Automatic Failure Detection and Techno-economic Prioritization for PV System Portfolios

Dr. Björn Müller
Eduardo Sarquis
Jefferson Bor

10.2023, Izmir

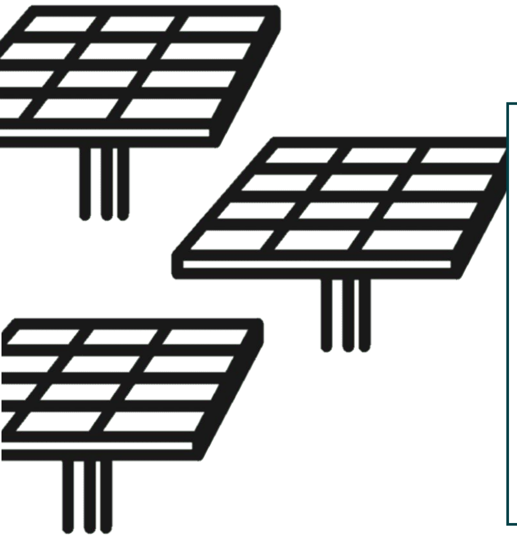
published in WCPEC-8 - TOPIC 4.3: Operation, Performance and Maintenance of PV Systems

intelligize your solar power
enmova

01 Automatic Failure Detection

intelligize your solar power
enmova

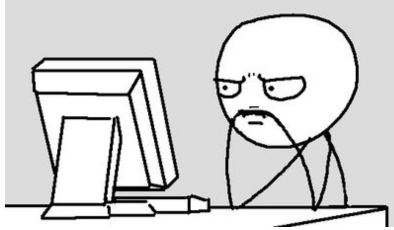
Monitoring of PV systems



PV systems' monitoring data

Operations center

Monitoring team



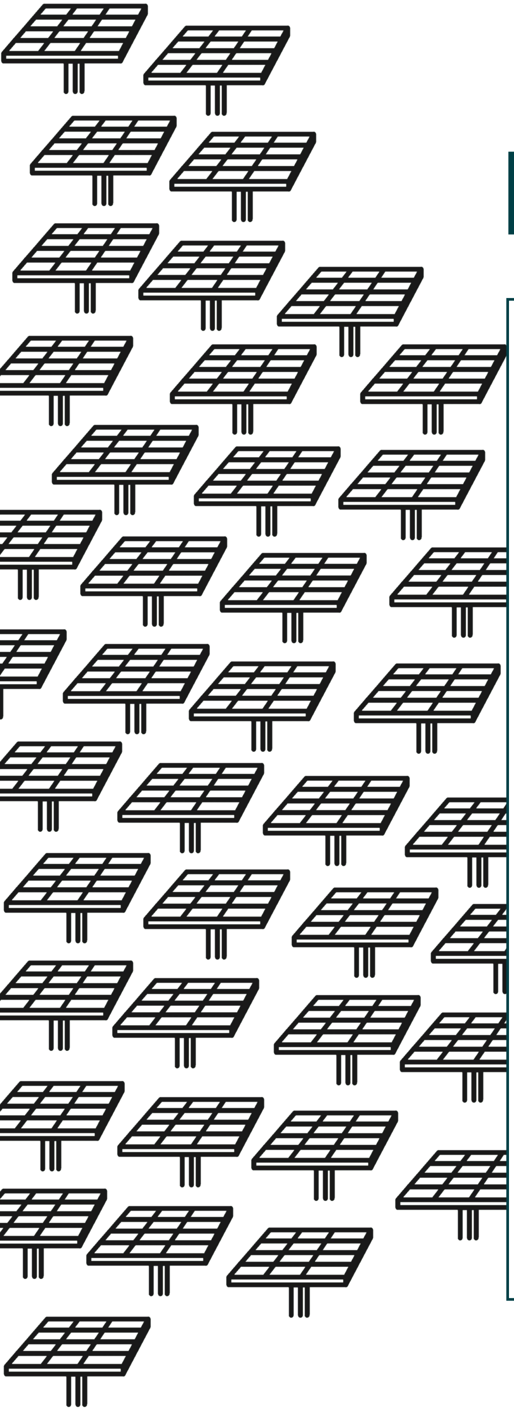
- Data analysis
- Performance assessment
- Fault detection

Tickets for the maintenance team

intelligize your solar power

enmova

Expansion requires automation

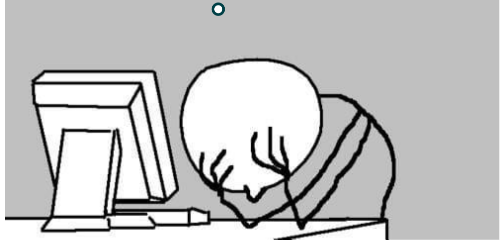


PV systems' monitoring data

This is a lot!

Operations center

Monitoring team



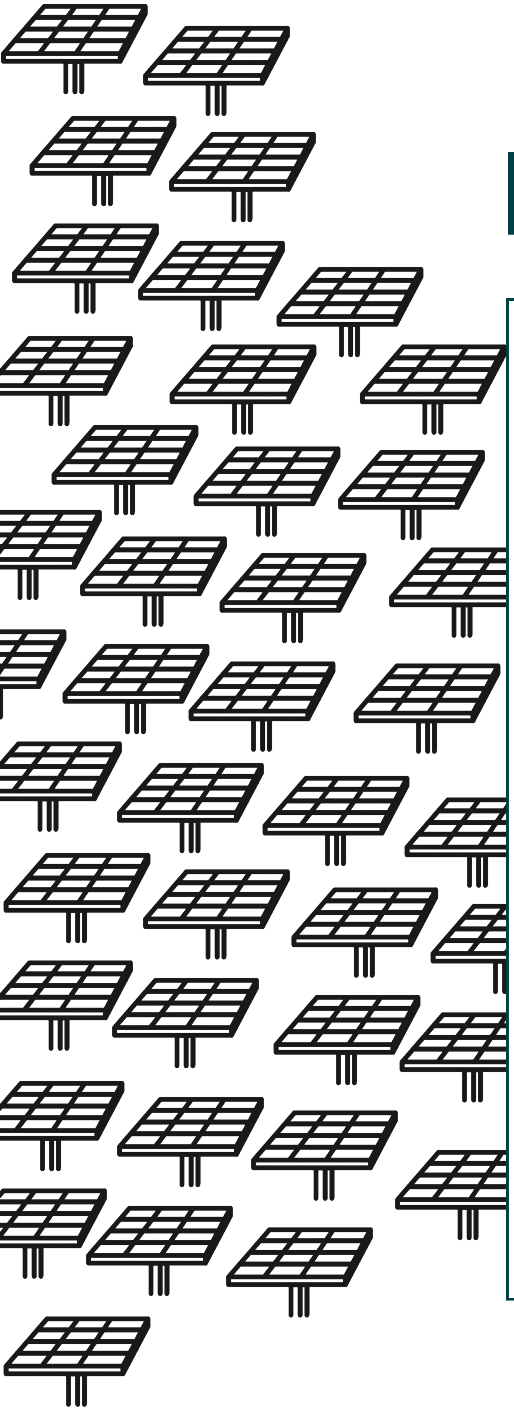
- Data analysis
- Performance assessment
- Fault detection

Tickets for the maintenance team

intelligize your solar power

enmova

Expansion requires automation

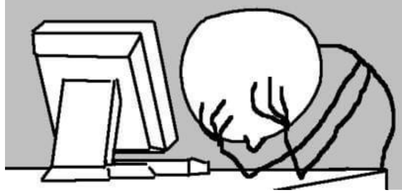


PV systems' monitoring data

This is a lot!

