



# Review Paper on Solar Power Improvisation Using Bypass Diode

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## ABSTRACT

*Photovoltaic systems require bypass diodes for safety, to prevent the deterioration of the PV array from negative voltage operation during partial shading conditions. However, the presence of bypass diodes affects the power generated by the PV arrays; therefore, an accurate bypass diode model is important to calculate the power generated by the PV array, which is essential to determine the feasibility of the PV system. In addition, this paper presents an alternate model for the bypass diodes used in the PV arrays, where the model uses the Schottky equation with series resistance. Moreover, the paper introduces a non-invasive and non-destructive approach for calculating the model parameters without opening the junction box, which is useful for commercial PV arrays. The findings, based on the proposed approach, prove that the suggested approach is more precise for calculating the parameters related to the bypass diode compared to the conventional bypass diode model for assessing power generated by the PV arrays. The output power of a solar panel that was reduced due to shading has been improved using bypass diodes. The position of the bypass diodes improved the output current and power. The new maximum points and peak power were identified on the current-voltage and power-voltage curves, respectively. In the absence of bypass diodes, the maximum output power available from the solar panel was approximately 50 W. After installing the bypass diodes, a new peak output power of approximately 115 W was identified, while another peak output power was identified at approximately 150 W for voltage levels approaching 31 V and 40 V, respectively.*

**Keywords:** - PV Cells, Bypass, Diodes, I-V Curves, Solar Panel, Doping, P-V Curves, etc

## 1. INTRODUCTION

PV systems are widely used because they have a very limited environmental impact, require low maintenance, and their installation is relatively simple. In addition, depending on the site, PV systems may become a profitable option to supply electrical energy; therefore, it is necessary to make energy and financial evaluations that guarantee the profitability of the PV installation, considering the losses due to the degradation of the components. PV systems are composed of modules connected in different configurations, among which we can mention Series-Parallel (SP), Total-Cross-Tied, Honey-Comb, and Bridge Linked, among others. The SP configuration is the most widely used by commercial applications; this is due to its simple connective scheme, because cable lengths are smaller than in other configurations, and because there is a commercial inverter designed to operate with SP arrays. An SP array consists of strings or columns of modules connected in series connected in parallel to form the array. The PV modules marketed in the world usually consist of several submodules connected in series, which in turn are a series of PV cells with an anti-parallel bypass diode. There is a continuous rise in demand for renewable resources over time, which is further needed as the planet is living out the fuel that it was provided millions of years ago. Using renewable resources will increase the lifespan of fossil fuels. The fossil fuels that we use are oil, coal, and gas. Oil has certain drawbacks because, with the use of oil, carbon dioxide is released, acid rain appears, and oil is not clean. Natural gas also has various disadvantages because it creates greenhouse gases, is volatile, and is non-safe unless proper care is taken during the transportation period. Aim of the Paper: In order to improve the accuracy of predicting the generated power in the PV array without access to the junction box, the paper proposes that the exponential equation used to model the bypass diodes be adjusted by adding resistance in series. The parameters used in modeling the bypass diode will be extracted by utilizing the I-V curve, which is extracted from experimental data taken at the submodule terminals. The aim is to reduce the high sensitivity of the solution proposed in the referenced paper, whereby the parameters of the bypass diode were extracted from just two points on the diode I-V curve. Instead, by using the method proposed in the paper, the parameters of the bypass diode would be extracted from the entire I-V curve. Like oil and natural gas, coal creates waste, acid rain, and health problems for the coal miners. The renewable resources are used as an alternative,



