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Analysis and design of wind energy system based on nonlinear speed controller

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Abstract - *This paper presents a control fuzzy robuste strategy for a squirrel cage Induction generator (SCIG)-based wind energy conversion system. Control strategies is presented along with the mathematical modeling of the employed configuration. The maximum power point extraction of the wind turbine is addressed along with the proposed strategy. The approach method is introduced to control the generator speed and regulate the flux. The wind system is then simulated in Matlab-Simulink and the developed model is used to illustrate the behavior of the system. The simulation results are presented and discussed at the end of this paper.*

Résumé - *Cet article présente une stratégie de contrôle robuste floue pour un système de conversion d'énergie éolienne basé sur un générateur d'induction (SCIG). Les stratégies de contrôle sont présentées avec la modélisation mathématique de la configuration utilisée. L'extraction maximale des points de puissance de l'éolienne est abordée avec la stratégie proposée. La méthode d'approche est introduite pour contrôler la vitesse du générateur et réguler le flux. Le système éolien est ensuite simulé dans Matlab-Simulink et le modèle développé est utilisé pour illustrer le comportement du système. Les résultats de la simulation sont présentés et discutés à la fin de cet article.*

Keywords: WECS - SCIG - MPPT - Wind turbine - TS fuzzy controller - Robust controller - Simulation.

1. INTRODUCTION

In recent years, there has been an evolution of wind electrical energy production. This source of energy has developed importantly considering the diversity of the exploitable zones and the relatively beneficial cost.

Now most wind turbines are equipped with a induction generator due to noticeable advantages: the variable speed generation (30 % around the synchronous speed) [1].

It is the reason for which one finds this device for the production in strong power. So, one of the most fundamental problems of the control theory of these systems types is the analysis of robust stability and synthesis of uncertain systems.

Recently [1, 2], the issue of stability of nonlinear systems begin to accrue interest for the researchers, because it can provide an effective solution for controlling complex processes, uncertain, unclear [3]. The robust stability is another important requirement to be considered in the control study of uncertain nonlinear systems [4].

To solve the problem of fuzzy control nonlinear system with uncertain parameters and subject to a disturbance of the wind, a robust controller for all non-linear systems [5] is used. This correspond to that proposed by (Takagi-Sugeno) which is close to the real system [6] models and to the nonlinear system [7].

In this context, many studies related to the control of the induction generator system have been developed over many countries worldwide by researchers [8-18].

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In this paper a proposed robust controller design makes it possible to control the wind turbine along the entire nominal operating trajectory using fewer controllers than ordinary robust design methods, while maintaining the required performance [17, 18].

Therefore, the principal goal of the present study is to show that the nonlinear controller with the parameter uncertainties have the better performance and better robustness, endure for wind turbine system stability under unstable wind circumstances.

The block diagram of a typical wind energy conversion system is shown in figure 1. The transfer of the power produced by wind power system is made by AC/DC converter. That operates as a rectifier [19].

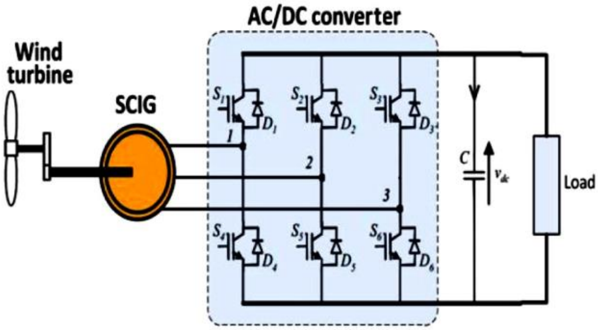

Fig. 1: SCIG-based Wind energy conversion system [19]

2. WIND ENERGY CONVERSION SYSTEM MODELING

2.1 The turbine model

The aerodynamic power P captured by the wind turbine is given by [20]:

$$P_{eol} = \frac{1}{2}.C_p(\beta, \lambda).\rho.S.V_V^3 \tag{1}$$

$$\lambda = \frac{R\ \Omega}{V_V} \tag{2}$$

Where ν is the wind, ρ is the air density, R is the rotor radius, C_p is the power coefficient and λ is the ratio of turbine blades tip speed to wind speed. Figure 2 illustrate generator power as a function of speed for different wind speeds.

