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Performance Enhancement of MPPT Based Solar PV System using Neural Network

Rakesh Kumar[1], Pramod Kumar Rathore[2]

[1]Student, [2]Assistant Professor,
[1,2]RKDF College of Engineering, Bhopal, Madhya Pradesh, India

ABSTRACT

In this paper, using artificial neural network (ANN) for tracking of maximum power point is discussed. Error back propagation method is used in order to train neural network. Neural network has advantages of fast and precisely tracking of maximum power point. In this method neural network is used to specify the reference voltage of maximum power point under different atmospheric conditions. By properly controlling of dc-dc boost converter, tracking of maximum power point is feasible. To verify theory analysis, simulation result is obtained by using MATLAB/SIMULINK.

KEYWORDS: *Maximum Power Point Tracking, ANN Method, DC-DC Boost Converter*

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I. INTRODUCTION

Recently, many countries of all over the world have paid a lot of their attention to the development of a renewable energy against depletion of fossil fuels in the coming future. The renewable energy means that the energy density is as high as fossil fuel or higher than that and the clean energy does not emit any polluted substances such as nitrogenous compounds, sulphate compounds, and dust. Hydrogen, as a future energy source, is thought as an alternative of fossil fuels in view of environment and energy security, because hydrogen itself is clean, sustainable, and emission-free. Hence, there are many ongoing active studies on the production and application of hydrogen in our society.

The main method for capturing the sun's energy is the use of photovoltaic. Photovoltaic (PV) utilizes the sun's photons or light to create electricity. PV technologies rely on the photoelectric effect first described by a French physicist Edmund Becquerel in 1839. Solar cells and modules using this PV effect are ideal energy generators that they require no fuel, generate no emissions, have no moving parts, can be made in any size or shape, and rely on a virtually limitless energy source, namely, the sun. The photoelectric effect occurs when a beam of ultraviolet light, composed of photons, strikes one part of a pair of negatively charged metal plates. This causes electrons to be "liberated" from the negatively charged plate. These free electrons are then attracted to the other plate by electrostatic forces. This flowing of electrons is an electrical current. This electron flow can be gathered in the form of direct current (DC). This DC can then be converted into alternating current (AC), which is the primary form of electrical current in electrical power systems that are most commonly used in buildings. PV devices take advantage of the fact that the energy in sunlight will free electrical charge carriers in certain materials when sunlight strikes those materials. This freeing of electrical charge makes it possible to capture light energy as electrical current [1].

In general, photovoltaic (PV) arrays convert sunlight into electricity. DC power generated depends on illumination of solar and environmental temperature which are variable. It is also varied according to the amount of load. Under uniform irradiance and temperature, a PV array exhibits a current-voltage characteristic with a unique point, called maximum power point, where the PV array produces maximum output power. In order to provide the maximum power for load, the maximum-power-point-tracking (MPPT) algorithm is necessary for PV array. Briefly, an MPPT algorithm controls converters to continuously detect the instantaneous maximum power of the PV array [2].

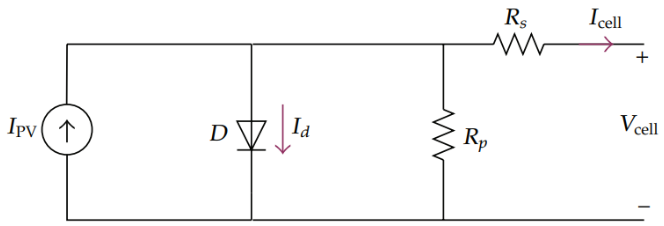


Figure 1: Equivalent circuit of PV model.

II. PHOTOVOLTAIC MODELLING

A. Ideal PV Cell Model

The equivalent circuit of the ideal PV cell is shown in Figure 1. The basic equation from the theory of semiconductors [3] that mathematically describes the I-V characteristic of the ideal PV cell is as follows:

$$I = I_{PV,cell} - I_{0,cell}\left[\exp\left(\frac{qV}{akT}\right) - 1\right] \quad (2.1)$$

$$I_d = I_{0,cell}\left[\exp\left(\frac{qV}{akT}\right) - 1\right] \quad (2.2)$$

where $I_{PV,cell}$ is the current generated by the incident light (it is directly proportional to the sun irradiation), I_d is the Shockley diode equation, $I_{0,cell}$ is the reverse saturation or leakage current of the diode, q is the electron charge ($1.60217646 \times 10^{-19}$ C), k is the Boltzmann constant ($1.3806503 \times 10^{-23}$ J/K), T (in Kelvin) is the temperature of the p-n junction, and "a" is the diode ideality constant [4].

