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An Analysis of Artificial Intelligence (ANN) Based Maximum Power Point Tracking for a Photovoltaic System

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ABSTRACT

There are number of maximum power point tracking techniques for photovoltaic systems. These techniques have been developed to maximize the generated energy. In this paper artificial intelligence based artificial neural network method for maximum power point tracking of photovoltaic system is discussed under varying irradiation and temperature conditions. The ANN BASED MPPT is simulated using Simulink. It is found that ANN based MPPT technique is better and more reliable.

KEYWORDS

Artificial Neural Network (ANN), Maximum power point tracking (MPPT), Photovoltaic (PV) , DC-DC converter

1. INTRODUCTION

Because of the fossil fuel exhaustion and the environmental problems caused by the conventional sources, renewable energy sources have been used for electricity generation. There are number of renewable energy sources like wind, solar, geothermal and biomass which can be used for electricity generation. Photovoltaic generation is widely used among them as it offers many advantages like it is clean, inexhaustible and free to harvest, require little maintenance and emits no noise. . However, PV system have two drawbacks which are high installation cost and the low conversion efficiency.

PV module is series or parallel connection of solar cells because single cell produces very less amount of power. DC-DC converter is used to change the level of voltage, they are of various types like- Buck, Buck-Boost, Boost, Cuk, Buck. For MPPT controller, Artificial Neural Network control has been employed. Maximum Power Point Tracking control strategies have been developed to modulate the operating point of the system to maximize the power, through a DC-DC converter which is generally connected between the PV array and the load as shown in Fig. 1.

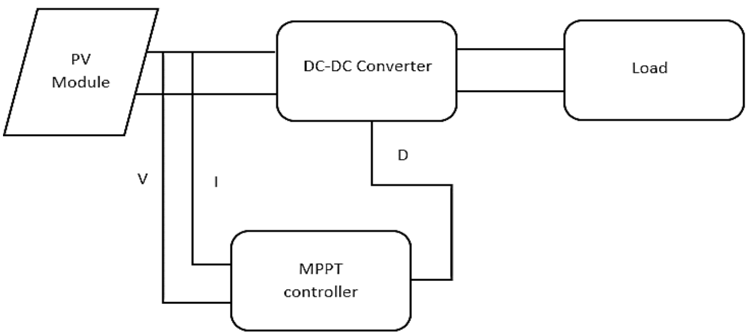


Fig. 1 PV with MPPT Configuration

The I-V characteristic of PV panel is nonlinear and changes with irradiation and temperature. There is a point on the I-V or P-V curves, called the Maximum power point (MPP), at which PV operates with maximum efficiency and generates maximum power. There are many MPPT techniques which are different in their efficiency, speed, hardware implementation, cost, popularity. Most widely used conventional MPPT technique is P&O because it is easy to implement and simple as it is based on iterative algorithms but it has oscillations.

In this paper, a model of PV has been developed using Simulink with DC-DC boost converter with tracking technique based on ANN to improve efficiency of the PV system. The aim of this work is to extract the maximum power from the PV system in different atmospheric condition like changing irradiance and temperature and in case of load resistance variation, it means the MPPT technique should be robust in both atmospheric conditions and load variation. Figures 2 and 3 show the effect of changing the temperature and solar irradiance on PV's output current, voltage and power.

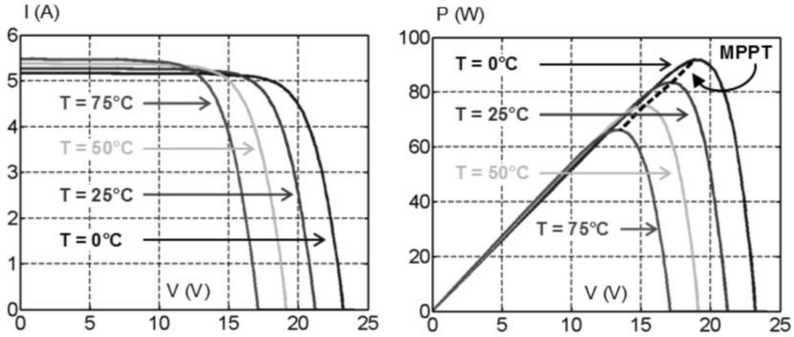


Fig. 2. I-V and P-V characteristics of a typical PV module for varied Temperatures.

