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PV O&M Optimization by AI Practice

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Company Profile

Sinogreenergy

Sinogreenergy acts as an Invest Platform for PV Project Development and O&M Service.

20MW Saltland Project in Chiayi, Taiwan

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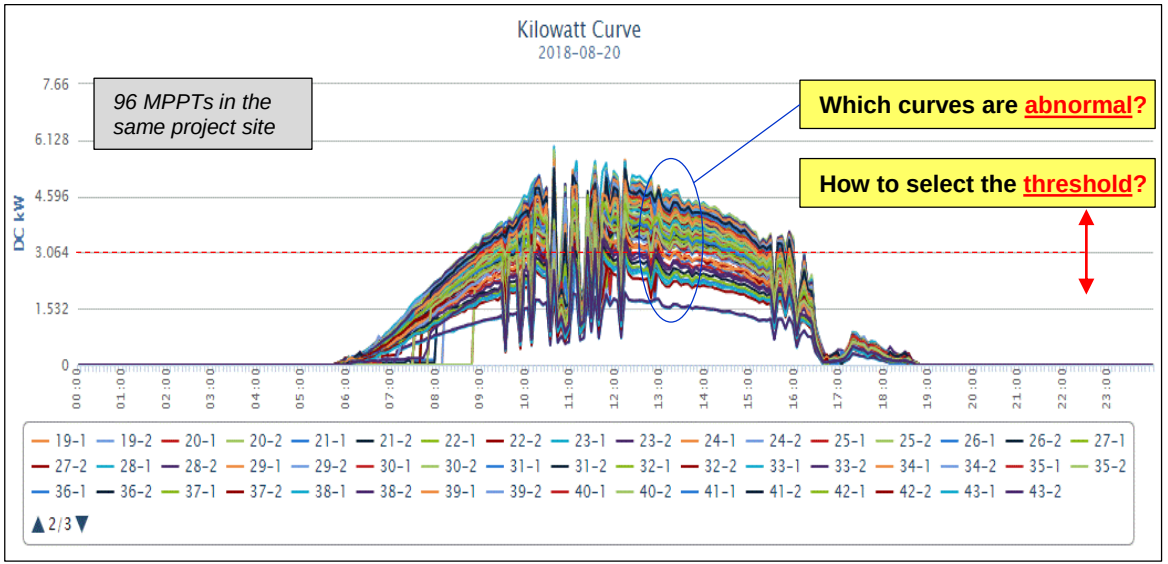
Background & Motivation

Typical Monitoring System

- By manual (visual) monitoring.
- Lacking of the failure mode diagnosis.
- Do not provide enough information for recovery plan.
- It is also difficult to monitor for many projects at the same time.



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Background & Motivation

Power Prediction Model

– by Machine Learning

Each MPPT model is built as the Finger-Print Model

Only 7-day Learning for each project

In-situ analysis completed in every 5-min

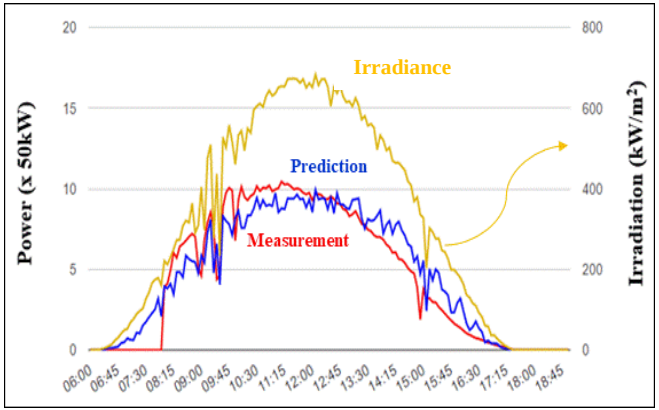
No need for Complex Input

- Location / Sea-Level
- Inclination / Azimuth Angle
- PV Module (type/vendor/PAN file)
- Inverter (type/supplier)

Input Parameters

- Solar Irradiance
- MPPT (P, I, V) & capacity

Modeling Result



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Power Prediction Model

Power Prediction

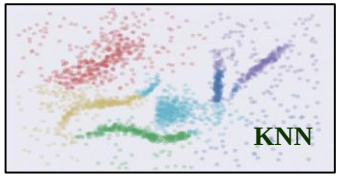
- *For 7-day model training: > 6 Million data-sets*
- *Computing within every 5 min for 120 projects (6,023 MPPTs)*

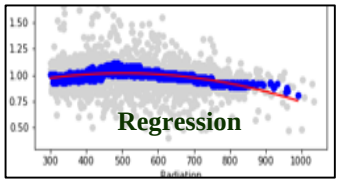
Artificial Intelligence (AI) - Machine Learning Algorithm

