# Artificial Neural Network-based Fault Detection and Classification for Photovoltaic System

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**Abstract**

*This work focuses on detecting faults in Photovoltaic (PV) systems using Artificial Neural Networks (ANNs). A fault is defined as a deviation from the standard condition, and early detection is crucial to prevent damage and ensure safety. The PV panels, enduring harsh conditions, are prone to faults that can impair system operation and longevity. ANNs, mirroring human brain behavior, offer a powerful pattern recognition and problem-solving tool. Comprising input, hidden, and output layers, ANNs process data effectively. The project's aim is to enhance efficiency by identifying fault conditions affecting power output in utility-scale PV arrays. Customized algorithms tailored for monitoring device data analysis are being developed. A framework for using feedforward neural networks for fault detection and identification is in progress. This approach promises to uphold the reliability and safety of PV systems, addressing the increasing demands for dependable technical plants. The research aligns with the rapid growth of neural computing, showcasing its potential in critical applications like fault detection.*

*Keywords:ANN, PV SYSTEMS, PV FAULTS, PNN.*

## I. INTRODUCTION

Photovoltaic (PV) solar energy systems have experienced substantial global growth, now boasting an installed capacity of 627 GW. It stresses that faults in PV setups can lead to diminished power production, potentially resulting in losses of up to 18.9%. These issues can arise in both the Direct Current (DC) and Alternate Current (AC) sides of the system, particularly impacting the vital PV modules.[1]

A variety of faults are outlined, including mismatch, bypass diode, circuit, asymmetrical, arc, ground, and lightning faults. These can be either temporary or permanent. Circuit faults, a specific area of research, can manifest as either open-circuit or short-circuit situations and can severely impede power generation. The text discusses two broad categories of fault detection methods: those that rely on visual observation and specialized equipment, and those that utilize electrical output signals such as voltage, current, and power.[2]

Methods leveraging machine learning techniques, including artificial neural networks (ANNs) and probabilistic neural networks (PNNs), have been explored as promising tools for identifying and diagnosing faults. [3] Notable studies include one employing ANNs to pinpoint short-circuited modules based on variables like module temperature, irradiance, and power-related metrics. Another approach combines ANN with an analytical method to predict and compare maximum power points for fault identification.[4] Additionally, a PNN was trained to identify short-circuited and open-circuited modules.

This study employs a three-layer feed-forward neural network with sigmoid activation functions, implemented using MATLAB, to discern faults in photovoltaic arrays. The adoption of sigmoid neurons, known for their smooth output transitions, proves advantageous as they facilitate more gradual responses to input variations.[5] This signifies a meticulous calibration of the network's weights and biases, resulting in a commendable precision in replicating the output data. Impressively, the regression value closely approximates 1, affirming a striking correlation between predicted outputs and actual targets.[6]

The principal objective of the paper is the precise identification of specific faults in photovoltaic arrays, encompassing shading irregularities and PV module inversion anomalies. The neural network's training is rooted in historical data pertaining to similar faults, providing a robust foundation for accurate fault prognosis

Drawing a parallel to the adaptive nature of the human brain, the neural network exhibits behavior akin to human learning, responding based on prior experiences or trained values. To enhance fault detection and parameter determination, a carefully curated set of values inclusive of crucial parameters is supplied to the neural network.

## II. PHOTOVOLTAIC

### 2.1 Photovoltaic Array

A photovoltaic array is an interconnected assembly of photovoltaic modules, each comprising multiple linked photovoltaic cells. These cells harness solar energy and convert it into direct current electricity. While commonly referred to as solar panels, their distinction lies in their convenient size, weather-resistant housing, and straightforward installation for various residential, commercial, and industrial applications. The field of study and application dedicated to photovoltaic devices is known as photovoltaics.

PV cells operate on the principle of the photovoltaic effect, where specific materials absorb sunlight, initiating a flow of current between oppositely charged layers. Although individual solar cells yield relatively modest power, their collective electrical output can be substantial. Cells, modules, and arrays can be configured in series, parallel, or a combination to achieve the desired peak voltage output.

Photovoltaic cells are electrically linked in series and parallel circuits to generate higher voltages, currents, and power levels. Photovoltaic modules, encompassing PV cell circuits encased in an environmentally protective laminate, serve as the foundational components of PV systems. Photovoltaic panels comprise one or more pre-wired PV modules, ready for field installation. A photovoltaic array comprises any number of PV modules and panels, forming a self-contained power-generating unit.

