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Artificial Neural Network for Solar Photovoltaic System Modeling and Simulation

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ABSTRACT

This paper presented neural network based maximum power point tracking on the design of photovoltaic power input to a DC-DC boot converter to the load. Simulink model of photovoltaic array tested the neural network with different temperature and irradiance for maximum power point of a photovoltaic system. DC-DC boot converter is used in load when an average output voltage is stable required which can be lower than the input voltage. At the end, the different temperature and irradiance of the data collected from the photovoltaic array system is used to train the neutral network and output efficiency of the designed DC-DC boot converter with MPPT control strategy is accepted the maximum power amount to show the result voltage, current and power output for each different have been presented. And also demonstrated that the neural network based MPPT tracking require less time and more accurate results than the other algorithm based MPPT.

KEYWORDS: *Neural Network; Maximum Power Point; Irradiance & Temperature; DC-DC Boot Converter*

1. INTRODUCTION

The main principle of MPPT is responsible for extracting the maximum possible power from the photovoltaic and feed it to the load via DC to DC converter which steps up/steps down the voltage to required magnitude. Various MPPT techniques have been used in past but Perturb & Observe (P&O) algorithm is most widely accepted. [1,2] P&O algorithm has also been shown to provide wrong tracking with rapidly varying irradiance.[3-4]

In this paper, we presented neural network based MPPT method. Artificial Neural Network (ANN) is an artificial network that can able to mimic the human biological neural networks behavior. ANN widely used in modeling complex relationships between inputs and outputs in nonlinear systems. ANN can also be defined as parallel distributed information processing structure. The ANN consists of inputs, and at least one hidden layer and one output layer. These layers have processing elements which are called neurons interconnected together. To calculate error contribution of each neuron after a batch of data processing a method called 'back propagation' is used. Back propagation is commonly used by the gradient descent optimization algorithm to adjust the weight of neurons by calculating the gradient of the loss function. This technique is also called back propagation error. This is because the error is calculated at the output and circulated back through the network layers.[5] At the end, the result based on the simulation of the data collected from the photovoltaic array system is used to train the neutral network and output efficiency of the designed DC-DC boot converter with MPPT control strategy is accepted the maximum power amount and showed the result voltage, current and power output for each different have been recorded.

2. MATHEMATICAL MODELING of PV ARRAY

The reference modules of PV array is 200.143 W. The basic building block of PV arrays is the solar cell, which is basically a p-n semiconductor junction, shown in Figure 1.[6]

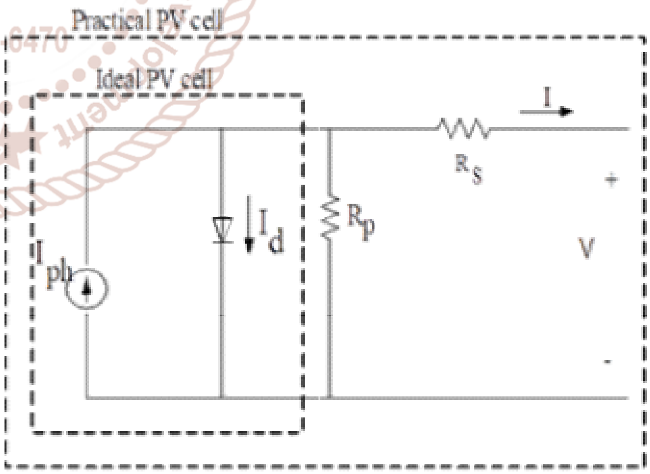


Figure1 Electrical Equivalent Circuit Diagram of a PV Cell

The following equations define the model of a PV panel:

$$I_{ph} = I_{out} + I_d + I_{sh} \tag{1}$$

$$I_d = I_{sat}\left[\exp\left(\frac{q(V + IR_s)}{N_s KT}\right) - 1\right] \tag{2}$$

$$I_{out} = I_{ph} - I_d - I_{sh} \tag{3}$$

$$I_{out} = I_{ph} - I_{sat}\left[\exp\left(\frac{q(V + IR_s)}{nKT}\right) - 1\right] - \left(\frac{V + IR_s}{R_{sh}}\right) \tag{4}$$

In this equations, Isat is the reverse saturated current of diode, q is the electron charge, V is the voltage across the diode, I is output current, Rse is series resistance, Rsh is shunt resistance, n is ideality factor of the diode, k is the Boltzman's constant and T is the junction temperature in Kelvin.

