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New Algorithm for the IV Characteristic Modeling of the Photovoltaic Generator Malfunction within Impedance and Reversed Polarity Faults

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Abstract— In this paper, we proposed a new methodology that can improved and developed the faults detection and diagnosis methods of the photovoltaic generator, especially when it subjected to the impedance and reversed polarity defects. This proposed algorithm is based on the mathematical modeling of the IV characteristic, of the faulty photovoltaic generator hierarchies as: cell, cells group, module, string and the entire generator, when they submitted to one or more of: cells, bypass and blocking diodes in impedance and reversed polarity faults.

This new methodology can facilitated the study of the faulty generator characteristics, and obtained a database for the learning phase and the classification of the new observations collected on the system during its operation.

Index Terms —PV Generator; I-V Characteristic; Modeling; Simulation; Impedance and Reversed Polarity Faults.

NOMENCLATURE

I_{phi}	= Photo-Current.
N_{Cells}	= Cells Number in Each Group.
N_{Groups}	= Groups Number in Each Module.
$N_{Modules}$	= Modules Number in Each String.
$N_{Strings}$	= Strings Number in the Generator.
V_{Cell_Imp}	= Cell Voltage Imposed.
I_{Cells}	= Cell Current.
V_{Cells}	= Cell Voltage.
I_{PV}	= Generator Current.
V_{PV}	= Generator Voltage.
R_S	= Cell Series Resistance.
R_{SH}	= Cell Shunt Resistance.
I_{S1}	= Reverse Saturation Current of 1 st Diode.
I_{S2}	= Reverse Saturation Current of 2 nd Diode.
$m1$	= Ideality Factors of 1 st Diode.
$m2$	= Ideality Factors of 2 nd Diode.

I. INTRODUCTION

Any PV system consists generally of three main parts: a PV generator - subject of this work - that produces continuous power by converting the solar radiation, it consists of a set of cells in series or in parallel. The second part is the converters group, which consists of two parts: the first is the chopper to extract the maximum power of the PV generator, and the second is an inverter to convert the DC into the AC. Finally, the third part of the PV

system is the consumers that can a local network or a general network [1-2].

The generator productivity is based on the rapport value of the two main factors: 1) solar radiation energy captured by the generator and 2) the generator output energy, which is in the form of a direct current. So, the shortage of the last two factors means the presence of the faults at the PV generator [3-4].

The presence of these defects like the impedance and reversed polarity types reduce the power produced by the generator, and consequently reduce its productivity. So, the objective of this paper is the modeling of the faulty generator behavior [5-6]. The resulting model can simplify the prediction of the faults detection, and protect the system before its crashes [10-12].

So, our contribution presented in this paper is to propose a new methodology for modeling the faulty PV generator characteristics based 1) on the mathematical formulation of the IV characteristic of its faulty basic components: cells, bypass and blocking diodes, to study the behavior of these defective elements itself, and 2) on the mathematical formulation of the IV characteristic of its hierarchy: cell, cells group, module, string and finally all the PV generator, to study the influence of this defective elements on the generator operation.

II. MODELING THE PHOTOVOLTAIC GENERATOR IN MALFUNCTIONING

In this article, our objective is to propose a new model of the faulty generator operation, when it subjected to the impedance and reversed polarity faults at its basic components. But, this model needs a landmark, which facilitates the detection of the abnormal cases by the results comparison with the normal case.

And for the simulation of the proposed mathematical models in this work, we selected a generator presents in Figure1. It contains nine hundred photovoltaic cells, distributed on five parallel strings to maximizing the generator current, and each string contains 180 cells in series, to maximizing the generator voltage, so this generator can produce a maximum 90 volte.

