The MPPT Control of PV System by Using Neural Networks Based on Newton Raphson Method

NAOUFEL KHALDI*, HASSAN MAHMOUDI
Mohammedia School of Engineer, LEEP
Mohamed V University Agdal
Rabat, Morocco
naoufelkhaldi@gmail.com, mahmoudi@emi.ac.ma

MALIKA ZAZI,YOUSSEF BARRADI
Higher School of Technical Education, LMIP
Mohammed V University Souissi
Rabat, Morocco
m.zazi@um5s.net.ma, barradiyoussef@hotmail.fr

Abstract— **The maximum power point tracking (MPPT) system controls the voltage and the current output of the photovoltaic (PV) system to deliver maximum power to the load. Present work deals a comparative analysis of perturb and observe (PO), incremental conductance (IC) and neural network based MPPT techniques. Parameters values were extracted using Newton Raphson method from characteristics of Shell SP75 module. The simulations have been carried out on MATLAB/SIMULINK platform for solar photovoltaic system connected to boost dc-dc converter. For three MPPT algorithms, Performance assessment covers overshoot, time response, oscillation and stability as described further in this paper. These results show that the objective is achieved and the MPPT controller based on Back Propagation (BP) neural networks play an effective role to improve the efficiency and reduce the oscillations of PV power system comparing with others control strategies.**

Keywords— Artificiel neural networks, Photovoltaic systems, MPPT, Perturb and observe , incremental conductance, Newton Raphson

I. INTRODUCTION

Among the renewable energy resources, the energy through the solar photovoltaic effect can be considered the most necessary and prerequisite sustainable resource because of the ubiquity, large quantity, and sustainability of solar energy. Since long time ago, fossil fuels have served as the major source of generating electrical energy. However the transfer of energy resulting from photovoltaic conversion remains relatively weak. Therefore, many tracking control strategies have been proposed in existing literatures, such as perturb and observe, incremental conductance, parasite capacitance, and fuzzy logic methods [1,2,13]. But for this work a novel BP neural networks MPPT algorithm has been used. These new control techniques feature advantages of simplicity, high flexibility and less fluctuation around the maximum power point which increase efficiency of the PV system [3]. In [4], Newton Raphson method is used due to the nonlinearity relationship between the output voltage and the current of the PV array. Selection of appropriate converter is also very important for an efficient PV system. Previously buck, boost and buck-boost converters are used to transfer the power generated by PV to load connectivity, among them boost converter has been selected here due to its available use in standalone and grid connected PV system and simultaneous step up capability [5,6]. This paper results show that the proposed BP MPPT method can track maximum power point (MPP) in different temperature and irradiation, which has excellent output characteristic of high accuracy and good robustness as compare with other methods. The sequential workflow of this paper is as follows: In section II, complete working procedure of the system has been described. Section III covers mathematical modelling of PV using a Newton Raphson method, and followed by discussion on boost dc-dc converter and MPPT algorithms in Sections IV and V respectively. Simulation works and results are discussed in Section VI. Lastly, in section VII, a precise conclusion has been added for the end.

II. COMPLETE SYSTEM OVERVIEW

A photovoltaic cell is basically a PN semiconductor junction diode and this cell converts solar light energy into electricity [7]. The complete system block diagram is shown in Fig. 1. After that this energy will be supplied to the load through the buck-boost converter and the converter will be controlled by a MPPT controller.

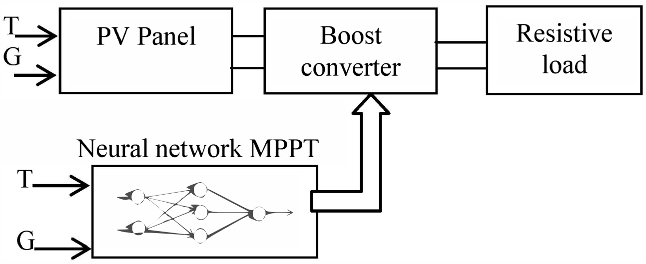


Fig. 1 Schematic arrangement for the complete system

III. PV MODELLING

A. Mathematical Modeling

There are various methods to perform modeling work on the PV module, and the most of them are described by using mathematical modeling [8,9]. The equivalent circuit of a photovoltaic (PV) array can be depicted in Fig. 2 where I_{ph} is current source of PV array, R_{sh} is an equivalent shunt resistance, R_s is an equivalent series resistance, i_{pv} and v_{pv} are the output current and output voltage of PV array, respectively. In general, for simplicity R_{sh} and R_s are assumed to be open circuit and short circuit, respectively. The simplified mathematical model of the output current is given as[10]:

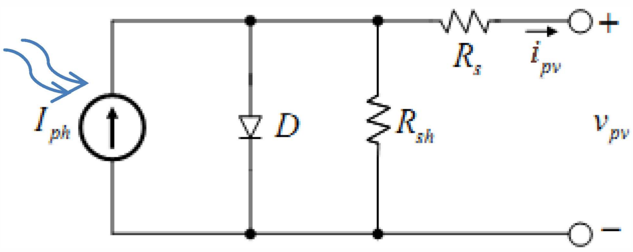


Fig. 2 The equivalent circuit of a photovoltaic array

$$i_{pv} = n_p I_{ph} - n_p I_{rs}\left[\exp^{\left(\frac{q}{pkn_s}\times\frac{v_{pv}}{T}\right)} - 1\right] \quad (1)$$

Where q is the electron charge, k the Boltzmann's constant (1.38×10^{-23} J/°K), p is the p–n junction ideality factor (p=1~5), T is the cell temperature (°K) and I_{rs} is the cell reverse saturation current, n_s is the number of solar cells connected in series and n_p is the number of solar cells connected in parallel.

In addition, the mathematical model of the reverse saturation current is given below:

$$I_{rs} = I_r (T/T_{ref})^3 \exp^{\left\{\left(\frac{qE_g}{pk}\right)\left(\frac{1}{T}-\frac{1}{T_{ref}}\right)\right\}} \quad (2)$$

With

$$I_r = \frac{I_{sc}}{\left[\exp^{\left(\frac{v_{co}}{pn_s v_{tr}}\times\frac{v_{pv}}{T}\right)} - 1\right]} \quad (3)$$

Where T_{ref} is the cell reference temperature, I_r is the reverse saturation current at T_{ref}, E_g is the band-gap energy of the semiconductor ($E_g \approx 1.1$eV) and V_{tr} is a thermal potential at T_{ref}.

The current source of PV array I_{ph}, varied according to solar irradiation and cell temperature, is given below:

$$I_{ph} = [(I_{sc} + K(T - T_r)] \times (\frac{E}{E_r}) \quad (4)$$

Where I_{sc} is short-circuit current at reference temperature and radiation, E is the solar irradiance and K, the temperature coefficient for short-circuit current. Using the equations 1 to 4 the PV panel can be modelled. In this work the equation of solar module is solved with the help of Newton-Raphson method. A program of solar module is programed in MATLAB software and the different characteristics of solar module are obtained.

B. Newton Raphson Method

In determining the operational point of a nonlinear circuit, Newton Raphson method is commonly used. The method is based on linearizing the nonlinear equations and solving the resulting linear equations repeatedly [10,11]. For example, we will consider solving one variable equation. First, the initial value $x^{(0)}$ should be chosen to be close to the true solution $\hat{x}$. Considering a Taylor series expansion of $f(x)$ around $x^{(0)}$, $f(x)$ can be transformed to (5).

$$f(x) = f(x^{(0)}) + \frac{df}{dx}\Big|_{x=x^{(0)}} (x - x^{(0)}) + \frac{1}{2}\frac{d^2f}{dx^2}\Big|_{x=x^{(0)}} + \cdots \quad (5)$$

The third term of (5) is expected to be very small due to the square. Therefore, the linearized model (6) can be formed.

$$f(x) = f(x^{(0)}) + \frac{df}{dx}\Big|_{x=x^{(0)}} (x - x^{(0)}) \quad (6)$$

Solving $f(x) = 0$ for x leads to (7) on the assumption of $df(I^{(k)})/dI \neq 0$.