B. Modeling the PV Array

Equations (2.1) and (2.2) of the PV cell do not represent the *V-I* characteristic of a practical PV array. Practical arrays are composed of several connected PV cells and the observation of the characteristics at the terminals of the PV array requires the inclusion of additional parameters to the basic equation [3, 4]:

$$I = I_{PV} - I_0\left[\exp\left(\frac{V + R_s I}{V_t a}\right) - 1\right] - \frac{V + R_s I}{R_p} \quad (2.1)$$

where I_{PV} and I_0 are the PV current and saturation currents, respectively, of the array and $V_t = N_s kT/q$ is the thermal voltage of the array with Ns cells connected in series. Cells connected in parallel increase the current and cells connected in series provide greater output voltages. If the array is composed of N_p parallel connections of cells, the PV and saturation currents may be expressed as $I_{PV} = N_p\ I_{PV,cell}$, $I_0 = N_p\ I_{0,cell}$. In (2.3), R_s is the equivalent series resistance of the array and R_p is the equivalent parallel resistance. Equation (2.3) describes the single-diode model presented in Figure 1 [4].

All PV array datasheets bring basically the following information: the nominal open- circuit voltage ($V_{oc,n}$), the nominal short-circuit current ($I_{sc,n}$), the voltage at the MPP (V_{mpp}), the current at the MPP (I_{mpp}), the open-circuit voltage/temperature coefficient (K_V), the short-circuit current/temperature coefficient (K_I), and the maximum experimental peak output power (P_{max}). This information is always provided with reference to the nominal condition or standard test conditions (STCs) of temperature and solar irradiation. Some manufacturers provide *I-V* curves for several irradiation and temperature conditions. These curves make easier the adjustment and the validation of the desired mathematical *I-V* equation. Basically, this is all the information one can get from datasheet of PV arrays [4].

Electric generators are generally classified as current or voltage sources. The practical PV device presents hybrid behavior, which may be of current or voltage source depending on the operating point. The practical PV device has a series resistance R_s whose influence is stronger when the device operates in the voltage source region and a parallel resistance R_p with stronger influence in the current source region of operation. The R_s resistance is the sum of several structural resistances of the device. R_s basically depends on the contact resistance of the metal base with the p semiconductor layer, the resistances of the p and n bodies, the contact resistance of the n layer with the top metal grid, and the resistance of the grid [5]. The R_p resistance exists mainly due to the leakage current of the p-n junction and depends on the fabrication method of the PV cell. The value of R_p is generally high and some authors neglect this resistance to simplify the model. The value of R_s is very low, and sometimes this parameter is neglected too.

The *V-I* characteristic of the PV array, shown in Figure 2, depends on the internal characteristics of the device (R_s, R_p) and on external influences such as irradiation level and temperature.

The amount of incident light directly affects the generation of charge carriers and, consequently, the current generated by the device. The light-generated current (I_{PV}) of the

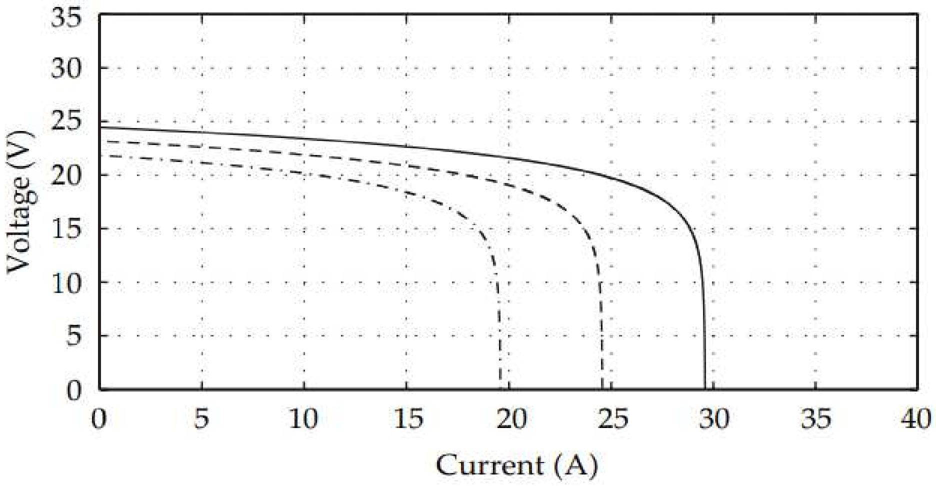


Figure 2: V-I characteristic of PV.

elementary cells, without the influence of the series and parallel resistances, is difficult to determine. Datasheets only inform the nominal short-circuit current ($I_{sc,n}$), which is the maximum current available at the terminals of the practical device. The assumption $I_{sc} \approx I_{PV}$ is generally used in the modeling of PV devices because in practical devices the series resistance is low and the parallel resistance is high. The light-generated current of the PV cell depends linearly on the solar irradiation and is also influenced by the temperature according to the following equation (2.4), [2, 4, 6–8]

$$I_{PV} = \left(I_{PV,n} + K_I \Delta T\right) \frac{G}{G_n} \quad (2.4)$$

where $I_{PV,n}$ (in amperes) is the light-generated current at the nominal condition (usually 25°C and 1000 W/m^2), $\Delta T = T - T_n$ (T and T_n being the actual and nominal temperatures (in Kelvin), resp.), G (watt per square meter) is the irradiation on the device surface, and G_n is the nominal irradiation. $V_{t,n}$ is the thermal voltage of N_s series-connected cells at the nominal temperature T_n.

