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Control of a wind power system based on a doubly fed induction generator with a sliding mode controller

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ABSTRACT

Wind energy is a type of renewable energy when wind turbines convert the wind into mechanical or electrical energy. This energy is used to generate the energy needed in many different areas, such as industry and agriculture. Wind power is one of the most important energy sources for scientific researchers because of its importance. The main factor of this energy is the wind, a natural phenomenon that occurs in the world without human interference. This work presents the description and modelling of the wind power system based on the dual-feed generator. The technique of maximum power point tracking with speed control has been used to achieve the objective of good operation with improved effective utilization of the wind turbine. Two different methods are applied for speed control. A classical proportional-integral controller and an advanced sliding mode controller are considered by speed control and reactive and active power control. At the end of the modelling and simulation of the whole in the MATLAB/Simulink environment, the analysis of the results shows good performances.

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1. INTRODUCTION

Renewable power is a form of power produced from herbal sources, because of this that it's far always renewed and inexhaustible. This sort of power deferred from the non-renewable kind is unlimited and environmentally friendly, its effect is low as compared to that of fossil fuels, increases the economic system of the country, and protects the fitness of humanity. In recent years, wind energy has become one of the main types of energy used in many areas: military, domestic commercial, agricultural, and industrial [1, 2].

This paper presents a wind power system that varies according to wind speed based on the doubly fed induction generator (DFIG). Due to the variation of wind speed which imposes unstable environmental conditions and nonlinearity of the system, it is difficult to extract the maximum bridge for proper operation [1]. To achieve this objective, the technique of maximum power point tracking with speed control is used to improve the ability of wind turbines to be used efficiently.

The wind power system consists of three parts: the mechanical part, the electrical part, and the control part, regarding the control part, among its most important elements is the controller. Recent developments in uncontrolled loops allow the optimization of wind turbine operation [1].

In addition, it is still necessary to implement each control loop separately using conventional proportional-integral (PI) or proportional-integral-derivative (PID) controllers and reduce inter-loop coupling by using iterative tuning [3]. A traditional PI controller requires an accurate linear mathematical model of the system, which is difficult to achieve in the presence of parameter variation, nonlinearity, and load disturbances [4].

Conventional controllers such as PI and PID are not adjustable under transient conditions, although they perform well under steady-state conditions. However, modern wind turbine engineering, increased dimensions, improved adaptability and ecological conditions make traditional regulations unsuitable for momentary situations, despite favourable steady-state conditions. Therefore, the need for advanced control methods is increasing. Previous work has focused on improving the dynamics of PI controllers, such as the application of fuzzy logic control [5] and sliding mode control [6, 7, 8, 9].

On the other hand, a sliding mode controller has greater advantages over some controllers. For example, as mentioned in [10], the fuzzy logic controller (FLC) can be expensive, which is a drawback. However, the cost of this approach can be a major problem. In addition, determining the exact fuzzy rules and

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membership functions are difficult tasks, and selecting the input and output ranges of the FLC is time-consuming.

Deploying the imprecise logic controller is time-consuming, which can lead to disappointment. The FLC's dependence on an expert to achieve optimal results is a disadvantage, given its lack of expertise. If the expert provides imprecise rules, the FLC is likely to perform worse than the PID controller [11].

Sliding mode control is a very robust nonlinear control, very powerful against external disturbances and errors. It is a strategy that can operate at high switching speeds [12]. At present, sliding mode analysis has emerged as a favourable option in the field of monitoring and fault tolerance [12]. As a result, numerous control researchers opt for sliding mode control, which can serve as a feasible replacement in the field of monitoring [13, 14]. Unlike traditional controllers, the sliding mode controller does not require exact mathematical models. However, it necessitates the identification of the parameter range to ensure robustness and favourable circumstances [15, 13].

The main objective of this paper is to realize an advanced sliding mode control to regulate the active and reactive power of a wind power system based on a dual-feed generator. The first section description of the DFIG-based wind power system, and then the second section focuses on the system modelling. The third section discusses the control of the turbine and the DFIG, and the last section is devoted to the presentation of the simulation results.

2. DESCRIPTION OF A WIND TURBINE MODELING

A wind turbine is a system composed of three main parts: a mechanical part, an electrical part and a control part. It converts the kinetic energy of the wind into mechanical energy and then into electrical energy, and is commonly referred to as a wind generator.

The design of the system is shown in Figure 1. The mechanical part consists of the turbine and gearbox, while the electrical part consists of a doubly fed induction generator (DFIG). The last part is the control system, for which we used two distinct control methods: a classical approach with a proportional integral controller, and an advanced approach using sliding mode control.