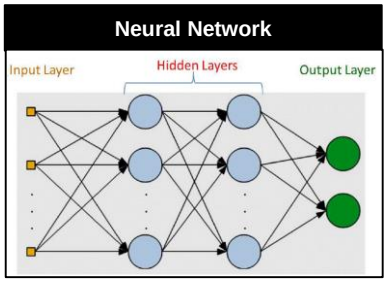
Statistical Method
- **SVM**
- **KNN**
  (K-Nearest Neighbors)
- **Regression**

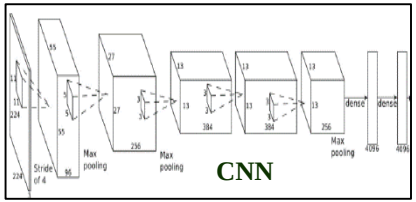
Artificial Neural Network (ANN)

Machine Learning
- **CNN**
- **RNN**
- **LSTM**
  (Long Short-Term Memory)









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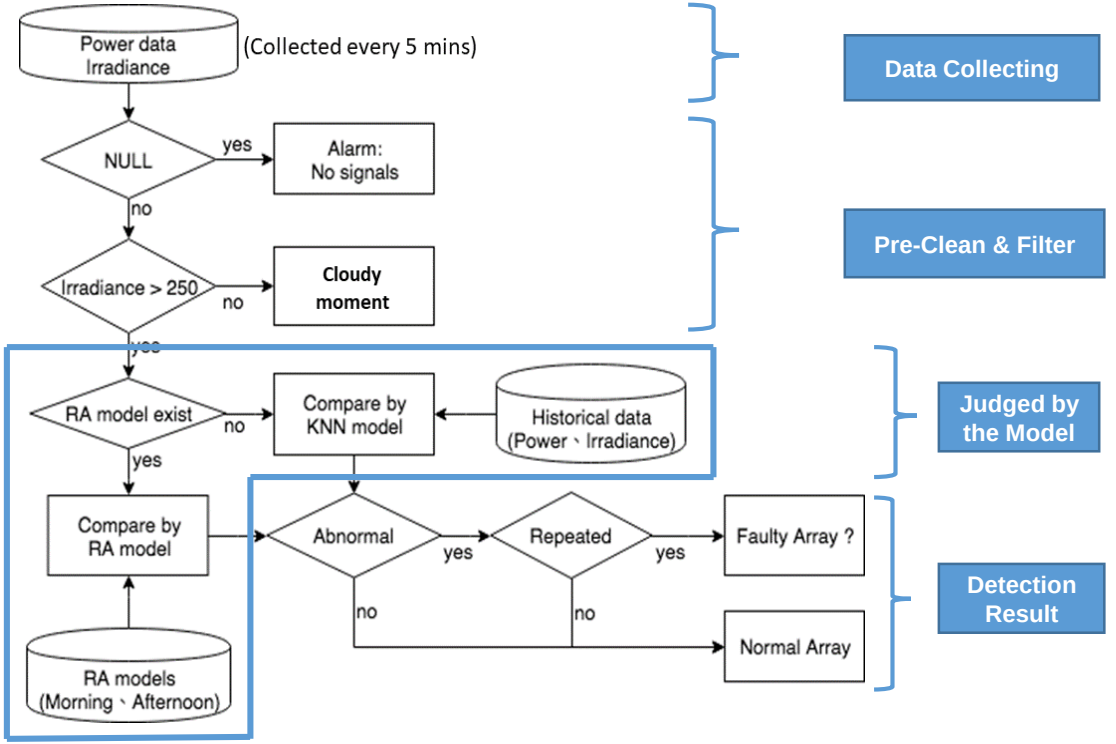
Fault Detection Algorithm

Fault Detection Flowchart



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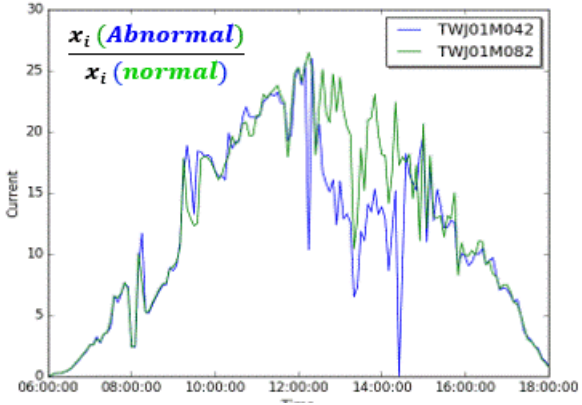
Detection & Diagnosis Algorithm

Detection & Diagnosis Algorithm

- *When the MPPT power is less than certain% of the prediction over the time frame, the MPPT is judged as Abnormal.*
- *The abnormal MPPT is then compared with other Same-Capacity MPPTs in the same project site.*
- *Not limited by specific inverter brands or data logger types.*

- *The Abnormal Ratio is introduced for Failure Mode Diagnosis..*



$$\text{Abnormal Ratio} = \sum_{i=1}^{n} \frac{x_i\ (abnormal)}{x_i\ (normal)} / n$$

x_i *(abnormal)*: feature value for low efficient equipment
x_i *(normal)*: feature value for normal equipment
n: number of data points

