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TOOL TO ANALYZE PERFORMANCE OF PHOTOVOLTAIC SYSTEM UNDER UNIFORM AND NON-UNIFORM ENVIRONMENTAL CONDITIONS

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OTHER PUBLICATIONS

Patel, Hiren, and Vivek Agarwal. "MATLAB-based modeling to study the effects of partial shading on PV array characteristics." IEEE transactions on energy conversion 23.1 (2008): 302-310.

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ABSTRACT

A tool to analyze the performance of a photovoltaic (PV) system is disclosed, the tool includes:

1- a method for parameter extraction of the two diode (equivalent circuit) model of PV module,
2- a **generalized analytical method** to compute the PV array output under uniform and non-uniform (partial shading) insolation condition for any series parallel PV array configuration subjected to any temperature/irradiance profile,
3- a method to compute the effect of bypass and blocking diodes on the output of a PV array,
4- a **computer program product** employs the three above-mentioned methods to comprehensively compute the electrical characteristics of a PV array receiving uniform and non-uniform temperature/irradiance profile,
5- a **graphical-user interface** that allows user to customize the inputs and utilize the three above-mentioned methods to compute and visualize the PV array electrical characteristics.

20 Claims, 17 Drawings

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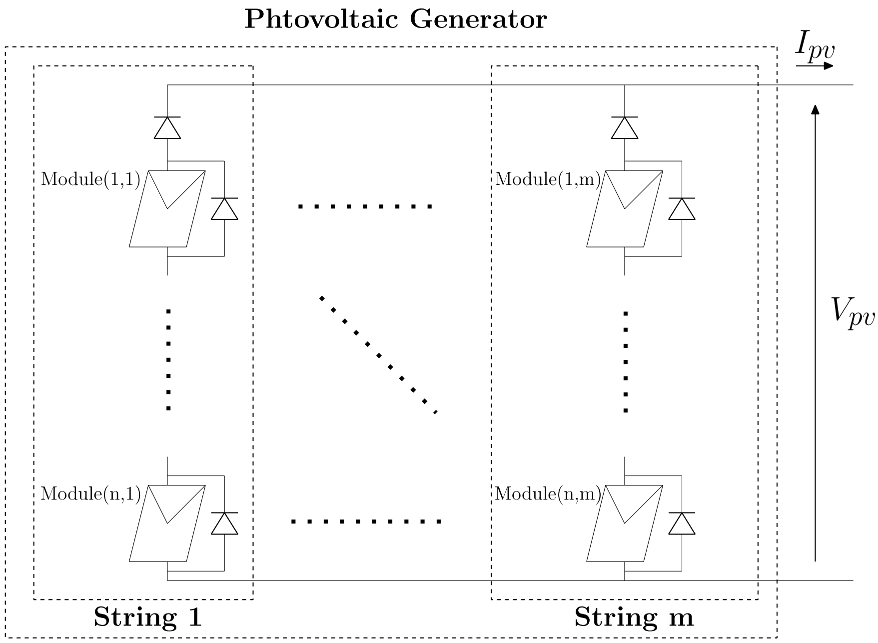

FIG 1. General configuration of PV array, where m is the number of strings and n is the number of the series-connected modules in each string.

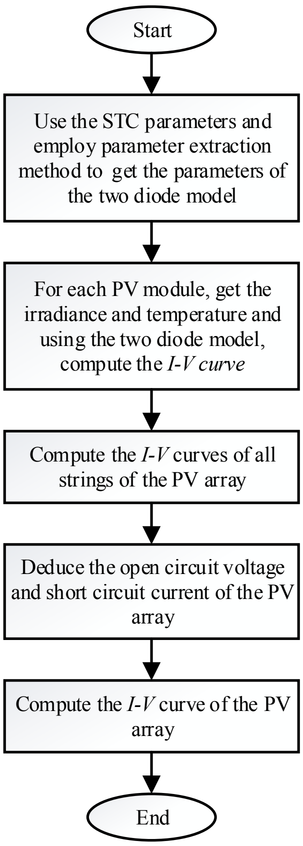

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FIG 2. Flowchart to compute the electrical characteristics of shaded PV arrays.