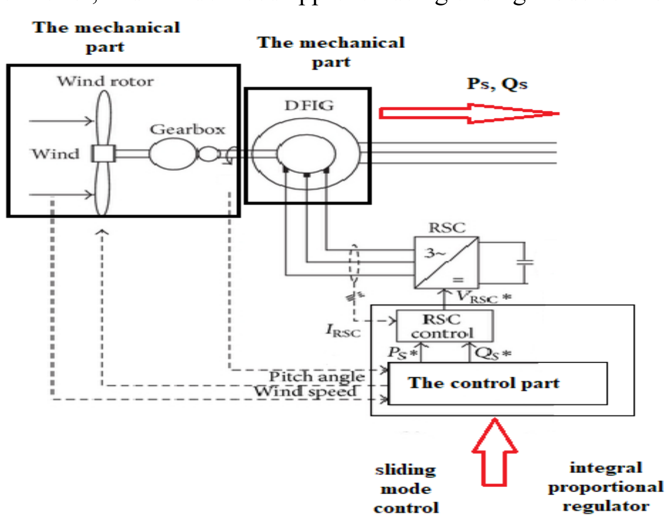


Fig. 1. The design of the conversion system of the wind turbine.

3. MODELING OF THE WIND TURBINE GENERATOR

The aerodynamic power, which is converted by a wind turbine, depends on the power coefficient C_P, which is expressed by Equation 1 [15]:

$$P_w = \frac{1}{2} C_p(\lambda, \beta) \rho \pi R^2 {V_w}^3 \tag{1}$$

Where ρ is the air density (kg/m³), R is the turbine radius (m), V_w is the wind speed (m/s), C_P is the coefficient of the turbine and β is the angle of orientation of the blades.

The tip speed ratio is defined in Equation (2) [16]:

$$\lambda = \frac{\Omega_t R}{v} \tag{2}$$

Where λ is the relative speed representing the ratio between the linear speed at the end of the wind turbine blades and the wind speed and Ω_t is the angular speed of the wind turbine rotor shaft.

The aerodynamic torque equation is defined in Equation (3) [17]:

$$T_{aer} = \frac{\frac{1}{2} C_p(\lambda, \beta) \rho \pi R^2 {V_w}^3}{\Omega_t} \tag{3}$$

C_p depends on the TSR and the pitch angle β such as presented in Equation (4) [18]:

$$C_p = C_1 - C_2 * (\beta - C_3).\sin(A) - C_4 * (\lambda - C_5) * (\beta - C_3) \tag{4}$$

4. MODELING OF THE DFIG GENERATOR

The electrical equations for the DIFG in the park setting are presented in Equation (5), Where R_s and R_r are respectively the stator and rotor phase resistances, ω_a and ω_r are respectively the stator and rotor speeds [19, 20]:

$$\begin{cases} V_{ds} = R_s . i_{ds} + \frac{d\phi_{ds}}{dt} - \omega_a . \phi_{qs} \\ V_{qs} = R_s . i_{qs} + \frac{d\phi_{qs}}{dt} + \omega_a . \phi_{ds} \\ V_{dr} = R_r . i_{dr} + \frac{d\phi_{dr}}{dt} - \omega_r . \phi_{qr} \\ V_{qr} = R_r . i_{qr} + \frac{d\phi_{qr}}{dt} + \omega_r . \phi_{dr} \end{cases} \tag{5}$$

The stator and rotor fluxes can be written as shown in Equation (6):

$$\begin{cases} \Phi_{ds} = \Phi_s = L_s . i_{ds} + M . i_{qr} \\ \Phi_{qs} = L_s . i_{qs} + M . i_{dr} \\ \Phi_{dr} = L_r . i_{dr} + M . i_{ds} \\ \Phi_{qr} = L_r . i_{qr} + M . i_{qs} \end{cases} \tag{6}$$

Where i_{dr} i_{qr} i_{ds} i_{qs} are the respective direct and quadrature currents of the rotor and stator.

The reactive and active powers at the stator are given as shown in Equation (7) [21].

$$\begin{cases} P_s = V_{ds} i_{ds} + V_{qs} i_{qs} \\ Q_s = V_{qs} i_{ds} - V_{ds} i_{qs} \end{cases} \tag{7}$$

The DFIG torque is presented in Equation (8):

$$T_{em} = \frac{PM}{L_s} (i_{dr} \phi_{qs} - i_{qr} \phi_{ds}) \tag{8}$$

5. TURBINE CONTROLLER

In this part we have used two different types of controllers, one classical proportional integral and the other advanced sliding mode control and Figure 2 shows the block diagram of the turbine control.

