Hierarchical Fault Detection and Multimodal Diagnosis in Large-Scale Photovoltaic Systems

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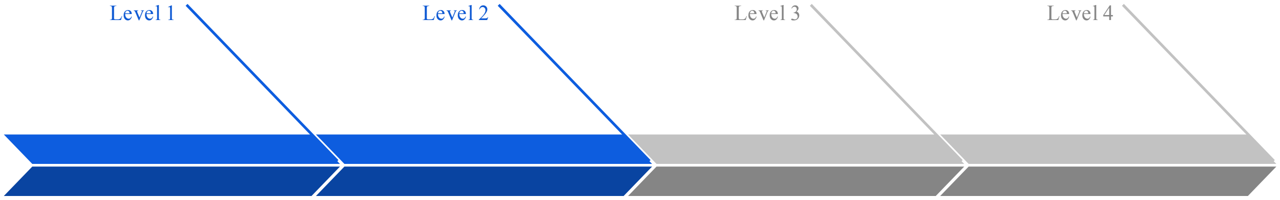
Outline

—FDD (Fault Detection and Diagnosis) in large-scale photovoltaic (PV) systems

Intelligent Operation and Maintenance (O&M) in large-scale Photovoltaic (PV) Systems



Hands-on level	Data level	Insight level	Knowledge level
5S and Kaizen model	Learn manufacturing systems and six-sigma	Predictive analysis	Decision making and optimization

FDD:

- **Eeffectiveness**
- **Reliability and robustness against unforeseen circumstances**

1st Challenges: diverse and complex faults

Glass (front-cover) breakage | Grassing shading | Building shading | Hot spot | Surface soiling

Fig. 1: Commonly occurred faults in PV system.

2nd Challenge: limited information collected

SCADA systems only provide <u>current</u> and <u>voltage</u> information at individual string level

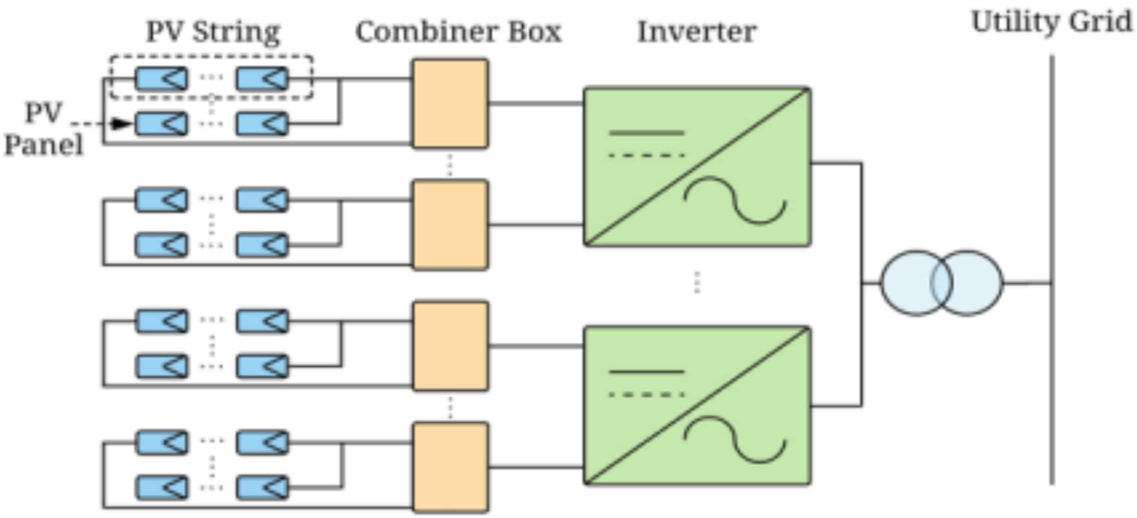


Fig. 2: Diagram of a grid-connected large-scale PV system.

FDD Solution overview

- **Data preprocessing**
- **Hierarchical fault detection**
- **Multimodal fault diagnosis**