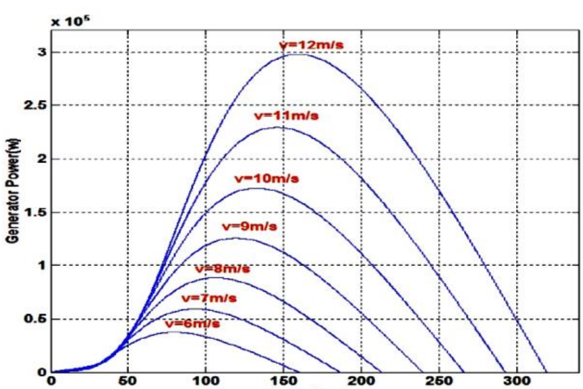

Fig. 2: Output power for different values of wind speed [21]

2.2 The SCIG model

The squirrel cage Induction generator voltages of the windings of the stator and the rotor according to the d-q axes are given by the following relations [22]

$$\begin{cases} V_{sd} = R_s\, i_{sd} + \dfrac{d\phi_{sd}}{dt} - \omega_s\, i_{sq} \\ V_{sq} = R_s\, i_{sq} + \dfrac{d\phi_{sq}}{dt} - \omega_s\, i_{sd} \\ V_{rd} = 0 = R_r\, i_{rd} + \dfrac{d\phi_{rd}}{dt} - \omega_r\, i_{rq} \\ V_{rq} = 0 = R_r\, i_{rq} + \dfrac{d\phi_{rq}}{dt} - \omega_r\, i_{rd} \end{cases} \tag{3}$$

The electromagnetic torque is given by the following relation,

$$T_{em} = P \times M(\Phi_{sq} \,.\, i_{rd} - \Phi_{sd} \,.\, i_r) \,/\, L_s \tag{4}$$

The active and reactive stator powers are expressed by,

$$\begin{cases} P_s = V_{sd}\; I_{sd} + V_{sq}\; I_{sq} \\ Q_s = V_{sq}\; I_{sd} + V_{sd}\; I_{sq} \end{cases} \tag{5}$$

2.3 Fuzzy Takagi-Sugeno model

To achieve the wind energy maximum power point tracking (MPPT) control, we have to drive the DC voltage to follow the maximum power point voltage [23]. First, due to the fact that the SCIG is viewed as a current source, only the dynamics of the buck converter is considered and expressed in T-S fuzzy rules, the buck converter is described by the following T-S fuzzy [24],

$$\begin{aligned} \dot{x}(t) &= A(x).x(t) + Bu(t) \\ y(t) &= C(x)\, x(t) \end{aligned} \tag{6}$$

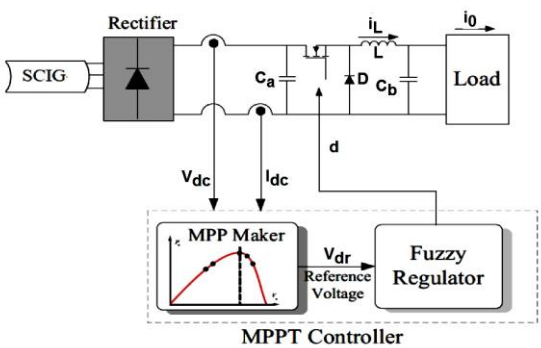

Fig. 3: Fuzzy control system [25]

for the state and input vector respectively, the SCIG state model can be presented as a eight-order model [25]

$$\begin{cases} \dot{x}_1 = a_1(x_2.x_3 - x_7.x_4) - a_2.x_1 - a_3.x_8 \\ \dot{x}_2 = -a_4.x_2 - a_5.x_4 + a_5.x_7 - a_7.x_1.x_3 + a_8.x_6 \\ \dot{x}_3 = -a_9.x_4 - a_{10}.x_3 + a_5.x_7 - a_{11}.x_1.x_7 \\ \dot{x}_4 = -a_4.x_4 + a_5.x_2 + a_6.x_3 + a_7.x_1.x_7 + a_8.x_5 \end{cases} \tag{7}$$