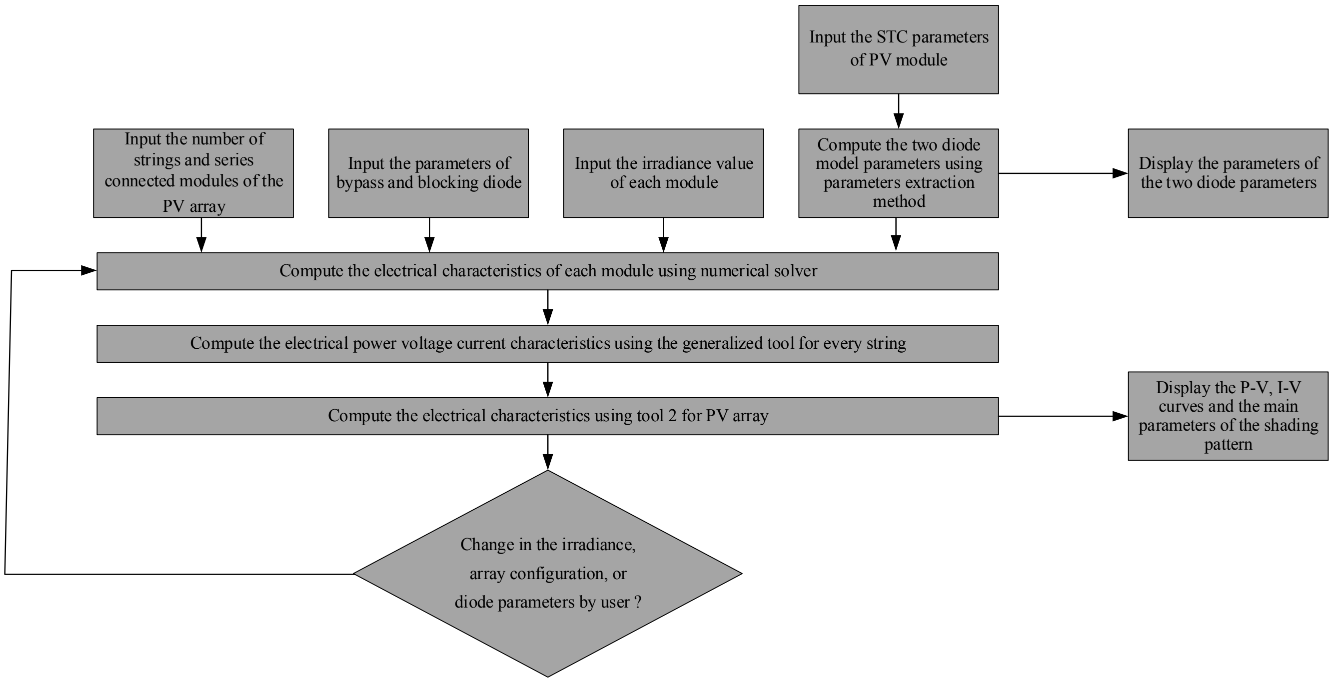

FIG 3. Software flowchart of the proposed analysis tool.

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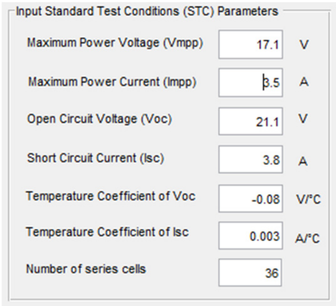

FIG 4. Window for insertion of STC parameters of a PV module.

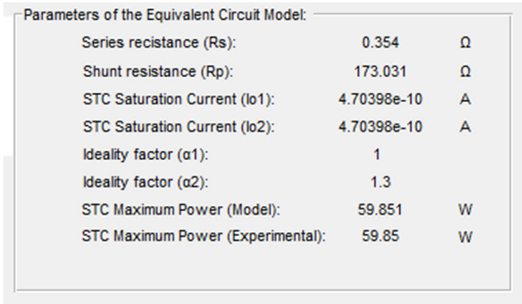

FIG 6. Window to display the computed parameters of the two diode model using parameter extraction method.

