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Stability and nonlinear controller analysis of wind energy conversion system with random wind speed

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ABSTRACT

In the recent years, globally wind energy has played a vital role in renewable sources in order to minimize the environmental consequence on power generation, As a result of this, computer models of wind turbines for power system stability studies have been developed and supplied to the consumer. Therefore, the development of such models is of particular consequence for stability of power system, which has been studied and can be structured and integrated into network simulation software are needed. However, in this contribution a nonlinear control design modeling is required to stabilize and analyze wind energy conversion system (WECS) by regulating the electrical frequency and stator voltage amplitude of the squirrel-cage induction generator (SCIG) at random wind speed approach is presented. A design scheme consists of dynamic wind turbine system and 3-phase SCIG unit. In this research study, we employ a unique technique based on feedback linearization technique through field oriented control concepts. The controllers were designed in simulated software Matlab in order to regulate the SCIG constraints. The validation of the developing system models will be appropriate to provide for large system stability and control.

Introduction

New Social life due to growing environmental needs are driving force for growth of renewable energies. The most important compensation of power generation from renewable sources is the lack of harmful effects in the environment, and an inexhaustible availability of the prime mover that is converted to electricity. One way of producing electricity from renewable sources is to employ mechanical wind turbines that convert kinetic energy of wind stress into electrical power. However, wind energy conversion systems are nowadays becoming one of the most noteworthy sections of the renewable energy sources. In modern wind turbine technology, a variable wind speed operation of a large scale wind turbine system with SCIG is proficient as a preferred technology for its low investment and more flexible control systems. Moreover, wind turbines typically do not take part in frequency and voltage control if a disturbance occurs, when it is connected and disconnected when normal operation has been resumed. Therefore, despite the existence of wind turbines, maintained the frequency and voltage by controlling the bulk power house as would have been the case except any wind turbines present. However, power system stability defines the capability of a powerful network to maintain the voltage and synchronize it during severe transient disturbances such as faults. The power system consists of a large number of power devices with significant nonlinear performances [1]. This composite is difficult and time consuming to study power system stability for various scenarios and setups. Furthermore, Power system unsteadiness occurs usually in the range from 0.1–10 Hz [2]. As referring to (see [3]), power system dynamic constraints such as angle, flux, speed of electrical machines, excitation system, voltage regulator responses, mechanical turbines; power devices that can contribute the instability modes and stability are illustrated by differential equations. In the last few decades, different researchers have introduced several control techniques for the cage induction machine combined with wind turbine unit for the stability due to uncertain wind speed circumstances; their common goal was the development and design methods for controlling nonlinear system structures in order to track reference signals at the output side. Even though these schemes are prevailing, but suffer due to system uncertainties such as constraint disparities, because dynamic wind turbine model often exists in nonlinear structure except feedback linearization techniques which is simple, reliable and low cost techniques [4–6]. Numerous algorithms are

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important and frequently used in concurrence with a controller that guarantees other feedback ideal performance conditions [7–13]. A design is available, which is similarly one we consider in our work for the controller, and focus on speed sensor less closed-loop algorithm [14]. In addition, Jacobian linearization employs a design for a control purpose, and oscillatory in the dynamic system variations. One more idea based on fuzzy logic concept is used for wind power system performance as illustrated in [15]. The model dependent designs have some shortcomings that power system performance technique and nonlinear controller have to be redesigned carefully for each wind energy conversion system. Referring to (see [3,9,11]), presented the same design technique but dissimilar from our work in several aspects, including some assumptions of system performance, robustness and dynamic model based on field oriented control concept. None of the previous research study the linearization system performance except [2]. It is essential that the output wind turbine power stays at a bounded stable at rapidly untrustworthy wind speed circumstances. The main contribution of the proposed approach is to design the nonlinear controller based on feedback linearization techniques which compensate the modeling errors, in order to stabilize the system. To the best of our knowledge, this is a new research work in this paper which will examine the development of wind turbine models stability studies that have good performance and better robustness to uncertainty, at rapidly varying wind speed circumstances.

In this research study, a general wind speed model is introduced for representation of variable wind turbine speed in power system dynamics simulations is presented. The general model has been developed to facilitate and investigate the impact of large amounts of wind turbines on the behavior of power system.

Wind speed model

The wind speed model contains a source that generates a wind speed signal to be applied to the wind turbine. The wind speed signal consists of four modules, namely, the basic wind speed; a gust wind speed; a gradient wind speed which is a steady increase in the basic wind speed, and a random wind speed. The concluding wind speed applied to the automated wind turbine is the summation of these four modules and can be characterized as follows [16–18].

