Photovoltaic Panels

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In the realm of solar power generation, photovoltaic (PV) panels are used to convert solar radiation into energy. They are subjected to the constantly changing state of the environment, resulting in a wide range of defects.

fault detection Photovoltaic Panels

1. Faults Occurring in PV Panels

In addition to large-scale solar panels initiatives, a major chunk of studies analyze various faults caused by issues such as installation faults, poor maintenance by the consumer, system overload, hardware issues, connection faults, malfunctions, and other environmental influences such as dust, water droplets, bird droppings, and partial shadowing conditions. **Figure 1** shows the classification of faults that occur in PV panel arrays and **Figure 2** shows the possible faults that occur in the life cycle of a PV panel. Recent research into PV systems failure has resulted in the development of novel approaches for detecting and locating the different kinds of defects existing. These methods have assisted in the improvement of PV systems dependability and longevity. **Figure 1** depicts the classification of several defect discovery procedures used to determine the kind and locality of faults in PV systems on both the DC and AC sides [1].

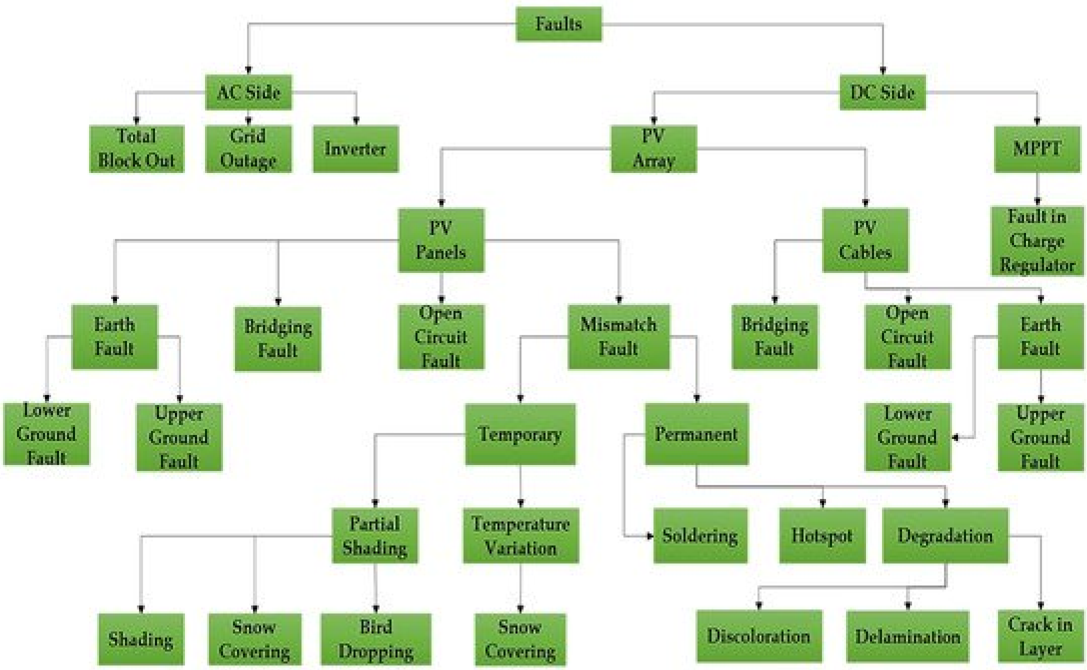

Figure 1. Classification of faults that occur in PV array panel.

