TASK 13: PERFORMANCE AND RELIABILITY OF PV SYSTEMS

Improving Efficiency of PV Systems Using Statistical Performance Monitoring

IEA PVPS TASK 13 WORKSHOP AT EU PVSEC 2017; AMSTERDAM, THE NETHERLANDS

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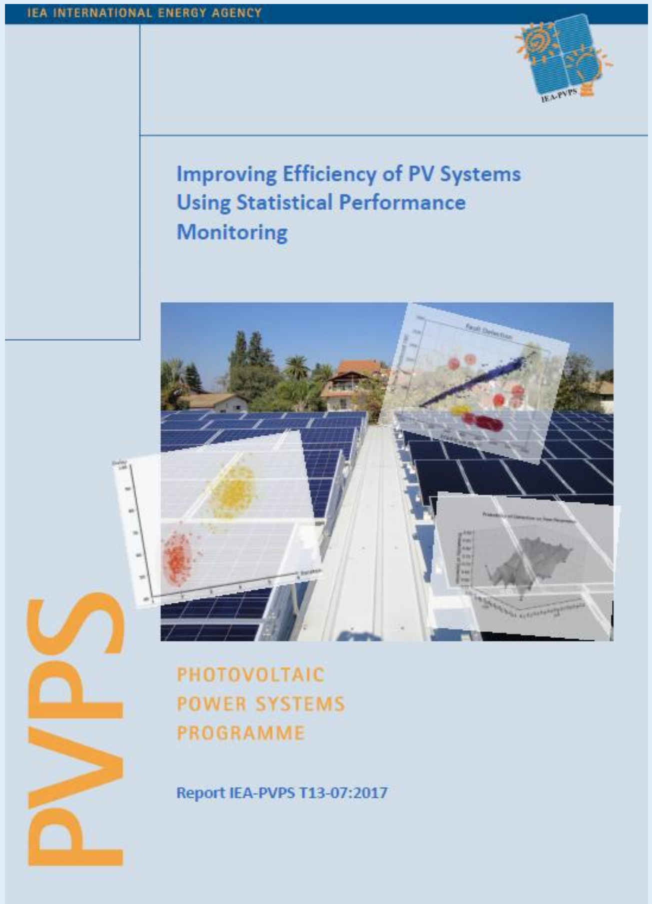
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IEA-PVPS

Improving Efficiency of PV Systems Using Statistical Performance Monitoring

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PHOTOVOLTAIC POWER SYSTEMS PROGRAMME

Report IEA-PVPS T13-07:2017

www.pvpredict.com

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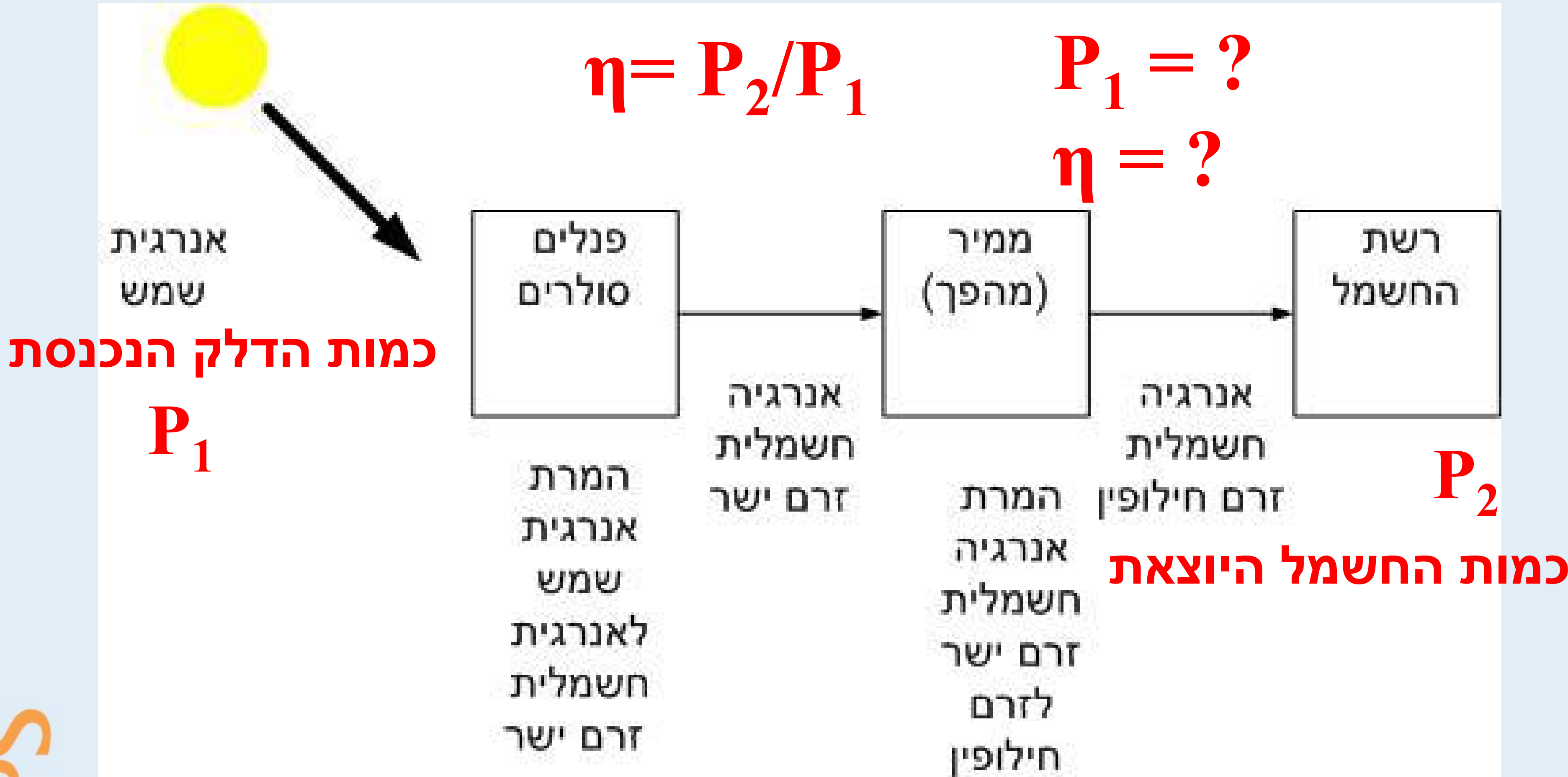
Independently Motivated Development

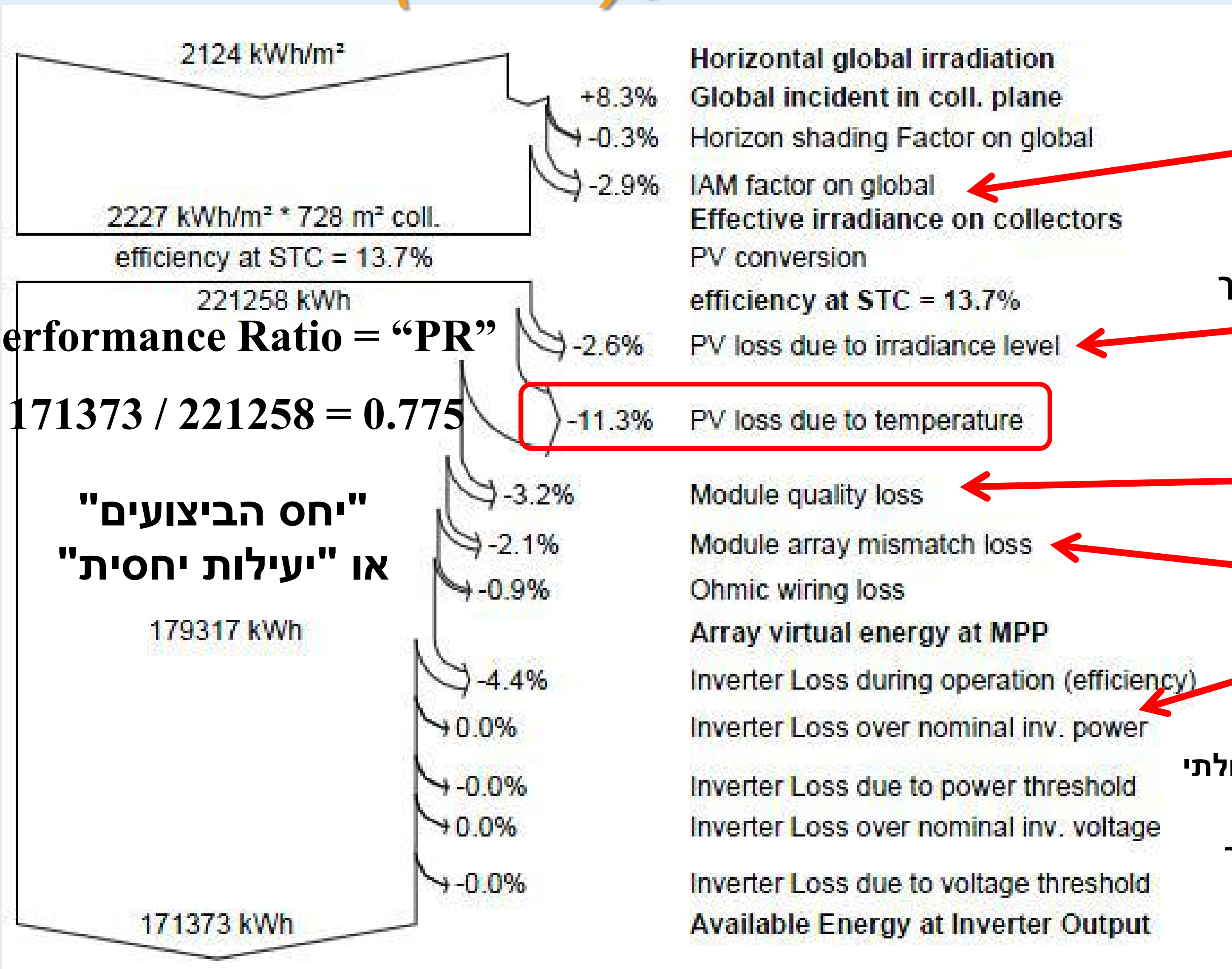
09:00 AM **18:00 PM** **01:00 AM**

ניטור אפקטיבי

יעילות = רווחיות



PR - יחס הביצוע (נצילות)



Performance Ratio = "PR"

171373 / 221258 = 0.775

"יחס הביצועים"
או "יעילות יחסית"

