Different Control Strategies by using Maximum Power Point Tracking for Variable Speed Wind Turbine

Chaima Yasmine ELBAR[1], Belkacem SEBTI[2]

[1]LI3CUB, Lab of Identification, Command, Control and Communication,
University of Mohamed Khider, Biskra, Algeria

[2] LEB, Dep. of Electrical Engineering Batna-2
University, Mostefa Ben Boulaid, Batna, Algeria

Email : chaimayasmine.elbar@univ-biskra.dz

Abstract - Due to the proliferation of wind power facilities in various geographic locations, extensive research endeavors have been undertaken to assess the interplay between power generation facilities and the broader electrical distribution network. This research paper is dedicated to an examination of the modeling and simulation of a horizontal axis wind turbine operating under variable speed conditions, with a particular emphasis on the development of control systems aimed at optimizing energy extraction. The investigation extends to a comprehensive analysis of diverse speed control systems, accompanied by a comparative evaluation. Additionally, this research delves into the implications of power fluctuations within the distribution grid under varying wind speed conditions.

MATLAB/Simulink has been used to implement the models. In the simulation results obtained in this study, we found that after analyzing the performance of the wind turbine, wind speed greatly affects the output, mechanical speed, electrical power, and power coefficient.

Keywords - MATLAB/SIMULINK, Modelling, MPPT, PI controller, Wind turbine.

I. INTRODUCTION

The benefits of wind energy are limitless, unrestricted, and cost-free [1, 2]. There are two main categories: fixed speed and variable speed wind turbines. Due to advancements in power conditioning technology, variable-speed wind turbines are preferred over their fixed-speed counterparts [3, 4]. In fixed-speed turbines, the generator is directly connected to the grid, leading to power fluctuations caused by wind turbulence and resulting in lower power quality. Conversely, variable-speed turbines use a power electronic converter in conjunction with the generator, offering numerous advantages, including increased power capture, improved power quality, and enhanced efficiency. As a result, the adoption of variable-speed technology is gaining prominence in wind generation systems.

To ensure precise control and the delivery of high-quality power, robust controllers are essential [5, 6]. Various techniques have been proposed in wind turbine control systems, each designed to achieve different objectives such as maximum wind power tracking and consistent electrical power generation.

The paper is organized as follows: Section 2 provides a description and modelling of wind turbines, including the modelling and control aspects using PI controllers. In Section 3, MPPT techniques and strategies are described and compared to PI controllers.

Before reaching the conclusion, Section 4 is dedicated to presenting simulation results that validate the implemented control algorithms. The dynamic model of the system is created and simulated using the MATLAB/Simulink platform. Finally, the paper concludes by summarizing the key findings of this work.

II. MODELING OF THE WIND TURBINE

The first figure shows the studied horizontal axis wind power generating system.

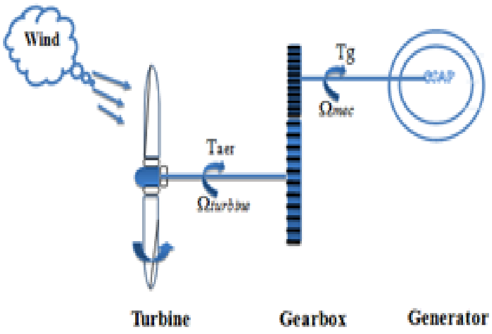

Fig. 1. Horizontal wind power generation system.

A) *Wind Turbine Modeling*

The wind turbines convert kinetic energy into mechanical energy. The power of wind is proportional with the cube of the wind speed can be calculated by:

$$P_{\text{wind}} = \frac{1}{2}.\rho.S.v^3 \qquad (1)$$

$$S = \pi.R^2$$

The wind power captured by the blade and converted into mechanical power can be calculated by:

$$P_{aero} = C_p.P_{wind} \qquad (2)$$

$$P_{aero} = \frac{1}{2}.S.\rho.C_p.v^3 \qquad (3)$$

The wind couple corresponding given by:

$$T_{aero} = \frac{P_{aero}}{\Omega_{tur}} \qquad (4)$$

$$T_{aero} = \frac{1}{2}.S.\rho.C_p.v^3 \qquad (5)$$

Cp is the power coefficient depend of the Tip ratio speed (λ) and the angle of attack (β).[4]

$$C_p(\lambda,\beta) = (0,3-0,0167.\beta)\sin\left[\frac{\pi.(\lambda+0,1)}{(10-0,3\beta)}\right] - 0,00184\cdot(\lambda-3)\cdot\beta \qquad (6)$$

