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Design & Analysis of Optimal Maximum Power Point Tracking Algorithm for PV systems under Climatic Parameters Estimation

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ABSTRACT: This paper presents a maximum power point tracking (MPPT) method for photovoltaic (PV) systems with reduced hardware setup. It is realized by calculating the instantaneous conductance and the junction conductance of the array. The first one is done using the array voltage and current, whereas the second one, which is a function of the array junction current, is estimated using an adaptive neuro-fuzzy (ANFIS) solar cell model. Knowing the difficulties of measuring solar radiation and cell temperature, since those require two extra sensors that will increase the hardware circuitry and measurement noise, an analytical model is proposed to estimate them with a denoising-based wavelet algorithm. The proposed MPPT technique helps to reduce the hardware setup using only one voltage sensor, while increases the array power efficiency and MPPT response time. The simulation results are provided to validate the MPPT algorithm operation as well as the climatic parameters estimation capabilities.

KEYWORDS: Adaptive neuro-fuzzy (ANFIS) solar cell model, instantaneous conductance, junction conductance, junction current, maximum power point tracking (MPPT), photovoltaic (PV) system.

I. INTRODUCTION

Rapid depletion of fossil fuel reserves, ever increasing energy demand and concerns over climate change motivate power generation from renewable energy sources. Solar photovoltaic (PV) and wind have emerged as popular energy sources due to their ecofriendly nature and cost effectiveness. However, these sources are intermittent in nature. Hence, it is a challenge to supply stable and continuous power using these sources. This can be addressed by efficiently integrating with energy storage elements. In order to overcome the undesired effects such as low conversion efficiency on output power of PV and draw maximum power, well known "maximum power point tracking(MPPT)" is used through a particular control of a converter. Many methods have been proposed to extract maximum power from PV module, which can be classified according to convergence speed , implementation complexity ,periodic tuning ,sensed parameters.

Among various techniques of MPPT, perturb and observe (P&O) and the incremental conductance (InCond) are most common methods. P&O is simplest method among all, as it contains only one sensors (voltage sensor), cost of implementation and time complexity is less. However, it wastes energy by oscillating around the MPP, as it cannot differentiate between the radiation and the trackers perturbation. The second method InCond has good accuracy as error due to varying climatic conditions is eliminated due to its usage of both current and voltage sensors. But complexity and cost of implementation increases due to hardware setup. There are other MPPT methods like open circuit voltage and short circuit current, which can be used at low level of irradiance.

Many improvements are proposed using variable and modified step size algorithms. Nowadays an intelligent artificial technique can be used to determine the maximum power point (MPP) based on artificial neural networks (NN) algorithm with climatic conditions as input and applied to a boost tracker. This can reduce the noises and oscillations.

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Another technique is fuzzy logic (FL) based which have advantages on working with imprecise inputs. It is good in handling nonlinearity and does not require accurate mathematical model. Combination of NN and FL seems to be more attractive since if associates the learning capability of ANN with the ability of the FL to train inaccurate data, which makes it suitable for PV applications.

This paper provides an efficient Grid connected PV system with MPPT method with reduced components. It computes the instantaneous and junction array conductance. The first one is done using the array current and voltage, whereas the second one uses the array junction current, which is estimated using ANFIS cell model. Still, it requires information on the climatic parameters. Hence, it is proposed ANFIS control as an analytical model with a denoising based wavelet algorithm to estimate them, which helps reducing the hardware using only one voltage sensor. The simulation results are provided to validate the proposed ANFIS - PV based MPPT scheme capabilities. This paper is organized as follows: Section II provides an overview of modeling of PV system. Section III explains PV system with proposed MPPT technique and grid connected PV system is given by Section IV. The simulation results based on MATLAB are presented in Section V. Section VI gives conclusion.

