Solar Energy 158 (2017) 1006–1015

Contents lists available at ScienceDirect

Solar Energy

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

An improved particle swarm optimization based maximum power point tracking algorithm for PV system operating under partial shading conditions

G. Dileep*, S.N. Singh

Alternate Hydro Energy Centre, Indian Institute of Technology Roorkee, Uttarakhand 247667, India

ARTICLE INFO

Keywords:
MPPT
PSO
Partial shading
Photo voltaic (PV) generation system (PGS)

ABSTRACT

Concerns over environment and increased demand for energy have led the world to think about alternate energy sources such as the wind, hydro, solar and fuel cells. Out of these photovoltaic (PV) generation systems (PGS) become increasingly important all over the world due to its availability, cleanness, low maintenance cost, and inexhaustible nature. The probability of partial shading conditions (PSC) is also high for large PGS. Under PSC, the P–V curve of PGS exhibits multiple peaks, which reduces the effectiveness of conventional maximum power point tracking (MPPT) methods. In this paper, an improved particle swarm optimization (PSO) based MPPT algorithm for PGS operating under PSC is proposed. Conventional PSO is modified to meet practical consideration of PGS operating under PSC. Problem formulation, design details, and experimental results are discussed in detail. The proposed technique is independent of system, it is easy to implement, tracking efficiency is high and performance under PSC is good. The effectiveness of the proposed method is validated by analyzing the experimental results obtained from 110 W solar power generation systems.

1. Introduction

Renewable energy tracking becomes one of the interesting areas in recent years due to increased energy demand all over the world and issues related to the environment (Wu et al., 2016). Out of all renewable energy sources, solar energy has gained much more attention due to its availability, cleanness and inexhaustible nature (Hu et al., 2016). Tracking solar power is difficult due to non-linear current – voltage (I-V) characteristics of panel with a unique maximum power point (MPP) (Hiroshi, 2004). Power produced by PV panel varies with variation in atmospheric conditions such as solar irradiation and cell temperature. MPP of solar panel also varies with variation in atmospheric conditions. So, in order to extract maximum power, PV panel must be operated at a voltage corresponding to MPP (V_{MPP}). Maximum power point trackers are used to achieve this (Rezk and Eltamaly, 2015; Yousra et al., 2013; de Cesare et al., 2006; Li, 2014). MPPT is an art of extracting maximum power from PV panel and it is regarded as the critical component of a PV system. The internal resistance of PV panel varies with variation in atmospheric conditions but the load resistance remains the same. Converter controlled with MPPT algorithm is used to achieve load matching and extracting maximum power from PV panel (Hiroshi et al., 2003; Salas et al., 2005). PV system with MPPT achieves load matching and extracts maximum power thereby increases the efficiency of solar power tracking. In order ensure that the PV system is operating at MPP, a DC-DC converter along with an MPPT controller is inserted in between load and PV module (Chowdhury and Saha, 2010; Mohammad and Ali, 2011; Yu et al., 2004; Chen et al., 2014). Various MPPT algorithms such as short circuit current based (Noguchi et al., 2002), open circuit voltage based (Masoum et al., 2002), ripple correlation control (RCC) (Casadei et al., 2006), slide mode control technique (Kim et al., 2006), perturb and observe (P & O) (Chia et al., 2011) have been already proposed. Conventional hill climbing methods are simple and easy to implement but have problems such as oscillations of operating point around MPP, requires more time to determine MPP, can be fooled under quickly changing atmospheric conditions and it is not effective under PSC's (Castellano et al., 2015), which in turn reduces the overall system efficiency. Linearization based MPPT (Ching et al., 1999) and state space based MPPT (Solodovnik et al., 2004) techniques convert nonlinear current and power equations to linear first and track MPP. Temperature based MPPT (Mutoh et al., 2002) technique requires less number of sensors to track MPP. Most of the MPPT techniques mentioned above fail to track MPP effectively under rapidly changing atmospheric conditions and under PSC's.

To achieve the required voltage and current rating PV panels are connected in parallel, series or combination of two. Few of the PV panels connected in PV generating system (PGS) may be placed in an area where less solar irradiation is available due to shading of trees or large buildings nearby. Depending upon the shading pattern, bypass diode

* Corresponding author.
E-mail address: dileepmon2@gmail.com (G. Dileep).

http://dx.doi.org/10.1016/j.solener.2017.10.027
Received 14 December 2016; Received in revised form 25 September 2017; Accepted 9 October 2017

Nomenclature

List of abbreviations

ANN	artificial neural network
GMPP	global maximum power point PV generating system
GP	global peak PV generating system
INC	incremental conductance based MPPT technique
LP	local peak PV generating system
MPP	maximum power point (Knee of P-V curve)
MPPT	maximum power point tracking of PV generating system
PGS	PV generating system
P&O	perturb and observe based MPPT technique
PSC	partial shading condition
PSO	particle swarm optimization
PV	photovoltaic panel
STC	standard test conditions

