ADAPTIVE CONTROL WITH REFERENCE MODEL OF A DOUBLY FED INDUCTION GENERATOR FOR WIND TURBINE WITH SLIDING MODE

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ABSTRACT

When the system is non-linear and the parameters of the model are unknown or changing in large proportions, adaptive control will allow us to better control our machine. In this paper, we recall initially adaptive technique whose objective is the automatic adjustment online and real-time our controllers that allow us to maintain a certain level of performance if the system is changing Then we develop adaptive control by pursuit of model (MRAS), then we strengthen our regulator by sliding mode control. We conclude with a simulation of both control technology to see performance and difference between MRAS and MRAS with sliding mode.

KEYWORDS

Modeling, simulation, DFIG, MRAS, adaptive technique, sliding mode

1. INTRODUCTION

The development of wind energy in recent years has been remarkable as a result to global large needs power because the intense industrialization and the multiplication of electric domestic appliances; so many researchers have been interested on this type of energy. Classified as a renewable energy wind clear prominently, replaced conventional sources of energies like thermal energy or nuclear; because it is not polluting and easy to exploiting. The technically exploitable potential of renewable energies in Algeria is considerable knowing that the Adrar region is in a wind corridor of 6 m / s and extend up to 20 m / s while for Amenas the plan does not exceed 14 m / s.

In the works, the use of the asynchronous machine is selected for reasons explained, so in this article we will try to model a wind turbine mechanical parts and electrical parts (generator), and then we will try to model and control this machine. The generator control must be robust to ensure good response for this we use adaptive control reinforced by the sliding mode

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2. Modeling of the wind turbine

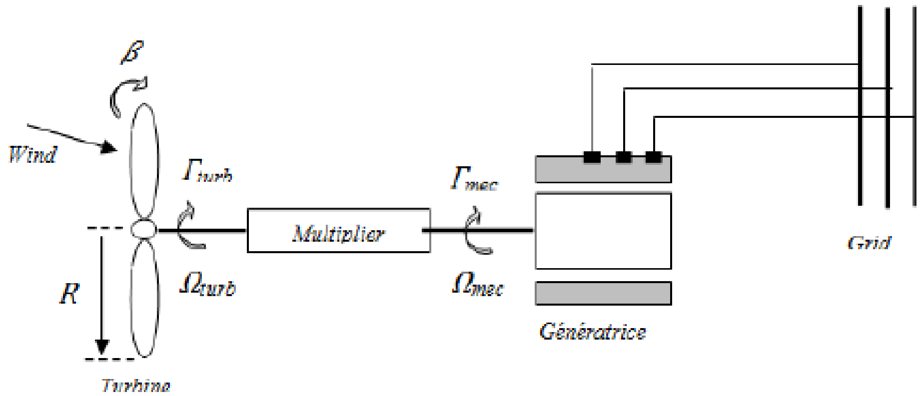

Figure 1. DFIG coupled to network

The turbine, which will be modeled, has three adjustable blades with languor R fixed to a drive shaft turning at a speed Ω_{turb} which turns a generator by a multiplier The kinetic power of the wind through the wind disc:

$$P_v = \frac{1}{2}\rho\pi R V_v^3 \tag{1}$$

The shaft power of the turbine rotor is then:

$$P_{turb} = C_p P_v = C_p(\lambda,\beta)\rho S V_v^3 / 2 \tag{2}$$

Knowing the speed of the turbine the aerodynamic torque is determined by:

$$\Gamma_{turb} = P_{turb} / \Omega_{turb} = \left(C_p\left(\rho S V_v^3\right)/2\right) * \left(1/\Omega_{turb}\right) \tag{3}$$

The multiplier is mathematically modeled by the following equations:

$$\Gamma_m = \Gamma_{turb} / G \tag{4}$$

$$\Omega_m = \Omega_{turb} / G \tag{5}$$

$$J_T = J_{turb} / G^2 + J_g \tag{6}$$

Mechanical torque applied to the rotor

$$J_T d\Omega_{mec} / dt = \Gamma_{mec} \tag{7}$$

$$\Gamma_{mec} = \Gamma_m - \Gamma_{em} - \Gamma_{visc} \tag{8}$$

The resistive torque caused by friction

$$\Gamma_{visc} = C_f \Omega_{mec} \tag{9}$$

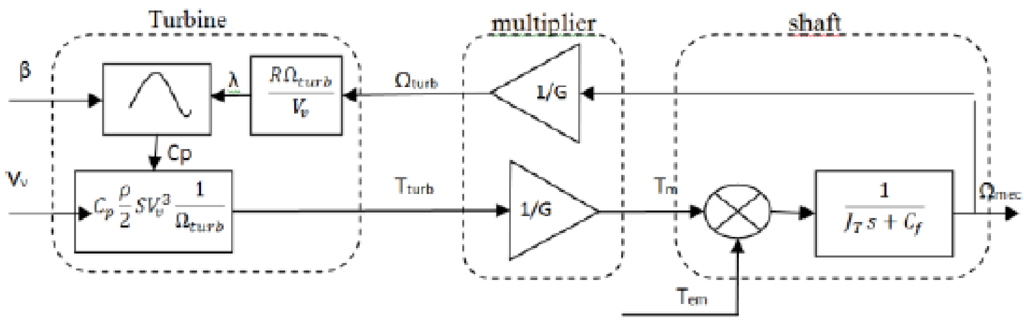

Figure 2. Block diagram of the model of the turbine

3. Choice of generator

For the choice of electric generator we have a generator that will allow us to independently control both active and reactive power asynchronous double-fed generator (DFIG)

Asynchronous double feed induction (DFIG) allows us optimal production of electricity Whatever wind speed and provides a rotational speed variation of ± 30% around the synchronous speed moreover control of rotor voltages allows us to control the active and reactive power produced.

The DFIG has a competitive price and superior strength and has several modes of engine operation motor hypo and hyper synchronous generator hypo and hyper but only the synchronous mode with the stator directly connected to the network and the twisted powered by an inverter we are concerned in our study

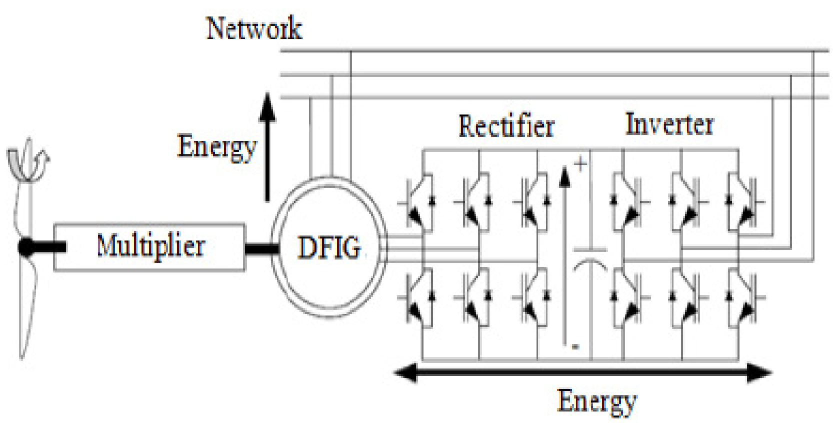

Figure 3. DFIG coupled to network by a converter

The modeling of the DFIG is described in the d-q Park reference frame. The following equations systems describe the total generator model.

4. Modeling of the MADA

The turbine, which will be modeled, has three adjustable blades with languor R fixed to a drive shaft turning at a speed Ω_{turb} which turns a generator by a multiplier The kinetic power of the wind through the wind disc:

$$V_{ds} = R_s I_{ds} + d\phi_{qr} / dt - \dot{\theta}_s \phi_{qs} \tag{10}$$

$$V_{qs} = R_s I_{qs} + d\phi_{qs} / dt - \dot{\theta}_s \phi_{ds} \tag{11}$$

$$V_{dr} = R_s I_{dr} + d\phi_{dr} / dt - \dot{\theta}_s \phi_{qr} \tag{12}$$

$$V_{qr} = R_s I_{qr} + d\phi_{qr} / dt - \dot{\theta}_s \phi_{ds} \tag{13}$$

$$\phi_{ds} = L_s I_{ds} + M I_{dr} \tag{14}$$

$$\phi_{qs} = L_s I_{qs} + M I_{qr} \tag{15}$$

$$\phi_{dr} = L_r I_{dr} + M I_{ds} \tag{16}$$

$$\phi_{qs} = L_r I_{qr} + M I_{dr} \tag{17}$$

And

$$\Gamma_{em} = \Gamma + f\Omega + J\mathrm{d}\Omega / \mathrm{d}t \tag{18}$$

The résulting:

$$V_{dr} = R_r I_{dr} + \left(L_r - \left(M^2 / L_s \right) \right) \mathrm{d} I_{dr} / \mathrm{d}t - g\left(L_r - \left(M^2 / L_s \right) \right) \omega_s I_{qr} \tag{19}$$

$$V_{qr} = R_r I_{qr} + \left(L_r - \left(M^2 / L_s \right) \right) \mathrm{d} I_{qr} / \mathrm{d}t - g\left(L_r - \left(M^2 / L_s \right) \right) \omega_s I_{qr} + g\left(\mathrm{MV}_s \right) / L_s \tag{20}$$

