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Simulation and experimental design of a new advanced variable step size Incremental Conductance MPPT algorithm for PV systems

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ABSTRACT

Improvement of the efficiency of photovoltaic system based on new maximum power point tracking (MPPT) algorithms is the most promising solution due to its low cost and its easy implementation without equipment updating. Many MPPT methods with fixed step size have been developed. However, when atmospheric conditions change rapidly , the performance of conventional algorithms is reduced. In this paper, a new variable step size Incremental Conductance IC MPPT algorithm has been proposed. Modeling and simulation of different operational conditions of conventional Incremental Conductance IC and proposed methods are presented. The proposed method was developed and tested successfully on a photovoltaic system based on Flyback converter and control circuit using dsPIC30F4011. Both, simulation and experimental design are provided in several aspects. A comparative study between the proposed variable step size and fixed step size IC MPPT method under similar operating conditions is presented. The obtained results demonstrate the efficiency of the proposed MPPT algorithm in terms of speed in MPP tracking and accuracy.

1. Introduction

Recently, the increasing energy demand has been growing dramatically and improved standards of living will likely put added pressure on energy supplies, rotating outages, and increasing fossil fuels prices which have motivated many utilities and consumers to developing and harnessing new forms of energy sources that are highly reliable. In this context, renewable energy is the form that is produced through resources which naturally replenish themselves over a short period of time by natural processes such as sunlight, wind, rain, wave power, flowing water and geothermal heat, ocean energy, hydrogen and fuel cells [1–3].

Renewable energy is considered not only as a source of energy, but also as a promising solution to many problems such as energy security, CO_2 emissions, creating jobs and reducing poverty, electricity costs [4–6] etc. Therefore, these sources have become the subject of advanced research for extracting power with high reliability, lower cost and increased energy efficiency.

Power generation from solar energy is one of the most promising renewable energies that attract the attention of researchers, which is clean, renewable, inexhaustible, free and abundant in the most parts of the world, and it has proven to be an economical source of energy in many applications [1,2,7–9]. Solar energy can be employed in two major methods. Firstly, the captured heat can be used as solar thermal energy, with applications in space heating. The second technique converts the incident solar irradiation into electrical energy, which is the most usable form of energy [2–10]. Photovoltaic (PV) is currently envisaged to be one of the most popular renewable energies due to its several advantages. It is a simple, clean, noiseless, low operational and maintenance cost and environmentally benign [1–2,7]. However, it still presents some drawbacks compared to conventional energy resources especially its high fabrication cost, low energy conversion efficiency, and nonlinear characteristics. Therefore, the energy harvesting at maximum efficiency is not simple enough [1–2,7].

PV systems can be classified into three types: autonomous, grid-connected and hybrid. The autonomous systems are completely independent of other power sources. The common applications for this system are water pumps, power remote homes, cottages or lodges. However, in most cases, autonomous systems require batteries for storage. The second category is the grid-connected systems [2,11]; that are used to reduce the consumption from the electricity grid and, in some instances to feed the surplus energy back into the grid. This system can produce significant quantities of high-grade energy near the consumption point, avoiding transmission and distribution losses. In addition, DC/AC converters are required by which many topologies and

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control strategies have been developed and improved continuously [2,12,13].

The third category is the hybrid systems [2,14], in which a portion of their power is received from one or more additional sources. This system is selected for high energy demand.

To optimize the efficiency of large photovoltaic modules; maximum power point tracker algorithm (MPPT) is required. In this context, a large number of MPPT methods have been developed and improved [1,2,15–22]. These techniques vary in complexity, accuracy, speed, oscillation around the MPP, hardware implementation sensor requirement, [1,13].The widely used MPPT techniques are the perturbation and observation (P&O) algorithm [23–25], Incremental Conductance (IC) method [2,16,20] and Hill Climbing (HC) [26,27]. For faster speed and more accuracy, MPPT controllers using particle swarm optimization (PSO) and genetic algorithms have been proposed [28]. Moreover, fuzzy and neural-network methods are well adopted for handling nonlinearity in many applications [29–31]. Despite these methods have a good performance in dealing with the nonlinear characteristics of the *I–V* curves, they require extensive computation the versatility of these methods is limited [22,28].

The perturbation and observation P&O, Incremental Conductance (IC) and Hill Climbing (HC) methods based on fixed iteration step size are simple and have good performances. However, they are characterized by slow convergence; oscillations in the PV power around the MPP, operation fail under rapidly changing atmospheric conditions, using small perturbation step size, oscillation can be reduced, but the speed of tracking MPPs remains slower. To acquire a fast response speed and to overcome the aforementioned drawbacks, a modified MPPT algorithms with variable step size have been the subject of many investigations [2,7,17], in which the step size is automatically adapted according to the derivative of power to voltage (dP/dV) of a PV panel.