Operations center

Monitoring team



- Data analysis
- Performance assessment
- Fault detection

Tickets for the maintenance team

Challenges

intelligize your solar power
enmova

Objective

- Develop an automatic fault detection system
  - suitable for the data available in commercial systems
  - grounded in expert knowledge combined with statistical and ML methods
- Validate its performance under real operating conditions
  - monitoring data from commercial systems
  - conventional monitoring tickets

Field Data Available

- Portfolio of rooftop systems in Germany
  - 150 kWp average installed capacity
  - 25 kW string inverters
- The data collected by the monitoring system
  - power, voltage, and current at the inverters' input and output,
  - POA irradiance.
- Daily maintenance tickets created by the monitoring team
  - 5 years history

Not 1 but 9

Nine algorithms that analyze different aspects of the PV system in search of abnormal behavior.

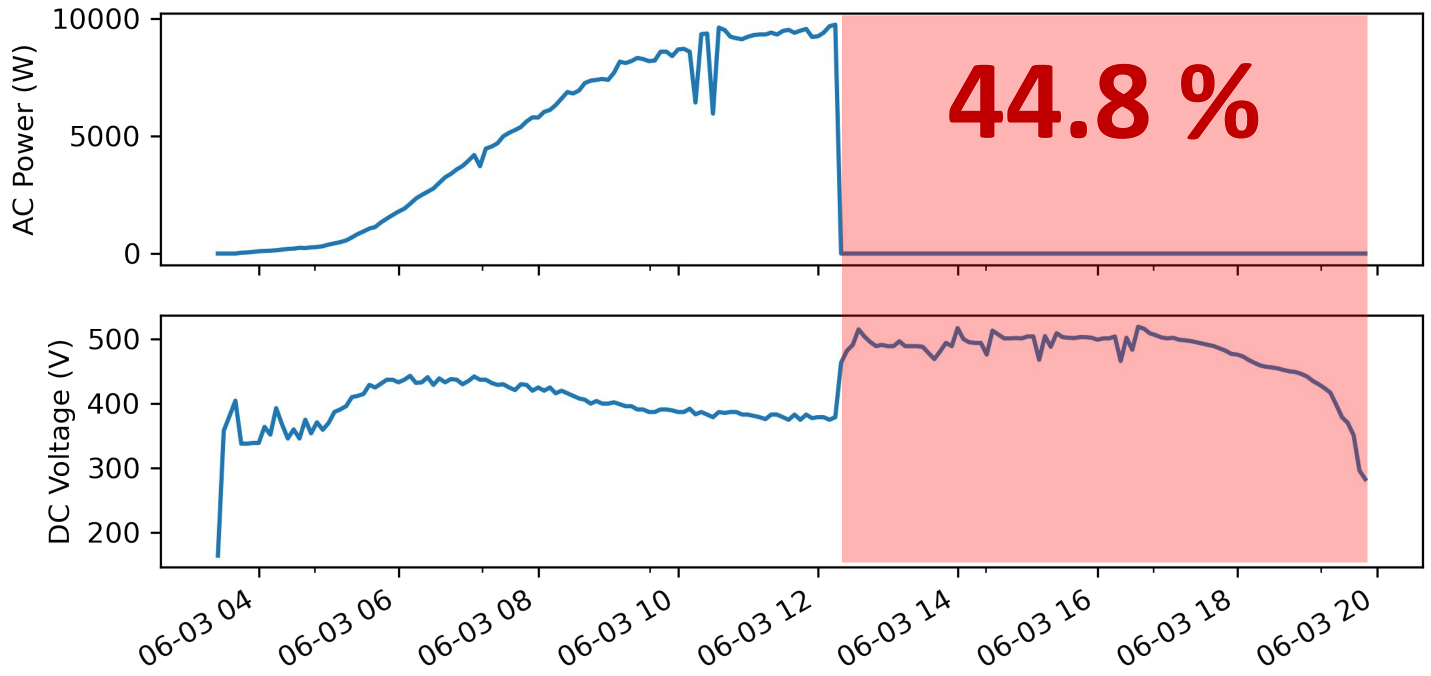
Methods[1]	Algorithm	Problem detected
Identifying electrical signatures	1. Communication Fault (COMM)	Loss of communication
	2. Inverter Outage (IOUT)	Inverters completely out of service
	3. Open Circuit Condition (OPC)	Deactivation (idle state) of inverters
Comparing performance of different components	4. Inverter Relative Underperformance (IRU)	Inverters operating with very different efficiencies
	5. DC Current Comparison (DCC)	Strings operating with different efficiencies
	6. Inverter Late Wake Up (LWU)	Sensitivity to morning dew due to insulation problems
Comparing present with historical performance	7. PR Sudden Drop (PRSD)	Sudden drop of PV system performance
Comparing predicted energy with produced energy	8. High Specific Energy Loss (HSEL)	Significant energy loss
	9. High-Performance Loss (HPL)	Significant performance loss

[1] "The Use of Advanced Algorithms in PV Failure Monitoring," tech. rep., Report IEA-PVPS T13-19, 2021.