The saturation current I_0 of the PV cells that compose the device depend on the saturation current density of the semiconductor (J_0, generally given in [A/cm^2]) and on the effective area of the cells. The current density J_0 depends on the intrinsic characteristics of the PV cell, which depend on several physical parameters such as the coefficient of diffusion of electrons in the semiconductor, the lifetime of minority carriers, and the intrinsic carrier density [9]. In this paper the diode saturation current I_0 is approximated by the fixed value (6 mA).

The value of the diode constant "*a*" may be arbitrarily chosen. Many authors discuss ways to estimate the correct value of this constant. Usually, $1 \leq a \leq 1.5$ and the choice depends on other parameters of the *I-V* model. Some values for "*a*" are found in [6] based on

empirical analyses. Because "*a*" expresses the degree of ideality of the diode and it is totally empirical, any initial value of "*a*" can be chosen in order to adjust the model. The value of "*a*" can be later modified in order to improve the model fitting, if necessary. This constant

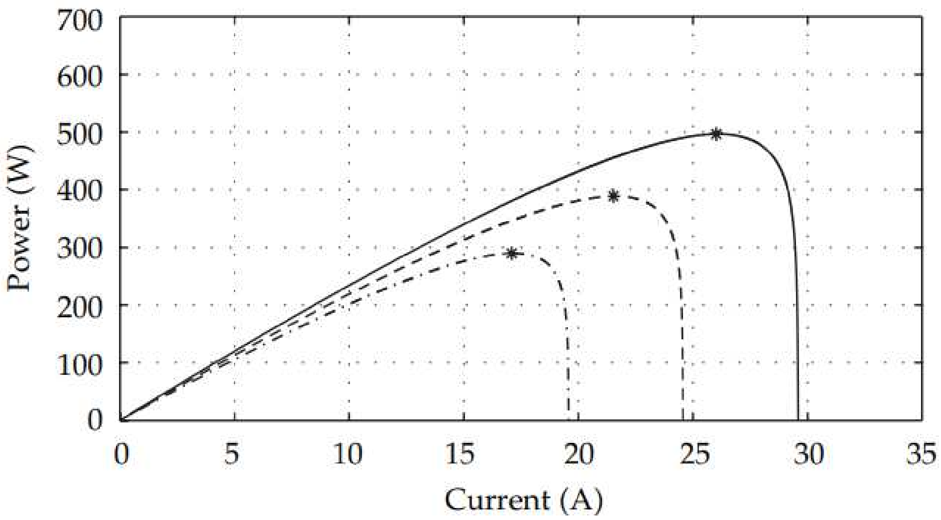


Figure 3: P-I characteristic of PV.

affects the curvature of the *V-I* curve and varying *a* can slightly improves the model accuracy [4].

III. MAXIMUM POWER POINT TRACKING

By change of environment temperature and irradiance, the maximum power is variable (Figure 3). Since the maximum available energy of solar arrays continuously changes with the atmospheric conditions, a real-time maximum power-point tracker is the indispensable part of the PV system. Proposed maximum power point tracking (MPPT) schemes in the technical literature [10] can be divided into three different categories [11].

1. Direct methods.
2. Artificial intelligence methods.
3. Indirect methods.

In the direct methods, which are also known as true seeking methods, the MPP is searched by continuously perturbing the operating point of the PV array. Under this category, Perturb and Observe (P&O) [12], Hill Climbing (HC) [13], and Incremental Conductance (INC) [14] schemes are widely applied in PV systems. P&O scheme involves perturbing the operation voltage of the PV array to reach the MPP. Analogous to P&O scheme, hill climbing method perturbs the duty cycle of the dc-dc interface converter. Simplicity is the main feature of these methods; however, intrinsic steady state oscillation limits these methods to low-power applications. Reduced steady state oscillation is possible with the incremental conductance method, which is based on the fact that the slope of the power versus voltage is zero at the MPP. Artificial intelligence and indirect methods have been proposed to improve the dynamic performance of MPP tracking. Concentrating on nonlinear characteristics of the PV arrays, the artificial intelligence methods provide a fast, and yet, computationally demanding solution for the MPPT problem.

The indirect methods are based on extracting the MPP of the array from its output characteristics. Fractional open-circuit voltage (OCV) [15] and short-circuit current (SCC) [16] schemes provide a simple and effective way to obtain the MPP.

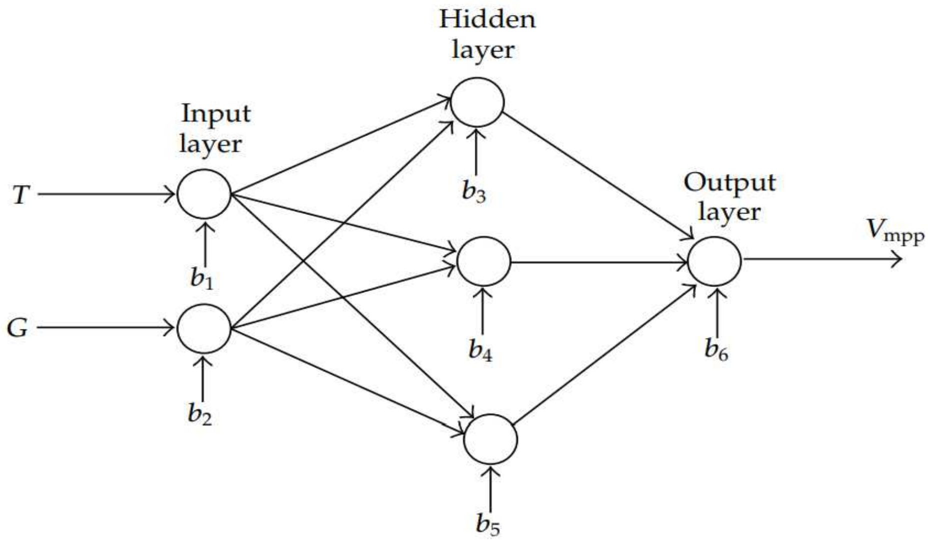


Figure 4: Neural network structure.

