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Intelligent Controller for Maximum Power Point Tracking Control of Solar Power Generation System

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Abstract –

This paper presents the improved model of solar photovoltaic module and back propagation neural network based maximum power point tracking (MPPT) for boost converter in a standalone photovoltaic system under variable temperature and insolation in static and dynamic conditions.Solar panel is a power source having nonlinear internal resistance. As the intensity of light falling on the panel varies, its voltage as well as its internal resistance both varies. To extract maximum power from the panel, the load resistance should be equal to the internal resistance of the panel. Maximum power point trackers are used to operate a photovoltaic panel at its maximum power point in order to increase the system efficiency. This is done, with the aid of MATLAB-7.6 environment and Artificial Neural Network (ANN).

Keywords : Solar Photovoltaic system (SPV), ANN, SNN, DNN,MPPT, Boost converter, MATLAB.

I. Introduction

Renewable energy sources play an important role in electric power generation. Various renewable sources such as solar energy, wind energy, geothermal etc. are harness for electric power generation. Solar Energy is a good choice for electric power generation. The Earth receives 174 petawatts (PW) of incoming solar radiation (insolation) at the upper atmosphere. Approximately 30% is reflected back to space while the rest is absorbed by clouds, oceans and land masses. The solar energy is directly converted into electrical energy by solar photovoltaic module. The output power of a PV panel array depends on the PV voltage and unpredictable weather conditions. In order to optimize the ratio between output power and installation cost, DC/DC converters are used to draw maximum power from the PV panel array. Many approaches have been proposed to adjust the duty cycle of the converter for maximum power point. Most of MPPT methodsincludingperturb and observe, incremental conductance, parasiticcapacitance, constant voltage and fuzzy logic algorithms [1]-[4].These methods have disadvantages like costly, difficult toimplement and non-stable. For this purpose ANN comes with asolution. ANN is suitable to handle non-linearity, uncertaintiesand parameter variations in a controlled environment in conventional techniques. Hencemany number of ANN algorithms have been developed for thispurpose [5]-[9].

The purpose of this paper is to develop ANN based MPPT scheme for solar photovoltaic system with varying static and dynamic conditions. Thecomplete system is simulated using MATLAB-7.6 environment.

II. Solar PV Array Modeling

Solar Photovoltaic system cell can be modeled as an ideal current source in parallel with an ideal diode. Fig.1 represents the simplified circuit model of a PV cell. The output of the currentsource is directly proportional to the light falling on the cell (photocurrent I_{ph}). Duringdarkness, the solar cell is not an active device; it works as a diode, i.e. a p-n junction. Itproduces neither a current nor a voltage. However, if it is connected to an external supply (large voltage) it generates a current I_D, called diode (D) current or dark current. The diodedetermines the I-V characteristics of the cell.

Modeling of Photovoltaic Array

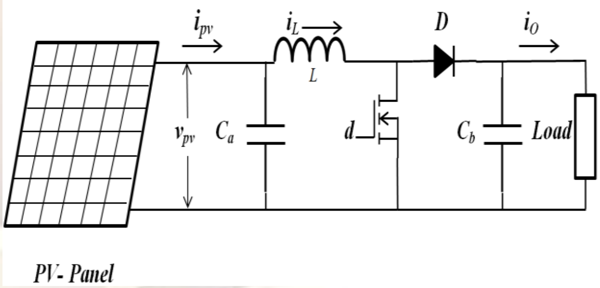

Fig. 1 Solar power generation system with dc/dc boost converter.

Consider a PV panel array composed of solar cells arranged in an np-parallel, ns-series configuration. Let v_{pv} and i_{pv}, respectively, denote the output voltage and current of the PV array. The voltage/current characteristic equation of the PV array can be described by a light-generated current source and a diode.If the internal shunt and series resistances are neglected, the output current of the PV array is given by,

$$i_{pv} = n_p I_{ph} - n_p I_{rs}(e^{\frac{k_{pv} v_{pv}}{n_s}} - 1) \text{------ (1)}$$