עקב קרינה שלא מגיע אל התאים – החזר בזכוכית או נופל בין תאים

עקב נצילות הפנל נמוך מהמוצהר בSTC ברמות הארה נמוך יותר

עקב סטיות בהספק המוצהר של הפנל

הפרשים בין צורת IV של הפנלים במערך

עקב פעילות מעל הספר הממיר

זרם מתחת לזרם התחלתי של ממיר

עקב מתח מעל המותר

עקב מתח מתחת למינימום

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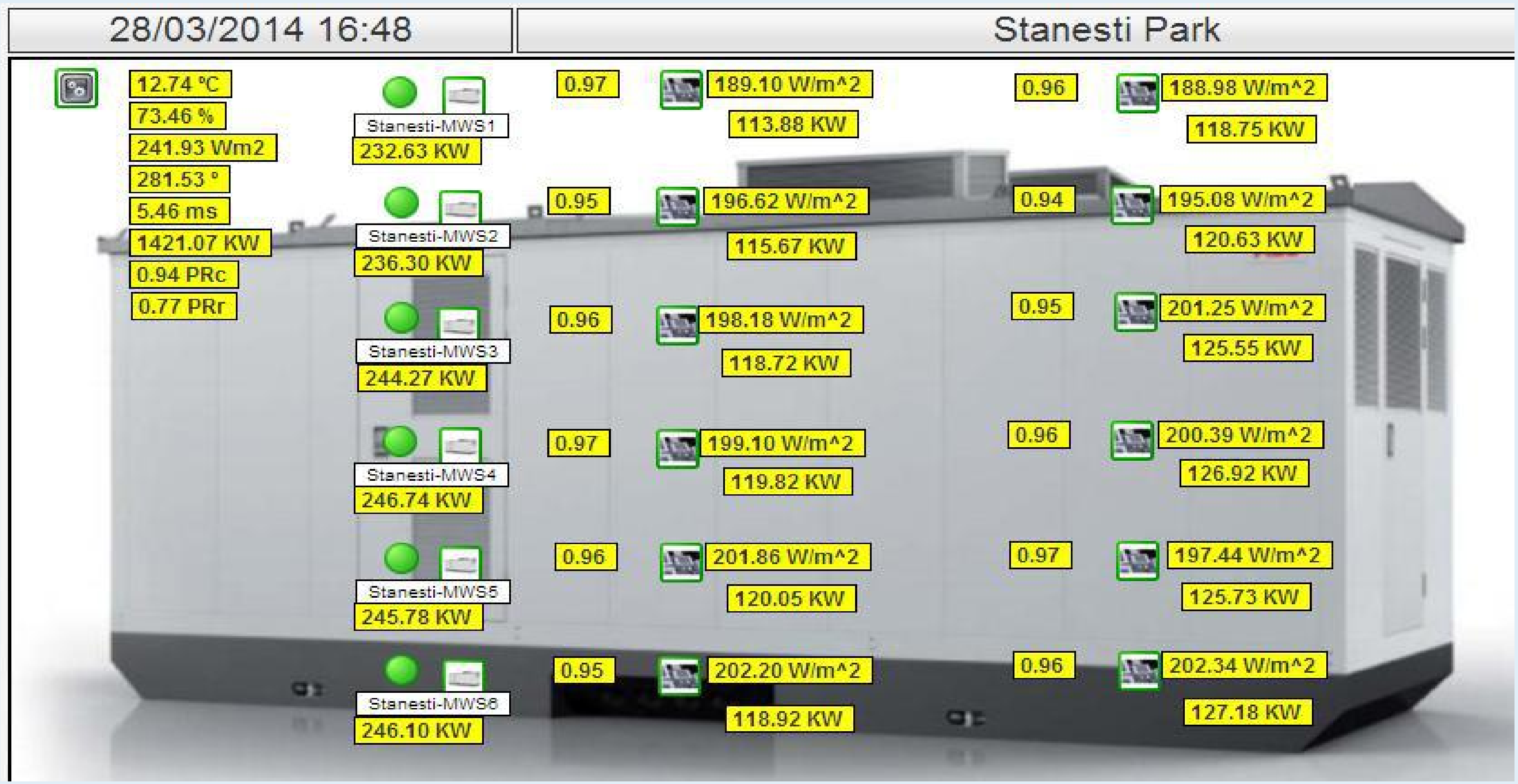
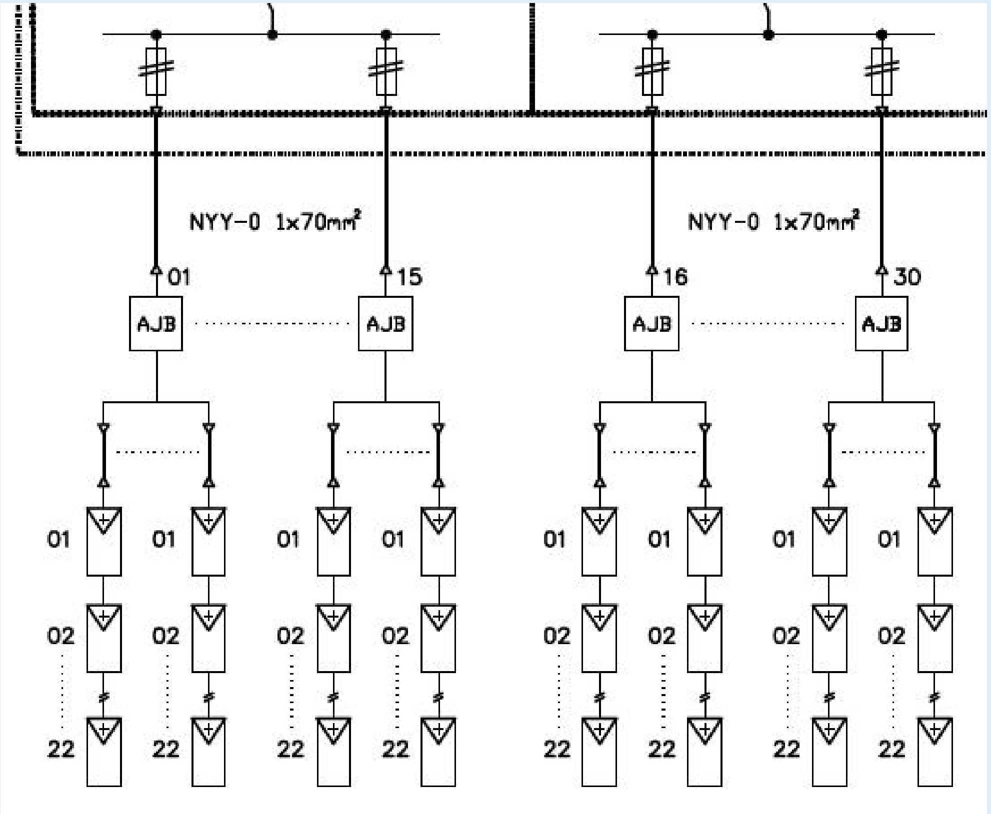
Current State of the Art

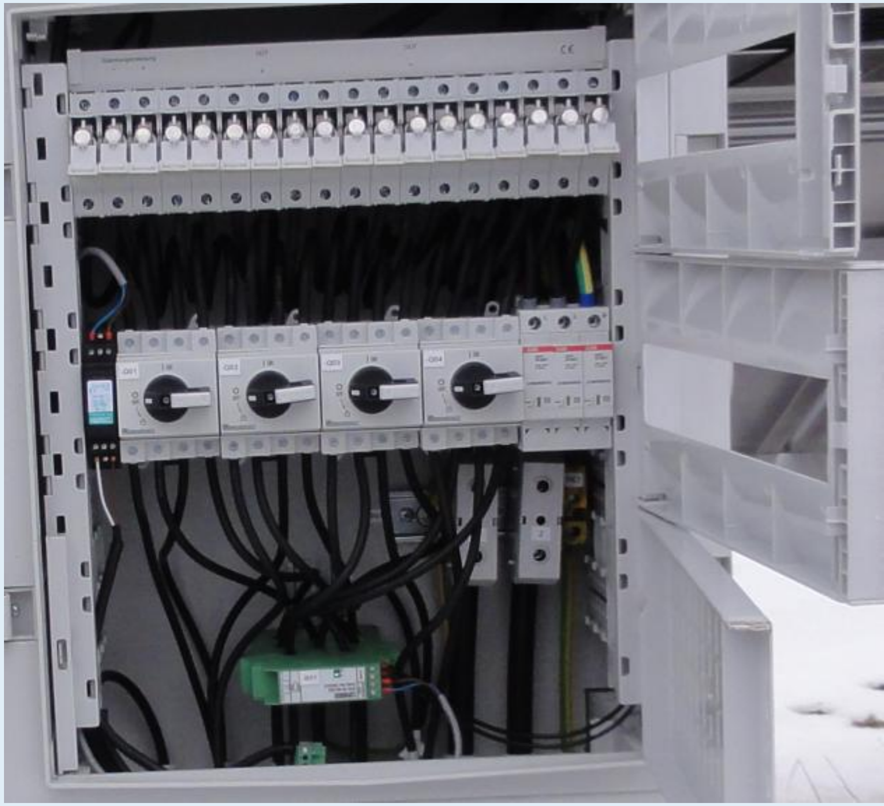
- Performance Ratio
- Temperature Corrected PR



Current State of the Art

➢ String Monitoring





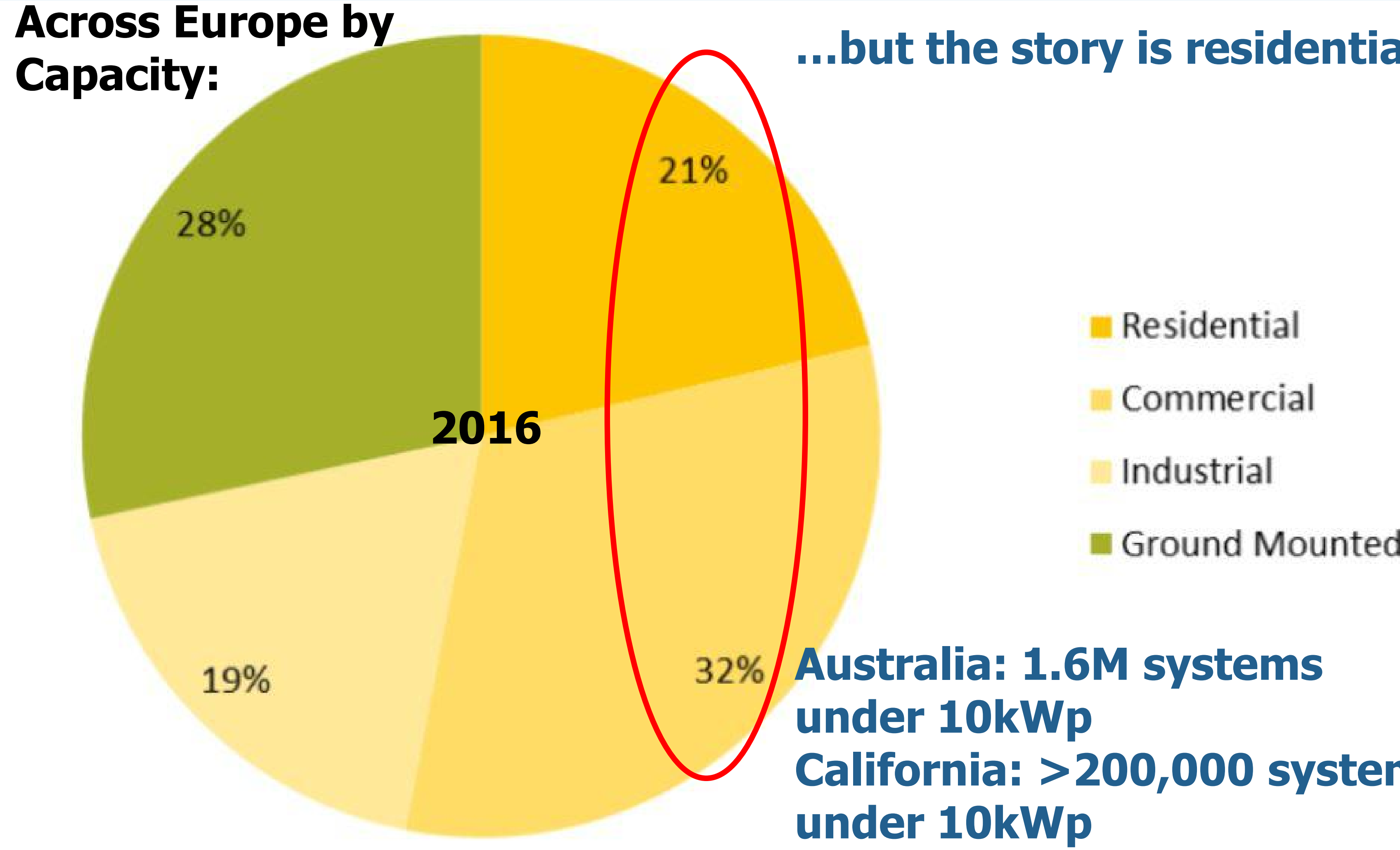
8 strings x 15 SB x 12 inverters = 1440 monitored channels