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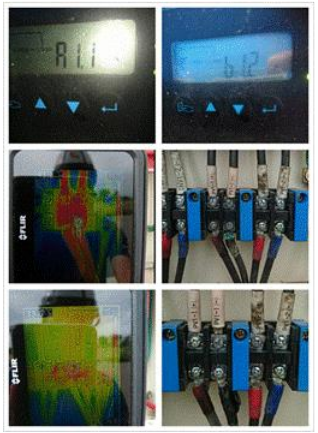
Failure Mode Diagnosis

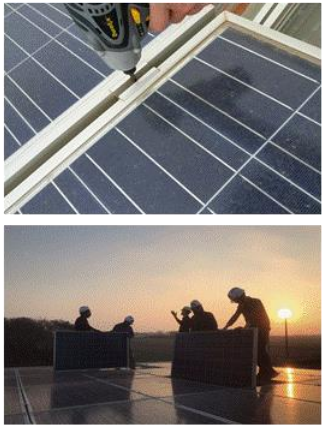
Knowledge Database

Every detected alert is checked by our O&M engineers in the field, and thus the failure mode is verified.

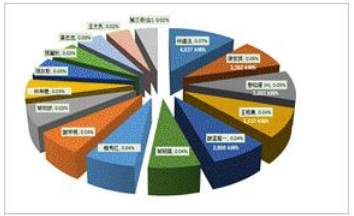
- **Problem Shooting**



- **Regular Maintenance**



- **Performance Review**



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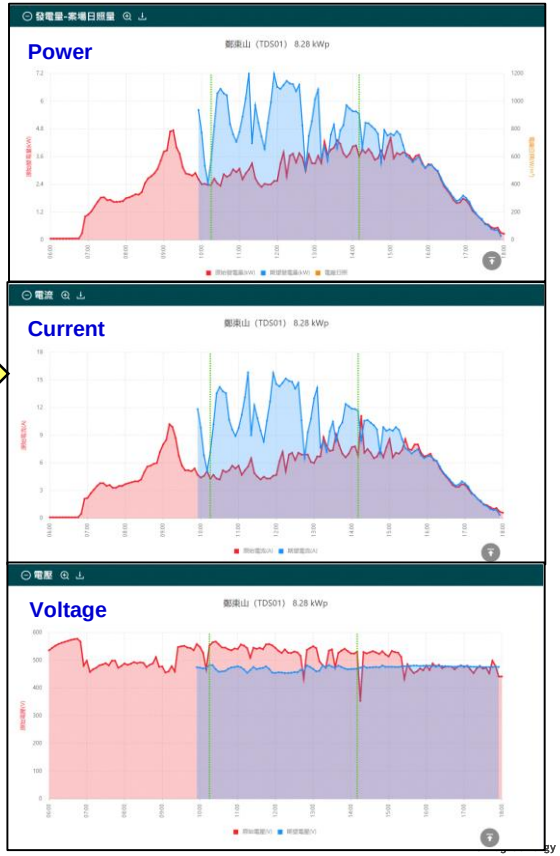
Fault Detection & Diagnosis (AI System)

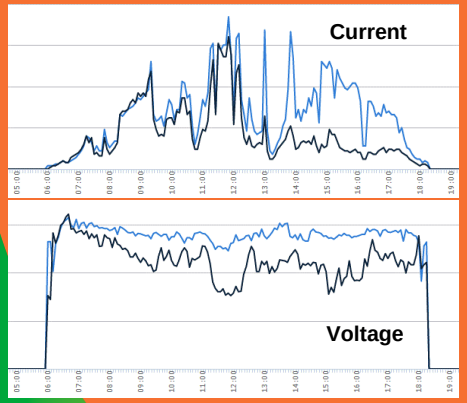
異常診斷資料　　電廠損失資訊

⊖ 異常診斷列表　　2021-08-12 ~ 2021-08-19

Project Name	MPPT ID	EQ. Capacity	Time Duration	Failure Mode Diagnosis	Progress Status	Selecting Defect Code by O&M Engineers
鄭東山	M091	8.28 kWp	2021-08-12 10:15 ~ 14:10 持續約 4 小時	熱降	已處理	THD01 / THD01 熱降(清潔風扇)
鄭東山	M092	8.28 kWp	2021-08-12 10:15 ~ 14:10 持續約 4 小時	熱降	已處理	THD01 / THD01 熱降(清潔風扇)
賴景村	M061	6.12 kWp	2021-08-19 12:00 ~ 14:50 持續約 3 小時	保險絲燒壞或迴路問題	尚未處理	尚未填寫回報結果 / 未填寫代碼
戴榮宗(萬東88)	M041	2.7 kWp	2021-08-19 10:15 ~ 12:05 持續約 2 小時	不穩定設備	已處理	UNS02 / UNS02 逆變器供電不穩