The performance of PV modules and arrays is typically evaluated based on their maximum DC power output (in watts) under Standard Test Conditions (STC), defined by specific operating parameters. Actual performance often falls between 85 to 90 percent of the STC rating due to real-world conditions.

Today's photovoltaic modules are characterized by their outstanding safety, reliability, and minimal failure rates. Designed for long-term operation, they typically offer projected service lifetimes of 20 to 30 years. Major manufacturers commonly provide warranties of 20 years or more, ensuring a high percentage of the initial rated power output. When selecting PV modules, it is advised to consider product listings (UL), qualification testing, and warranty details outlined by the module manufacturer.

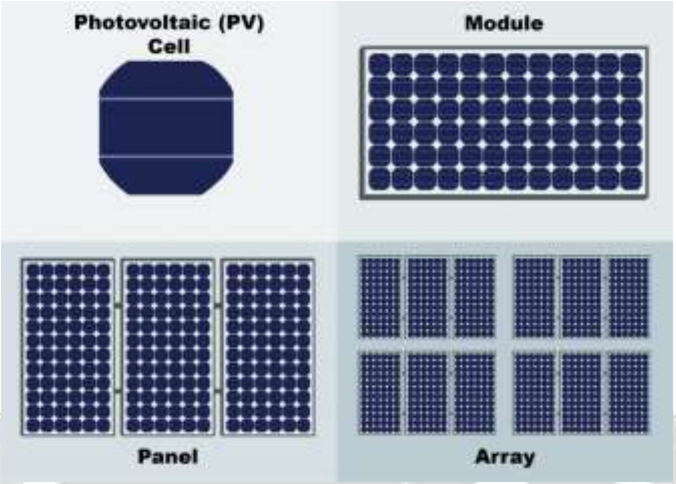
### 2.2 Difference between PV Module and PV Array

A solar panel comprises three fundamental components: the solar cells, module, and array. The pivotal element, the solar cell, plays a crucial role in harnessing energy from the sun. It is this component that ensures the acquisition of a substantial amount of energy.

The PV module, or the solar panel itself, acts as the housing for these solar cells. It is within this structure that the solar cells are strategically arranged to produce the requisite amount of energy in kilowatts or electrical voltage.

Complementing these components is the PV array, where solar PV modules or panels are interconnected to aggregate the desired energy voltage and subsequently transmit it to the panel.

In essence, each element carries out a unique function, and their interdependence in operation is evident. Together, they form an integral system for the efficient absorption and generation of energy.




## III.Artificial Neural Network

### 3.1 Introduction

Artificial neural networks (ANNs), often referred to simply as neural networks (NNs) or neural nets, are computational systems inspired by the biological neural networks found in animal brains. ANNs are constructed from interconnected units known as artificial neurons, which loosely emulate the neurons in biological brains. Similar to synapses in natural neural networks, each connection can transmit signals to other neurons. An artificial neuron receives and processes signals and subsequently transmits signals to connected neurons. The "signal" at a connection is represented as a real number, and the output of each neuron is determined by a non-linear function applied to the sum of its inputs. These connections are termed edges. Neurons and edges typically possess a weight that adapts during the learning process. This weight either amplifies or diminishes the strength of the signal at a connection. Neurons may also have a threshold, allowing a signal to be sent only if the cumulative signal surpasses that threshold.

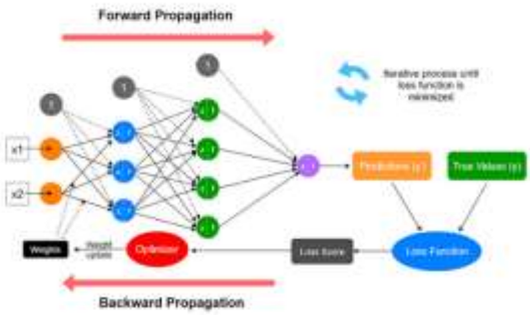
Neurons are commonly organized into layers. Different layers may carry out distinct transformations on their inputs. Signals progress from the initial layer (the input layer) to the final layer (the output layer), potentially traversing the layers multiple times.