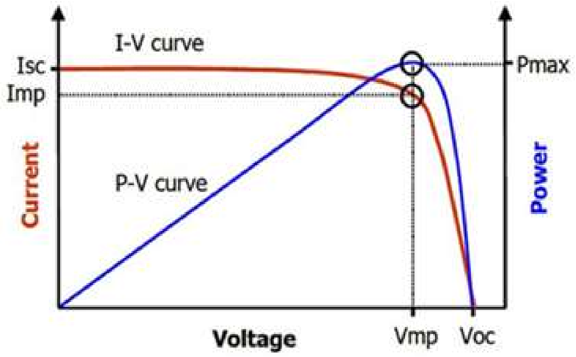


Figure2 Typical I-V and PV characteristics of a PV module [7]

In the figure can be observe that at voltage Vm the power is at the maximum. This is the maximum power point of PV characteristics that we need to track using MPPT algorithm.

A. Modeling and Simulation of PV Array

For the modeling of PV array, we used MATLAB Simulink. The simulation model is based on equations 1 to 4. Simulink model of PV array subsystem is constructed and P-V characteristics of the PV array with different irradiance and temperature are shown in Figure 3 & Figure 4.

TABLE I. Parameters of the KC200GT PV Module at 25°C

Parameters	Symbols	Ratings
Current at Maximum Power	Imax	7.62 A
Voltage at Maximum Power	Vmax	26.3 A
Maximum Power	Pmax	200.143 W
Short Circuit Current	Isc	8.21 A
Open Circuit Voltage	Voc	32.9 V
Ideality Factor	Ns	54

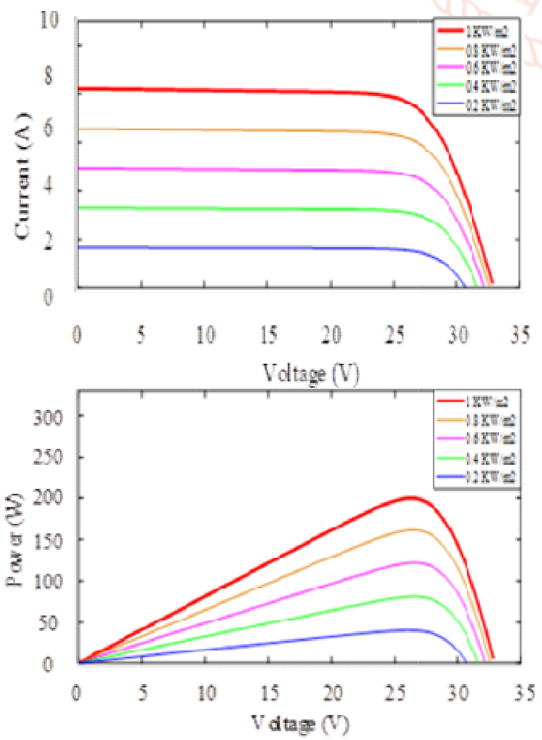


Figure 3 P-V Characteristics of PV Array Various irradiance

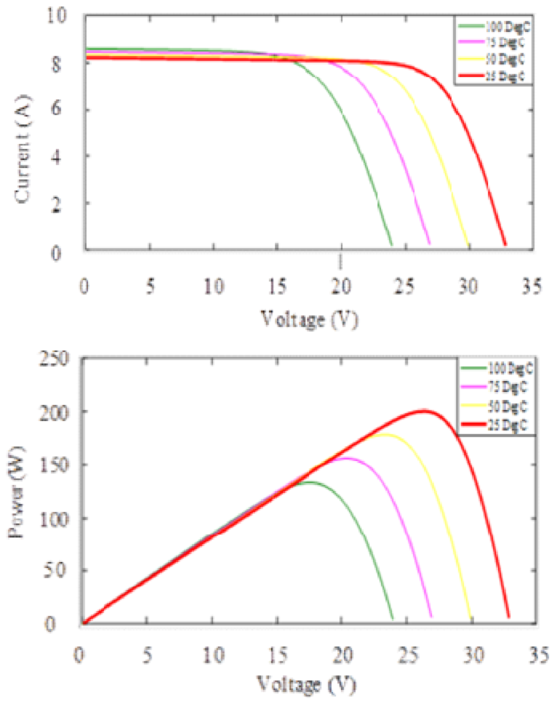


Figure4 P-V Characteristics of PV Array Various temperature

From Figures, we saw with irradiance increased, power increased and temperature increased, power decrease. Hence, this Simulink model is determine the characteristics of PV array. Hence the Simulink model is correct.