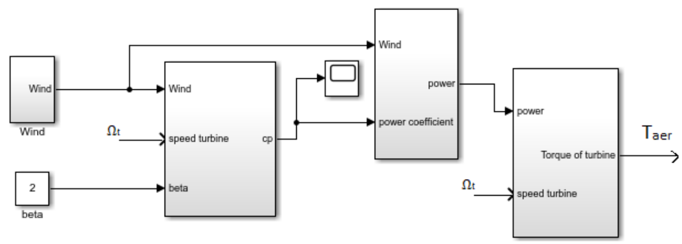


Fig.2. The block diagram of the turbine control.

5.1. *Proportional Integral Control*

It is a classic controller simple to develop, this conventional controller has good efficiency in stable conditions and accurately monitors wind speed in severe situations. In this work, we are interested in the method of pole placement. The transfer function is expressed by:

$$TF(p)=\frac{2.\xi.\omega_0.p+\omega_0^2}{p\hat{}2+2.\xi.\omega^2+\omega_0^2} \tag{9}$$

5.2. *Sliding Mode Control*

The SMC is an advanced non-linear control, this control is more efficient and precise than other control techniques. The following surface is taken:

$$S(\Omega)=\dot{\Omega}-\Omega \tag{10}$$

Calculate the equivalent equation: from which we derive the expression of the equivalent command:

$$T_{emeq}=-KJ\dot{\Omega}-\mathrm{K}f\Omega+T_m \tag{11}$$

Where T_{emeq} is the equivalent torque and T_m is the mechanical torque, f is the coefficient of friction, and K is a positive constant.

The command for attractiveness: to ensure the convergence of Lyapunov's function, we must pose:

$$T_{emn}=-K.s(S(\Omega)) \tag{12}$$

Where T_{emn} is the discrete couple, K is a positive constant.

6. CONTROL STRATEGY OF DFIG

By aligning the d-axis in the direction of flux us [20, 21] we have:

$$\begin{cases}\varphi_{sd}=\varphi_s\\ \varphi_{sq}=0\end{cases} \tag{13}$$

Therefore, by using Equations (9) and (19) we obtain:

$$T_{em}=P\frac{M}{L_s}(I_{qr}\emptyset_{ds}) \tag{14}$$

The stator flux can be in Equation (15):

$$\begin{cases}\Phi_{ds}=\Phi_s=L_s.i_{ds}+M.i_{qr}\\ 0=L_s.i_{qs}+M.i_{dr}\end{cases} \tag{15}$$

Neglecting the stator phase resistances and assuming that the stator flux is also constant, the stator and rotor direct and quadrature voltages can be written as presented in Equation (16) [22]:

$$\begin{cases}V_{ds}=0\\ V_{qs}=V_s=\omega_a.\phi_s\\ V_{dr}=R_r.i_{dr}+\dfrac{d\phi_{dr}}{dt}-\omega_r.\phi_{qr}\\ V_{qr}=R_r.i_{qr}+\dfrac{d\phi_{qr}}{dt}+\omega_r.\phi_{dr}\end{cases} \tag{16}$$

Stator currents are given with rotor currents:

$$\begin{cases}i_{ds}=\dfrac{\Phi_s}{L_s}+i_{dr}.\dfrac{M}{L_s}\\ i_{qs}=-i_{qr}.\dfrac{M}{L_s}\end{cases} \tag{17}$$

Relations between stator powers and rotor currents:

$$\begin{cases}\mathrm{Ps}=\mathrm{V_s}\dfrac{\mathrm{M}}{\mathrm{L_s}}\mathrm{I_{qr}}\\ \mathrm{Qs}=-\mathrm{V_s}\dfrac{\mathrm{M}}{\mathrm{L_s}}\mathrm{I_{dr}}+\dfrac{\mathrm{V_s^2}}{\mathrm{L_s}\omega_s}\end{cases} \tag{18}$$

6.1. *Control Synthesis by PI for Controlling the Active and Reactive Power of the DFIG*

The open loop transfer function integrating the controllers is given by Equation (19):

$$G_{Bo}(s)=\frac{P_s}{P_s{}^*}=\left(k_p+\frac{k_i}{s}\right).\left(\frac{M_{sr}\,V_s}{R_rL_s+sL_sL_R\,\sigma}\right) \tag{19}$$

In a closed loop, we obtain the following transfer function in Equation (20):

$$G_{BF}(s)=\frac{P_S}{P_S{}^*}=\frac{\dfrac{(k_p.s+k_i).M_{sr}.V_s}{L_S.L_R.\sigma}}{s^2+s.\dfrac{R_rL_s+k_p.M_{sr}.V_s}{L_S.L_R.\sigma}+\dfrac{k_i.M_{sr}.V_s}{L_S.L_R.\sigma}} \tag{20}$$

