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Maximum Power Point Tracking of Photovoltaic Generation System using Artificial Neural Network with Improved Tracking Factor

[1]K. Arthishri, [1]R. Balasubramanian, [1]Parkavi Kathirvelu,
[2]Sishaj P. Simon and [1]Rengarajan Amirtharajan
[1]School of Electrical and Electronics Engineering,
SASTRA University, Thanjavur, Tamil Nadu, India
[2]National Institute of Technology, Trichy, Tamil Nadu, India

Abstract: This study presents an analysis of neural network scheme for tracking Maximum Power Point (MPP) of the PV panel. The performance in terms of energy conversion efficiency is compared with the most commonly used P and O algorithm. The method used for MPP Tracking (MPPT) is tuned for giving its best efficiency using a planned calibration procedure. The non linearity of the PV panel is replicated considering the mathematical equations of the solar cell. MATLAB/Simulink is used to simulate the PV panel model along with a conventional DC-DC boost converter for MPPT.

Key words: Photovoltaic generation, artificial neural network, tracking factor, MPPT

INTRODUCTION

In recent years, the demand for renewable energy resources is a global priority due to the environmental issues, reduced supply and increase in the consumption cost of the conventional sources. Photovoltaic Panels play a critical role as an alternate renewable energy source because of its sustainability, absence of moving parts, very less maintenance, availability at free of cost etc. (Hosseinpour *et al*., 2008; Hosseinpour *et al*., 2009). But the efficiency of the panels in terms of energy conversion is less which leads to the necessity of a tracking system to utilize maximum energy from the PV source using Maximum Power Point Tracking (MPPT) techniques (Wu *et al*., 1998; Noguchi *et al*., 2002).

PV panel being highly non-linear, it has a particular operating point for every change in temperature and irradiance at which the efficiency is high. The system has to be tuned to this point as frequently as the environmental condition changes. Various MPPT techniques have been implemented and analyzed in literature (Reisi *et al*., 2013; Enslin *et al*., 1997; Yu *et al*., 2004; Cheng *et al*., 2013; Yu *et al*., 1996). Neural Network is proved to give excellent prediction accuracy for the control of non linear systems.

In this context, an Artificial Neural Network scheme with back propagation algorithm is implemented for MPPT in this study. This scheme with a detailed calibration procedure is proposed to have an effective utilization of the panel. The performance of the proposed scheme is compared with the most commonly used P and O technique for the aforementioned parameters.

MATERIALS AND METHODS

PV panel modeling: In order to simulate the PV panel the mathematical equations of the same has to be considered. Figure 1 shows the equivalent circuit of the photovoltaic cell.

The series and parallel combination of the solar cells form a PV module. Table 1 indicates the parameters considered for PV panel. The module characteristics can be simulated using the following mathematical equations:

$$Iph = [Isc+Ks(T-298)\times\Phi/1000] \quad (1)$$

Where:
Iph: Photocurrent of the PV module (A)
Isc: Short circuit current of the PV module (A)
Ks: Short circuit current temperature coefficient (A/°C)
Φ: PV module illumination (W m^{-2})

$$Ir = \frac{Isc}{\left[\exp\left(\frac{qVoc}{NsekCt}\right)-1\right]} \quad (2)$$

Corresponding Author: K. Arthishri, School of Electrical and Electronics Engineering, SASTRA University, Thanjavur, Tamil Nadu, India