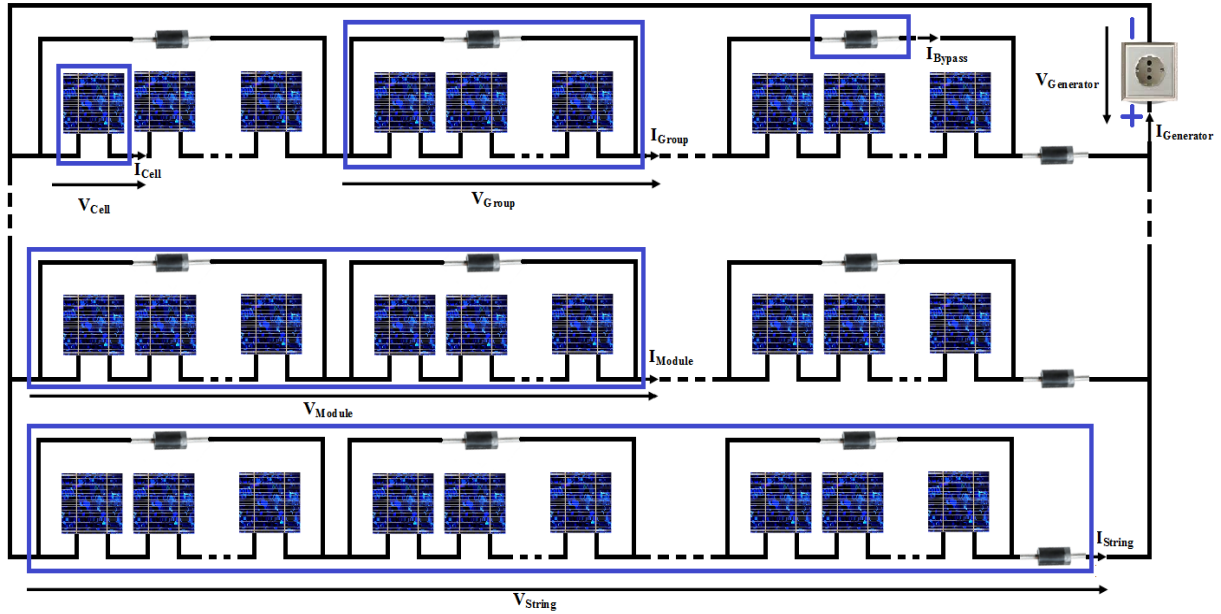


Figure1. PV generator description

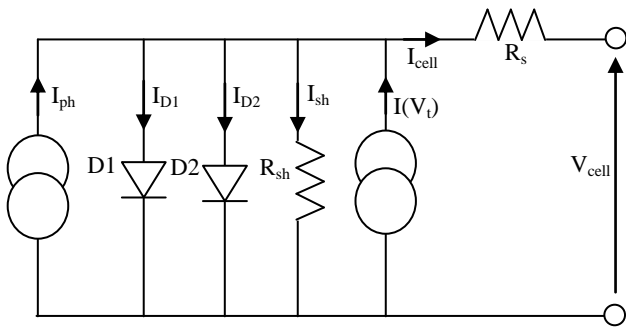


Figure2. Two diodes Model of a photovoltaic cell

The cell model used in this work for the PV generator modeling is based on the *two-diode* model presents in Figure2, because it describes in the literature as the model closer to the reality. So, the IV characteristic of a good photovoltaic generator is:

$$\begin{cases}
 V_{PV} = N_{Modules} \times N_{Groups} \times N_{Cells} \times V_{Cell_imp} \\
 I_{PV} = N_{Strings} \times \begin{pmatrix} I_{phi} - I_{S1} \left(e^{\frac{V_{Cell} + I_{Cell} \times R_S}{m_1 VT}} - 1 \right) \\ - I_{S2} \left(e^{\frac{V_{Cell} + I_{Cell} \times R_S}{m_2 VT}} - 1 \right) \\ \frac{V_{Cell} + I_{Cell} \times R_S}{R_{SH}} \end{pmatrix} \quad (1)
 \end{cases}$$

Figure3 shows the IV characteristic and the power of a good photovoltaic generator.

