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Review on Different Types of Faults in PV Systems and Reducing PV Module Mismatch

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Abstract: *Photovoltaic effect plays a major role in photovoltaic cells as it makes the process of converting the solar energy into the electrical energy. PV modules are connected in series for the highest output voltage and in parallel for the highest output current. A photovoltaic (PV) system's performance is significantly impacted by various power losses that electrical equipment experiences or by changing weather conditions.*

I. Introduction

When exposed to light, photovoltaic (PV) systems, which are solid state semiconductor devices, produce electricity. Solar cells are the building blocks of a solar panel. The series and parallel connection of several solar cells creates a photovoltaic module. PV modules are connected in series for the highest output voltage and in parallel for the highest output current. Due to their advantages, including long-term advantages and maintenance-free operation, solar PV power systems have been commercialized in many nations. Dealing with the nonlinear properties of PV arrays is the main difficulty in using PV power generation systems. The level of radiation and the temperature affect the PV properties.Due to moving clouds, nearby structures, or nearby trees, PV arrays experience varying levels of irradiance. Figure 1 depicts the block diagram of a PV generation system. Photovoltaic systems are primarily categorized based on how well they operate, how their components are configured, and what equipment is connected to electrical loads. They are primarily categorized as standalone and grid-connected systems that are made to offer DC and AC power service so that users can use their devices without dependent on the utility grid and other energy sources and storage systems.

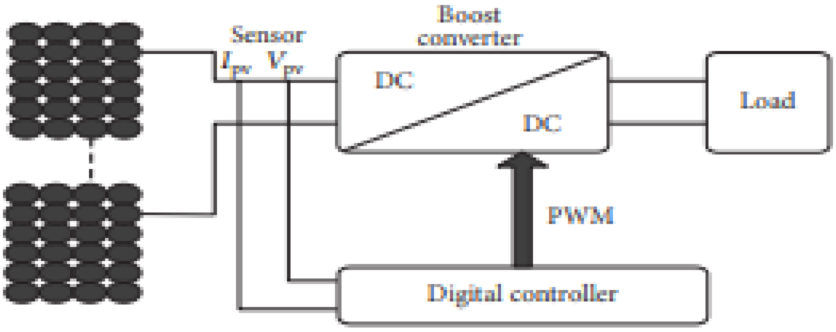

Figure 1: Block diagram of PV generation systems

The most practical and cost-effective way to harness solar energy is through the grid-connected photovoltaic (GCPV) system, which has gained widespread acceptance [1,2]. Due to its highly efficient design, it does not need expensive energy storage devices (batteries) to support the system when photovoltaic (PV) electricity is not available. The electrical grid itself fills this job; it can be thought of as a huge energy reserve that constantly distributes enough electricity to the load. The central inverter is the ideal option for DC-AC conversion because to its easy installation, low maintenance requirements, and excellent reliability. PV modules are often joined in an array (series-parallel configuration), with the inverter supplying the grid with power.

The cost of a PV module and its lifespan affect how much electricity it produces. Only until PV systems are reliable for more than 20 years can the cost economics associated with them be effective. PV modules go through extensive qualification tests in accordance with International Electro-technical Commission (IEC) standards [3] to guarantee these levels of dependability. Common names for these examinations include design qualification tests and kind of approval tests. The degree and length of these tests are set up to evaluate the dependability and quality of PV modules. These tests aid in reducing the PV module infant mortality rate. These tests, however, are not helpful in determining the module lifetime. It is discovered that the performance of PV modules under real-world outdoor conditions differs significantly from that assessed in a controlled laboratory setting during qualification or certification testing. This distinction is made because, in true outdoor settings, factors like solar radiation, temperature, humidity, wind, and operational voltage all occur simultaneously, but during certification or qualification testing, these factors are applied in a particular order that has been defined.

The performance of PV modules is reduced and early failure results from the accumulation of a range of faults during outdoor operation. Recent research on PV module failure/degradation modes and efforts to raise quality standards has revealed that even qualified modules can fail or degrade beyond expectations [4]. The behavior of PV modules under actual outdoor conditions must therefore be studied in order to comprehend their performance, degradation, losses in energy yield, nucleation, growth, and impact of faults. These studies aid in estimating module lifetime time and characterizing long-term behavior.

