

Power Control for High Speed Wind by Using the Backstepping Strategy

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Abstract— This paper proposes a new approach based on the association of backstepping control with genetic algorithm for power generation control of variable speed wind turbine under the effect of high wind. The Genetic algorithms are used to estimate the values of the pitch angle and Tip speed ratio and the backstepping control is used to calculate electromagnetic torque applied to the system to enslave the speed of the generator. The simulation results demonstrate the effectiveness of the proposed control strategy.

Keywords-genetic algorithm, Backstepping control, wind turbines, pitch angle.

I. INTRODUCTION

Recently, the majority of wind turbine used in wind farms is based on doubly fed induction generator (DFIG) due to some advantages like, the variable speed generation, the improvement of the power quality....[1-2]. Many previous research works have treated the problem of controlling the turbine in high wind speed; Bianchi et al. [3] have proposed the use of the optimal control for regulate the power, Boukhezzer et al. [4] have used a multivariable control strategy by combining a nonlinear dynamic state feedback torque control strategy with a linear control strategy for the blade pitch angle, in the other side, Serdar al. [5] proposed the use of the artificial neural network, Bououden et al [6] the LMI design with predictive control and Camblong [7] the Digital robust control. The aim of this paper is to establish a control law that maintains the power to its nominal value in high wind speed. For this, we use the nonlinear backstepping control associated with genetic algorithm; this combination can not only increase the performance of the electrical power but also optimize the pitch angle of the blades. In the first part of our work, we describe the model of the turbine, then, we present the control strategy of wind turbine system. With the backstepping technique, we develop the command (Electromagnetic torque) applied to the system to enslave the speed of the generator and to further improve the performance of the proposed control, we use the genetic algorithm to optimize the pitch angle of the blades.

II. MODELLING OF THE TURBINE

As is shown in fig.1 [6], the mechanical part of the wind turbine is constituted of: a rotor which is generally composed of three blades, a speed multiplier whose role is to adjust the speed of the rotor to that of the electric generator. The generator only represents the electrical part. The energy contained in the wind depends on the following parameters: rotor radius (R), the wind speed (v), and the air density (ρ), this energy is given by [9]:

$$P_v = \frac{1}{2} \rho S v^3 = \frac{1}{2} \rho \pi R^2 v^3 \quad (1).$$

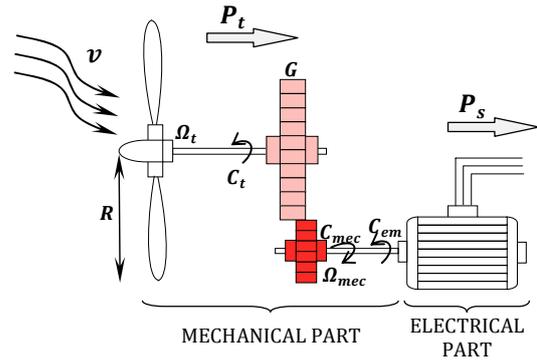


Figure.1. Configuration of a wind turbine.

[10] give the wind power captured by the rotor: $P_t = C_p \left(\frac{1}{2} \rho \pi R^2 v^3 \right)$ (2), where, the power coefficient (C_p) represents the aerodynamic efficiency of the turbine and depends on the specific speed (λ) and the pitch angle (β) [11]. It is given by:

$$C_p(\lambda, \beta) = c_1 \left(c_2 \left(\frac{1}{\lambda + 0.08\beta} - \frac{0.035}{\beta^3 + 1} \right) - c_3\beta - c_4 \right) e^{-\left(\frac{1}{\lambda + 0.08\beta} - \frac{0.035}{\beta^3 + 1} \right)} + c_6\lambda \quad (3), \text{ with, } c_1 = 0.5109, c_2 = 116, c_3 = 0.4, c_4 = 5, c_5 = 21, c_6 = 0.0068.$$

