Renewable and Sustainable Energy Reviews 16 (2012) 3220–3227

Contents lists available at SciVerse ScienceDirect

Renewable and Sustainable Energy Reviews

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

A review of maximum power point tracking algorithms for wind energy systems

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ARTICLE INFO

Article history:
Received 6 January 2012
Received in revised form 31 January 2012
Accepted 4 February 2012
Available online 24 March 2012

Keywords:
Wind energy
MPPT
PMSG
Boost converter

ABSTRACT

This paper reviews state of the art maximum power point tracking (MPPT) algorithms for wind energy systems. Due to the instantaneous changing nature of the wind, it is desirable to determine the one optimal generator speed that ensures maximum energy yield. Therefore, it is essential to include a controller that can track the maximum peak regardless of wind speed. The available MPPT algorithms can be classified as either with or without sensors, as well as according to the techniques used to locate the maximum peak. A comparison has been made between the performance of different MPPT algorithms on the basis of various speed responses and ability to achieve the maximum energy yield. Based on simulation results available in the literature, the optimal torque control (OTC) has been found to be the best MPPT method for wind energy systems due to its simplicity. On the other hand, the perturbation and observation (P&O) method is flexible and simple in implementation, but is less efficient and has difficulties determining the optimum step-size.

Contents

1. Introduction

Wind energy systems have gained tremendous attention over the past decade as one of the most promising renewable energy sources due to the probable depletion, high costs, and negative environmental impacts of conventional energy sources. Wind energy is a pollution-free and inexhaustible source. Therefore, a wind energy generation system could be one of the potential sources of alternative energy for the future [1,2]. In Malaysia, numerous research studies have been conducted in the area of renewable energy, which include economic feasibility studies in renewable energy utilization, such as PV-diesel system [3] and PV-wind-diesel [4].

Wind turbines are controlled to operate only in a specified range of wind speeds bounded by cut-in ($V_{cut\text{-}in}$) and cut-out ($V_{cut\text{-}out}$) speeds. Beyond these limits, the turbine should be stopped to protect both the generator and turbine. Fig. 1 shows the typical power curve of a wind turbine [5,6]. From the figure, it can be observed that there are three different operational regions. The first is the low-speed region, where the turbine should be stopped and disconnected from the grid to prevent it from being driven by the generator [7]. The second is the moderate-speed region that is bounded by the cut-in speed at which the turbine starts working, and the rated speed (V_{rated}), at which the turbine produces its rated power. The turbine produces maximum power in this region, as

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doi:10.1016/j.rser.2012.02.016

Nomenclature

$V_{\text{cut-in}}$	cut in wind speed (m/s)
$V_{\text{cut-out}}$	cut out wind speed (m/s)
V_{rated}	rated wind speed (m/s)
λ, TSR	tip speed ratio
λ_{opt}	optimal tip speed ratio
PMSG	permanent magnet synchronous generator
MPP	maximum power point
DCM	discontinuous conduction mode
PFC	power factor correction
THD	total harmonic distortion
MPPT	maximum power point tracking
ρ	air density (kg/m^3)
V_w	wind speed (m/s)
C_p	power coefficient
β	blade pitch angle (degree)
ω_m	mechanical angular velocity of the rotor (rad/s)
R	turbine radius (m)
$C_{p\,\text{max}}$	maximum coefficient of power
P_m	mechanical power of the turbine (kW)
T_m	mechanical torque of the turbine (N m)
PSF	power signal feedback
P&O	perturbation and observation
HCS	hill climb searching
d	duty cycle of the converter
I_{in}	input current of the converter (A)
V_{in}	input voltage of the converter (V)
ω	generator speed (rad/s)
ω^*	optimal generator speed (rad/s)
α	constant scaled factor
V_{ref}	input voltage reference of the converter (V)
V_{dc}	output voltage of the rectifier (V)
WRBFN	Wilcoxon radial basis function network
MPSO	modified particle swarm optimization
OTC	optimal torque characteristics

it is controlled to extract the available power from the wind. In the high speed region (i.e., between V_{rated} and $V_{\text{cut-out}}$), the turbine power is limited so that the turbine and generator are not overloaded and dynamic loads do not result in mechanical failure [7,8]. It is noteworthy that to protect the turbine from structural overload, it should be shut down above the cut-out speed. This paper focuses on the moderate-speed region, where the maximum power point tracking (MPPT) algorithm is needed.