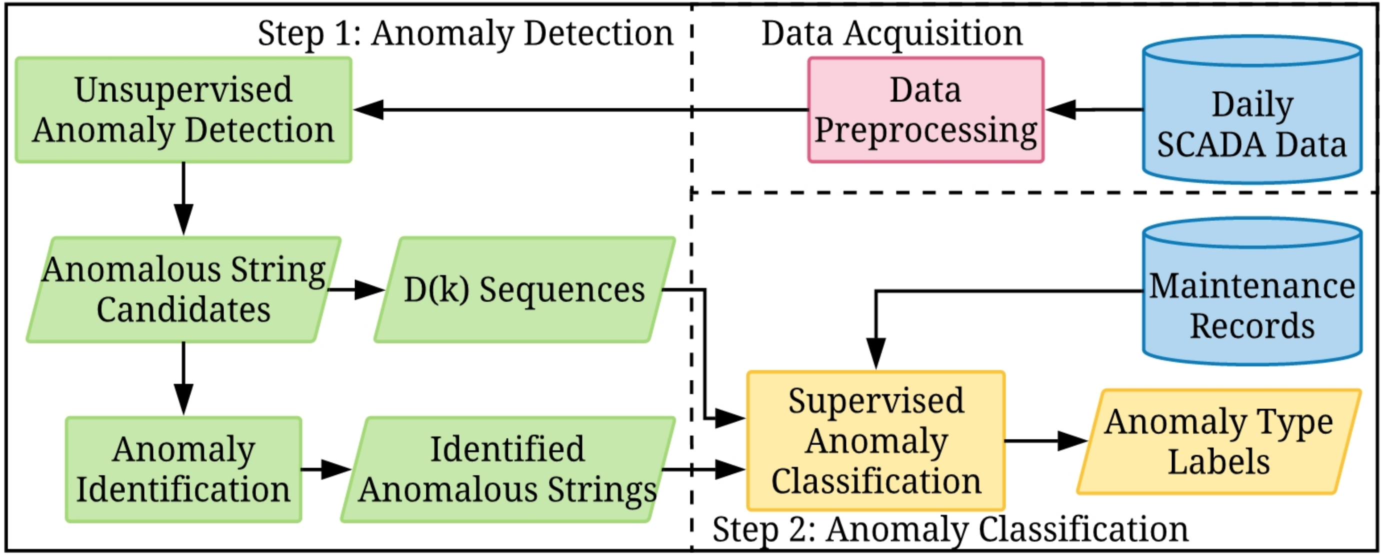


Fig. 3: Overview of the proposed FDD solution for PV systems.

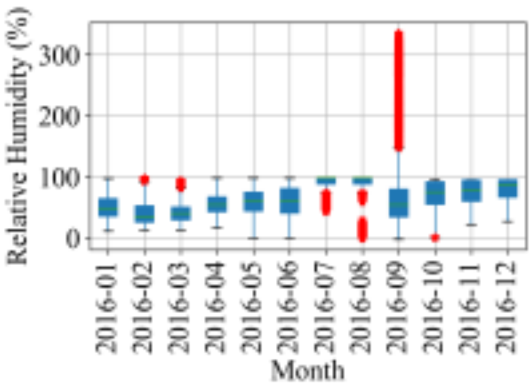
Data preprocessing

Data cleaning

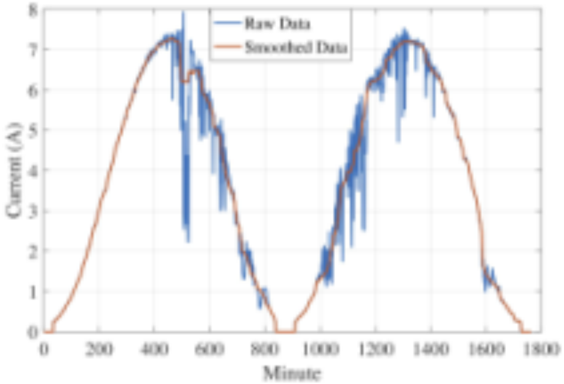
Data filtering

Data downsampling

Remove errors



Smooth noise caused by environmental variations (e.g., drifting clouds) and measure variabilities



Reduce computation cost

- 1min
- 5 min
- 10 min

Motivations of fault detection

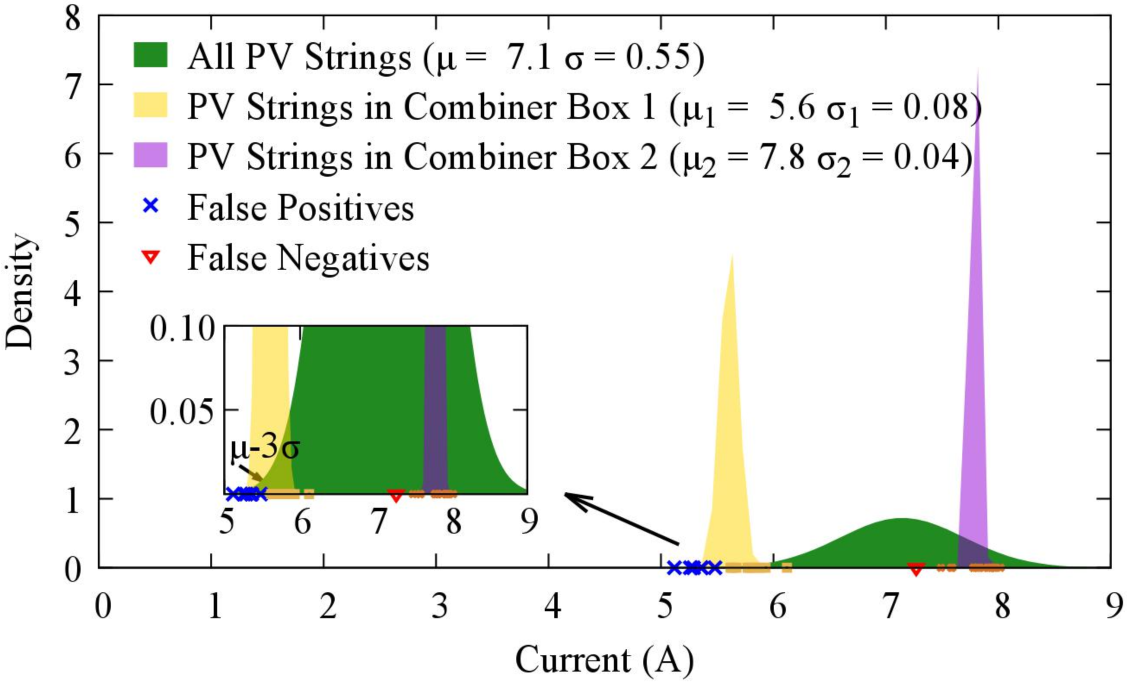


Fig. 4: Gaussian distributions of PV strings at the same timestamp for a 39.36 MWp PV system

Hierarchical detection:

- **Local**: combiner box level

- **Global**: system level

Fault detection

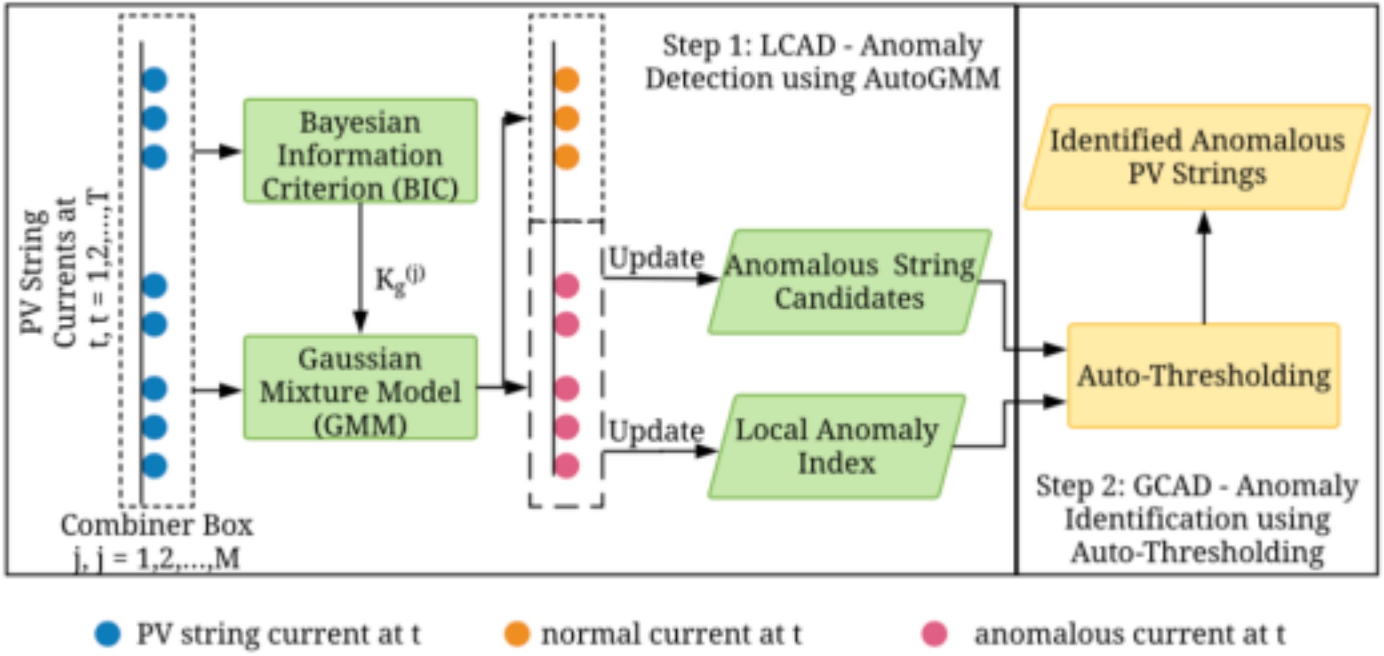


Fig. 5: Diagram of fault detection process.

A case study of hierarchical fault detection

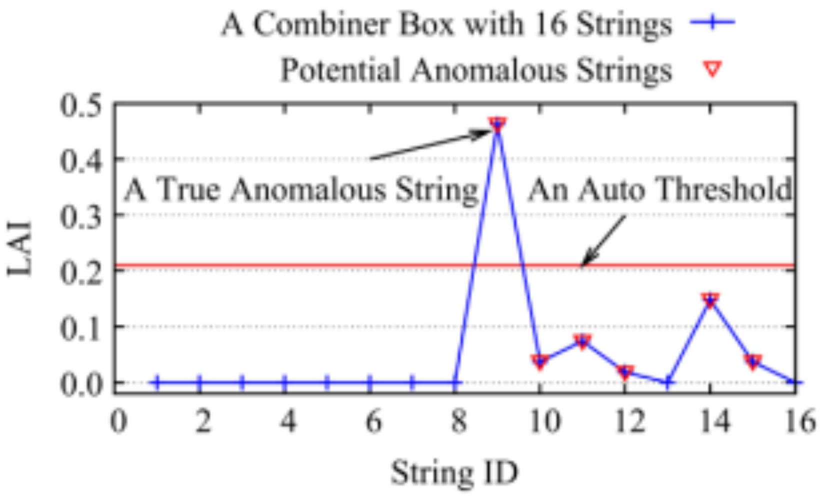


Fig. 6: A case study: local anomaly indices for 16 strings in the same combiner box.