Failure Mode Verification



Shading or Module Dirty

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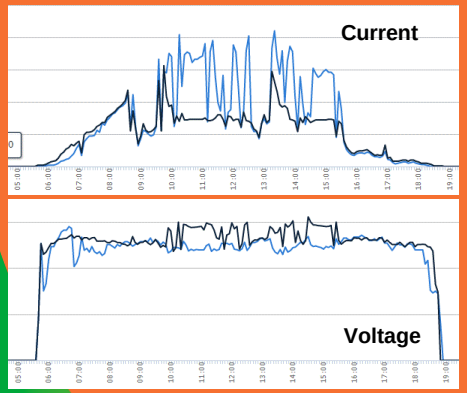
Inverter Thermal Degradation

Failure Mode Verification



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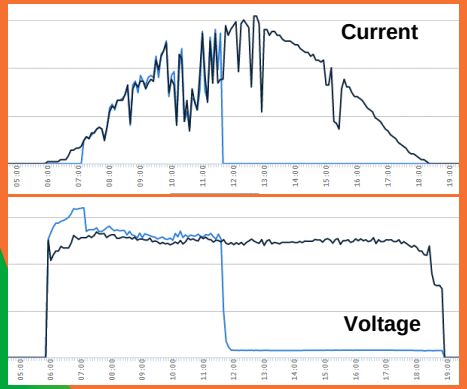
Fuse Burnt & String Issue

Failure Mode Verification



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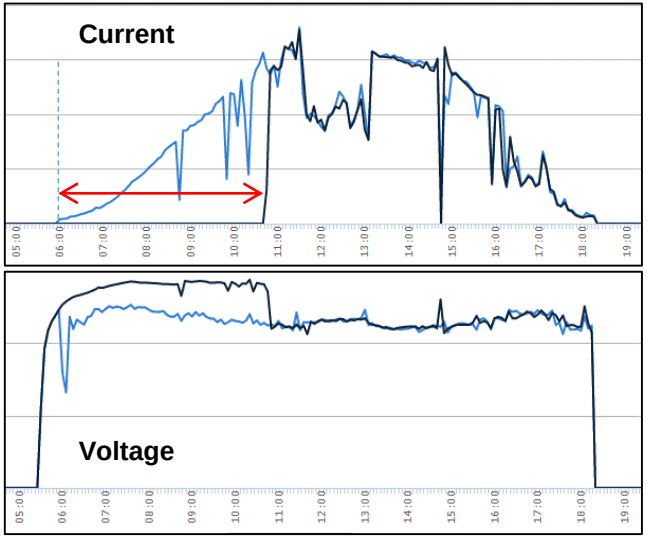
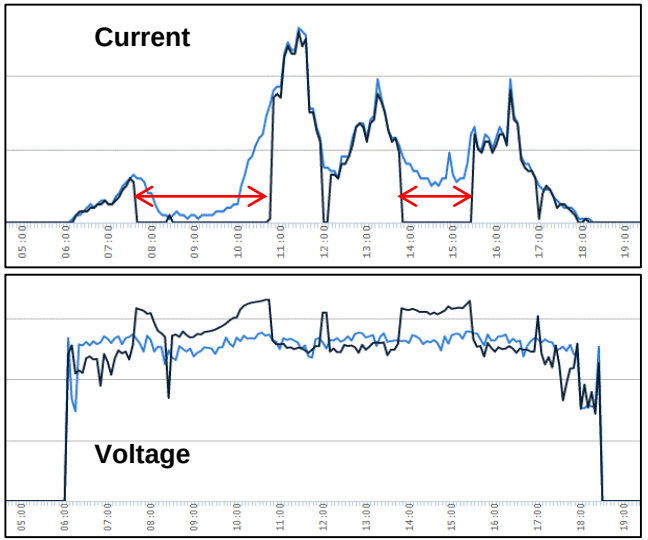
Failure Mode Verification

Inverter Issue

Late Operating Inverter



Faulty Inverter



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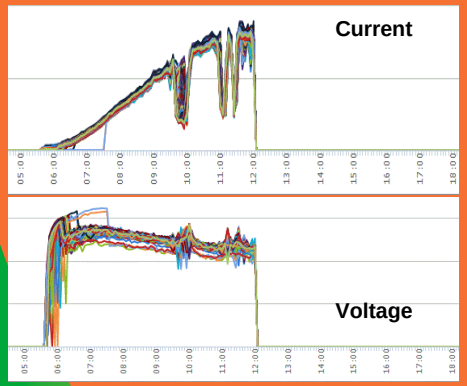
Outage & Utility Pole Issue