Where, λ represents the ratio between the blades linear speed and the wind speed, it is given by: $\lambda = \frac{R\Omega_t}{v}$ (4). Ω_t , is the mechanical angular speed of the turbine (rad/sec). The mechanical torque available on the axis of the turbine is given by:

$$C_t = \frac{P_t}{\Omega_t} = \frac{0.5C_p\rho\pi R^2 v^3}{\Omega_t} \quad (5).$$

The mechanical torque (respectively, the mechanical angular speed) on the axis of the generator are given by:

$$\begin{cases} C_{mec} = \frac{1}{G} C_t \\ \Omega_{mec} = G\Omega_t \end{cases} \quad (6),$$

where, G is the multiplication ratio.

The model of the generator shaft is given by the following expression [12]:

$$J\dot{\Omega}_{mec} = C_{mec} - C_{em} - f\Omega_{mec} \quad (7),$$

with, J , the total inertia of the rotating parts ($Kg \cdot m^2$), f , the coefficient of viscous damping. C_{em} , the electromagnetic torque of the generator

$$(N.m). J = \frac{J_{Turbine}}{G^2} + J_{Generator} \quad (8).$$

According to (4), (5) and (6)

$$: C_T = K_1 K_2 \Omega_{mec}^2 - C_{em} \quad (9),$$

where,

$$K_1 = \frac{0.5\rho\pi R^5}{G^3} \quad (10),$$

$$K_2 = \frac{C_p}{\lambda^3} \quad (11).$$

Then, the dynamic of the system is given by:

$$\dot{\Omega}_{mec} = \frac{1}{J} (K_1 K_2 \Omega_{mec}^2 - f\Omega_{mec} - C_{em}) \quad (12).$$

III. BACKSTEPPING CONTROL

The idea of backstepping control [13] consists in calculating a control law in order to guarantee that the derivative of Lyapunov function (definite positive) is always negative. First, we calculate the first virtual command from the tracking error $e_1 = y - y_{ref}$, this command will be used in the second step as a reference signal for the next state. We repeat the operation until reaching the n^{th} step where we obtain a command that will be applied to the system. In our work, the state vector contains only one variable (Eq.12). So, the synthesis of the backstepping control law is composed of a single step.

We have as a reference, $y_{ref} = \Omega_{mec}^{ref}$. The tracking error is given by: $\varepsilon_\Omega = \Omega_{mec} - \Omega_{mec}^{ref}$ (13).

The time derivative is written: $\dot{\varepsilon}_\Omega = \dot{\Omega}_{mec} - \dot{\Omega}_{mec}^{ref} = \frac{K_1 K_2}{J} \Omega_{mec}^2 - \frac{f}{J} \Omega_{mec} - \frac{1}{J} C_{em} - \dot{\Omega}_{mec}^{ref}$ (14).

The Lyapunov function is given by: $v(\varepsilon_\Omega) = \frac{1}{2} \varepsilon_\Omega^2$ (15). If this function is always positive definite and its derivative is always negative, then the error will be stable and will tend towards zero. The derivative of the error is given by: $\dot{v}(\varepsilon_\Omega) = \varepsilon_\Omega \dot{\varepsilon}_\Omega = \varepsilon_\Omega \left(\frac{K_1 K_2}{J} \Omega_{mec}^2 - \frac{f}{J} \Omega_{mec} - \frac{1}{J} C_{em} - \dot{\Omega}_{mec}^{ref} \right)$ (16). A good choice of C_{em} would render $\dot{v}(\varepsilon_\Omega)$ negative and ensure the stability of the

origin of (14). Then: $\frac{K_1 K_2}{J} \Omega_{mec}^2 - \frac{f}{J} \Omega_{mec} - \frac{1}{J} C_{em} - \dot{\Omega}_{mec}^{ref} = -k\varepsilon_\Omega$ ($k > 0$) $\Rightarrow \frac{1}{J} C_{em} = \frac{K_1 K_2}{J} \Omega_{mec}^2 - \frac{f}{J} \Omega_{mec} - \dot{\Omega}_{mec}^{ref} + k\varepsilon_\Omega \Rightarrow C_{em} = K_1 K_2 \Omega_{mec}^2 - f\Omega_{mec} - J\dot{\Omega}_{mec}^{ref} + Jk\varepsilon_\Omega$ (17). With this choice, we obtain: $\dot{v}(\varepsilon_\Omega) = -k\varepsilon_\Omega^2 \leq 0$. By neglecting losses, the electrical power produced by the generator is given by:

$$P_e = C_{em} \Omega_{mec} \quad (18).$$

IV. OPTIMIZATION WITH GENETIC ALGORITHMS

If we apply the command C_{em} while keeping the pitch angle (β) null, we can never limit the power at its nominal value, hence the necessity to optimize β . The optimization by a genetic algorithm [14] of β from equation (3) will stabilize C_{em} , which brings us to obtain a nearly constant electric power around its nominal value.

V. SIMULATION RESULTS

300 KW wind turbine is used in simulation. The numerical values are given in Tab. 1.

The wind speed is comprised between 12.7 m/s and 19.2 m/s (fig.02), the rated speed is 12 m/s. The nominal value of the generator speed is 159.6857 rad/s and $0^\circ < \beta < 90^\circ$. The aim of controlling is to limit the electrical power to 300 KW.

In fig.3 we present the not optimized pitch angle. In fig.4, the pitch angle (β) optimized with the genetic algorithm is presented.

TAB. 1. PARAMETERS OF WIND TURBINE WITH THREE BLADES

Parameters	$R_s (\Omega)$	$R_r (\Omega)$	$L_s (H)$
Numerical value	0.0063	0.0048	0.0118
Parameters	$L_r (H)$	$L_m (H)$	P
Numerical value	0.0116	0.0116	2
Parameters	Number Generations	Mutation probability	$J (Kg \cdot m^2)$
Numerical value	20	5%	50
Parameters	f	$R (m)$	G
Numerical value	0	14	23
Parameters	ρ	Pop size	Crossover probability
Numerical value	1.22	100	80%

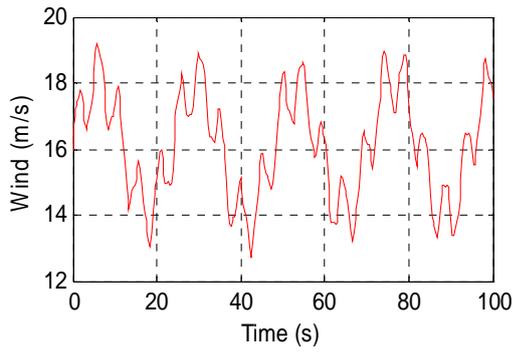


Figure.2. Wind profile.

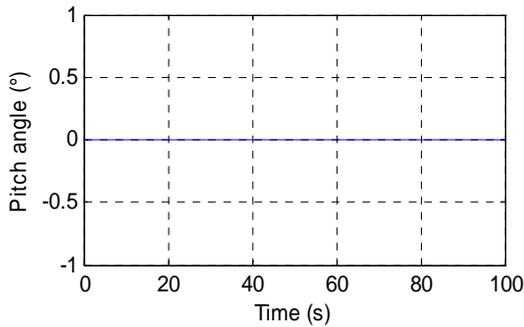


Figure.3. Pitch angle not optimized.

In fig.5 and fig.6, the tip speed ratio (λ) does not exceed the optimal value ($\lambda_{opt} = 8.1$), which is normal. It is not affected by the pitch angle change; we obtained almost the same result with and without optimization of β (fig.4).

In fig.07 the power coefficient exceeds its maximum value ($C_p^{max} = 0.4745$), which is unacceptable. By optimizing the pitch angle with genetic algorithms, the power coefficient is optimized below its maximum (fig.8).