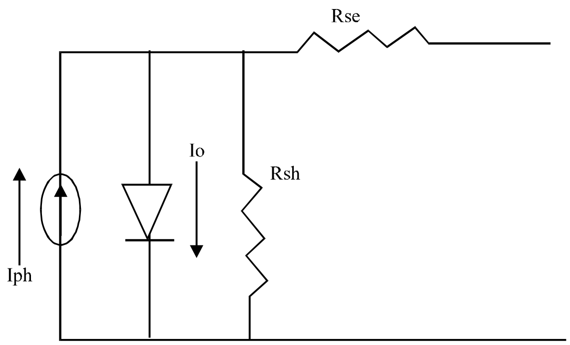

Fig. 1: Equivalent circuit of solar cell

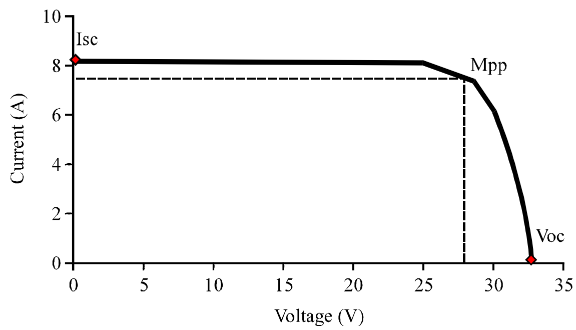

Fig. 2: V-I characteristics of the PV panel

Table 1: Parameters of PV panel

Parameters	Values
Maximum power (P_{max})	200 W
Open circuit voltage (V_{oc})	32.9 V
Short circuit current (I_{sc})	8.21 A
Temperature coefficient (Ks)	3.18×10^{-3}A/°C

Where:

Ir: Reverse saturation current of the module. (A)
q: Electron charge (C)
Nse: Number of cells in series
C: Ideality factor

$$Ip=Np\times Iph-Np\times Io[\exp\left\{\frac{q\times(Vpv+IpRse)}{NseCkT}\right\}-1] \quad (3)$$

Np: Number of cells in parallel
Ip: PV module current (A)
Io: Module saturation current (A)
PV: Module is simulated for the parameters mentioned in the table using the above equations using MATLAB/simulink. Figure 2 represents the current Vs Voltage characteristics of the simulated model

Figure 3 shows the power versus voltage characteristics of the simulated PV model for constant temperature and varying irradiance.

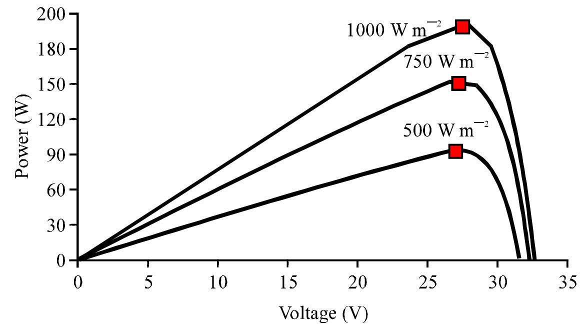

Fig. 3: P-V characteristics of the PV panel

In order to track the point at which maximum power can be extracted from the panel, the PV model simulated is integrated to the conventional DC-DC boost converter (Yasin *et al*., 2011; Khatib, 2010a, b). A capacitor is used as an integrator which is used to store the current injected from the PV panel. PV panel acts as a voltage source to the converter.

MPPT algorithms: In this study, different versions of neural network techniques are implemented. Also, the version which is giving the best performance is compared with the most commonly used Perturb and Observe algorithm in terms of critical parameters for the effective utilization of PV panel (Alonso *et al*., 2012).

Perturb and observe algorithm: In this algorithm, the critical working point of the system is controlled by means of periodic variation in the output voltage of the PV panel depending upon the variation in the power. If the output power from the PV panel in the current cycle is more when compared to the previous cycle, then the voltage change is compared. If it is increased then the operating point will be moved accordingly and the same procedure is followed for the decrease in the voltage for the increase in the power. Accuracy of this method mainly depends on the increment or decrement step. Figure 4 shows the simple flow diagram of P and O technique.

In the above flowchart, D (Duty cycle of the switch) controls the operating point of the system. Based on the switching, the voltage and in turn the current are adjusted relatively and the maximum power is obtained from the panel.

The algorithm is simulated using MATLAB/Simulink. The initial value of the duty cycle is set to be 0.25 and the ideal step size for increment or decrement of duty cycle is taken as 0.05. Figure 5 shows the output response

