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A new Golden Section method-based maximum power point tracking algorithm for photovoltaic systems

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ABSTRACT

One way to improve the efficiency of solar powered systems is to maximize the energy harvesting from the photovoltaic module by using a maximum power point tracking algorithm. The latter must be simple for implementation, fast and accurate to cope with fast changing atmospheric conditions and partial shading operations. The paper presents a new maximum power point tracking method based on Golde n-Section Optimization technique for photovoltaic systems. The proposed method converges to the Maximum Power Point by interval shrinking. Initially, two points are selected from the search space whose boundaries are known, evaluated then a new point is accordingly generated. At given iteration the algorithm has a new narrowed interval bounded by the new point and one of the initial points according to the evaluation results. The algorithm stops iterating (interval shrinking) when the interval becomes small enough and the photovoltaic system is forced to operate at the average value of the last found interval without perturbing either the voltage or the duty cycle. This makes the photovoltaic system converges rapidly to the maximum power point without voltage or power oscillations around the maximum power point thereby lower energy waste. A comparison results with recently published work are provided to show the validity of the proposed algorithm under fast changing conditions and partial shading.

1. Introduction

The steadily increasing demand on electric energy and rising prices of the fuel used in conventional power plants together with increasing concerns about their environmental effects, have encouraged intensive research for, friendly environmental, low-cost generation plants, particularly solar energy which has proved its worth for power plants of multiple MW proportions, as well as smaller applications such as rural electrifications [1]. Solar energy is considered as one of the most promising renewable energy of the future in Algeria [2] and has become a necessity for people living in the southern to cope with the long hot season [3]. Besides the availability of the sunlight along the year, PV systems are easy to install, present neither moving parts nor combustion processes hence environmentally friendly and almost maintenance free [2]. However, PV systems, which mainly comprise the PVG and power electronic processor, suffer from very low system efficiency, a problem that arguably needs to be addressed. One should differentiate between conversion efficiency and utilisation efficiency of PV modules. Conversion efficiency, being difficult to estimate as a parameter [1], is very low compared to utilisation efficiency which is the ratio of output power to the maximum power that can be extracted at given atmospheric conditions (irradiance, temperature and air mass). In the present work, the latter efficiency is the only parameter of interest. Therefore, one of the most economical ways to improve the utilisation efficiency of PVGs is to ensure that it is always operating at its maximum power point irrespective of the environment conditions. This can be achieved by associating a maximum power point tracking (MPPT) controller to the power electronic converter (usually a chopper) in order to adjust the duty cycle to match the load.

Much work has been devoted to improve the performance of PV systems through developing new or upgrading already existed MPPT algorithms. To this, several papers have been published to

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Nomenclature

Abbreviation

ACO	ant colony optimization
ANN	Artificial Neural Network
ANFIS	Adaptive Neuro-Fuzzy Inference System
AI	Artificial Intelligence
CS	Cuckoo search
FL	fuzzy logic
GA	Genetic Algorithm
GMPP	global maximum power point
GSO	Golden Section Optimization
HC	Hill Climbing
IC	Incremental Conductance
MPPT	maximum power point tracking
MPP	maximum power point
P&O	Perturb & Observe
PSO	Particle Swarm Optimization
PV	photovoltaic
PVG	photovoltaic generator
PWM	pulse width modulation
STC	Standard Test Conditions

List of symbols

ε	voltage precision
a	diode ideality constant
G	irradiation level in W/m^2
G_{STC}	nominal irradiation level (in 1000 W/m^2)
I	PV array current output
I_{MPP}	current of maximum power point
I_{PV}	light-generated current
I_S	Diode's reverse saturation current
I_{SCN}	nominal short circuit current of the PV module
K	Boltzmann's constant
K_I	short circuit current coefficient
K_V	open circuit voltage coefficient
N_p	number of parallel-connected cells
N_S	number of series-connected cells
q	electron's electric charge
R_{sh}	parallel or shunt resistance
R_s	series resistance
V	PV module's voltage output
V_{OCN}	PV module's nominal open-circuit voltage
V_{MPP}	voltage of maximum power point
V_{PV}	PV array voltage
V_T	thermal voltage of the PV cell
T_{STC}	nominal temperature (298 K)
ΔT	variation from the nominal temperature