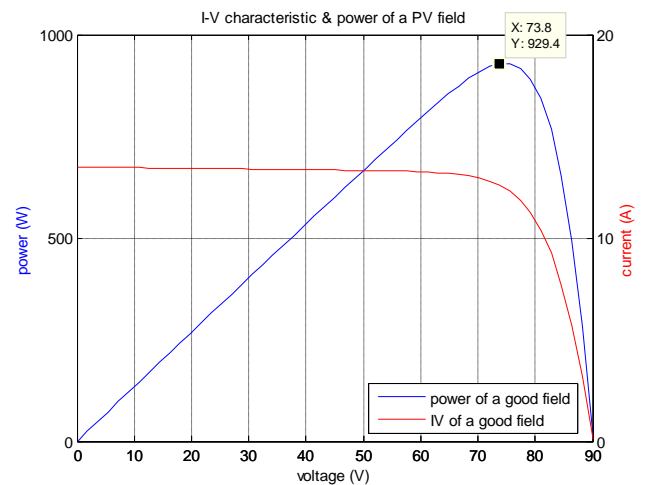


Figure3. I-V & power of a good PV generator

Among the electrical faults that have a significant influence on the generator operation: the impedance and reversed polarity faults. These defects in a photovoltaic generator affect its three basic components: cell, bypass and blocking diodes. The existence of cells heating, cells crack, shading, the interconnections degradation and others defects can participates in the appearance of these two defects that reduce the generator productivity.

These faults eliminate outright the string power contains defective blocking diode. They create short-circuit at the cells group comprising by a defective bypass diode. Finally, they decrease the group power that contains defective cells.

The influence modeling of the impedance and reversed polarity faults on the PV generator hierarchy consists of five main parts as they present in Figures 4-8.