II. MODELING OF PV MODULE

The schematic diagram of a three-phase grid-connected PV system which is main focus of this paper is shown in Fig. 1. The system consists of a PV array, a DC link capacitor C, a three-phase inverter, a filter inductor L and connected to the grid with line voltages. In this paper, the main aim is to control the voltage V_{dc} across the capacitor C and to make the input current in phase with grid voltage for unity power factor by means of appropriate control signals through the switches of the inverter. The mathematical model of PV system is presented with a solar cell which is basically a p-n semiconductor junction. When exposed to light, a dc current is generated which varies linearly with solar irradiance. Fig. 2 shows an equivalent circuit diagram of the PV cell which consists of single diode connected in parallel with a light generated current source $I_{L.}$ R_S and R_{Sh} represent the series and shunt resistance of solar cell. Usually the value of R_{Sh} is very large and that of R_S is very small, so this can be neglected to simplify the analysis.

(i)The diode current I_{ON} can be written as:

$$I_{ON} = I_s\left[exp\left[\alpha\left(V_{pv} + R_s i_{pv}\right)\right] - 1\right] \quad (1)$$

Where, I_s is the saturation current, $\alpha = q/AKT_C$ in which q is electron charge ($1.6 * 10^{-19}$ C), K is the boltzmann constant ($1.38 * 10^{-23}$ JK^{-1}), T_c is the cell temperature in the standard test condition (STC), A is the ideal factor of cell dependent on PV technology whose value is in between 1 and 5,V_{PV} and I_{PV} are voltage and current generated by PV cells. The output voltage V_{PV} considered as voltage source C in this paper i.e. $V_{dc.}$

(ii) The output current (I_{PV}) generated by PV cell can be written as;

$$i_{pv} = I_L - I_s\left[exp\left[\alpha\left(V_{pv} + R_s i_{pv}\right)\right] - 1\right] - \frac{v_{pv} + R_s i_{pv}}{R_{sh}} \quad (2)$$

Where, I_L is light generated current that depends on solar irradiance which can be written as follows:

$$I_L = \left[I_{sc} + K_i\left(T_c - T_{ref}\right)\right]\frac{G}{1000} \quad (3)$$

Where, I_{SC} is cell short circuit current, K_i is short circuit current temperature coefficient, T_{ref} is the cell reference temperature, G is the solar radiation in KW/m^2.

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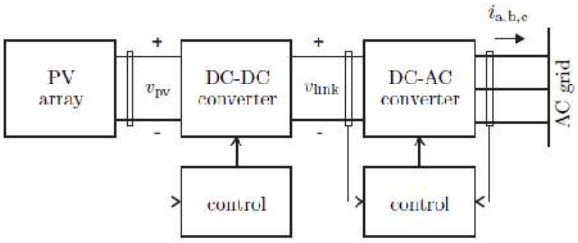

Fig. 1.Block diagram of the PV system.

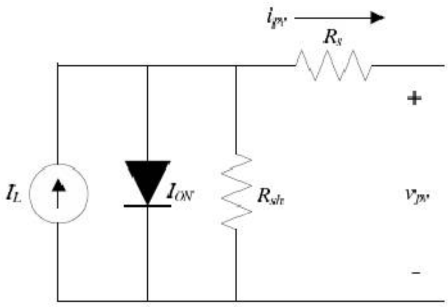

Fig. 2. Equivalent circuit diagram of PV cell

(iii)The module saturation current I_s varies with the cell temperature according to the following equation:

$$I_s = I_{RS}\left[\frac{T_C}{T_{ref}}\right]^3 exp\left[\frac{qE_g}{Ak}\left(\frac{1}{T_{ref}} - \frac{1}{T_C}\right)\right] \quad (4)$$

Where, I_{RS} is the reverse saturation current at a reference temperature and solar radiation, E_g is the band gap energy of the semiconductor used in the cell.

(iv)The output power of single solar cell is very less and it cannot be used for almost any application. So in order to increase the capability of the overall PV systems, a PV module is formed by arranging number of PV cells together and encapsulated with glass, plastic, and other transparent materials to protect from harsh environment. Then the solar cells are connected in series and parallel configuration to form solar modules and arrays.Fig.3 shows an electrical equivalent circuit diagram of a PV array.