3. MATHEMATICAL EQUATION of DC-DC BOOT CONVERTER

$$D = \frac{V_{in}}{V_{out}} \quad (5)$$

$$I_{out} = \frac{P_{out}}{V_{out}} \quad (6)$$

$$d_i = I_{ripple} \times I_{out} \times \frac{V_{out}}{V_{in}} \quad (7)$$

$$L = \frac{V_{in} \times (V_{out} - V_{in})}{d_i f_s V_{out}} \quad (8)$$

$$C = \frac{I_{out} \times D}{d_v f_s V_o} \quad (9)$$

Where, D = duty cycle of the boot converter; Vin = input voltage of the PV module; Vout = output voltage of the converter; Iout= output current of the boot converter; Pout= output power of the boot converter; Iripple= ripple current of the inductor; L= inductor of the boost converter; C= capacitor of the boot converter.

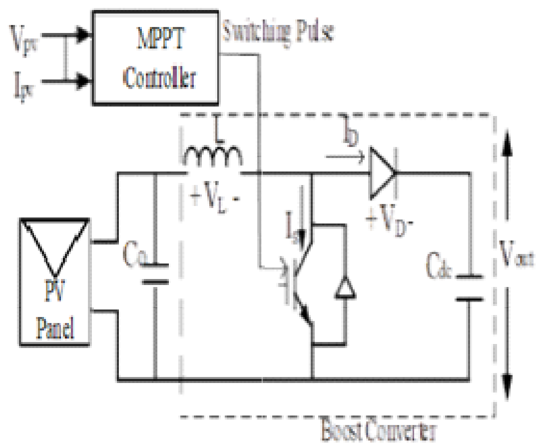


Figure 5 DC-DC Boot Converters and Control Algorithm [8]

The principle drives the boost converter is the tendency of an inductor to resist changes in the current. When being charged it acts as a load and absorbs energy; when being discharged it acts as an energy source. The voltage it produces during the discharge phase is related to the rate of change of current, and not to the original charging voltage, thus allowing different input from the PV array and output voltages to the DC load. In MPPT systems, this signal is controlled by MPPT controller is shown in proposed model in Figure 6. By changing the duty cycle the load impedance as seen by the source is varied and matched at the point of the peak power with the source so as to transfer the maximum power. The simulation results of the solar PV with MPPT controller algorithm is shown in Figure 7.

TABLE II. Parameter of DC Load for Simulation

Parameters	Specification
Constant Torque	0.9 Nm
Initial Speed	10 rad/s
Armature Resistance	1.2 Ω
Inductance, La	2.4 mH

TABLE III. Parameter of DC-DC Boot Converter Simulation Result

Parameters	Ratings
Output Current	4.5 A
Input Voltage	26.3 A
Power Converter	200.143 W
Switching Frequency	20 kHz
Output Voltage	45 V
Inductance	0.1774 mH
Capacitance	220.7 µF

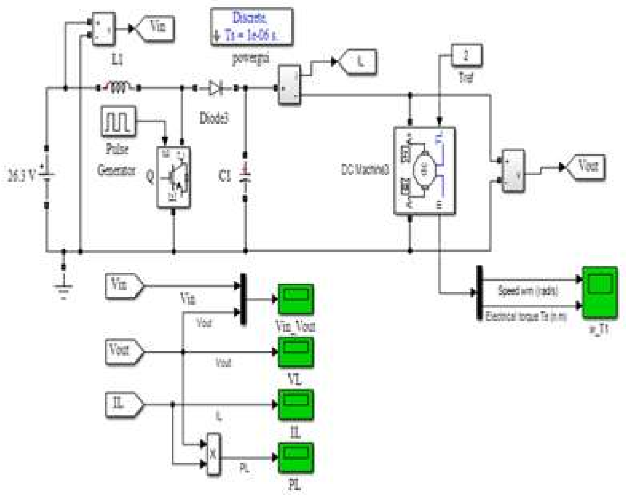


Figure6 Simulink Model of DC-DC Boot Converter

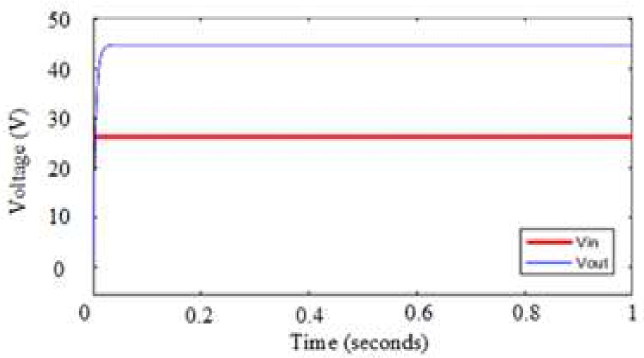


Figure7 Outputs and Input Voltage of Boot Converter.