Fault Detection Example

Open Circuit Condition (OPC)

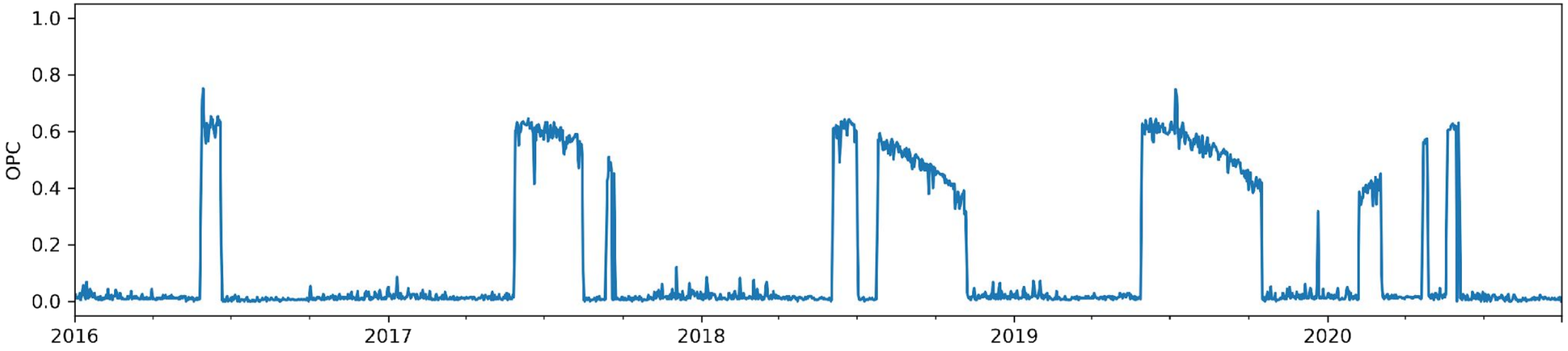
- Deactivation (idle state) of inverters
- Identify zero (or almost zero) AC power output and input of DC voltage above normal.
- Daily occurrence



intelligize your solar power

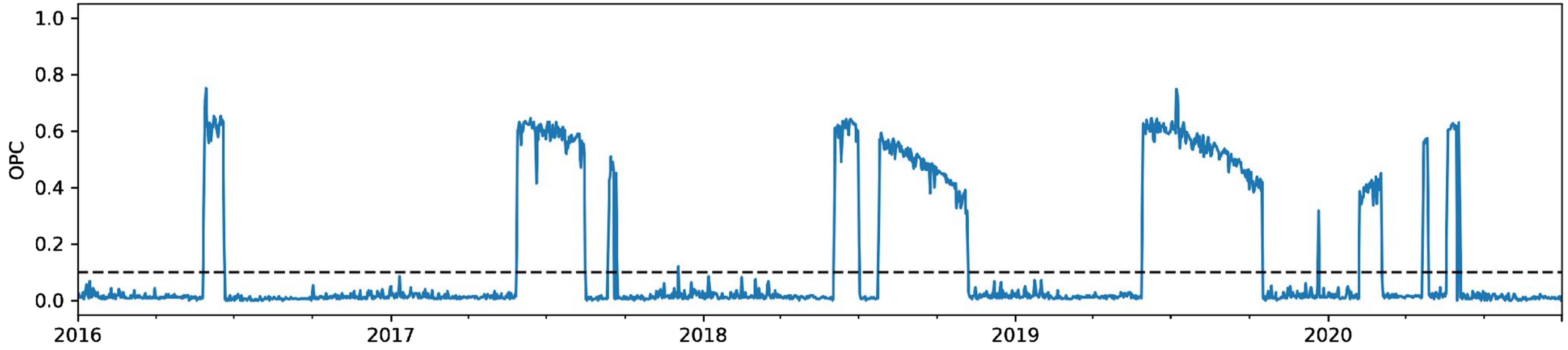
enmova

Fault Detection Example



intelligize your solar power
enmova

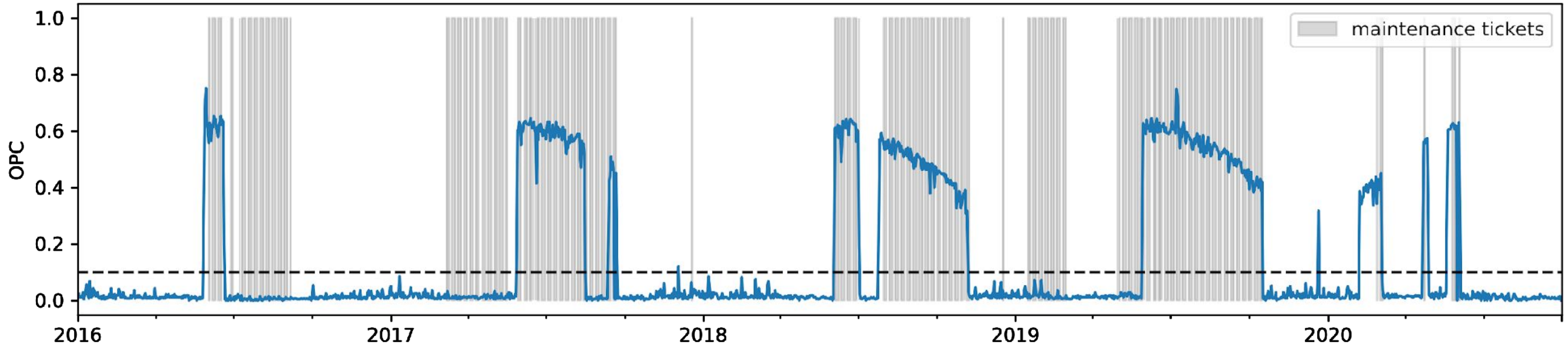
Fault Detection Example



- Fault Alert = Daily occurrence > Threshold
- Comparison of alerts and maintenance tickets