Failure Mode Verification



Utility Power Pole Faults

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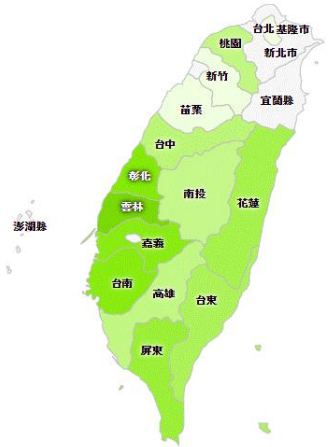
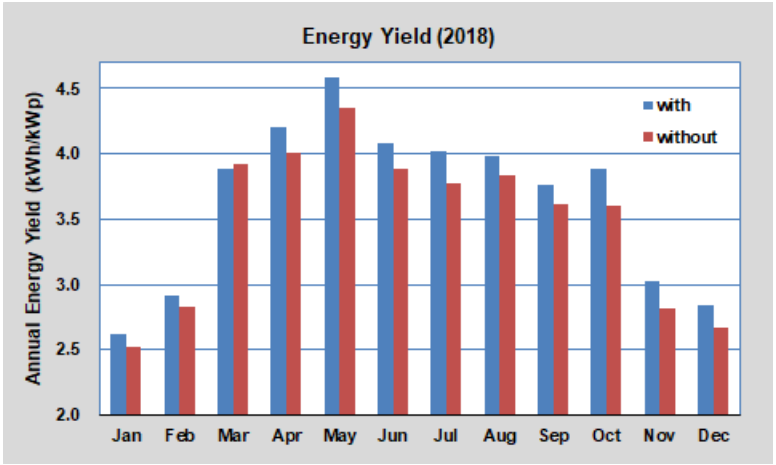
Energy Yield Improvement

Energy Yield Improvement

(First year implement result is 2018, V1)

- *120 projects With AI: 3.65 kWh/kWp (+4.7% ⬆)*
- *120 projects Without AI: 3.49 kWh/kWp*





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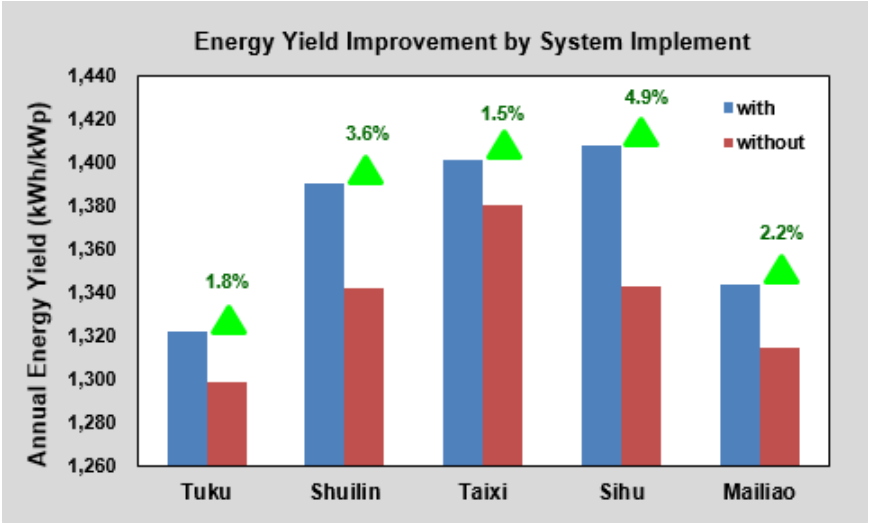
Energy Yield Improvement

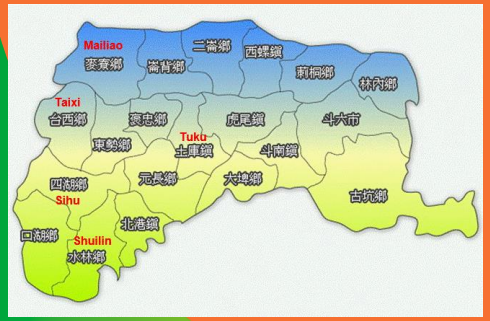
1.8% ~ 4.9% increased in Yunlin County

County	Township	With		Without		Benefit
		Annual kWh/kWp	Project Site (Q'ty)	Annual kWh/kWp	Project Site (Q'ty)	
Yunlin	Tuku	1,322	4	1,298	3	1.8%
	Shuilin	1,391	4	1,342	17	3.6%
	Taixi	1,401	11	1,381	18	1.5%
	Sihu	1,408	7	1,343	4	4.9%
	Mailiao	1,344	8	1,315	8	2.2%



Energy Yield Improvement

Comparison in the same Geographic & Weather Condition



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Fault Detection & Failure Diagnosis
(First year result is 2018, V1)

Detection & Diagnosis Precision

120 projects (39.2 MWp)

applied with 11 inverter brands and 9 module suppliers

- ✓ *The fault detection precision : 99.2%*
- ✓ *The overall failure mode diagnosis precision : 92.3%*

Equipment Faulty Alert	Total	TRUE	FALSE	Precision
	3558	3529	29	99.2%
Failure Mode	**Total**	**TRUE**	**FALSE**	**Precision**
Inverter Issue	1539	1489	50	96.8%
Thermal Degradation (Inverter)	233	218	15	93.6%
Shadowing	766	673	93	87.9%
Fuse Burnt / String Problem	332	318	14	95.8%
Outage for project site / Communication Error	61	58	3	95.1%
Other Faults	583	534	49	91.6%
Unable to Classify	74	23	51	31.1%
Sum	3588	3313	275	92.3%

"Shading" Diagnosis needs to be further improved.

