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Adaptive Robust Control of Variable Speed Wind Turbine Generator

Ahmad Zare*[1], Ahmad Forouzantabar[2]
[1]Department of Electrical Engineering, Mehriz Branch. Islamic Azad University, Mehriz, Iran.
[2]Department of Electrical Engineering, Marvdasht Branch. Islamic Azad University, Marvdasht, Iran
*Corresponding author, e-mail:ahmadzare3218@gmail.com; Ahmad.foruzan@gmail.com
Ph./Fax: +983525229100

Abstract

In this work we want to propose a control strategy to maximize the wind energy captured in a variable speed wind turbines, for this goal the speed of turbine should keep in optimum speed when the wind speed is changing. Many control approach has been suggested that is base on approximate models that it causes unsuitable behavior of system because of Uncertainty parameters of the system. Hence at this work we use adaptive robust control approach that it can to compensate Uncertain of the parameters and present a smooth system with maximum energy production. Numerical simulations are given to illustrate the effectiveness and validity of the proposed approach.

Keywords: *Variable Speed Wind Turbine, Controller, Adaptive controller, Robust controller, Adaptive robust controller.*

1. Introduction

Wind power was recognized as a valuable resource thousands of years before internal combustion engines and modern power plants were developed. Long ago, for example, people built windmills for milling grain and installed sails on their boats in order to reduce human labor demands. In recent decades, wind has experienced resurgence in popularity by helping to meet the increasing energy consumption of a growing world population through the use of a renewable, non-polluting energy source.

Wind energy is currently the fastest-growing source of electricity in the world. Wind power investment worldwide is expected to expand three-fold in the next decade, from about $18 billion in 2006 to $60 billion in 2016 [1].

There are many different types of wind turbines in use around the world, many different configurations of variable speed wind turbines have been developed, a configuration presently being examined by many authors is the use of a doubly fed induction generator.

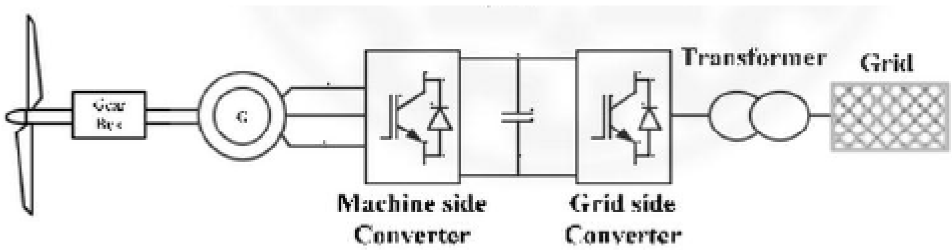

Figure 1. Variable pitch wind turbine connected to an asynchronous machine

Several control strategies were proposed for the control and maximize the wind energy captured in a variable speed wind turbines. Some of these strategies are reviewed below:

S.A. Salle and et. al. has been reviewed wind turbine control in 1990 [3]. E. Muljadi and et. al. present a work entitle Variable speed operation of generators with rotor-speed feedback

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in wind power applications in 1996[4]. A.R. Bergen, Power System Analysis has been presented and one section of this book is about wind turbine [5]. In [5] Robust Control of Variable-Speed Wind Turbines Based on an Aerodynamic Torque Observer, has been suggested by Corradini and et. al. and in [6] Mullane, has been designed an Adaptive Control of Variable Speed Wind Turbines. Laks and et. al. present Control of wind turbines: Past, present, and future[7]. Song and et. al. suggested and design an Variable speed control of wind turbines using nonlinear and adaptive algorithms. But this works don't consider Uncertainty parameters of the system, in this work we will apply this Uncertainty parameters of the system and control and optimum the Variable Speed Wind Turbine.

2. System Modeling

The power extraction of wind turbine is a function of three main factors: the wind power available, the power curve of the machine and the ability of the machine to respond to wind fluctuation. The expression for power produced by the wind is given

$$p_m(u) = \frac{1}{2} c_p(\lambda, \beta) \rho \pi R^2 u^3 \tag{1}$$

Where ρ is air density, R is radius of rotor, u is wind speed, C_p denotes power coefficient of wind turbine, λ is the tip-speed ratio and β represents pitch angle. Note that the tip-speed ratio is defined as

