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Research paper

MPPT Design for Photo Voltaic Energy System Using Backstepping Control with a Neural Compensator

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Abstract

It is very important to have maximum power point trackers for photo voltaic systems to improve their efficiency. This paper deals with the converter based maximum power point tracking by robust backstepping controller along with the neural network. The neural network provides the output reference PV voltage to the backstepping controller. Back propagation neural network is used for a standalone photovoltaic system under robust environmental conditions. Unlike Conventional solar-array mathematical model, neural network does not require any physical data for modeling since it has the superior potential to derive non-linear models without requiring the physical data of the models. In this paper the maximum power point of photovoltaic module is predicted with the simulation trained back-propagation neural network using a random set of data collected from a real photovoltaic array. The neural network based PV system with backstepping controller is modeled in MATLAB/Simulink. At different atmospheric conditions the developed model is simulated. The simulation results of PV system depict that with the proposed converter based controller, the maximum power is tracked accurately and successfully.

Keywords: *Photovoltaic(PV) array, Back propagation neural network, Maximum power point tracker, Artificial neural networks(ANN), MATLAB, DC to DC converter, Backstepping Control.*

1. Introduction

The electrical energy demand is increasing steadily due to the industrial revolution across the globe. The Increasing prices and depletion in the abundance of fossil fuels motivates towards the usage of renewable energy sources. Among all the energy sources solar energy sources draws attraction because of their abundance in mass, absence of fuel cost and energy production without environmental pollution. PV power-generation system is the promising technology in the present situation. However, the heavy installation cost and less efficiency of the PV systems limiting the implementation PV systems. In order to overcome these limitations, it is necessary to design maximum power point trackers (MPPT) while implementing PV systems. Since the atmospheric conditions temperature and irradiation decides the power generation from the photovoltaic module, these factors also dictates the design of maximum power point tracker. The main aim of any MPPT tracker is to bring the operating voltage of the module to the voltage where the PV module delivers maximum power [1].

So many approaches are addressed in the literature to design the MPP. In general an ideal MPP tracker requirements are simple and low cost, small output fluctuation and fast maximum power tracking under robust conditions [2-3]. As neural network technology has the superior potential to derive non-linear models without requiring the physical data of the models, among all the addressed approaches neural network technology draws wide attention [4]. In the design of efficient PV generation systems converter role also very crucial. Here boost converter is selected among dc-dc converter due to its simultaneous step up capability along with available utilization in standalone and grid connected PV system [5]. This paper presents the boost converter based maximum power point tracking by robust backstepping controller along with the neural network. The neural network provides the output reference PV voltage to the backstepping controller. In this case, the control starts in a power point which is close to the optimal PV module output voltage and hence the control is initially faster. MATLAB R-2014/Simulink environment is used for the simulation of the proposed system and simulation results are presented at different atmospheric conditions.

2. Proposed system

The proposed system consists of a PV module from which maximum power is to be extracted is connected to DC to DC (boost) converter and is shown in figure 5. In this case, backstepping control technique is employed to control the duty cycle of the boost converter to track the maximum power point using ANN. This ANN model makes the control action faster initially itself by providing the optimal PV reference voltages for a wide range of atmospheric temperature and solar irradiation.

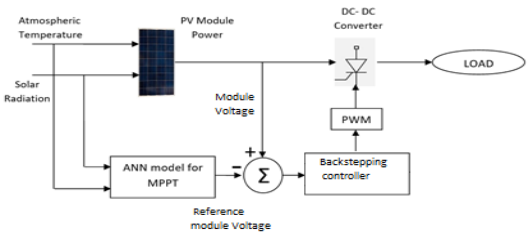


Fig.1: Proposed PV System

2.1 Mathematical Modelling of PV Module

Initially solar cell is to be modelled to start modelling of any PV system since solar cell is the basic building block of any PV module. Figure 2 shows the simplest electrical equivalent circuit of solar cell. It consists of one series, one shunt resistances accounts the metal contact losses in the solar cell in current path and small intrinsic leakage current losses in the cell. The mathematical equation of output current (I) derived from standard theory as,