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Experiment

Multiple Orientation PV Arrays

For roof-top project (< 500kWp), there is usually only one on-site pyranometer due to cost pressure, but there might be multiple orientations for PV arrays.



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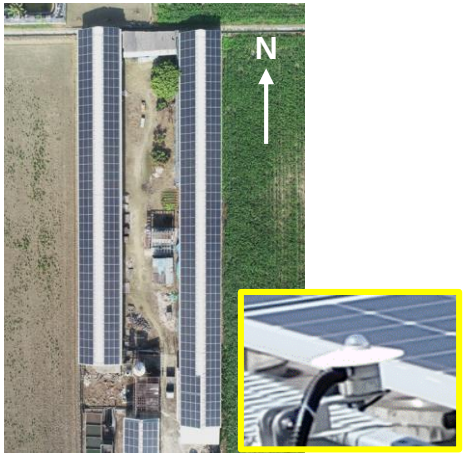
Experiment

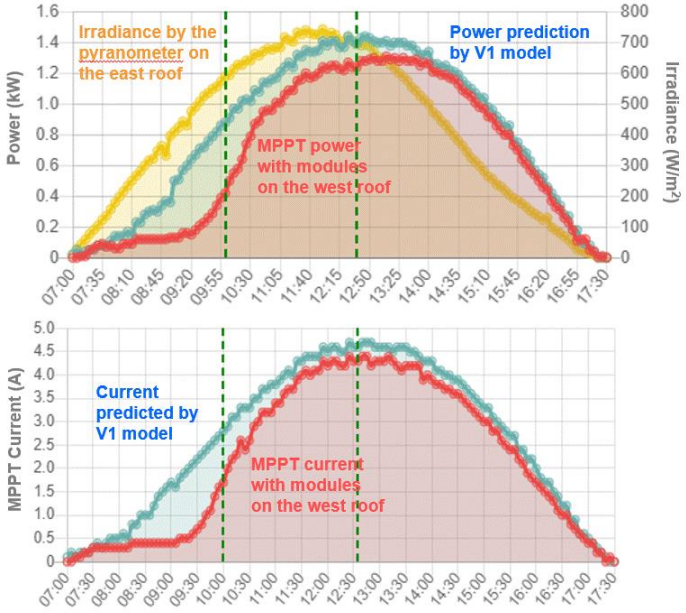
It explains why one-pyranometer irradiance model results in diagnosis mistake.

Diagnosis Mistake

*In the case, we apply **the Irradiance** by the **East-Roof** pyranometer.*

*The **West-Roof MPPT** has lower power and current than the prediction in the morning, therefore the AI performs **wrong diagnosis judgement** as **Shading or Module dirty** failure mode.*



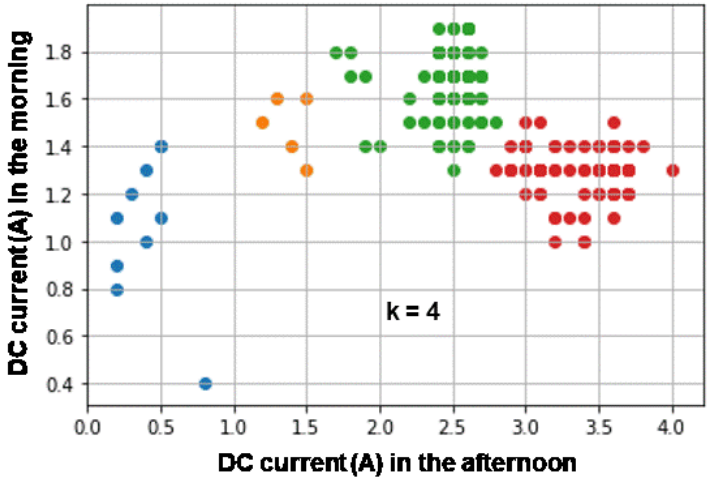


Experiment

$$RA_t = \frac{P_t/P_0}{IRR_t/IRR_0}$$

Simulated POA Irradiance

- ***To distinct PV arrays in each orientation, the data pre-treatment by Clustering algorithm is performed.***
- ***Then it is assumed that normal MPPTs might have the equal RA in other orientations.***
- ***The simulated POA irradiance in other orientations would be obtained by the inversion from RA equation.***



All MPPTs in the project are separated into 4 orientation groups.