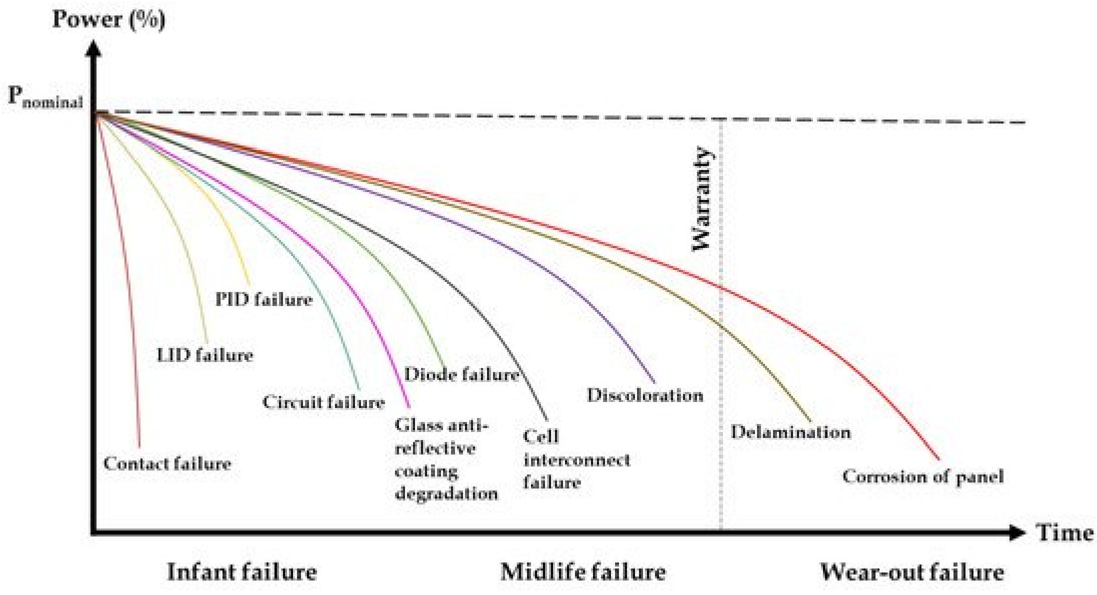

Figure 2. Possible faults that occur in the life cycle of PV panels.

If the defect is found on the PV system's DC side, a microscopic study can be performed to determine the cause. Analytical approaches have been found to be quite beneficial for microscopic analysis. ATIR, SEM, and X-ray microtomography are some of the most important and latest microanalysis methods documented in the literature [2]. The decline in DC power output is the first sign that a PV system is malfunctioning. However, after examining the electrical properties of a PV system, it can be determined that a problem exists. The modules are visually inspected when the defect location has been determined [3]. Yellowing, cell fractures, corrosion in connectors links, electrical short circuit defects, bypass diode failure, back-layer polyethylene fractures, bubble formation and matrix cracking in the encapsulate, oxidation and discoloration in intersection wires, encapsulate discoloration, and other defects are visually inspected on the module. If a malfunction occurs on the PV system's AC side, the system's power flow will be zero. Concerning **Figure 1**, from the literature [4], the DC side of PV panels are more affected compared to the AC side and thus the major faults of the DC side of PV panels are discussed below such as partial shading fault, short circuit (SC) fault, open circuit (OC) fault, and faults in diode-blocking and bypass diode.

1.1. Partial Shading Fault

The chief source of power for solar panels is sunlight. Whenever the radiation of the sun is interrupted, the solar panels cannot be utilized efficiently. Most of the solar panels fail to receive sunlight due to passing clouds, snowfall, the panel being covered by water, dirt and bird droppings, and due to tree shadow, which finally results in power loss. Referring to **Figure 3**, in perilous situations, it is necessary to diagnose and indicate the problem to the operator [1].