The Motivation

Utility Grade PV:

- High level of predictability
- High level of availability

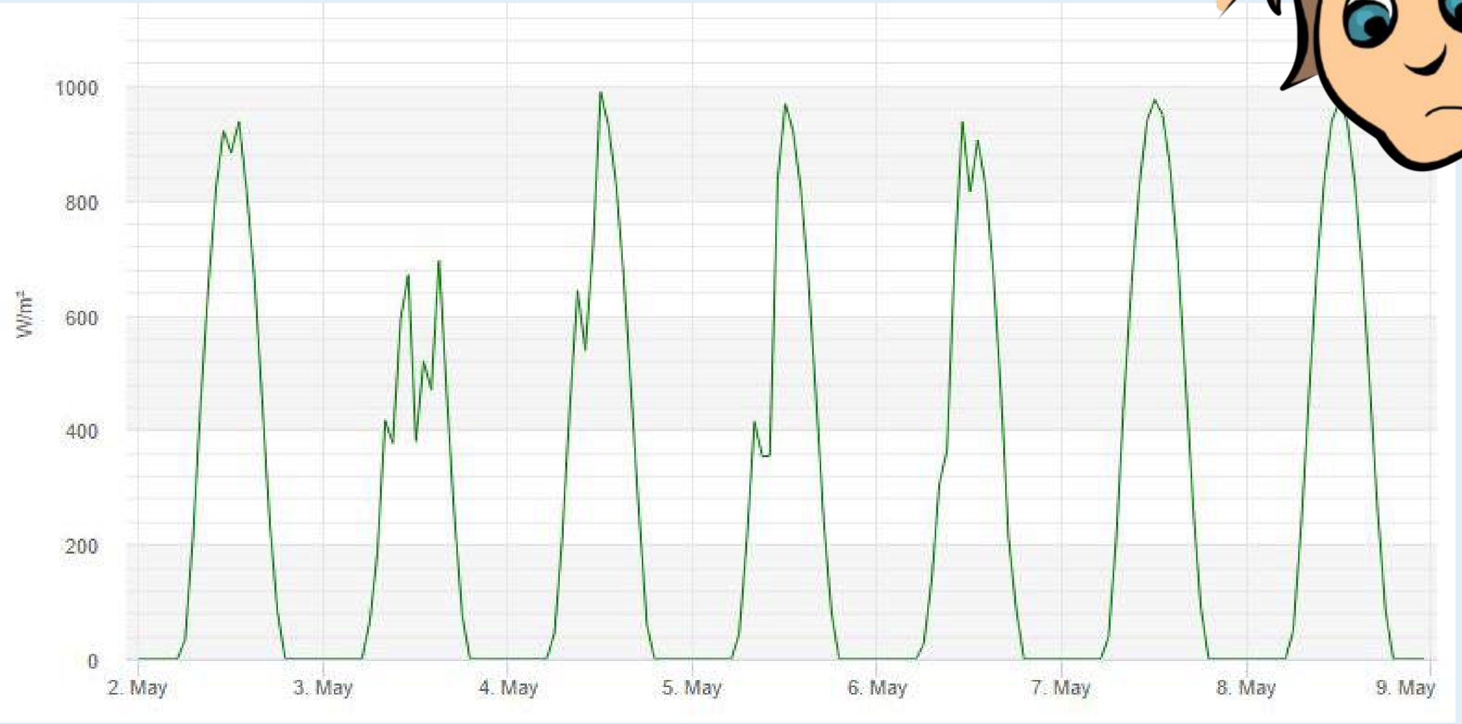
The Motivation



…but the story is residential

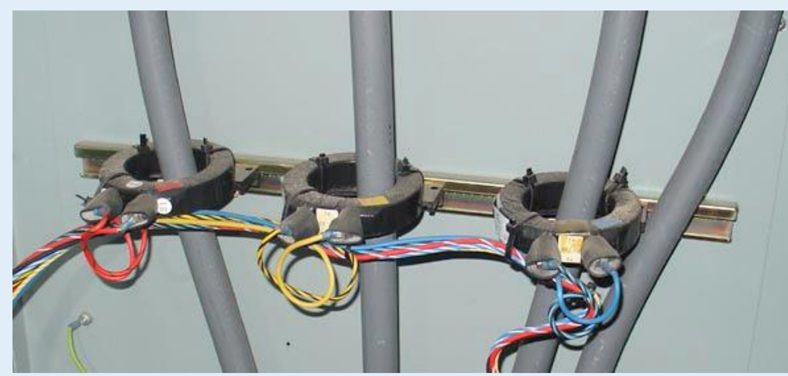
Australia: 1.6M systems under 10kWp
California: >200,000 systems under 10kWp

The Motivation



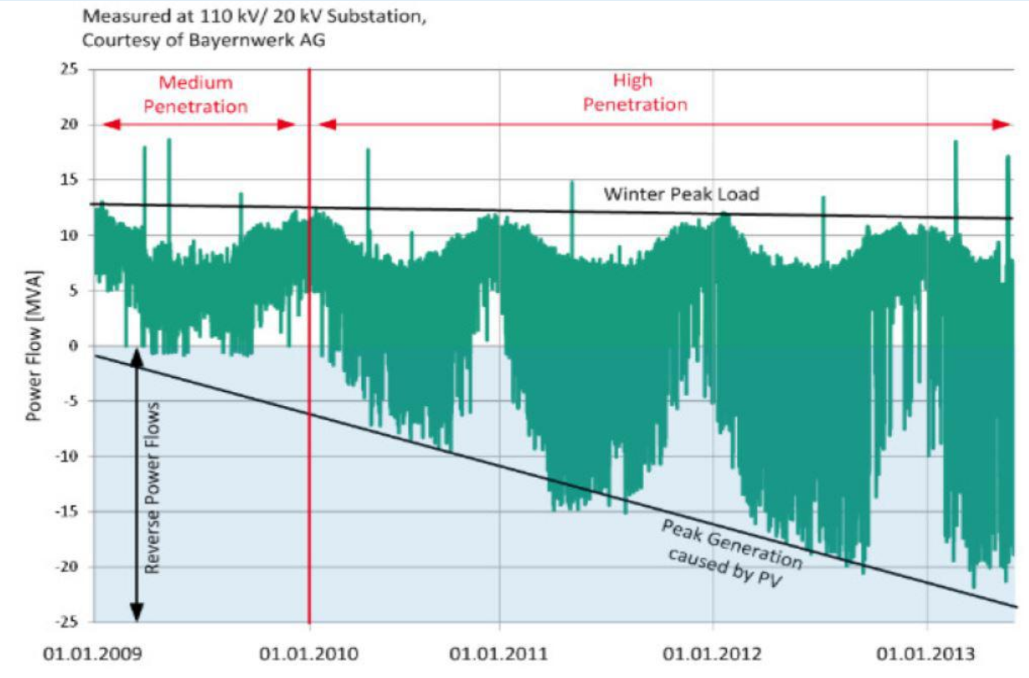
Current State of the Art?

≈



The Motivation

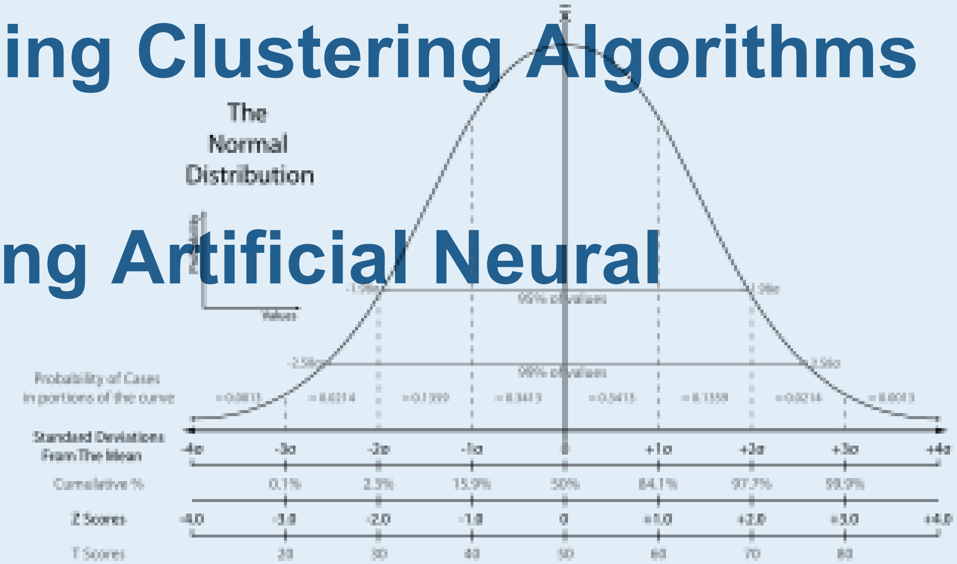
ניטור – חיוני לרשת...



אני מוכר פחות חשמל...
משלם יותר עבור עתודות...
וסובל מבעיות באיזון מתחים!!!