For different values of the pitch angle, we have the characteristics of the power coefficient. We can see that there is only one optimum value (λ_{obt}) for each attack angle β, when a maximum value of $C_{p\text{-}max}$= 0.3 for β=0° and λ_{obt}=5.

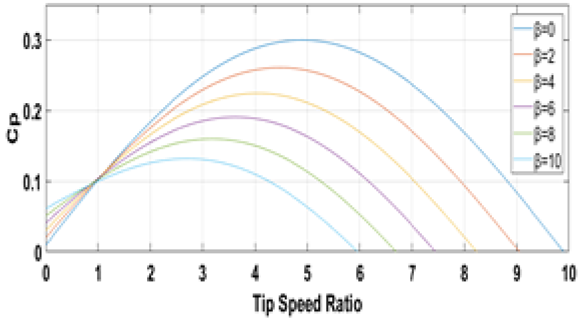

Fig. 2. Power Coefficient versus TSR with pitch angle as a parameter.

B) *Gearbox Modeling*

Gearbox or the multiplier is a mechanical converter that increases the speed of the slow shaft of the wind turbine to a faster speed, which allows the drive of the electric generator at the mechanical speed Ω_{mec} so the multiplier mathematical model

$$\Omega_{tur} = \frac{\Omega_{mec}}{G} \qquad (7)$$

$$T_{gear} = \frac{T_{aero}}{G} \qquad (8)$$

C) *Drive Train Modeling*

The differential equation which characterizes the mechanical behavior is:

$$(J_t + J_m)\frac{d\Omega_{mec}}{dt} = T_{eol} - T_{em} - (f_m + f_t)\Omega_{mec} \qquad (9)$$

Consider only the friction generator:

$$f = f_t + f_m \approx f_m \approx f \qquad (10)$$

$$J = J_t + J_m \qquad (11)$$

So the mechanical equation of the system is:

$$T_{aero} - T_{em} = J_t\frac{d\Omega_{mec}}{dt} + f.\Omega_{mec} \qquad (12)$$

III. STRATEGIES OF CONTROL

The Maximum Power Point Tracking (MPPT) algorithm is the foundation of the maximum extraction command, which tracks the maximum power point of a wind turbine's fluctuating wind speed.

$$\lambda_{obt} = \frac{R.\Omega_{ref}}{v} \rightarrow \Omega_{ref} = \frac{v.\lambda_{obt}}{R} \qquad (13)$$

A) *Direct Control of the Wind Turbine Speed*

In order to get the MPPT, we must find the electromagnetic torque, considers that the variation of the wind turbine's [194] dynamic speed is negligible (viscous torque = 0)

$$T_{gear} = T_{em} \rightarrow T_{gear\_est} = T_{em\_reg} = \frac{T_{aero\_est}}{G} \qquad (14)$$

$$T_{aero\_est} = \frac{P_{aero\_est}}{\Omega_{tur}} \qquad (15)$$

$$T_{aero\_est} = \frac{S.C_{p\_\max}.\rho.v_{est}^3.G}{2.\Omega_{mec}} \qquad (16)$$

With

$$v_{est} = \frac{R.\Omega_{tur}}{\lambda_{obt}} = \frac{R.\Omega_{mec}}{G.\lambda_{obt}} \qquad (17)$$

$$T_{em\_reg} = k.\Omega_{mec}^2 \qquad (18)$$

$$k = \frac{C_{p\_\max}.\pi.\rho.R^5}{2.G^3.\lambda_{obt}^3} \qquad (19)$$

B) *Closed Loop Control of the Wind Turbine Speed*

The speed is measured and compared with a reference value, [11] [12] and then a corrector adapt the reference torque in order to reduce this error

$$T_{em\_ref} = r_{ass}\left(\Omega_{mec\_ref} - \Omega_{mec}\right) \qquad (20)$$