5. Adaptive control with reference model

There are three main structures for adaptive control with reference model: MRAS parallel, MRAS series and series-parallel MRAS.

The adaptation is done either by adjusting parameters of the system variable, either by a signal adaptive synthesis or by combining these two methods.

The reference model and that of the adjustable system are defined by the following state equations

$$\mathrm{d}X_m / \mathrm{d}t = A_m X_m + B_m U_m \tag{21}$$

$$dX_s / dt = AX_s + BU_m \tag{22}$$

$$e = X_m - X_s \tag{23}$$

The objective of the synthesis of MARS is to find a parametric adaptation law for adjusting the matrices A and B

$$\mathrm{Lim}_{t\to\infty} e(t) = 0 \tag{24}$$

$$\mathrm{Lim}_{t\to\infty} A(e;t) = A_m \tag{25}$$

$$\mathrm{Lim}_{t\to\infty} B(\boldsymbol{e},t) = \boldsymbol{B_m} \tag{26}$$

And we want the adaptation mechanism has memory so:

$$A(\boldsymbol{e},t) = F(\boldsymbol{e},\tau,t) \ + \boldsymbol{A}(0) \tag{27}$$

$$B(\boldsymbol{e},t) = G(\boldsymbol{e},\tau,t) \ + \boldsymbol{B}(0) \tag{28}$$

Using the above equations, we can establish the differential equation that characterizes the dynamics of the error:

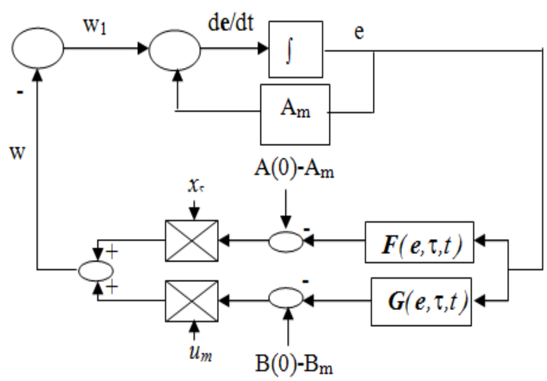

Figure 4. Equivalent representation of the generalized state error

5.1. Linear control by fallowing a model LMFC

We will develop a controller that ensures a perfect model reference tracking. The figure (5) shows the structure of such a controller.

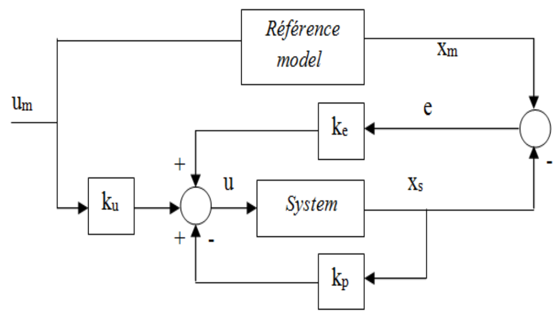

Figure 5. Linear control by pursuing a model Equivalent

The objective of this controller is to minimize the error state *e*. From Figure2 the control law is given by

$$u = -\boldsymbol{K}_p \boldsymbol{X}_s + \boldsymbol{K}_e + \boldsymbol{K}_u \boldsymbol{u}_m \tag{29}$$

5.2. Simplified adaptive control (MRAS)

The synthesis of model reference adaptive regulator requires the availability of a knowledge linear model satisfying the conditions Erzenberger for calculating $\boldsymbol{K_p}, \boldsymbol{K_u}$. We seek in this section to develop a controller with minimal information about the system. This is a controller wherein the command comes fully the mechanism of adaptation and assumes no prior non-adaptive controller implementation. The structure of such a controller is illustrated in Figure 7