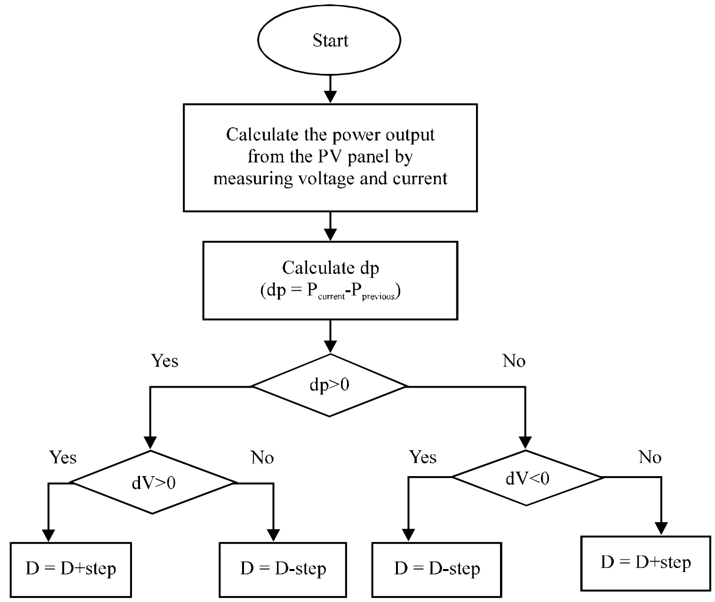

Fig. 4: Flow chart of P and O algorithm

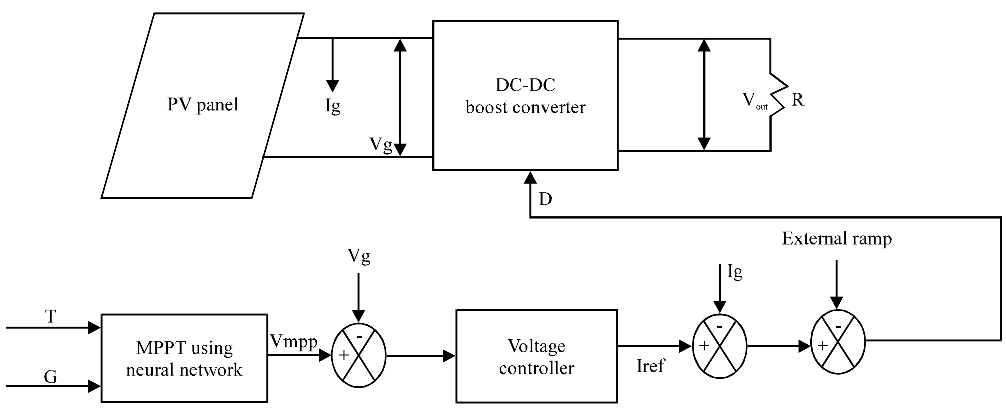

Fig. 5: Block diagram of the overall system for the proposed scheme

obtained using P and O tracking technique for different irradiation. Figure 10 shows the ripple present in the output after reaching the steady state. The obtained results with this method are further analyzed by comparing it with Artificial Neural Network using Back propagation algorithm.

Artificial neural network for maximum power point tracking: One of the most efficient methods to track MPP of the PV panel is Artificial Neural Network. In this study, Artificial Neural network using BP scheme is used to track MPP.

For MPPT, a conventional boost converter along with a PV panel is implemented in this study. Ig and Vg indicate the current and Voltage output of the PV panel. Neural Network based MPP tracker takes temperature (T) and Irradiation (G) as input and the output is Voltage at maximum power point (Vmpp). Based on the predicted output from the neural network, the voltage (Vg) is controlled using the voltage controller. The critical working point of the system is varied so as to obtain maximum power from the panel by scheming the duty cycle of the converter switch (Khatib *et al*., 2009; Sharifian *et al*., 2009).

Network architecture: The network architecture consists of input, hidden and the output layers. The input and output neurons is decided based on the application. For this MPPT, Temperature (T) and Irradiance (G) are the two inputs and the voltage corresponding to the point at