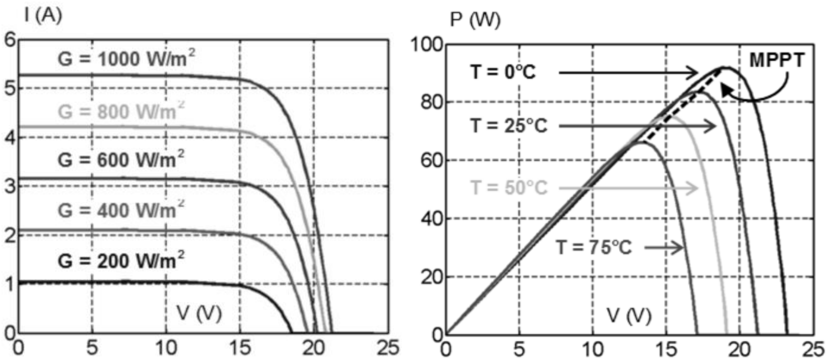


Fig. 3. I-V and P-V characteristics of a typical PV module for varied solar Irradiances.

In the MPPT based PV system, PV module contains PV cells in series and parallel to produce energy by photovoltaic phenomenon, when light falls on polycrystalline silicon cells they produce current which is responsible for production of energy.

The controlling purpose is fulfilled by using maximum power point tracking which is based on artificial intelligence method of artificial neural network. It works on the basis of memory just like human brain. The output of MPPT control is fed to the DC- DC converter in the form of duty cycle. In our work, we have used buck-boost converter. The DC-DC converter changes the duty cycle and hence keeps voltage at maximum.

The DC-DC converter output is connected to a voltage source inverter which converts DC power to AC power and it is supplied to grid system, and it feeds power to grid. The load maybe standalone also in case of small purposes.

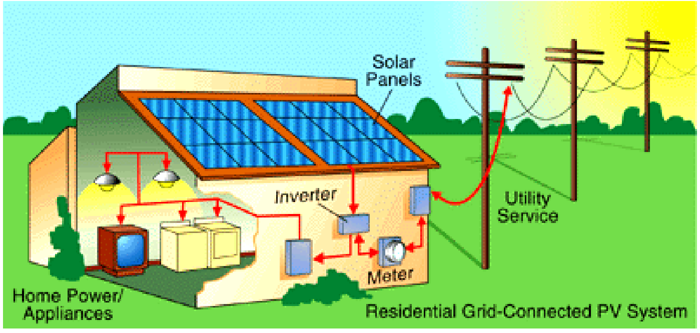


Fig. 4. Example of grid connected PV system.

1.1. DC- DC Converter

For operating the Photovoltaic module at its maximum power point, Maximum Power Point Tracker (MPPT), is employed. DC–DC converters are used to convert a DC voltage from one level from input to another DC level at the output terminal. It is composed of switching devices, inductors and capacitors. Various switches like an IGBT or MOSFET are used. A PWM signal operates at the gate of switches and switches it on and off. In MPPT systems, this signal is controlled by MPPT controller. DC-DC converter is connected between the PV generator and the load (battery), thus, acting on the converter duty cycle (D) it is possible to guarantee that PV module is operating at its MPP [13]. Fig. 5 shows the circuit of the buck- boost converter, whose output voltage (Vo) is less than or greater than to the input voltage Vs (PV generated voltage).