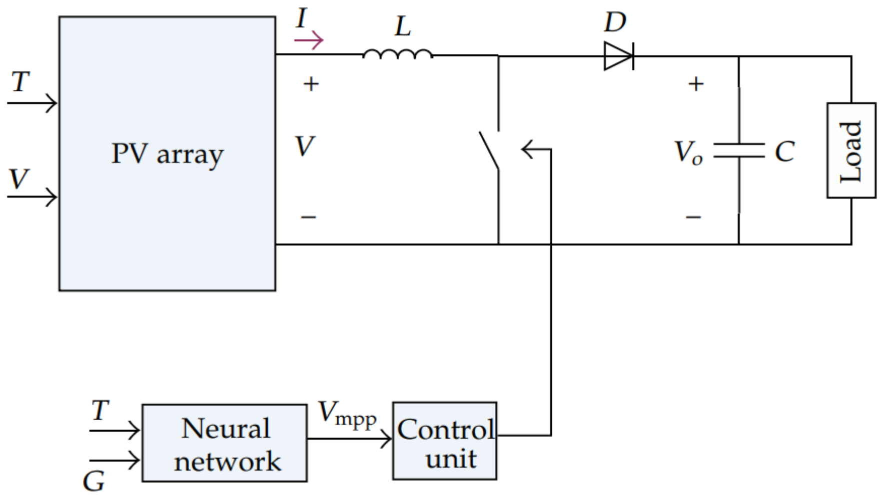


Figure 5: DC-DC chopper includes PV as a input and its control units.

A. MPPT by Using Neural Network

In this paper for tracking maximum power point, an artificial neural network is used. A three- layer neural network is used to reach MPP, which is shown in Figure 4.

Temperature (T) and irradiance (G) are two input variables and voltage of MPP (Vmpp) is the output variable of ANN. It is necessary to obtain some data as input and output variable to train the neural network. Consequently, weights of neurons in different layers are acquired. PV model programming in MATLAB is used in order to obtain data. There are several methods to train ANN. In this paper error back propagation method is used to train the ANN.

After training the ANN and specification of neuron weights, for any T and G as inputs of ANN, output of ANN is the Vmpp. Now, current of maximum power point (Impp) can be obtained by using V-I characteristic of the modelled PV. Consequently, maximum power (Pmax) is reached by multiplying Vmpp and Impp.

Figure 5 shows PV and maximum power point tracker system, which is composed of a dc-dc boost converter and neural network-based control unit. In every moment to control chopper with specified Vmpp and Impp duty cycle of chopper is obtained by the following equation:

$$D = 1 - \sqrt{\frac{V_{mpp}}{I_{mpp}} \times \frac{I_{out}}{V_{out}}} \quad (3.1)$$

IV. SIMULATION AND RESULTS

To verify theoretical analysis mentioned in previous sections, a stand-alone PV system which is connected to a boost dc-dc converter is simulated by using MATLAB/SIMULINK. The simulated model are as shown in Figure Below.