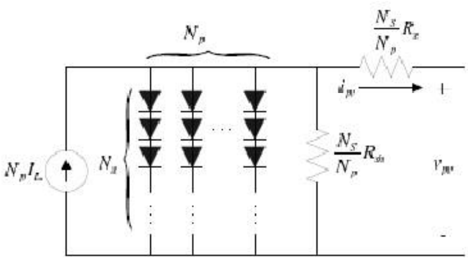

Fig. 3. Equivalent circuit diagram of PV array

The output current of this PV module can be given as follows:

$$i_{pv} = N_pI_L - N_pI_s\left[exp\left[\alpha\left(\frac{v_{pv}}{N_s} - \frac{R_si_{pv}}{N_p}\right)\right] - 1\right] - \frac{N_p}{R_{sh}}\left(\frac{v_{pv}}{N_s} - \frac{R_si_{pv}}{N_p}\right) \quad (5)$$

Where, N_s is the number of cells connected in series and N_p is the number of cells connected in parallel.

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III. PROPOSED MPPT TECHNIQUE USING ANFIS

In this paper a new method is adapted for tracking the maximum power point i.e. using an Adaptive Neuro Fuzzy Inference system (ANFIS) which is described in detail in this section. The Matlab/Simulink model of ANFIS based MPPT controllers as shown in the Fig. 4.This model requires two input training data sets which are taken as irradiance level and operating temperature of PV module. Using these data sets the ANFIS reference model gives out the crisp value of maximum available power from the PV module at a specific temperature and irradiance level. This tool enables the construction of a Fuzzy Inference System (FIS) whose membership function parameters are tuned using specific algorithm. According to figure the input data is same for both ANFIS and PV module. The actual output power of PV module is calculated using multiplication algorithm of operating voltage and current and this calculation has been done at same level of temperature and irradiance of ANFIS. The oscillations produced at the output voltage, current and power can be reduced by denoised temperature and irradiance values as inputs, which are formed by using wavelet algorithm.

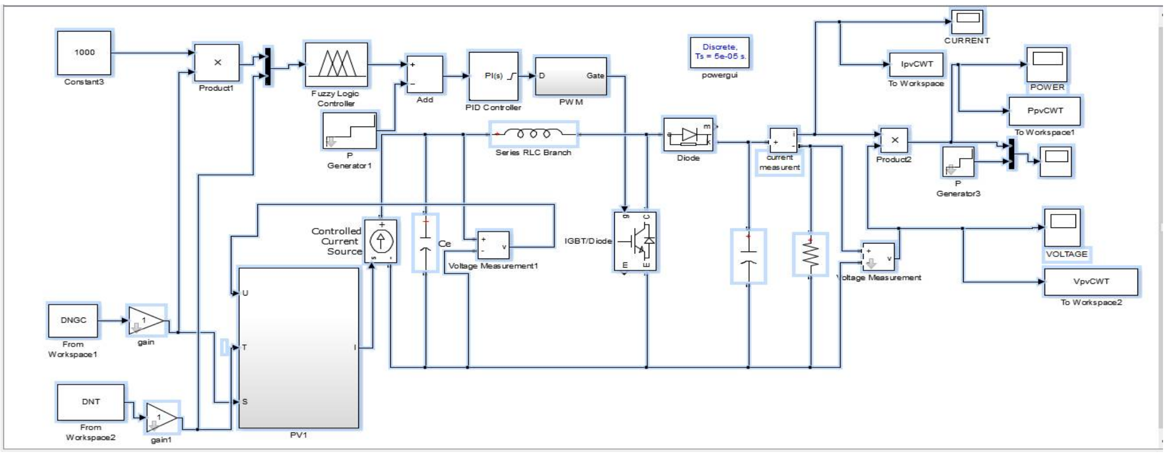

Fig. 4. Matlab/Simulink model of ANFIS based MPPT controller.

The two powers from PV module and ANFIS are compared and the obtained error is given to a proportional integral(PI) controller, which will generate control signals and this signals are given to PWM generator.Then PWM signals are generated by comparing high frequency carrier signals to reference modulating (or) control signals.The frequency of carrier signal used is $50KH_Z$.These PWM signals are given to the DC-DC converter, that is used to control the duty cycle and in order to adjust the operation point of PV module.