We can deduce:

$$\Omega_{mec\_ref} = \frac{G.v.\lambda_{obt}}{R} \qquad (21)$$

✓ PI Phase Delay Controller

Expression of corrector is :

$$T_{em\_ref} = \frac{a_1.s + a_0}{\tau.s + 1}.\,(\Omega_{mec\_ref} - \Omega_{mec}) \qquad (22)$$

The closed-loop transfer function :

$$\Omega_{mec} = F(s).\Omega_{mec\_ref} + P(s).T_{gear} \qquad (23)$$

Reference transfer function is speed:

$$F(s) = \frac{a_1.s + a_0}{J\tau.s^2 + (f\tau + J + a_1).s + a_0 + f} \qquad (24)$$

Perturbation transfer functi

$$P(s) = \frac{\tau.s + 1}{J\tau.s + (f\tau + J + a_1).s + a_0 + f} \qquad (25)$$

In order to damp the perturbation input a$_0$must be large≥1000.Then the other parameters are chosen to set a classical 2^{snd} order function with:

$$w_n = \sqrt{\frac{a_0 + f}{J\tau}} \qquad (26)$$

$$\varepsilon = \frac{\tau f + J + a_1.w_n}{2.(a_0 + f)} \qquad (27)$$

$$a_0 = w_n^2.J\tau - f \qquad (28)$$

$$a_1 = \frac{2\varepsilon(a_0 + f)}{w_n} - f\tau - J \qquad (29)$$

And :

$$T(s) = \frac{J.\tau s^2 + (f.\tau + J + a_1).s + f + a_0}{(a_1 s + a_0).\left(\frac{T_r}{3}s + 1\right)} \qquad (30)$$

✓ PI Anticipation Controller

Expression of corrector:

$$T_{em\_ref} = \frac{b_1.s + b_0}{s}.\left(\Omega_{mec\_ref} - \Omega_{mec}\right) \qquad (31)$$

The closed-loop transfer function:

$$\Omega_{mec} = F(s).\Omega_{mec\_ref} + P(s).T_{gear} \qquad (32)$$

Reference transfer function is speed:

$$F(s) = \frac{b_1.s + b_0}{J.s^2 + (f + b_1).s + b_0} \qquad (33)$$

Perturbation transfer function:

$$P(s) = \frac{s}{J.s^2 + (f + b_1).s + b_0} \qquad (34)$$

Then the other parameters are chosen to set a classical 2^{snd} order function with:

$$w_n = \sqrt{\frac{b_0}{J}} \tag{35}$$

$$\varepsilon = \frac{f + b_1.w_n}{2.b_0} \tag{36}$$

$$b_0 = W_n^2.J \tag{37}$$

$$b_1 = 2.J.\varepsilon.w_n - f \tag{38}$$

$$T(s) = \frac{Js^2 + (f + b_1).s + b_0}{(b_1 s + b_0).\left(\frac{T_r}{3} s + 1\right)} \tag{39}$$

✓ **PI Controller**

The open loop transfer function is given as follows:

$$H_0 = \left(k_p + \frac{k_i}{s}\right)\left(\frac{1}{Js + f}\right) \tag{40}$$

Use the pole compensation. So let's compensating of poles $\left(\frac{f}{J}\right)$ by $\left(\frac{k_i}{k_p}\right)$ written:

$$H_0 = \frac{k_p}{Js}.$$

The closed-loop transfer function:

$$H_1 = \frac{H_0}{1 + H_0} \rightarrow H_1 = \frac{k_p}{Js + k_p} \tag{41}$$

$$H_1 = \frac{k_p}{k_p\left(1 + \frac{Js}{k_p}\right)} \tag{42}$$

We get a 1st order system with a time constant $\tau = \frac{J}{k_p}$ if choose the response time $t_r(5\%) = 3\tau$ So

$$k_i = \frac{3f}{t_r(5\%)} \tag{43}$$

And :

$$k_p = \frac{3J}{t_r(5\%)} \tag{44}$$

w_n : Natural pulsation.

ε : Damping ratio.

s = Laplace quantity.