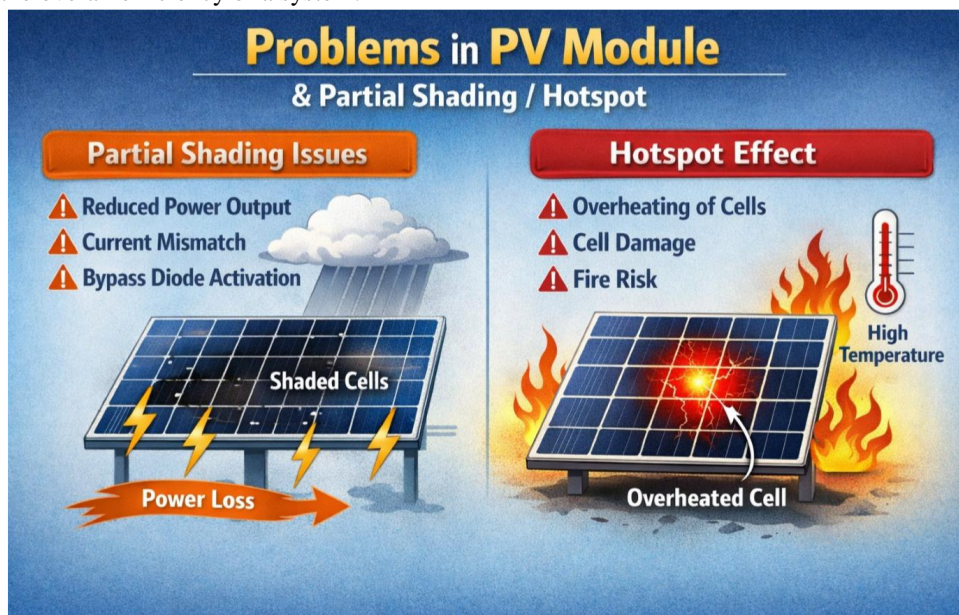
which reduces the use of fossil fuels. Various types and numbers of resources assist us with renewable resources. There are disadvantages associated with wind energy resources; they create noise, are unpredictable, and affect television and radio signals. As compared to other available alternatives for renewable resources, solar energy is more promising because it is clean, less expensive, abundant, noiseless, and creates electricity no pollution. The energy from the sun is converted into electrical energy, which is used by different devices. A solar cell is an electronic device that uses the photovoltaic effect to convert sunlight into electrical energy. A p-n junction is the smallest unit of a solar cell that can produce electricity. When photons, or packets of energy, hit the p-n junction, atoms within the n type, for example, will absorb a photon, and an electron along with a hole will be knocked out. Then, a free electron and a free hole will be created. Free electrons and free holes will generate current afterwards. Monocrystalline, polycrystalline, and thin-film solar cells are common types of solar cells all over the world. Silicon, which is commonly used in the semiconductor industry, is the main raw material for both mono crystalline and poly crystalline solar cells. In the meanwhile, gallium diselenide, amorphous silicon, and cadmium telluride are the common materials used to manufacture thin film solar cells. Their primary advantage among other types of solar cells is their greater efficiency. However, due to methods used to enhance the purity, mono Crystalline solar panels are expensive as compared to other types of solar cells. Mono crystalline solar cells have a maximum efficiency of around 17% to 18%. Many factors reduce the effectiveness of the solar cell, including high temperature, high radiation, sand, dust on the solar cell surface, and partial shade. This paper discusses improving the efficiency of solar cells using bypass and blocking diodes.

## 2. PROBLEMS IN PV MODULES

### 2.1 Partial Shading & Hotspots

The partial shading effect on photovoltaic modules due to obstructions such as trees and chimneys often results in power loss, hot spots, and cell failures. The shaded cells are reverse-biased, acting as loads and consuming power, which leads to high temperatures high enough to melt the encapsulants and cause cell destruction and fires.