Where,

$$a_1 = \frac{P.M}{J.L_r}, \; a_2 = \frac{f}{J}, \; a_3 = \frac{1}{J}, \; a_4 = \frac{L_r^2.R_s + L_m^2.R_s}{\sigma.L_s.L_r^2}, \; a_5 = 1$$

$$a_6 = \frac{R_r.M}{\sigma.L_s.L_r^2}, \; a_7 = \frac{R_r.P}{\sigma.L_s.L_r^2}, \; a_8 = \frac{1}{\sigma.L_s}$$

$$a_9 = \frac{R_r.M}{L_s}, \; a_{10} = \frac{R_r}{L_s}, \; a_{10} = P$$

and,

$$x_1 = \omega_m; \; x_2 = i_{sd}, \; x_3 = \phi_{rd}, \; x_4 = i_{sd}$$

$$x_5 = V_{sd}, \; x_6 = V_{sq}, \; x_7 = \phi_{rq}, \; x_8 = T_m$$

Controls the electromagnetic torque and rotor direct flux will be obtained by controlling the d-q axes stator currents of the SCIG.

By choosing the two-phase d-q related to rotating rotor field, and placing the rotor flux vector on the d-axis, we have $\phi_{rd} = \phi_{rd} = \phi_r$ and $\phi_{rq} = 0$. In this case, the model (7) becomes:

$$\begin{cases} \dot{x}_1 = a_1.x_2.x_3 - a_2.x_1 - a_3.x_8 \\ \dot{x}_2 = -a_4.x_2 - a_5.x_4 - a_7.x_1.x_3 + a_8.x_6 \\ \dot{x}_3 = -a_9.x_4 - a_{10}.x_3 \\ \dot{x}_4 = -a_4.x_4 + a_5.x_2 + a_6.x_3 + a_8.x_5 \end{cases} \quad (8)$$

4. RESULTS AND DISCUSSION

Simulations were performed in Matlab using the nonlinear model.

Figure 4 shows the wind profile applied to the wind turbine. Figure 5 show the rotational speed the wind turbine. Figure 6 show the power profile of the wind turbine. Figure 7 show the power coefficient.

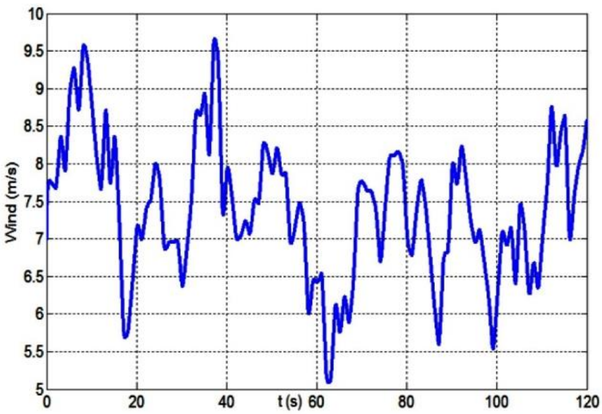

Fig. 4: Wind speed profile

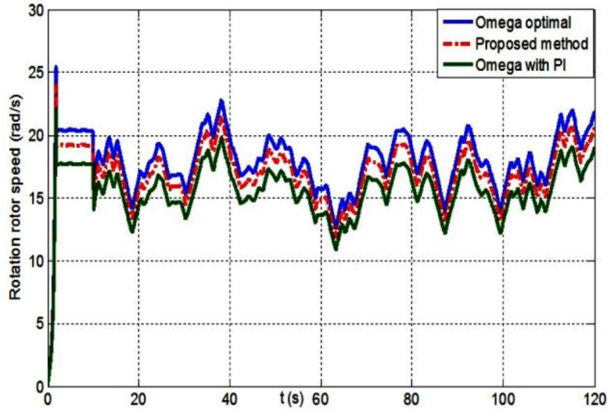

Fig. 5: Rotation speed profile (with three cases)