In general, the conventional IC MPPT algorithm uses a fixed step size to track the maximum power point (MPP). Thus the tracking speed and accuracy are highly dependent on the fixed step size. The extracted power from the PV array using a large step size contributes to faster dynamics, but increases the losses in steady state due to large perturbations around the MPP, using small perturbation step size, oscillation can be reduced, but the tracking speed stays slower. Thus, depending on each operational condition, the corresponding design should satisfactorily address the tradeoff between the dynamics and steady state oscillations as shown in Fig.1.Thereby, and in order to operate the PV system according to a suitable performance, a new MPPT methods based on variable step size have been developed [1,2,7].

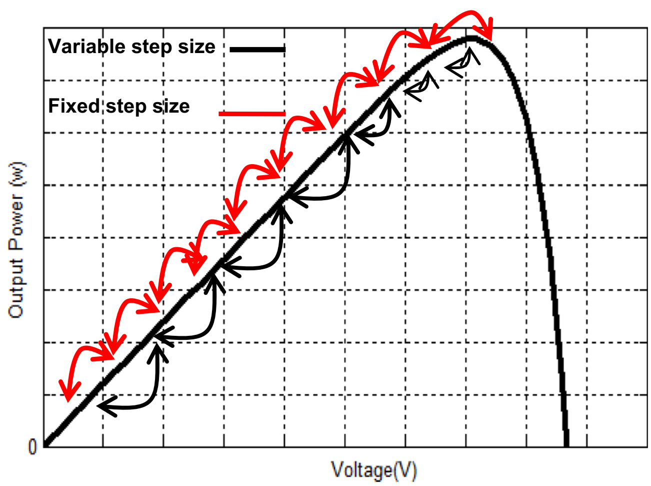

Fig. 1. Fixed and variable step size MPPT operation.

A large number of variable step size Incremental Conductance MPPT algorithm with direct control have been proposed and investigated [8,15,21,32–35], in which the step size is automatically adjusted according to the first derivative of power with respect to voltage (dP/dV), to current (dP/dI) or (dP/dD) [8,15,21,22,32]. The variable step size Incremental Conductance MPPT algorithms are mostly similar to the conventional incremental conductance and the only difference is the step size calculation, a constant value N is often multiplied with the derivative (dP/dV, dP/dI,dP/dD).

Tey and Makhilef [8] introduced new tracking steps to identify the changes in solar irradiation level using the variations in current (dI) and voltage (dV) of the PV module instead of the slope (dP/dV) of the *P–V* curve. Liu et al. [22], Ishaque et al. [28], Abdourraziq et al. [33] and Rahman et al. [34], proposed new variable step size IC MPPT, in which, the fixed step size is multiplied with the slope of the *P–V* curve.

In Ref. [21], Pandey et al. used the derivative (dP/dD) as the variable step size, the scaling factor is tuned at design time to adjust the step size, which is proportional to dP/dV term.

In Ref. [16], Qiang et al. used the derivative of power to current (dP/dI) to determine the variable increment for the IC MPPT algorithm. Comparison of common variable step size Incremental Conductance MPPT with direct control is summarized in Table. 1.

In addition, to improve the efficiency of PV systems, many DC/DC converters have been used in PV systems, Flyback converter is one of the most common topologies considered for PV modules since it is an isolated power converter through transformer and it provides a simple topology, low cost, reduced number of semiconductor switches, operates over wide range of input voltage variation, and is capable of achieving the optimal operation regardless of the load value [36,37].

In this paper, a new variable step size Incremental Conductance MPPT algorithm with direct control has been proposed. Modeling and analysis of different operational conditions of Incremental Conductance method have been presented. The proposed variable step size and fixed step size IC MPPT methods are tested and validated using Matlab/Simulink model and experimental prototype MPPT system was developed, using Flyback converter, which is controlled by control circuit based on Dspic30F4011. The different aspects of the system and parameters have been implemented. A comparative study between the proposed variable step size and fixed step size IC MPPT method under similar operating conditions is presented. Many efficiency parameters have been suggested: tracking accuracy, response time, ripple, and duty cycle oscillations.

2. Modeling of photovoltaic cell

In 1839, French scientist Edmund Becquerel discovered that certain materials would give off a spark of electricity when struck with sunlight. The effciency of solar cells depends on many factors, such as the solar irradiation, the temperature, the spectral characteristics of sunlight, shaded condition, the dirt, and the output voltage of the PV module, etc. The simplest equivalent PV panel can be modeled as a current source in parallel with a diode, shunt resistance R_{sh} and a series resistance R_s as shown in Fig. 2. To increase the output power of the system, PV modules are generally made up using several PV cells connected in series and/or in parallel.

Based on Fig. 2 the output current of the solar cell can be given by:

$$I_o = I_{ph} - I_d - I_{sh} \quad (1)$$

where:

I_{ph} is the current generated by the incident light (it is directly proportional to the Sun irradiation),