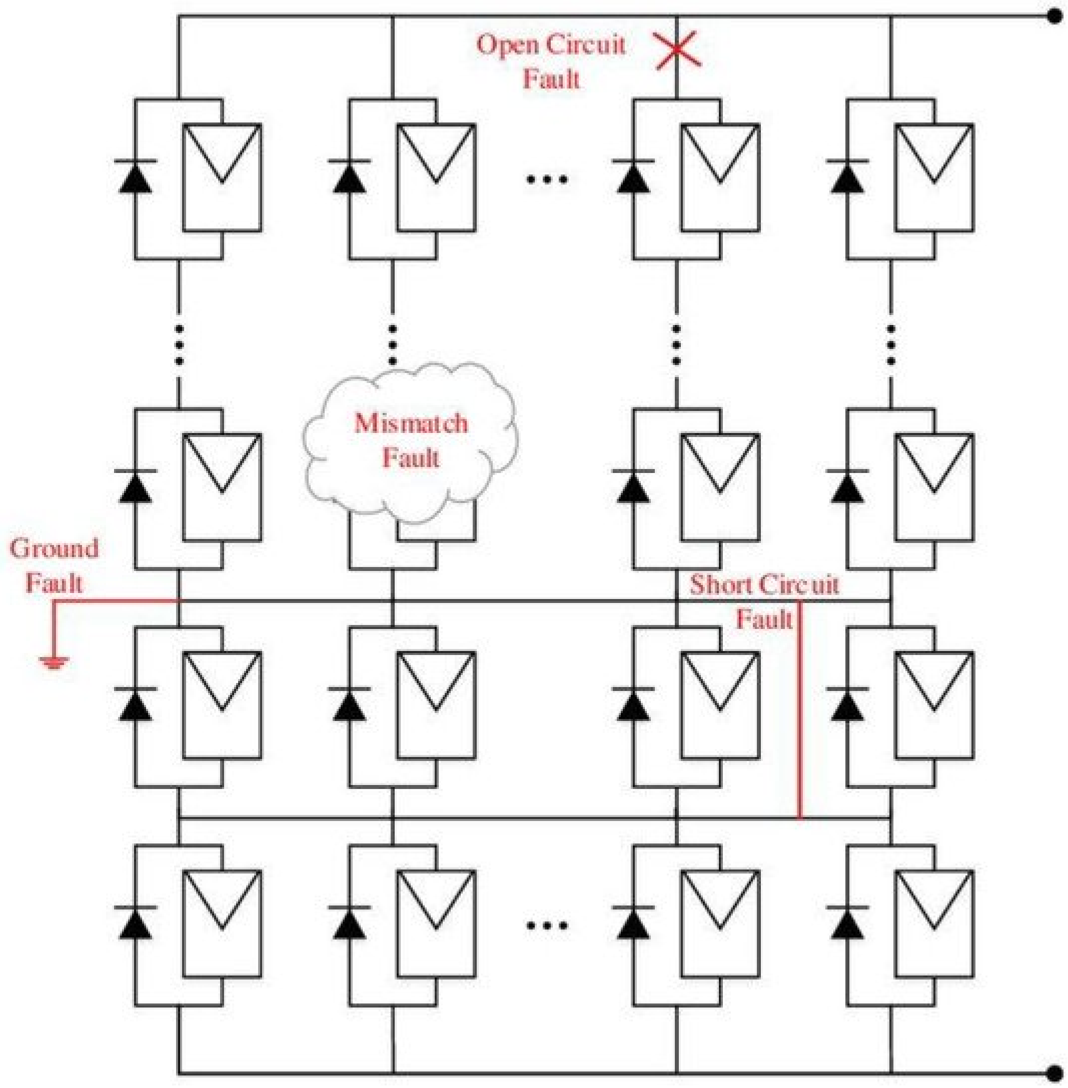

Figure 3. Faults in PV panel array [1].

1.2. Short Circuit (SC) Fault

The solar panel suffers not only when it is exposed to sunlight but also during rain and snowfall; the water droplets might by chance descend into the PV modules. In addition to the above-mentioned situations, aging is a main factor for the short circuit fault, particularly when the solar panel is used for a long period. **Figure 3** shows the short circuit fault.

1.3. Open Circuit (OC) Fault

In solar panels, the manufacturer uses many connections between PV modules or solar cells. Due to the aging of low-quality electrical wires and more loads, some disconnection might occur in the circuit. In such situations, the solar power panel fails to produce electrical energy. This kind of fault is called an open circuit fault. An example of an open circuit fault is shown in **Figure 3**.

1.4. Faults in Diodes—Blocking and Bypass Diodes

The diode used in solar PV panels is used as a feed check valve. Most commonly, two types of diodes are used: one is blocking diode and the other one is bypass diode. Blocking diodes are used to allow the electrical current only in one direction and are connected in series to the solar cell. Bypass diodes are connected in parallel and are used to prevent the backflow of current from strongly exposed cells to a weaker solar cell. Hence, it is highly essential to diagnose faults in solar panel diodes [2]. The online/remote supervision approach helps improve the fault detection of a solar system. The faults mentioned above are to be monitored with the help of remote supervision methodology as it helps the consumer with further maintenance activity [3].

2. Online/Remote Supervision of PV Panel

Online monitoring systems comprise various sensors such as a temperature sensor, a voltage sensor, and a smart monitoring system with prescribed machine learning techniques adapted for system monitoring. The sensors measure the voltage and the temperature. Moreover, solar radiation is measured using reference solar cells [4]. In this type of monitoring system, communication is carried out via existing DC power lines, requiring no extra installation. This technology is called power line communication. The PV systems are arrayed to measure solar irradiance, voltage, and temperature. Santiago Silvestre et al. describe the monitoring of current, voltage, power, cosine, frequency, irradiance, partial shading, and module temperature. The parameters mentioned above are measured using Pt100 sensors and various sensors with calibrated solar cells closer to the geometric center. The invertor's data acquisition system is used to record the data. Downloading data is handled by software that employs OPC HDA technology, and OPC uses fault detection algorithms for day-to-day review [5].

Specific sets of fault test data must be selected under different operating situations to maximize the fault detection in PV power generation. In certain temperature and irradiance conditions, a combination of PIC18F8720 microcontroller and Zigbee wireless sensor has been used to carry out the fault diagnosis [6]. One researcher used a wireless sensor for fault diagnosis in solar power panels by placing WSN nodes along with opposite sensors on the group of panels. After sensing a particular parameter, the diagnosing sensor is taken into consideration for continuing the simulation process. Furthermore, the fault diagnosis system must be equipped with telemonitoring panels for the successful implementation of a graphic user interface [7]. Another paper analyzed the characteristics of the terminals used in faulty PV strings and arrays. The paper primarily focused on how to decrease the current and voltage sensor by optimizing the sensor location and investigated the connections to analyze both healthy and faulty PV panels with MPPT tracking and solar array configuration [8].

