



Diagnosing Faults in Solar Energy Systems: Innovative Tools and Methods

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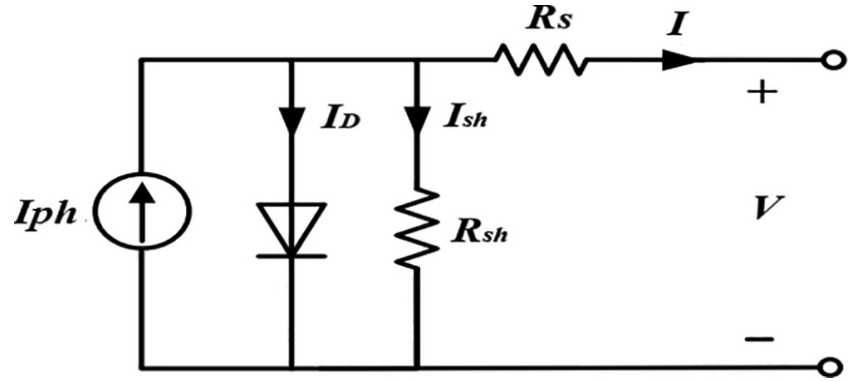
INTRODUCTION

Solar panels are a critical component in renewable energy generation, playing a significant role in converting sunlight into electricity sustainably. However, their performance and efficiency can be severely impacted by various faults that may occur during operation. Among the most common faults is partial shading, where parts of the panel are covered by shadow, leading to a significant reduction in power output. Additionally, soiling, or the accumulation of dust and dirt on the surface of the panels, also plays a major role in lowering efficiency, as it blocks sunlight from reaching the photovoltaic cells. Electrical disconnections, resulting from issues with wiring or connections, can lead to complete or partial system failure, further diminishing energy production. Another issue is degradation due to environmental factors, such as humidity and extreme temperatures, which can cause long-term damage to the materials used in the panels. If left undetected, these faults may result in permanent damage to the solar panels, affecting overall system performance. Therefore, early detection and accurate classification of these faults are crucial for maintaining optimal performance, extending the lifespan of the panels, and maximizing energy yield. This study explores advanced methods that utilize data-driven approaches and artificial intelligence to enhance fault detection accuracy. By leveraging data analysis techniques, the aim is to improve maintenance efforts, reduce unplanned downtime, and ultimately increase overall solar energy output.

Photovoltaic Module Modeling

Photovoltaic (PV) module modeling is a crucial tool in understanding and predicting the electrical performance of solar panels under different environmental and operational conditions. By providing a mathematical framework, this modeling allows researchers and engineers to simulate how the panel behaves in response to variations in light intensity, temperature, and load conditions. The current-voltage (I-V) characteristics of a PV module, which define its electrical output at any given time, can be determined through these models, offering insights into efficiency and performance. The equation for I_{pv} , the current generated by the PV module, typically takes into account factors like the panel's saturation current, temperature effects, and solar irradiance, all of which influence the module's output. By understanding these relationships mathematically, one can predict the panel's behavior across a range of operating conditions, optimize its design, and improve the overall efficiency of solar power systems.

$$I_{pv} = I_{ph} - I_0 \cdot \left[\exp \left(\frac{V + R_s \cdot I}{V_t \cdot a} \right) - 1 \right] - \frac{V + R_s \cdot I_{pv}}{R_{sh}}$$



I_{ph} : Photo-current [A]. I_0 : Saturation current [A]. V : Cell voltage [V]. V_t : Thermal voltage. N_s : The total number of cells connected in series. T : Cell temperature [K]. q : Electron's charge $e = 1.6 \cdot 10^{-19}$ C. K : Boltzmann constant $(1.3854 \cdot 10^{-23})$ JK⁻¹. a : Ideality factor of the junction

PV module characteristics



Electrical characteristics
 P_{max} : Maximum power 54 W
 V_{mp} : Voltage at Maximum power 7.4V
 I_{mp} : Current at Maximum power 7.4 A
 V_{oc} : Open Circuit Voltage 21.8 V
 I_{sc} : Short Circuit Current 3.13 A
The total number of cells connected in series 36
Number of bypass diodes 2