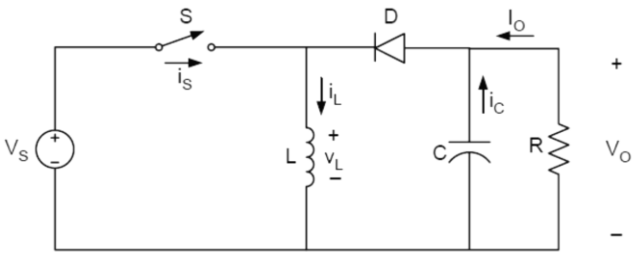


Fig. 5. The buck-boost DC-DC converter circuit.

2. PHOTOVOLTAIC SYSTEM

A PV system consists of a solar array which is a group of series-/parallel-connected modules, the solar cell rated power varies between 1 and 2 W depending on the material of solar cell and the surface area; thus, to design a solar module, the solar cell power is measured, and then, the modules are connected in series based on the desired output.

2.1. PV cell modelling

PV cell is a current source consists of an inverted diode, shunt resistance to minimize leakage current and series resistance shown in Fig. 6. Different analytical model of the PV system have been proposed in literature, and among them a single diode model representation have been taken into consideration.

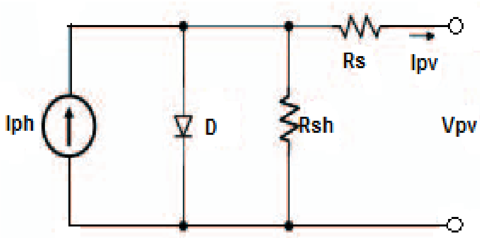


Fig. 6. Model of a PV cell

A single PV cell produces only a little amount of power hence several PV cells are connected in series and parallel to produce PV module to generate the required amount of power shown in Fig. 7.

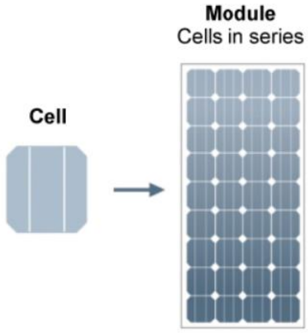


Fig. 7. PV module

The output current of a PV cell by applying KCL is shown in equations below-

$$I_{PV} = n_p\left(I_{ph} - I_o\left[e^{\frac{q(V_{PV}+R_S I_{PV})}{AkTn_S}} - 1\right] - \frac{(V_{PV}+R_S I_{PV})}{n_s R_{sh}}\right) \quad (1)$$

$$I_{ph} = I_{ph\_STC} + K_1(T - T_{STC})\frac{G}{G_{STC}} \quad (2)$$

$$I_o = \frac{I_{SC_{STC}} + K_1(T-T_{STC})}{e^{\left(V_{OC_{STC}} + \frac{K_V(T-T_{STC})}{V_{T-1}}\right)}} \quad (3)$$

where,
Iph= Solar-induced current
Rs = Series resistance of the module.
Is = Diode saturation current.
T= Cell temperature (K).
I_L= Cell photo-current (A).
q=$1.6*10^{-19}$(Coulomb).
k=$1.38*10^{-23}$(J/K).

2.2. Maximum Power Point Tracking using Neural Network

In general, an artificial neuron is a processing element with n inputs x_1, x_2… x_n (which are the external inputs or the outputs of the other neurons) and only one output. Its processing consists in assigning to its output yi the result of an activation function.

$$y_i = f(a_i) = f\left(\left[\sum_{j=1}^{n} w_{ij}.x_j\right]\right) + b_i \quad (4)$$

Where ai: is the neuron activation state, f: is the neuron activation function, bi: bias (representing the interne threshold of the neuron). The parameters w_{ij} connecting the inputs to the neurons are called synaptic weights or simply weights.