Based on the survey discussed above, it can be concluded that usually most of the people-using sensors can directly communicate through the power line and cables. However, nowadays in large-scale solar power plants, both combined management and security maintenance are essential for the timely detection of problems, ensuring efficiency in the functioning of the equipment. This work proposes a combined usage of an ATMEGA processor and IoT. These are all the techniques used for data processing thanks to which unwanted wiring, accessories, and unwanted expenditures could be controlled in solar panel fault diagnosis. **Figure 4** shows the proposed experimental work for fault diagnosis in PV panels +.

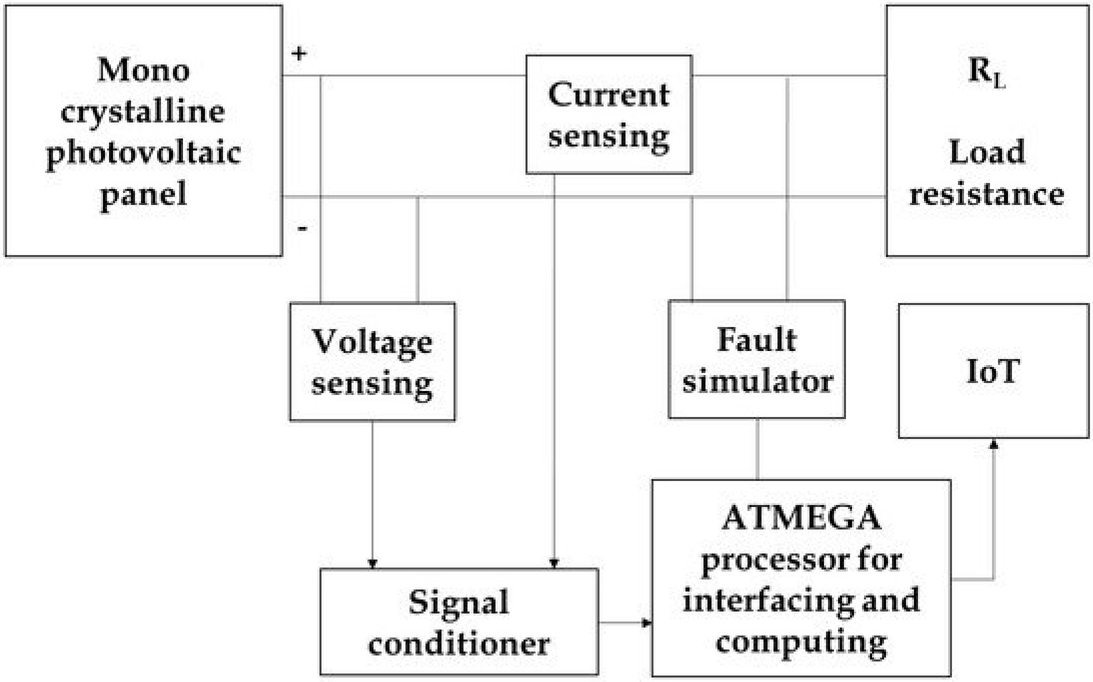

Figure 4. Proposed experimental work for fault diagnosis in PV panel.

Table 1 shows the factors/faults which affect the performance of PV panels in the home grid, small-scale (mini) grid, and large grid farms. These faults are the most prominent problems in PV panels around the world and a monitoring suggestion is provided concerning the grid.

Table 1. Comparison of methodologies used for predominant defects in PV panel.

Monitoring Factors	Methodology Used	Methodology Adopted in the Grid System	Monitoring Method
Shading	Multi-objective optimization [9]	Home/large grid	Online
	Hungarian PV system [10]	Mini-grid/large grid	Online
	Sky illumination model [11]	Large grid	Online
Soiling	Quantile regression neural network [12]	Home/large grid	Online
	Machine learning approach [13]	Mini-grid/large grid	Online
	Infrared thermography [14]	Home/large grid	Offline
Dust Accumulation	Deep residual neural network [15]	Mini-grid/large grid	Online
	Acoustic wave method [16]	Mini-grid/large grid	Online

Monitoring Factors	Methodology Used	Methodology Adopted in the Grid System	Monitoring Method
	Imaging technique [17]	Mini-grid/large grid	Offline
Weather	Inverse distance weighting [18]	Home/mini-grid/large grid	Online
	Data analytics [19]	Home/mini-grid/large grid	Online
	Theta-krill herd algorithm [20]	Home/mini-grid/large grid	Online
Delamination	Electric discharge channel [21]	Mini-grid/large grid	Online
	Thermal imaging [22]	Mini/large grid	Offline
	Aging test [23]	Mini/large grid	Offline
Discoloration	I-V characteristic analysis [24]	Mini/large grid	Offline
	Accelerated testing (AT) [25]	Mini-grid/large grid	Online
	Spectroscopic investigation [26]	Mini-grid/large grid	Offline

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