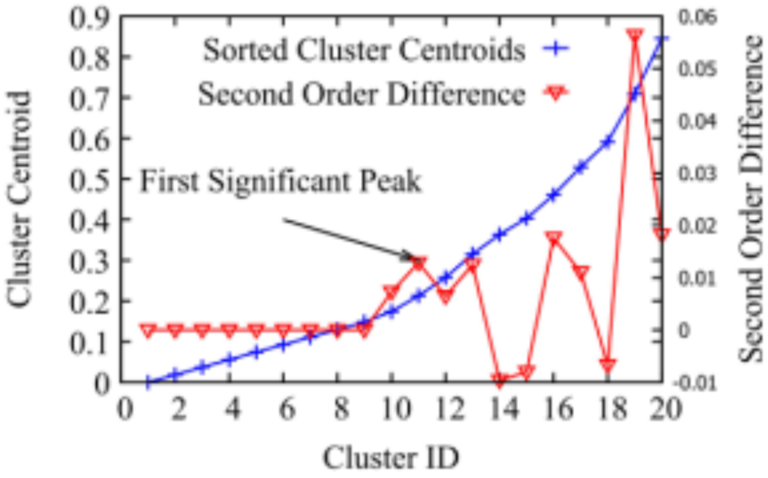
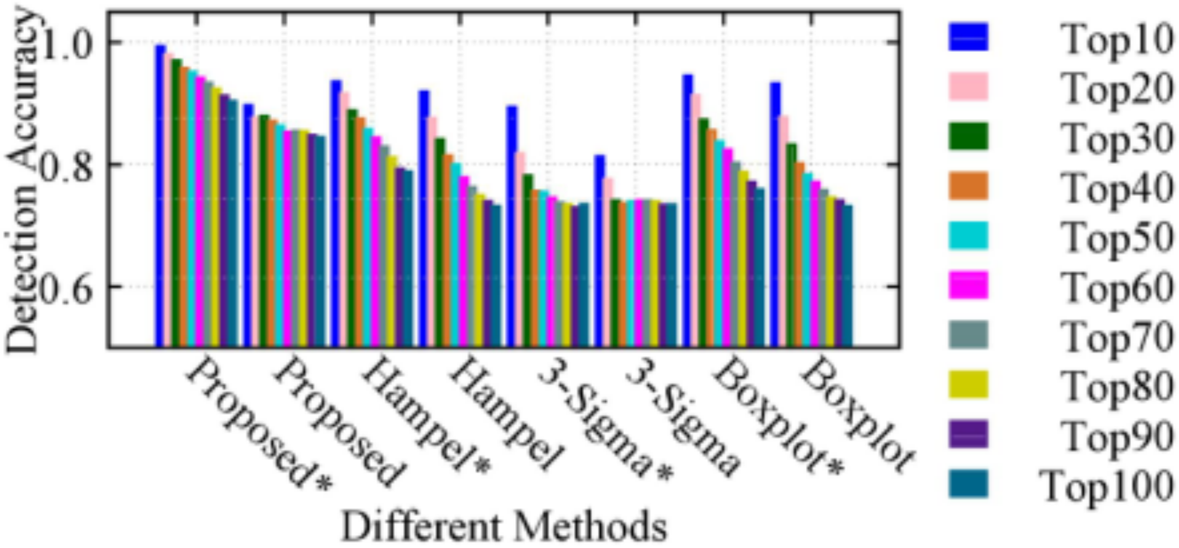


Fig. 7: An illustration of automatically identifying local anomaly index threshold.

Overall performance of fault detection



Improved detection accuracy:
from 78.8% to 90.2%

Fig. 8: Detection accuracy with top-k faults.（* indicates the use of filtered data）

Sensitivity analysis

- The proposed solution achieves **higher detection accuracy**.
- This accuracy exhibits **less variation** under the same conditions.

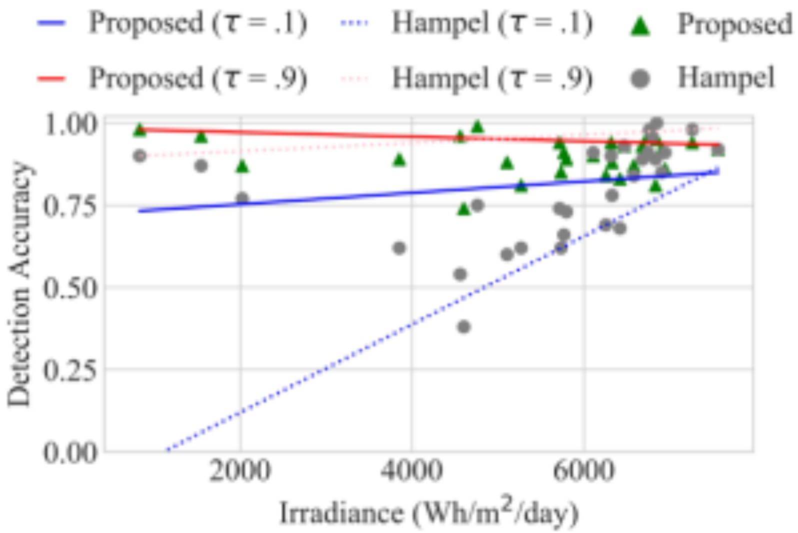


Fig. 9: Fault detection accuracy vs. irradiance.

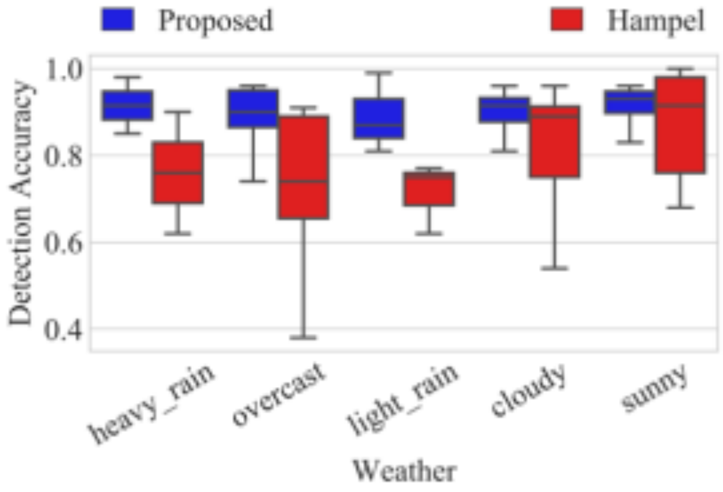


Fig. 10: Fault detection accuracy vs. weather.