A. Artificial Neural Network Base MPPT Technique

In this work, the Levenberg-Marquardt algorithm is implemented using MATLAB to train the neural network. The Levenberg-Marquardt method is a very fast and accurate technique for solving nonlinear least squares problems. Since the variations of temperature and irradiance effect are highly nonlinear in producing the output power and voltage, we decided to use the LevenbergMarquardt algorithm to train the neural network. The following steps describe how we implement the neural network based MPPT for a PV array.[9,10].

B. Selecting Network Structure

The input information is connected to the hidden layers through weighted interconnections where the output data is calculated. The number of hidden layers and the number of neurons in each layer controls the performance of the network. Neural network is a trial and error design method. The ANN developed in this paper with two inputs solar irradiance and temperature, one output layer consists of two neurons (Vmax, Pmax) and one hidden layer, shown in Figure 8.

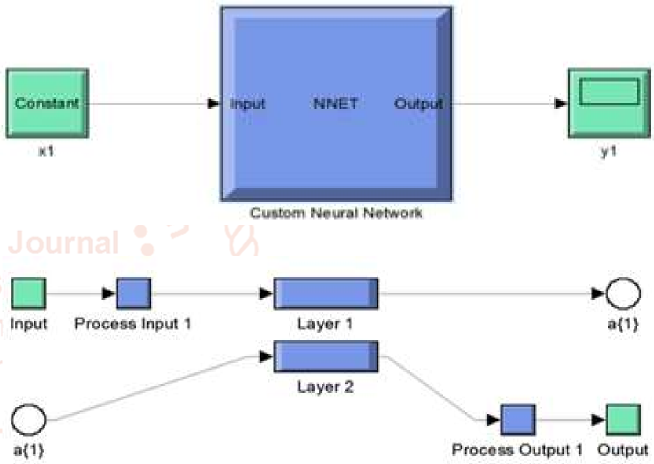
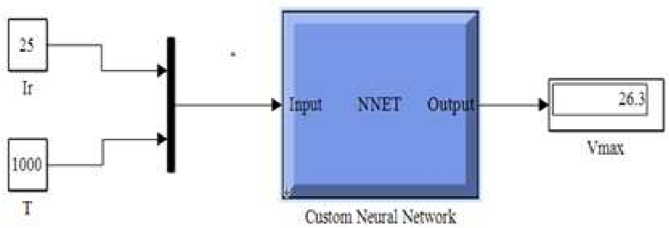


Figure8 Block Diagram of ANN with Two Layers

C. Collecting Data and Training the Network

The Simulink model of PV array is simulated for a range of solar irradiances and temperatures to find corresponding Pmax and Vmax shown in Figure 9. The training points are passed into the designed network to teach it how to perform when different points than the training points are inserted to it. After training of the neural network is completed, then 5 of the collected data points are used as test points. The function of test points is to evaluate the performance of the designed ANN after its training is finished. The error is then feedback to the neural network for further training. The network is trained using the MATLAB NNET tool box.