A PV module's performance in actual outdoor conditions depends on a number of variables, including the PV technology employed and the site's ambient conditions. To reduce mismatch losses, distributed maximum power point tracking (DMPPT) architectures are proposed, which would decouple each PV unit in the system. Differential power processing (DPP), submodule integrated converters (SI), string MPPT, tends to be lower, module parallel converters, and module cascaded converters are the primary types of DMPPT techniques (MCCs).

Table 1 Modular Cascaded Converter topologies

DC Converter Topology	No. of Modules	Topological Constraints	Bypassing Ability	Voltage/Current Limitation
Buck	High	$I_{string}>I_{PV}$ $V_{OUT}<V_{PV}$	Free wheeling	Switch current limitation
Boost	Low	$I_{string}<I_{PV}$ $V_{OUT}>V_{PV}$	Body diodes in main and rectification MOSFETS	Output voltage limitation
Four Switch buck boost	Moderate	Flexible	Body diodes in main and rectification MOSFETS of the boost legs	Switch current limitation Output voltage limitation

II. Literature review

Juan David Bastidas-Rodriguez [1] In order to give the reader a thorough understanding of both the control strategies and the structures for obtaining the most power from a mismatched PV field, this study discusses the generic architectures employed by 61 various MPPT techniques. Additionally, the widely used approaches for each hardware structure are described in a systematic and condensed manner, giving the reader some suggestions the technique's operating principle and hardware needs.

M.R. Maghami et al. [2] The outcome demonstrates that gentle shadowing has an impact on the current generated by the PV module, but the voltage is unaffected. When there is harsh shadowing, the PV module's performance relies on whether some or all of its cells are shaded. Even if the PV module's voltage output will reduce if some of the cells are shaded, there will still be some output as long as the unshaded cells receive solar irradiation. This study also offers a few cleaning techniques to avoid dust buildup on solar array surfaces.

M.M. Fouad et al. [3] The study findings will relieve the stress of having to look through multiple studies under each category of factors by providing practitioners and researchers with an exhaustive overview of the various aspects that can affect the performance of the PV panels. Additionally, researchers might build on this study by investigating novel approaches to lessen the impact of specific parameters, which can further improve the system's effectiveness. On the other hand, experts can present novel technologies that can actually be applied in our daily life to prevent the impact of elements that adversely affect the performance of PV panels.

D. Picault et al. [4] This study proposes a brand-new technique for predicting PV array production under various environmental circumstances. This method relies on field measurement data to definitively determine module parameters. In order to minimize mismatch losses, the suggested method replicates PV arrays using adjustable module connectivity schemes. Experimental findings on a 2.2 kWp plant with three different connections systems have been used to test the model. They demonstrate dependable power output forecast precision in both partially shaded and normal operating conditions. In order to reduce module mismatch losses, field measurements indicate interest in adopting alternate plant topologies in PV systems.

L. C. Hirst and N. J. Ekins-Daukes [5] This study examines the inherent loss mechanisms that constrain solar cell efficiency at a fundamental level. All incident solar radiation is quantified through five inherent loss processes. Physical mechanisms that were hidden in earlier numerical research are brought to light using an analytical method. It is discovered that three factors—carrier thermalization, a Boltzmann factor coming from the mismatch between absorption and emission angles, and the conversion of thermal energy into entropy free work—limit the amount of free energy that is available per carrier. It is demonstrated that entropy transfer during carrier cooling results in a free energy advantage for a degenerate band absorber over a discrete energy level absorber.

B. Hashemi et al. [6] A photovoltaic (PV) system's performance is significantly impacted by various power losses that electrical equipment experiences or by changing weather conditions. An precise study of a PV system's power losses in this situation is crucial. Therefore, this study investigates the systematic computation of the power losses of the PV system based on recorded data of the primary electrical and meteorological factors.