List of symbols

a	diode ideality factor
C	capacitor
C_1	cognitive coefficient of PSO
C_2	social coefficient of PSO
D	diode
G_{best}	global best of all individual best
I	current
I_d	diode current
I_{MPP}	current corresponding to MPP
I_o	load current
I_{ph}	photo generated current source
i_{pv}	solar cell generated current
I_s	dark saturation current of diode
I_{sc}	short circuit current of PV panel
k	Boltzmann constant
L	inductor
P_{best}	local best of all individual best
P_{MPP}	maximum output power of PV panel
P_{PV}	PV panel generated power
Q	MOSFET switch
q	charge of the electron
r_1 and r_2	uniformly distributed random numbers
R_S	series resistance of solar panel
R_{sh}	shunt resistance of solar panel
T	solar cell temperature
u	output of controller
V	voltage
V_{MPP}	voltage corresponding to MPP
V_{oc}	open circuit voltage of PV panel
v_{pv}	solar cell generated voltage
ω	inertial weight of PSO

incorporated in the PV module and system configuration, the output power of PV string varies. Due to the uneven solar irradiation falling on different panels of the same string, PV characteristics of entire string gets modified and multiple power peaks occur. It becomes very difficult to track peak power from a set of peaks using conventional MPPT algorithms. Normal hill climbing algorithms may stick at local maxima rather than global maxima which in turn reduce overall system efficiency. This led researchers to work on conventional MPPT algorithms and introduce a new technique to track global maximum under these conditions. Carannante et al. (2009) proposed a system dependent MPPT algorithm to track power under PSC by considering voltage factors of previously analyzed global maximum power point (GMPP). Kobayashi et al. (2006) proposed a two-stage MPPT algorithm in which operating point is moved near to GMPP using load line in the first stage. In second stage, convergence of operating point to GMPP is done. When GMPP lies on left of load line proposed method was found to be ineffective. Ahmed and Miyatake (2008) proposed a variable step based P & O MPPT technique in which step size determined by Fibonacci sequence. Proposed method doesn't track GMPP under all conditions. Renaudineau et al. (2011) proposed a two-stage MPPT algorithm in which a scanning process is done to find GMPP in the first stage followed by P & O technique for convergence to GMPP. This technique requires more time to find GMPP since all MPP's are determined and compared to find GMPP. Lei et al. (2011) developed an extreme seeking control algorithm to find GMPP based on the findings obtained by analysis of PV module under various PSC. Proposed technique is efficient and tracks GMPP under different test condition, but the method is system dependent, not universal. ANN based MPPT technique proposed Syafaruddin et al. (2009) uses a 3-layered ANN network trained with PSC data's to determine GMPP voltage. This method tracks GMPP efficiently and quickly but it is system dependent. Femia et al. (2008) proposed a method in which each PV panel in the string connected to separate DC-DC converter with MPP trackers. The efficiency of tracking is superior but the cost of implementation is on the higher side. Chowdhury et al. proposed an adaptive perspective PSO to find GMPP; the proposed technique is cost effective. Miyatake et al. (2011) proposed a novel technique to track GMPP using PSO, their technique provided better results under various PSC's but is limited PGS with multiple converters.

These MPPT algorithms have good performance under various PSC; however, these methods are only suitable for systems that consist of multiple converters. However, for PGS, the use of one central high-power single-stage electronic converter is very common for economical reasons and the relative simplicity of the overall system. This paper aims to develop an accurate and system independent MPPT algorithm for centralized-type multimodule PGS operating under PSC. The PSO method has been successfully employed to solve different engineering optimization problems. According to these investigations, the PSO method is a simple and effective metaheuristic approach that can be applied to optimization problems having many local optimal points. Consequently, it will be adopted in this paper to realize the MPPT algorithm which is suitable for centralized PGS under PSC.

In this paper, the standard version of PSO will be modified to meet the practical consideration of PGS under PSC. Detailed design procedures which take the hardware limitation into account will be presented first, and a 75 W prototype will be implemented to demonstrate the validity of the proposed MPPT algorithm. Experimental results show that the proposed MPPT technique can obtain the GMPP in all test cases no matter where the GMPP locates. The tracking efficiencies in all

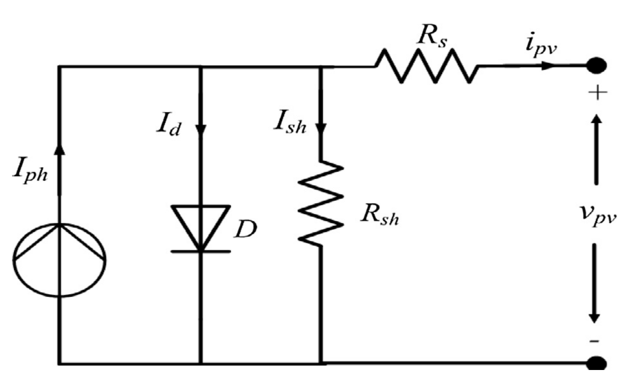

Fig. 1. Single diode five parameter model of a solar cell.