intelligize your solar power
enmova

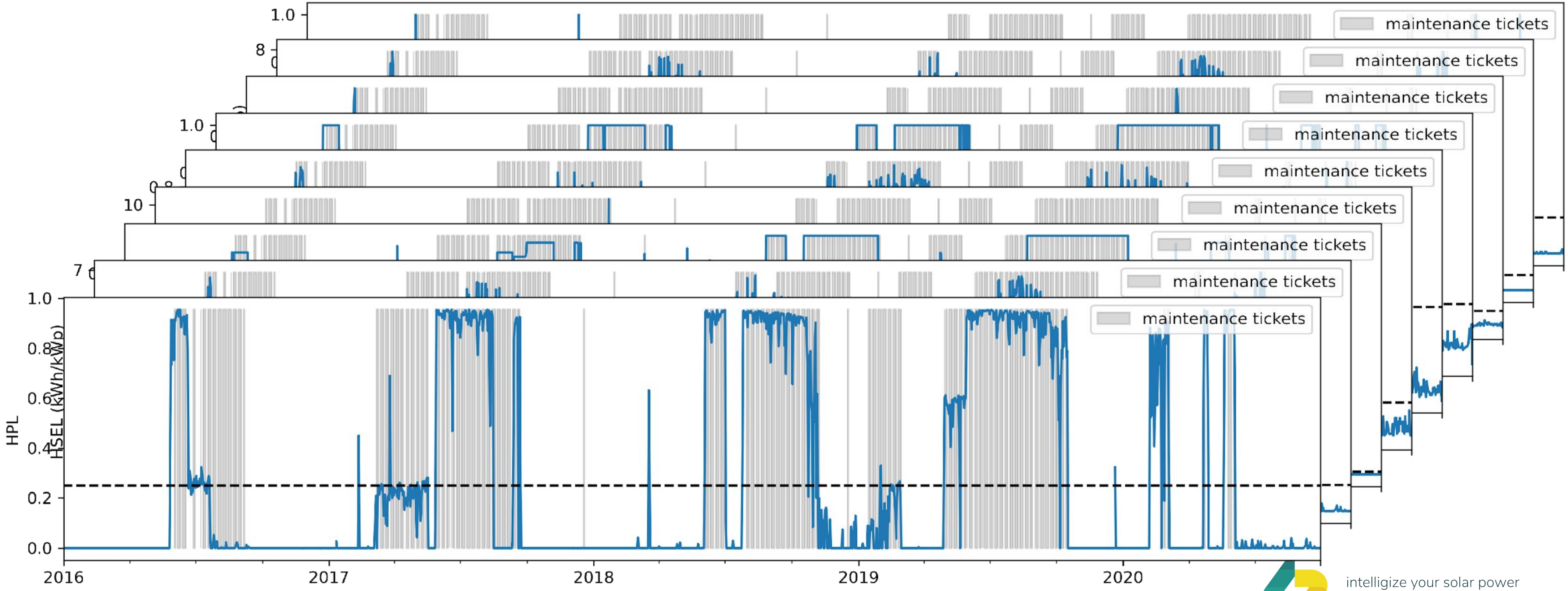
Fault Detection Example



- Fault Alert = Daily occurrence > Threshold
- Comparison of alerts and maintenance tickets

intelligize your solar power
enmova

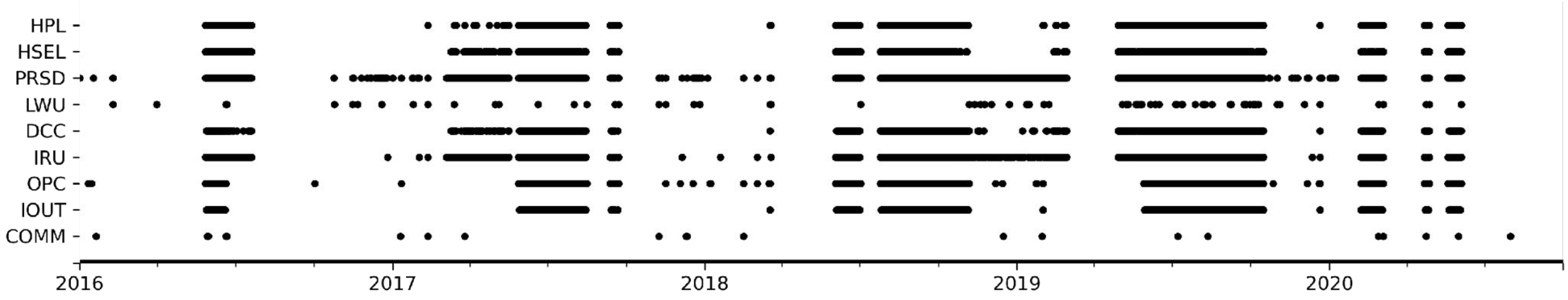
Multiple Fault Detection



intelligize your solar power
enmova

Combination of Alerts

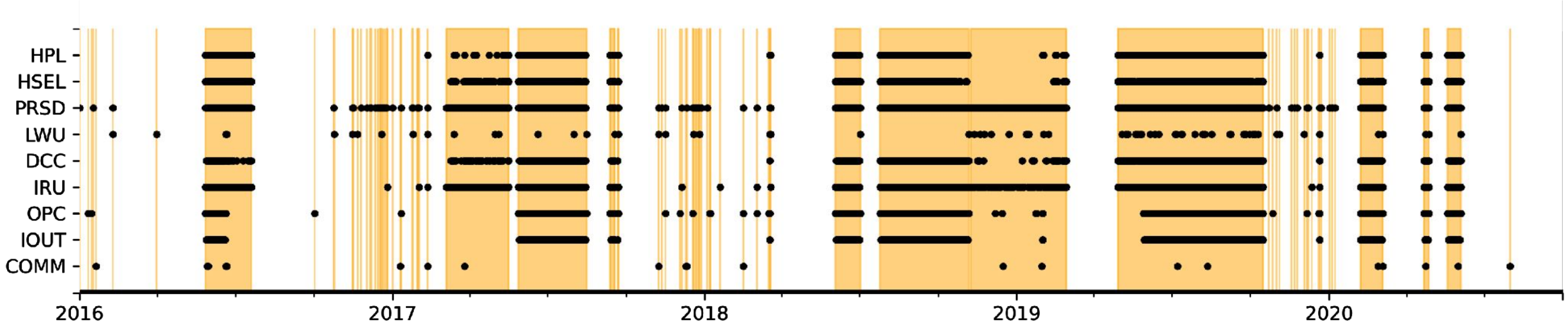
- Daily Automatic Alerts = Combination of All Boolean Alerts