G. Sai Krishna and T. Moger [7] The most recent reconfiguration techniques for PV arrays are discussed in this work in order to maximize maximum power under partial shade and mismatch conditions. Additionally, this study discusses the difficult problems associated with the hardware implementation of both dynamic and static reconfiguration strategies. Based on the review study, it can be inferred that while project is moving approaches are more expensive than static ones, they are more effective in mitigating partial shading and mismatch effects in PV arrays.

Author name	**Title**	**Work done**	**Results**	**Conclusion**
Hussain Bassi	Hardware Approach to Mitigate the effects of Module Mismatch in a Grid-connected Photovoltaic System: A Review	the micro-inverter, the DCO and energy recovery circuits employed in the distributed MPPT concept.	DCO is a good option	highlighted their merits/drawbacks, and evaluate their comparative performance
V. Sharma, S.S. Chandel	Performance and degradation analysis for long term reliability of solar photovoltaic systems: A review	The most significant recent information available on the performance, degradation and reliability of the PV modules has been reviewed	The present qualification tests indicate the infant mortality of PV modules and are not sufficient to estimate the module life.	The PV industry has started finding applications world-wide in all the climatic zones with various Configurations which makes the task more challenging
Mohammad K. Al-Smadi1	Photovoltaic module cascaded converters for distributed maximum power point tracking: a review	distributed maximum power point tracking (DMPPT) architectures have been proposed	Several limitations and challenges are discussed	a list of potential research areas in this field is introduced
J. de Wild	Upconverter solar cells: materials and applications	Different types of upconverter materials are investigated, based on luminescent ions or organic molecules	upconversion efficiencies well above 1% for excitation densities of several mW cm$^{-2.}$	The challenges are improving the upconversion efficiency
KJAER et al.	A review of single-phase grid connected inverters for photovoltaic modules	examination of the demands for the inverters, set up by utility grid companies, the PV modules, and the operators	amplitude of the ripple across a PV module should not exceed 3.0 V in order to have a utilization efficiency of 98% at full generation	The rules to judge the examined inverters were then established, and seven ac module inverters and four multi-string inverters were reviewed

III. Types of faults

A PVM failure is usually relevant to the system warranty when it occurs under conditions which the module normally experiences. Any type of fault that occurs in PVS leads automatically to unexpected safety hazards, reduced efficiency, power availability, systems reliability and safety. These include discolouration, cracking, snail tracks, antireflection coating damage, bubbles, soiling, busbar oxidation and corrosion, and split encapsulation over cells and interconnections, back sheet adhesion loss, etc. Some failure modes detection strategies are discussed in literature above, the investigated failure modes are: encapsulation, module corrosion, cells cracking, and PV inverter. Generally, faults in PVM can be classified into two main categories: permanent and temporally. Permanent faults are, for example: delamination, bubbles, yellowing of cells, scratches and burnt cells. So, this category of faults can be eliminated simply by replacing the faulty modules. While, temporal faults are basically due to partial shading effects, dust accumulation (soiling), dirt on PVM, and snow that can be removed by operators without replacing the faulty PVM. In addition, the cause of the fault could be external or internal, and both may lead to a decrease in the output power, efficiency and reliability of the PVS. The faults include: hotspot, bypass and blocking diodes faults, faults in a junction box, faults in a PVM, PVA, arc, ground and line-to-line faults.

Most electrical-based fault detection and diagnosis methods rely on some type of PVS model to detect various types of faults. In this section, only electrical methods will be reviewed and discussed. Electrical methods can be also classified into five groups:

- statistical and signal processing approaches (SSPA);
- I-V characteristics analysis (I-VCA);
- power losses analysis (PLA);
- voltage and current measurement (VCM);
- artificial intelligence techniques (AIT).

IV. Conclusion

Most electrical-based fault detection and diagnosis methods rely on some type of PVS model to detect various types of faults. A PVM failure is usually relevant to the system warranty when it occurs under conditions which the module normally experiences. Any type of fault that occurs in PVS leads automatically to unexpected safety hazards, reduced efficiency, power availability, systems reliability and safety.

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