The groundwork for artificial neural networks (ANNs) was laid in the late nineteenth and early twentieth centuries, with a focus on interdisciplinary research in physics, psychology, and neurophysiology. This early work centered on general theories of learning, vision, conditioning, and other phenomena, without specific mathematical models of neuron operation. These recent advances have revitalized the field of neural networks. Over the past two decades, numerous papers have been published, exploring various types of ANNs. Neural networks have found applications in a wide range of fields, including aerospace, automotive, banking, defense, electronics, entertainment, finance, insurance, manufacturing, medical, oil and gas, speech, securities, telecommunications, transportation, and environmental sciences. In the realm of ecology, the utilization of ANN models gained traction in the early 1990s, with increased popularity in the latter part of the decade.

### 3.2 Artificial Neurons

Artificial Neural Networks (ANNs) are constructed from artificial neurons, drawing conceptual inspiration from biological neurons. Each artificial neuron receives inputs and generates a single output, which can then be transmitted to multiple other neurons. These inputs may be feature values extracted from external data samples, such as images or documents, or they can originate from the outputs of other neurons. The final output neurons of the neural network perform the designated task, such as object recognition in an image.

To determine the output of a neuron, the weighted sum of all inputs is computed, with weights assigned to the connections from the inputs to the neuron. A bias term is added to this sum. This weighted sum, often referred to as activation, subsequently undergoes a (typically nonlinear) activation function to generate the final output. The initial inputs typically comprise external data like images and documents, while the ultimate outputs fulfill the designated task, such as recognizing objects in images.




## IV. FAULT DETECTION IN PV SYSTEM

### 4.1 Shading Effect

Shading poses a significant challenge in PV modules, as even shading a single cell within the module can lead to a complete loss of power output. Furthermore, this shading not only affects the individual cell but also diminishes the output of the entire string of cells or modules. Any surplus power generated by unshaded cells is dispersed within the shaded cell. To mitigate this issue, bypass diodes are employed to isolate the shaded cell from the rest of the array, allowing for more efficient energy production.

Shading significantly impacts the output of a photovoltaic cell. The reduction in output is directly proportional to the extent of shading caused by objects like tree branches, buildings, or module dust. For completely opaque objects like leaves, the decrease in current output corresponds to the obscured portion of the cell.

Individual solar cells typically produce an output of around 0.5 volts. To increase voltage, cells are connected in series within a module. In series circuits, the current remains consistent across all cells. Consequently, shading one cell leads to a drop in the current throughout the string of cells, often reducing the modules short-circuit current (Isc) to the lowest Isc value among all cells in the string.

Even shading just one cell in a module by half results in a proportional reduction of the entire module's output power by half, regardless of the number of cells in the string. If one cell is completely shaded, the module's output power diminishes to zero. The lost output power from the unshaded cells is absorbed by the shaded cell.

At the system level, where multiple modules are connected in series to elevate the system voltage to levels like 600 or 1000 volts, shading one cell would have a cascading effect on the entire module string, underlining the criticality of shading mitigation in photovoltaic systems.

### 4.2 Partial Shading

Partial shading, caused by factors like buildings, trees, and changing sunlight angles, disrupts uniform PV panel illumination. This leads to power losses and mismatched currents and voltages in PV strings. Bypass diodes are installed in crystalline silicon modules to prevent damage from shaded cells. These diodes allow current to flow in one direction, protecting against issues like hot spots. They're especially important when modules receive uneven illumination, preventing power loss and ensuring consistent performance.