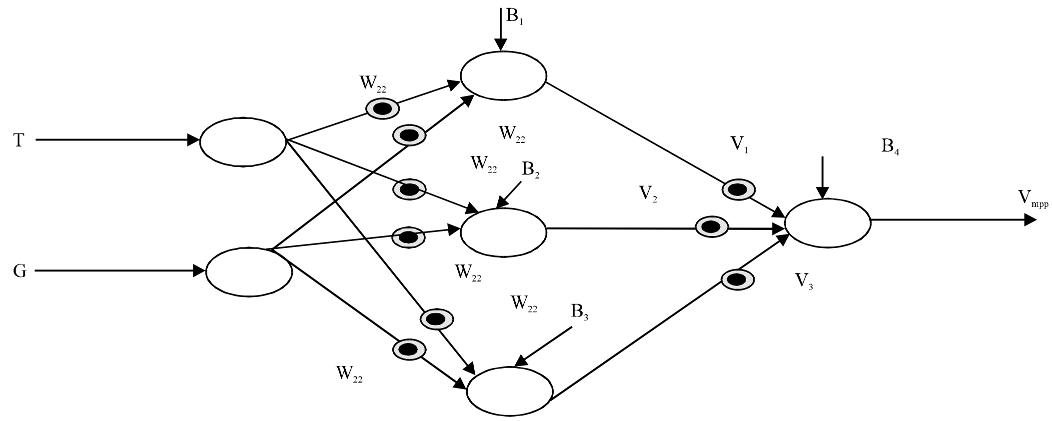

Fig. 6: Architecture of the neural network

which maximum power is obtained is the output. So, the proposed model has two inputs and one output architecture. As per Kolmogrov's theorem, the number of neurons in the hidden layer can be up to two times of the input. The architecture of the proposed scheme is shown in Fig. 6.

For the proposed network, the input vector and the output vector for various samples of input is represented as:

Input = $[T_iG_i]$
Output = $[O_i]$
T = Temperature
G = Irradiance
O = Output (Voltage at maximum power point)
i = Is the number of Input samples

The weights are represented as:

$$W_i = \begin{matrix} W_{11} & W_{12} & W_{13} \\ W_{21} & W_{22} & W_{23} \\ W_{31} & W_{32} & W_{33} \end{matrix}$$

where, W_i is Weight from the input to the hidden layer:

$$V_i = \begin{matrix} V_{11} \\ V_{21} \\ V_{31} \end{matrix}$$

where, V_i is Weight from the hidden to output layers.

In order to train the neural network with any specific scheme, the data corresponding to the input and output is obtained using the PV panel simulation in MATLAB/Simulink. For different combination of temperature and irradiance the output power is measured (Bahgat *et al*., 2005). Also, the voltage corresponding to the maximum power is obtained. This data is used to train the neural network.

ANN with back propagation algorithm: Back propagation algorithm is the conventional scheme for the ANN to train any set of input and output. From the literature it can be inferred that BP algorithm is the most efficient which can be implemented to many control features. It involves forward and backward propagation. Figure 7 shows the flowchart of the BP algorithm.

The most important part of training the neural network is the selection of control parameters. Random selection of these parameters may reduce the accuracy of the algorithm. Also the critical region where the algorithm can be executed efficiently may be left out. To overcome this, a step by step procedure has to be followed. For the network with Back propagation algorithm the weights in each layer and learning factor are the key parameters which influence the training process.

The learning factor is initially fixed to a value n and different ranges of weights are chosen. For different ranges of weights like [p,q]; [c,d]; [m,n] the training is performed and the results are compared based on accuracy and number of epochs taken. Based on these factors one range is chosen. On the chosen range further improvements can be done. The range is split into two and again the comparison is done. Likewise the process is continued till the best point is reached. The range can be split as shown in Table 2.

The input for the feed forward network is represented as $[I_i]$. The weight for the input to the hidden layer is represented as $[W_i]$. The weight for the hidden layer to the output layer is represented as $[V_i]$.

The input to the ouput layer from the hidden layer is obtained as:

$$\Lambda_i = I_i \times W_i \quad (4)$$

where, i represents the input sample.