We can derived this controller e directly with the following hypothesis

$$K_p = K_e = K_u = 0 \tag{30}$$

We have

$$u = \Delta K_p(\boldsymbol{e},t)\, \boldsymbol{X}_s + \Delta K_u(\boldsymbol{e},t)\, \boldsymbol{u}_m \tag{31}$$

The dynamics of the error is defined by the equation

$$\mathrm{d}e / \mathrm{d}t = \boldsymbol{A}_m \boldsymbol{e} + \left(\boldsymbol{A}_m - \boldsymbol{A}_s - \boldsymbol{B}_s \Delta \boldsymbol{K}_p(\boldsymbol{e},t)\right)\boldsymbol{X}_s + \left(\boldsymbol{B}_m - \boldsymbol{B}_s\, \Delta \boldsymbol{K}_u(\boldsymbol{e},t)\right)\boldsymbol{u}_m \tag{32}$$

Adjustable system:

$$\mathrm{d}\boldsymbol{X}_s / \mathrm{d}t = \boldsymbol{A}(\boldsymbol{e},t)\boldsymbol{X}_s + \boldsymbol{B}(\boldsymbol{e},t)\boldsymbol{u}_m \tag{33}$$

With

$$A(e,t) = \boldsymbol{A}_s + \boldsymbol{B}_s\, \Delta \boldsymbol{K}_p(e,t) \tag{34}$$

$$B(e,t) = \boldsymbol{B}_s\, \Delta \boldsymbol{K}_u(e,t) \tag{35}$$

$$A(0) = \boldsymbol{A}_s + \boldsymbol{B}_s \ \Delta \boldsymbol{K}_p(0) \qquad (36)$$

$$B(0) = \boldsymbol{B}_s \ \Delta \boldsymbol{K}_u(0) \qquad (37)$$

We then deduce

$$\Delta K_p(\boldsymbol{e},t) \ = \int_0^t \varphi_1(v,t,\tau) d\tau + \varphi_2(v,t) + \Delta k_p(0) \qquad (38)$$

$$\Delta K_u(\boldsymbol{e},t) \ = \int_0^t \Psi_1(v,t,\tau) d\tau + \Psi_2(v,t) + \Delta k_u(0) \qquad (39)$$

$$v = \mathrm{D}e \qquad (40)$$

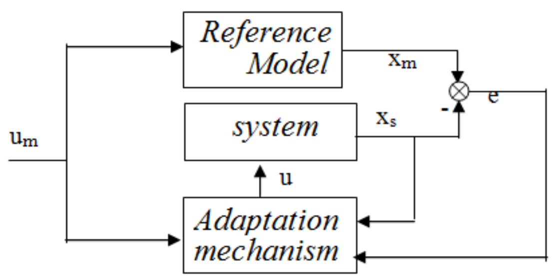

Figure 5. Linear control by pursuing a model Equivalent

5.3. Model similink MRAS of DFIG

Modeling machine and controller with adaptive reference model has been implemented in the MATLAB environment Simulink to conduct tests of our control so we submitted this system on echelons of active and reactive power to observe the behavior of the MRAS control.

Parameters for our DFIG are:

p=2, *Rs*=5, *Rr*=0.5, *M*=0.034, *Lm*=0.08, *Lr*=0.4, *Ls*=0.07, *Ws*=314, *g*=0.03, *J*=1000, *fr*=0.0024.

5.4. The simulation result

We can see that the echelons of power are followed by the generator for both the active power for reactive power and a dynamic that reacts quickly and without overshoot; the functioning of reactive power control allows us to have a negative reactive power capacitive behavior or positive inductive behavior.

But it brings up a small static error in active and reactive power which is due to the fact that this regulation there is and the currents are in open loop; and during the time period] 0,4 0,7[,] 1,2 1,5[,] 1,9 2,2[,] 2,7 3 [,] 3,4 3,7[, we observe the effect of coupling between the two control axes d and q as the echelon of reactive power has changed induced low overshoot on active power but if the active power changes that do not affect on the reactive power.