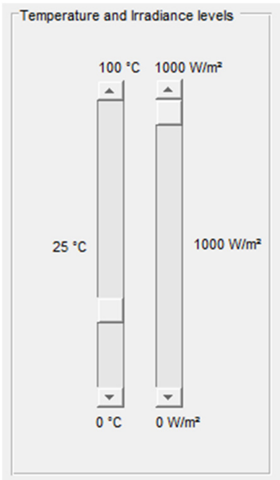

FIG 5. Window contains two sliders allowing user to change temperature and irradiance values.

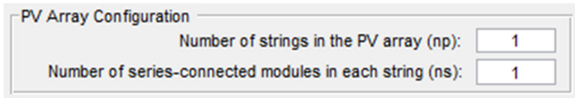

FIG 7. Window to configure the PV array under study.

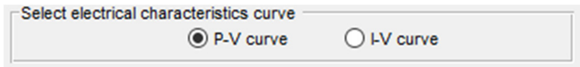

FIG 8. Window for electrical characteristics display.

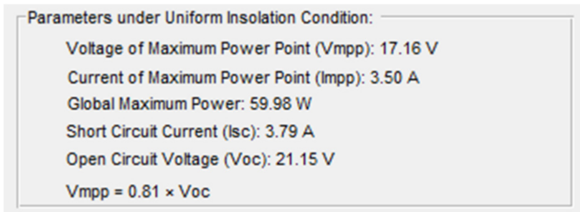

FIG 9. Window to display the main parameters of the PV output electrical characteristics.

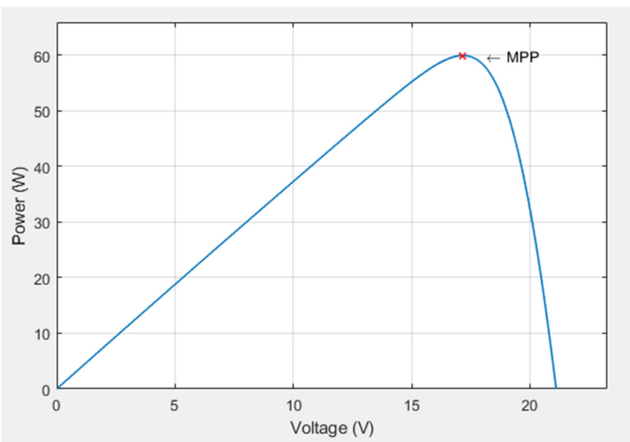

FIG 10. Window to depict the P-V characteristics.

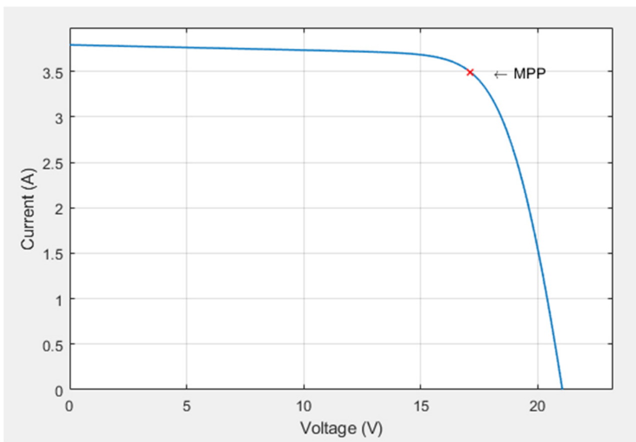

FIG 11. Window to depict the I-V characteristics.