$$x^{(1)} = x^{(0)} - \left(\frac{df}{dx}\Big|_{x=x^{(0)}}\right)^{-1} f(x^{(0)}) \quad (7)$$

If $x^{(1)}$ satisfies $f(x^{(1)}) < \delta$ which is the threshold value of the end condition, $x^{(1)}$ can be determined as the approximate solution of $\hat{x}$. Otherwise, the above procedure is calculated repeatedly until satisfying $|f(x^{(1)})| < \delta$. An iterative scheme of the method is described by the equation (8).

$$x^{(k+1)} = x^{(k)} - \left(\frac{df}{dx}\Big|_{x=x^{(k)}}\right)^{-1} f(x^{(k)}) \ \ (k = 0,1,2,\ldots) \quad (8)$$

The graphical illustration of Newton-Raphson method in one dimension is depicted in Fig. 3. The process in Newton Raphson method corresponds to drawing the tangent lines to the curve of $f(x)$ repeatedly.

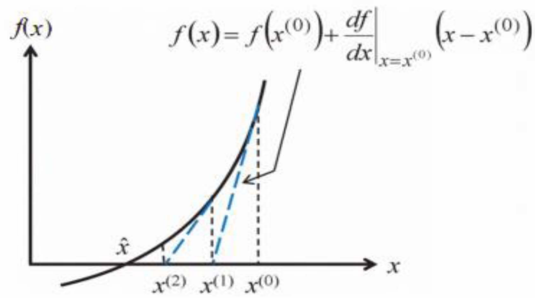


Fig. 3 The graphical illustration of Newton Raphson method in one dimension.

The proposed method using one variable Newton Raphson method, will allow us to calculate the current i_{pv} with the initial value $x^{(0)} = I_{ph}$ as shown in Fig. 4.

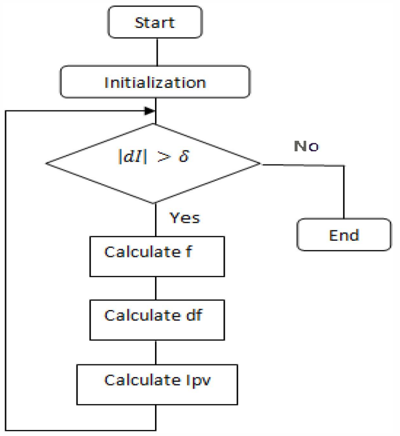
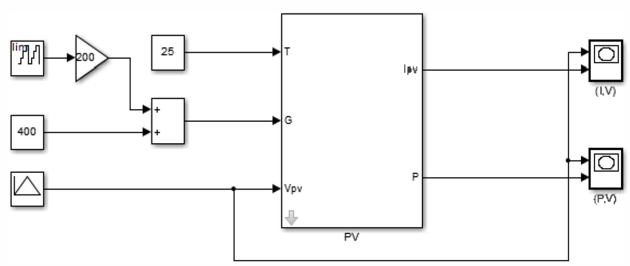


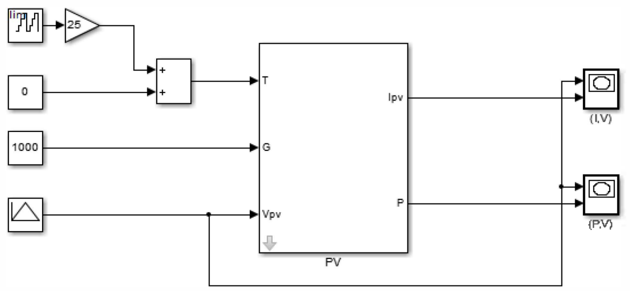
Fig. 4 A flow chart of the proposed method of calculating current i_{pv} of PV

C. Caracteristic of solar panels

A complete Simulink block diagram of PV system by varying the inputs is demonstrated bellow:



(a)



(b)

Fig. 5 External view of PV module in Simulink window using Newton Raphson method

Cell parameters are shown in Table I. PV module is made by Shell solar company and product name is SP75.