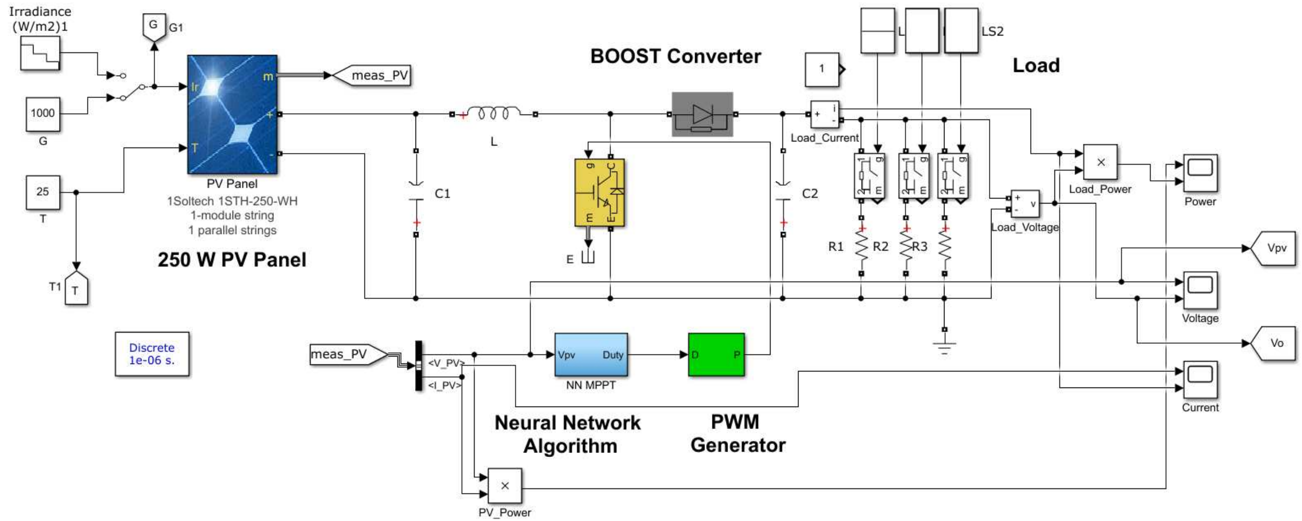


Fig 6 MATLAB/ Simulink ANN MPPT Algorithm for Solar PV System

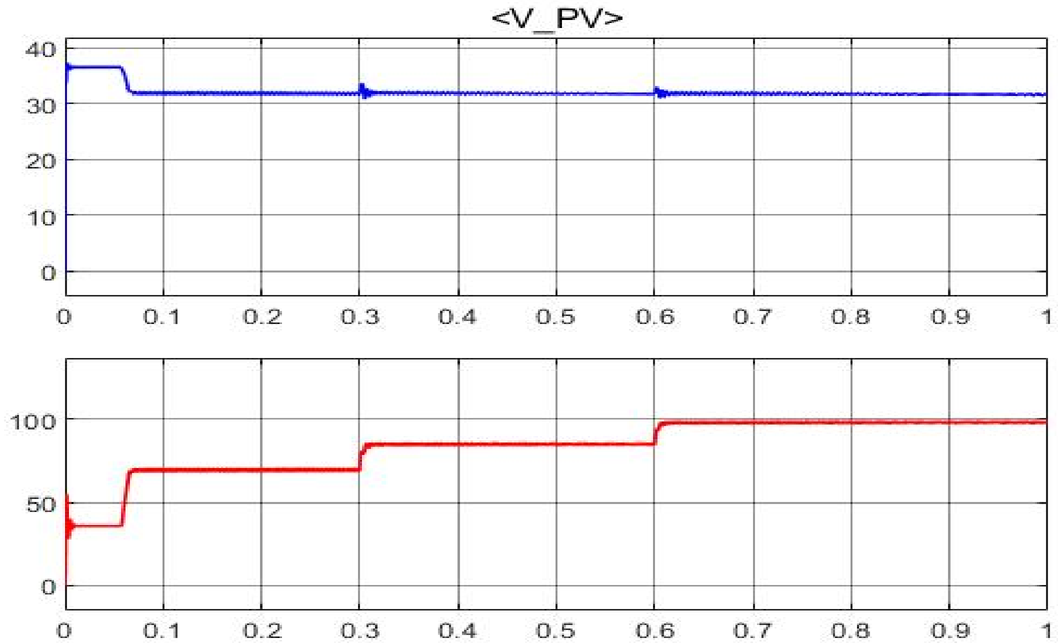
To analyse the performance of the output voltages, the output currents and the output power are measured as shown. The PV parameters of the system are shown in Table I.

TABLE I PV PARAMETERS

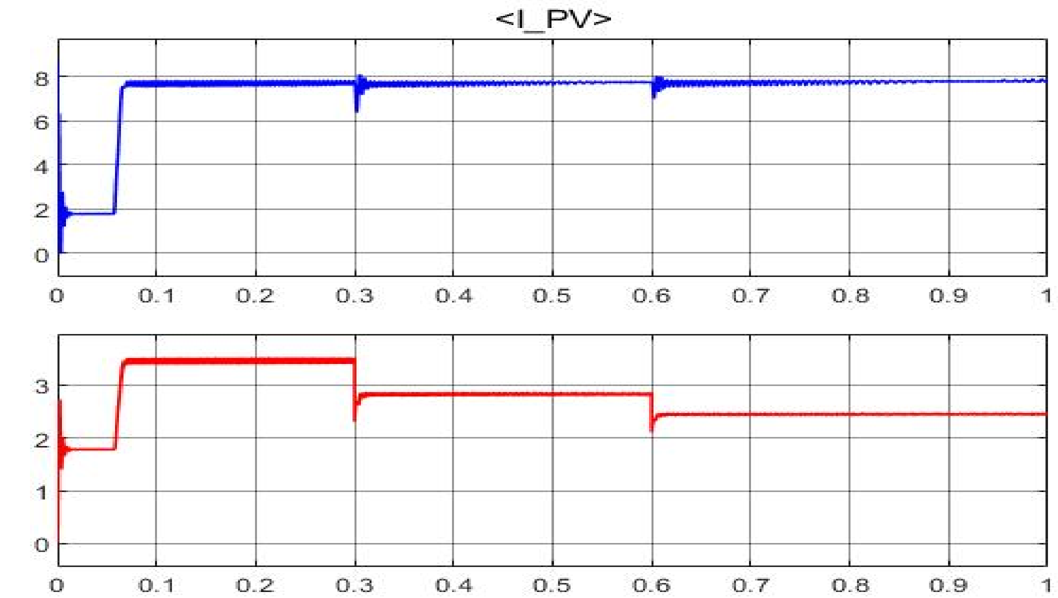
Parameters	Specifications
Maximum power, P_m	250 W
Series-connected modules per string	1 nos
Parallel strings	1 nos
Cells per module (Ncell)	60
Maximum power voltage, V_{pm}	30.7 V
Maximum power current, I_{pm}	8.15 A
Open circuit voltage, V_{oc}	37.3V
Short circuit current, I_{se}	8.66 A