- ❑ **Loss in Power:** The loss in power due to uneven power dissipation causes a decline in efficiency, as an increase in power by merely 1/36th loss can account for an overall decline in efficiency by as much as 75%.
- ❑ **Hotspot Formation:** A cell experiencing partial shading becomes reverse-biased and starts to consume power from regular cells, leading to a hotspot.
- ❑ **Irreversible Damage:** High temperatures can lead to EVA meltdown, backsheet, fractures in cells, and eventually degrade module efficiency.
- ❑ **Long-term Reliability Issues:** Partial shading causes cells to degrade at an ever-increasing rate and, as stated in a YouTube tutorial, is responsible for as much as 80% of all fire hazards faced by solar systems.
- ❑ **Impact on MPPT:** “Multiple peak points exist on the P-V curve,” which negatively impacts MPPT mechanisms and brings down the overall efficiency of a system.

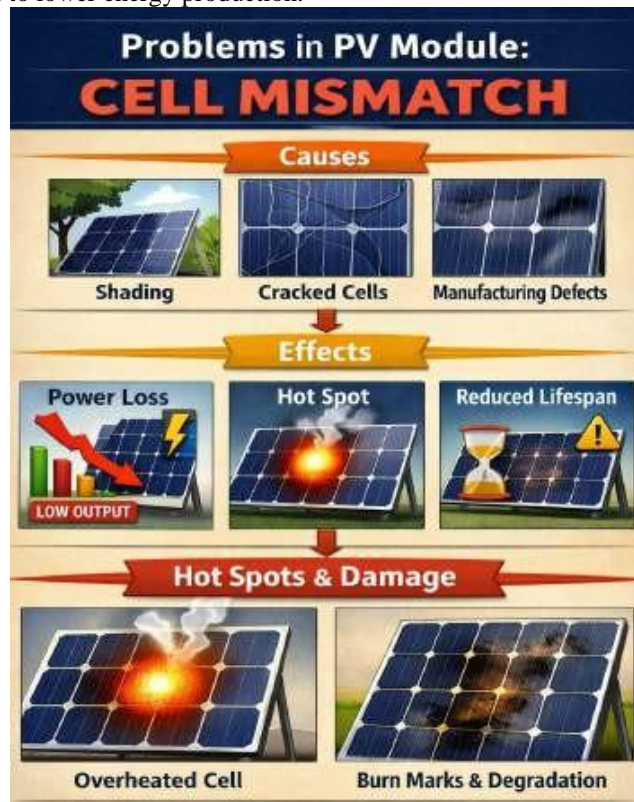




### 2.2 Cell Mismatch

PV module cell mismatch due to shading, aging, or manufacturing defects severely reduces the output power by forcing the entire string current to the magnitude of the worst cell. It creates hotspots with high temperatures in the inefficient cells, which may lead to more permanent destruction, accelerated degradation, and even a fire hazard.

- ❑ **Substantial Power Reduction:** When cells in a series configuration exhibit different current-voltage behaviors, the cell with the lowest current controls the maximum output of the whole module or string.
- ❑ **Hot Spot Formation:** The darker or weak cell becomes reverse-biased and hence will start drawing power from the nearby cells, converting it into heat, thereby causing a potential threat to encapsulants and a fire hazard.
- ❑ **Localized Damage and Degradation:** Sustained hot spots may lead to permanent damage, such as delamination of the encapsulation material and damage to the backsheet.
- ❑ **Accelerated Aging:** Inconsistencies from irregular soiling (dust, bird droppings) or manufacturing processes can lead to non-uniform aging, causing permanent damage in some of the cells in a module.
- ❑ **Higher Operating Expenses:** Variation effects, like higher module temperature, decrease the performance ratio of the entire solar array and lead to lower energy production.



### 2.3 Power Loss Mechanism

The main mechanisms of power loss in Photovoltaic (PV) modules, which affect the reduced output of energy by lowering it to levels less than nominal, comprise various environmental elements, optical elements, electrical elements, as well as elements of degradation. This leads to a typical reduction rate of 0.5-0.8% every year.