TABLE I. PARAMETRS OF SHELL SP75

Parameters	**Values**
Open Circuit Voltage(Voc)	21.7Volt
Short Circuit Current(Isc)	4.8Amp
Voltage at Pmax(Vmpp)	17Volt
Current at Pmax(Impp)	4.41Amp
Maximum Power (Pmpp)	75Watt
Number of Cell	36

With the increment in the temperature short circuit current increases but the open circuit voltage of cell decreases. So the I-V characteristics shift to the left to previous curve. Power output of cell is also decreased. Figs. 6 and 7 show the variation in the characteristics curves at different temperature when the irradiance is kept constant at 1000w/m^2.Temperature varies from 0°C to 75°C, which is in degree Celsius.

Fig. 8 and 9 show the variation in characteristics curve of the selected PV module by changing irradiance values from 400w/m^2 to 1000w/m^2 and T=25°C . The maximum power is higher if the irradiance is getting higher and for the current, if the irradiance is kept increasing, it also increases.

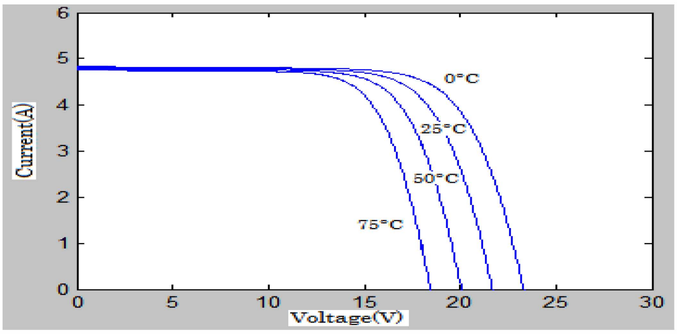


Fig. 6 I-V characteristics of solar module for different temperature

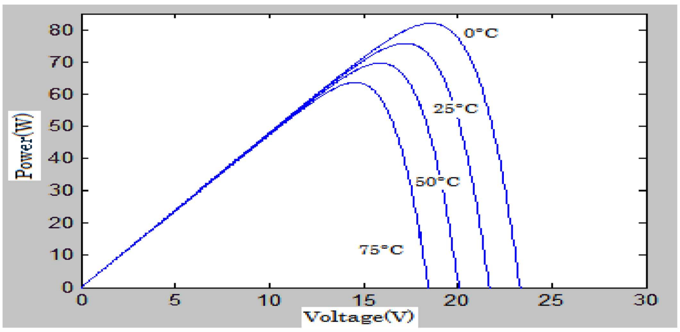


Fig. 7 P-V characteristics of solar module for different temperature

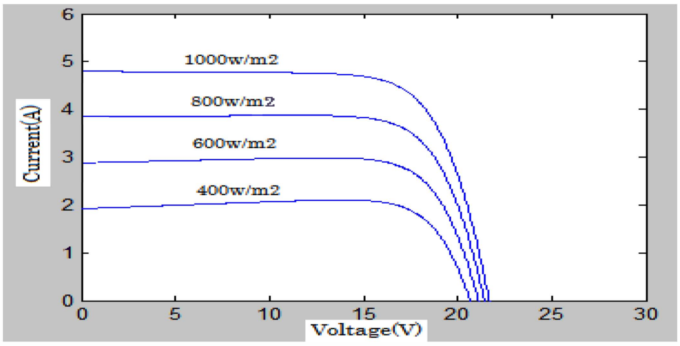


Fig. 8 I-V characteristics of solar module for different irradiance level

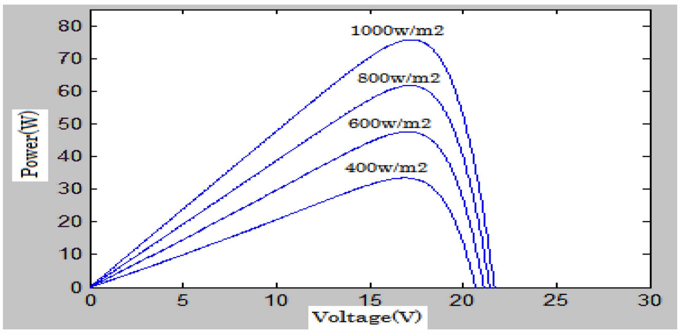


Fig. 9 P-V characteristics of solar module for different irradiance level

IV. DC-DC CONVERTER

DC-DC converters are used to transfer power of solar panel to load side ensuring that maximum power has been transferred [12]. The regulation is normally achieved by pulse within modulation (PWM) and the switching device is normally MOSFET or IGBT. Boost dc-dc converter's function is to step up dc voltage. Fig. 10 shows configuration of dc-dc boost converter with PV as input. Maximum power is reached when the MPPT algorithm changes and adjusts the duty cycle of the boost dc-dc converter.