A. Simulation Results with ANN Based MPPT Algorithm.

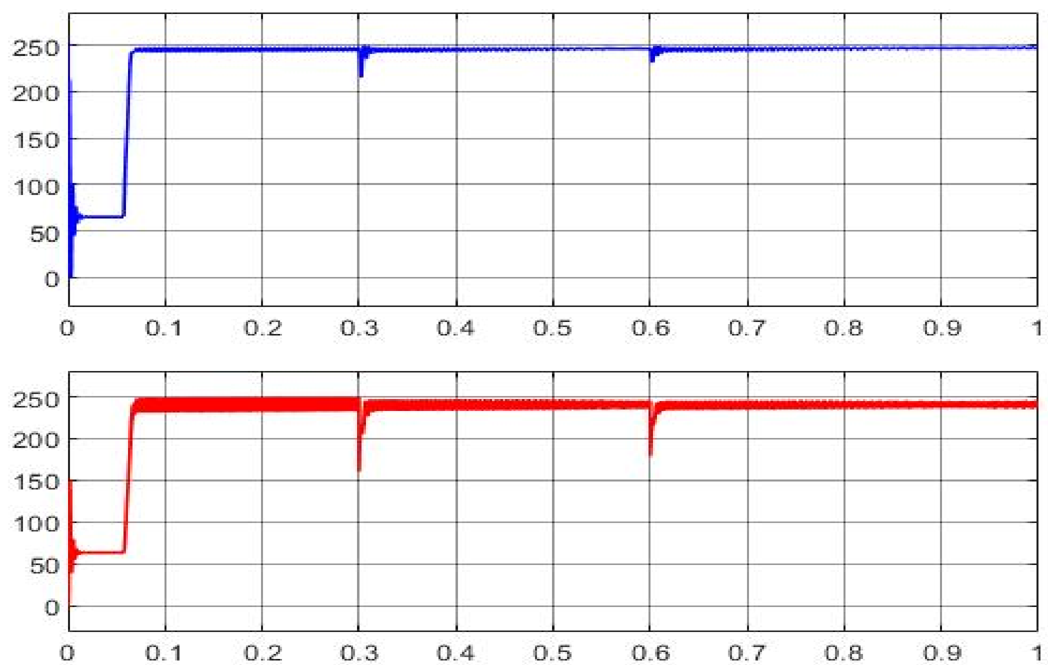
The simulation results for ANN algorithm under standard condition, 1000 W/m2 irradiation and 25^0C temperature are shown in the following figures.

