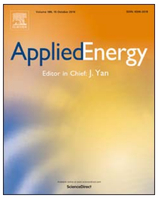
Applied Energy 210 (2018) 303–316

Contents lists available at ScienceDirect

Applied Energy

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



A novel tangent error maximum power point tracking algorithm for photovoltaic system under fast multi-changing solar irradiances

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HIGHLIGHTS

- A novel tangent error maximum power point tracking algorithm is presented.
- The proposed method not only has dynamic performance but also the high efficiency.
- The robust tracker has ease implementation and reliability under fast multi-changing irradiances.
- The MPPT algorithm can be applied to provide energy for moving carriers such as UAVs.

ARTICLE INFO

Keywords:
Photovoltaic system
Modeling
Maximum power point tracking
Perturb and observe
Tangent error method
Fast multi-changing irradiances

ABSTRACT

In this paper, a novel tangent error maximum power point tracking algorithm based on perturb and observe method is presented to achieve the high efficiency for photovoltaic system under fast multi-changing solar irradiances. In order to get a proper initial value, the mathematical model of optimal voltage is established. By using tangent error method, a dynamic perturbation step is calculated. Meanwhile, the characteristics for tracking direction is analyzed in detail to distinguish oscillating power from changes in irradiances and perturbation step. Moreover, the tracking performance of the proposed algorithm is investigated by modeling, simulation and experiment of PV system. Furthermore, errors and statistical analyses are carried out to illustrate the accuracy of the tangent error algorithm. Compared with previous methods in other works, the results demonstrate that the proposed method not only has the fast tracking speed but also the high efficiency. In addition, it is found that the overall energy conversion efficiency of the photovoltaic module has increased by approximately 3% during the whole time. Besides, due to its ease implementation, high efficiency and reliability under fast varying irradiances, the proposed method can be applied to provide energy for moving carriers, such as UAVs, cars and trains.

1. Introduction

As one of the important renewable energy, solar energy has received considerable attention and the application of photovoltaic (PV) generation system has been used in moving carriers, such as UAVs, cars and trains [1–4]. In order to access to development, a great deal of research work has been carried out in recent years. And one of the fundamental issues is to improve the conversion efficiency of light energy to electricity and reduce power generation costs [5,6]. However, due to only one and unique particular maximum power point for PV module at given solar irradiance and temperature, it is necessary to utilize the maximum power point tracking (MPPT) technique to achieve high power generation [7–11]. According to previous studies, the scheme of the MPPT technique is generally as follows: first, the reference working state is calculated by MPPT algorithm, and then PV system is tuned to the given state by using DC-DC converter, which is controlled by a switch tube. Consequently, MPPT algorithm plays a vital role in PV system, more work should be done to improve this algorithm.

The aim of MPPT algorithm is to automatically find the particular point, in which PV module can extract the maximum power at solar irradiance and temperature. From a view of control structure, MPPT algorithm can be divided into three categories: the voltage MPPT algorithm (VMPPT) [12,13], the current MPPT algorithm (CMPPT) [14] and the duty cycle MPPT (DMPPT) [15]. The output of DMPPT is duty ratio, which directly control the DC-DC converter. Unfortunately, the DMPPT suffers the disadvantage of slower transient response and lower efficiency under rapidly changing irradiances [16]. In addition, the current of CMPPT is easily affected by the irradiance levels, resulting in

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https://doi.org/10.1016/j.apenergy.2017.11.017
Received 14 July 2017; Received in revised form 13 October 2017; Accepted 2 November 2017