A. Influence Modeling of the Impedance Cells on the PV Generator Hierarchy

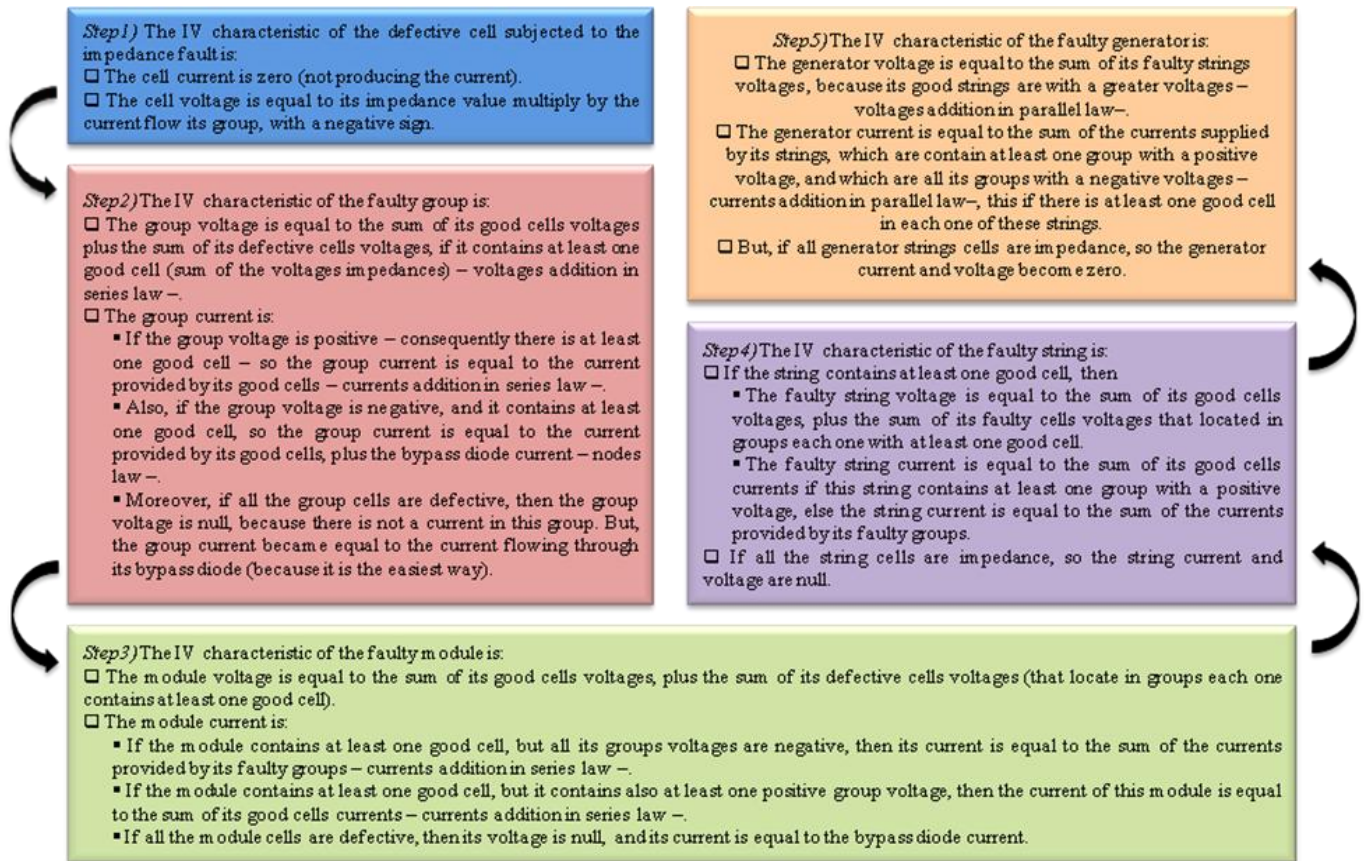


Figure4. Flowchart for Influence Modeling of the Impedance Cells on the PV Generator Hierarchy

B. Influence Modeling of the Reversed Polarity Cells on the PV Generator Hierarchy

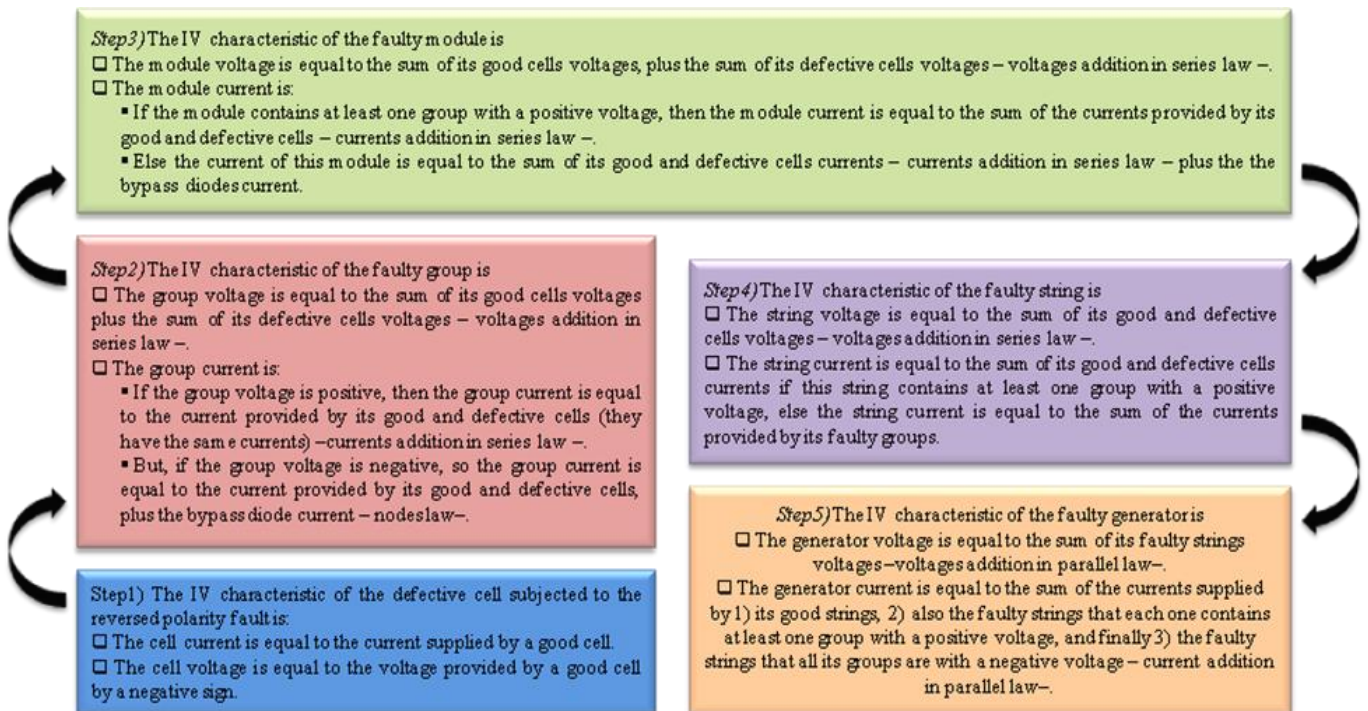


Figure5. Flowchart for Influence Modeling of the Reversed Polarity Cells on the PV Generator hierarchy