Tuning of ANFIS using Matlab/Simulink can be done by tuning the parameters of a sugeno-type fuzzy inference system. The training data sets for this can be taken as, the operating temperature varied from 15^oC to 65^oC in a step of 5^oC and the solar irradiance level is varied from $100W/m^2$ to $1000W/m^2$ in a step of 50 W/m^2.From this 209 training data sets are formed and 1000 epochs are used to train the ANFIS.To form the FIS , the grid partition is selected in Matlab ANFIS block and number of inputs and outputs are chosen with the shapes of their membership function, this system consists of two inputs and one output. Then FIS is constructed by ANFIS whose membership function parameters are tuned using hybrid optimization method. This method is combination of least square type and the back propagation algorithm.

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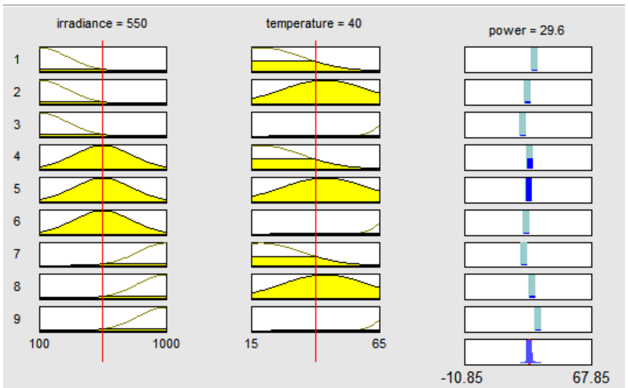

Fig. 5. Output from fuzzy rules for specific value of temperature and irradiance.

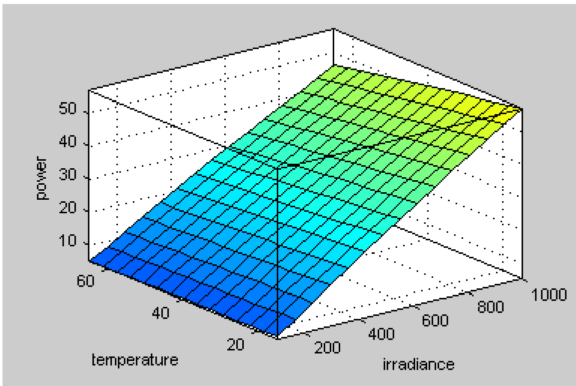

Fig. 6. Surface between two inputs (temperature and irradiance) and one output (maximum power).

FIS system consists of nine rules that are derived from six input membership function which can be formed by two inputs (operating temperature and irradiance level), one output(maximum power) and three membership function for each input. These rules are derived according to the mapping of this inputs and output, so as to produce maximum output power for a specific value of inputs, as shown in Fig. 5. The surface generated by ANFIS is a 3-dimensional plot between temperature, irradiance level and maximum power which is shown in Fig. 6.

IV. SIMULATION RESULTS AND DISCUSSION

Simulations were done using a PV array built of two mono crystalline 80−W modules (Figs. 1 and 2). To examine the performance of the proposed MPPT algorithm by means of MATLAB/Simulink, we simulated, in a short time period of 0.4 s, three step variations in solar radiation (250, 500, 750, and 1000W/m2) with a constant cell temperature Tc = 25◦C. The resulting array operating voltage and current are shown in Figs. 8 and 9.

We can notice that the array voltage and current track significantly their corresponding references, which means that the array is operating at its maximum power. This can be confirmed by observing its power, which is following precisely the corresponding MPP (Fig. 8). The tracking capability of the algorithm under varying solar radiation is shown in Fig. 9. It is shown in Fig. 11 that, due to the first radiation value, the voltage varies through a certain range before it converges to its first MP point $P1$ at Vpv = Vm1. Then, Vm1 is used as the initial value for the next iteration. This procedure is continued to reach P2, P3, and P4 when Vpv equals to Vm2, Vm3, and Vm4, respectively. Then, the instantaneous and junction conductances are tested if they satisfy the condition in expression (17), It is seen clearly that the curves of Ypv(Vpv) and Yd(Vpv) intersect exactly when the MPP is achieved, which confirms the validity of the proposed scheme. Moreover, this condition can also be verified by confirming that the difference between the two conductances at the MPP condition is equal to zero, i.e., [Ypv(Vpv) − Yd(Vpv)]MPPT = 0 as predicted in expression (17).