Motivations of fault diagnosis

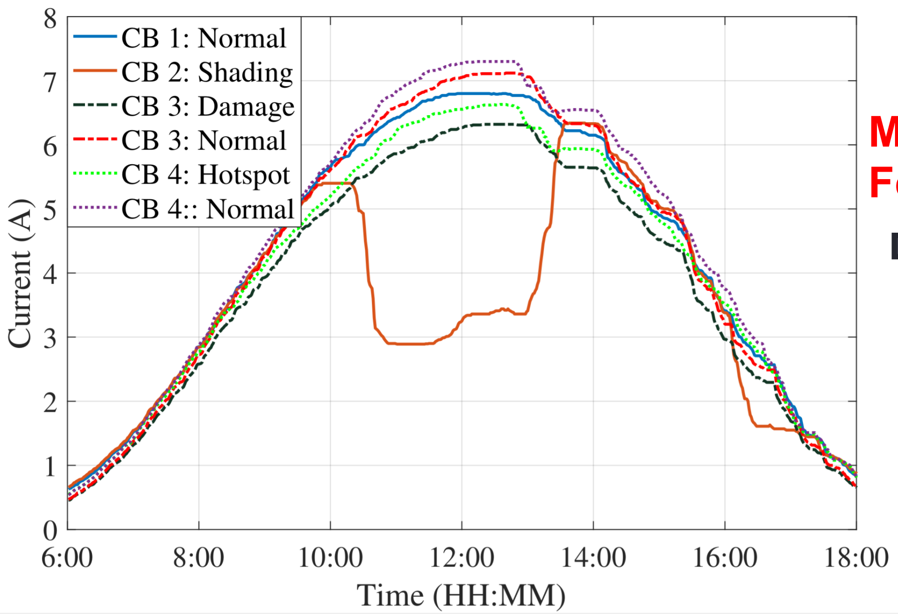


Fig. 11: Commonly occurred faults.

Multimodal Features

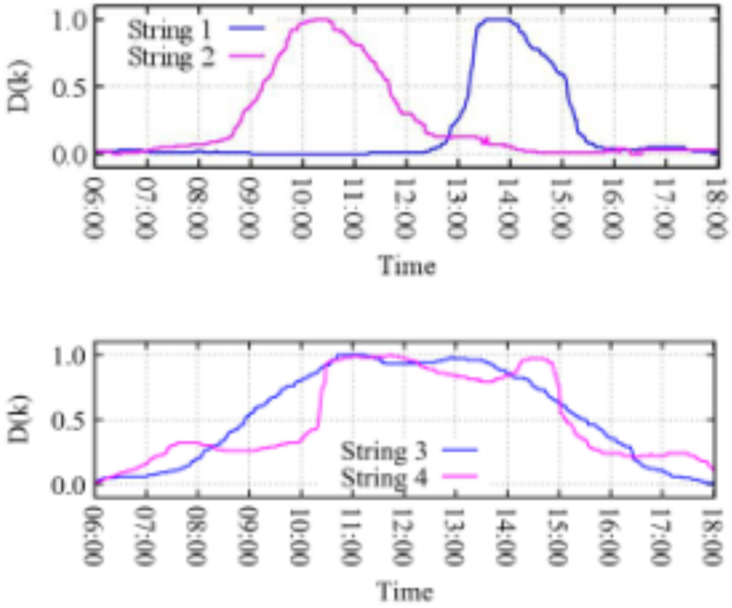


Fig. 12: Scaled D(k) sequence examples for two building shading faults (string No.1 and No.2), a hot spot fault (string No. 3), and a grassing shading faults (string No. 4).