C. Influence Modeling of the Impedance Bypass Diodes on the PV Generator Hierarchy

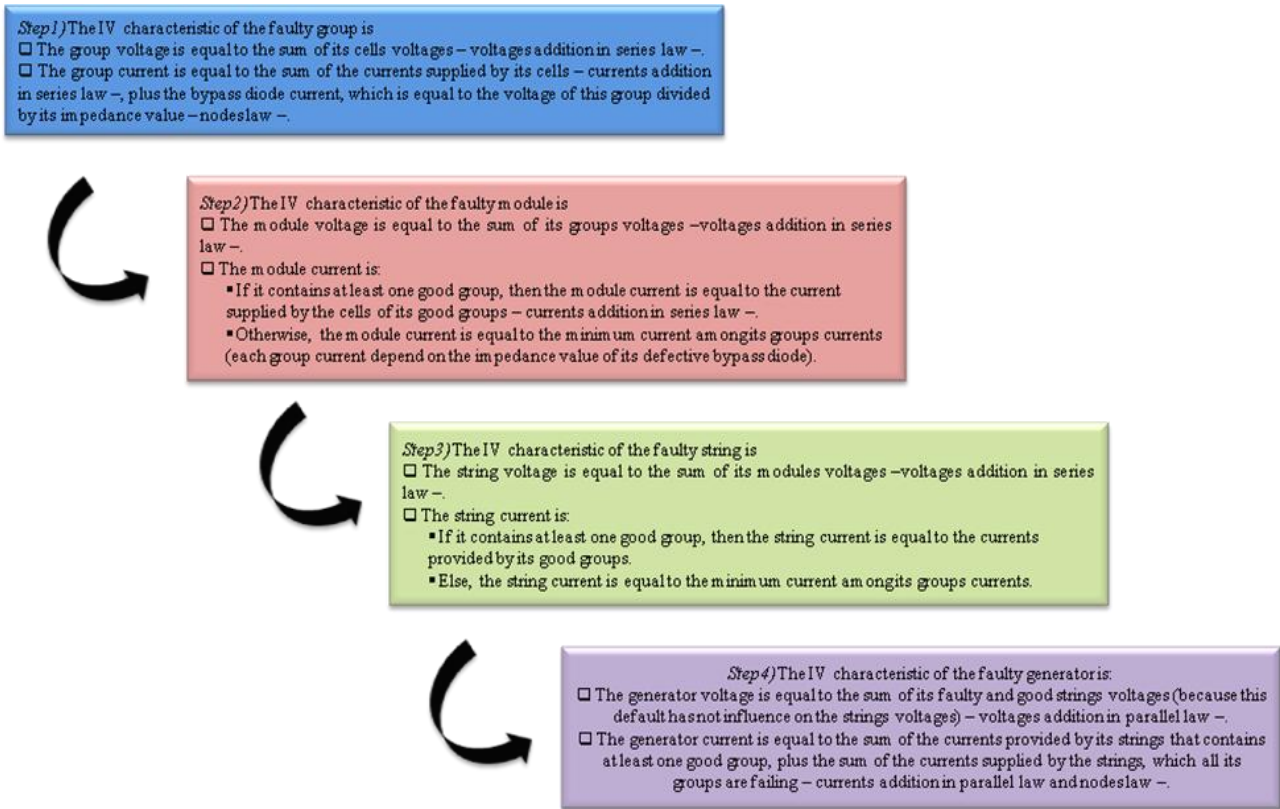


Figure 6. Flowchart for Influence Modeling of the Impedance Bypass Diodes on the PV Generator hierarchy

D) Influence Modeling of the Reversed Polarity Bypass Diodes on the PV Generator Hierarchy