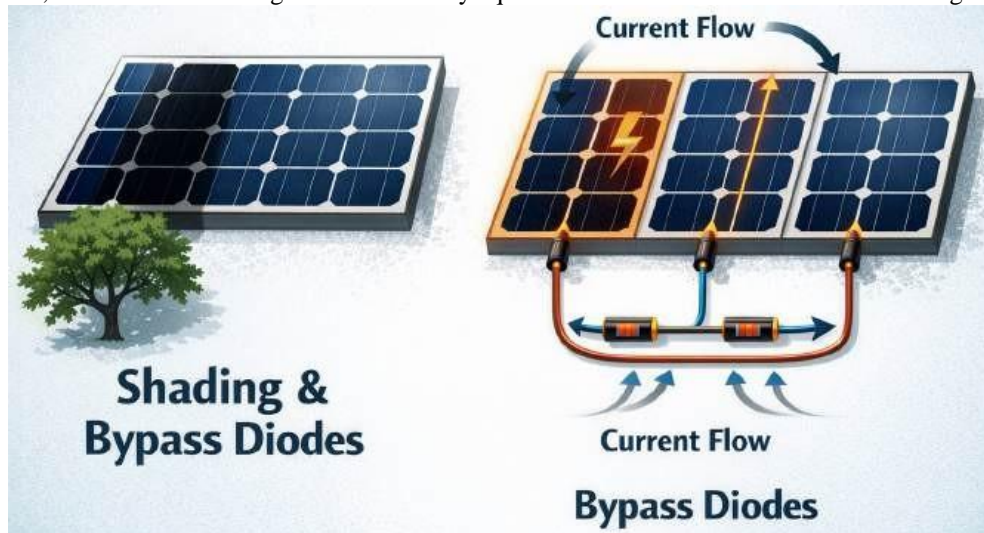
- ❑ **Soiling (Dust, Dirt, and Debris):** Soiling caused by the accumulation of dirt, bird droppings, and other pollutants interrupts solar radiation, and this leads to losses in the range of 2–7%, which may increase up to 60% in desert climates.
- ❑ **Reflection:** The reflection of sunlight on the glass, whereas it would have been absorbed. Even with coatings, it is common to lose around 2.5-4% of the light.
- ❑ **Potential Induced Degradation (PID):** Wide voltage fluctuations between the cells and the frame cause leakage currents, leading to a loss of 10-30% power, especially when conditions are moist.
- ❑ **Ohmic/Resistance Losses:** The energy loss that occurs inside the wire due to the wire's internal resistance, which increases with the rise of heat due to deteriorating connectors.



### 3. BYPASSING DIODE

The bypass diodes help the solar panels in providing power at a reduced voltage in the form of a series of interconnected solar cells or panels, rather than not providing any power at all. Bypass Diodes are connected in reverse bias between the positive output and negative output terminals of solar cells (or panel) and do not affect the output. Ideally, bypass diodes should be connected in series with individual solar cells, but this is not cost-effective; instead, one bypass diode is commonly connected for every group of series solar cells. The photovoltaic cells harness the surrounding light photons entering the pn-junction, converting them into electric current without any mechanical or moving parts. PV cells use the energy of the Sun, not heat, to generate power. The truth is, photovoltaic cells function best when they're cold!

Also, when the above solar cell is placed in front of the sunlight (or other intense light source), the generated voltage is almost 0.58 DC voltage, and the current flow in amps is nearly equal to the photons. The voltage of most solar cells is almost stable, whereas the current generated is nearly equal to the dimensions of the cell and the light intensity.



#### 3.1 Purpose

- Provide an alternate or optional current path when cells become underperforming.
- Prevent entire module, starting from being dominated by a weak cell.



## 4. TYPICAL IMPLEMENTATIONS

### 4.1 Cell String Division

A sub-string is a part of a PV module, which contains normally 60, 72 or 144 cells.

