Solar Energy 159 (2018) 134–141

Contents lists available at ScienceDirect

Solar Energy

journal homepage: www.elsevier.com/locate/solener

Backstepping based non-linear control for maximum power point tracking in photovoltaic system[☆]

Naghmash[a,*], Hammad Armghan[a,1], Iftikhar Ahmad[c], Ammar Armghan[b], Saud Khan[c], Muhammad Arsalan[c]

[a] School of Electrical Engineering, The University of Faisalabad, Faisalabad, Pakistan
[b] Department of Electrical Engineering, Aljouf University, Aljouf, Saudi Arabia
[c] School of Electrical Engineering and Computer Science, National University of Sciences and Technology, Islamabad, Pakistan

ARTICLE INFO

Keywords:
MPPT
Backstepping
Power converters
Photo voltaic

ABSTRACT

The increasing energy demands, depleting fossil fuels and increasing global warming due to carbon emission has arisen the need for an alternate, overall efficient and environment-friendly energy system. Solar energy is considered to be one of the most promising alternative energy sources, but it has the problem of low efficiency due to varying environmental conditions. To increase its efficiency, a maximum power point tracking (MPPT) algorithm is required to harvest maximum power from the Photovoltaic (PV) array. In this paper, a non-linear backstepping controller is proposed to extract the maximum power from the PV system. A non-inverting buck-boost converter is used as an interface between the load and the PV array. Reference voltages for the controller are generated by a regression plane. Asymptotic stability of the system is verified through Lyapunov stability analysis. The performance of the proposed controller is tested under MATLAB/Simulink platform. The simulation results validate that the proposed controller offers fast and accurate tracking. Comparison with perturb & observe and fuzzy logic controller is provided to show the performance of the proposed controller under abrupt variation of the environmental conditions.

1. Introduction

The unstable oil prices, increasing energy demand and the recent concern about the global warming has encouraged us to move towards renewable and sustainable energy sources. Solar energy is considered to be one of the most prominent renewable energy sources for power generation (Dincer, 2011). In 2015, Solar Photo Voltaic (PV) had made a recorded history of adding 55 Gigawatts (GW) to the global installed capacity, making it a total of about 227 GW (Ren21, 2016).

PV Panels have low installation cost and are environmentally friendly, but they have the problem of low-efficiency (Başoğlu et al., 2015). To increase their efficiency (output power of PV/maximum power of PV), they must operate at the maximum power point. A typical PV system is shown in Fig. 1, which consists of:

1. PV module which generates electric energy from solar energy.
2. DC-DC converter to transfer the maximum power according to the load requirements.
3. MPPT controller that generates the maximum power from the PV with the help of DC-DC converter.
4. Electric Load.

As tracking the MPP is the most important part of a PV system, intensive research work is being done in this particular area to develop new and more efficient MPPT controllers. The characteristics curve of the PV module is shown in Fig. 2. In almost every MPPT technique, we have to trace the V_{mpp} voltage or I_{mpp} current at which the PV module will supply maximum power. The MPP depends upon weather conditions i.e. temperature and irradiance. There are various methods to trace the MPP which are divided into three broad categories: conventional techniques, population-based algorithms, and artificial intelligence (AI) techniques.

Perturb and observe (P & O) (Xiao and Dunford, 2004; Jain and Agarwal, 2004) and Incremental Conductance (INC) (Hussein et al., 1995; Reisi et al., 2013) are the most commonly used MPPT methods. In P & O, the difference in power ($dP = P_1 - P_2$) is checked at different

[☆] This document is a collaborative effort.

* Corresponding author.
E-mail addresses: 14mseenmr@seecs.edu.pk (Naghmash), 14mseeharmghan@seecs.edu.pk (H. Armghan), iftikhar.rana@seecs.edu.pk (I. Ahmad), ammar.armghan@gmail.com (A. Armghan), 14mseeskhan@seecs.edu.pk (S. Khan), marsalan.msee15seecs@seecs.edu.pk (M. Arsalan).
[1] Principal corresponding author.

http://dx.doi.org/10.1016/j.solener.2017.10.062
Received 20 August 2016; Received in revised form 20 October 2017; Accepted 21 October 2017
0038-092X/

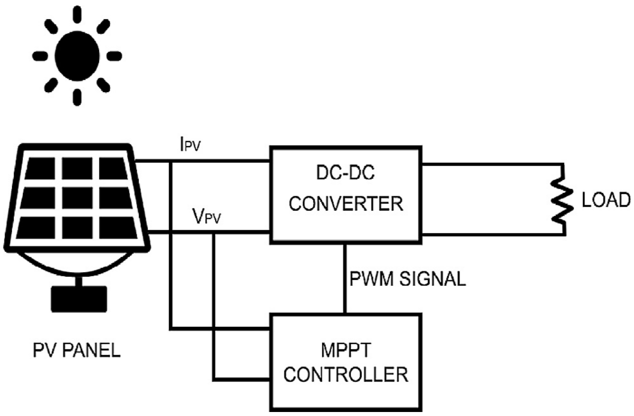

Fig. 1. Block diagram of MPPT.

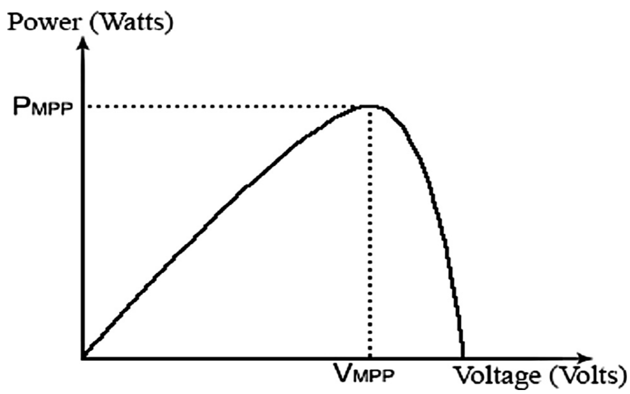

Fig. 2. PV characteristics curve.