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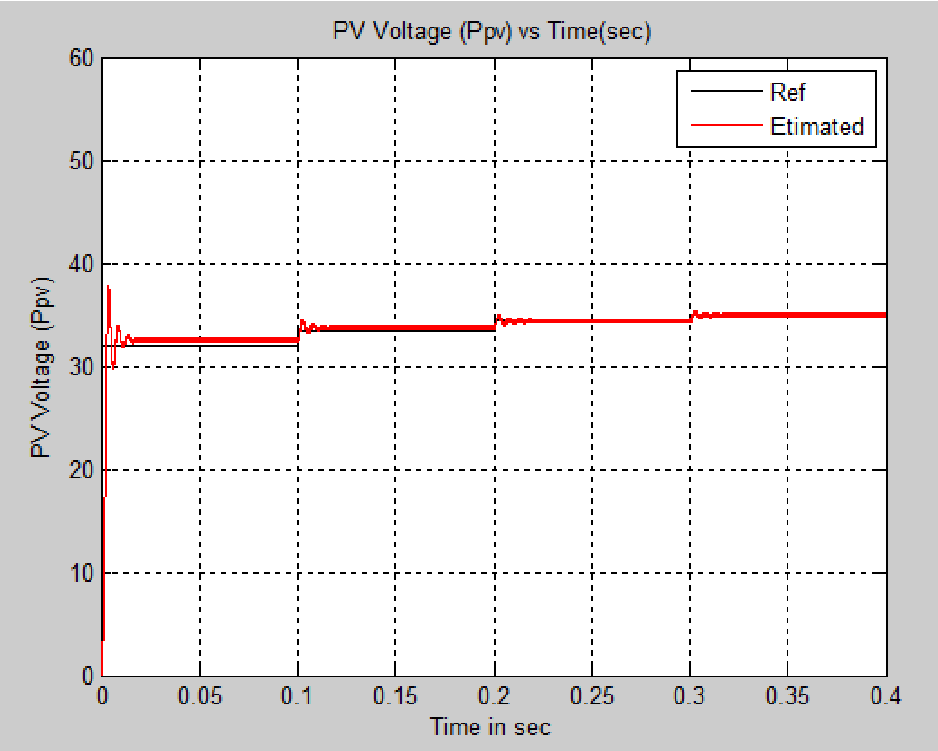

Fig. 8. Array voltage *V*pv.

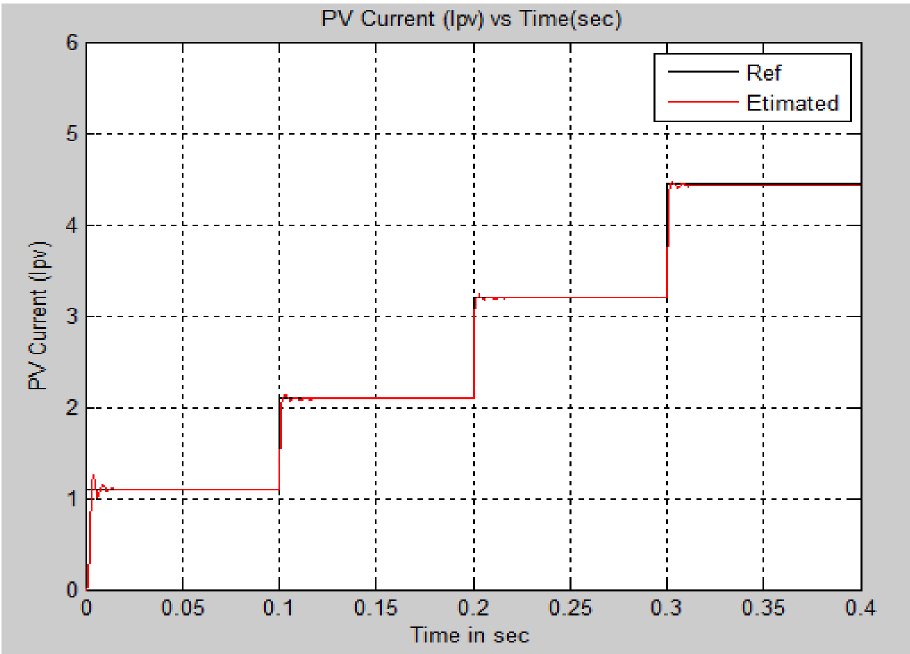

Fig. 9. Array current *I*pv.