The k_p and k_i represent the PI controller gain as in Equation (21):

$$\begin{cases}k_p=\dfrac{\sigma.L_r.L_s2.\xi.\omega_n-R_r.L_s}{M_{sr}.V_s}\\ k_i=\dfrac{\sigma.L_r.L_s.\omega_n^2}{M_{sr}.V_s}\end{cases} \tag{21}$$

This system has the canonical form of a second-order transfer with Equation (22):

$$G(s)=\frac{2.\xi.\omega_ns+\omega_n^2}{s^2+2.\xi.\omega_ns+\omega_n^2} \tag{22}$$

Where ξ is the depreciation coefficient and ω_n is the proper pulsation and they are presented in Equation (23):

$$\begin{cases} 2.\xi.\omega_n = \dfrac{R_r.L_s + k_p.M_{sr}.V_s}{\sigma.L_r.L_s} \\ \omega_n^2 = \dfrac{k_i.M_{sr}.V_s}{\sigma L_r L_s} \end{cases} \tag{23}$$

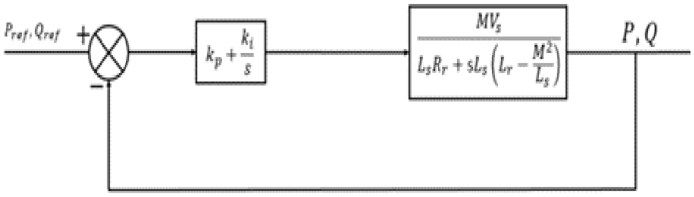


Fig. 3. System regulated by a PI controller.

6.2. Control Synthesis by Sliding Mode Control for Controlling the Active and Reactive Power of the DFIG

The sliding-mode controller structure for controlling the active and reactive power of the DFIG-based wind power system is shown in Figure 4. The reactive and active power errors and their derivation are shown below:

$$\begin{cases} SP = P_{s-ref} - P_s \\ \dot{SP} = \dot{P}_{s-ref} - \dot{P}_s \end{cases} \tag{24}$$

$$\begin{cases} SQ = Q_{s-ref} - Q_s \\ \dot{SQ} = \dot{Q}_{s-ref} - \dot{Q}_s \end{cases} \tag{25}$$

$$\begin{cases} \dot{SP} = \dot{P}_{s-ref} - V_s \dfrac{M}{L_s} i_{rq} \\ \dot{SQ} = \dot{Q}_{s-ref} - V_s \dfrac{M}{L_s} i_{rd} \end{cases} \tag{26}$$

$$\begin{cases} \dot{SP} = \dot{P}_{s-ref} - V_s \dfrac{M}{\sigma.L_r.L_s}(V_{rq} - R_r i_{rq}) \\ \dot{SQ} = \dot{Q}_{s-ref} - V_s \dfrac{M}{\sigma.L_r.L_s}(V_{rd} - R_r i_{rd}) \end{cases} \tag{27}$$

During the sliding surface is the steady state, we write:

$$\begin{cases} SP = 0; \quad SQ = 0 \\ \dot{SP} = 0; \quad \dot{SQ} = 0 \\ {V_{rq}}^n = 0; \quad {V_{rd}}^n = 0 \end{cases} \tag{28}$$

By replacing V_{qr} by $Vrq^{eq} + Vrq^n$ and V_{dr} by $Vrd^{eq} + Vrd^n$:

$$\begin{cases} \dot{SP} = \dot{P}_{s-ref} - V_s \dfrac{M}{L_s L_r \sigma}\left(V_{rq}^{eq} + V_{rq}^n - R_r I_{rq}\right) \\ \dot{SQ} = \dot{Q}_{s-ref} - V_s \dfrac{M}{L_s L_r \sigma}\left(V_{rd}^{eq} + V_{rd}^n - R_r I_{rd}\right) \end{cases} \tag{29}$$

Then the equivalent command V_{rq}^{eq} *and* V_{rd}^{eq} can be written as:

$$\begin{cases} V_{rq}^{eq} = -\dot{P}_{s-ref} \dfrac{L_s L_r \sigma}{MV_s} + R_r I_{rq} \\ V_{rd}^{eq} = -\dot{Q}_{s-ref} \dfrac{L_s L_r \sigma}{MV_s} + R_r I_{rd} \end{cases} \tag{30}$$

During the convergence mode, the power condition:

$(SP).(\dot{SP}) \leq 0, (SQ).(\dot{SQ}) \leq 0$, is verified, so:

$$\begin{cases} \dot{SP} = -V_s \dfrac{M}{L_s L_r \sigma} V_{rq}^n \\ \dot{SQ} = -V_s \dfrac{M}{L_s L_r \sigma} V_{rd}^n \end{cases} \tag{31}$$

Therefore, the switching term is given by:

$$\begin{cases} V_{rq}^n = K_1 sign(SP) \\ V_{rd}^n = K_2 sign(SQ) \end{cases} \tag{32}$$

The parameters of the SMC gains are shown in Table 1.