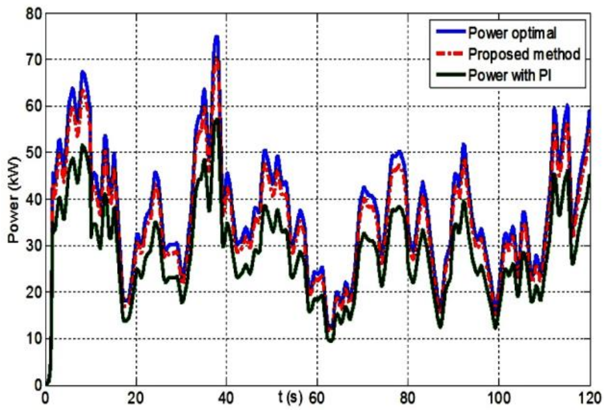

Fig. 6: Wind turbine power profile (with three cases)

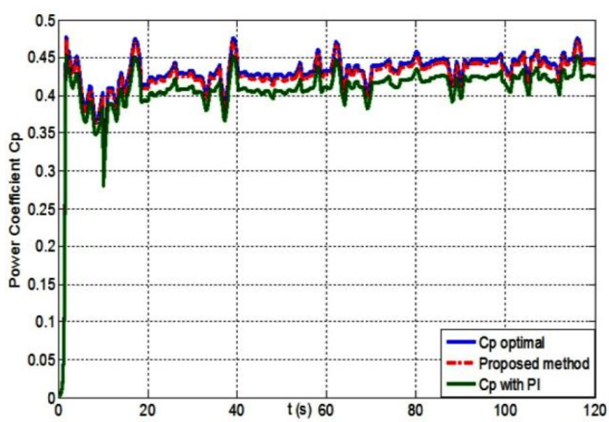

Fig. 7: Power coefficient profile (with three cases).

In summary results, we can be seen that the system trajectory follows the trajectory of the reference input. Thus, the TS fuzzy model based controller is robust against norm bounded parametric uncertainties, and wind disturbance.

Comparing the results of the proposed algorithm with those given by the previous algorithms, it can be noticed that the proposed controller has the following advantages:

- Control of the plant over a wide range of wind speeds;
- Stability over a wide range of uncertainties;
- Increased robustness over conventional controllers such as PI.

5. CONCLUSION

In this paper, a mathematical model of an asynchronous machine with variable wind turbine speed model has been proposed and simulated via simulation tool namely: Matlab using controller uses Fuzzy logic systems of Takagi-Sugeno models and operates local systems obtained by linearization around a few operating points.

In this article, the results obtained by the proposed control algorithm concept are well and suitable with that were intended which was shown in the simulation environment. The simulated consequences can be easily visualized in Sec. 3, have a good and stable performance for wind turbine system applications.

According to the simulation results, the control proposed ensured with better efficiency the regulation of the rotational speed of the turbine which allows operation of the wind power system at maximum power and providing a decoupling between the control flux and speed.

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NOMENCLATURE

ω_s, ω_r, Stator, rotor angular frequency	N_p, Number of pole pairs
Ω_g, Mechanical generator speed	V_s, Stator voltage magnitude,
i_{sd}, i_{rd}, Stator, rotor currents in axis d,	i_{sq}, i_{rq}, Stator, rotor currents in axis q,
R_s, R_r, Stator and rotor resistance,	L_s, L_r, L_m, Stator, rotor leakage, and magnetizing inductances
n_b, Gearbox ratio,	
D_r, D_g, D_{ls}, Damping constants for the rotor, generator, the equivalent low-speed shaft,	K_{ls}, Equivalent torsional stiffness of the low-speed shaft,
T_g, Time constant of the model,	T_h, High-speed shaft torque,
J_r, J_g, Moments of inertia of the rotor and generator.	T_g, $T_{g.ref}$, Generator torque and required generator torque.

SCIG parameters are:

P_n = 75 kW, V = 690 V and f = 50 Hz,

Stator resistance: $R_s = 0.039\ \Omega$;

Rotor resistance: $R_r = 0.022\ \Omega$;

Stator inductance: $L_s = 0.017$ H ;

Rotor inductance: $L_r = 0.017$ H;