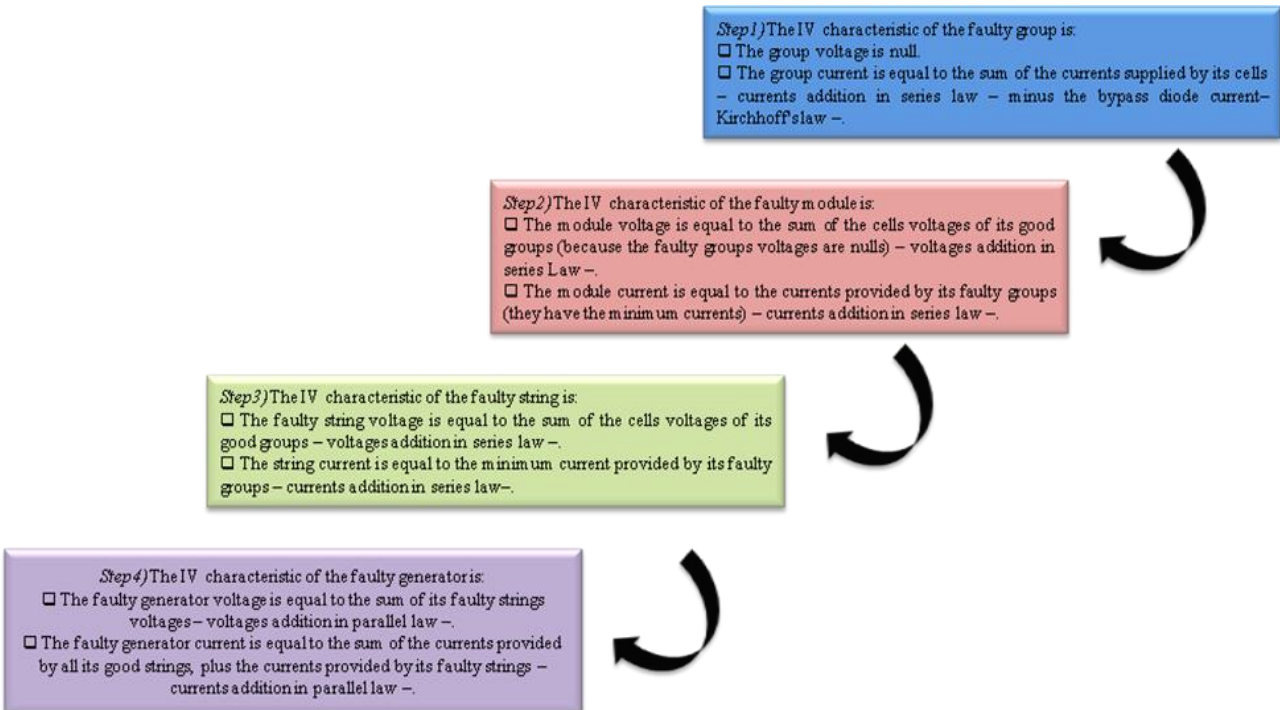


Figure 7. Flowchart for Influence Modeling of the Reversed Polarity Bypass Diodes on the PV Generator hierarchy