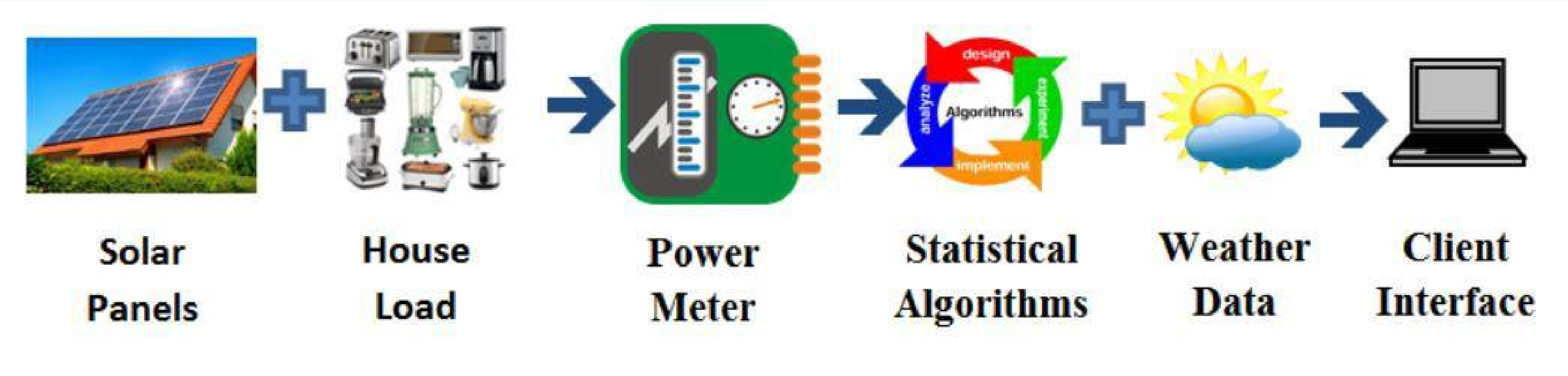
Statistical Performance Monitoring

- Smart Monitoring for Residential Solar
- Machine Learning for Fast Fault Recognition
- Fault Prediction Using Clustering Algorithms
- Fault Detection Using Artificial Neural Networks



Smart Monitoring for Residential Solar

- Monitor mounted in the household electrical panel
- Australian NWS →Meteo data and satellite maps



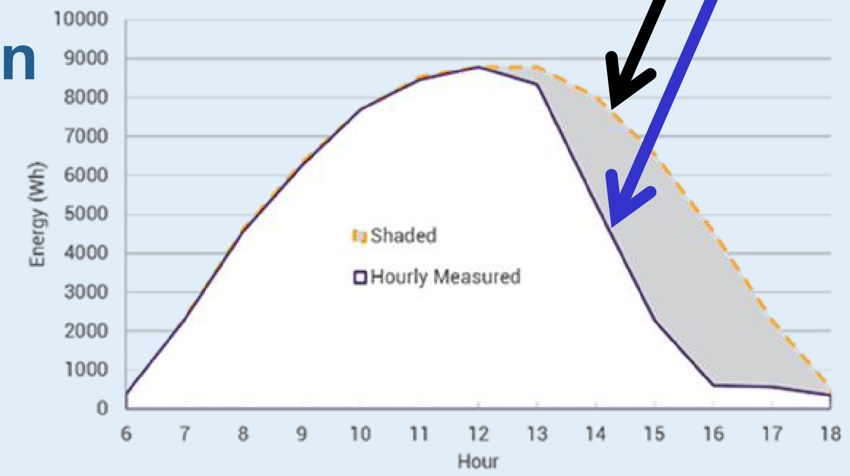
Smart Monitoring for Residential Solar

System parameters:

- Location
- PV module type
- Inverter type
- PV module orientation
- PV module tilt
- String configuration

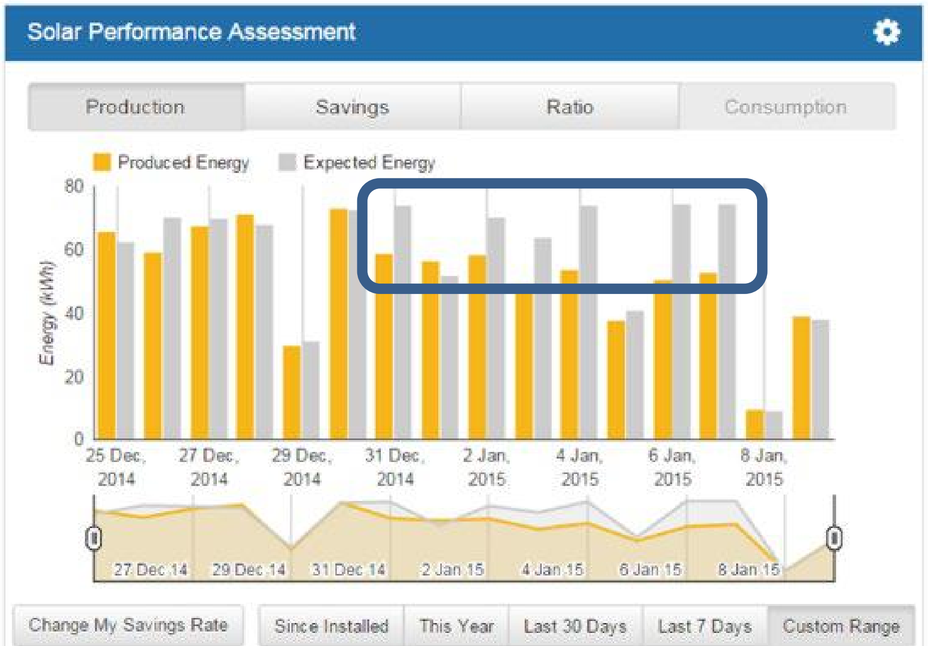
Smart Monitoring for Residential Solar

- Generation Estimation
- Real-time monitoring - day end evaluation
- Performance losses:
  - Shading
  - Inverter clipping
  - Power Factor correction
  - Degradation
  - String/Module faults



Smart Monitoring for Residential Solar

Finding faults in strings without string monitoring



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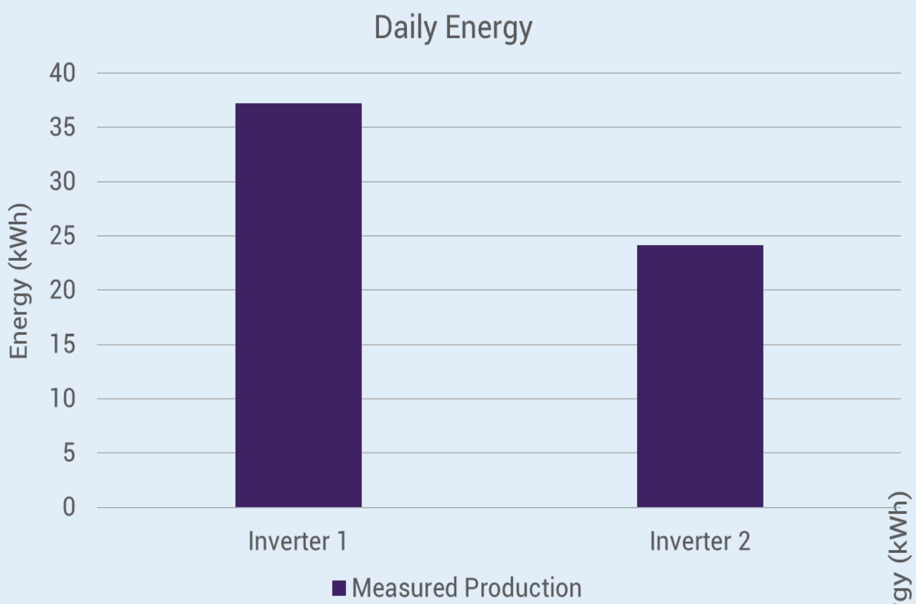
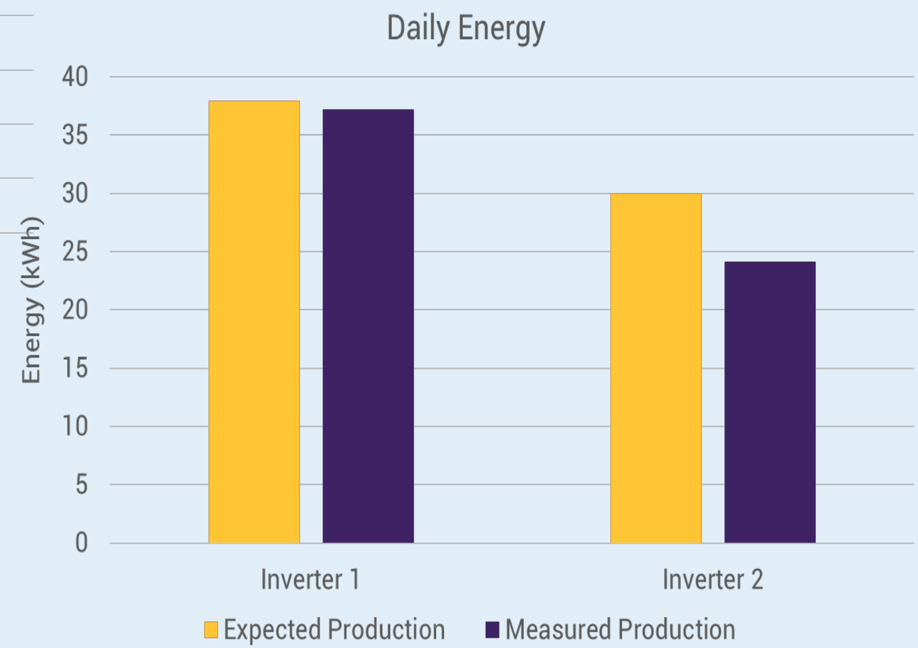
Smart Monitoring for Residential Solar