review, discuss and classify these MPPT algorithms. For instance, in [4] two main groups of MPPTs are distinguished: conventional group that includes Perturb and Observe (P&O), Incremental Conductance (IC), and Hill Climbing (HC) techniques and stochastic based methods group, then a comparison between those techniques within the same group is done in terms of convergence speed, complexity, ability to truck the true MPP, etc. Different MPPT algorithms which are based on the use of either AI or evolutionary methods have been listed in [5]. A focus has been given to their implementation using FPGA ships and subsequently a comparison between them is made in terms of complexity, efficiency, rapidity and memory space requirement. Classification adopted in [6] is based on the ability of MPPT technique to cope with uniform and non-uniform irradiance. This paper raises the outcome that evolutionary algorithms based MPPT techniques outperform others in terms of seeking GMPP but there are still many concerns when it comes to implementation. A comparison through simulation and implementation using FPGA of four MPPT techniques is presented in [7]. Fuzzy logic, Artificial Neural Network (ANN), Adaptive Neuro-Fuzzy Inference System (ANFIS) and GA-optimized FLC based MPPTs are considered and compared in terms of complexity, rapidity, oscillation around MPP and memory space requirement.

None of the previously mentioned review paper has considered MPPTs which are based on the mathematical model of the PVG. Finding relationship between weather parameters and PVG output voltage and current using either curve fitting or training techniques would make deriving the MPP parameters (duty cycle, current or voltage) an easy forward task. These relationships can be obtained by training an ANFIS to become MPPT controller [8], estimating the input resistance of the PV system (PVG + chopper) which has a direct relationship with MPP [9] or applying nonlinear model identification methods [10]. Model-based MPPT techniques offer the advantage of being very fast but valid only for the PVG under test and cannot cope with partial shading operations.

In general, MPPT algorithms are classified according to the type of the algorithm used. This classification makes difference between conventional methods, Artificial Intelligence techniques (AI) and population-based techniques. Conventional MPPT methods include P&O, IC, HC and their modified version techniques [4]. AI-based MPPT methods use one or combine two of the soft computing techniques: In [11] the authors have designed a fuzzy-logic controller (FLC) for seeking the MPP deliverable by a photovoltaic module using the measured values of the photovoltaic current and voltage. The simulation results show a satisfactory performance with a good agreement between the expected and the obtained values. An adaptive fuzzy logic based MPPT method is proposed in [12]. It consists to integrate two different rules; the first one is used to adjust the duty cycle of the DC–DC converter, while the second one is employed for an online adjusting of the controller's gain. Results indicate that the proposed method outperforms the conventional fuzzy-logic controller. A new embedded digital MPPT system based on ANN is recently developed in [13]. The advantages of the proposed system include low computation requirement, fast tracking speed and high static/dynamic tracking efficiencies. In addition, using the developed neural network model, the photovoltaic generation systems user can apply the developed MPPT controller to any photovoltaic module without the need to modify the firmware of the photovoltaic generation system.

The AI-based MPPT techniques take advantage of the expert's knowledge to develop their control strategy. Population based techniques or evolutionary algorithms are introduced to tackle multivariable optimization problems with multiple optimal points. Some of them have been adapted to deal with MPPT problem. Particle Swarm optimization (PSO) proposed in [14] has been combined with direct duty control to truck the GMPP and eliminate power oscillations at steady state (around MPP). Genetic Algorithm (GA) in [15] has been modified to behave like the conventional P&O by selecting individuals of three chromosomes: voltage, search direction and step size. New individuals are obtained by performing crossover and mutation which integrate the principle of P&O. This results in fast convergence to GMPP. A continuous version of ant colony optimization has been employed to develop a global MPPT in [16] using the archive of solution. As the PSO, ACO has