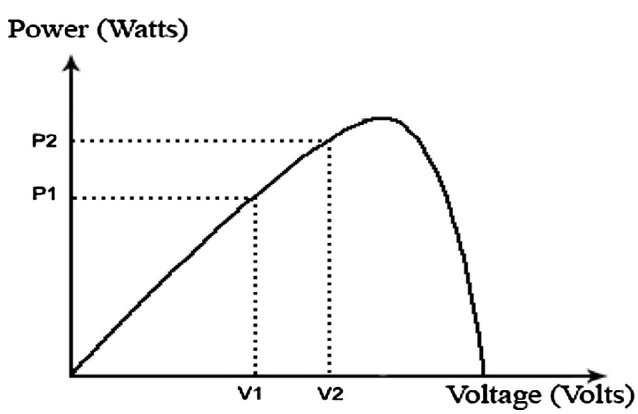

Fig. 3. Power at different voltage levels.

voltage levels (V_1 & V_2) shown in Fig. 3. The voltage is perturbed in either direction. If $dP > 0$, the voltage is perturbed in this direction, else the perturbation is done in the opposite direction. In INC, change in power with respect to voltage (dP/dV) is checked. MPP is achieved when the slope of the PV characteristic curve is zero i.e. $dp/dv = 0$. Comparison of the instantaneous conductance (I/V) to the incremental conductance (dI/dV) is done in this method (Brambilla et al., 1999). At MPP, $dI/dV = -I/V$. If $dI/dV > -I/V$, we are at the left of MPP, so we have to perturb the voltage to the right side. If $dI/dV < -I/V$, we are at the right of the MPP, so we have to perturb the voltage in left direction. The main problem with these conventional methods is that at MPP, the perturbation doesn't stop and there are oscillations around the MPP which results in the loss of power.

Artificial intelligence based MPPT techniques include fuzzy logic controller (FLC) and neural network (NN). FLC doesn't need a mathematical model that's why it can handle non-linearities (El Khateb et al., 2014). FLC based MPPT has good performance in varying irradiance levels, but it needs a good rule base table (Messai et al., 2011). In Guenounou et al. (2014), the author has proposed an adaptive FLC, which integrates into two different rules. The first one adjusted the duty cycle of the power converter while the second one adjusts the gain of the controller. It is shown that the adaptive FLC outperforms the conventional one. In Liu et al. (2013), an artificial neural network (ANN) based MPPT technique is proposed. The proposed controller has advantage of low computation requirement and fast tracking speed irrespective of the PV module used. In Kharb et al. (2014), author proposed adaptive neuro-fuzzy inference system (ANFIS) based MPPT technique. Temperature and Irradiance levels are taken as inputs to train the ANFIS. It is shown that the ANFIS works well under varying temperature and irradiance levels. To be robust, the AI based MPPT techniques require a massive database which needs long computation time and large memory size.

Particle swamp optimization (PSO), Genetic Algorithm (GA) and Ant Colony Optimization (ACO) are the commonly used population-based MPPT techniques. In Ishaque et al. (2012) author has proposed a PSO based MPPT algorithm. It is shown that the proposed algorithm has slow oscillations around the MPP and can find the MPP under varying environmental conditions. A modified GA-based MPPT technique is proposed in Daraban et al. (2014). The proposed algorithm has been integrated with P & O, which results in less iterations and small population size. In Jiang et al. (2013), ACO based MPPT technique is proposed which shows fast convergence in varying weather conditions. It is shown that the proposed technique works better than PSO and P & O. Population-based MPPT techniques are complex and require many parameters such as population size, selection of chromosome, mutation and crossover rate. These parameters need to be readjusted during varying environmental conditions or else MPP cannot be tracked down.

In this paper, a nonlinear backstepping controller for MPPT is proposed. The proposed controller uses regression plane to generate a reference voltage (V_{ref}) and tracks the MPP using non-inverted buck-boost converter. The non-inverted buck-boost converter is selected because of its high capability for MPPT (Başoğlu and Çakır, 2016). The non-linear controller is chosen due to the non-linear nature of the non-inverted buck-boost converter for global stability (El Fadil and Giri, 2007). Asymptotic stability is guaranteed using Lyapunov stability analysis and MPP is achieved under varying temperature and irradiance levels.

The paper is structured as follows. Section 2 presents the modeling of the PV array. Modeling of the non-inverted buck-boost converter is shown in Section 3. In Section 4 the regression plane and analysis of the proposed controller is done. Simulation results are explained in Section 5. Comparison of the proposed controller with perturb and observe technique and fuzzy logic controller is showed in Section 6. Section 7 includes the conclusion and future work.

2. Modeling of PV module

A practical model of PV module is shown Fig. 4. This model is known as single diode model (Villalva et al., 2009). It consists of:

1. Current source I_{pv}, which depends on irradiance and temperature.

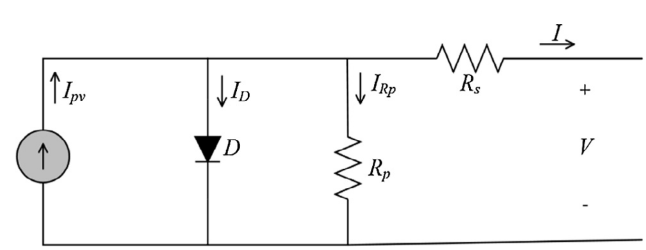

Fig. 4. One diode model of PV module.