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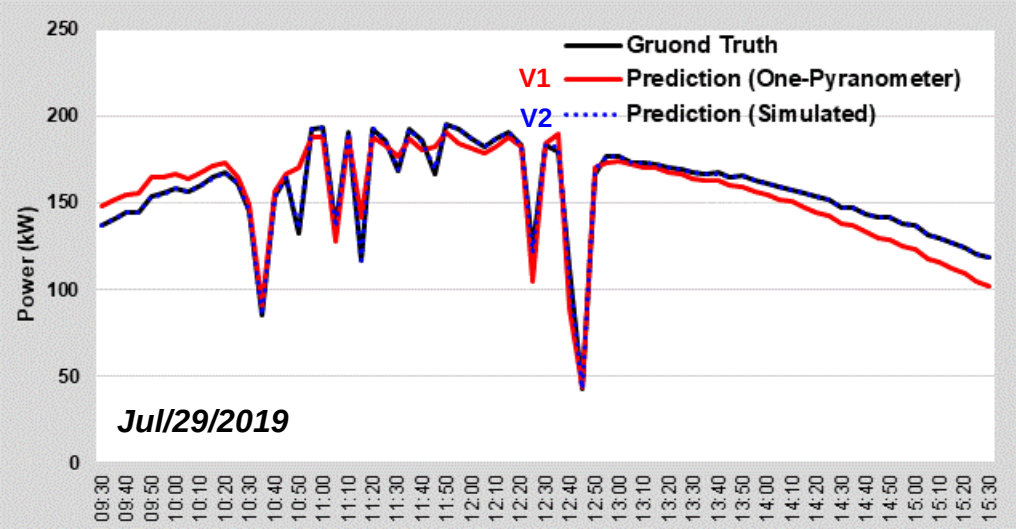
Power Prediction (V2)

Experiment

V1 : One-Pyranometer Irradiance

V2 : Simulated POA Irradiance from 2019

The power prediction with simulated POA irradiance (V2) fits quite well with the real power output (ground truth).



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Power Prediction

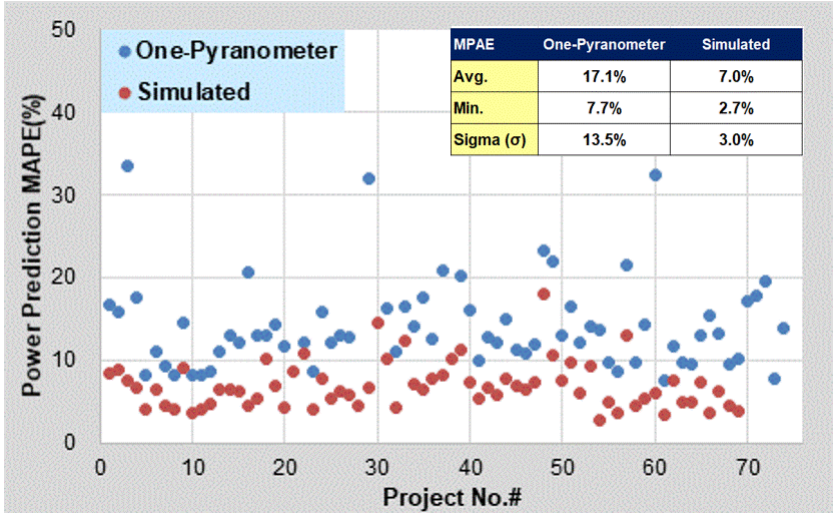
Result

The comparison of the power prediction error by the indicator of MAPE with 74 projects

***M**ean **A**bsolute **P**ercentage **E**rror*

$$\text{MAPE}\ (\%) = \frac{100}{n}\sum_i^n \left|\frac{\bar{p}_i - p_i}{p_i}\right|$$

- ***Power Prediction Error (MAPE) is obviously reduced by Simulated POA Irradiance model (V2).***
- ***The MAPE for one-Pyranometer model (V1) is 17.1%***
- ***The MAPE for Simulated Irradiance model (V2) is only 7.0%***



MPAE	One-Pyranometer	Simulated
Avg.	17.1%	7.0%
Min.	7.7%	2.7%
Sigma (σ)	13.5%	3.0%

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Detection and Diagnosis Precision

Result

V1 : One-Pyranometer Irradiance

V2 : Simulated POA Irradiance

- ✓ ***The fault detection precision for V1 and V2 are almost the same.***
- ✓ ***The overall precision of Failure Mode Diagnosis : 94.0% (+1.7%)***
- ✓ ***The precision of Shading issue : 92.8% (+5.0% improved)***

Fault Detection		Total	True	False	Precision
	V1	3,558	3,529	29	99.2%
	V2	11,181	11,028	153	98.6%