$$\lambda = \frac{R\omega}{u} \tag{2}$$

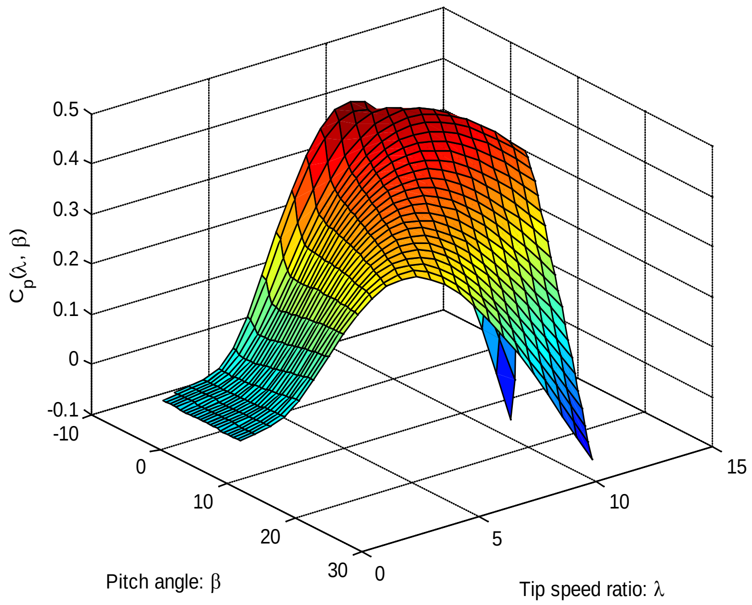

Figure 2. Illustration of the power coefficient, Cp.

Where ω is the rotor speed. It is seen that if the rotor speed is kept constant, then any change in the wind speed will change the tip-speed ratio, leading to the change of power coefficient C_p as well as the generated power out of the wind turbine. If, however, the rotor speed is adjusted according to the wind speed variation, then the tip-speed ratio can be maintained at an optimal point, which could yield maximum power output from the system. From Eqs. (1) and (2) we can see that

$$P_m(\omega) = k_w \omega^3 \quad (3)$$

where

$$k_w = \frac{1}{2} c_p \rho \pi \frac{R^5}{\lambda^3} \quad (4)$$

For a typical wind power generation system, the following simplified block diagram (Figure 2) is used to illustrate the fundamental work principle. We see that such a system primarily consists of an aeroturbine, which converts wind energy into mechanical energy, a gearbox, which serves to increase the speed and decrease the torque and a generator to convert mechanical energy into electrical energy. Driving by the input wind torque T_m the rotor of the wind turbine runs at the speed ω. The transmission output torque T_p is then fed to the generator, which produces a shaft torque of T_e at generator angular velocity of ω_e. Note that the rotor speed and generator speed are not the same in general, due to the use of the gearbox.
The dynamics of the system can be characterized by the following equations:

$$T_m - T = J_m \dot{\omega} + B_m \omega + k_m \theta \quad (5)$$

$$T_p - T_e = J_m \dot{\omega}_e B_e \omega_e + k_e \theta_e \quad (6)$$

$$T_p \omega_e = T\omega \quad (7)$$

γ the gear ratio is defined as:

$$\gamma = \frac{\omega_e}{\omega} \quad (8)$$

Upon using Eqs. (6) and (7), we can combine Eqs. (4) and (5) to get

$$J \dot{\omega} + B \omega + k \theta = T_m - \gamma T_e \quad (9)$$

or equivalently

$$J \dot{\omega} + B \omega + k \theta = \frac{P_m}{\omega} - \gamma \frac{P_e}{\omega_e} \quad (10)$$

With

$$J = J_m + \gamma^2 J_e \quad (11)$$

$$B = B_m + \gamma^2 B_e \quad (12)$$

$$k = k_m + \gamma^2 k_e \quad (13)$$

Where P_m denotes the wind power given by Eq. (3) and P_e represents the electric power generated by the system. It is well known that P_e is related to the excitation current of the generator via [5].

$$P_e = k_\Phi \omega_e c\,(I_f) \quad (14)$$

Where K_Φ is a machine-related constant, *c*(.) is the flux in the generating system, and I_f is the field current.
Power generated by turbine is:

$$P_g = T_g \omega_r \qquad (15)$$

3. Control Design

In this section we suppose that the wind turbine in variable speed is in maximum power, and our goal is design a suitable input for turbine dynamic to get suitable speed. The main problem is the uncertainty in dynamics of system that rise from Lack of knowledge parameter dynamics of system or despite the noise. For this reasons by use of adaptive approach for track the input we want to control the system after that because of despite the noise by adaptive robust controller we control and optimum operation of system. At the end simulation of all methods will be present.