intelligize your solar power
enmova

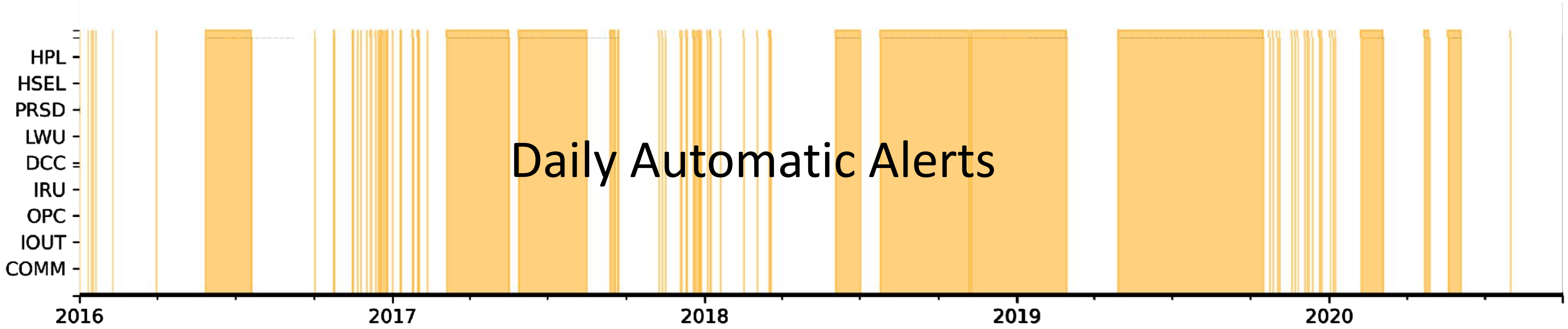
Combination of Alerts

- Daily Automatic Alerts = Combination of All Boolean Alerts



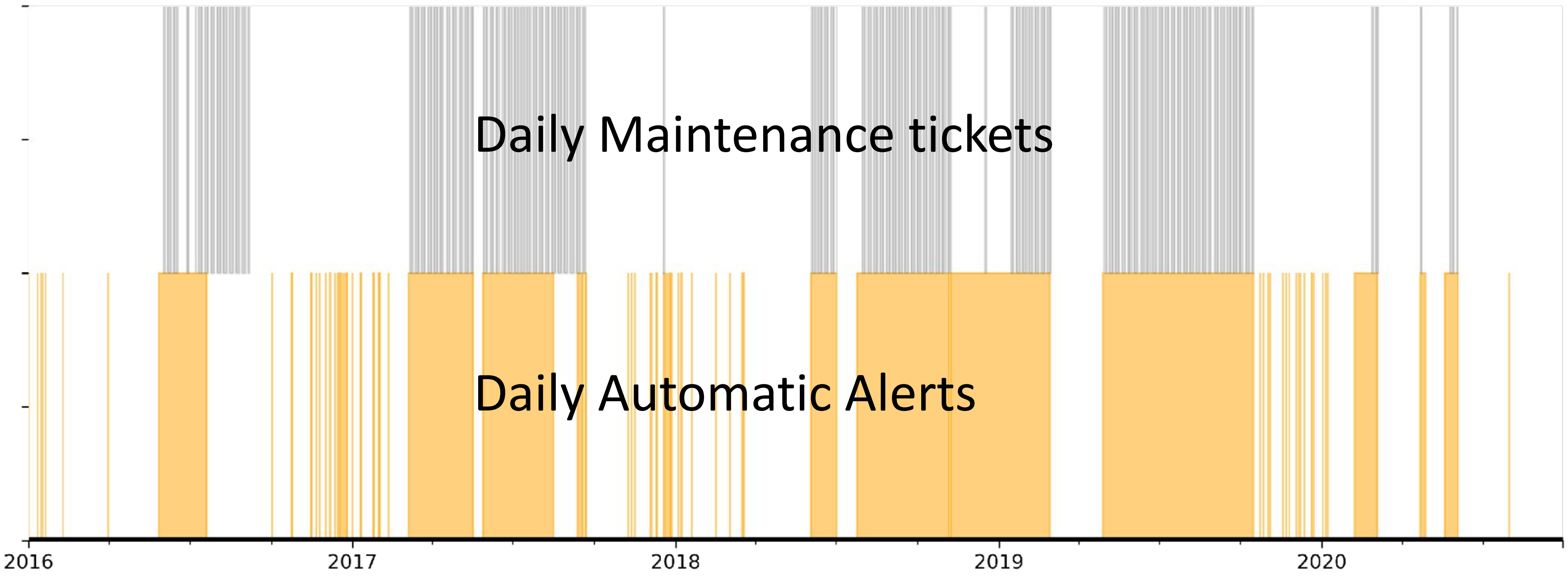
Combination of Alerts

- Daily Automatic Alerts = Combination of All Boolean Alerts



intelligize your solar power
enmova

Comparison of alerts and tickets



intelligize your solar power
enmova

Validation Methodology

Daily Alerts from the
Automatic Fault Detection algorithms

Daily Maintenance
tickets

		Predicted Class	
		Positive	Negative
Actual Class	Positive	True Positive (TP) Fault Detected	False Negative (FN) Type II Error Undetected Fault
	Negative	False Positive (FP) Type I Error False Alarm	True Negative (TN) Normal operation

Sensitivity: how many of the existing faults were correctly detected.

$$Sensitivity = \frac{\sum TP}{\sum TP + \sum FN}$$

Specificity: how many of the negatives are truly negative.

$$Specificity = \frac{\sum TN}{\sum TN + \sum FP}$$

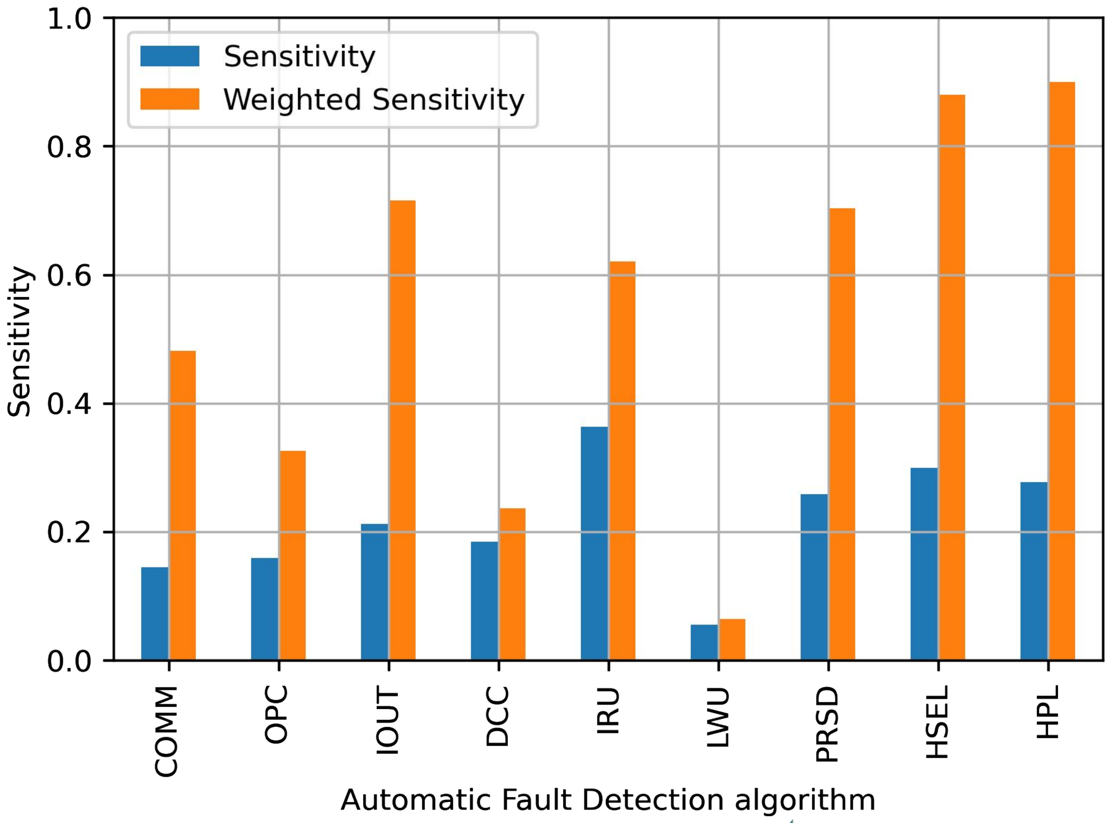
Weighted Sensitivity: how much of the existing energy loss were detected.

$$Weighted\ Sensitivity = \frac{\sum TP_{rel}}{\sum TP_{rel} + \sum FN_{rel}}$$

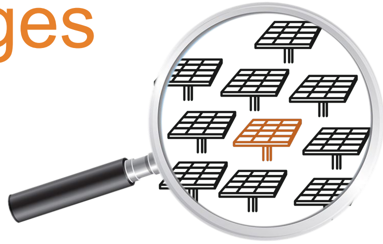
intelligize your solar power
enmova

Algorithms Performance
with 5 years of field data

- In the best case, the algorithms could detect 36.3% of the tickets.
- Tickets detected represent up to 90% of the energy losses.
- Specificity ranging from 88.2% to 97.5%.
- This means 4.0 to 27.4 false alerts per year per system.