Visualization of features and confusion matrix

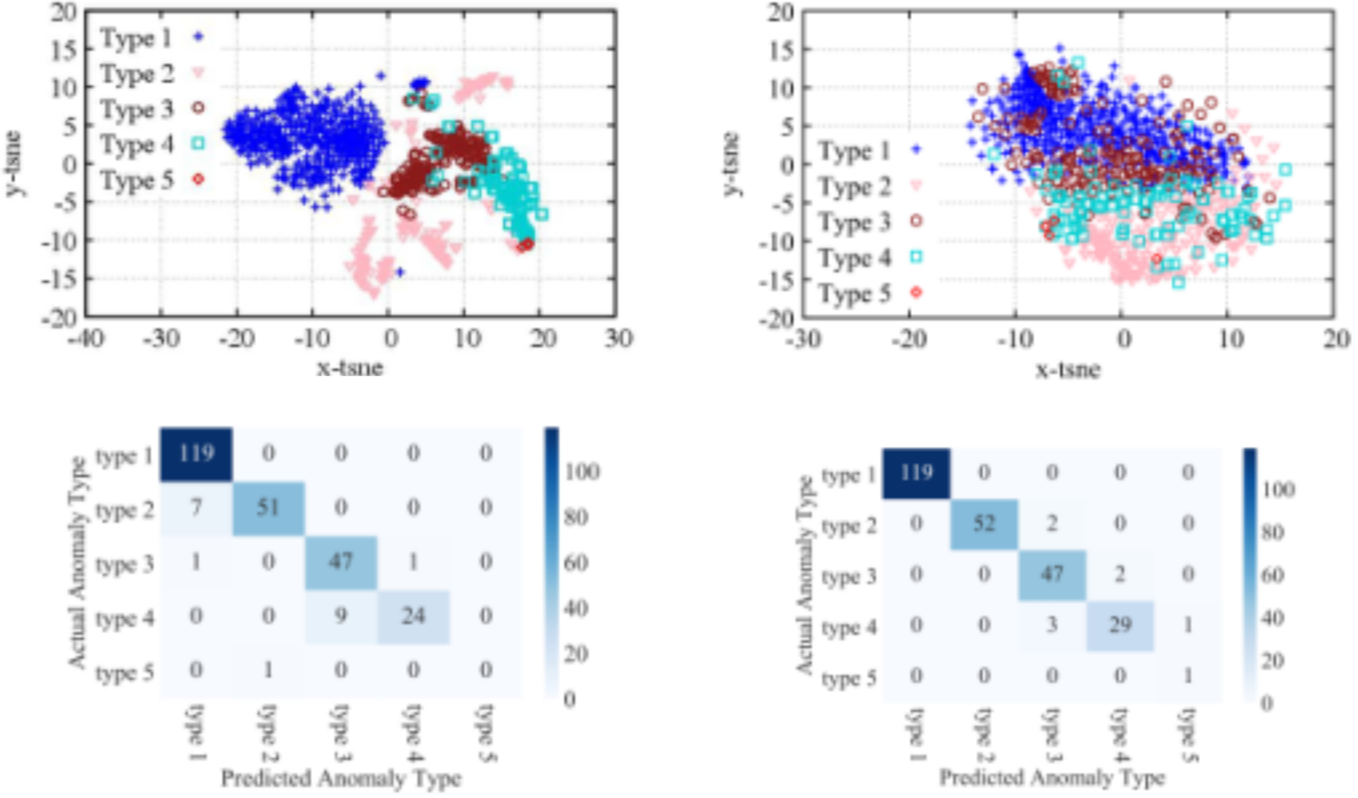


Fig. 13: Visualization of features (upper), confusion matrix (bottom), based on D(k) features (left), and based on multimodal features (right).

Fault diagnosis

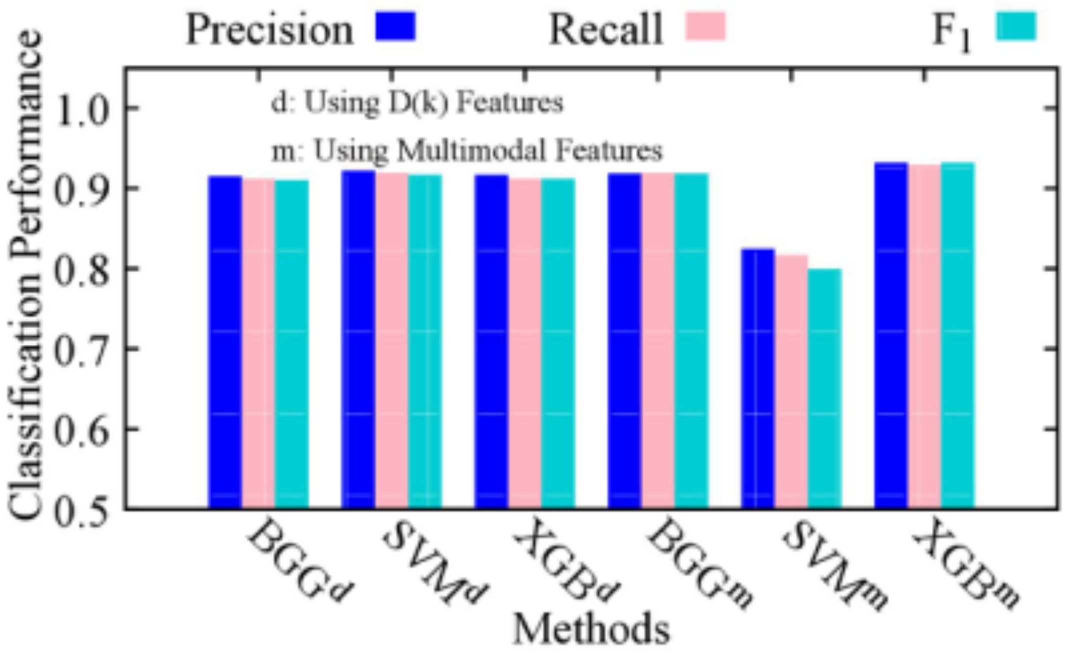


Fig. 14: Classification performance of different methods.

To the best of our knowledge, this is the first work that uses SCADA data to classify commonly occurring anomalies at the PV string level in large-scale PV systems.

- **Precision: 93.0%**
- **Recall: 92.8%**

Automatic soiling loss quantification

Under soiling conditions, the lowest mean relative error (MRE) of the estimated power production:

1. Drops from 0.315 (using the soiling- station-based method) and 0.075 (using the CPR-based method) to **0.007** at one PV site.
2. At another PV site, the MRE drops from 0.452 (using the soiling-station-based method) and 0.061 (using the CPR-based method) to **0.046**.