Where, k_{pv} = q/ (pKT) with the electronic chargeq = 1.6 × 10−19 C, Boltzmann's constant K = 1.3805 × 10−23 J/K, cell temperature T, and the ideal p-n junction characteristic factor p = 1–5, I_{ph} is the light-generated current, and I_{rs} denotes the reverse saturation current. Besides, the reverse saturation current and the light-generated current depend on insolation and temperature with the following expressions,

$$I_{rs} = I_{rr}\left(\frac{T}{T_r}\right)e^{qE_{gp}\left(\frac{1}{T_r}-1/T\right)/pK} \text{--- (2)}$$

$$I_{ph} = (I_{sc} + K_I(T - T_r))\frac{\lambda}{100} \text{--- (3)}$$

Where I_{rr} is the reverse saturation current at the reference temperature T_r, E_{gp} = 1.1eV is the band gap energy of the semiconductor making up the cell, I_{sc} is the short-circuit cell current at reference temperature and insolation, K_I (in mill amperes per Kelvin) is the short-circuit current temperature coefficient, and λ is the insolation (in mill watts per square centimeter). The expression of the array power is obtained as follows,

$$P_{PV} = i_{pv}v_{pv} = n_p I_{ph} v_{pv} - n_p I_{rs} v_{pv}(e^{k_{pv}v_{pv}/n_s} - 1) \text{--- (4)}$$

According to this equation, Fig. 2 depicts the characteristics of the array power with respect to the PV voltage, the insolation, and cell temperature. It can be observed that the maximum power point is maximized by the PV voltage and is dependent on various insolation and temperature.

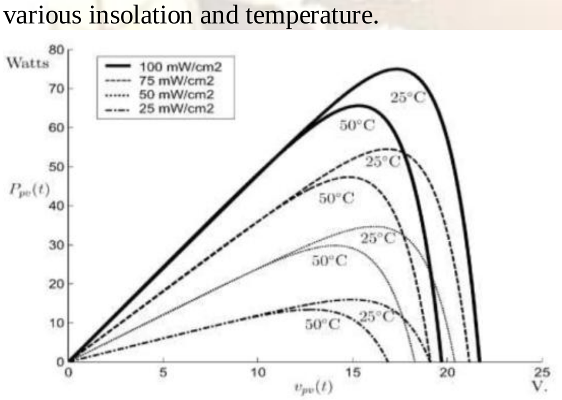

Fig. 2 Characteristics of the array power with respect to the PV voltage.

According to the array power in equation (4) and by taking the partial derivative of P_{pv} with respect to the PV voltage V_{pv}, we obtain,

$$\frac{dP_{PV}}{dv_{PV}} = i_{pv} + v_{pv}\frac{di_{pv}}{dv_{pv}} \text{--- (5)}$$

$$\frac{dP_{PV}}{dv_{PV}} = i_{pv} - \frac{n_p k_{pv}}{n_s} I_{rs} v_{pv} e^{k_{pv}v_{pv}/n_s} \text{--- (6)}$$

PV Module

A single PV cell produces an output voltage of less than 1 volt, it is necessary to string together a number of PV cells in series to achieve a desired output voltage. Solar panel is a power source having nonlinear internal resistance. As the intensity of light falling on the panel varies, its voltage as well as its internal resistance both varies. To exact maximum power from the panel the load resistance should be equal to the internal resistance of the panel. The solar panel module, which contain 36 cells in series, 1 sets are in parallel is selected for the purpose of this project. Each cell open circuit voltage is 0.585V. The data sheet for the proposed model provides the following information on the module.

Table 1 SP75 data sheet

Electrical Characteristics	Numerical value
Maximum power (Pmax)	75W
Voltage at Pmax (Vmp)	17V
Current at Pmax (lmp)	4.4A
Warranted minimumPmax	45W
Short-circuit current (Isc)	4.8A
Open-circuit voltage (Voc)	21.7
Temperature coefficient of Isc	2.06mA /°C
Temperature coefficient of Voc	-(0.077)mV/°C
Temperature coefficient of power	-(0.5±0.05)%/°C

Simulated Characteristics of SP75 Module

The following are the voltage versus current (V-I) and power versus voltage (P-V), characteristics simulated using the data of proposed module.

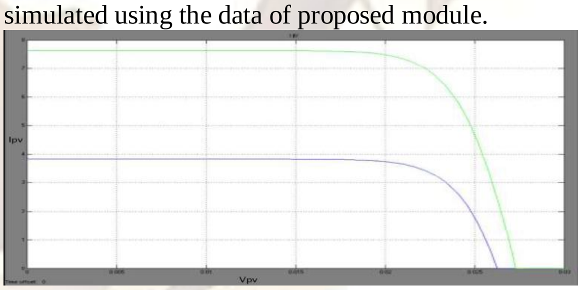

Fig. 3 I –V curves for various ir-radiation levels (G= 0.5, 1.0 Suns, T=320C, n=1)