Although the speed of the wind turbine could be fixed or variable, maximization of the extracted energy is achievable with variable speed wind turbines only. Since these turbines can change their rotational speed to follow instantaneous changes in wind speed, they are able to maintain a constant rotational speed to wind speed ratio [9]. It can be noted that there is a specific ratio called the optimum tip speed ratio (TSR) for each wind turbine for which the extracted power is maximized [1]. As the wind speed is instantaneously changing, it is necessary for the rotational speed to be variable to maintain the optimal TSR at all times. To operate in variable-speed conditions, a wind energy system needs a power electronic converter to convert the variable-voltage–variable-frequency of the generator into a fixed-voltage–fixed-frequency that is suitable for the grid [10–13]. In addition to increasing the energy capture, variable-speed turbines can be controlled to reduce the load on the drive-train and tower structure, leading to potentially longer installation life [8]. Researchers [10,14,15] have discussed the different possible configurations of power converters and electrical generators for variable-speed wind turbine systems.

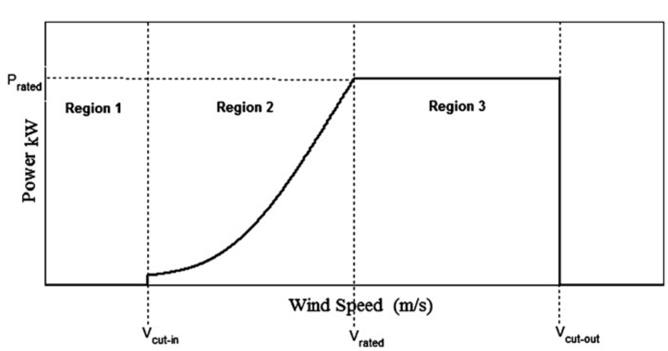

Fig. 1. Ideal power curve of a wind turbine.

Among electric generators, the permanent magnet synchronous generator (PMSG) is preferred due to its high efficiency, reliability, power density, gearless construction, light weight, and self-excitation features [16–20]. Controlling the PMSG to achieve the maximum power point (MPP) can be done by varying its load using a power electronic interface circuit. The interfacing can be done by a back-to-back converter or by a three-phase diode rectifier connected to a boost converter. According to Zhipeng et al. [20], using a rectifier and a boost converter is less expensive and more reliable. By controlling the duty cycle of the converter, the apparent load developed by the generator can be adjusted, and thus, its output voltage and shaft speed can also be adjusted. In addition, operating the boost converter in discontinuous conduction mode (DCM) and applying a power factor correction (PFC) technique contributes to a total harmonic distortion (THD) reduction and increases the power factor (PF) of the wind-power generator [21,22].

In order to determine the optimal operating point of the wind turbine, including a MPPT algorithm in the system is essential. Much has been written on the topic of MPPT algorithms, especially for wind energy systems. Raza Kazmi et al. [23] reviewed many published wind MPPT algorithms and concluded that the two methods described in Hui and Bakhshai [24] and Kazmi et al. [25] are the best solution due to their adaptive-tracking and self-tuning capabilities. Studies [1,26–28] have compared some of the wind MPPT algorithms particularly for PMSG driven wind turbines. Musunuri and Ginn Iii [29] categorized the available MPPT algorithms into nine groups based on the specified performance and measurement requirements. The authors also reported that there is an increasing trend of MPPT algorithm use among researchers over the past decade. Therefore, recent trends in the proposed wind MPPT technology should be reviewed and compiled. To the best of the current authors' knowledge, there is limited peer-reviewed literature on the MPPT algorithms for wind energy systems. This review complied and analyzed recently developed MPPT algorithms especially for wind energy systems, particularly the PMSG integrated with boost converter. The fundamentals of the available MPPT algorithms for wind energy systems are also reviewed and revised.

2. System overview

Fig. 2 illustrates the schematic diagram of the reviewed wind turbine system. The system supplies a resistive load and consists of a wind turbine rotor, PMSG, rectifier, and a boost converter.

Wind turbine converts the wind energy into mechanical energy, which then runs a generator to create electrical energy. The mechanical power generated by a wind turbine can be expressed as [30–32]:

$$P_m = \frac{1}{2}\rho\pi R^2 V^3 C_p(\lambda, \beta) \tag{1}$$