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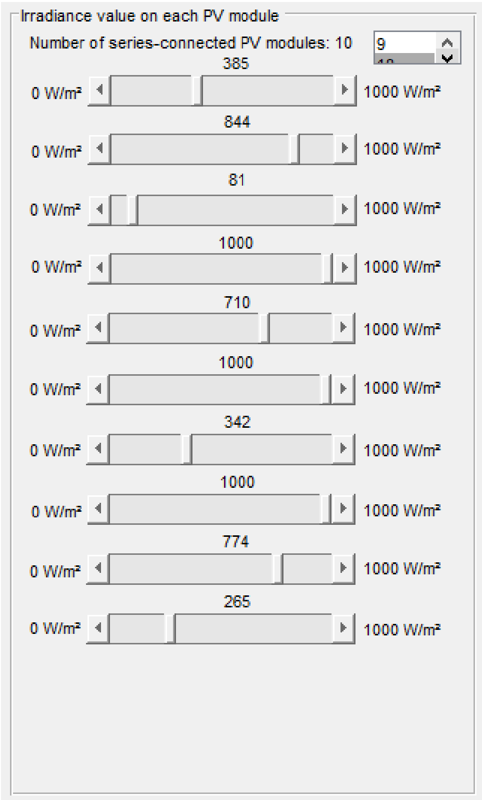

FIG 12. Window to select the number of series connected modules of the PV string to be simulated. Accordingly, sliders popup to allow user variate the irradiance on each module.

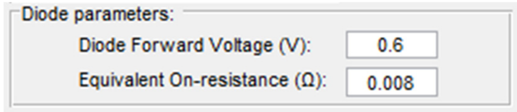

FIG 13. Window to input the diodes characteristics

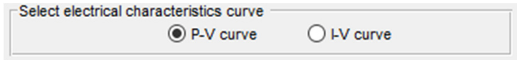

FIG 14. Window to select the electrical characteristics to be displayed

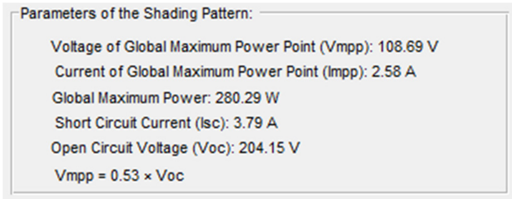

FIG 15. Window to display the main parameters of the PV output electrical characteristics.

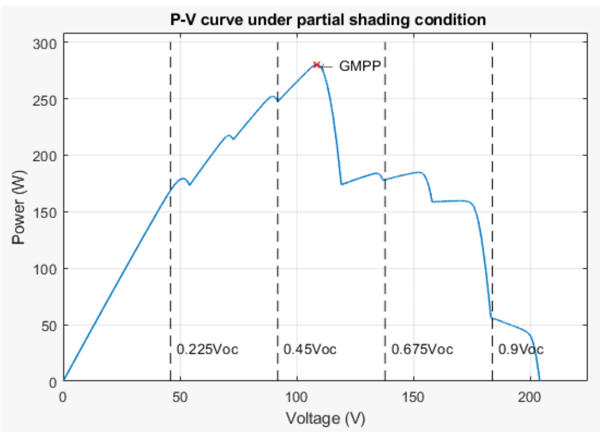

FIG 16. Window to depict the P-V characteristics under partial shading.

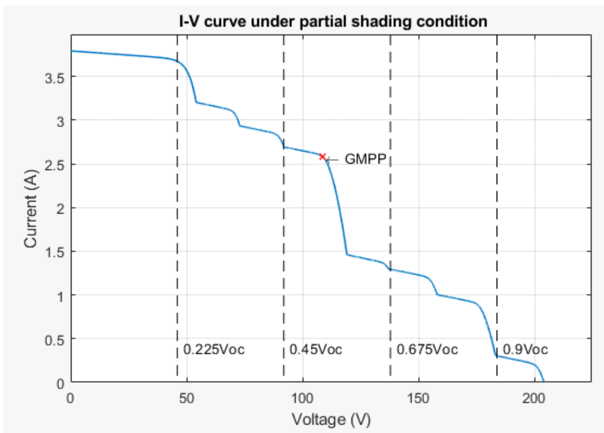

FIG 17. Window to depict the I-V characteristics under partial shading.