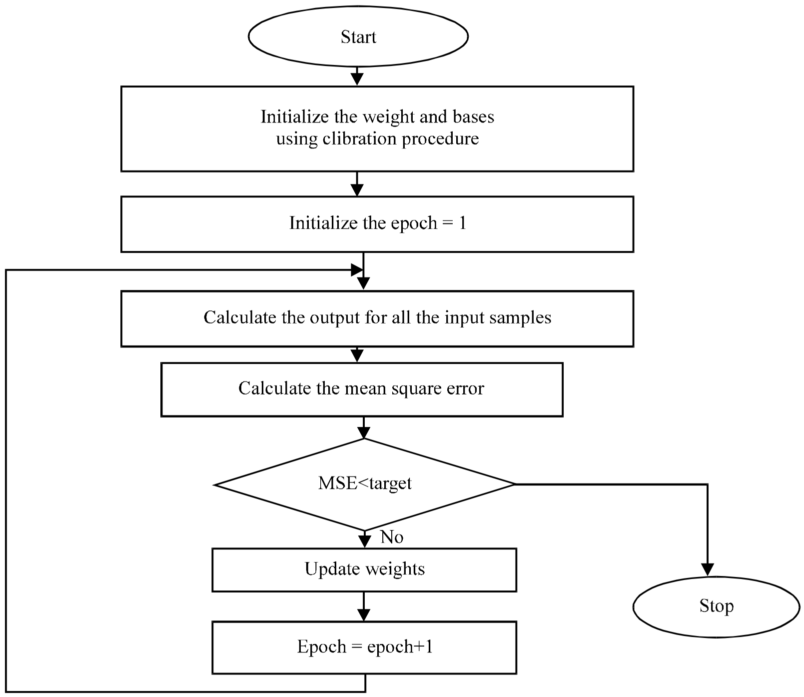

Fig. 7: Flow diagram of the ANN with back propagation algorithm

Table 2: Range of weights

Iteration	Range of weights
1st	[p,q] [c,d] [m,n]
2nd	[p,(p+q)/2] [(p+q)/2,q]
3rd	[p,(3p+q)/4] [(3p+q)/4,(p+q)/2] [(p+q)/2,(p+3q)/4] [(p+3q/4), q]

Table 3: Energy conversion efficiency

	Efficiency of energy conversion (%)	
Irradiation (W m^{-2})	ANN	P and O
200	95.25	95.03
300	96.17	94.98
400	97.21	95.11
500	97.26	94.32
700	98.10	95.02
1000	98.20	94.98
Average	97.03	94.99

The activation function used is the binary sigmoidal function. Therefore after activation the input to the output layer is represented as ρ_i.

The output is calculated as:

$$\Phi_i = \rho_i \times V_i \tag{5}$$

where, O_i is the output after activation.

The mean square error is calculated as:

$$\frac{\sum_{i=1,2...n}(T_i - O_i)^2}{n} \tag{6}$$

where T_i is the actual target of the input sample, n represents the number of input samples.

From the MATLAB simulation of PV panel, data required for training the neural network for various combinations of temperature and irradiation is obtained. The output from the neural network is Vmpp. This is used to control the operating point of the system.

The output obtained for different irradiation level is summarized in the Table 3. Figure 9 indicates the conversion efficiency of the algorithm. When compared to the P and O technique having the efficiency of 95%, ANN is having improved efficiency of 97%.

RESULTS AND DISCUSSION

In the proposed system, mathematical modeling of PV panel is done and the same is simulated using MATLAB/Simulink. Table 1 Indicates the parameters of PV panel considered for modeling. This panel is integrated with a conventional boost converter for MPPT. In order to obtain the most efficient MPPT technique, Perturb and Observe algorithm and Artificial Neural Network is used for tracking. The results are compared for energy conversion efficiency, ripple in the output power, dependency on PV panel, CUF and complexity of implementation. All the results are taken under the same condition of temperature and irradiation of PV panel for both P and O and ANN algorithm.