E. Influence Modeling of the Impedance and Reversed Polarity Blocking Diodes on the PV Generator hierarchy

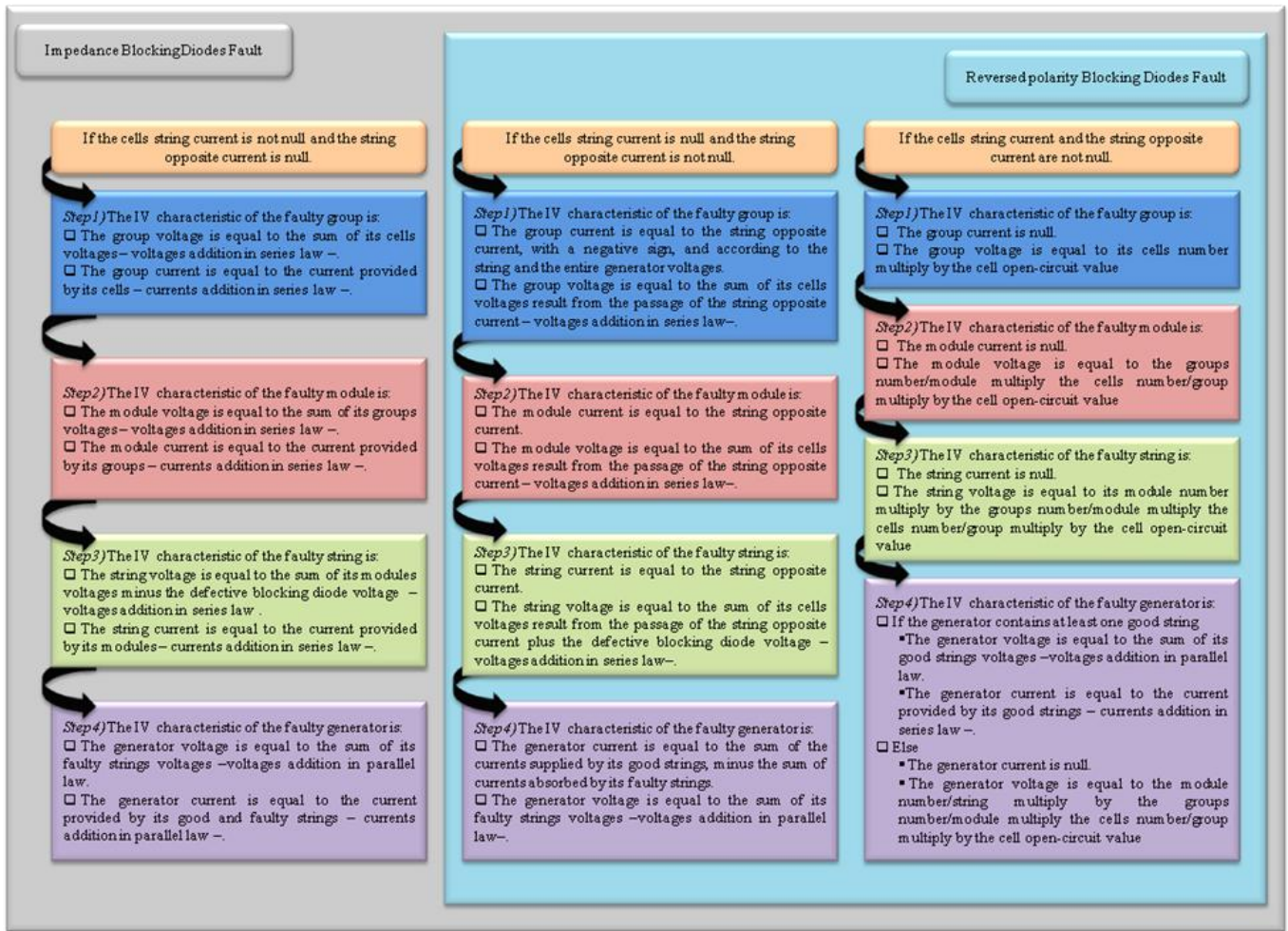


Figure8. Flowchart for Influence Modeling of the Impedance and Reversed Polarity Blocking Diodes on the PV Generator hierarchy

III. MODELS SIMULATION AND RESULTS INTERPRETATION

From the proposed models and its simulations (Figures.9-11), we concluded that:

- The cell impedance fault eliminates the defective cell current. Consequently, it removes the string current, which all its cells are defective.
- The bypass diode impedance increased the generator power by increasing its current. Because, this fault increases the faulty string current that all its bypass diodes are defective, thanks to the increasing in its faulty groups currents. Also, this fault has not an influence on the generator voltage. But unfortunately, the generator current increasing is dangerous, because it changes the generator characterization to the receiver mode if its current exceeds its short-circuit current value.
- The blocking diode impedance fault changes its faulty string behavior to the receiver mode, if its cells string current is null, and to the open-circuit mode in the opposite case. Because, this fault authorizes the passage of the current in both ways.