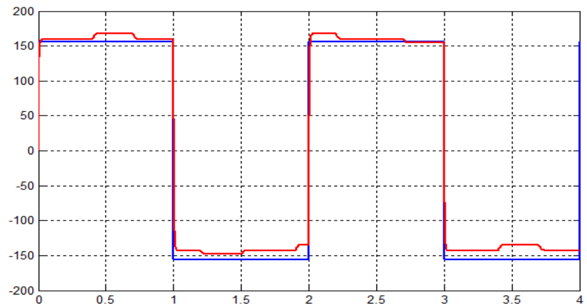

Figure 6. Response of the active power by MRAS control

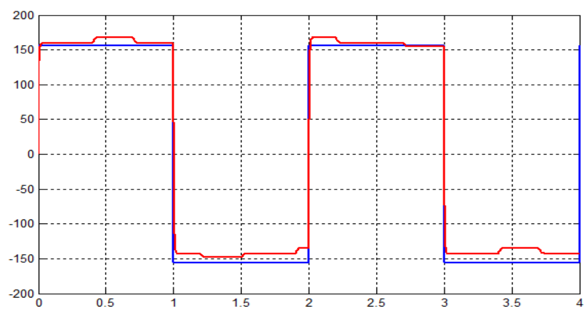

Figure 7. Response of the reactive power by MRAS control

6. Adaptive control with model reference of DFIG with sliding mode

To improve and reinforce the response of our system we add another loop sliding mode this type of control appeared in the Soviet Union during the sixty and has been very successful in recent years because it's easy to use in industry and it is robust to uncertainties in the system and outside perturbations as adaptive control so we wanted to mix these two mode command to take of their advantage

This control law is defined to force the system to reach a vicinity of the sliding surface and stay at this level.

6.1. Design of sliding mode control

The design of the control by sliding mode is made mainly in three steps

6.1.1. Choice of switching surface

The following equation defines a non-linear system:

$$\dot{X} = f(X,t) + g(X,t)\, u(X,t) \quad X \in R^n,\ u \in R \tag{41}$$

To determine the sliding surface we take the form which is determined by J.J.Slotine

$$S(X) = ((d/dt) + \lambda)^{n-1} e \tag{42}$$

And

$$e = X^{d} - X,\ X = \left[x, \dot{x}, \ddot{x}, \ldots\ldots \right]^{T}, X^{d} = \left[x^{d}, \dot{x}^{d}, \ddot{x}^{d}, \ldots\ldots \right]^{T} \tag{43}$$

6.1.2. Condition de convergence and control calculation

The Lyapunov equation satisfies the convergence condition

$$S(X)\ \dot{S}(X) \leq 0 \tag{44}$$

Then to define the control algorithm

$$u = u^{eq} + u^{n} \tag{45}$$

$$u^{n} = u^{\max}\ \mathrm{sat}\left(S(X)/\varphi\right) \tag{46}$$

$$\mathrm{sat}\,(S(X)/\varphi) = \mathrm{sign}(S)\,\mathrm{si}\ |S| > \varphi \ \text{ or }\ \mathrm{sat}\left(S(X)/\varphi\right) = S/\varphi\ \mathrm{si}\ |S| < \varphi \tag{47}$$

6.2. Control active and reactive power

We will take n = 1 for control for both powers then we will have for the surface:

$$S(P) = P_{s}^{ref} - P_{S} \tag{48}$$

$$\dot{S}(P) = \left(\dot{P}_{s}^{ref} - V_{S}\ (M / L_{S})\,\dot{I}_{qr} \right) \tag{49}$$

$$\dot{S}(P) = \left(\dot{P}_{s}^{ref} - V_{S}\ (M / L_{S}\, L_{r}\sigma)\left(V_{qr} - R_{r} I_{qr}\right) \right) \tag{50}$$

$$\dot{S}(P) = \left(\dot{P}_{s}^{ref} - V_{S}\ (M / L_{S}\, L_{r}\sigma)\left(V_{qr}^{eq} + V_{qr}^{n}\right) - R_{r} I_{qr} \right) \tag{51}$$

It is in sliding mode $S(P)=0$, $\dot{S}(P)=0$, $V_{qr}^{n}=0$ so:

$$V_{qr}^{eq} = -\dot{P}_{s}^{ref}\ (L_{S} L_{r}\sigma / M\ V_{S}) + R_{r}\ I_{qr} \tag{52}$$