Challenges

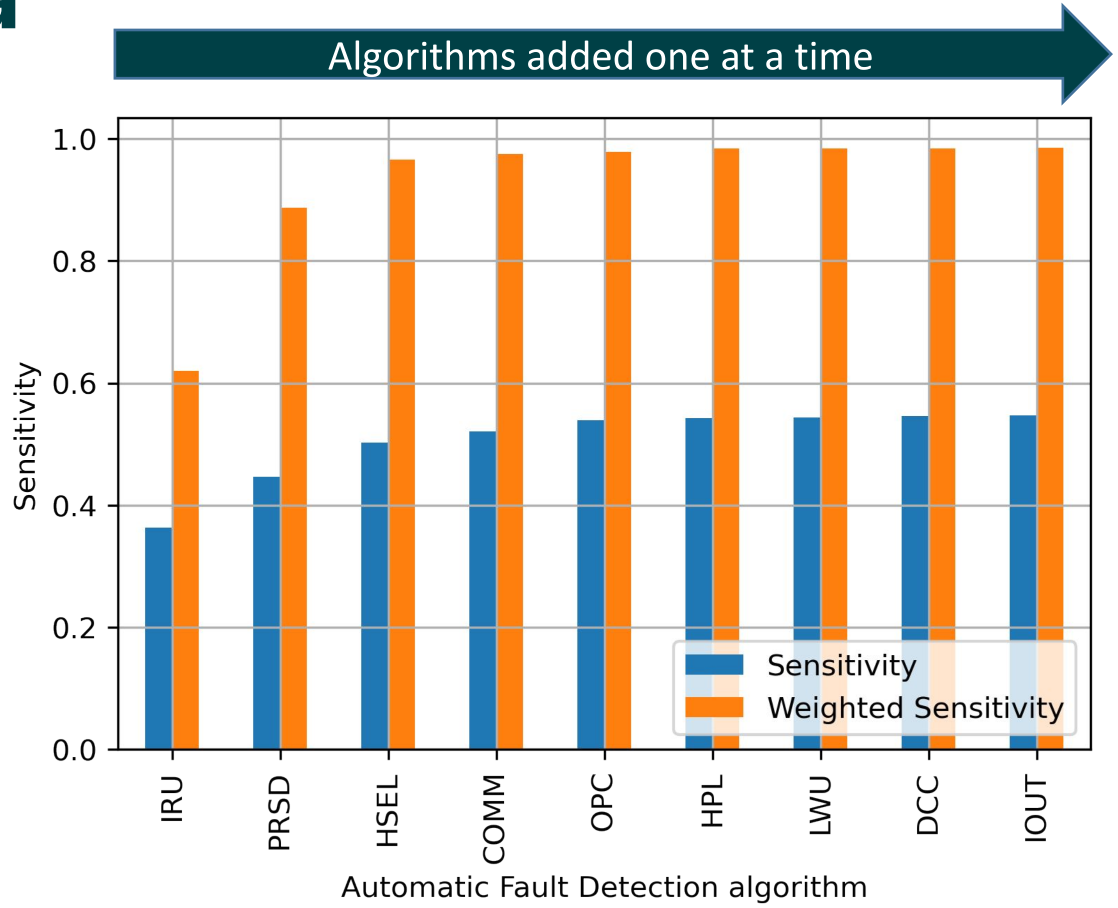


intelligize your solar power

enmova

Combined Performance
with 5 years of field data

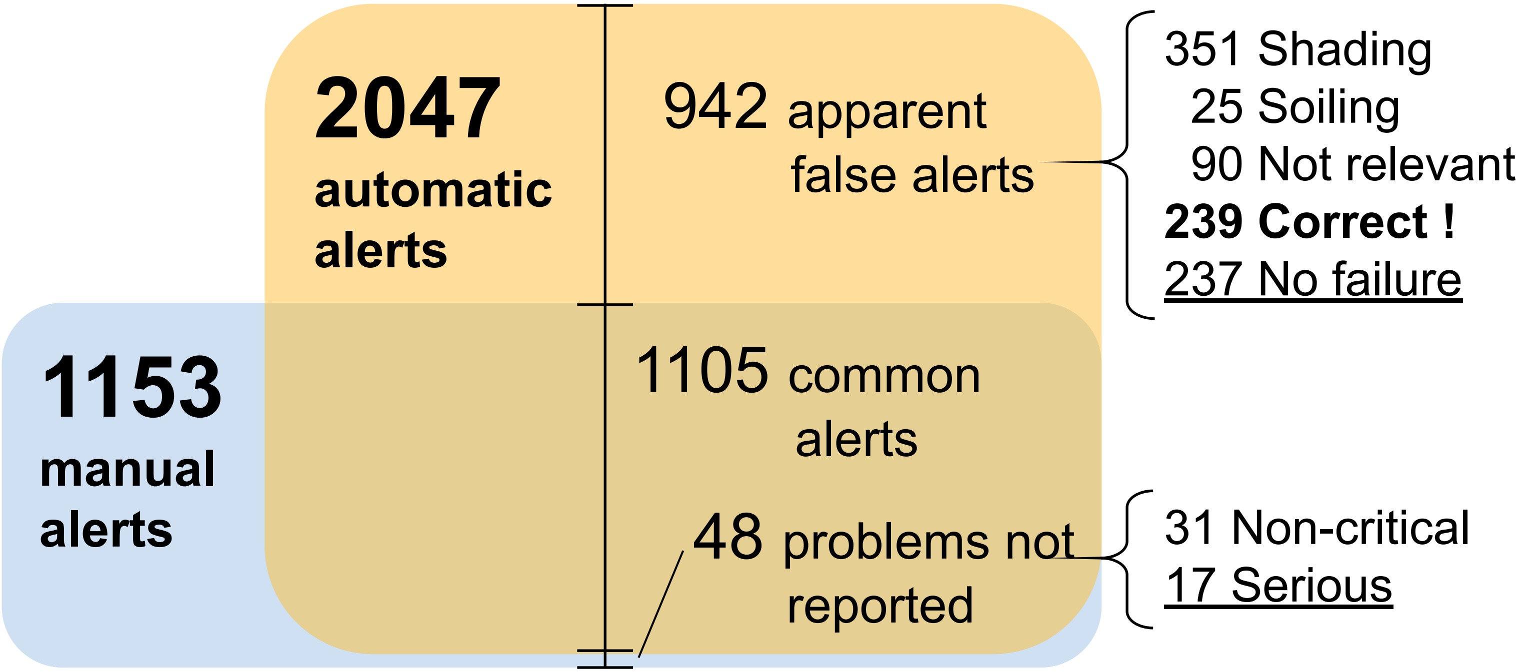
- Higher sensitivity and weighted sensitivity.
- 55% of the tickets and 98.5% of the energy losses.
- Lower specificity, down to 81%,
- Average of 46 false alerts per year per system.