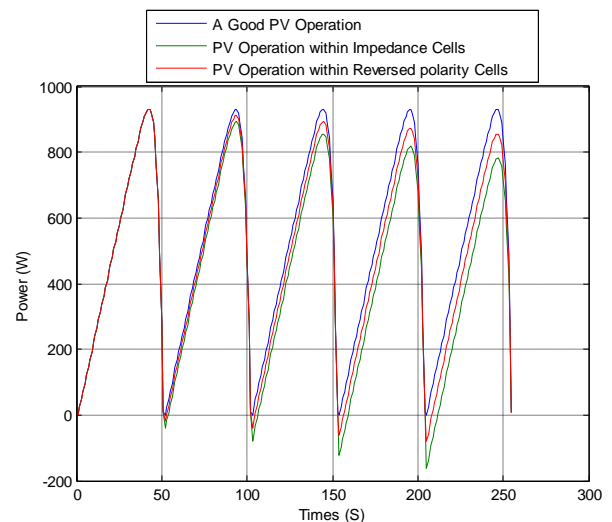


Figure9. The influence of the impedance and reversed polarity cells faults on the PV generator operation.

- The cell reversed polarity and bypass diode reversed polarity faults degrade the generator power by the decrease in its voltage. Because, the cells reversed polarity eliminates the group voltage if the half of its

cells are defective, and it changes the group behavior to the receiver mode if its defective cells number is greater than the healthy ones. And bypass diode reversed polarity fault creates short-circuit at its group, which removes its group voltage.

- The blocking diode reversed polarity fault decreases the generator current, while it contains at least one good string. Because, the faulty strings currents are null in both cases: if the strings cells currents are not null, then the faulty strings are in the open-circuit mode. Or, if the strings cells currents are null, then the faulty strings are in the receiver mode.

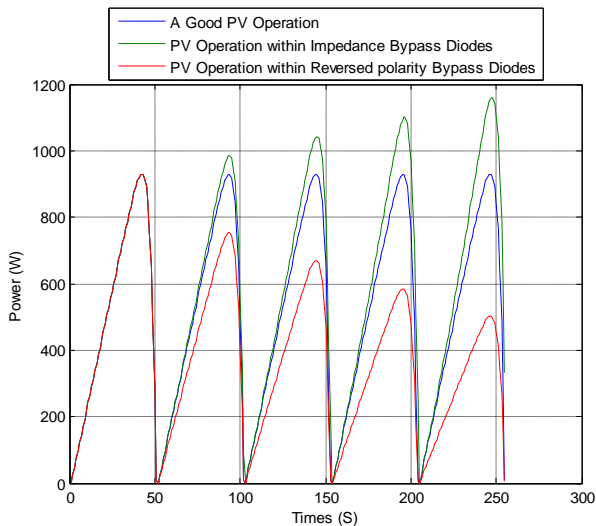


Figure10. The influence of the impedance and reversed polarity bypass diodes faults on the PV generator operation.

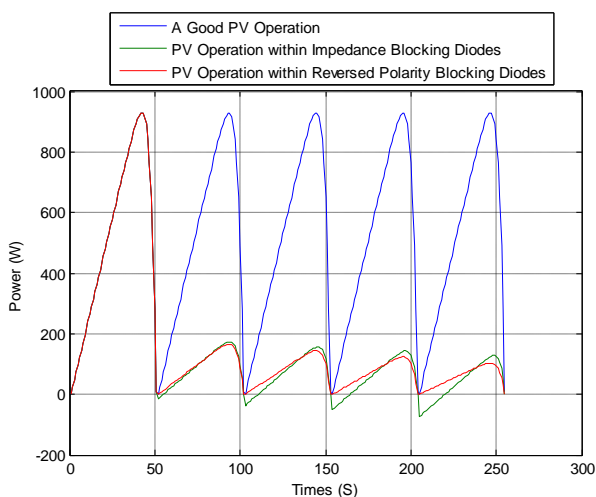


Figure11. The influence of the impedance and reversed polarity blocking diodes faults on the PV generator operation.

IV. CONCLUSION

In this paper, we proposed a new strategy for the mathematical modeling - by known electrical laws - of the electrical faults influence in the generator operation, particularly when it subjected to the impedance and reversed polarity faults at its basic components like its cells, bypass and blocking diodes.

This new strategy is for objective to quantify the influence of these defects types, not just for the faulty

basic components, but also to quantify the influence of these defects at the cells joined, cells group, module, string, and finally the entire generator.

The future work of this paper is to propose a hybrid model of the PV generator, for modeling the existence influence of these two defects at the same time, in terms of type and quantity of defaults and also components.

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