Energy Conversion and Management 97 (2015) 298–306

Contents lists available at ScienceDirect

Energy Conversion and Management

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

Implementation of a new maximum power point tracking control strategy for small wind energy conversion systems without mechanical sensors

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ARTICLE INFO

Article history:
Received 7 December 2014
Accepted 16 March 2015
Available online 2 April 2015

Keywords:
Small wind energy conversion systems (SWECS)
Maximum power point tracking (MPPT)
Perturbation and observation (P&O)
Permanent magnet synchronous generator (PMSG)
Sensorless

ABSTRACT

This paper proposes a modified perturbation and observation maximum power point tracking algorithm for small wind energy conversion systems to overcome the problems of the conventional perturbation and observation technique, namely rapidity/efficiency trade-off and the divergence from peak power under a fast variation of the wind speed. Two modes of operation are used by this algorithm, the normal perturbation and observation mode and the predictive mode. The normal perturbation and observation mode with small step-size is switched under a slow wind speed variation to track the true maximum power point with fewer fluctuations in steady state. When a rapid change of wind speed is detected, the algorithm tracks the new maximum power point in two phases: in the first stage, the algorithm switches to the predictive mode in which the step-size is auto-adjusted according to the distance between the operating point and the estimated optimum point to move the operating point near to the maximum power point rapidly, and then the normal perturbation and observation mode is used to track the true peak power in the second stage. The dc-link voltage variation is used to detect rapid wind changes. The proposed algorithm does not require either knowledge of system parameters or of mechanical sensors.

The experimental results confirm that the proposed algorithm has a better performance in terms of dynamic response and efficiency compared with the conventional perturbation and observation algorithm.

1. Introduction

Wind energy is one of the most promising renewable energy sources that can serve as an alternative to traditional sources based on fossil fuels. This is not only for high power, but also for the small power range (1–100 kW) [1].

Small wind energy conversion systems (SWECS) equipped with permanent magnet synchronous generator (PMSG) have several benefits compared to those using induction generators. First, PMSG can provide high-reliability power generation since there is no need for external magnetization. Second, the high torque-density of the PMSG allows a reduction in the cost of the system [2]. Moreover, a wind turbine with a multi-polar PMSG removes the need for a gearbox. Thus, the system requires less servicing [3].

To realize a maximum power point tracking (MPPT) operation, a power electronic interface is necessary. The converter topology based on a three-phase diode rectifier cascaded with a boost converter is more suitable for SWECS applications due to its low cost and high reliability [4]. The control objective of the power electronic interface is to extract the maximum available power from the incident wind for different wind speed values. Typically, two MPPT methods are commonly used for the control of SWECS; namely, the perturbation and observation (P&O) technique, and the technique based on optimum relationship [5].

With the first MPPT technique, the control variable allowing the system to operate at the maximum power point (MPP) is obtained, based on a pre-established optimum relationship. Numerous optimum relationships have been presented in the literature, which are all suitable for MPPT control. For example, the power versus rotor speed relationship has been used in [6]. The optimal rotational speed is generated from the measured power by [7]. In Ref. [8], the desired optimum torque is obtained from the wind turbine's optimum torque curve. The control algorithm using such

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http://dx.doi.org/10.1016/j.enconman.2015.03.062
0196-8904/

relationships to achieve the MPPT control requires rotor speed information, which is obtained from a mechanical sensor placed on the shaft of the PMSG, increasing the cost and complexity of the overall system [9]. Some authors have reported the possibility of using only the dc-variables for wind generation systems equipped with diode rectifiers to implement the MPPT without mechanical sensors, making the system more reliable. The output power and the dc-voltage were taken as input and output of the lookup table in [10]. Instead of a look up table, the authors [11] have expressed the optimal dc-voltage as a function of the dc output power with one coefficient. The dc-voltage versus dc-current optimum relationship was calculated analytically based on the system parameters in [5]. In [12], an optimum relation between the dc-voltage and the dc-current was used to track the MPP. The authors of [13] further simplify this relationship to a linear equation between the dc-current and the square of the dc-voltage.

The method based on the optimum relationship has the advantage of a good dynamic response. Nevertheless, to implement the MPPT successfully, a priori relationship needs to be known, which is not easy to determine for real wind energy systems. Moreover, the optimum relationship does not *remain constant throughout* the wind generation system's operational *lifetime* due to changes in the wind generation system itself (the aging of the system, debris built-up on the blades...) and/or in its surrounding environment (air density changes). Consequently, the MPPT controller fails to track the MPP [14].