Types of PV Faults

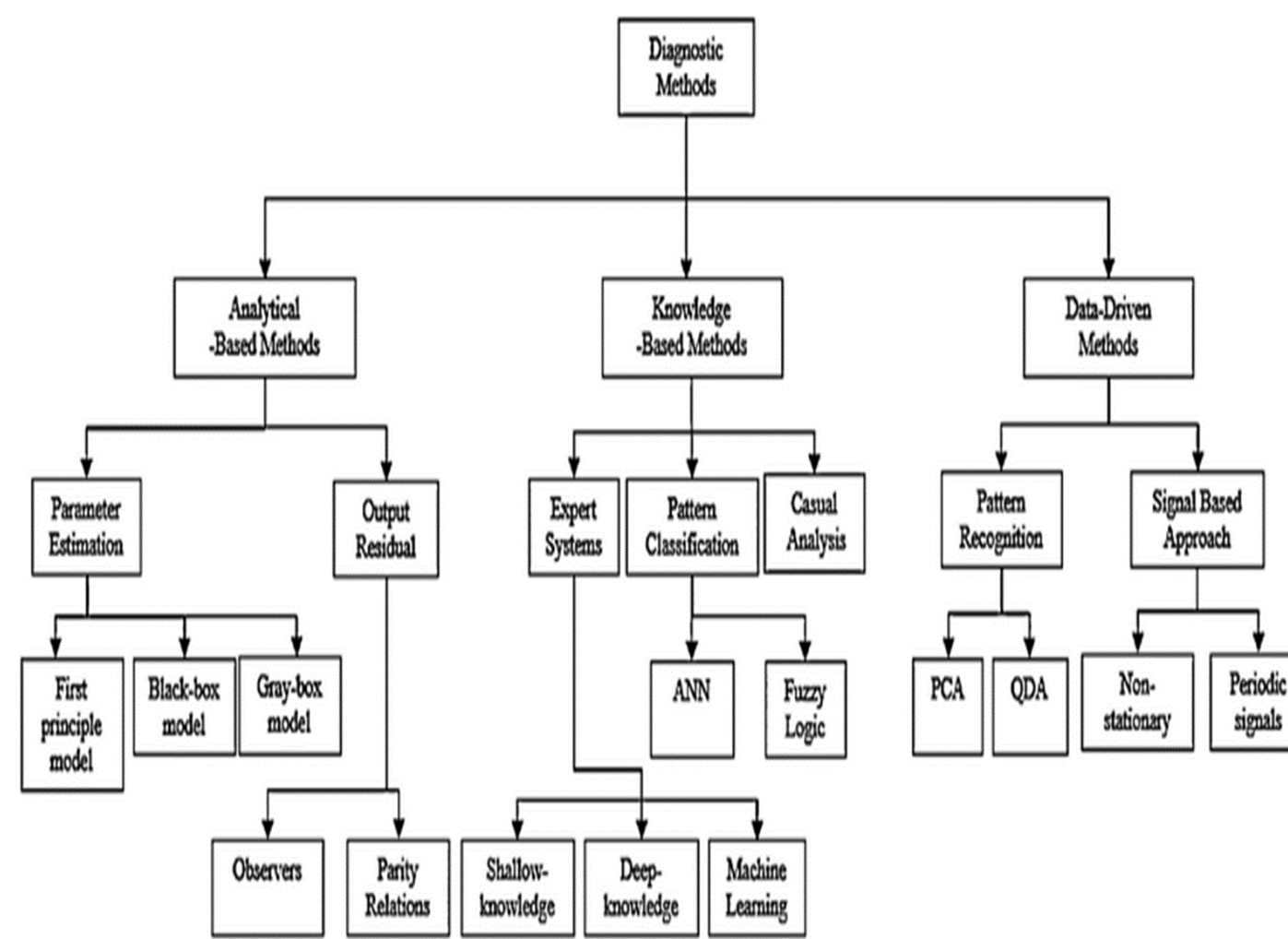
Partial Shading: Caused by obstructions such as dirt, leaves, or nearby structures blocking sunlight, leading to reduced power output and potential hotspots.
Soiling: Dust, pollution, and debris accumulate on the panel surface, reducing efficiency and blocking sunlight absorption.
Module Degradation: Aging and prolonged exposure to environmental conditions cause a gradual decline in panel efficiency.
Connection Issues: Loose or faulty connections within modules or wiring can disrupt the electrical flow, causing intermittent or permanent losses in output.