$$I = I_L - I_0\left(e^{\frac{q(V+IR_s)}{nkT}} - 1\right) \ldots\ldots(1)$$

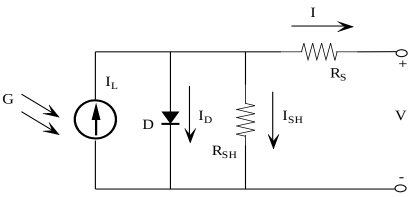


Fig.2: Simplest solar cell equivalent circuit

Where I_L and I_0 represent the photo current and diode saturation currents of the solar cell, R_s and R_{sh} represent the series and shunt resistances of the solar cell respectively.

Above mathematical modelling along with the electrical parameters listed in the Table 1 are used to simulate the PV module in MATLAB Simulink platform shown in figure 3. And the simulated characteristics of the PV module are shown in figure 4 at different irradiation levels.

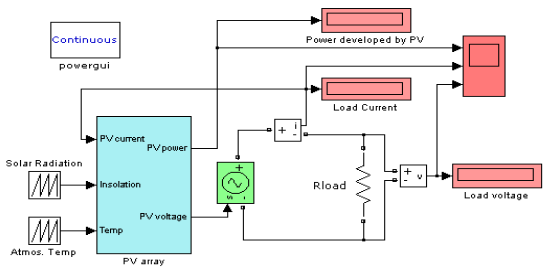


Fig.3: GUI block of the Complete Photo Voltaic module in MATLAB characteristics of PV module

Table 1

Electrical Parameters of PV module at STC (1KW/sq.m and 25 °C)	
Voc, Voltage across the module when circuit is opened	21.06V
Isc, Current through the module when circuit is short circuited	4.90A
Pm, Maximum power delivered by module	75W
Vm, Voltage across the module at Pm	17.1V
Im, current through the module at Pm	3.5A
Number of cells in series	36

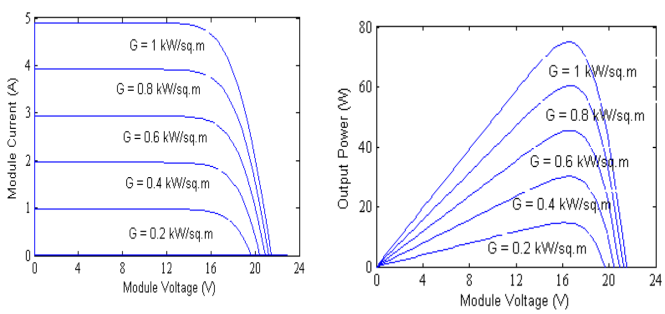


Fig.4: MATLAB model Voltage - Current and Power-Voltage

From the above characteristics, it can be observed that either the operating current or voltage needs to be carefully controlled in order to achieve the MPPT of PV module under robust environmental conditions.

2.2 ANN model

Back propagation neural network is trained in order to train proposed ANN model for the PV MPPT scheme. Figure 5 illustrates the structure neural network trained. It involves two inputs and three outputs along with 2 hidden layers having 10 neurons each. To identify voltage, current values at maximum power point under different temperature and radiation conditions, the network is trained. The 1172 data points are accumulated from the PV model which is simulated in the above section for training the network. The following table shows the error of predicted current, voltage and power of MPPT using back propagation neural network.