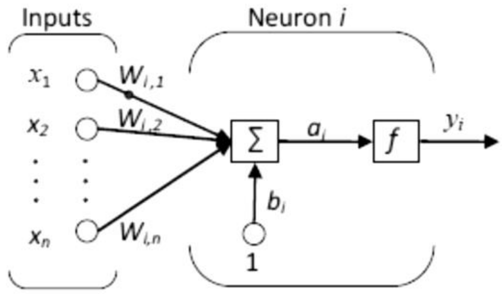
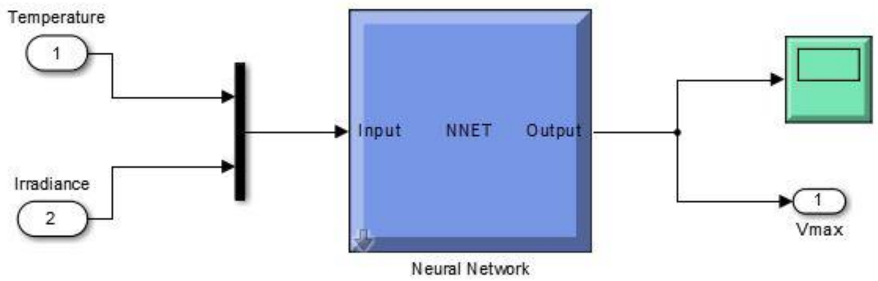


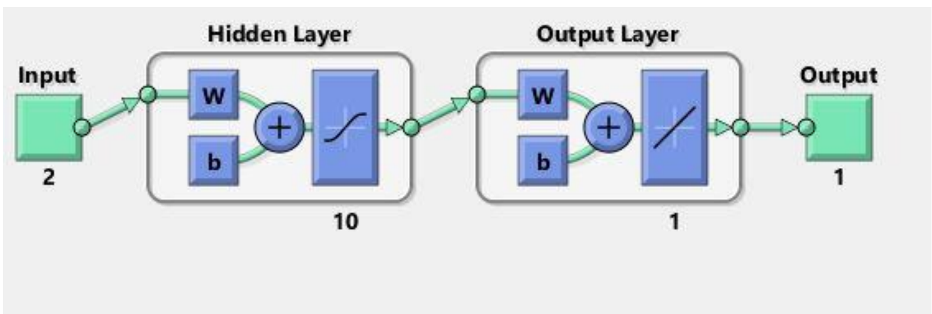
Fig. 8. Artificial Neuron representation

An artificial neural network (ANN) is a set of information processing elements (elementary neurons), with a specific topology of interconnections between these elements and a training law to adapt the connection weights. A very important number of models and network architectures exist.

2.3. Network Training

The back-propagation is the supervised training method more used to adjust the weights and bias of a MLP network (so as to satisfy an optimization criterion). In this method, the error between the two outputs (desired output and network output) is calculated. It is used to update the weights w_k,i (and bias b_k) of the output layer . Then by error back-propagation, the intermediate errors, corresponding to the hidden layer are thus calculated and allow the adjustment of the weights w_{ij} (and bias b_i) of hidden layer. In our case, to train the neural network, a set of *3-D* figures is proposed to cover the most probable situations at various irradiances, various temperatures with corresponding MPP current (I_{mpp}), voltage (*Vmpp*) and power (*Pmax*). It can be seen from this figure that the correlation between the optimum voltage (current, power) and irradiance/temperature is nonlinear. In this respect, estimation of the MPP using ANN can give a good promising solution. Offline training was carried out using Matlab software with Levenberg-Marquardt (L-M) back-propagation algorithm. Although the L-M needs an important memory space in training stage, this algorithm is preferred because it shows a faster convergence and a better accuracy than other algorithms. The neural network designed from training is shown in fig 9 and the training result of our ANN is shown in Fig.10.