2. Electrical Faults
Open Circuit Faults: Breaks in the electrical circuit stop current flow, leading to a complete loss of power in affected modules or strings.
Short Circuit Faults: A low-resistance path in the circuit can cause excessive current, potentially damaging the PV system.
Ground Faults: Unintended connections between electrical conductors and the ground, which may pose safety hazards and reduce performance.

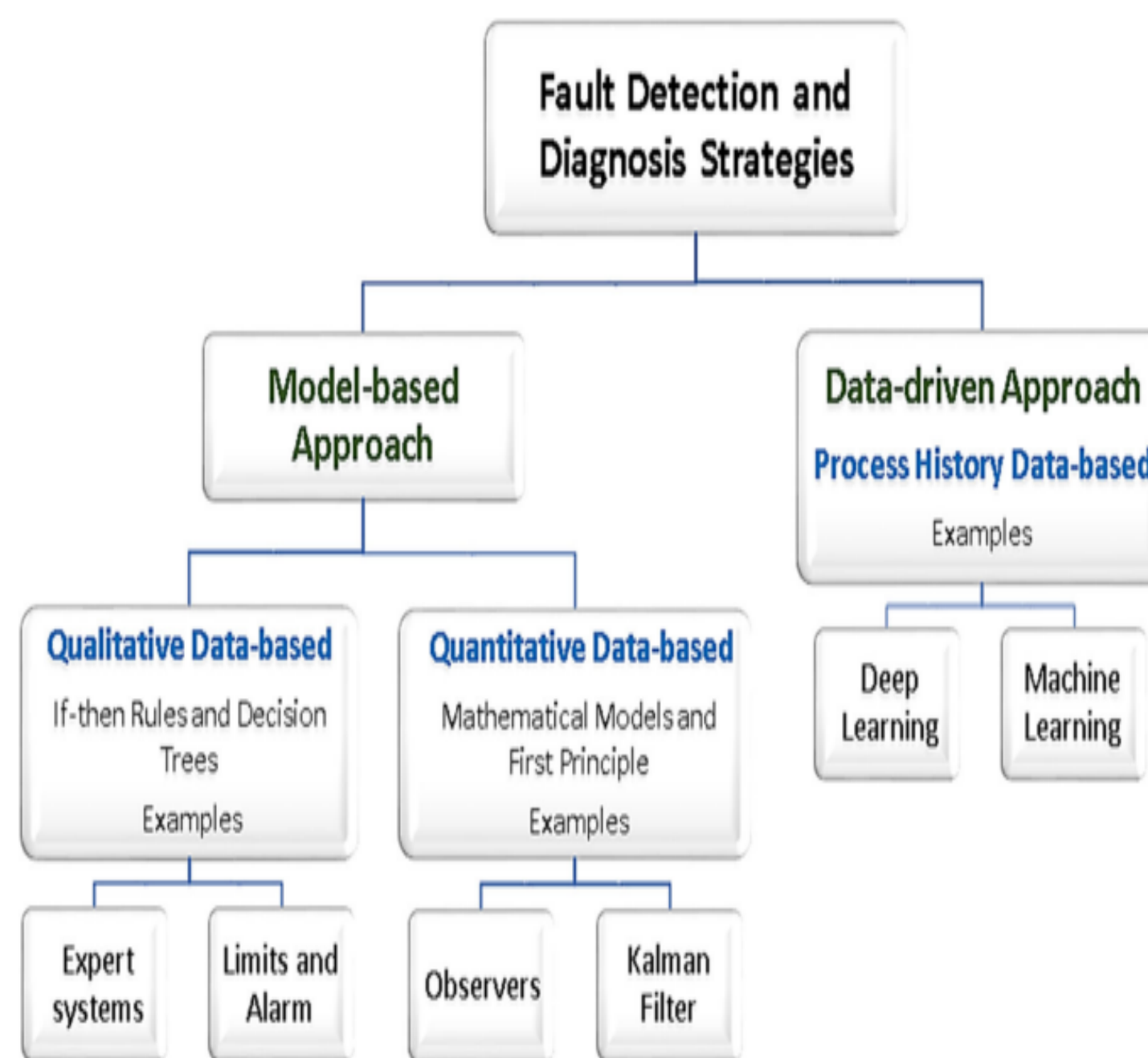
3. Impact on System Performance
PV faults decrease the overall efficiency and energy yield of the solar system, often leading to energy losses, overheating, and shortened lifespan of system components.