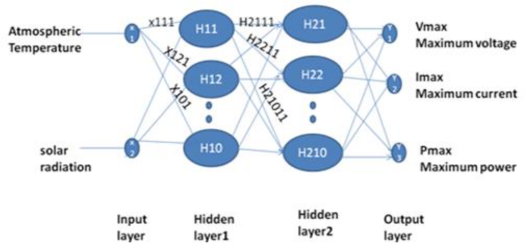


Fig.5: Architecture of Back propogarion Neural Network

Table 2

Error (%)	**Number of data for training (1172 samples)**		
	Pmax	**Imax**	**Vmax**
<1	1136	942	454
1-10	29	227	712
11-20	4	1	6
21-30	3	2	0
31-40	0	0	0
41-50	0	0	0
51-60	0	0	0
61-70	0	0	0
71-80	0	0	0
81-90	0	0	0
91-100	0	0	0

The outputs of this trained network can provide the reference signals to the backstepping controller. Ultimately the controller is able to provide the switching pulses to the converter to obtain PV module MPPT.

2.3 Backstepping control strategy

The backstepping control proposed by Aranzazu D. Martin and J. R. Vazquez, [6]. Being a robust non-linear controller, Lyapunov functions also guarantees the system stability along with reaching its control objective, to track optimum power under variable atmospheric conditions. The outputs of the trained neural network can provide the reference signals to the backstepping controller. In order to design the backstepping controller and to make the input voltage of the converter reaches reference voltage, the dynamic equations (2) and (3) of the boost converter shown in figure 6 are used. In this case, input voltage and inductor currents are chosen as controlled parameters.

The backstepping control follows a procedure, [6]. The first step is to define the error and its derivative of input voltage of voltage to enforce the output voltage of PV module to reach the reference.

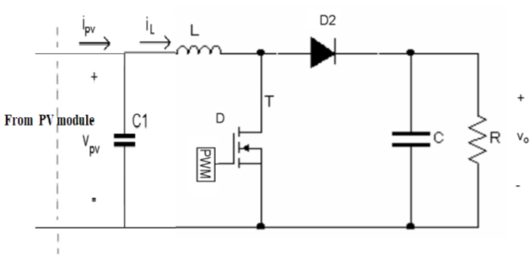


Fig.6: Boost Converter

$$\frac{dV_{PV}}{dt} = \frac{1}{C1} I_{PV} - \frac{1}{C1} I_L \tag{2}$$

$$\frac{dI_L}{dt} = \frac{1}{L} V_{PV} - \frac{1}{L}(1-D)V_o \tag{3}$$

The second step is the local stability of the system is to be assured by a Lyapunov function and its derivative. These two steps are also to be repeated for the second controlled parameter, inductor current in order to reach control objective. Ultimately, the controller output value, i. e. the duty cycle, is worked out, (4), being *k* is the backstepping parameter, α_1 is the control reference current, z_1 is the voltage error and z_2 is the current error.

$$D = 1 - \frac{1}{V_o}[x_1 - L\dot{\alpha}_1 - L(\frac{1}{C_1} z_1 - kz_2) \tag{4}$$

2.4 Simulation Results

MATLAB R2014/Simulink is used for the modeling of the proposed system. The PV module and the trained neural network developed in the above sections are used along with the developed backstepping controller to switch on the boost converter in order to simulate the proposed system.

In order to evaluate the robustness of the proposed MPPT model three main aspects are considered. They are, irradiance, temperature and load changes. Figure 7 illustrates the system response with step irradiance input (1000→ 520 W/sq.m) under the same temperature (25 °C) and load (10 Ω). Figure 8 depicts the tracking response under step temperature variation (25 → 55°C) under the same insolation (1000 W/sq.m) and load (10 Ω). Finally, figure 9 shows the tracking result under rapid load change (100 Ω →10 Ω) under the same insolation (1000 W/sq.m) and temperature (35°C).