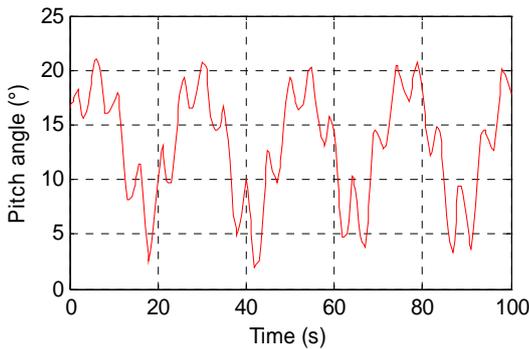


Figure.4. Pitch angle optimized with GA.

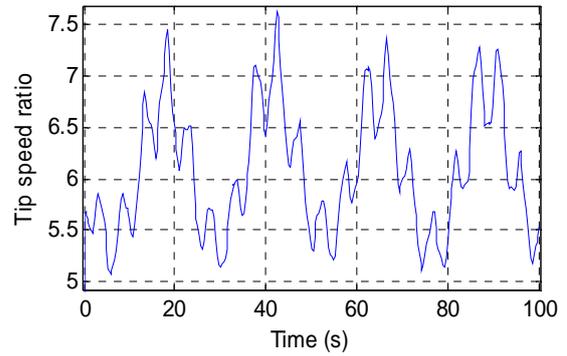


Figure.5. Tip speed ratio without pitch angle optimization.

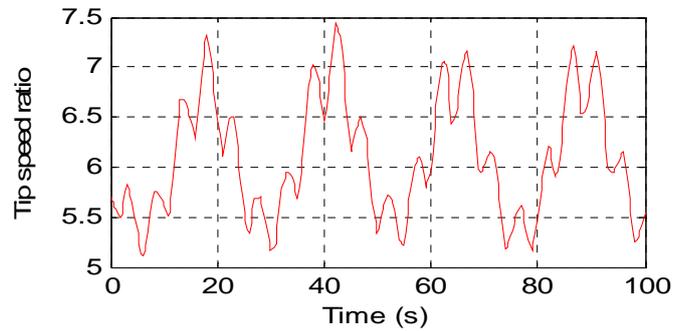


Figure.6. Tip speed ratio with pitch angle optimization.

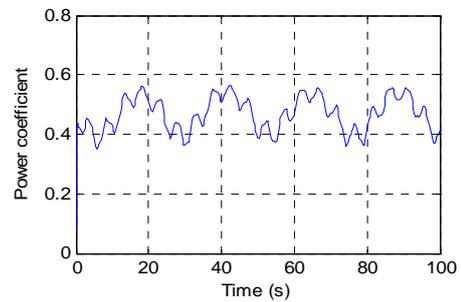


Figure.7. Power coefficient without pitch angle optimization.

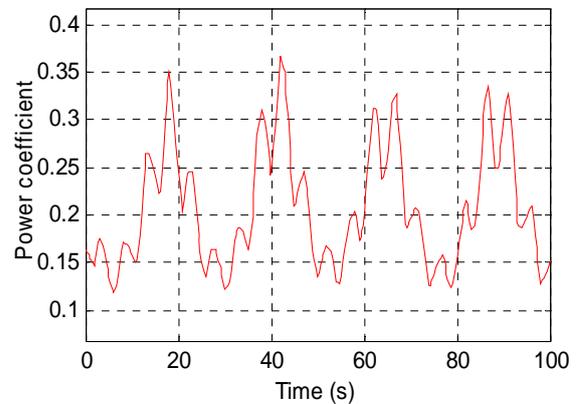


Figure.8. Power coefficient with pitch angle optimization.

VI. CONCLUSION

In this paper, the problem of variable speed wind turbine was discussed. The command of the generator was designed to limit the electrical power produced. The backstepping technique is used to design the command (Electromagnetic torque) that will be used to follow the reference generator speed. The power obtained does not represent the desired one, because in the steady state the electromagnetic torque presents large variations. Subsequently, the use of a genetic algorithm to optimize the pitch angle has yielded a couple with small variations (compared to the first case) in the steady state. And the final results, an electrical power that stabilizes around its nominal value.

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