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Simulation model of ANN based maximum power point tracking controller for solar PV system

Anil K. Rai [a,*], N.D. Kaushika [b], Bhupal Singh [a], Niti Agarwal [b]

[a] Department of Electrical & Electronics Engineering, Ajay Kumar Garg Engineering College, Ghaziabad 201009, India
[b] School of Research & Development, Bharati Vidyapeeth College of Engineering, A-4 Paschim Vihar, New Delhi 110063, India

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ABSTRACT

In this paper the simulation model of an artificial neural network (ANN) based maximum power point tracking controller has been developed. The controller consists of an ANN tracker and the optimal control unit. The ANN tracker estimates the voltages and currents corresponding to a maximum power delivered by solar PV (photovoltaic) array for variable cell temperature and solar radiation. The cell temperature is considered as a function of ambient air temperature, wind speed and solar radiation. The tracker is trained employing a set of 124 patterns using the back propagation algorithm. The mean square error of tracker output and target values is set to be of the order of 10^{-5} and the successful convergent of learning process takes 1281 epochs. The accuracy of the ANN tracker has been validated by employing different test data sets. The control unit uses the estimates of the ANN tracker to adjust the duty cycle of the chopper to optimum value needed for maximum power transfer to the specified load.

1. Introduction

The efficient operation of solar PV system requires an optimum transfer of energy generated in the array to load offered by the combination of battery bank and load. This optimum load requirement varies with insolation and solar cell's operating temperature. The load offered by battery to PV array also varies with the state of the charge of the battery and its temperature. The condition for maximum energy transfer from PV array to the battery bank can be achieved by inserting an intermediate dc–dc converter [1–3]. The dc–dc converter (chopper) must continuously adjust the voltage and current level to match both the variable PV output and the load. The schematic diagram of such a system is shown in Fig. 1. The unit comprising a dc–dc converter and a controller is sometimes referred to as the maximum power point tracker (MPPT).

Different methods of peak power tracking schemes had been proposed in the past using different control strategies [4–7] some use conventional PID controllers [8] whereas others use rule based fuzzy logic tracking regulators [9]. Review of maximum power point tracking algorithms for stand-alone photovoltaic systems has been presented [10]. These techniques vary in complexity, sensors required, convergence speed, and cost, range of effectiveness and implementation hardware. Recently the artificial neural network (ANN) approach has generated new interest in electrical power control applications. In this paper we have applied a neural network approach, which is well suited for micro controller implementation. In this technique the input variables to converter are currents and voltages of the solar panel corresponding to a given solar radiation and operating cell temperature conditions. The measured solar radiation and estimated module temperature are fed to the ANN tracker; trained and tested offline to yield maximum power voltage (V_{max}), maximum power current (I_{max}) and required optimum load corresponding to maximum power transfer. The control unit is used to estimate and adjust the duty cycle of the chopper to optimum value needed for maximum power transfer to the specified load. Essential input data are the values of load resistance, ambient temperature, wind speed and solar radiation. The main purpose of this paper is to develop an ANN based maximum power point tracking controller that extracts maximum power from the solar panel via the chopper under variable radiation and weather conditions.

2. Model of solar PV array

The solar PV array is formed by an appropriate series-parallel combination of solar cells that provides the required rated output voltage and current under normal conditions. A solar cell is basically a p–n junction semiconductor that directly converts solar energy into electricity. The solar cell terminal current can be expressed as a function of photo-generated current, diode current and shunt current.

The photo-generated current (I_{ph}) depends on both irradiance and temperature. It is measured at some reference conditions such as reference temperature $T_{c,ref}$, reference radiation G_{ref} and reference

* Corresponding author.
E-mail addresses: anilkrai@yahoo.com (A.K. Rai), ndkaushika@yahoo.com (N.D. Kaushika).

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Nomenclature

A	Ampere
D	duty cycle of the converter
D_{opt}	optimum duty cycle
E	electron charge 1.602×10^{-19} C
E_g	energy band gap (eV)
G	actual solar radiation (W/m^2)
G_{ref}	reference radiation (W/m^2)
I_D	diode current (A)
I_{in}	converter input current (A)
I_{max}	maximum power current (A)
I_n	current estimated by ANN tracker corresponding to peak power point (A)
I_0	reverse saturation current (A)
I_{out}	converter output current (A)
I_{ph}	photo-generated current (A)
$I_{ph,ref}$	reference photocurrent (A)
I_{scc}	manufactured supplied temperature coefficient of the short circuit current (A/K)
I_{SH}	shunt current (A)
K	Boltzmann constant, 1.38×10^{-23} J/K
R_L	load resistance (Ω)
R_{Lin}	input resistance of the converter (Ω)
R_s	series resistance (Ω)
T_A	ambient air temperature (°C)
T_c	actual operating temperature of cell (K)
$T_{c,ref}$	reference temperature (°C)
V	voltage
V_{max}	maximum power voltage (volt)
V_c	voltage across diode (volt)
V_{in}	converter input voltage (volt)
V_n	voltage estimated by ANN tracker corresponding to peak power point (volt)
V_{out}	converter output voltage (volt)
η	diode ideality factor