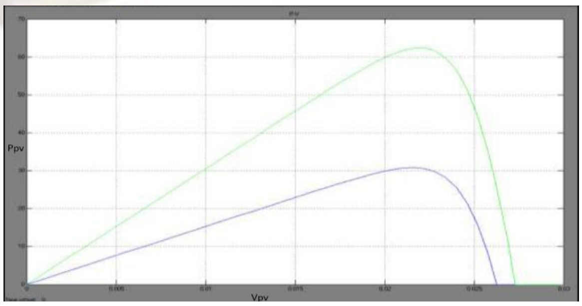

Fig. 4 P-V curves for various i_r-radiation levels (G= 0.5, 1.0 Suns, T=320C, n=1)

Figure 3 and Figure 4 represents the I-V and P-V characteristics of a PV module, with change in solar irradiation (G). As the solar irradiation is increased, the powerdelivered by the PV is increased substantially.

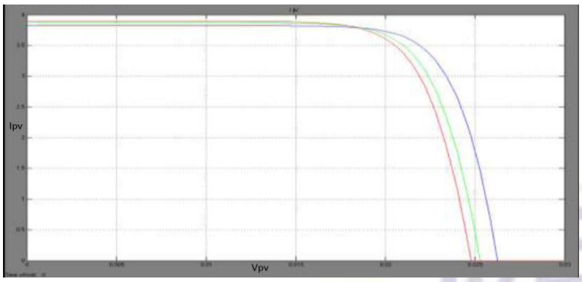

Fig. 5 I-V curves for various temperatures (T= 30, 40, 45 C, G = 0.5Suns, n=1)

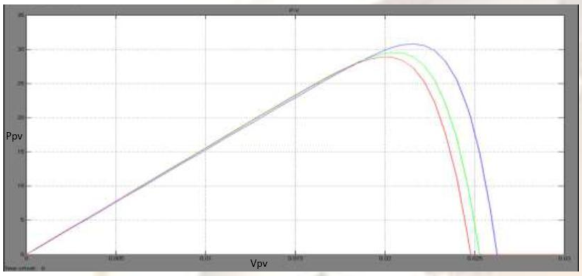

Fig. 6 P-V curves for various temperatures (T= 30, 40, 45 C, G = 0.5Suns, n=1)

Fig. 5 and Fig. 6 represent the I-V and P-V characteristics of a PV module, withchange in temperature (T). As the temperature is increased, the power delivered by the PV isreduced substantially.

Maximum Power Point Tracking

The objective of MPPT is to extract maximum power from the solar panels. TheI-V and P-V characteristics of the solar panels are affected by atmospheric changes such aschange in solarirradiance (G), temperature (T) and diode ideality factor (n). Hence theMPPT should track the maximum power from the solar panel subject to these changes.

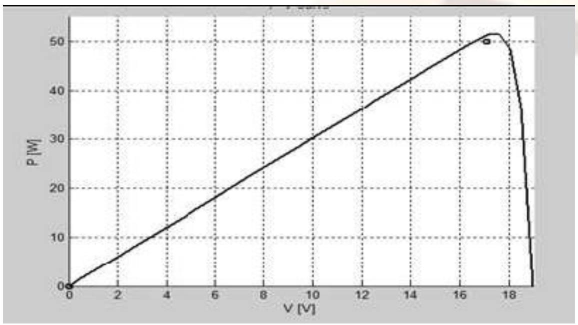

Fig. 7 PV array characteristics with MPPT

DC/DC Boost Converter

A step-up converter is used in this research to connect a PV panel with a load in order to adjust the operating voltage and current of the PV panel at optimal values.The boost converter contains an MOSFET and a diode which are represented as a dual ideal switch U in order to simplify the circuit analysis. If U is a state of 0, the diode is ON and the MOSFET is OFF and vice versa if U is a state of 1. The boost converter contains also passive componentsan inductor L, an capacitor C and a resistance R. The operation principle of the boost converter can be demonstrated for each switching period under the continuous conduction mode (CCM) into two modes, the first mode is an ON mode in the duration the period $0 \le t \le ton$ and its state equations can be represented as follows.

$$L\frac{dI_L}{dt} = V_s - uV_O$$

$$C_b\frac{dV_O}{dt} = uI_L - \frac{V_O}{R_L} \qquad \text{--- (7)}$$

$$L\frac{dI_L}{dt} = V_s - V_O$$

$$C_b\frac{dV_O}{dt} = I_L - \frac{V_O}{R_L} \qquad \text{--- (8)}$$

where t_{on} is the ON mode time and $i_L$the continues inductor current. The second mode is an OFF mode in the duration $ton \le t \le Ts$ and its state equations can be represented as the following:

$$L\frac{dI_L}{dt} = V_s$$

$$C_b\frac{dV_O}{dt} = -\frac{V_O}{R_L} \qquad \text{--- (9)}$$

whereTs is the switching period.