Failue Mode Diagnosis		Judged Q'ty		Precision		
		V1	V2	V1	V2	V2 - V1
Burnt Fuse or String Issue	True	318	664	95.8%	96.2%	0.4%
	False	14	26			
Shading or Module Dirty	True	673	1,485	87.9%	92.8%	5.0%
	False	93	115			
Inverter Issue	True	1,489	5,334	96.8%	95.6%	-1.2%
	False	50	248			
Thermal Degradation (Inverter)	True	218	2,021	93.6%	94.0%	0.4%
	False	15	129			
Outage or Communication Error	True	58	99	95.1%	97.1%	2.0%
	False	3	3			
Other Abnormality	True	557	768	84.8%	85.0%	0.2%
	False	100	136			
Sum	True	3,313	22,277	92.3%	94.0%	1.7%
	False	272	1,115			

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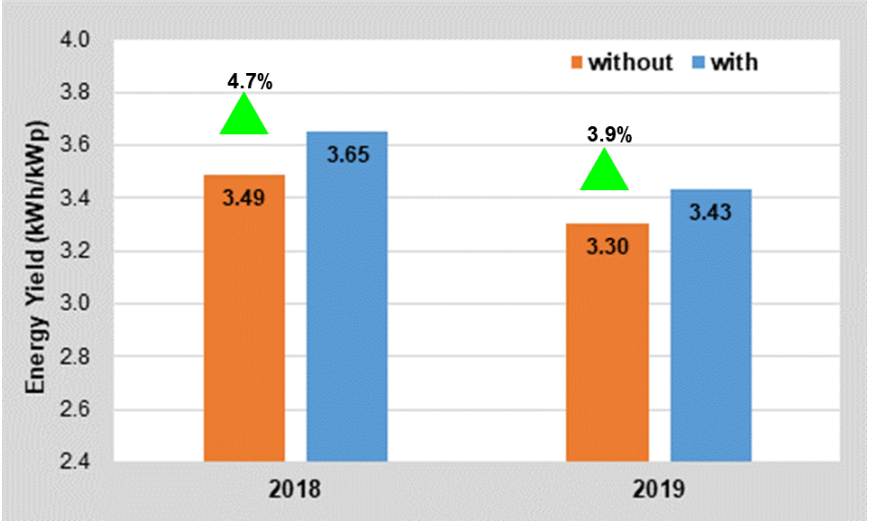
Energy Yield

Result

Test Group :
120 Projects with AI solution
39.2MW (6,023 MPPTs)

Control Group :
another randomly selected
120 Projects without AI

- ***V1 (2018): 0.16 kWh/kWp (4.7%) increased.***
- ***V2 (2019) : 0.13 kWh/kWp (3.9%) improved.***



Note: The solar irradiation in 2019 is 7.6% decreased compared to that in 2018.

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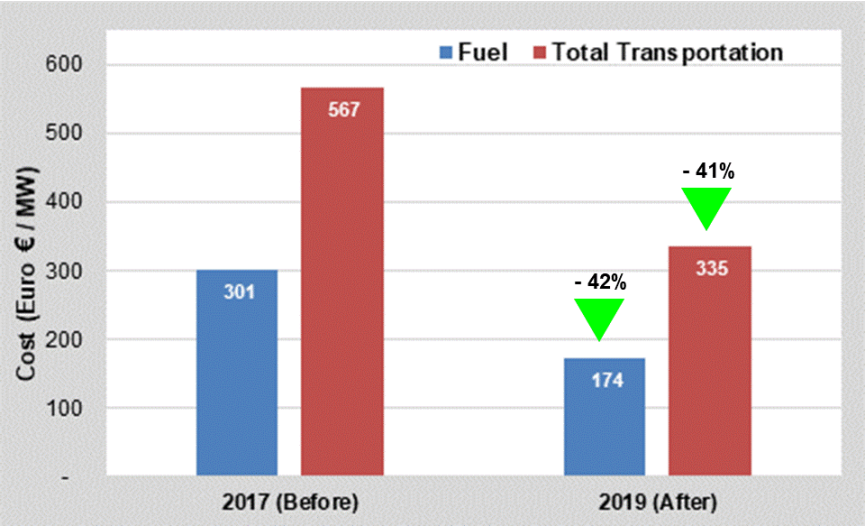
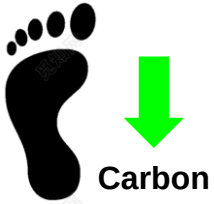
O&M Transportation Cost

Result

The transportation cost includes vechicle fuel, mass-transit, parking and vehicle maintenance costs.

- ***After AI implantation, vehicle fuel and transportation cost reduce 42% and 41% respectively.***
- ***Lower carbon footprint O&M task is achieved.***





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Conclusion

Summary

- *120 projects (39.2MW) are implanted more than two years.*
- *The precision of fault detection : 98.6%*
- *The precision of failure mode diagnosis : 94.0%*
- *The precision of Shading diagnosis by simulate POA irradiance (V2) model is 92.8% (+5% improved).*
- *Energy Yield is 3.9%~4.7% improved.*
- *Low carbon footprint O&M is achieved by 41% transportation cost reduction.*

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Thanks for your Attention !

Acknowledgments to Our Team