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SOFTWARE TOOL TO ANALYZE PERFORMANCE OF PHOTOVOLTAC SYSTEM UNDER UNIFORM AND NON-UNIFORM ENVIREMENTAL CONDITIONS

FIELD OF THE INVENTION

The invention is a tool to analyze Photovoltaic (PV) arrays electrical characteristics under uniform and non-uniform insolation condition. The tool employs a generalized analytical approach to compute the electrical characteristics of photovoltaic array with any series-parallel configuration receiving any distribution of irradiance. The effect of the blocking and bypass diodes integrated in the PV array is incorporated in the model.

The approach can be incorporated as a computer-aided design (CAD) tool to compute the generated PV power in building integrated PV and in building information modeling (BIM) in the architecture. The tool can be also adopted in commercial PV simulators as a graphical-user-interface (GUI) to generate instantaneous shading patterns for different irradiance levels manipulated by the user.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG 1. General configuration of PV array, where m is the number of strings and n is the number of the series-connected modules in each string.

FIG 2. Flowchart to compute the electrical characteristics of shaded PV arrays.

FIG 3. Software flowchart of the proposed analysis tool.

FIG 4. Window for insertion of STC parameters of a PV module.

FIG 5. Window contains two sliders allowing user to change temperature and irradiance values.

FIG 6. Window to display the computed parameters of the two diode model using parameter extraction method.

FIG 7. Window to configure the PV array under study.

FIG 8. Window for electrical characteristics display.

FIG 9. Window to display the main parameters of the PV output electrical characteristics.

FIG 10. Window to depict the P-V characteristics.

FIG 11. Window to depict the I-V characteristics.

FIG 12. Window to select the number of series connected modules of the PV string to be simulated. Accordingly, sliders popup to allow user variate the irradiance on each module.

FIG 13. Window to input the diodes characteristics

FIG 14. Window to select the electrical characteristics to be displayed

FIG 15. Window to display the main parameters of the PV output electrical characteristics.

FIG 16. Window to depict the P-V characteristics under partial shading.

FIG 17. Window to depict the I-V characteristics under partial shading.

DETAILED DESCRIPTION OF THE INVENTION

The invention claimed is:

1. A **tool to analyze the electrical characteristics of photovoltaic (PV) array** under uniform and non-uniform insolation condition. The tool could be implemented using a calculator and data memory to store five data structures:

    - A first data structure comprising the standard test condition (STC) parameters of the PV module constituting the array:
        - Maximum Power Voltage (Vmpp)
        - Maximum Power Current (Impp)
        - Open Circuit Voltage (Voc)
        - Short Circuit Current (Isc)
        - Temperature Coefficient of Voc
        - Temperature Coefficient of Isc
        - Number of series-connected cells

    - A second data structure comprising the number of series-connected modules and the number of parallel strings that the PV array is made of:
        - Number of Series-connected PV modules (n) (FIG 1)
        - Number of parallel strings of the PV array (m) (FIG 1)

    - A third data structure comprising the parameters of bypass and blocking diodes integrated in the PV array (FIG 13):
        - Equivalent On-resistance
        - Diode Forward Voltage

    - A fourth data structure comprising irradiance and temperature of each PV module:
        - An $(n \times m)$ matrix which contains Irradiance values of all PV modules constituting the PV array
        - An $(n \times m)$ matrix which contains Temperature values of all PV modules constituting the PV array

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The analysis tool of claim 1**,** further comprising:

2. A parameter extraction method wherein a numerical solver further applies the first data structure to compute the parameters of the two diode model.

3. A fifth data structure to store the parameters of the two diode model:
   - Series Resistance (Rs)
   - Shunt Resistance (Rp)
   - Saturation Currents at STC (I_{o1} and I_{o2})
   - Ideality Factors (α_1 and α_2)

4. A numerical solver that employs the first and fourth data structures to compute the electrical characteristics (power-voltage and current-voltage) of each PV module in the array.