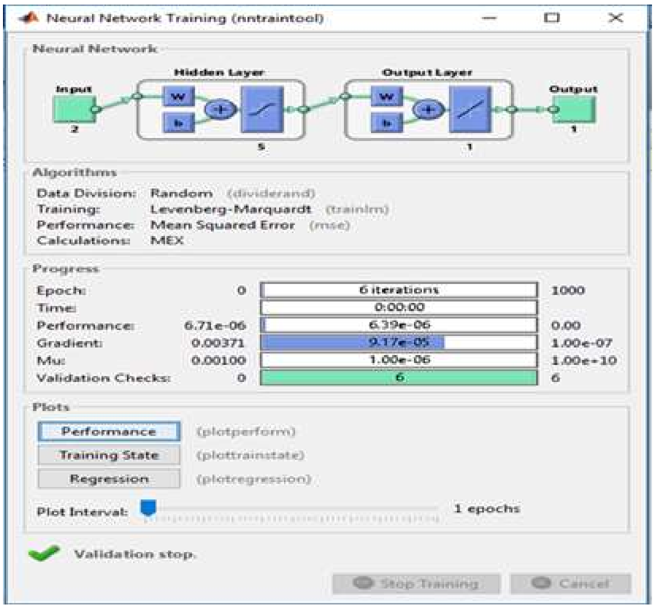


Figure 9 Training the Neural Network with MATLAB NNET toolbox

D. Result and Discussion for Neural Network MPPT

The network which was fully trained with the lowest error is capable to be used in the testing process. Performance result of ANN to minimize the RMS error in the training performance curve. Network was trained until it achieved a very small MSE typically 6.19e-06 which reached after 6 epochs. We can observe that the outputs from the neural model closely match the target values. For 5 new testing input irradiance and temperature data points the neural network has been tested. In shown in Figure 11 to Figure 16 we can see that, at each time, the neural network provided Pmax and Vmax data points clearly matched with measured data points from the actual Simulink model.

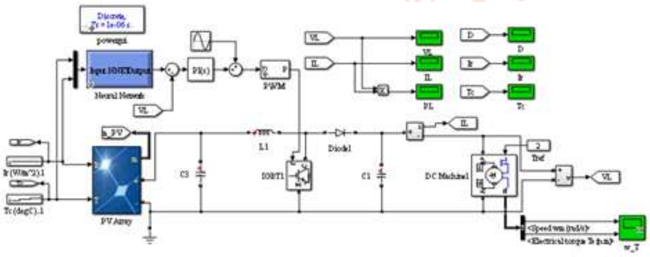


Figure10 Simulink Model Data Collection for ANN

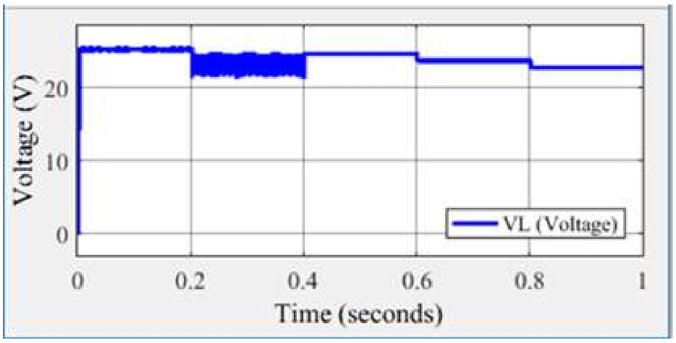


Figure11 Vmax from Neural Network and actual Simulink model with different temperature testing point

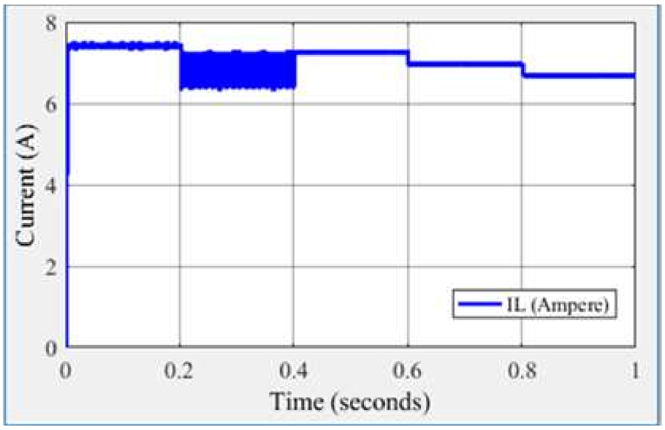


Figure12 Imax from Neural Network and actual Simulink model with different temperature testing point

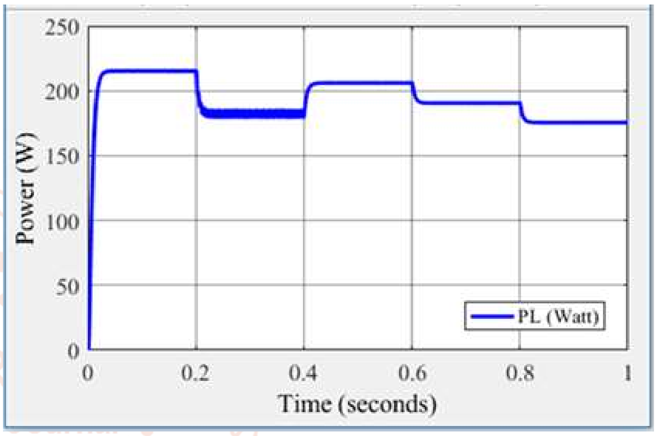


Figure13 Pmax from Neural Network and actual Simulink model with different temperature testing point