Table.1. Parameters of the SMC control gains.

Symbol	*Value*
K_1	100
K_2	100
$\frac{L_s L_r - M^2}{M_s}$	*1.0608 e-4*
$-\frac{L_r R_r}{M}$	-0.0130

The synthesis equations for SMC are specifically applied to obtain rotor voltage values for the *d* and *q* axes as shown in Figure 4 (a) and (b) for active and reactive power. From Figure 5, which shows the DFIG block diagram, we obtain the active and reactive power of the system using sliding mode control.

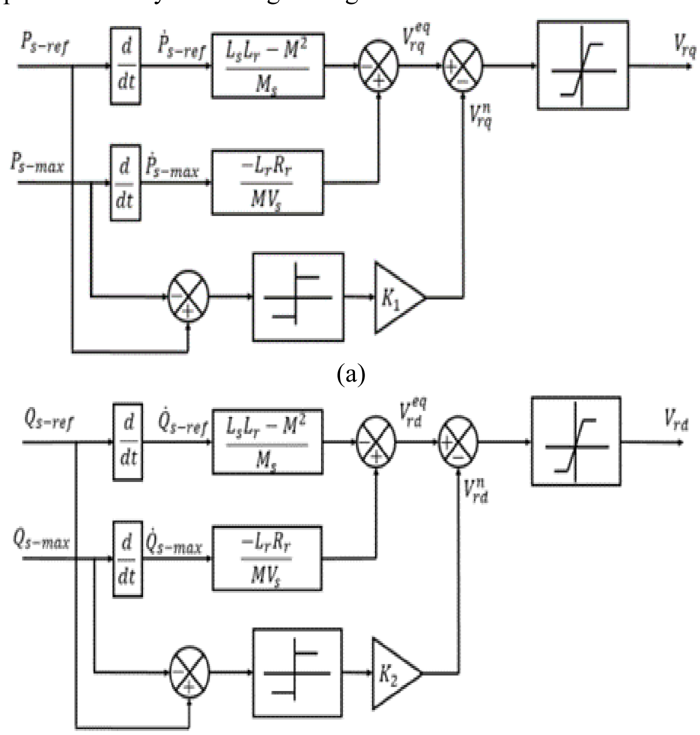


Fig. 4. Sliding mode controller structure, (a) Sliding mode controller structure for active power, (b) Sliding mode controller structure for reactive power.