5. A sixth data structure to store the electrical characteristics (voltage current and power) of all PV modules comprising the PV array:
   - ($n \times m$) Voltage Vectors
   - ($n \times m$) Current Vectors
   - ($n \times m$) Power Vectors

6. A **generalized analytical method** to compute the electrical characteristics of PV arrays**,** wherein the second, third and sixth data structures are used to compute the comprehensive electrical characteristics of the PV array under uniform/non-uniform (partial shading) insolation conditions.

7. The **generalized analytical method** of claim 6, further comprising (FIG 2):

   a. A Parameter extraction method to calculate the two diode model parameters.
   b. A numerical solver to generate the electrical characteristics of each PV module comprising the PV array.
   c. A generalized mathematical formula that utilizes the second, third and sixth data structures to compute the current-voltage characteristics of every string in the array.
   d. A seventh data structure to store the electrical characteristics (voltage current and power) of all PV strings comprising the array, containing:
      - (m) vectors to store the output voltage of all PV strings,
      - (m) vectors to store the output current of all PV strings,
      - (m) vectors to store the output power of all PV strings.
   e. A generalized mathematical formula utilizes the seventh data structure to compute the electrical characteristics of the PV array.

8. An eighth data structure to store the electrical characteristics of the PV array, comprising:
   - A vector contains the output voltage of the PV array,
   - A vector contains the output current of the PV array,

- A vector contains the output power of the PV array.

9. A **computer program product** embodied on a non-transitory computer-readable and executable by a calculator to acquire the inputs, compute and display the electrical characteristics of a photovoltaic (PV) array.

10. The **computer program product** of claim 9 further comprising computer instructions whereby the following steps are executed (FIG 3):

    a. Receiving the first data structure which comprising the STC parameters of the PV modules.
    b. Receiving the second data structure which comprising the diode parameters.
    c. Receiving the third data structure which comprising the number of series and parallel module connection in the array.
    d. Computing the two diode model parameters, storing the values in the fifth data structure, and printing it in the output.
    e. Receiving the fourth data structure which comprising the irradiance and temperature values for each PV module in the array.
    f. Computing the electrical characteristics of each PV module and storing the corresponding results in the sixth data structure.
    g. Computing the electrical characteristics of all PV strings, then storing the corresponding results in the seventh data structure.
    h. Computing the comprehensive electrical characteristics of the array, storing the results in the eighth data structure, plotting the power-voltage and current-voltage curves and printing the main parameters of the electrical characteristics:
        - Voltage, current and power of the global maximum power point (Vmpp, Impp, and Pmpp)
        - Short circuit current (Isc)
        - Open circuit voltage (Voc)
        - The ratio (Vmpp/Voc)

11. A **graphical-user interface** for easy interaction with the tool of claim 1.

    The **graphical-user interface** of claim 11, further comprising:

12. A window comprising text entry boxes to input the values of first data structure which includes the STC parameters of the PV modules (FIG 4).

13. A window comprising text entry boxes to input the values of second data structure which includes the number of series modules and parallel strings of the array (FIG 7).

14. A window comprising text entry boxes to input the values of third data structure which includes the parameters of bypass and blocking diodes (FIG 13).

15. A window, for analysis under uniform insolation, comprising two sliders whereby the irradiance and temperature of the array can be varied (FIG 5) and their corresponding values are stored in the fourth data structure.

16. A window, for analysis under non-uniform insolation, wherein a number of sliders (corresponds to the second data structure) popup whereby the user can manipulate the irradiance value of each PV module (FIG 12) and update the fourth data structure accordingly.

17. A button to execute the parameter extraction algorithm of the two diode model. The results are displayed in a window (FIG 6) and stored in the fifth data structure.

18. A button to execute the **generalized analytical method** and store the comprehensive electrical characteristics of the PV array in the eighth data structure.

19. A window wherein the power-voltage and current-voltage curves of the PV array under analysis are plotted using 2D graphs (FIG 10 and FIG 11 for uniform insolation condition; FIG 16 and FIG 16 for non-uniform insolation condition).

20. A window to display the main parameters of the PV array under analysis (FIG 9 for uniform insolation condition, and FIG 15 for non-uniform insolation condition).