4. Importance of Fault Detection
Early and accurate fault detection is critical to maintaining system reliability, ensuring safety, and reducing maintenance costs. Advanced detection and classification techniques are used to identify and diagnose these faults promptly, enabling effective maintenance and preventing potential damage to the PV system.

Detection Methods

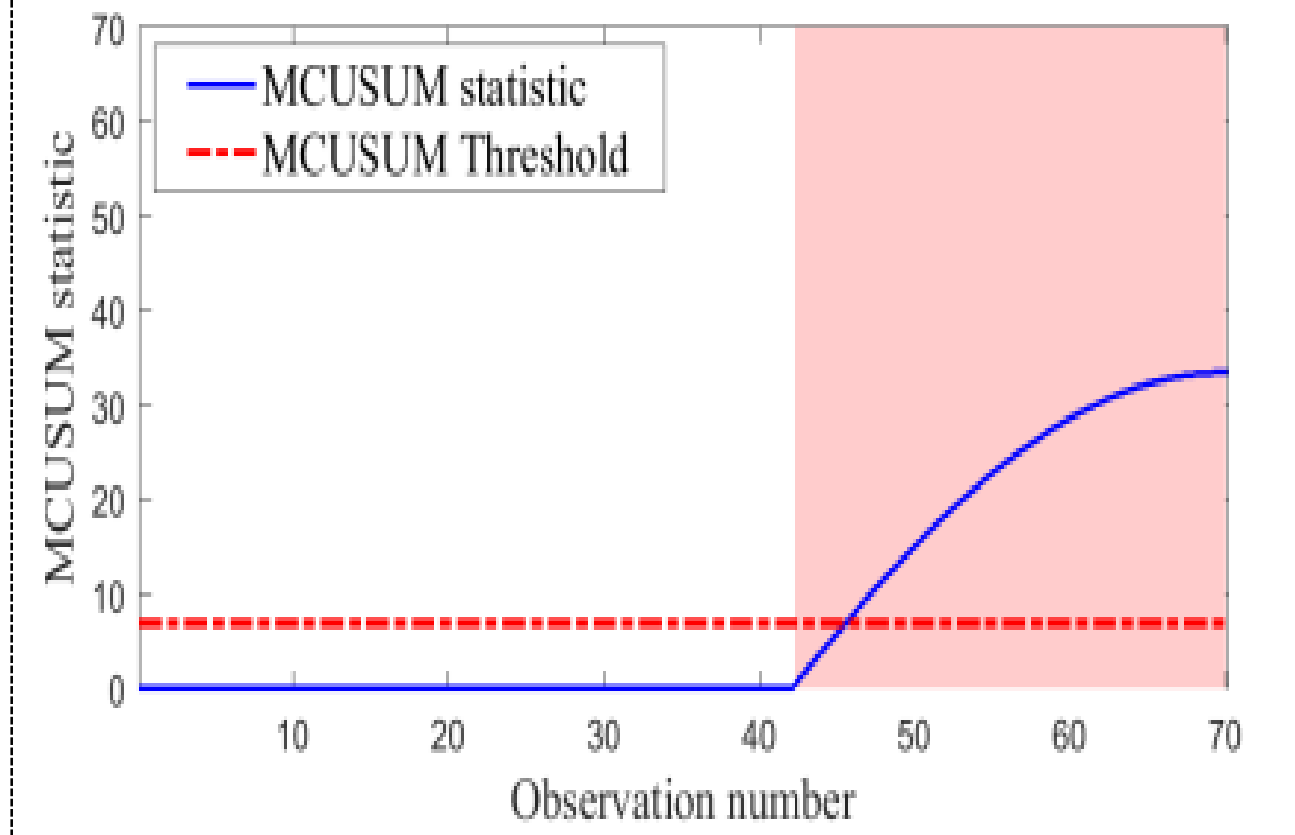


Detection Techniques

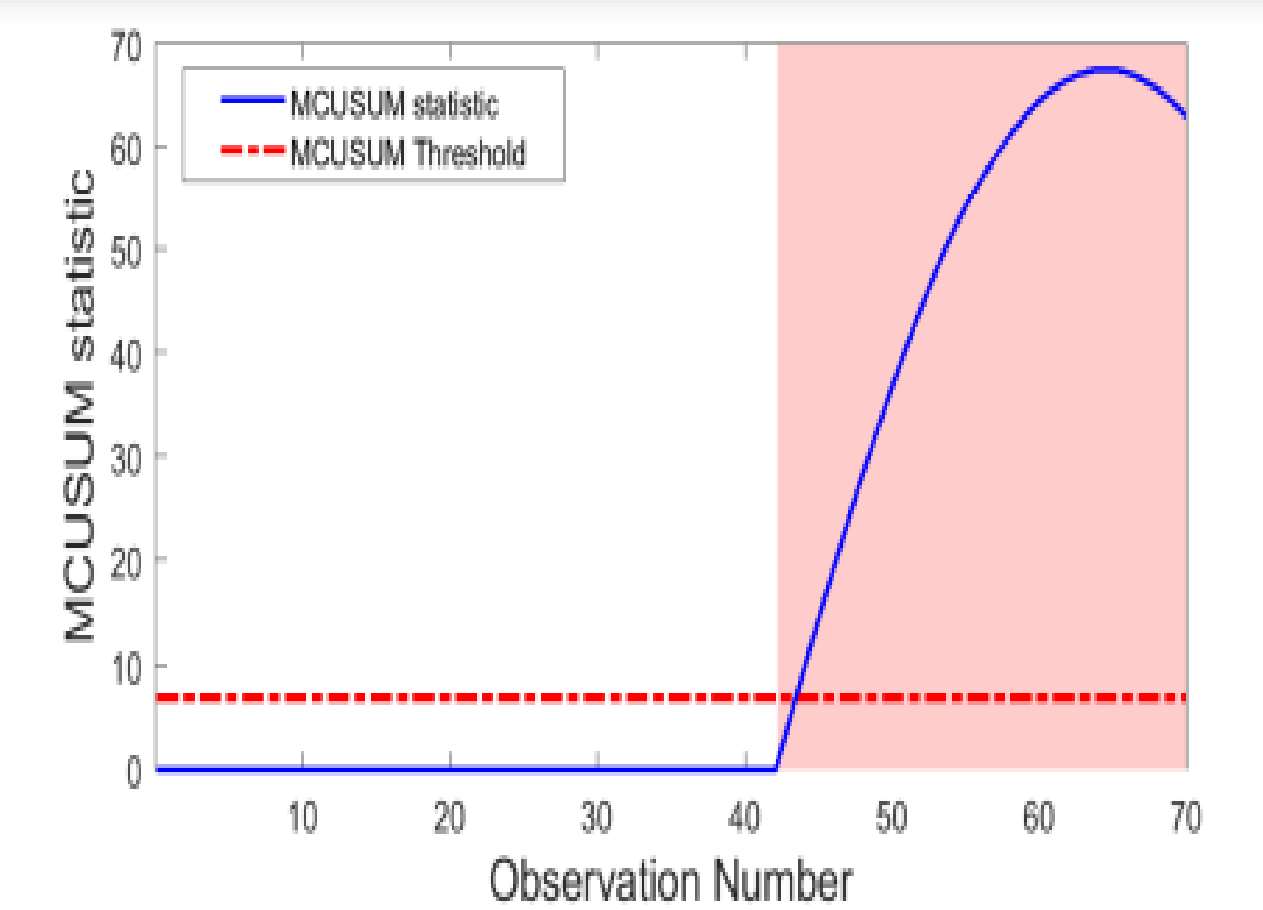


Results

In the case of short circuited it is mandatory set a threshold a in the following figures



in the presence of eight short-circuited modules



CONCLUSION

This simulation study focused on detecting faults in solar panels using a model-based approach. By analyzing variations in power, voltage, and current, the study set three synchronized thresholds to accurately diagnose potential faults within the system. These thresholds were carefully calibrated to identify deviations from normal operating conditions, such as partial shading, soiling, or electrical disconnections, enabling early detection and timely intervention. The results demonstrated the effectiveness of this technique, showing its potential for improving the reliability and performance of solar power systems by quickly identifying faults that could otherwise go unnoticed. The model-based approach proved to be a valuable tool for fault diagnosis, offering a non-invasive method for continuous monitoring of solar panel health. Looking ahead, future research will aim to refine this fault detection system by incorporating more advanced algorithms, improving the accuracy of detection under diverse real-world conditions. Additionally, experimental verification will be a key focus, allowing for the validation of the model in practical, real-world scenarios. This will help ensure that the technique can be reliably applied across various solar installations, ultimately contributing to enhanced system longevity, reduced maintenance costs, and increased energy yield.

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