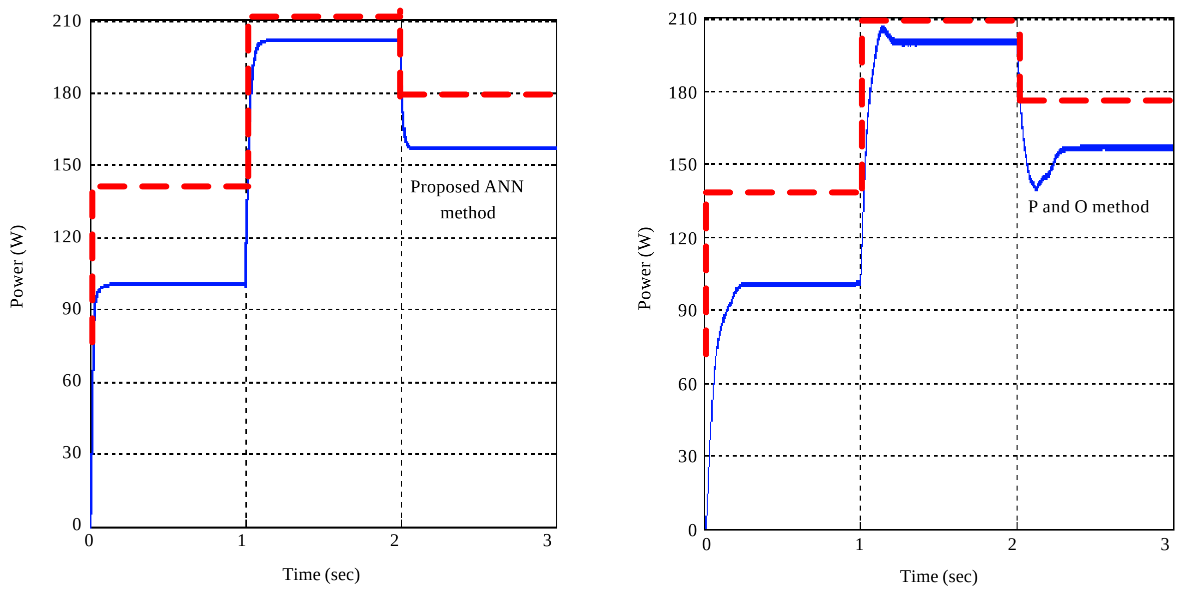

Fig. 8: Response of the system with the (a) Proposed ANN and (b) P and O/method

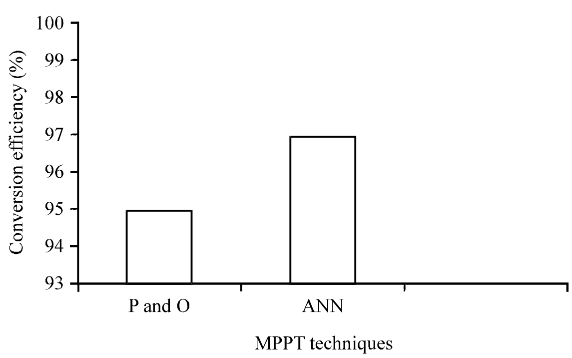

Fig. 9: Comparison of energy conversion efficiency for different techniques

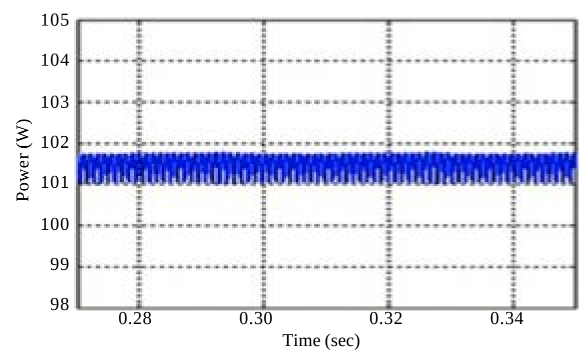

Fig. 10: Ripple in the output power during steady state

Figure 8 indicates the output of the system implemented with both P and O and ANN algorithm for different levels of irradiation. The response indicates the power extraction using P and O and the proposed Neural Network MPPT techniques. The most important parameter to evaluate a MPPT technique is the energy conversion efficiency which can also be indicated as tracking factor (De Brito *et al*., 2013). Figure 9 shows the comparison of energy conversion efficiency for P and O and ANN. It can be inferred that the ANN scheme with BP algorithm is having best efficiency of 97%. From the literature (Enslin *et al*., 1997) it is seen that there are so many other methods for MPPT. But the proposed ANN method stands ahead of all the methods with only one percent deviation from the ideal maximum power of the panel at every operating point.

Figure 10 indicates the ripples in the output for the proposed ANN method. For the panel to give effective performance, the ripple present in the output has a limit. In order to extract 98% of the power using MPPT, the ripple at MPP is not supposed to exceed 8.5% (Chen *et al*., 2013). The proposed method has reduced ripple of the order 0.67% in the output which is a considerable improvement in the output.

CONCLUSION

At present photovoltaic panels are playing a major role as a renewable energy source. Extracting maximum power from the panel is vital to achieve best performance. So MPPT has become inevitable in the implementation of PV panel as an alternate source of energy. There are many methods implemented for maximum power point tracking. In this study, artificial network scheme is implemented to compare its performance with conventional P and O algorithm. From the simulation results it is clear that to the proposed scheme which is calibrated as mentioned in section III is standing ahead of the other technique.

The tracking factor otherwise called the efficiency in the energy conversion is in the range of 97% which is again higher than other techniques scheme of neural network and also the most commonly used P and O algorithm. For the high non linear behavior of PV panel the proposed hybrid scheme will give better performance for even a small change in temperature and irradiation. For sensitive applications like spacecraft the proposed scheme with good dynamic response would be a healthier option.

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