T(s): Tracking transfer function.

a_1, b_1, k_p: proportional gain.

a_0, b_0, k_i: integral gain.

IV. SIMULATION RESULTS

This figure shown the results obtained for the simulations by MATLAB Simulink, an averaged 12 m/s wind speed has been used (Fig. 3) the wind speed is a three-dimensional vector. Even so, the direction of the vector of wind speed considered in this simulation is limited to one dimension.

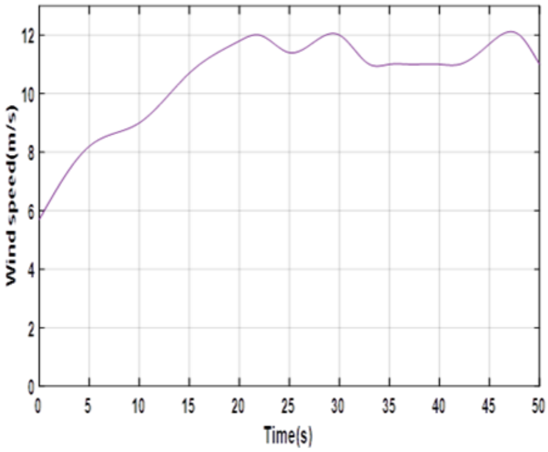

Fig. 3. Wind speed (m/s).

We illustrate how the power coefficient is pressed to that maximum value (Fig.4), resulting in the effect of adapting the rotor generator speed to variations in wind speed. There are significant variations in the electricity produced.

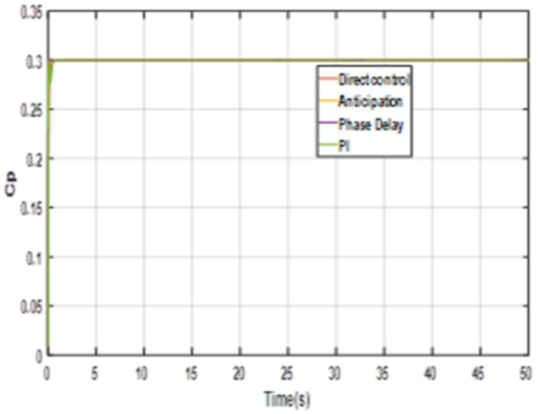

Fig. 4. Power coefficient Cp.

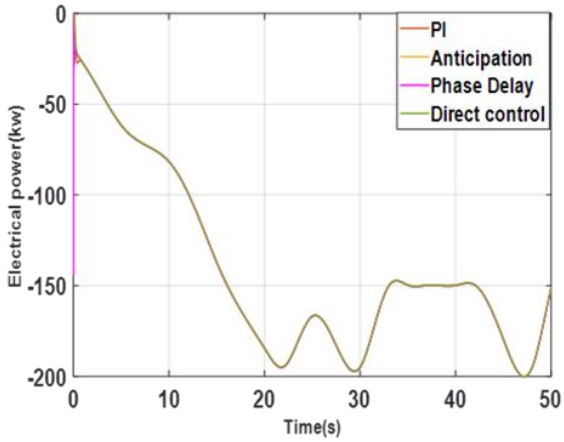

Fig. 5. Electrical power (Kw).

The electromagnetic power is defined as follows: this power will be measured negatively (like in the fig.5) since it opposes the aerodynamic power. By ignoring the losses of electrical origins, when these two powers are equal, the wind turbine rotates at a constant speed (zone 3).

The simulation results for the method without speed control reveal that the results are well matched to the applied wind speed, although with a significant margin of error.

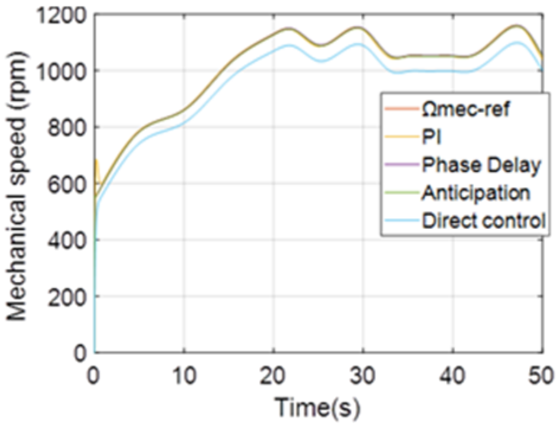

Fig. 6. Mechanical speed (rpm).

