Type-2 Fuzzy Logic Pitch Controller for Wind Turbine Rotor Blades

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***Abstract*—Wind energy contribution as a new source of green energy in electric utility systems around the world is on fast increase. One of the major challenges is its natural intermittency; unpredictability, and uncertainty. In this paper, two and three dimensional profiles are presented for the torque coefficient and turbine output torque surface response. Interval Type-2 Fuzzy Controllers (IT2FCs) are proposed to control the nonlinear pitch angle system of the rotor blades in variable speed wind turbine. The IT2FCs proposed in this paper were designed to deal with uncertainty and noisy inputs. In addition, the nonlinear pitch angle system is piecewise linearized based on two linear time invariant (LTI) models. The LTIs were controlled using a regional switched controller schemes that allow the controllers to cover the state space of the pitching system.**

Keywords-component; Uncertainty, Interval Type-2 Fuzzy Logic Controller, Torque Coefficient, Regional controller.

I. INTRODUCTION

The wind has served mankind well for many centuries by propelling ships and driving wind turbines to grind grain and pump water [1]. Wind energy is considered one of the very fast growing green energy resources all over the world, especially in the Europe, USA, Canada, Middle-East, and Africa [2]. A wind turbine (WT) transforms the energy of the wind stream blowing through its blades into useful mechanical energy. It consist of three main parts; turbine blades, turbine body and turbine mill that is connected to the gear box (unless the WT is gearless) which is subsequently connected to an electric generator. A tower carries all these parts, which form a single unit in the wind farm [3].

Wind power generation became a great challenge for both mechanical and electrical engineers because of the problems encountered in the electrical grid (network) due to the continuous variation in wind speed and wind direction [4]. WTs can operate either at fixed or variable speed. In variable-speed wind turbine; generator is controlled by power electronics (PE). There are several reasons for using variable-speed operation of wind turbines like: the possibilities to reduce stresses of the mechanical structure, reducing the acoustic noise and the possibility to decouple both active and reactive power [5]. Large WTs are all based on variable-speed operation with pitch control, or in other words active-stall wind turbine, which has a pitch system, allowing the turbine to vary the pitch angle of the blades [6, 7].

Pitch angle control of the wind turbine blades is a main control loop in variable speed wind turbines. Blade pitch is an effective method of response to aerodynamic loads [6, 7]. Pitch angle control is used to limit, or even to stall (additional Yaw rotation control, or mechanical brakes may be used), the rotation speed above rated wind speed based on the concept of cut-in and cut-out speeds.

This paper is organized as follows. Section II presents the wind energy calculations and the torque coefficient and tip speed ratio (TSR) profiles, as well as, the turbine output torque profiles. Section III describes the proposed type- 2 fuzzy (T2FS) system approach. Section IV introduces the nonlinearities associated with pitching system. Section V presents the results obtained for the case studies, as well as, discusses the results before Section VI concludes.

II. SIGNIFICANCE OF WIND ENERGY

The main objective of most of the WECS is to extract the maximum power available in the wind stream [4]. WECS transforms the available ideal energy of the wind blowing through its blades into mechanical energy.

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

where, P_w is the total power existing in the wind stream in Watts, ρ is the air density in kg/m^3, A is the swept area of the wind turbine blades in m^2, and V_w is the wind-stream speed in m/s. According to so called Betz limit (16/27) which shows that that an actual turbine cannot extract more than 59.3% of the power in an undisturbed tube of air of the same area. In practice, the fraction of power extracted can be utilized [1].

$$P_m = \frac{1}{2}\rho A C_p(\lambda,\beta) V_w^3 \tag{2}$$

$$\lambda = \frac{\omega R}{V_w} \tag{3}$$

where, P_m is the mechanical power that could be captured from the total wind power, C_p is the power coefficient which is a function of the TSR (λ) and the pitch angle of the wind turbine blades (β) in degrees. Equation (3) shows the TSR is the ratio between the linear speed of the rotor and the wind-speed, where ω is the generator speed in rad/s and R is the blade length in meters. The power coefficient $C_p(\lambda, \beta)$ has a common generic form, [8], as shown in (4) and (5)