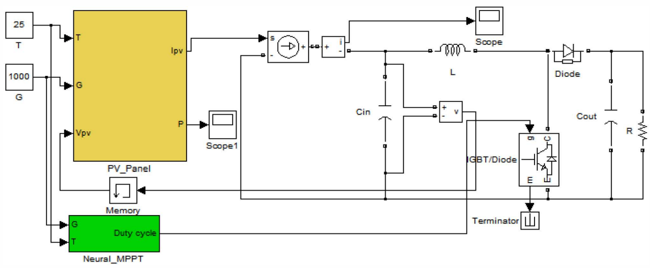


Fig. 10 Boost dc-dc converter with PV as input

V. THE PROPOSED MPPT SCHEME

Maximum power point tracking is a technique to extract maximum available power from PV module. This is done with the help of dc-dc converter which operate is such way that the output of converter is always give the maximum power that is produced by module in specific environment. At present, the most commonly used MPPT is PO method which is also has some shortcomings, such as the tracking speed is slow, and the output oscillation is big.

For this, this paper introduced a MPPT method based on back propagation neural network (BP NN). The trained neural networks can output the optimal voltage for the maximum power point under the various environment conditions. For training, gradient descent rule has been adopted. The two input (irradiance and temperature) and one output (duty cycle) is taken into consideration.

The training parameter of the network architecture is shown in Table II. The trainlm function is used to train the network, which has three hidden layer. The output of the function will give the output of the network. This algorithm updates the network weights so as to minimize the SSE (sum square error) function.

TABLE II. NEURAL ETWORK PARAMETER FOR SIMULATION

Parameters	**Values**
Error Goal	0.000001
Epochs	10000

Fig. 11 shows the block diagram representation of neural network.

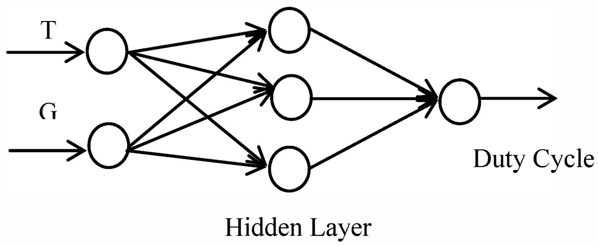


Fig. 11 Neural Network Block Diagram

The trainlm function is used to train the network, which has three hidden layer. The selection of architecture for our neural network will come down to trial and error. The output of the function will give the output of the network. This algorithm updates the network weights so as to minimize the SSE (sum square error) function.

The weights and bias are extracted during the learning phase (Fig. 12).

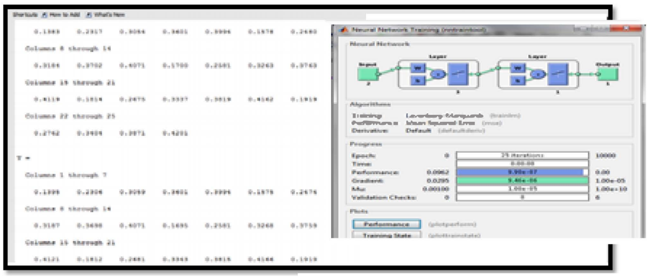


Fig. 12 Results of Training ANN in Matlab/Simulink

We normalize climatic conditions in order to unify the range of variation of our inputs:
Tn=T/60; Gn=G/1000.

Fig. 13 and 14 shows the curves of our inputs by changing climatic conditions, in case to validate the behavior of our neural control.