However, these methods do not allow for the electrical power to be optimized during significant wind speed transients, and closed loop control techniques are presently being suggested for this purpose.

Now comparing the results of a method with speed control, for simulation of delay-phase control, we compare the power coefficient to the prior control technique, the power coefficient exhibits less volatility. As a result, when transitory fluctuations in the wind occur, a small quantity of electricity is converted, but there isn't much more. An apparent mismatch between the speed and the reference value manifests in steady state (Fig.6).Simulation results are shown with the regulator with anticipation. The power coefficient is kept at its maximum to extract maximum power the results are well a adapted to the variation in wind speed and the electrical power produced is variable because this control system is highly dynamic. A PI regulator demonstrates that both in the temporary and permanent states, better closed-loop control of the speed are obtained.

V. CONCLUSION

In this study, a simplified model of a wind turbine generator is described. The wind turbine direct control system has been recalled. We demonstrate that a control loop of the mechanical speed is necessary for an appropriate response change when the set-point changes since the system is quite dynamic.

The obtained variations of the electrical power generated using different control methods are then compared. The efficiency of the wind/electric conversion appears to be increased by closed-loop control systems of the turbine speed. For this, the wind speed must be measured precisely.

VI. REFERENCES

[1] M. Nadour, A. Essadki, and T. Nasser, Comparative analysis between PI & backstepping control strategies of DFIG driven by wind turbine, *International Journal of Renewable Energy Res, 7(3),*2017,1307-1316.

[2] J. Chen, C. Jie, G. Chunying, New overall power control strategy for variable-speed fixed-pitch wind turbines within the whole wind velocity range, *IEEE Transactions on Industrial Electronics, 60(7),*2013, 2652-2660.

[3] M. Hannachi, O. Elbeji, and M. Benhamed, et al, Comparative study of four MPPT for a wind power system,Wind Eng, 45 (4), 2021,1613–1622.

[4] B. Wu, Y. Lang, and N. Zargari, S. Kouro, *Power Conversion and Control of Wind Energy Systems,*

(John Wiley&Sons, First Edition, 2011)

[5] HE. Aissaoui, AE. Ougli, and B. Tidhaf, Neural networks and fuzzy logic based maximum power point tracking control for wind energy conversion system, *Advances in Science, Technology and Engineering Systems Journal, 6 (2),* 2021, 586–592.

[6] FD. Bianchi, FD. Battista, and RJ. Mantz, Wind Turbine Control Systems: Principles, Modelling and Gain Scheduling Design. Springer, 2007.

[7] H. Chojaa, A. Derouich, Y. Bourkhime, et al, Comparative Study of MPPT Controllers for a Wind Energy Conversion System, *Advanced Technologies for Humanity. ICATH 2021. Lecture Notes on Data Engineering and Communications Technologies*,110(Springer,2022)1-11.

[8] E. S. Abdin, W. Xu, Control Design and Dynamic Performance Analysis of a Wind Turbine-Induction Generator Unit, *IEEE Transactions on Energy Conversion,15(1),*2000,91-96.

[9] O. Apata, D.T.O. Oyedokun, An overview of control techniques for wind turbine systems, *Scientific African, 10 (1),*2020.

[10] E. Muljadi,Pitch-Controlled Variable-Speed Wind Turbine Generation, *IEEE Transactions on Industry Applications,37 (1),*2001,240-246.

[11] M.Yessef, B. Bossoufi, and H. Chojaa, Overview of control strategies for wind turbines: ANNC, FLC, SMC, BSC, and PI controllers,*Wind Engineering, 46 (6),* 2022,1675–1688.

[12] S. Elaimani, *Modeling of the different wind turbine technologies integrated into a medium voltage network*, doctoral diss., Central School of Lille, France, 2004.

PARAMETERS

Number of blades	3
Gain gearbox	28
Inertia	2 kg.m^2
Viscous coefficient	0.007
Air density	ρ=1.225 k$_g$/m^3
Diameter	28 m