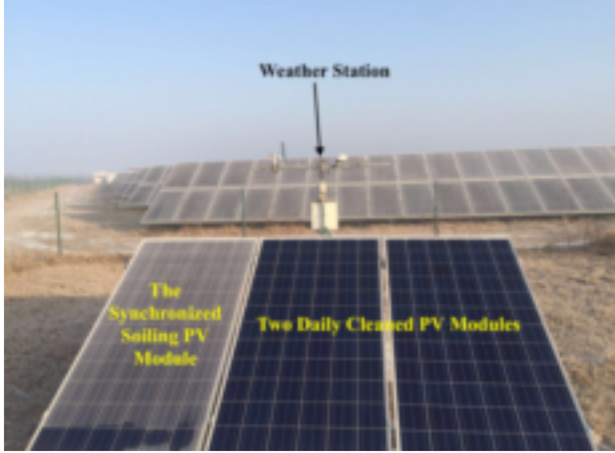


Fig. 15: Picture of the weather station.

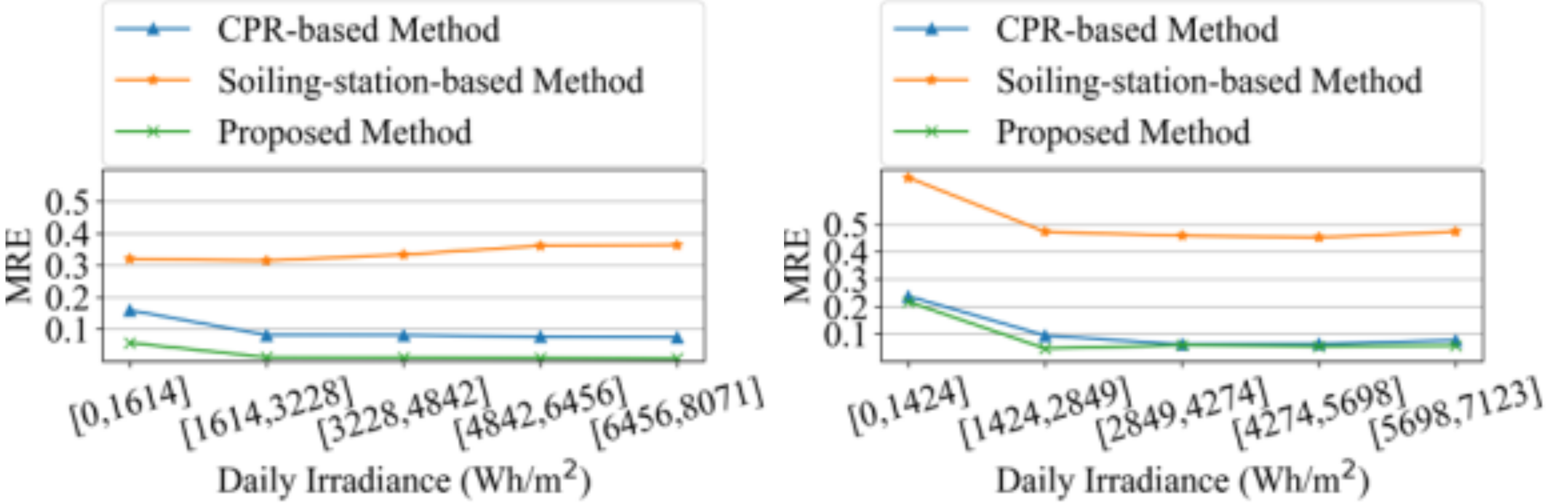


Fig. 16: Performance comparison of different methods.

Industrial Application

Concord New Energy Group Limited
协合新能源集团有限公司
(0182.hk)

Sustainable Energy

Wind Power

- 52 wind power farms
- Installed Capacity 2,483 MW
- 28 GW wind Power stored

PV Power

- 18 PV power farms
- DC Nominal capacity of 313 MW
- 8 GW PV power stored

Intelligent Sustainable Energy

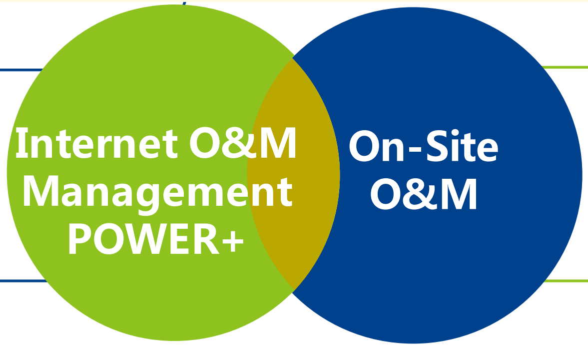
POWER+

- Consulting，design
- Intelligent O&M
- Finance Leasing
- EPC
- Electricity Allocation and Sale
- Energy Storage

Building Intelligent O&M by Energy Internet

By taking advantage of its "POWER+" products, the Group actively builds a cloud-based O&M model, which provides the centralized management, personalized and precise operation as well as maintenance services manned by no one or only a few people

Energy internet cloud platform **"POWER+"** has undergone continuous optimization and has been applied total installed capacity of **5GW+**