Inverter 1 Inverter 2

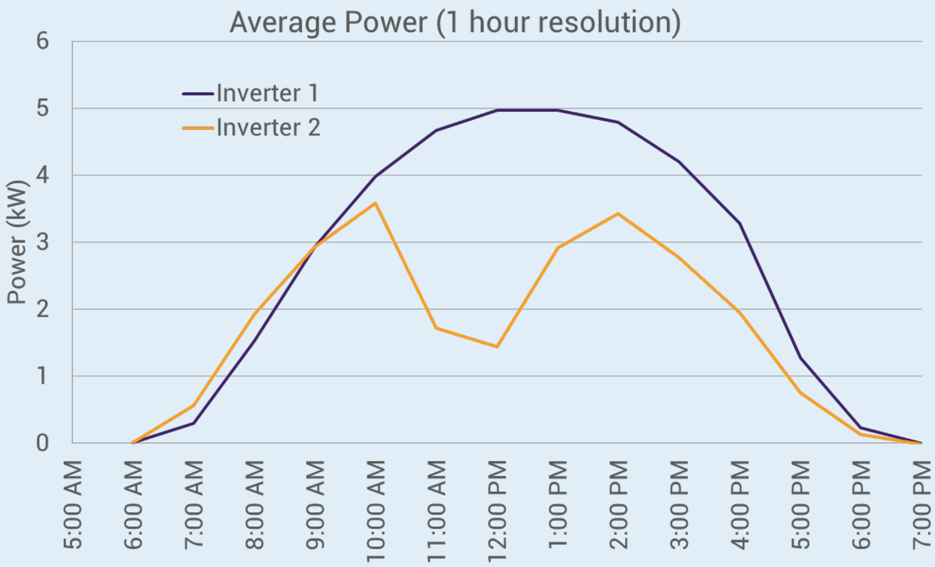
Measured Production

Measured vs Expected Production



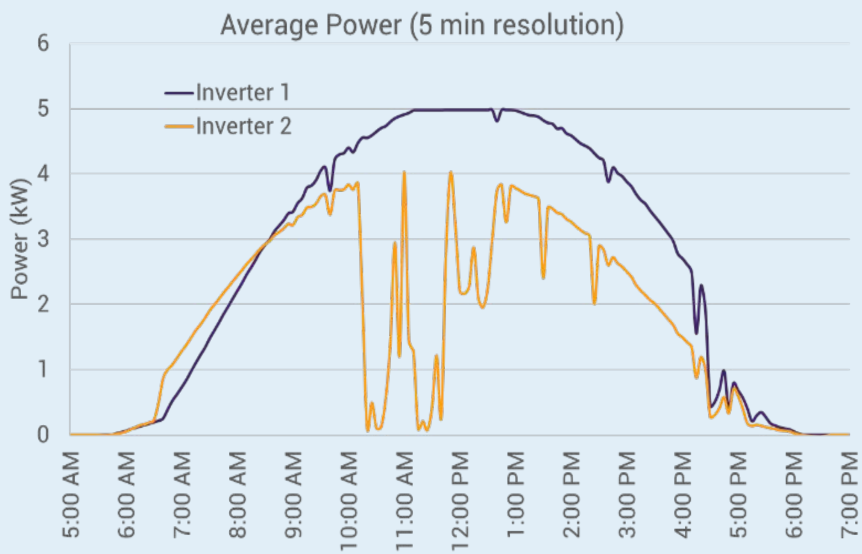
Inverter 1 Inverter 2

Smart Monitoring for Residential Solar



1 hour resolution

5 minute resolution



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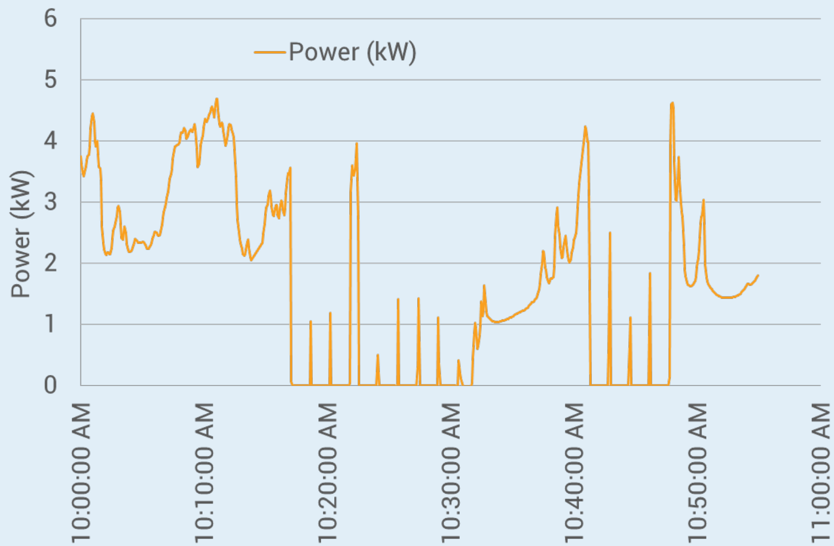
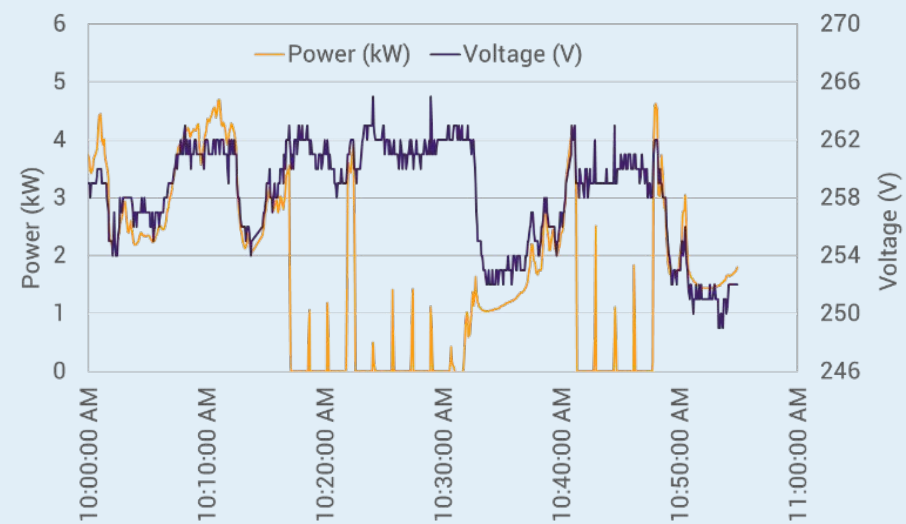
Smart Monitoring for Residential Solar



**Power:
5 second resolution**

**Power and Voltage:
5 second resolution**



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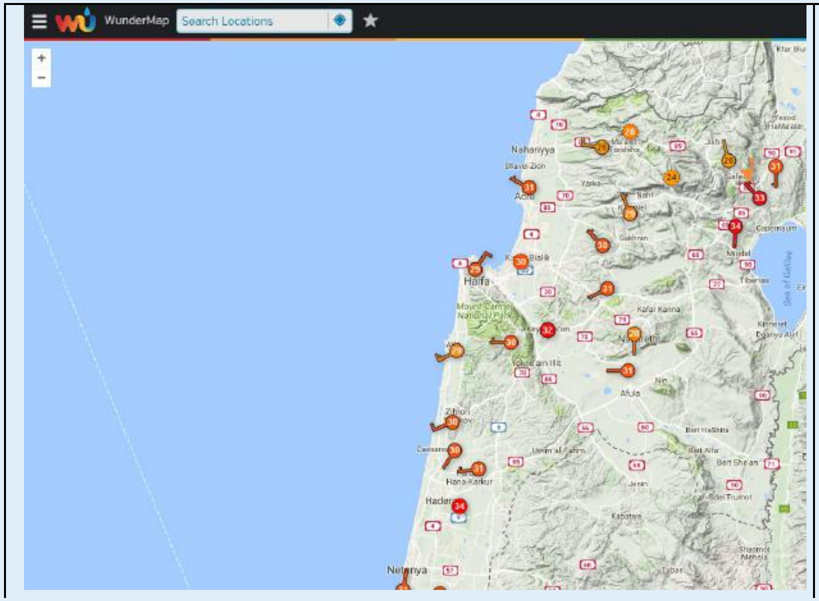
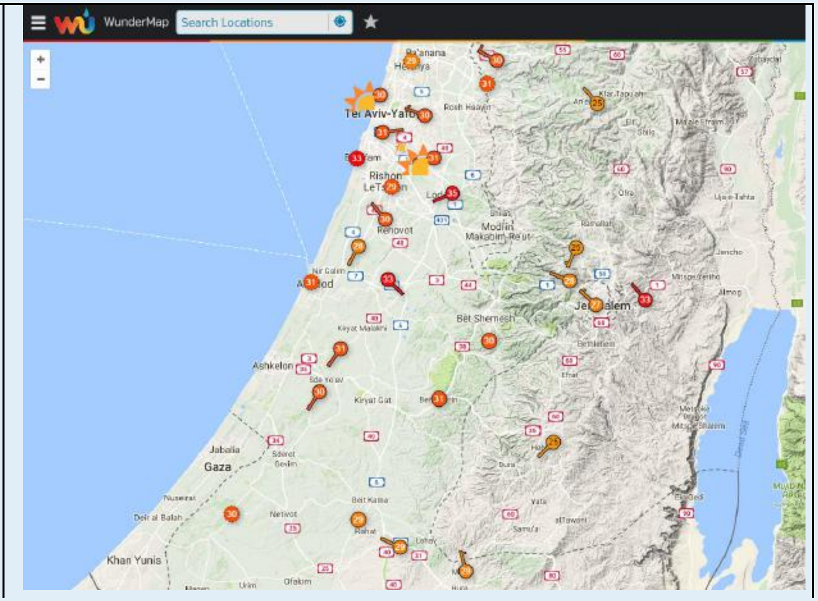
Machine Learning for Fast Fault Recognition

- Prediction software
- No sensors
- No irradiation maps
- No system configuration





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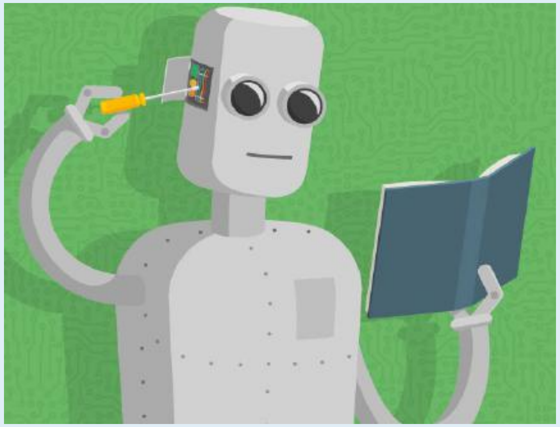
Machine Learning for Fast Fault Recognition

- Temperature
- Humidity
- Barometric pressure
- Wind speed
- Dew point
- Rain
- Sky view

+ Hourly generated power

→



No irradiance

Machine Learning for Fast Fault Recognition

Daily State of Health Score

No	Inverter	Health Index	Relative Index	Production (kWh)	Prediction (kWh)	Self Health	Relative	Revenue (NIS)	Normalized (kWh)	Installed (KWp)	Health History
1	2001451939	A	A	59.02	59.37	0.99	0.98	38.4	5.02	11.76	AAAAAAC
2	2001452028	A	A	60.05	60.74	0.99	1.00	39.0	5.11	11.76	ABABBAC
3	2001452162	A	C	55.43	55.99	0.99	0.92	36.0	4.71	11.76	ABAABAC
4	2110317438	A	B	92.75	91.14	1.02	0.95	60.3	4.87	19.04	AAAAAAA
	Total			267.24	267.25			173.71	19.71	54.32	

A = 100 to 97 %
B = 97 to 95 %
C = 95 to 90 %
D = 90 to 85 %
E = 85 to 80 %
F = less than 80 %

Ratio between PREDICTED energy and PRODUCED energy

Previous week in daily SoH

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Machine Learning for Fast Fault Recognition

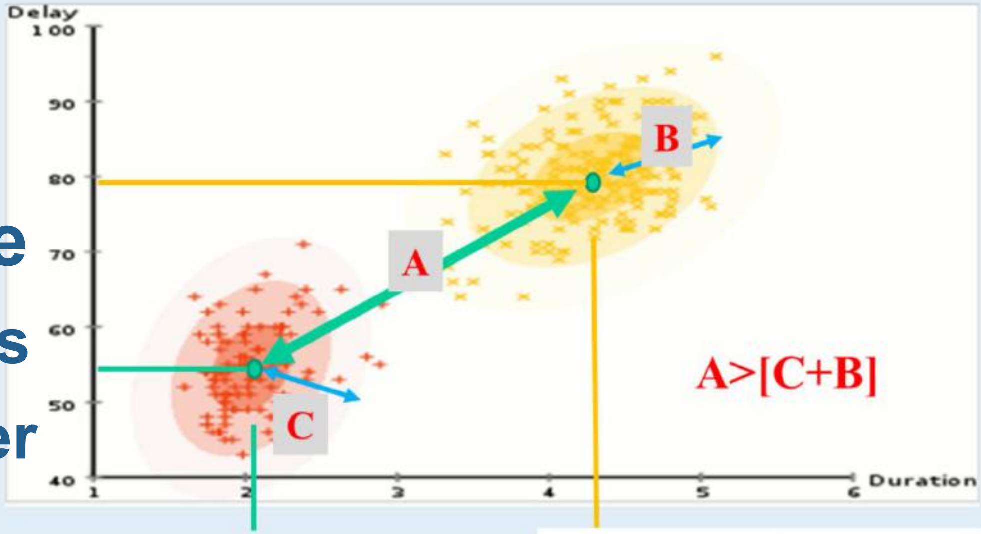
Regression Tree:

- Dependent Variable
  - Energy
- Independent Variable
  - Temperature
  - Humidity
  - Barometric pressure
  - Wind speed
  - Dew point
  - Rain
  - Sky view

Fault Prediction Using Clustering Algorithms

Clustering:

- Dependent Variable
  - AC Power
- Independent Variable
  - Weather parameters
  - All available inverter parameters
  - Yesterdays generation
  - Last hours generation
  - Trigonometric transformation



$$f(x) = \frac{1}{\sqrt{2\pi\sigma^2}} e^{\frac{-(x-\mu)^2}{2\sigma^2}}$$

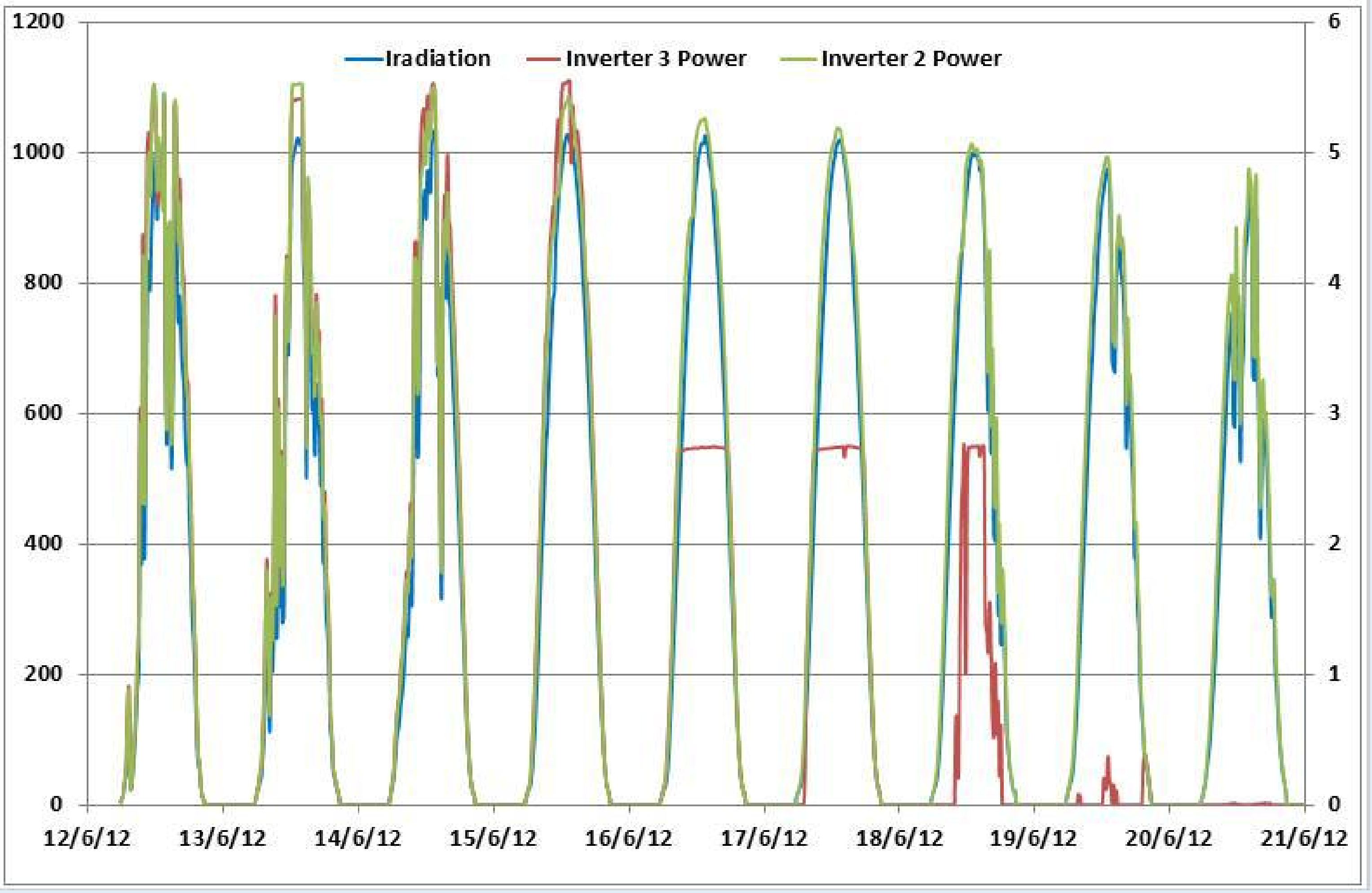
Fault Prediction Using Clustering Algorithms

1. Generate a clear data set
2. Choose an output value (dependent variable)
3. Add the following to each record
    1. Generation from previous hour
    2. Generation from this hour yesterday
    3. Day of the year expressed as:

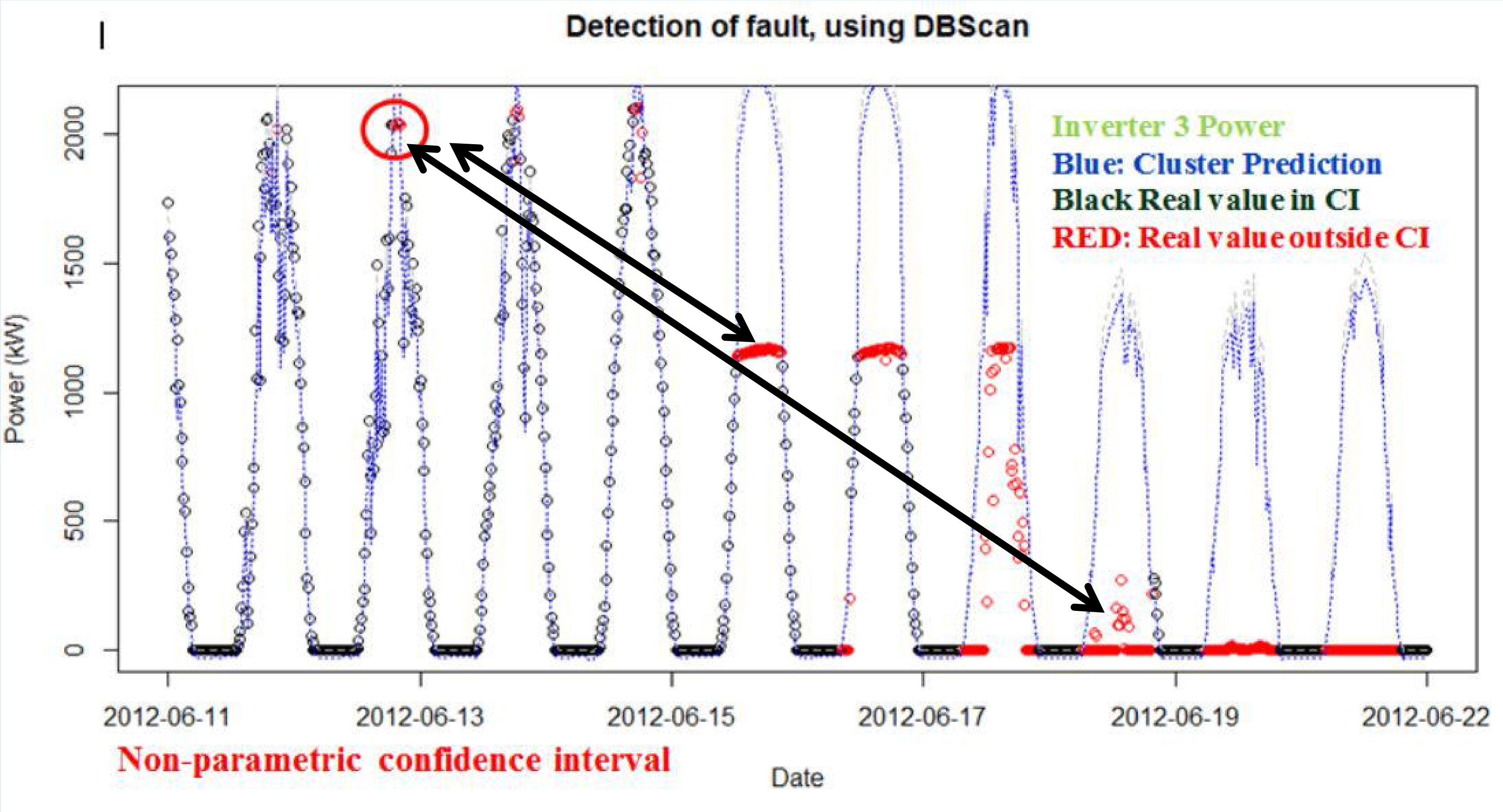
$$\sin\left(\frac{dayofyear \times 2 \times \Pi}{365}\right), \cos\left(\frac{dayofyear \times 2 \times \Pi}{365}\right)$$

4. Develop an equation for each cluster with CI of 99%
5. Test with new data; output should match data by 0.001
6. All new data run through equation; should fall within CI

Fault Prediction Using Clustering Algorithms



Fault Prediction Using Clustering Algorithms

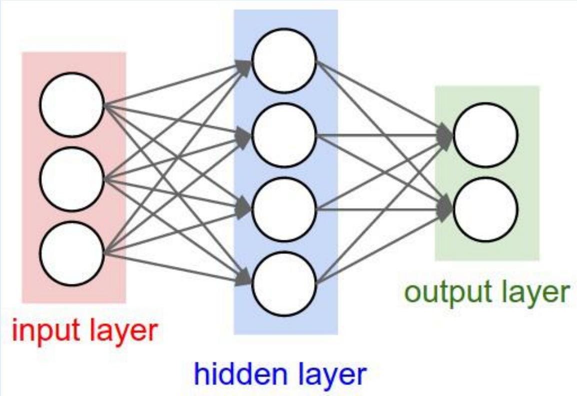


Fault Detection Using Artificial Neural Networks

Neural Network Algorithms

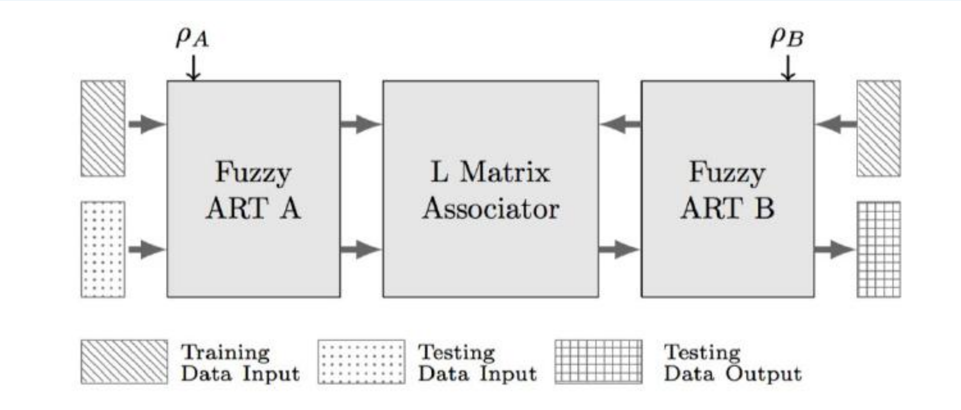
Three algorithms:

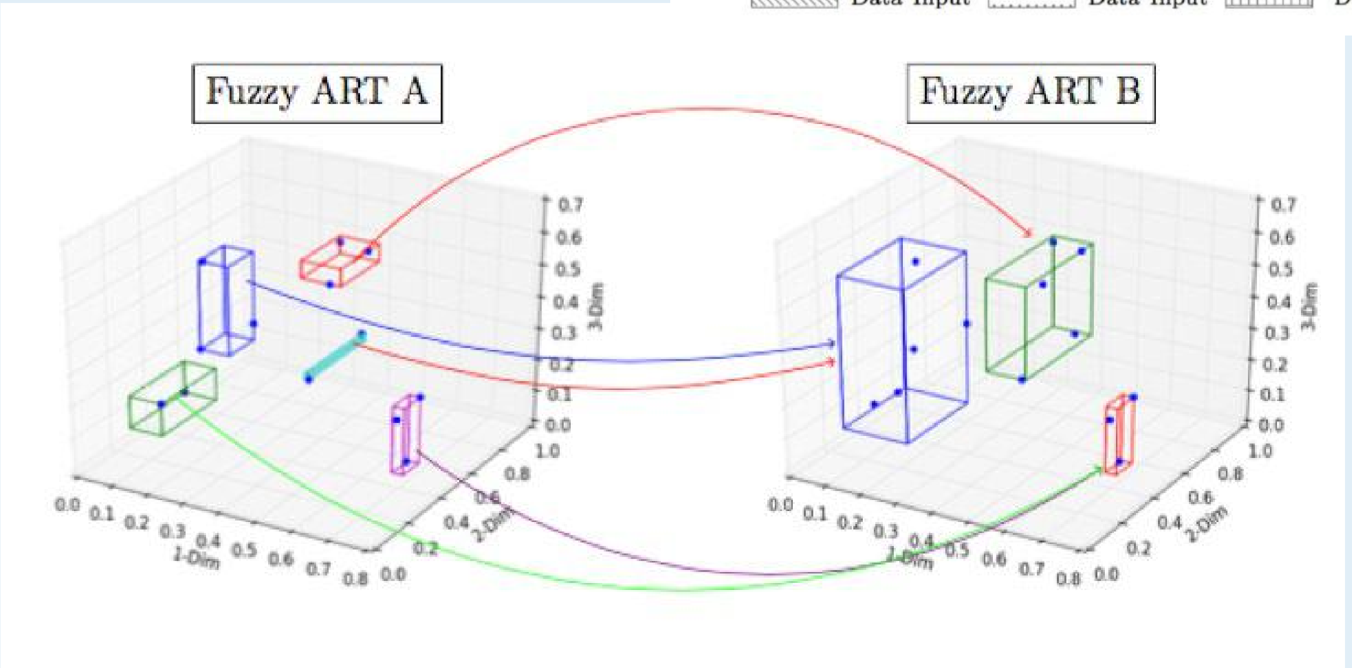
- LAPART - Laterally Primed Adaptive Resonance Theory
- SVM - Support Vector Machine
- GPR - Gaussian Process Regression



Fault Detection Using Artificial Neural Networks

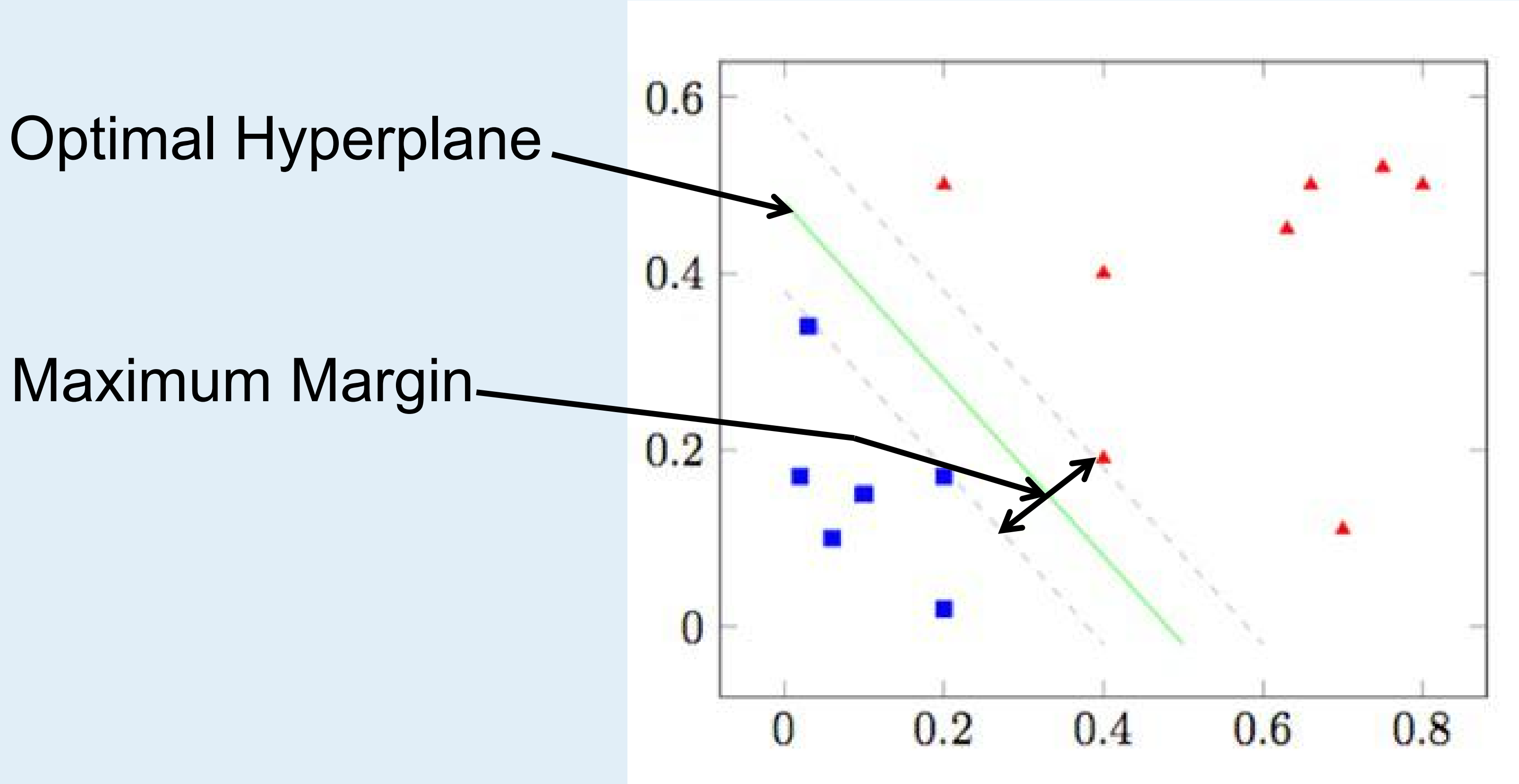
LAPART:





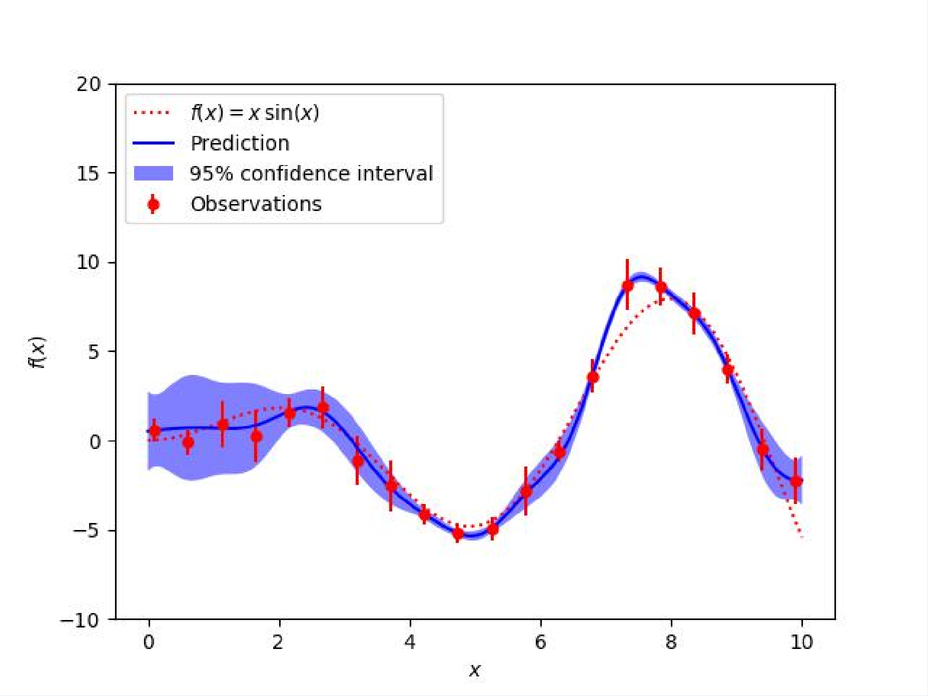
Fault Detection Using Artificial Neural Networks

Support Vector Machine (SVM):



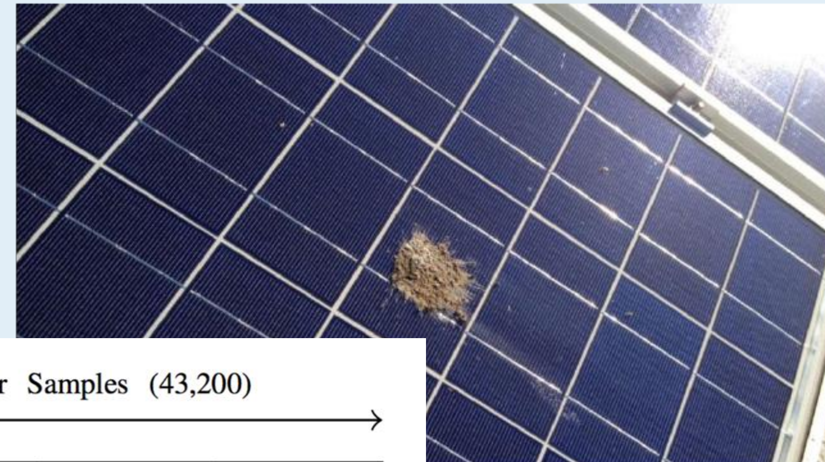
Fault Detection Using Artificial Neural Networks