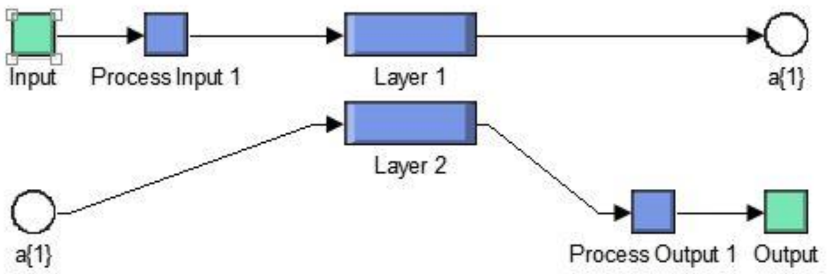


Fig. 9 ANN blocks for MPP prediction

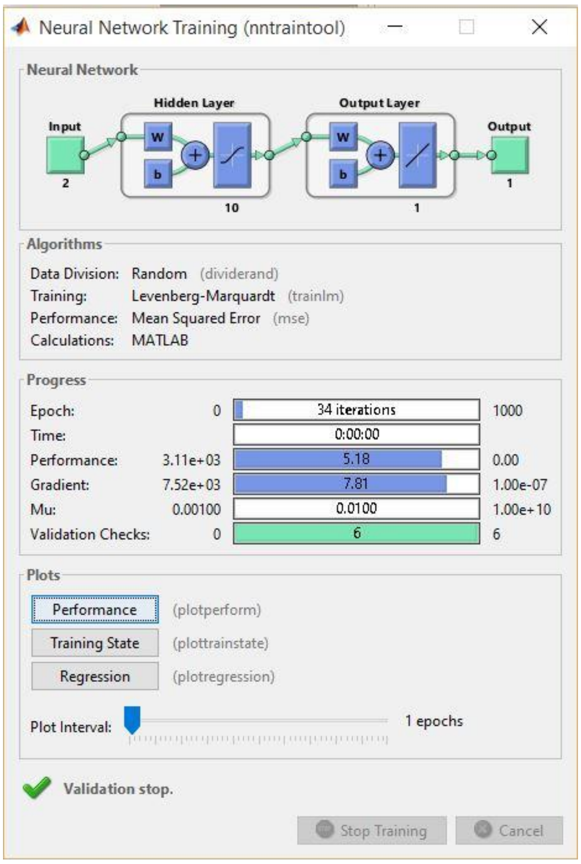


Fig. 10. Training result of ANN block for MPP prediction

The MATLAB Simulink model of grid connected MPPT system shown in Fig. 11 simulated under wide range of slow and fast changing solar irradiation level consists of PV module array, MPPT controller, Buck-Boost converter, three phase voltage source inverter (VSI), three phase transformer and utility grid.

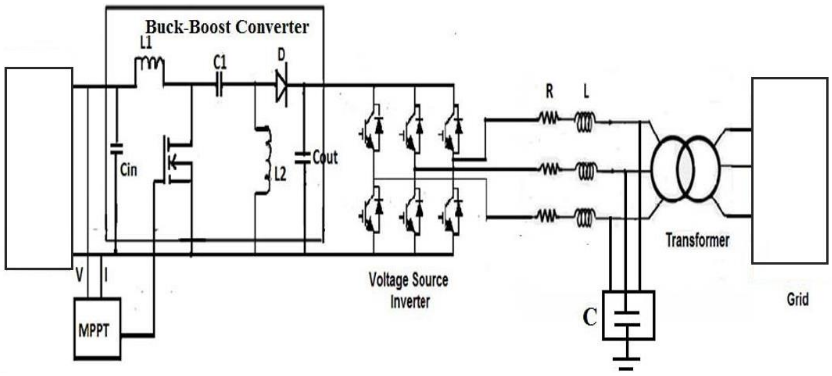


Fig 11- Simulink model for ANN based MPPT

The parameters of the KYOCERA KC200GT PV module and system parameters are shown in Table I and II-

TABLE I. KYOCERA KC200GT MODULE PARAMETERS AT NOMINAL OPERATION CONDITIONS (25OC- 1000W/m^2)

Quantity	**Value**
Imax Power	7.61 A
Vmax Power	26.3 V
Pmax	200.143 W
I short Circuit	8.21 A
V open circuit	32.9 V
I leakage	9.825×10^{-8}
Iphotovoltaic	8.211 A
Diode ideality constant(a)	1.3
Parallel resistance	415.406 Ω
Series resistance	0.221 Ω