In most of references for a wind turbine use from bellow equation [10]:

$$J_t \dot{\omega}_r = T_a - T_g - k_t \omega_r \qquad (16)$$

According to equation (8) in different wind speeds we have a fix value of λ that it cause maximize produce power.

For design a controller at the first we should describe error signal, hence suppose that ω_{rd} is desire velocity of rotor and ω_r is real speed of rotor error of system is As follows:

$$e = \omega_r - \omega_{rd}$$

And for dynamics error of signal will have:

$$\dot{e} = \dot{\omega}_r - \dot{\omega}_{rd} = \frac{1}{J_t} T_a - \frac{1}{J_t} T_g - \frac{k_t}{J_t} \omega_r - \dot{\omega}_{rd} \qquad (17)$$

The main equation of low control for this system is (16) and the low of adaptive is:

$$\dot{k}_t = -\gamma_1 \omega_r e - \sigma \gamma_1 k_t \qquad (18)$$

$$\dot{J}_t = -\gamma_2 \dot{\omega}_d e - \sigma \gamma_2 J_t \qquad (19)$$

After use roles of Lyapunov will obtain final system:

$$V(t) \le V(0) e^{-\beta t} + \frac{\beta_2}{\beta_1}\left(1 - e^{-\beta t}\right) \qquad (20)$$

At the end we gain controllers As follows:

a- Adaptive controller

$$T_g = T_a - k_t \omega_r - J_t \dot{\omega}_{rd} + \alpha e \qquad (21)$$

$$\dot{k}_t = -\gamma_1 \omega_r e \qquad (22)$$

$$\dot{J}_t = -\gamma_2 \dot{\omega}_d e \qquad (23)$$

b- Adaptive robust controller

$$T_g = T_a - k_t \omega_r - J_t \dot{\omega}_{rd} + \alpha e \qquad (24)$$

$$\dot{k}_t = -\gamma_1 \omega_r e - \sigma \gamma_1 k_t \qquad (25)$$

$$\dot{J}_t = -\gamma_2 \dot{\omega}_d e - \sigma \gamma_2 J_t \qquad (26)$$

4. Simulation Study

The simulation study was performed to verify the effectiveness of the proposed control algorithms. The following system parameters are considered.

Table 1. Value of parameters

P	1.25Kg.m^3
R	40
K_t	52 Nm.rad^{-1}.s^{-1}
J_t	16 Kg.m^2
α	15
γ_1	3
γ_2	3

The value of f chosen [1.5, 1.5] N.m and applied on system. We use from data of ref. [11].
The speed of wind supposed 8 Km/h, at the bellow see the simulation of rotor and error of tracking:

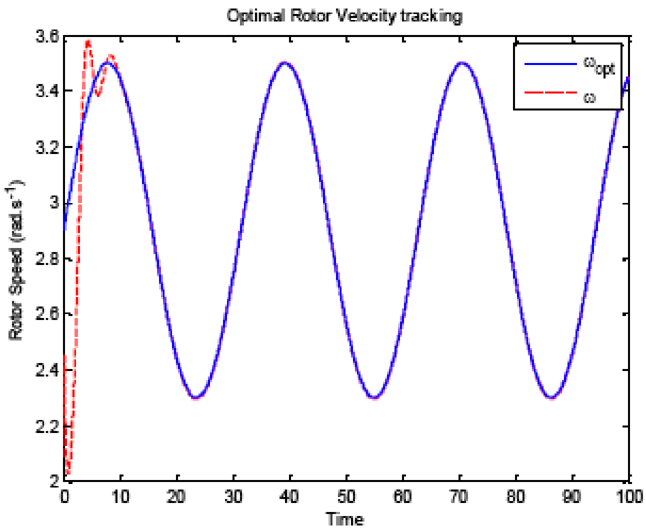

Figure 3. Speed of rotor in real and desire value with pure adaptive controller

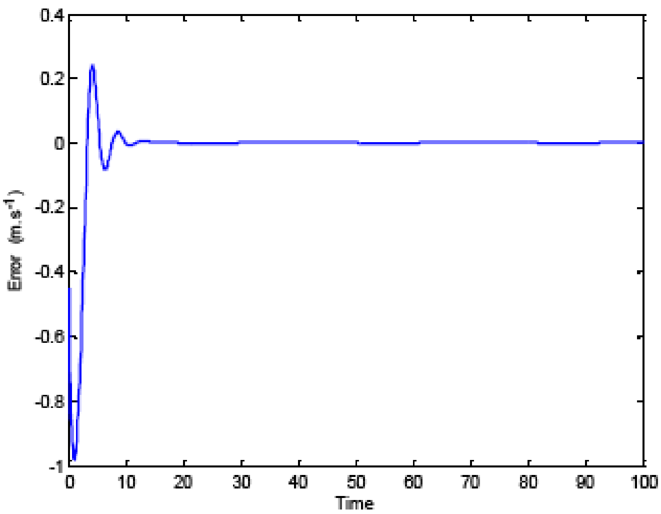

Figure 4. Tracking error in controlled system by pure adaptive controller

The system will work stable and after about 10 seconds we haven't error.
At the continue we want to control the system by use of adaptive robust method that all parameters of system is certain and we haven't uncertainty, at the bellow we have simulation results:
At the first step we apply a noise to system:

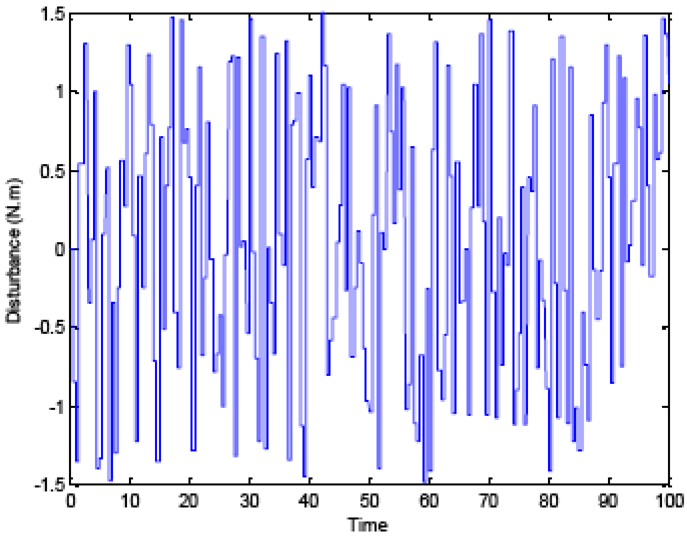

Figure 5. Applied noise to system

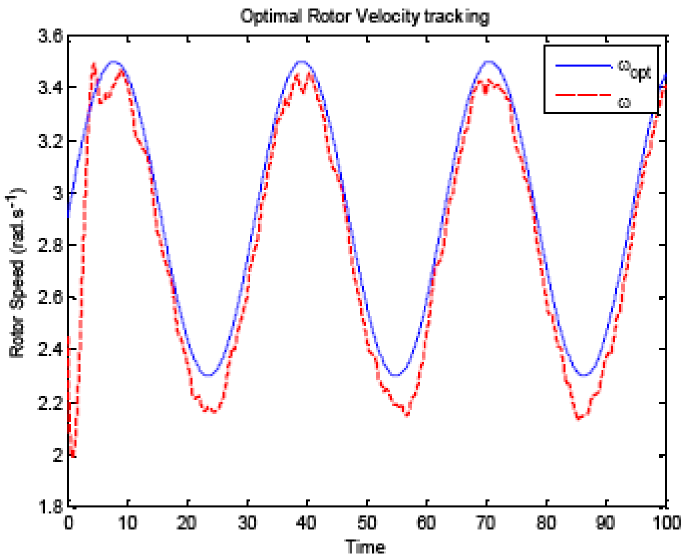

Figure 6. Speed of rotor in real and desire value with adaptive robust controller