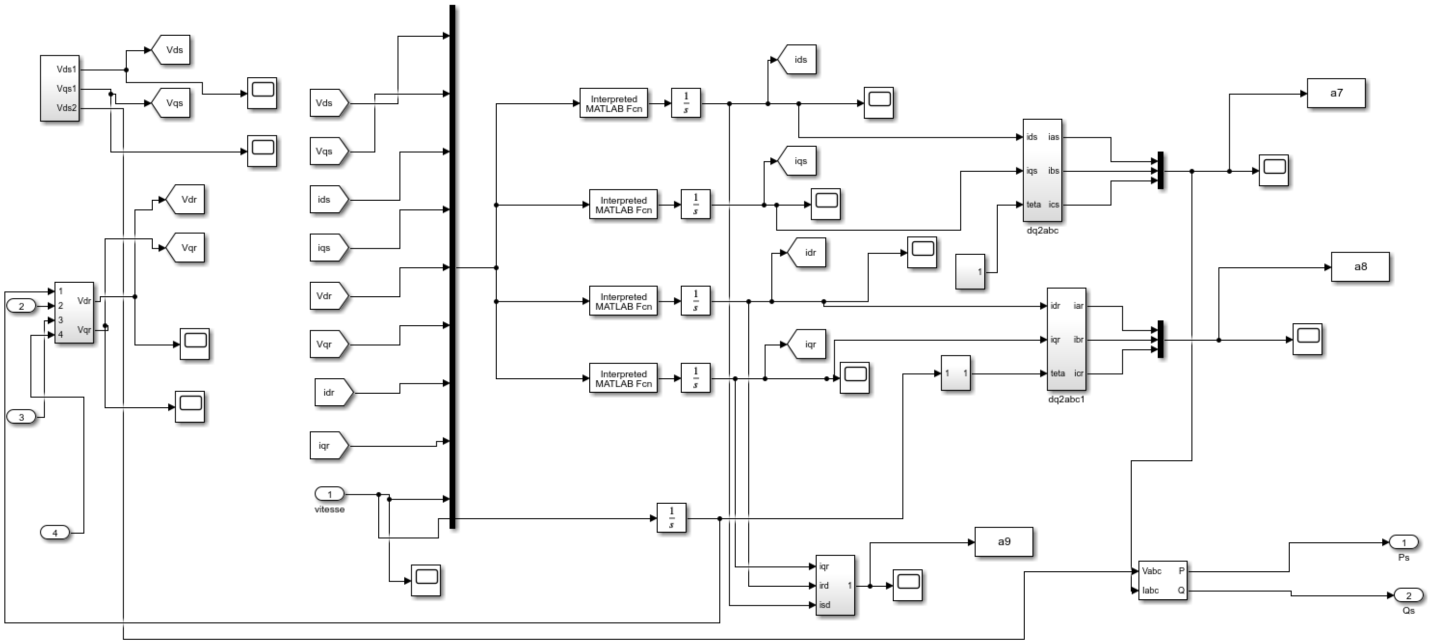


Fig. 5. Block diagram of the DFIG for active and reactive power control.

7. SIMULATION RESULTS

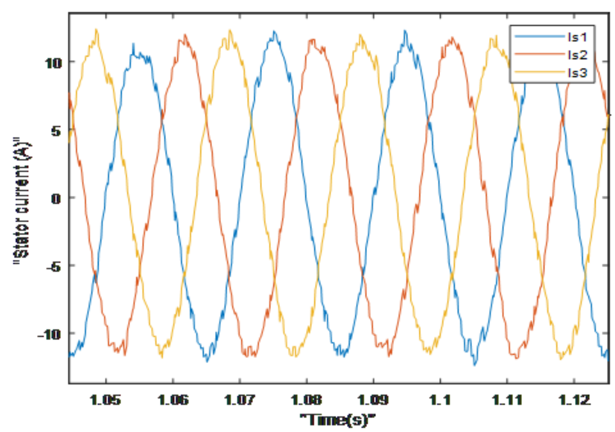
The design of the wind turbine system is based on a dual-feed induction generator and is simulated using MATLAB/Simulink environment with the objective of the control of the powers. We used the MPPT technique with speed control by utilizing two different types of controllers: sliding mode control and proportional integral.

Figures 6 and 7 show the simulation results of the wind energy conversion with power control by PI and SMC, such as Figure 6(a) stator current, Figure 6(b) rotor current, Figure 6(c) torque, Figure 6(d) active power, Figure 6(e) reactive power. Figure 7(a) stator current, Figure 7(b) rotor current, Figure 7(c) torque, Figure 7(d) active power, Figure 7(e) reactive power.

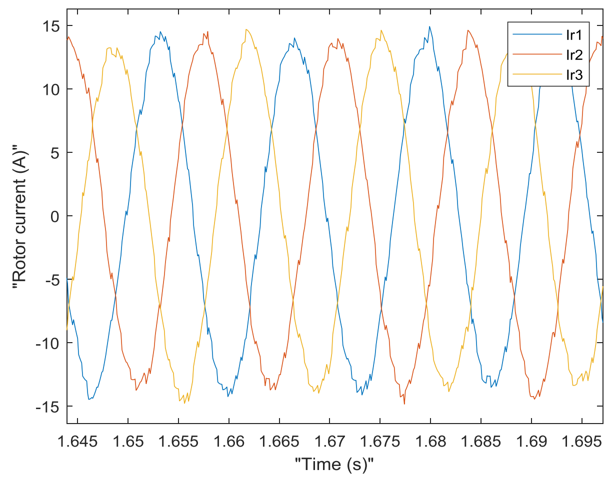
Figure 8 shows the mechanical error of the speed by SMC and PI, such as Figure 8(a) the mechanical error of the PI controller speed, Figure 8(b) the mechanical error of the SMC controller speed, Figure 8(c) comparison between the two mechanical speed errors.

The simulation results confirm that the MPPT control with mechanical speed control by sliding mode is better compared to the PI controller and Figures 8(a-c) confirm exactly from the error of the mechanical speed that the best is the SMC. In addition, the results for power management based on the PI controller and sliding mode show that we could control the active power and ensure a unit power factor.

From Figures 6(d) to 6(e) we can see that the active and reactive powers of the system follow perfectly the references and Figure 6(c) shows that the electromagnetic torque takes the same waveform as the active power. Figures 6(a) and 6(b) show that the three-phase stator and rotor currents generated by the DFIG are directly dependent on the active power supplied, and their waveforms are almost sinusoidal.