intelligize your solar power
enmova

Test with live monitoring data
with the help of the monitoring team

- 5491 days evaluated in 170 systems from Oct, 1st to Nov, 4th

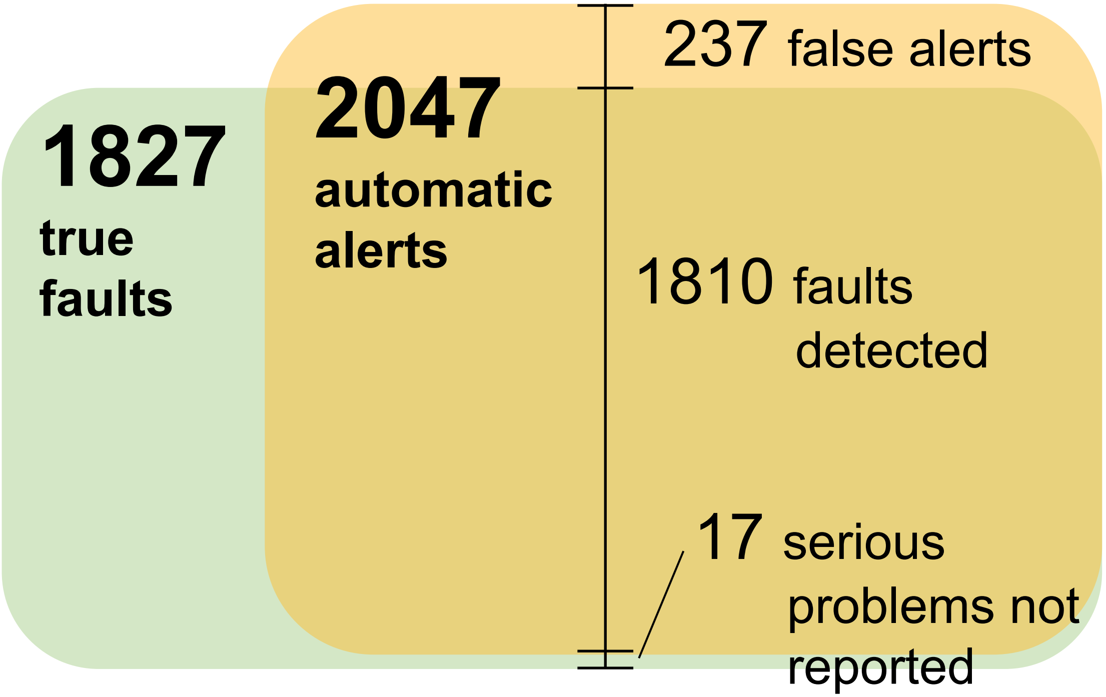


- 13.2% of the actual problems went unnoticed by the conventional monitoring routine
- < 12% of the automatic alerts are false.
- > 99% of the serious problems detected

intelligize your solar power
enmova

Test with live monitoring data
with the help of the monitoring team

- 5491 days evaluated in 170 systems from Oct, 1st to Nov, 4th



		Automatic Alerts	
		P	N
Manual Alerts	P	1810	17
	N	237	3427

$$Sensitivity = 99.1\%$$

$$Specificity = 93.5\%$$

intelligize your solar power
enmova

• Credibility

Most extensive validation of failure detection ever - 4 years R&D with Fraunhofer ISE and O&M experts with traceable publications

• Validation

Validation over +3.5 million hours real operational data and 5 years of O&M log across 80 PV systems

30 %
TIME SAVING

99 %
ENERGY LOSS DETECTED

12 %
MORE ISSUES DETECTED THAN O&M EXPERT

Is Good Automatic Detection Enough?

- There are still much false positives alarms
    - How to filter them?

- The will be a lot of detected incidents within a portfolio, the user must not be spammed with a lot of “automatic” alarms!
    - We may need another instrument to filter, aggregate and prioritize the results

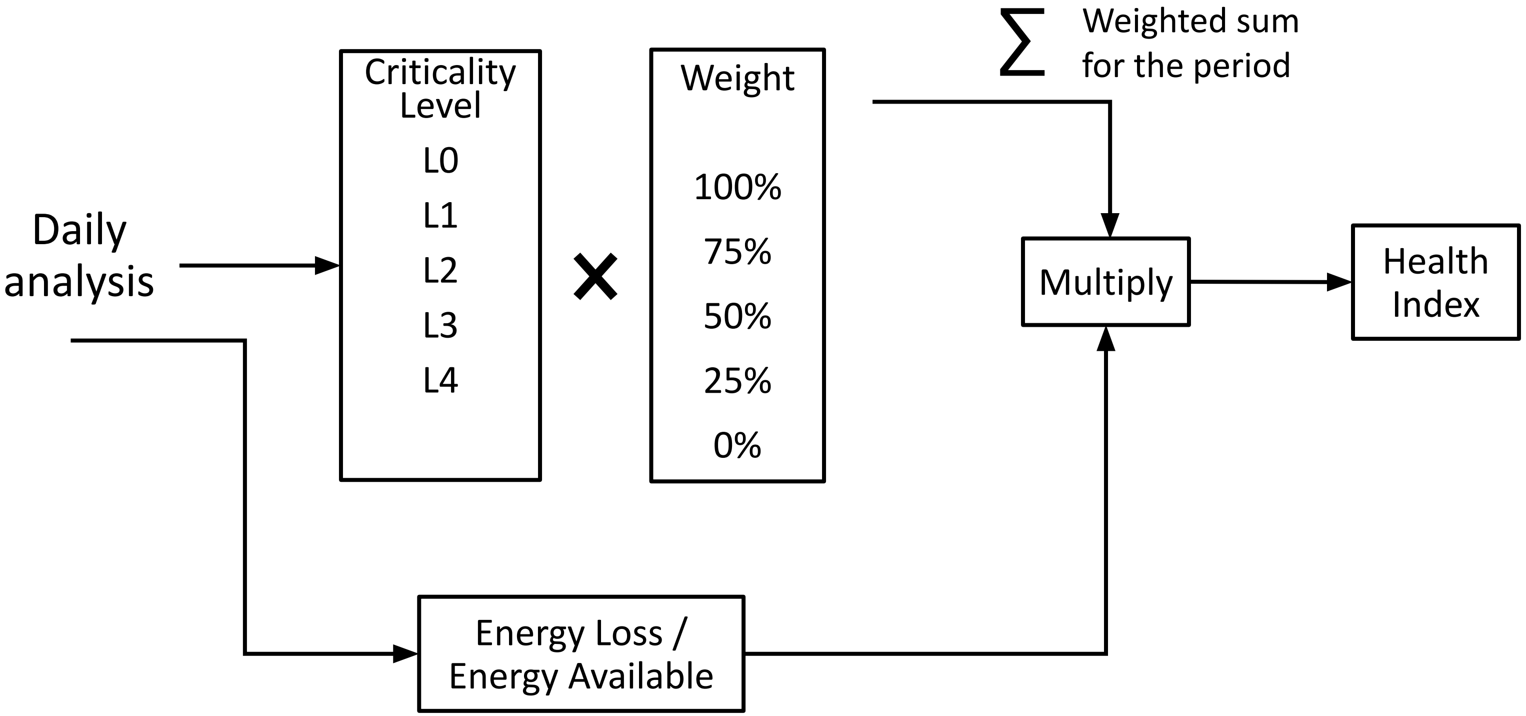
- **We need a simple way presenting a holistic view of the system's status**