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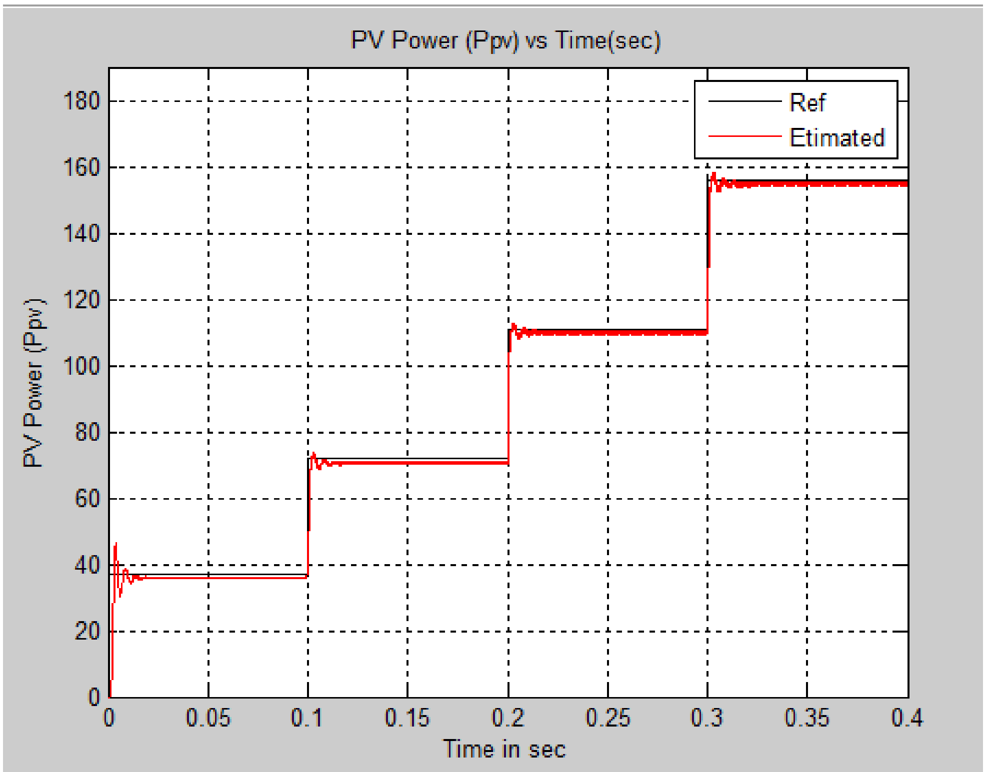

Fig. 10. Array power *P*pv.

The simulation results presented in Figs. 8–13 show obviously that the developed algorithm ensures the maximum power operation of the PV array. Its estimated power follows the maximum power under very fast varying solar radiation with a very good precision. The steady-state error is shown in Table I.

TABLE I
ARRAY POWER ESTIMATION ERROR

G (W/m^2)	P_{ref} (W)	P_{est} (W)	*er*_P (%)
250	35.2	34.2	2.8
500	75.5	74	1.9
750	118	116	1.7
1000	160	159	0.6

The mean MPPT error through the entire solar radiation range is found to be around 1.75%, which is very reasonable. Moreover, the radiation variations are done through a very short period of time (*t* = 0.4 s). Therefore, it can be said that the algorithm reacts adequately to fast fluctuations in climatic conditions and operates using only one voltage sensor, which results in a reduced hardware implementation.

V. CONCLUSION

This paper develops an optimal MPPT method that has been tested under varying climatic conditions. It has been shown that it can be implemented with reduced hardware setup since only one voltage sensor has been used. The array current, solar radiation and cell temperature are estimated using an ANFIS model and a climatic parameters estimator. The simulation results supported by experimental verification confirm the effectiveness of the presented

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method under varying solar radiation. The Simulation results exhibit a mean MPPT efficiency error of 2% with a response time of 1.7 ms, which ensures that the developed technique can extract accurately the maximum power from a PV array with a very low response time, which makes its operation optimal with reduced hardware.

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