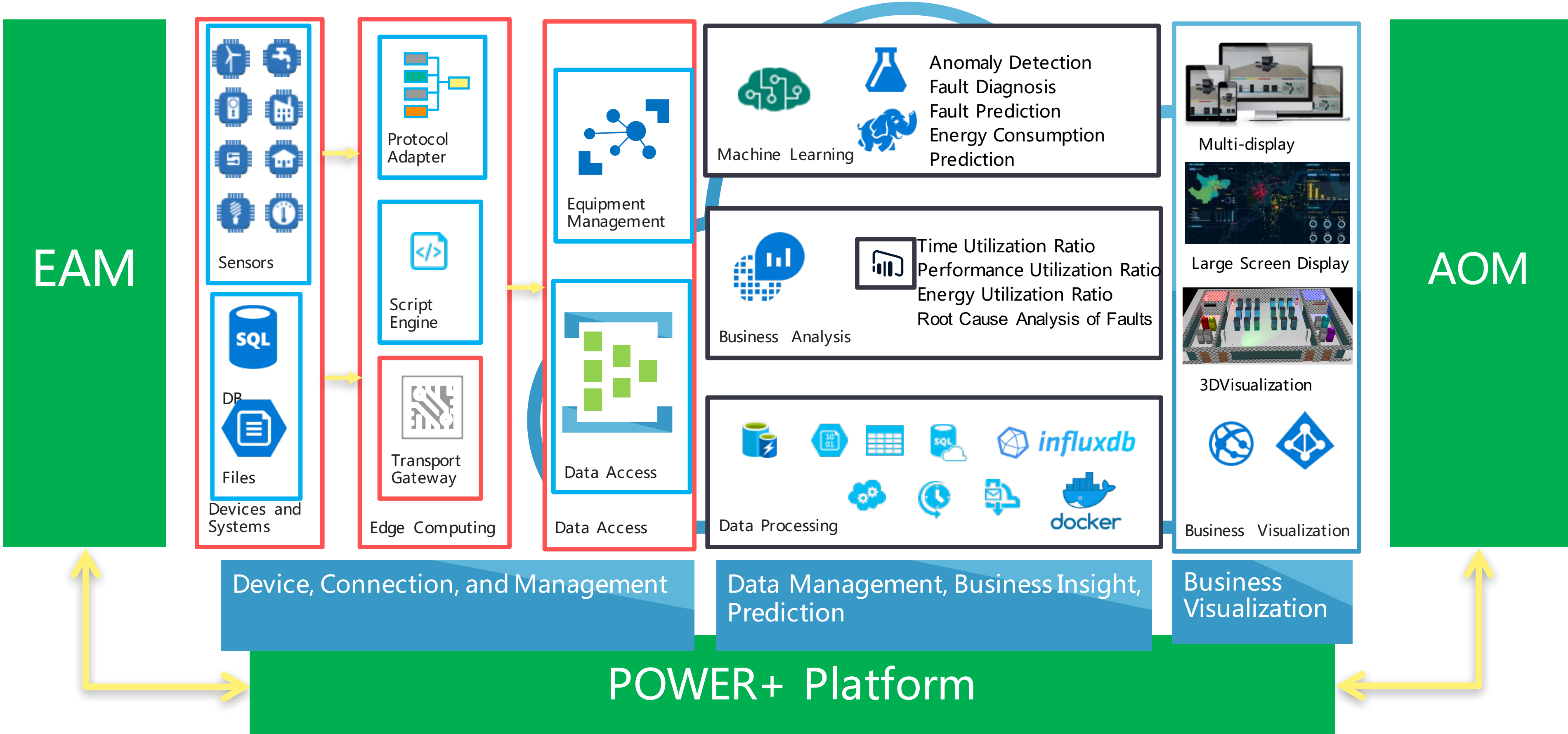


76 wind power and PV power plants' overall O&M in total, with DC nominal capacity 4600 MW

Through the diagnostic analysis by "POWER+" platform, the average power generation of wind power plants and PV power plants increased more than **1%** and **5%**, respectively.

Successfully passed the new standard certification of the "Three-standard System". Obtained the TÜV wind turbine O&M capability certification from Germany as the first third-party independent O&M company that has passed TÜV International certification

Framework of Intelligent O&M



Conclusions and Future Work

Conclusion

1. An **effective and robust FDD solution** for PV systems.
2. The proposed solution has been deployed in sustainable energy systems with the installed capacity larger than **5 GW**, and averaged power generation have increased more than **5%.**
3. Research papers

Future work

1. Combining **thermal-related** method with **data driven** method, so as to perform **more exact fault localization**.
2. Quantifying soiling loss in **mountainous areas**, as well as in lower irradiance conditions.

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- **Yingying Zhao**, Dongsheng Li, Qi Liu, Qin Lv, Li Shang. Deriving Customer Privacy from Randomly Perturbed Smart Metering Data. In IEEE 16th International Conference on Industrial Informatics (INDIN 2018) .
- Dongsheng Li, **Yingying Zhao**, Yawen Zhang, Qin Lv, Li Shang. An Algorithmic Method for Tampering-Proof and Privacy-Preserving Smart Metering. In IEEE 16th International Conference on Industrial Informatics (INDIN 2018) .
- Qi Liu, **Yingying Zhao**, Yawen Zhang, Dahai Kang, Qin lv, Li Shang. Hierarchical context-aware anomaly diagnosis in large-scale PV systems using SCADA data. In IEEE 15th International Conference on Industrial Informatics (INDIN 2017) .
- Ao Dong ; **Yingying Zhao** ; Xiwei Liu; Li Shang; Qi Liu; Dahai Kang, Fault diagnosis and classification in photovoltaic systems using SCADA data, 2017 International Conference on Sensing, Diagnostics, Prognostics, and Control (SDPC'17)
- Qi Liu, Yawen Zhang, **Yingying Zhao**, Duanfeng Gao, David W Gallaher, Qin Lv, Li Shang. Automatic multi-sensor data quality checking and event detection for environmental sensing, 2017 AGU Fall meeting, 2017.

Thank you!

Please feel free to contact us if you have any inquiries:

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