(a)



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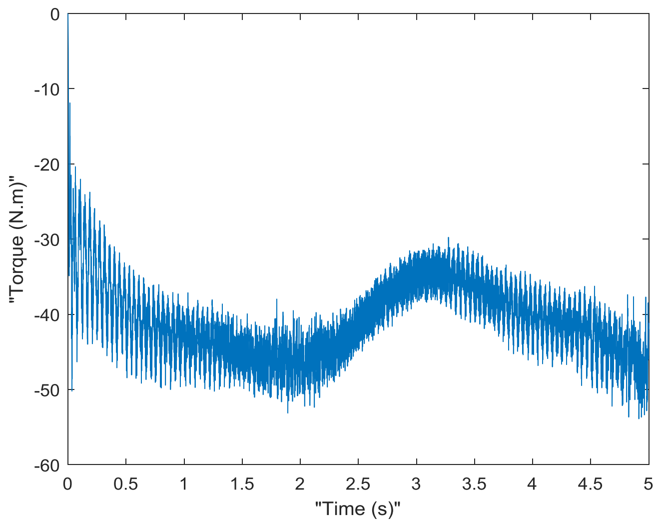
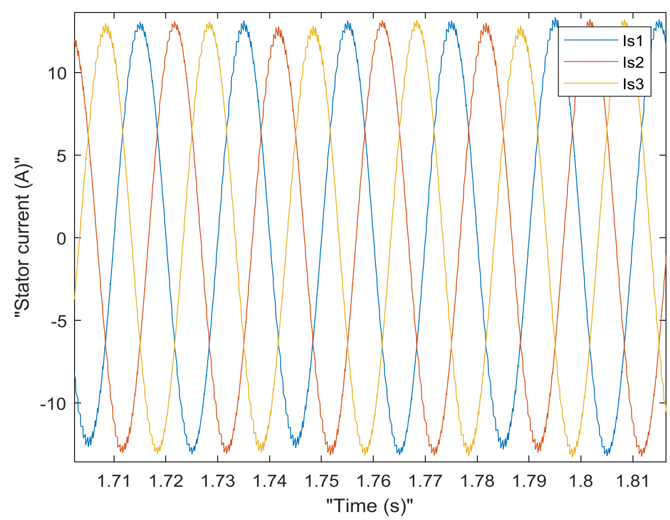
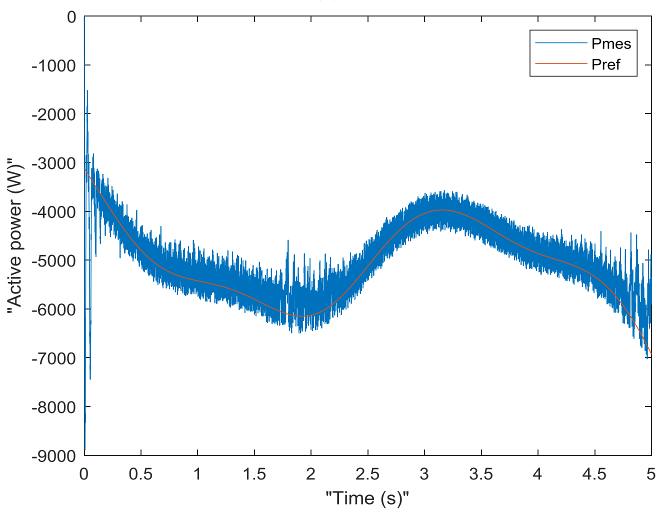


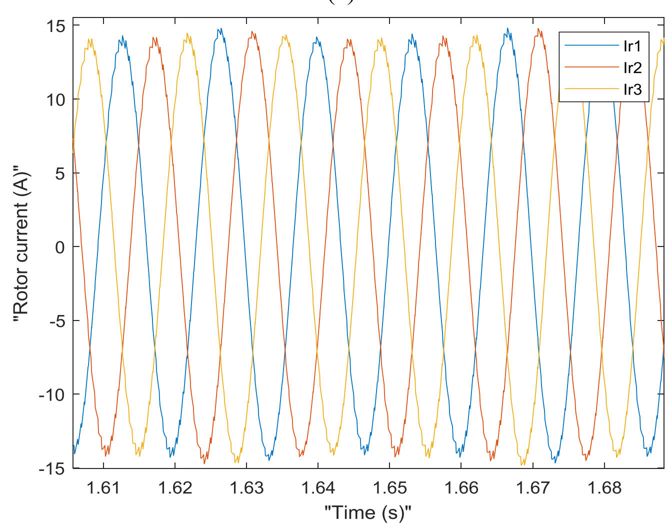
(c)



(a)



(d)