Every sub-string usually covers 18–24 cells [for 60/72-cell units]

One bypass diode for every sub-string

Sample (72-unit module): 48 cells → 4 segments × 12 cells

### 4.2 Electrical Connection

Bypass diodes are linked alongside each sub-string, Reverse-Bias State in Standard Functioning When a sub-string is highlighted its potential decreases. The diode is in a forward-biased condition. Current flows around the shaded cells instead of passing through them

### 4.3 Physical Placement

Bypass diodes are situated within the junction box at the rear of the module. Affixed to heat-resistant surfaces This maintains them Shielded from the elements

### 4.4 Physical Placement

Type of diode utilized frequently utilized diodes: Schottky rectifiers Minimal forward voltage drop (approximately 0.3–0.5V).

Quick reply

Reduced power consumption Standard evaluations: Present: 10–20 A

Voltage: 45–100 volts



## 5. RESULTS & ANALYSIS

### 5.1 Result of Using Bypass Diodes in a Solar Module

When bypass diodes are connected in parallel across the cell strings in the PV module, loss of power due to partial shading is minimized. Formation of hot spots is hindered. The module remains functional instead of being completely obstructed. The electrical characteristics (I–V and P–V curves) show multiple steps and peaks.

### 5.2 I–V Curve Analysis (With and Without Bypass Diodes)

#### a) Without Bypass Diode (Partial Shading Case)

The shaded cell limits current for entire series string.

A reverse bias occurs in the shaded cell → causing heating (hot spot) What the I–V curve indicates is:

Sudden decrease in current, Decreased short-circuit current ( $I_{sc}$ ), Extremely Low Power Output

#### b) With Bypass Diode

When the cell or cell-string gets tinted, the bypass diode is activated. There are currents flowing presently through the shaded region.

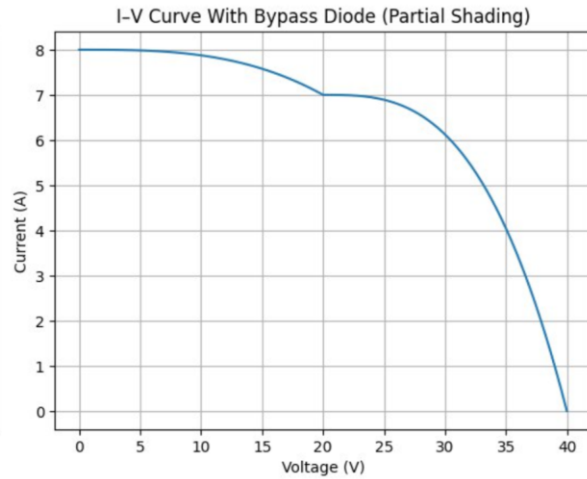
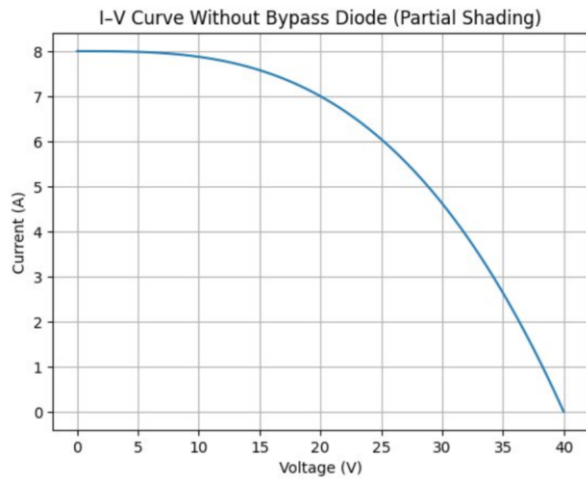


The I-V curve indicates:

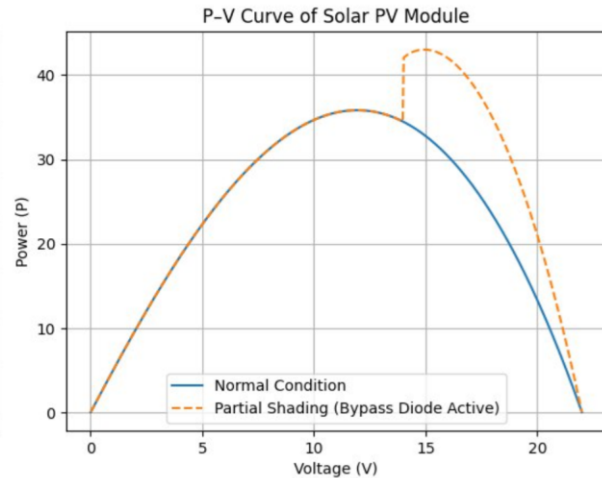
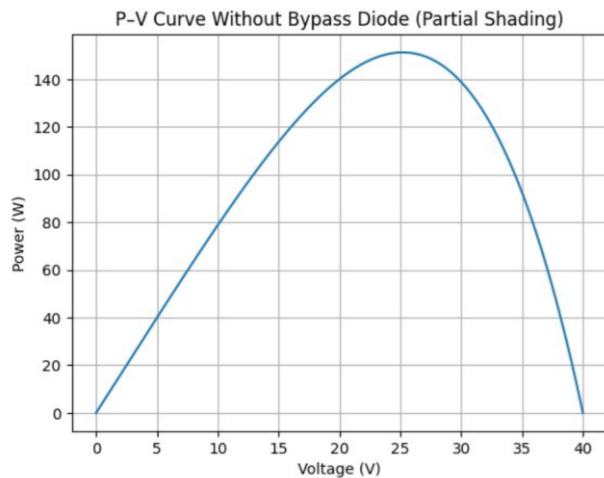
Staircase Form

Each step indicates that one of the bypass diodes is turning on. Minor voltage decreases, yet current is maintained.

Condition	Current	Voltage	Shape
No shading	Maximum	Maximum	Smooth curve
Shading, no diode	Very low	Low	Abrupt collapse
Shading with diode	High	Reduced	Stepped curve



**5.3 P-V Curve Analysis (Most Important for MPPT)**



Condition	I-V Curve	P-V Curve	Output Power	Protection
Without Bypass	Sharp drop	Single low peak	Very Low	No
With Bypass	Step curve	Multiple peaks	Higher	Yes

Example:

- ☑ Normal Power = 250W
- ☐ Under shading without diode = 130 W
- ☐ With bypass diode = 200 W

Efficiency improvement:

$$\eta_{\text{improvement}} = \frac{200 - 130}{130} \times 100 = 53.84\%$$



The I-V curves have many steps, and the P-V curves have multiple peaks. In the case of bypass diodes, the unshaded cells will conduct current. But in the case where the bypass diodes are not connected, the shaded cells will limit the current flow from the unshaded cells.

## 6. CONCLUSION

This paper introduces a modified model for bypass diodes that are used to protect submodules in commercial solar PV arrays. The model is based on the Schottky equation and includes a series resistance, which means there is a process needed to determine the model's parameters. To address this, the paper suggests a method that is both non-invasive and non-destructive for estimating these parameters, which means it doesn't require opening the module's junction box.

The simulation and experimental results show that the proposed solution, which includes both the model and the method for estimating parameters, gives a better match with the IV curve of bypass diodes connected to commercial PV modules compared to the traditional exponential model. As a result, this new approach allows for more accurate predictions of power output in PV systems when there is partial shading. Additionally, the improved accuracy can help in better identifying the performance of modules in the second quadrant, which can be useful for reconfiguring the PV array to prevent module degradation. One main limitation of the solution is that the parameters change under different irradiance levels—low, medium, and high—which means an irradiance sensor needs to be included in the experimental setup.

However, this is not unique to this model, as other high-precision diode models also have parameters that vary with conditions. The model could be further improved by using a non-linear element instead of a fixed resistance to better represent how parameters change with irradiance, and this is an area that is currently being studied.

## 7. FUTURE SCOPE

- Adaptive bypass switching
- Integrated module power electronics
- Smart bypass circuit with control logic
- Hybrid Approaches

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