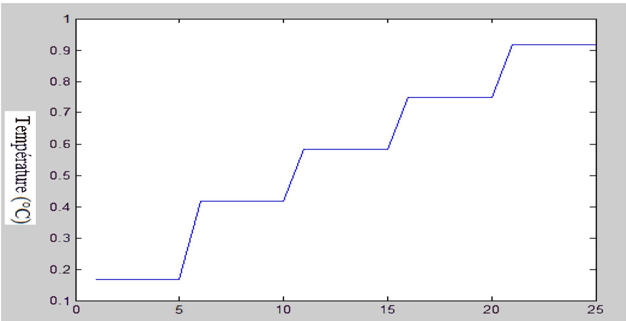


Fig. 13 Curve of temperature

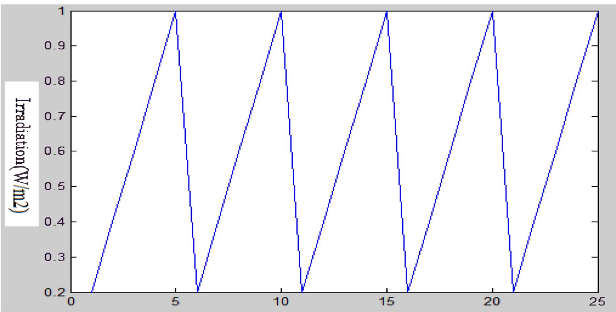


Fig. 14 Curve of irradiation

The ANN method is used to deliver the appropriate duty cycle signal used to drive boost converter to track the MPP even with variations of the input values (temperature, irradiation). The algorithm is described in the flowchart Fig. 15:

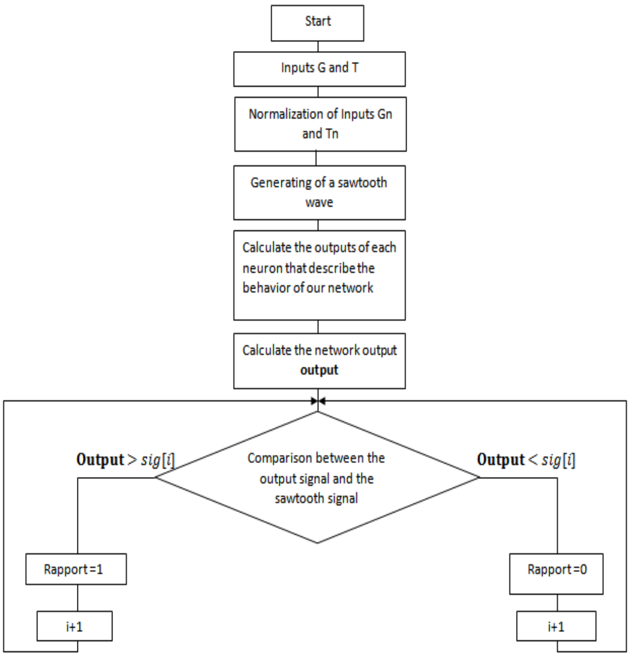


Fig. 15 Proposed ANN Based Algorithm

VI. SIMULATION AND RESULTS

The results are obtained in MATLAB Simulink environment. The proposed PV module was connected to boost dc-dc converter to form a unit of PV system. Simulation works were carried out with conventional PO algorithm, IC algorithm and further with a neural network MPPT control algorithms respectively for evaluation and comparison analysis. The output of dc-dc converter was 24V, The inductor value was 82.5 mH, the input capacitor was 150 µF, the output capacitor was 320 µF, and the load was 10 ohm.

The main importance factor to analyze performance of each MPPT algorithm is time response, oscillation, overshoot and stability. In Fig. 17 the output current curve by using the BP NN method has more excellent output characteristic and smaller oscillation than the PO and IC methods. Fig. 18 shows effect of each MPPT algorithm towards the maximum power point, the conventional PO and IC did not work well, they contribute to the slowest time response, high oscillation and not that stable as compared with the BP NN.

Despite effect towards maximum power point, the algorithms should also affect the boost dc-dc converter. From Fig. 19, the PO and IC produce high overshoot and oscillation as compared with BP NN method.

All simulations are done with a variation of irradiations shows in Fig. 16.