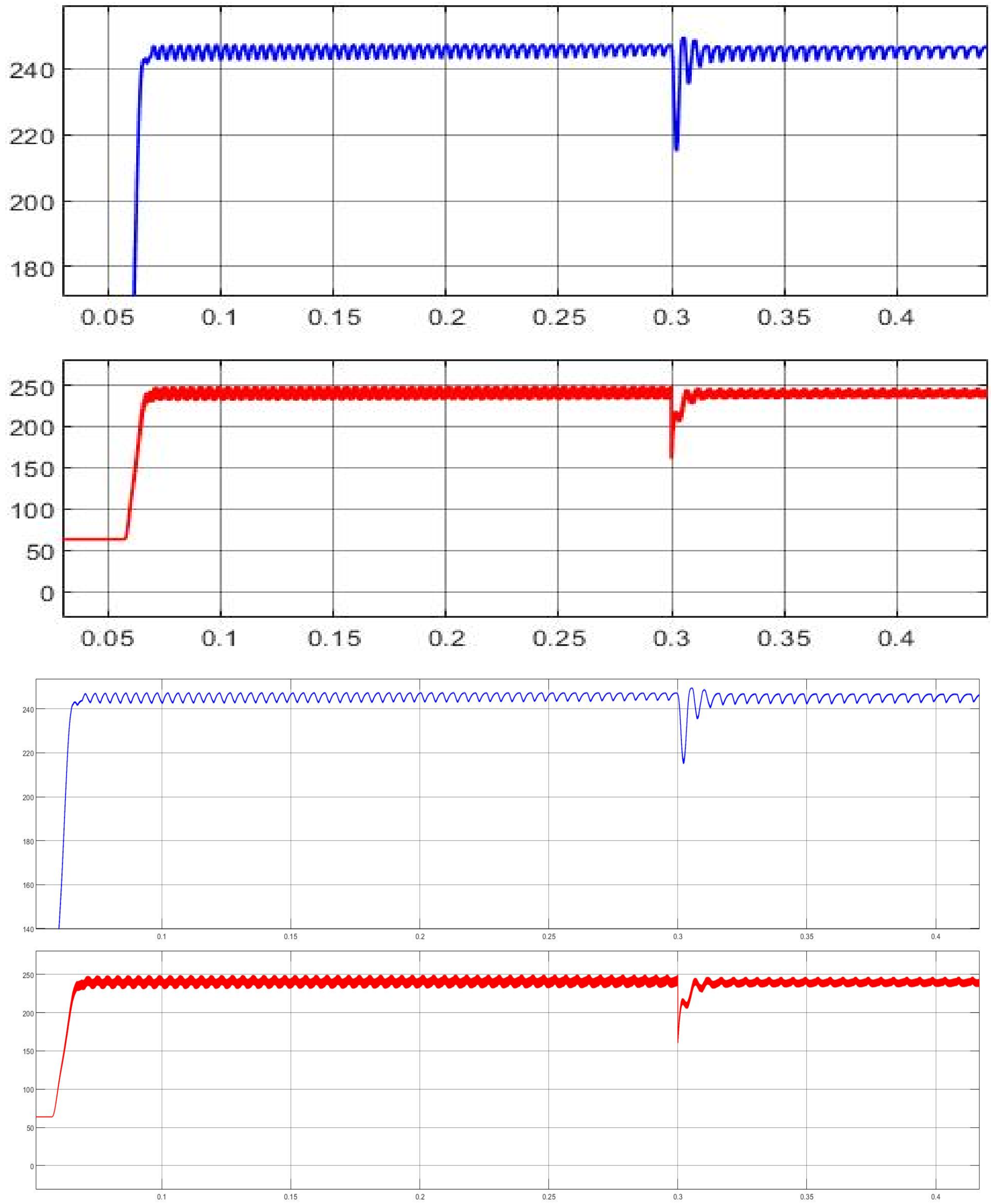


(a). Voltage

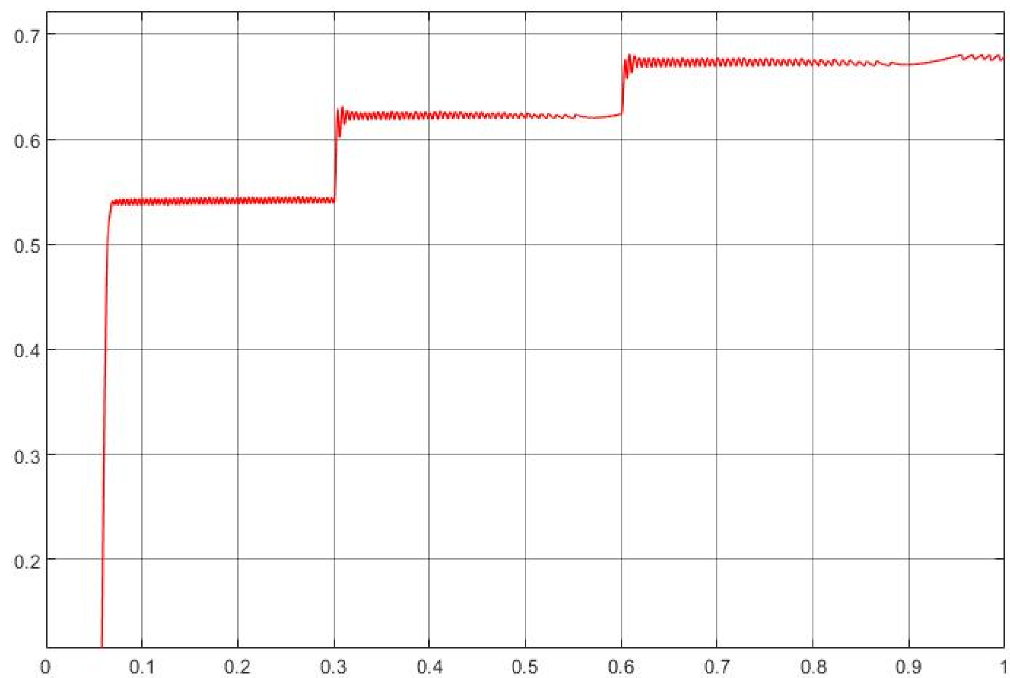


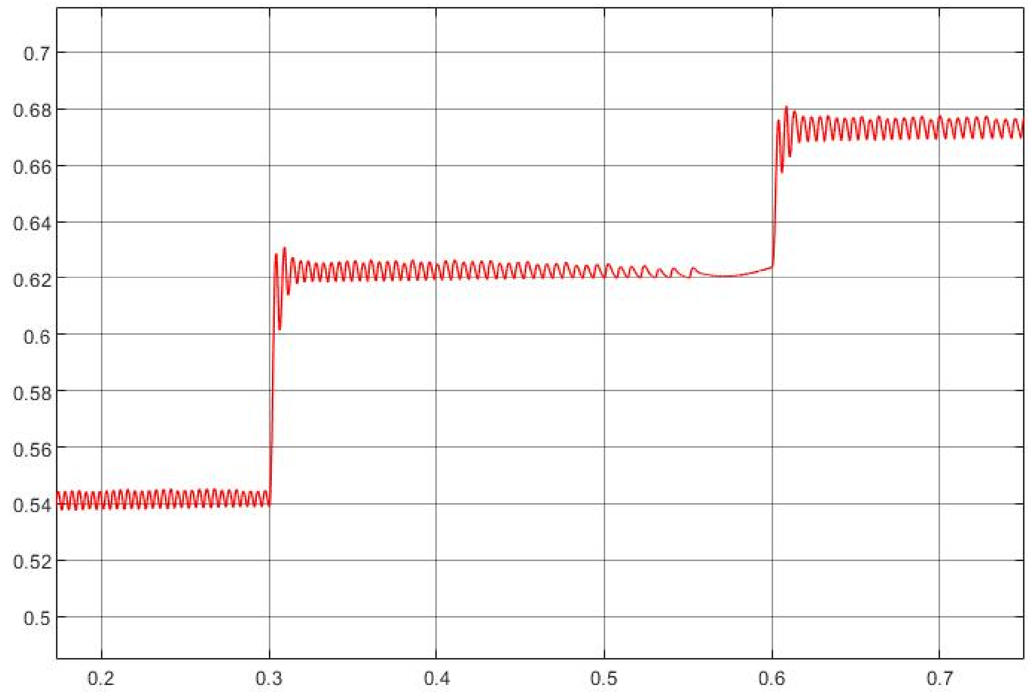
(b). Current

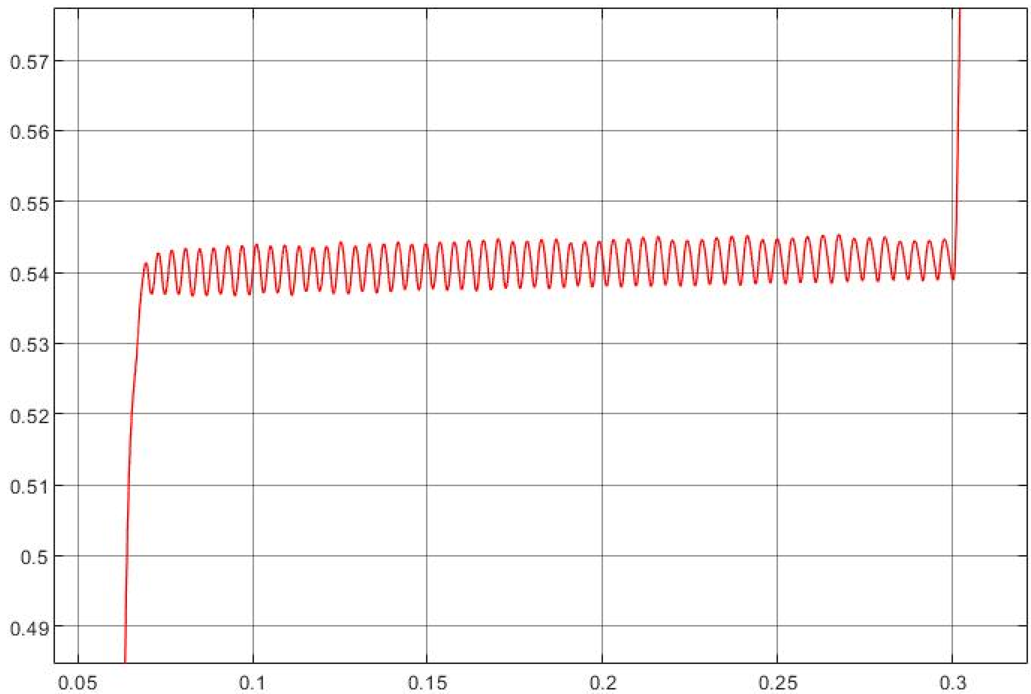



240
220
200
180
0.05
0.1
0.15
0.2
0.25
0.3
0.35
0.4
250
200
150
100
50
0
0.05
0.1
0.15
0.2
0.25
0.3
0.35
0.4

(c). Power


0.7
0.6
0.5
0.4
0.3
0.2
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1





(d). Duty Cycle

Fig 7. PV Output (a) Voltage, (b) Current, (c) Power & (d) Duty Cycle with ANN Method.

V. Conclusion

This Thesis discusses neural network based MPPT. Under variations in atmospheric conditions, by using neural network, point of maximum power is specified fast and precisely. Another advantage of the neural network in PV maximum power-point tracking is its better dynamic performance in comparison with the other methods. Also, the ANN technique exhibits better transient response and reaches steady state conditions more quickly, the maximum power point is tracked by dc-dc boost converter. So, the maximum power solar energy and the best efficiency are obtained.

VI. Future Scope

- A coordinated multi-input hybrid converter (DC-DC-AC) should be amended for hybrid system.
- Coordinated MPPT with energy management system should be proposed for hybrid RES.
- Combinations of algorithms and controllers, like P&O, PSO, GA, Fuzzy Logic, PID Controller and ANFIS, can be used to make PV systems work more efficiently.
- Reliability of PV energy conversion systems is very important owing to the typically high fixed costs.

- The execution of the MPPT can be additionally expanded by a novel hybrid optimization strategy for solar PV framework working under partial shading condition.

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