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Novel high efficient speed sensorless controller for maximum power extraction from wind energy conversion systems

Hassan Fathabadi

School of Electrical and Computer Engineering, National Technical University of Athens (NTUA), Athens, Greece

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A B S T R A C T

In this study, a novel high accurate sensorless maximum power point tracking (MPPT) method is proposed. The technique tracks the actual maximum power point of a wind energy conversion system (WECS) at which maximum output power is extracted from the system, not the maximum power point of its wind turbine at which maximum mechanical power is obtained from the turbine, so it actually extracts the highest output power from the system. The technique only uses input voltage and current of the converter used in the system, and neither needs any speed sensors (anemometer and tachometer) nor has the drawbacks of other sensor/sensorless based MPPT methods. The technique has been implemented as a MPPT controller by constructing a WECS. Theoretical results, the technique performance, and its advantages are validated by presenting real experimental results. The real static-dynamic response of the MPPT controller is experimentally obtained that verifies the proposed MPPT technique high accurately extracts the highest instant power from wind energy conversion systems with the MPPT efficiency of more than 98.5% and a short convergence time that is only 25 s for the constructed system having a total inertia and friction coefficient of 3.93 kg m^2 and 0.014 N m s, respectively.

1. Introduction

Due to reduction in fossil fuels availability and environmental issues such as greenhouse gas emissions, using renewable energy resources has been significantly raised [1]. Wind energy as an important type of the available renewable energies has been permanently attractive for man, and has been even utilized by some old devices such as windmills for centuries. A WECS essentially consists of a wind turbine and an electric generator [2], although for an efficient WECS supplied to a DC load, an AC/DC converter including a three-phase rectifier, and a MPPT controller are also necessary [3].

A wind turbine is the key device of a WECS which is used to convert wind energy into rotational mechanical energy [4]. Nowadays, big wind turbines located in large wind farms are widely used in wind energy conversion systems (WECSs) to produce a portion of the electric power consumed in many countries [5]. There are also small wind turbines which are widely used to provide electric energy for off-grid consumers such as remote villages [6,7]. Wind turbines are mechanical devices having high price and low energy conversion efficiency [8], so adopting an appropriate scheme to extract as much electric power as possible from WECSs is necessary [9]. It is particularly vital at low wind speed that the output power of a WECS significantly decreases [10]. For a certain wind speed, there is an optimum turbine speed at which the turbine output mechanical power reaches its maximum [11,12]. A MPPT controller tracks this optimum turbine speed [13], and then adjusts the turbine speed to this optimum speed [14]. There are various MPPT methods proposed for wind energy systems in the literature [15]. These methods such as extremum seeking control (ESC) and optimal torque control (OTC) all can be classified into the three main categories known as tip speed ratio (TSR) control based methods [16], power signal feedback (PSF) control based methods [17], and hill-climbing search (HCS) technique [18]. In the TSR control based methods, the wind and turbine speeds both should be first measured by the sensors or estimated using different physical parameters. Furthermore, the optimum TSR is also needed to adjust the actual TSR of the turbine to the optimum TSR by the controller [19]. The PSF control based methods need the mechanical power equation or maximum power curve of the wind turbine depicting the relationship between the turbine maximum power and the turbine speed [20]. For the turbine used in the system, this curve should be first obtained from off-line experiments or estimated by simulation. The turbine speed or wind speed is then used to extract the related maximum power from the mentioned power equation or curve to provide a reference power value for the controller, so that, it can adjust the

E-mail address: h4477@hotmail.com

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turbine output power to the reference value by varying the turbine speed. The OTC method is a well-known technique which belongs to this category of MPPT methods. The first problem associated with the TSR and PSF control based methods is that they all need speed sensors (anemometer and tachometer) to track the maximum output power of the wind turbine with an acceptable accuracy, otherwise, the accuracy is low, and this is the main defect of TSR and PSF control based sensorless methods reported in the literature such as those reported in [21,22]. Reduction in the tracking accuracy resulted from the variation in the environmental parameters such as ambient temperature is the second problem [23]. The HCS method is an algorithm originally proposed for photovoltaic systems, it searches the maximum power of the turbine by perturbing the wind turbine speed [24]. The main drawback of this technique is that the convergence of the algorithm and its convergence time strictly depend on the current position of the system operating point and the perturbation form [25], i.e., the algorithm may converge to wrong points that causes the turbine oscillation or even stall [26]. The maximum power point (MPP) of a wind turbine is defined as an operating point of the turbine at which the maximum mechanical power is extracted from the turbine. Similarly, the MPP of a WECS is an operating point of the WECS at which the maximum electric power is extracted from the WECS. As will be shown, the MPP of a WECS is different from the MPP of the wind turbine used in that WECS. As mentioned, all the above-mentioned MPPT methods only adjust the operating point of a wind turbine to its MPP, i.e., they do not track the MPP of a WECS, so what extracted is the maximum output mechanical power of the turbine, not the maximum power of the WECS [27].