The P&O control algorithm can overcome the problem associated with the method based on the optimum relationship. The MPP tracking can be achieved without any knowledge of the wind energy system's characteristics. This method consists of perturbing a control variable in fixed step-sizes and observing the resulting changes in the electrical output power, the sign of the next perturbation will be decided according to the comparison result between successive output power. If the power increases, the sign of the perturbation is maintained, it is inversed when the output power decreases. The authors of [15] have suggested to perturb the rotor speed and observe the output power. The measured rotor speed is controlled to track its reference provided by the P&O algorithm. Instead of measuring the rotor speed, an estimator was employed in [16] to implement the MPPT based P&O algorithm without mechanical sensor. Other control variables could be used to avoid the rotor speed measurement/estimation, such as the dc-link voltage, the dc-current or by directly adjusting the boost duty cycle [4]. Although this method is very simple and does not need any knowledge of the wind turbine system parameters, it suffers from some limitations. The efficiency/rapidity trade-off such as the large step-size means that the system reaches the MPP quickly, but exhibits large oscillations around the MPP when it is reached. Hence, the efficiency of the system is low. By using a small step-size, the efficiency of the system is improved, but the time taken by the system to reach the MPP is large, which renders the P&O algorithm incapable of tracking the MPP under rapidly varying wind conditions. Furthermore, the power variation caused by the wind changes can be misinterpreted by the P&O mechanism, resulting in a divergence of the P&O algorithm from the peak power [17].

The authors of [18] review the most proposed MPPT methods and conclude that the P&O method has not satisfactory performance under fluctuating wind speed.

Aiming to improve the efficiency and rapidity trade-off of the conventional P&O method, several researchers propose replacing the fixed step-size with a variable step-size. The perturbing step-size is obtained using the power slope with respect to the control variable. Thus, if the system is working far from the optimal point, due to the large value of the slope, a large step-size is applied, while a small step-size is imposed for an operating point close to the MPP. In one study [19], the up-dated duty cycle was selected based on the scaled measured of the slope of the power with respect to the duty cycle. In another study [20], dc-current step size was modified depending on the output power slope. The rectifier voltage variable step size has been defined based on Newton–Raphson method by the authors of [21].

Similarly, a fuzzy logic controller has been used by the authors of [22] to adjust the step-size, where the input variables of this controller are the power variation and the rotor speed variation. With the adaptive P&O technique proposed in [23], the fixed perturbing step-size used in the conventional P&O was multiplied by an adaptive coefficient, which is increased automatically during the tracking phase, so that the algorithm converges rapidly to the peak power. Once the MPP is reached, which is detected through observing the oscillations of the control variable, the algorithm gradually reduces the multiplicative coefficient to avoid the large oscillations of the system in the steady state.

The P&O which is based on a line search optimization method was proposed in [24]. In this approach, an adequate perturbing direction and step-size are computed for each iteration to satisfier the Wolfe criteria.

Generally speaking, the aforementioned P&O methods permit a high dynamic in the tracking of the MPP with fewer oscillations in the steady state. Nevertheless, the problem of the divergence from the MPP under rapid wind speed variations was not resolved by these techniques, and the system might still fail to track the MPP under these conditions. To deal with the divergence problem of the P&O method, the authors of [20] have proposed a dual- modes operation method, such as under slow wind speed fluctuations, the step-size and direction of the perturbation are defined based on the power slope, whereas they are computed from the rectifier voltage slope when the wind speed changes suddenly to avoid the divergence of the system from the MPP.

Reference [14] introduced an advanced P&O torque control to track the MPP under a fluctuating wind profile, in this approach the P&O mechanism was used to search for the optimum torque relationship.

In this paper, a modified P&O MPPT algorithm is proposed to accomplish a fast tracking of the MPP under a rapidly changing of the wind speed. The proposed MPPT is easily implemented; it requires neither the knowledge of wind system parameters nor mechanical sensors. This algorithm used in two modes of operation to deal with the aforementioned limitations associated with the traditional P&O technique. It switches from one operational mode to another according to the nature of the wind speed variation: the normal P&O mode with a small step-size is unable under a slow wind speed variation to track the MPP with fewer fluctuations in steady state, while the predictive mode is switched when a fast wind speed is detected in order to move the operating point rapidly to near the MPP .The dc-link voltage variation is employed to detect a fast wind speed variation.

Experimental work has been done to demonstrate the validity and performance improvement of the proposed MPPT control algorithm.

The rest of this paper is organized as follows: Section 2 is dedicated to the presentation and modeling of the studied system. The limitations of the conventional P&O technique are illustrated in Section 3. In Section 4, the proposed MPPT algorithm is detailed, and then the experimental prototype, as well as the validation results, are discussed in Section 5. In Section 6, we conclude this paper.

2. System configuration

The synoptic scheme of the SWECS configuration studied in this work is shown in Fig. 1. The PMSG is coupled directly to a