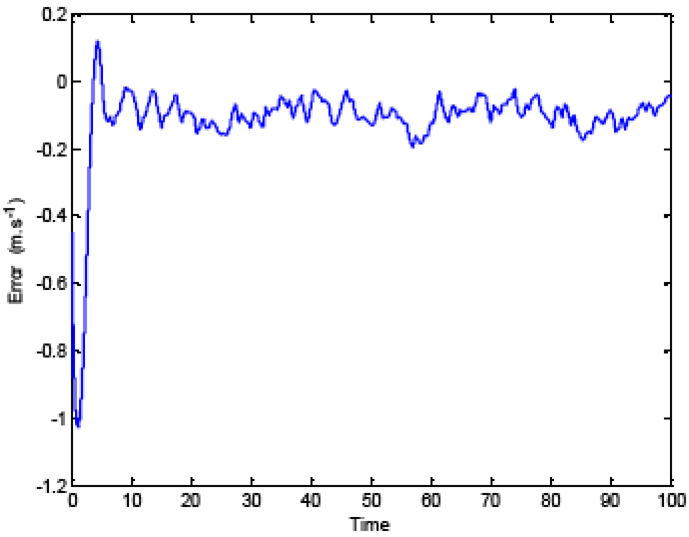

Figure 7. Tracking error in controlled system by adaptive robust controller

In the tracking error in controlled system by adaptive robust controller we see that despite the noise the system work acceptable with a small fluctuation around zero value.

5. Conclusion

Variable speed operation of wind turbine is necessary to increase power generation efficiency. In this paper at the first described the variable speed wind turbine, after that explained problems in generate electrical energy. To solve these problems and maximize the produce energy without noise design an adaptive controller and in next step applied noise to system and design an adaptive robust controller for system. In this controller we consider all parameters and we haven't any uncertainty, at the end we observed that the controller controlled system with a very small error around zero that it is acceptable.

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References

[1] World Wind Energy Association, http://www.wwindea.org/.
[2] Mike Robinson, Paul Veers. Wind Turbine Control Workshop. Santa Clara University, Santa Clara, CA. 1997.
[3] SA Salle, D Reardon, WE Leithead, MJ Grimble. Review of wind turbine control. *Int. J. Control*. 1990; 52(6): 1295-1310.
[4] E Muljadi, CP Butter"eld, P Migliore. Variable speed operation of generators with rotor-speed feedback in wind power applications. Fifteenth ASME Wind Energy Symposium, Houston, Texas. 1996.
[5] AR Bergen. Power System Analysis. Prentice-Hall, Englewood Cli!s, NJ. 1996.
[6] Corradini, Maria Letizia, Gianluca Ippoliti, and Giuseppe Orlando. "Robust Control of Variable-Speed Wind Turbines Based on an Aerodynamic Torque Observer". *IEEE Transactions on Control Systems Technology.* 2013; 21(4): 1199-1206.
[7] Mullane, Alan, G Lightbody, and R Yacamini. "Adaptive control of variable speed wind turbines". In *n proceedings of 36th Universities Power Engineering Conference, Swansea*. 2001.
[8] Laks, Jason H, Lucy Y Pao, and Alan D Wright. "Control of wind turbines: Past, present, and future." In *American Control Conference, 2009. ACC'09,* IEEE, 2009: 2096-2103.

[9] Song YD, B Dhinakaran, and XY Bao. "Variable speed control of wind turbines using nonlinear and adaptive algorithms". *Journal of Wind Engineering and Industrial Aerodynamics*. 2000; 85(3): 293-308.

[10] B Beltran, T Ahmed-Ali and M Benbouzid. "Sliding Mode Power Control of Variable-Speed Wind Energy Conversion Systems". *IEEE Transactions on Energy Conversion*. 2008; 23(2): 551-558.

[11] NA Cutululis, E Ceanga, AD Hansen and P Sorensen. "Robust multi-model control of an autonomous wind power syste". *Wind energy*. 2006; 12(9): 399-419.

[12] Gholipour, Yousof, and Mahmood Mola. "Investigation stability of Rikitake system". *Journal of Control Engineering and Technology*. 2014; 4(1).

[13] Gholipour, Yousof, Amin Ramezani, and Mahmood Mola. "Illustrate the Butterfly Effect on the Chaos Rikitake system". *Bulletin of Electrical Engineering and Informatics*. 2014; 3(4): 273-276.

[14] Gholipour, Yousof. "A Review on Comparision of the Effect of I and PI Controller on a Quadruple-Tank Process". *International Journal of Engineering*. 2015; 6(01): 8269.

[15] Gholipour, Yousof, and Mojtaba Chavooshi Zade. "Replacement Unstable Transmission Zeros for a Non Minimum Phase Quadruple-Tank Process". 2015.

[16] Gholipour, Yousof, Esmail Mirabdollahi Shams, and Iran Mehriz. "Introduction new combination of zero-order hold and first-order hold". 2014.

[17] Gholipour Y, and M Mola. "Stabilization of Chaos Rikitake System by use of Fuzzy Controller". *Sci. Int*. (Lahore). 2015; 27(1).