst performing inverter



Inverter	Energy (MWh)
B	109.69
E	109.68
D	109.64
C	109.63
F	101.19
K	101.17
I	101.17
H	101.10
J	101.08
G	72.41
Total	**1,016.75**



- List of O&M recommendations for resolving the detected incidents

Inverter	Subsystem	Incident detected	Start date	End date	Days	Recognized	Solved	Criticality
E	Strings	Check subsystem Strings due to String Shutdown in Stringbox E_CB6 (WARNING)	3 Apr 2021	20 May 2021	43	No	No	
D	Strings	Check subsystem Strings due to String Shutdown in Stringbox D_CB2 (WARNING)	6 Jul 2021	19 Aug 2021	43	No	No	
I	Strings	Check subsystem Strings due to String Shutdown in Stringbox I_CB4 (WARNING)	3 Apr 2021	16 May 2021	38	No	No	
F	Strings	Check subsystem Strings due to String Shutdown in Stringbox F_CB2 (WARNING)	9 Jul 2021	20 Aug 2021	38	No	No	
J	Strings	Check subsystem Strings due to String Shutdown in Stringbox J_CB1 (WARNING)	1 Jan 2021	31 Jan 2021	30	No	No	
G	Strings	Check subsystem Strings due to String Shutdown in Stringbox G_CB5 (WARNING)	31 Oct 2021	29 Nov 2021	25	No	No	
D	Strings	Check subsystem Strings due to String Shutdown in Stringbox D_CB4 (WARNING)	30 Aug 2021	27 Sep 2021	25	No	No	
E	Strings	Check subsystem Strings due to String Shutdown in Stringbox E_CB6 (WARNING)	26 Feb 2021	24 Mar 2021	21	No	No	
H	Global	Check Inverter due to deterioration between 2.3% and 3%	5 May 2021	5 Jul 2021	40	No	No	
K	Strings	Check subsystem Strings due to String Shutdown in Stringbox K_CB4 (WARNING)	6 Mar 2021	24 Mar 2021	16	No	No	
K	Strings	Check subsystem Strings due to String Shutdown in Stringbox K_CB1 (WARNING)	2 Jan 2021	18 Jan 2021	11	No	No	
J	Strings	Check subsystem Strings due to String Shutdown in Stringbox J_CB3 (WARNING)	14 Sep 2021	27 Sep 2021	12	No	No	
J	Inverter	Check subsystem Inverter due to Inverter Shutdown (WARNING)	29 Jul 2021	5 Aug 2021	4	No	No	

- **Approximately 7% of lost energy** production **could be recovered** by performing corrective actions [1]

CONCLUSIONS

- A cloud-based DSS platform for O&M cost reduction and revenue optimization was developed in this work
- It incorporates automated functions for data quality, problem and fault detection, energy loss analysis and plant status
- The DSS provides O&M recommendations for improved PV production

Acknowledgements

This work was funded by the 1C4PV project. Project 1C4PV is supported under the umbrella of SOLAR-ERA.NET Cofund by the Centro para el Desarrollo Tecnológico Industrial (CDTI), the Scientific and Technological Research Council of Turkey and the Research and Innovation Foundation (RIF) of Cyprus. SOLAR-ERA.NET is supported by the European Commission within the EU Framework Programme for Research and Innovation HORIZON 2020 (Cofund ERA-NET Action, N° 691664).
TEGNATIA ENERJI ÜRETIM SAN. VE TIC. is kindly acknowledged for providing the field data of the test PV plant.