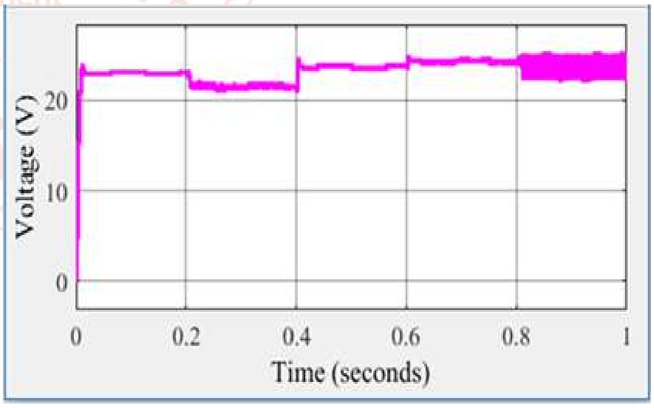


Figure 14 Vmax from Neural Network and actual Simulink model with different irradiance testing point

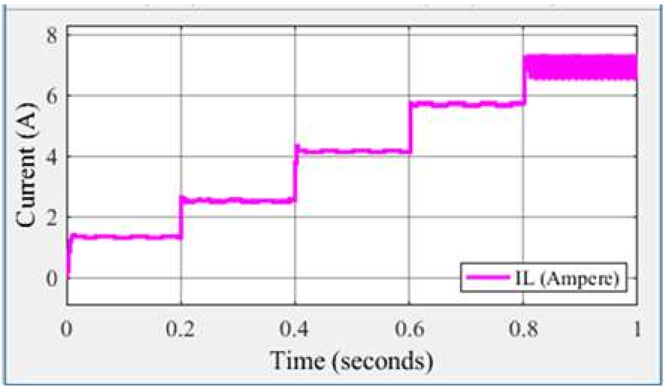


Figure 15 Imax from Neural Network and actual Simulink model with different irradiance testing point

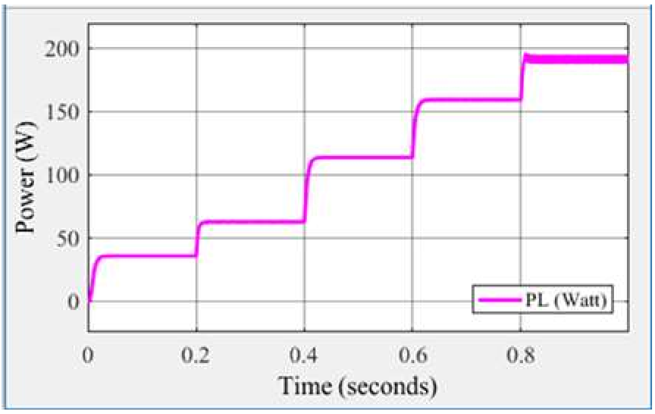


Figure16 Pmax from Neural Network and actual Simulink model with different irradiance testing point

4. CONCLUSION

The main goal of the MPPT technique is to extract the maximum power available in the PV array. 200.143W PV array is developed by using MATLAB/Simulink. The irradiance and temperature are two factors for which the PV array output power varies. But we are not showed the comparison with other MPPT technique methods. The neural network is trained by using Ir and T(°K) input data and Pmax and Vmax output data. From the figure, we observed that the tested data exactly matched with target values; hence training of neural network has been proved accurate. We tested the neural network for 5 new input data (Ir, T (°K)), we observed from the graph that the output (Pmax, Vmax) of neural network exactly matched with actual 200.143 W PV array output. By using the neural network at an irradiance of 1000 W/m2 and temperature of 25°C (298°K), we were able to obtain the output power of 198.1813W at 25.8174V. The actual 200.143 W Simulink model of PV array shows the maximum power of 200W at 26.3V. Hence the neural network algorithm can received more accurate results. The maximum power output we are getting from solar array alone is around 200W. To get this constant output voltage, we implemented the MPPT Algorithms with DC-DC Boost Converter. In future work, we would like to develop two different working model of Solar Photovoltaic system employing these algorithms practically using Buck and Cuk Converter.

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