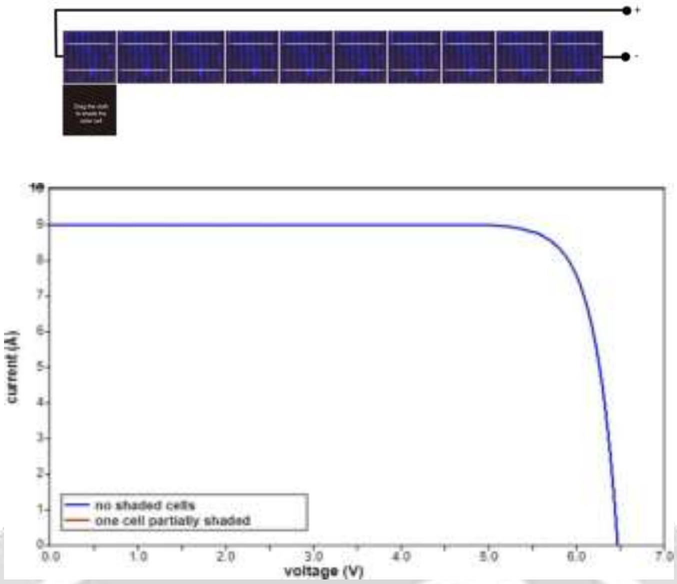



**Fig 1:No Shaded Cell**

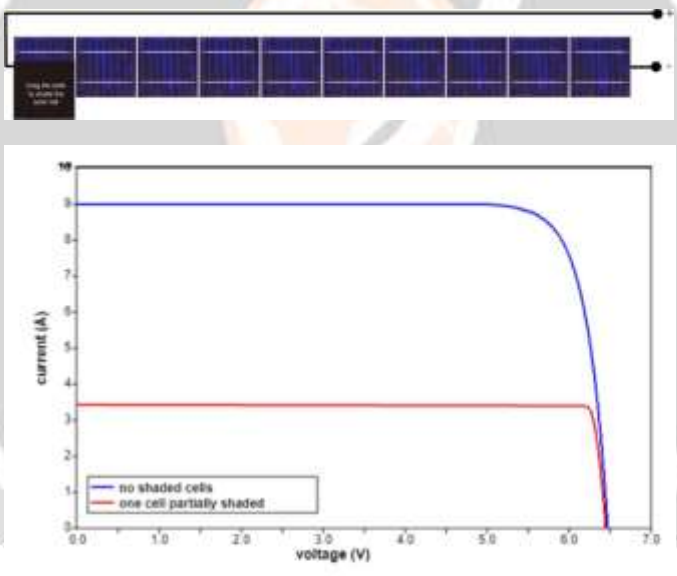



**Fig 2 Partial Shaded Cell**

V. Simulink Diagram& Outputs

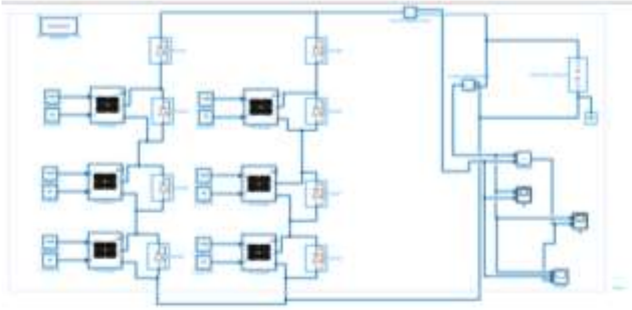


**Fig 3 Simulink Diagram for without shading**

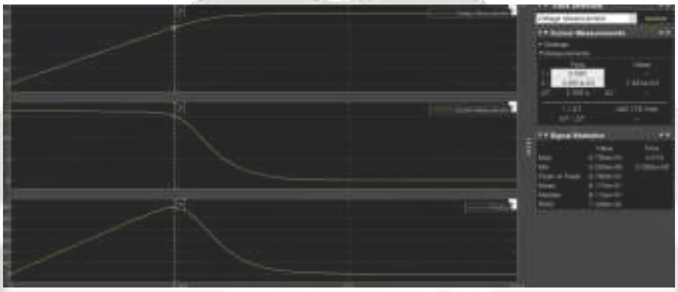


**Fig 4 Graph Without Shading**

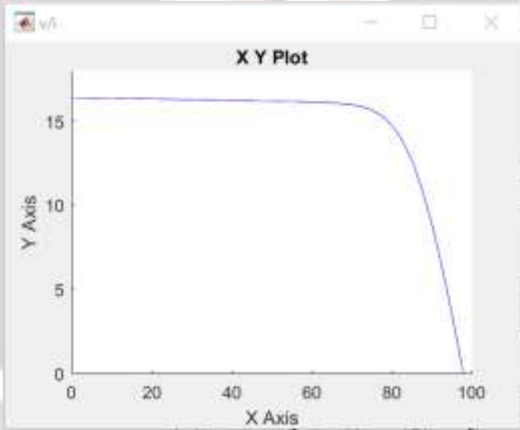



**Fig 5 VI Graph without shading**

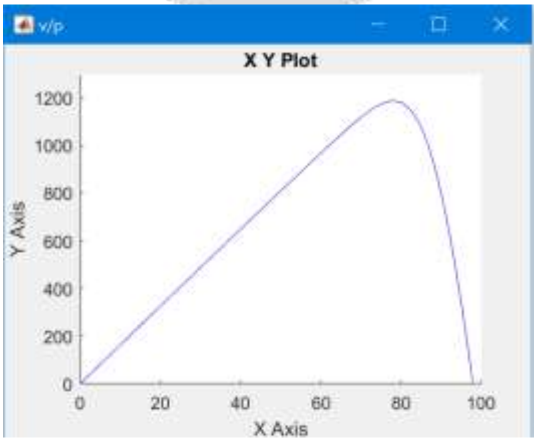



**Fig 6 VP Graph Without shading**

**Fig 7 Graph with Shading**

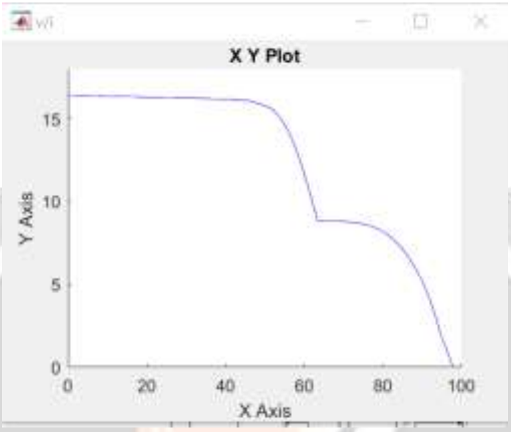



**Fig 8 VI Graph with shading**

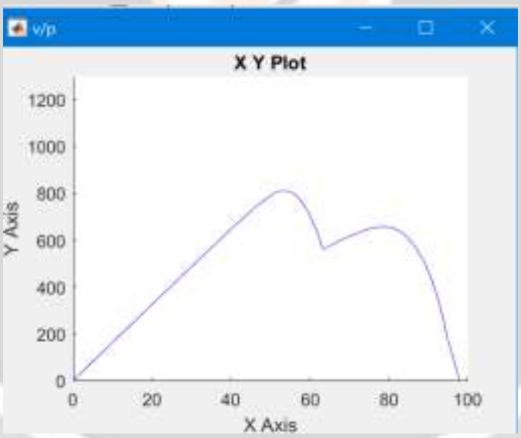



**Fig 9 VP Graph With shading**

## VI. CONCLUSION

A sophisticated approach for identifying faults in a photovoltaic system is outlined, employing MATLAB software for fault detection based on voltage, current, and power parameters. The study demonstrates the method's high accuracy in fault detection. The circuit design necessitates specific components with defined parameters to accurately evaluate the output parameters. This method can be expanded to detect various other types of faults, including photovoltaic array inversion issues. Thus, the proposed approach effectively simulates and identifies shading faults in a photovoltaic array.

REFERENCES

[1] Kim, G. G., Lee, W., Bhang, B. G., Choi, J. H., & Ahn, H.-K. (2021). Fault Detection for Photovoltaic Systems Using Multivariate Analysis with Electrical and Environmental Variables. IEEE Journal of Photovoltaics, 11(1), 202–212.