photocurrent $I_{ph,ref}$ and related as follows [11]:

$$I_{ph}=\frac{G}{G_{ref}}(I_{ph,ref}+I_{scc}(T_c-T_{c,ref})) \quad (1)$$

where G is the actual solar radiation (W/m^2), T_c the actual operating temperature of cell (K), and I_{scc} the manufactured supplied temperature coefficient of the short circuit current (A/K).

The diode current is given by the Shockley equation

$$I_D=I_0\left[\exp\left(\frac{e(V_c)}{\eta KT_c}\right)-1\right] \quad (2)$$

where V_c is the voltage across diode (V), I_0 the reverse saturation current (A), η the diode ideality factor, R_s the series resistance (Ω), e the electron charge 1.602×10^{-19} C, and K the Boltzmann constant, 1.38×10^{-23} J/K.

The reverse saturation (I_0) current is given by [11]

$$I_0=I_{0,ref}\left(\frac{T_c}{T_{c,ref}}\right)^3\exp\left[\left(\frac{eE_g}{\eta K}\right)\left(\frac{1}{T_{c,ref}}-\frac{1}{T_c}\right)\right] \quad (3)$$

whereas the shunt current I_{SH} is given by

$$I_{SH}=\frac{V_c}{R_p} \quad (4)$$

where R_p is the shunt resistance (Ω).

Eq. (1) can be written as

$$I=I_{ph}-I_0\left\{\exp\left[\frac{e(V+IR_s)}{\eta KT_c}\right]-1\right\}-\frac{V+IR_s}{R_p} \quad (5)$$

The actual cell temperature (T_c) has been found to be dependent on ambient air temperature, radiation and wind speed, which has been modeled by the following relationship [11]:

$$T_c\ (^\circ\mathrm{C})=0.943\,T_A+0.028\ (\text{irradiance})-1.528\ (\text{wind speed})+4.3 \quad (6)$$

where T_A is the ambient air temperature given in °C, irradiance in W/m^2 and wind speed in m/s.

Employing Eqs. (1)–(6), a non-linear equation involving photo-generated current (I_{ph}), diode reverse saturation current (I_0), shunt resistance (R_p) and load resistance (R_L) is obtained, which has been solved for V_c to supply an initial assumed value of V_c=0.

The above solar PV array model has been implemented in MATLAB and the model's accuracy is also analyzed through a comparison between experimental data and corresponding simulated data as shown in Fig. 2. In this figure the solar irradiance level and ambient air temperature are 1000 W/m^2 and 25 °C, respectively. It is found that the relative errors between experimental and corresponding simulated values on peak power, peak-power voltage and peak-power current are 3%, 4.98% and 1.5%, respectively, which is of the right order of magnitude and is in accordance with that reported by earlier author [12]. The incident solar radiation has larger effect on short circuit current, while the effect on open circuit voltage is rather weak. The solar PV array will generate more power when the irradiance is higher. With an increasing temperature the array voltage drops at high voltages. Operating the cell in this region leads to a power reduction at high temperature.

3. Model and training of ANN tracker

An ANN model of maximum power point as shown in Fig. 3 is implemented with SIMULINK. It has a three-layer feed forward

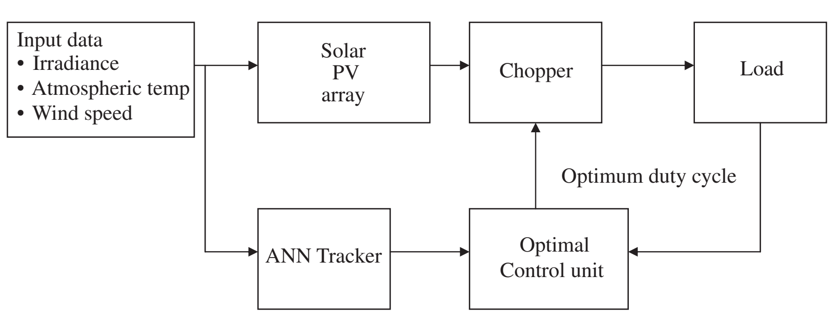

Fig. 1. Schematic diagram of ANN controlled SPV system.