The electric generator is the other important device used in a WECS; it converts mechanical energy into electric energy. There are different types of generators such as doubly fed induction generator (DFIG), opti-slip induction generator (OSIG), and dual-stator induction generators that are used in WECSs [28]. Permanent magnet synchronous generators (PMSGs) have higher efficiency compared to the other types due to less copper losses in the rotor [29]. High power density, reasonable price, and the possibility of direct-coupling to a wind turbine without using a gear box in the case of low variations in turbine speed are other benefits of utilizing PMSGs in WECSs [30], so a permanent magnet synchronous generator (PMSG) has been used in this study. Since a PMSG coupled to a wind turbine produces an AC electric power with variable voltage magnitude and frequency, so a power electronic converter is also needed to convert it to an appropriate form of the electric power [31]. An AC/DC converter is connected to the generator to provide an appropriate DC voltage and current for DC loads [32]. The first stage of the converter is usually a three-phase rectifier together with a filter capacitor [33]. Different converter topologies with different efficiencies can be chosen for a WECS, so the fixed structure of a WECS that determines its actual efficiency consists of the wind turbine, electric generator, and three-phase rectifier together with the filter capacitor [34].

In this study, a novel high accurate MPPT method is proposed for WECSs that only uses input voltage and current of the converter used in the system. The proposed technique neither needs any speed sensors (anemometer and tachometer) nor has the drawbacks of the other sensor and sensorless based MPPT methods which can be classified into the three main categories known as TSR control methods, PSF control methods, and HCS based methods that were explained in detail. Furthermore, the proposed technique tracks the MPP of a WECS, not its wind turbine, so it extracts the highest output power from the WECS. It is also shown that the convergence time of the technique is short enough. The proposed MPPT method has been implemented as a controller by constructing a WECS. Theoretical results, the performance of the method, and its advantages all are explicitly validated by presenting real experimental results. The rest of this paper is organized as follows. The implementation of the WECS including the proposed sensorless MPPT controller is explained in detail in Section 2. The performance evaluation of the MPPT controller is performed in Section 3 by presenting real experimental results, and the study is concluded in Section 4.

2. Implementation of the WECS including the proposed sensorless MPPT controller

The schematic diagram of the WECS implemented in this study to evaluate the performance of the proposed sensorless MPPT controller is shown in Fig. 1. The implemented WECS consists of a wind turbine, a PMSG, a three-phase diode bridge rectifier, a DC/DC boost converter, and the proposed sensorless MPPT method implemented as a MPPT controller that each unit is explained in detail in this section.

2.1. Wind turbine

The wind power P_w rotating a wind turbine is given as [35]:

$$P_w = \frac{1}{2}\rho A V_w^3 \tag{1}$$

where ρ is the air density, A is the cross sectional area of the turbine, and V_w is the wind speed. The output mechanical power P_m produced by the wind turbine is expressed as [35]:

$$P_m = C_p(\lambda, \beta) P_w \tag{2}$$

where C_p is the power coefficient, λ is the tip speed ratio, and β is the pitch angle of the turbine. The pitch angle of the turbine used in this study is zero, so

$$C_p(\lambda, \beta) = C_p(\lambda, 0) = C_p(\lambda) \tag{3}$$

The tip speed ratio is defined as [35]:

$$\lambda = \frac{R\omega_m}{V_w} \tag{4}$$

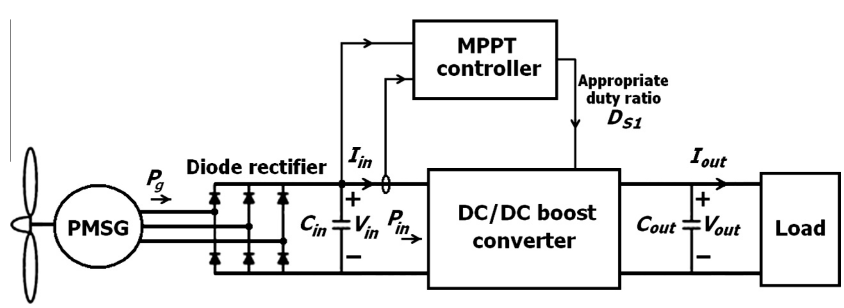

Fig. 1. Schematic diagram of the WECS implemented to evaluate the performance of the proposed sensorless MPPT controller.