[2] Aboshady, F. M., & Taha, I. B. M. (2021). Fault Detection and Classification Scheme for PV System Using Array Power and Cross-Strings Differential Currents. IEEE Access, 9, 112655–112669.

[3] Eskandari, A., Milimonfared, J., & Aghaei, M. (2021). Fault Detection and Classification for Photovoltaic Systems Based on Hierarchical Classification and Machine Learning Technique. IEEE Transactions on Industrial Electronics, 6[1]8(12), 12750–12759.

[4] Mudgal, S., Gupta, P. K., Yadav, A. K., & Mahajan, V. (2020). Artificial Neural Network for Reliability Evaluation of Power System Network with Renewable Energy. 2020 21st National Power Systems Conference (NPSC)

[5] Attouri, K., Hajji, M., Mansouri, M., Harkat, M.-F., Kouadri, A., Nounou, H., & Nounou, M. (2020). Fault detection in photovoltaic systems using machine learning technique. 2020 17th International Multi-Conference on Systems, Signals & Devices (SSD).

[6] Greche, L., Es-Sbai, N., &Lavendelis, E. (2016). Performance Review of a Multi-Layer Feed-Forward Neural Network and Normalized Cross Correlation for Facial Expression Identification. 2016 12th International Conference on Signal-Image Technology & Internet-Based Systems (SITIS).

[7] Laamami, S., Benhamed, M., &Sbita, L. (2017). Artificial neural network-based fault detection and classification for photovoltaic system. 2017 International Conference on Green Energy Conversion Systems (GECS).