Nomenclature

D	duty cycle
G	solar irradiance (W/m^2)
G_{ref}	solar irradiance at standard test condition (W/m^2)
f	switching frequency (kHz)
FTS	first time above MPPT efficiency (S)
I	integral constant
I_{cell}	output current of PV cell (A)
I_L	photocurrent of PV cell (A)
I_{L1}	inductor current of inductance L_1 (A)
$I_{L,ref}$	photocurrent at standard test conditions (A)
I_{mp}	current at the maximum power point for PV module (A)
$I_{mp,ref}$	current at the maximum power point at standard test conditions for PV module (A)
I_o	saturation current of the equivalent diode of PV cell (A)
$I_{o,ref}$	saturation current of the equivalent diode at standard test conditions (A)
I_{pv}	output current of PV module (A)
$I_{pv}(k)$	current output current of PV module (A)
$I_{pv}(k-1)$	previous output current of PV module (A)
$I_{pv}(k+1)$	next output current of PV module (A)
I_{sc}	short circuit current (A)
$I_{sc,ref}$	short circuit current at standard test conditions (A)
k	Boltzmann constant (1.38×10^{-23}J/K)
$K_{i,sc}$	temperature coefficient for short circuit current (A/K)
$K_{v,oc}$	temperature coefficient for open circuit voltage (V/K)
	number of PV cell in parallel
n	ideality factor of PV cell
n_{ref}	ideality factor at standard test conditions
n_s	number of PV cell in series
P	proportional constant
P_{pv}	output power of PV module (W)
$P_{pv}(k)$	current output power of PV module (W)
$P_{pv}(k-1)$	previous output power of PV module (W)
$P_{pv}(k+1)$	next output power of PV module (W)
$P_{\max,ref}$	output rating power at standard test conditions (W)
P_{mpp}	theoretical power of PV module (W)
q	electron charge (1.6×10^{-19} C)
RMSE_I	root mean squared error for output current (A)
RMSE_P	root mean squared error for output power (W)
RMSE_V	root mean squared error for output voltage (V)
R_s	series resistance of the cell of PV cell (Ω)
$R_{s,ref}$	series resistance of the cell at standard test conditions (Ω)
R_p	shunt resistance of the cell PV cell (Ω)
$R_{p,ref}$	shunt resistance of the cell at standard test conditions (Ω)
R_{pv}	equivalent resistance of PV module (Ω)
sig	direction of P&O algorithm
T	module temperature (K)
T_{ref}	module temperature at standard test conditions (K)
$\tan\theta_1$	I_{pv}/V_{pv}
$\tan\theta_2$	tangent of $I_{pv} - V_{pv}$ curve
V_{cell}	output voltage of PV module (V)
V_{pv}	output voltage of PV module (V)
$V_{pv}(k)$	current output voltage of PV module (V)
$V_{pv}(k-1)$	previous output voltage of PV module (V)
$V_{pv}(k+1)$	next output voltage of PV module (V)
$V_{pv,ref}$	reference maximum voltage of PV module (V)
V_{mp}	voltage at the maximum power point PV module (V)
$V_{mp,ref}$	voltage at the maximum power point at standard test conditions (V)
V_{oc}	open circuit voltage for PV module (V)
$V_{oc,ref}$	open circuit voltage at standard test conditions (V)
V_{C1}	capacitor voltage of C_1 (V)
V_{C2}	capacitor voltage of C_2 (V)
V_o	output voltage of DC-DC converter (V)
ΔV_{pv}	step size of P&O algorithm (V)
$\Delta V_{pv}(k)$	current step size of P&O algorithm (V)
$\Delta V_{pv}(k-1)$	previous step size of P&O algorithm (V)
ΔP_{pv}	oscillating power (W)
η_{mppt}	MPPT efficiency

control difficulty increment for DC-DC converter. Due to high efficiency and independence to DC-DC circuit parameters, VMPPT is chosen in this article. During the past decade, the theory of VMPPT has developed in a variety of directions, and typical algorithms are: fraction open circuit voltage/short circuit current [17], incremental conductance (IC) [15], perturb and observe (P&O) [18], artificial neural network (ANN) [19], fuzzy logic controller (FLC) [20], particle swarm optimization (PSO) [21], genetic algorithm (GA) [22], sliding-mode controller [23], and teaching-learning based optimization(TLBO) [24]. In all these algorithms perturb and observe is commonly carried out in PV system due to its ease implementation and reliability, especially in low cost practical system [15].

Although previous P&O algorithms can obtain high tracking performance under uniform and stable irradiance, there is a trade-off between the tracking speed and high efficiency under rapidly changing weather conditions. To address this issue, several improved P&O methods have been proposed. One of the method is called variable step size method, in which the perturbation step size is tuned according to the current PV module working status [25,26]. By using a criterion to resolve the problems of determining the zone of the operation point, Faraji et al. adopted different perturbation step to improve the speed and reduce oscillating power near the maximum power point [27].

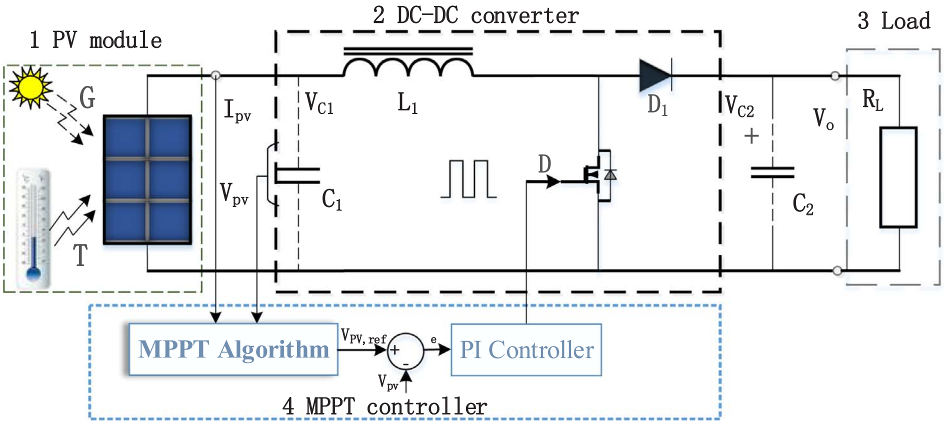

Fig. 1. Architecture of the PV system.