The design of a boost converter for a PV system is a complex task which involves many factors. In general, the input and output voltages of the boost converter are varied with the solar irradiances and load variations. The output voltage is also varied which follows the reference voltage generated from an MPPT controller. Thus the selection of boost converter components (the input inductor and the output capacitor) is a compromise between dynamic responses and the MPPT algorithm trigger time. The maximum value of the state variables should be calculated to estimate the value of the boost converter.

Feed Forward BackPropagation Neural Network

Artificial neural networks (ANNs) have been proven to be universal approximatorsof non-linear dynamic systems. They emulate nonlinear systems using a multilevel neuralnetwork Neural network has the potential to provide an improved method of deriving nonlinearmodels which is complementary to conventional techniques. This work deals with theapplication of an artificial neural networks based MPPT of PV systems.Back propagation neural network are utilized as pattern classifier. Back propagationneural network is an example of non-linear layered feed-forward networks. Backpropagation constructs global approximations to non-linear input-output mapping. There arecapable of generalizations in regions of the input space where little or no training data areavailable.In the proposed work, we develop an MPPT method for stand-alone solar powergeneration systems via the neural network approach. Here, the output power of the PV arrayis adjusted by a DC/DC boost converter. Then the system is represented in the neuralnetwork model, where the partial derivative of the PV power with respect to the PV voltage is taken as the control output. With this neural network is been trained for the desiredresponse.

Static neural network (SNN)

A Static Neural Network (SNN) is a neural network in which desired output is obtained from desired input. A SNN is the one in which the output produced will be same for the particular range of inputs.

Dynamic neural network (DNN)

A Dynamic Neural Network (DNN) is a neural network that can alter its owntopology to accept perpetual novelty.Perpetual novelty is data that is always changing. A DNN never finishes learning. ADNN always accepts the data shown to it. To achieve this, the DNN needs to not onlychange its knowledge, but the topology that stores it. A purely dynamic neuralnetwork never stops learning or changing its topology.The field of DNNs is in its infancy. Most DNN examples are only partially dynamic,that is that they are dynamic during a particular phase of their use.

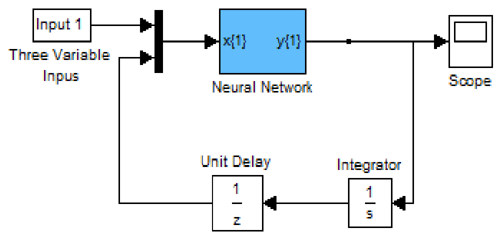

Fig. 8 Simulink for DNN

The three variable inputs are given insolation (sun), temperature and duty ratio (for controlling the MOSFET switch) and these values are trained using Feed Forward Back Propagation network by giving different delay as feedback till achieving maximum voltage.The response for the following input of [90, 319, and 0.55] in dynamic characteristics is as follows:

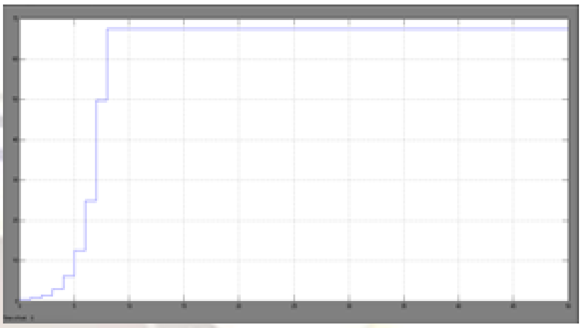

Fig. 9 Dynamic Characteristics

The Proposed MPPT model

The ANN is trained by a set of input and output datawhich are optimized using TRAINLM in neural network toolbox. In order to minimize the long-term system losses, it isrequired that converter input current has very small rippleand conversion efficiency is very high even at part load.Therefore the installation of a boost converter will be advised. In this paper a step-up converteris used as MPPT.

Conclusion

Interfacing an MPPT chopper between SPV and the load can maximize the power input to the load at all levels ofinsolation. This paper has presented the application of feed forward backpropagation neural networks for maximum power pointtracking of solar array. The back propagation neuralnetwork was modeled and simulated. The simulation resultshave shown that training of back propagation neuralnetworks gives closer maximum power point. As thedeveloped model takes care about the variations of all theparameters with respect to environmental conditions, it canbe used to predetermine the SPV characteristics. Theelectronic load is useful for observing panel characteristicsin the field conditions.

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