Gaussian Process Regression (GPR):



$$f(x)=GP(\mu(x),k(x,x'))$$

Fault Detection Using Artificial Neural Networks



Total Number Samples (43,200)

1	Test (10,800)	Train (10,800)	Train (10,800)	Train (10,800)
2	Train	Test	Train	Train
3	Train	Train	Test	Train
4	Train	Train	Train	Test

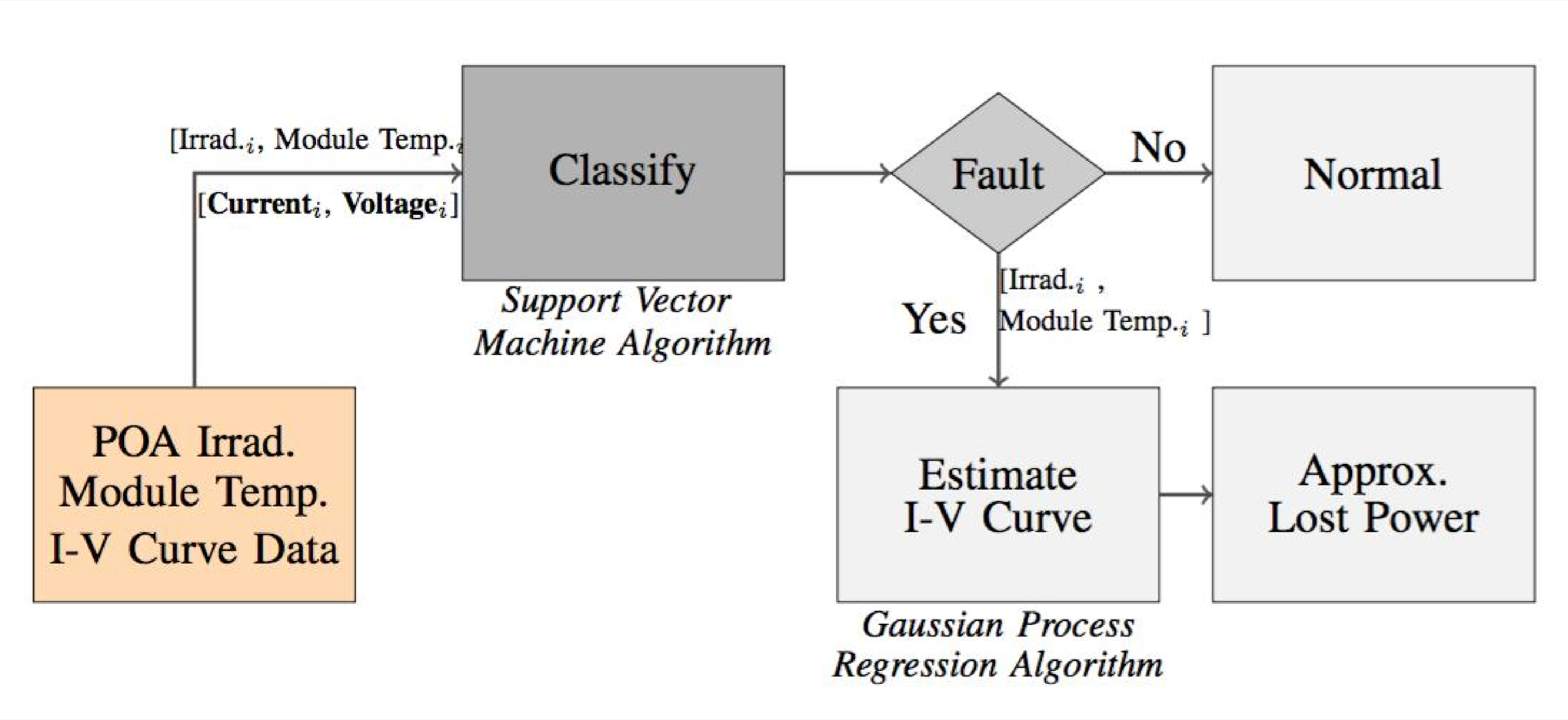
30 Days 1-min. data including 10,000 faults

LAPART

Fault Detection Using Artificial Neural Networks

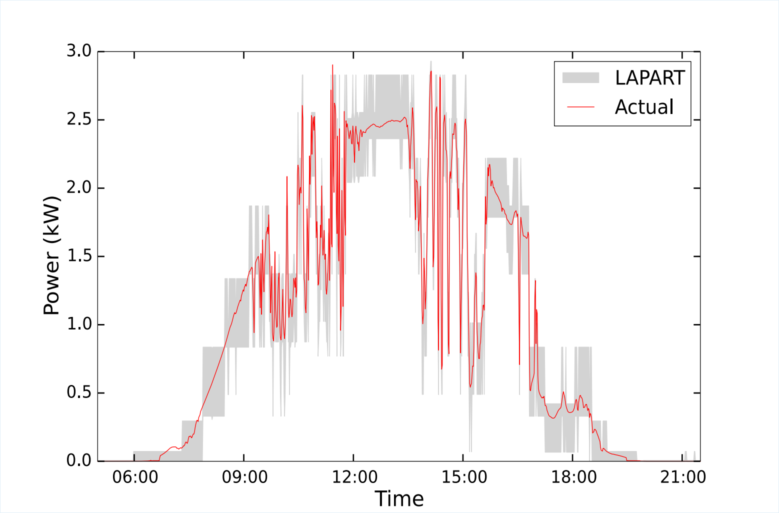
PV array – 10.8kWp; 4x10 modules
SVM

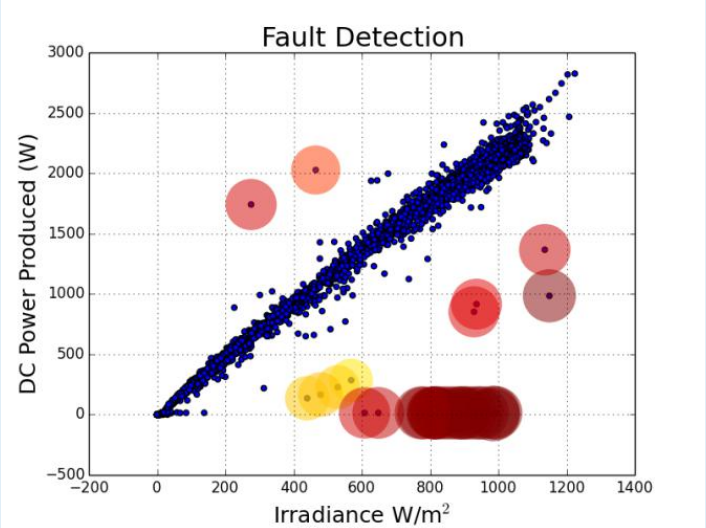
Fault Detection Using Artificial Neural Networks

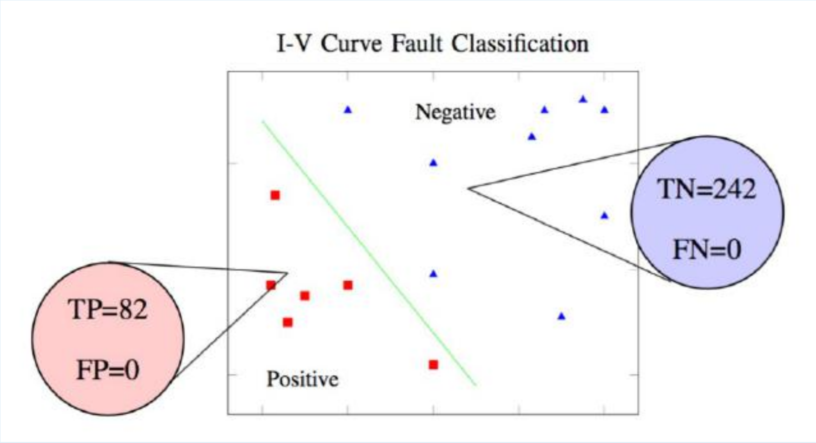


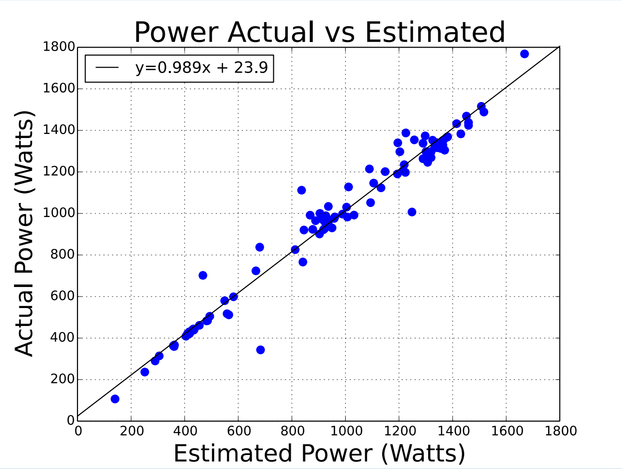
I-V Curve
SVM + GPR

Statistical Performance Monitoring









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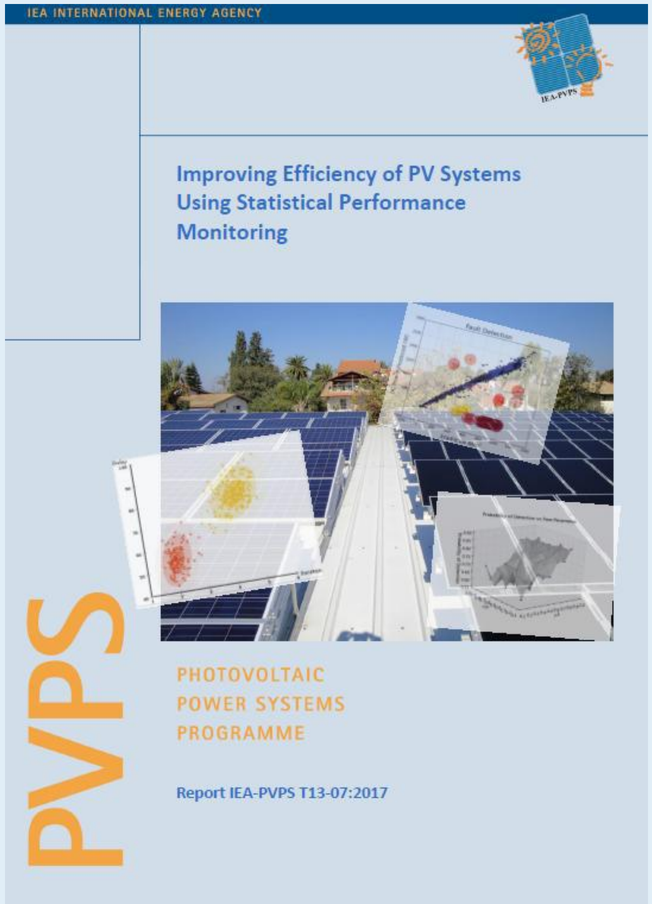

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