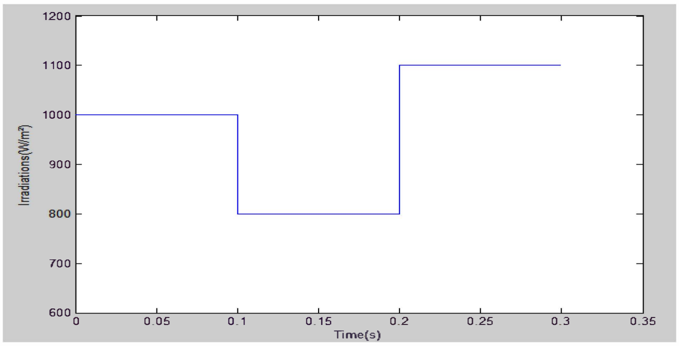


Fig. 16 The irradiations variation versus time

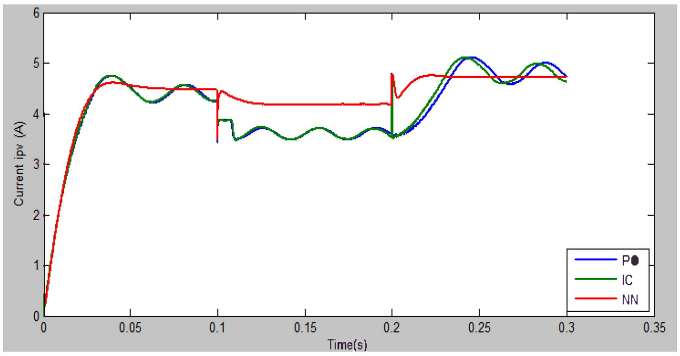


Fig. 17 Output current with various algorithms MPPT

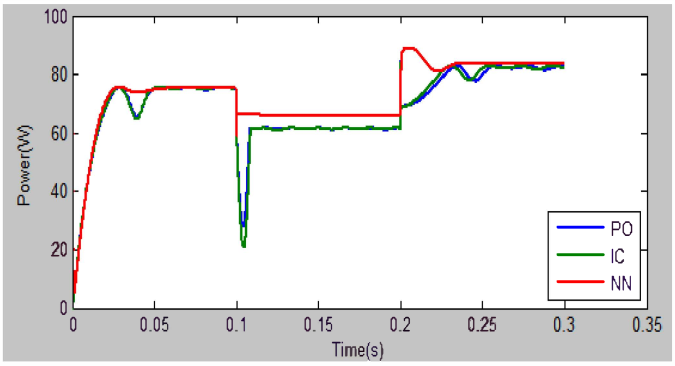


Fig. 18 Output power with various algorithms MPPT

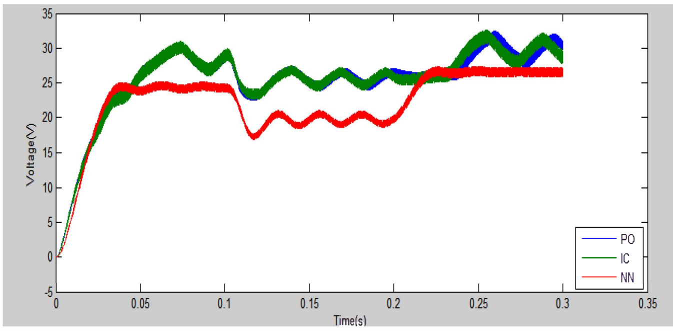


Fig. 19 Boost voltage effect with various algorithms MPPT

Sequentially all these figures coincide with theoretical prediction and company specified value which ensures the validity of the system.

VII. CONCLUSION

The PV has some characteristics such as nonlinear, easily affected by environmental conditions, and all these make the MPPT control of the PV array a complex and comprehensive problem. In this paper, a proposed neural network algorithm for MPPT control in boost dc-dc converter is presented. Comparison analysis clearly shows its better performance with fast time response, no overshoot, low oscillation, and more stable as compared to both conventional PO and IC algorithms. Meanwhile, it also worked well to produce the boost dc-dc converter's voltage. The simulation result shows that the proposed method gives very satisfactory results with a good efficiency.

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