TABLE II. PV MODULE AND SYSTEM PARAMETERS

Quantity	**Value**
Grid voltage	440 V
Frequency	60 Hz
Switching Frequency	1 KHz
DC link capacitor C	1 mF
DC link voltage	400 V
Converter inductance	0.0385 H
Converter capacitance	0.04 F
Sampling period	1 µS

2.4. Simulation Results

The complete integrated system is shown in Figure 11 where the PV array, the boost converter and the inverter are connected together along with the grid and the controllers. Table II shows all the parameters used in the simulation and Table I shows the KYOCERA photovoltaic module data supplied by the manufacturer that is used in the simulation as a form of an array of 15 series and 2 parallel modules with a total power of 6000W at 25ºC and 1000W/m2.

Figure 12 shows that when the temperature and the irradiance are 25ºC and 1000W/m2 respectively, the output power of the array is 6000W and the array terminal voltage is 395V.

The Figure 12 also shows that when the temperature and irradiance change to 33ºC and 1175 W/m2 respectively (at 1.5 seconds), if the proposed MPPT control is applied the output power is 6775W and the terminal voltage is 375V, But without the MPPT the power drops to 6670W because there is no control on the duty cycle, thus the boost converter will keep the terminal voltage of the array at 395V.

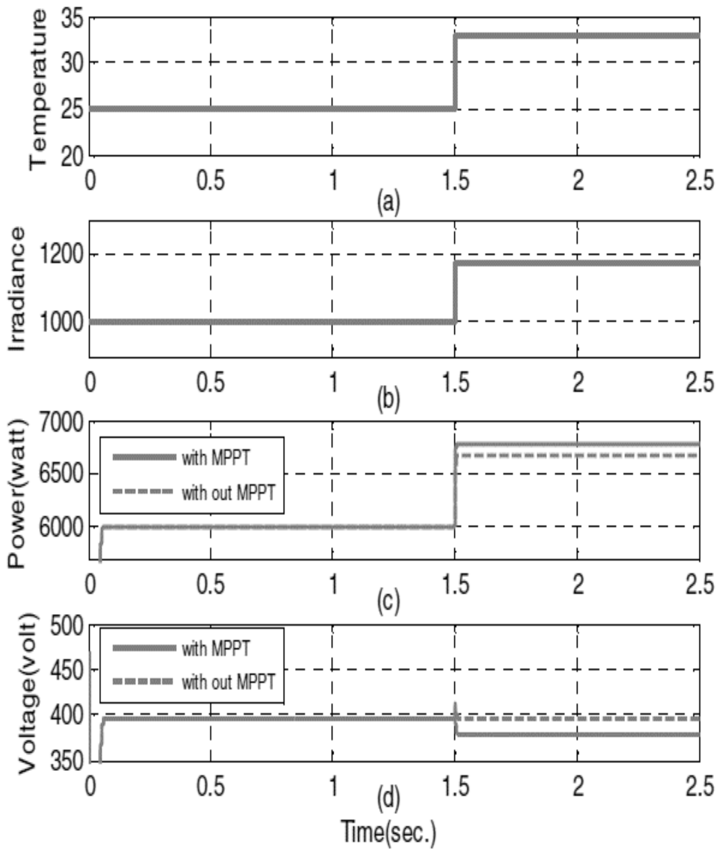


Fig 12- (a) Temperature, (b) Irradiance, (c) Output power of the array, (d) Terminal voltage of the array.

3. CONCLUSIONS AND FUTURE WORK

PV ANN based MPPT technique has been proposed in this paper. The presented technique utilizes two cascaded ANNs to minimize the number of the training sets. Based on actual data sheet based PV array model, the training sets are generated. The proposed technique enhanced performance, especially during rapidly changing environmental conditions.

In future works, experimental results of the proposed artificial neural network MPPT could highlight which hardware means are more suitable by consideration based on economical investment. It means, the trade-off among implementation costs and energy losses during generation can be found and calculated.

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