On convergence mode S(P) $\dot{S}$(P)≤0 so :

$$V_{qr}^{n} = K V_{qr}\ \mathrm{sign}\left(S(p)\right) \tag{53}$$

Using the same strategy as we did for the active power the reactive power we will find equation

$$\dot{S}(Q) = \left(Q_{s}^{ref} - V_{S}\ (M / L_{S} L_{r}\sigma\right)\left(\left(V_{dr}^{eq} + Vd_{r}^{n}\right) - R_{r} I_{dr}\right) \tag{54}$$

$$V_{dr}^{\ eq} = -\, Q_s^{ref}\,(L_S L_r \sigma \,/\, M\ V_S\,) + R_r\ I_{dr} \tag{55}$$

$$V_{dr}^{\ n} = KV_{dr}\ \text{sign}\left(S\left(Q\right)\right) \tag{56}$$

6.3. The simulation result

It is observed that this mode of control is more efficient than the previous regulator because there is no static error and the effect of coupling is very low and our generator spreads quickly to step For active energy the DFIG follows perfectly the step and even the response to reactive power is very satisfactory**.**

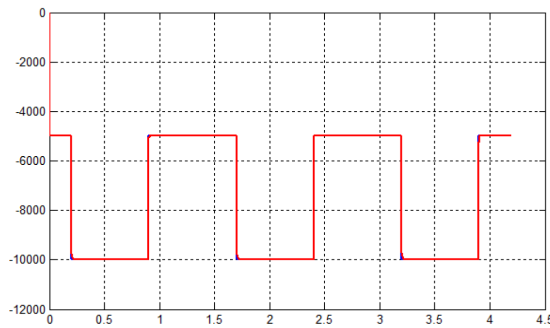

Figure 8. Response of the active power by MRAS control with sliding mode

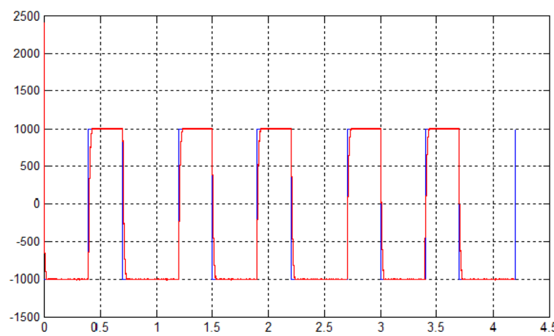

Figure 9. Response of the reactive power by MRAS control with sliding mode

7. CONCLUSIONS

In this paper we studied two power control for induction machine dedicated for a wind turbine adaptive control with reference model then adaptive control with reference model command with the sliding mode then we observed by MATLAB behavior of each regulation.

Both regulators are robust even after parametric changes like resistance and inductance because the machine follows the model reference whatever the perturbations but the second regulator is more robust and efficient because it's strengthen by the sliding mode used on a second regulating loop.

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Nomenclature

Xm and Xs: Dimensional state vector (nx1)
Um: Input vector of dimension (mx1).
e: State vector of the generalized error
Kp, Ke, Ku: Matrices
D: compensator
Vds, Vqs, Vdr, Vqr : Two-phase statoric and rotoric voltages
Ids, Iqs, Idr, Iqr : Two-phase statoric and rotoric currents
Φqs ,Φdr ,Φqs,Φds : Statoric and rotoric flux
Θs: the electrical angle of the rotating field stator
Θr: the electrical angle of the rotating field rotor
Rs,Rr : Per phase statoric and rotoric resistances.
M : Magnetizing inductance
Ls, Lr: Total cyclic statoric and rotoric inductances.
g: generator slip.
f, J: Inertia and viscous friction.
ωs :The angular speed
Γem: The electromagnetic torque
Γr : The resistant torque
Ω : The speed of rotation of the axis of the DFIG
f(X,t), g(X,t): Two continuous and uncertain non-linear functions, supposed limited.
λ: Positive coefficient
n: System order.
X^d: Desired signal
X: State variable of the control signal
u: Control signal
φ_1 (..), ψ_1 (..) : Matrices with respective dimensions (n x n) and (n × m), which determines a variable non-linear relationship in the time between A(..) and B(..) and the values of v
ρ: density of air (it is 1.25 kg / m in normal climate)
S: Surface swept by the turbine
R: blade length
V_v: wind speed
Cp: coefficient of performance
P_{turb} : aerodynamic power
β : orientation angle of the blades
λ : the relative speed
Ω_{turb} : turbine speed
Ω_{mec} : the mechanical speed
Ω_m : speed of the generator
Γ_{turb} : aerodynamic torque
Γ_m : Couple after multiplier

Γ_{em} : the electromagnetic torque
Γ_{visc} : torque of viscous friction
C_f : viscous friction coefficient
G: gain multiplier
J_g : The inertia of the generator
J_T : The total inertia that appears on the generator rotor
J_{turb} : The inertia of the turbine

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