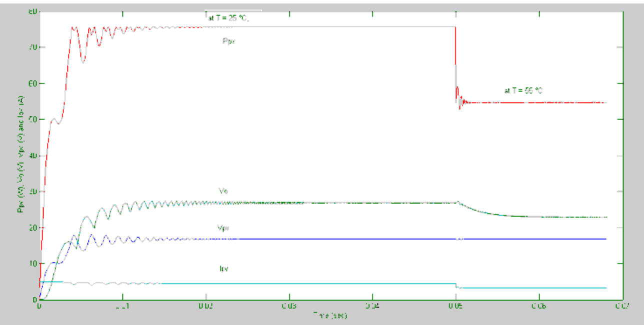


Fig.7: Simulation with step irradiance change under constant temperature and load conditions

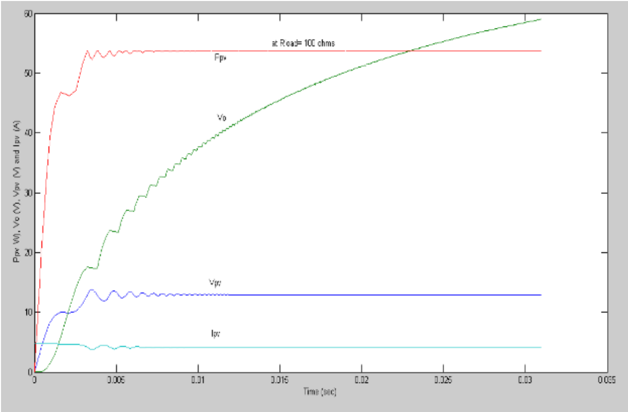
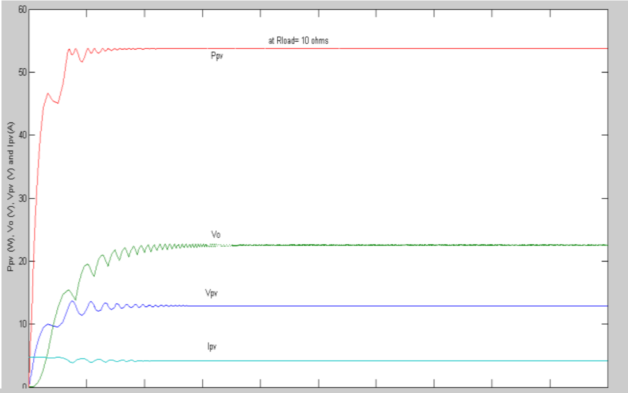


Fig.8: Simulation with step temperature change under same insolation and load conditions



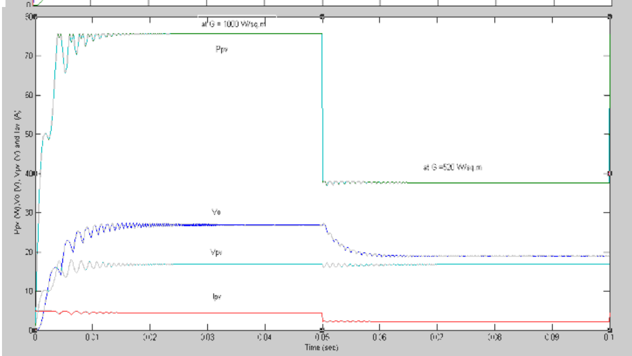


Fig.9: Simulation with step load change under constant insolation and temperature

From all the results above, the proposed MPPT model is robust to variations the external conditions and able to obtain the system response at optimum power point. It is also shown that within the order of milliseconds steady state response is reached, which concludes that the proposed MPPT model is much faster than the other conventional techniques. Furthermore, the practical maximum powers of the solar PVA module are tabulated in Table 3 are almost reached by the simulation results of the developed model.

Table 3

Insolation (w/sqrm)	Temperature (°C)	Vpv (max), in V	Ipv (max), in A	Ppv (max), in W
1000	25	17.1	4.39	75.00
520	55	13.8	3.98	54.92

3. Conclusion

An exact SPVA electrical model is presented in this paper to track robust MPPT. The developed model for solar photovoltaic power electronic conversion system is simulated in MATLAB/Simulink GUI environment. This paper has represented the neural network based prediction to the maximum power point of the PV module. Particularly back propagation neural network is trained to achieve the MPPT along with backstepping control technique. It is observed from the simulation results that at various atmospheric and load conditions, the proposed scheme is able to extract maximum power steadily and accurately.

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