The main interest is to evaluate the dynamic performance of the wind turbine unit with well known induction generator. The main model used for the simulations of the dynamic system is developed in the below discussed wind speed model sections. The general schematic structure diagram of wind speed model including wind turbine (WT) and SCIG can be depicted in Fig. 1.

Basic wind speed model

It is generally recognized that the basic wind speed can be considered as an average wind speed is often assumed to be constant; therefore the basic wind speed model is described as follows:

$$V_b = k_b, \tag{1}$$

A gust wind speed model

The gust wind speed is used to describe the characteristics of a sudden change on the grid voltage fluctuations due to the unreliable wind speed circumstances. The gust wind speed model can be described as follows:

$$V_g = \begin{cases} 0, (t < t_1) \\ \frac{V_{\mathrm{gmax}}}{2}\left\{1 - \cos\left[2\pi\left(\frac{t - t_1}{T_g}\right)\right]\right\}, & (t_1 \leqslant t \leqslant t_1 + T_g), \\ 0, (t > t_1 + T_g) \end{cases} \tag{2}$$

A gradient wind speed model

The gradient wind speed is modeled as a simple shear demonstrating a vertical speed profile variation, according to the power law with a constant exponential coefficient based on surface type. The gradient wind speed model can be characterized as follows:

$$V_r = \begin{cases} 0, & (t < t_{r1} \text{ or } t > t_{r2} + t_{r3}) \\ V_{\mathrm{rmax}}\frac{t - t_{r1}}{t_{r2} - t_{r1}}, & (t_{r1} \leqslant t \leqslant t_{r2}) \\ V_{\mathrm{rmax}}, & (t_{r2} < t \leqslant t_{r2} + t_{r3}) \end{cases}, \tag{3}$$

A random wind speed model

The random wind speed model can be described as follows [19]:

$$V_n = V_{\mathrm{nmax}} R_{am}(-1,\ 1)\cos(\omega_{nt} + \varphi_n), \tag{4}$$

where V_n is the random wind speed in (m/s), V_{nmax} is the maximum random wind speed measured in (m/s); R_{am} is the random variable, its random range is $[-1,\ 1]$.

The wind speed model recommends the opportunity to modify the standards of all characteristics of wind speed signal to be applied, individually from the initial value of the mean wind speed when the wind turbine distributes less than supposed power. This value is determined on the basis of power produced by the wind turbine at starting load flow.

Wind energy conversion system

The schematic diagram of a WECS including squirrel cage induction generator and wind turbine, interconnected to the power grid through the overhead transmission line configuration is depicted in Fig. 2. The power generated from wind turbine depends on the interaction between wind flowing toward wind turbine and wind turbine rotor [20–22].

The power produced by the wind on the turbine blade area is given as follows:

$$P_\omega = 0.5\rho A v_\omega^3; \quad A = \pi r^2, \tag{5}$$

where r is the length of turbine blade in (m), ρ is the wind density in (kg/m^3), A is the turbine blade swept area in (m^2), v_ω is the wind speed in (m/s).

The relationship among turbine torque T_t, wind turbine power P_t and wind turbine speed ω_t is described as follows:

$$T_t = P_t(\omega_t, v_\omega)\frac{1}{\omega_t} = P_\omega C_p(\omega_t, v_\omega), \tag{6}$$

$$P_t(\omega_t, v_\omega) = 14.33\, v_\omega^3 \frac{\left(\frac{151}{\lambda_c} - 0.58\delta - 0.002\delta^{2.14} - 13.2\right)}{\exp\left(18.4\frac{1}{\lambda_c}\right)}, \tag{7}$$

from Eq. (7), P_t represents the power produced through mechanical wind turbine, and it is the function of the wind speed v_ω and tip speed ratio λ_c. However, the wind speed is an input disturbance and we regulate the turbine speed to govern the wind turbine with bounded stable condition. As referring to (see [23]), the tip speed ratio (TSR) λ_c can be classified as follows:

$$\lambda_c = \left(\frac{1}{\lambda - 0.002\delta} - \frac{0.003}{\delta^3 + 1}\right)^{-1}. \tag{8}$$

From Eq. (6), C_p represents the wind power coefficient, expressing the aerodynamic rotor turbine efficiency, according to the Betz law theory, the theoretical value of C_p is about 0.590, but the practical range of variation is about 0.20–0.40 (see [10,16,17,24–26]).