intelligize your solar power
enmova

02 Techno-economic Prioritization for PV System Portfolios

intelligize your solar power
enmova

From Automatic Failure Detection to Health-Index



intelligize your solar power
enmova

Total System Insight
in one single
Health Index

- Encapsulate 12 automatic fault detection algorithms
- Integrate tech. criticality and potential energy loss

➔ Holistic view of system's true "health status"

➔ Avoid user from spam of fault messages and alerts

Contractual factors

- Reaction time
- Performance guarantee
- Service Level
- …

Financial factors

- Penalties
- Profit sharing
- Company strategy
- Additional cost
- …

Company's decision-making process in on single **Financial Index**

intelligize your solar power
enmova

Prioritize systems having technical issues based on economical urgency

Health Index

Financial Index

intelligize your solar power

enmova

If half of your portfolio shows 0% priority index, this means no investigation needed for 50% of the systems at all!

Focus solely on systems with issues and start from the most critical ones.

intelligize your solar power

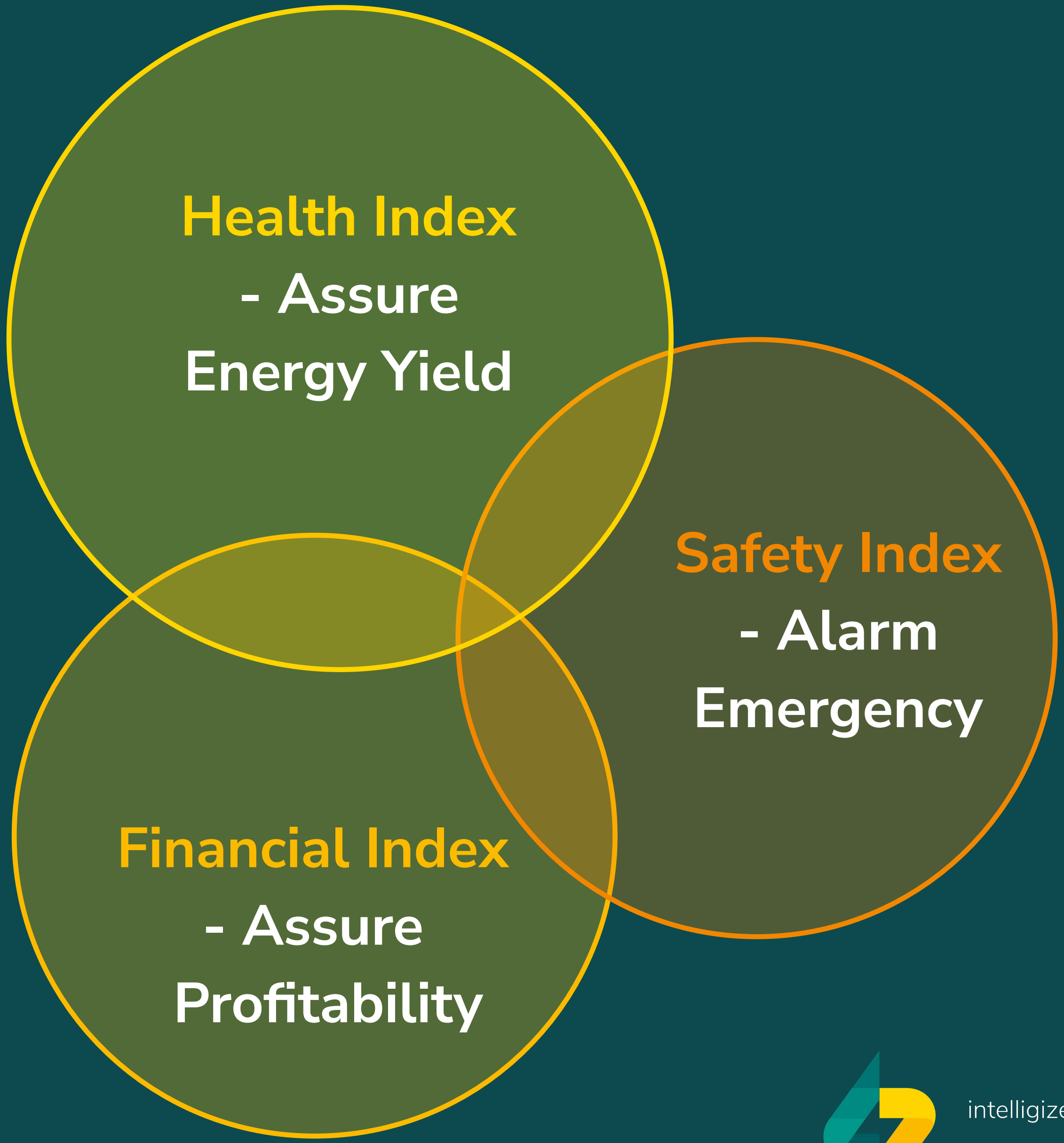
enmova

One step further -

Priority

Prioritize systems with technical issues based on economical impact in routine monitoring

Alarm systems having potential security issues that require immediate intervention



intelligize your solar power
enmova

Thank you for your attention!

Do you have any further questions?

intelligize your solar power

enmova