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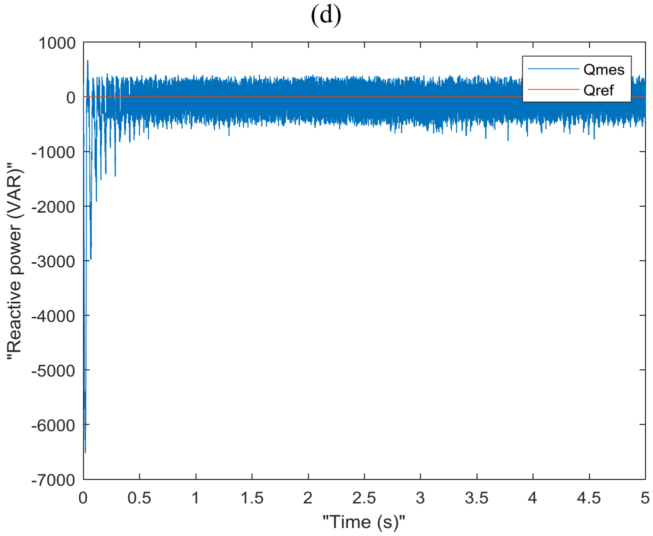

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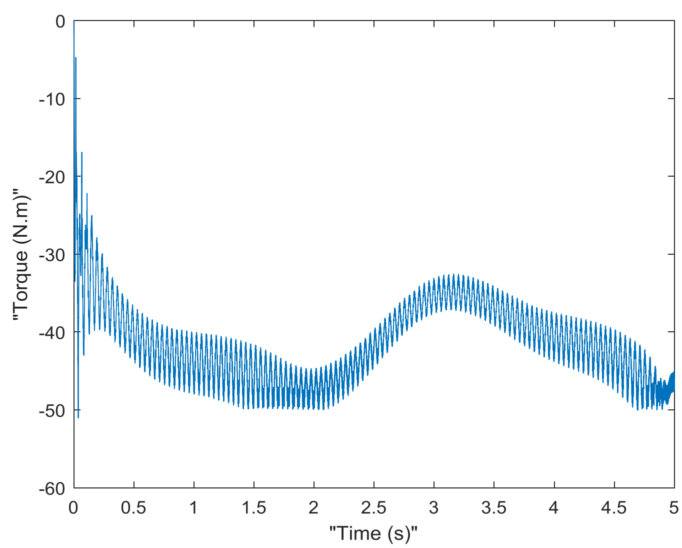
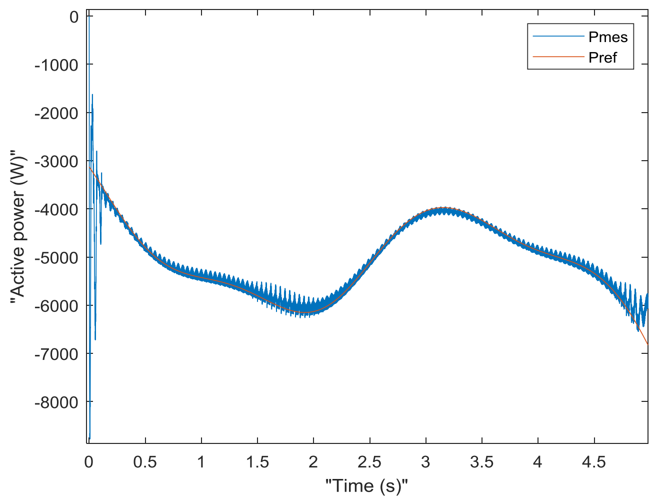
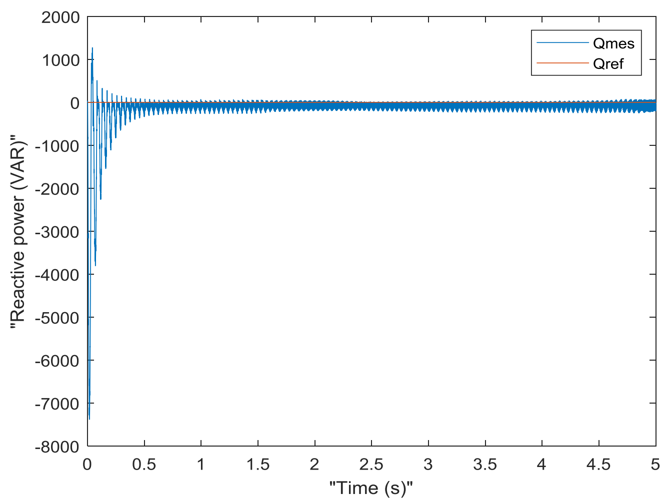


(c)

Fig. 6. The result of the system simulation with power control by the PI controller, (a) stator current, (b) rotor current, (c) torque, (d) active power, (e) reactive power.

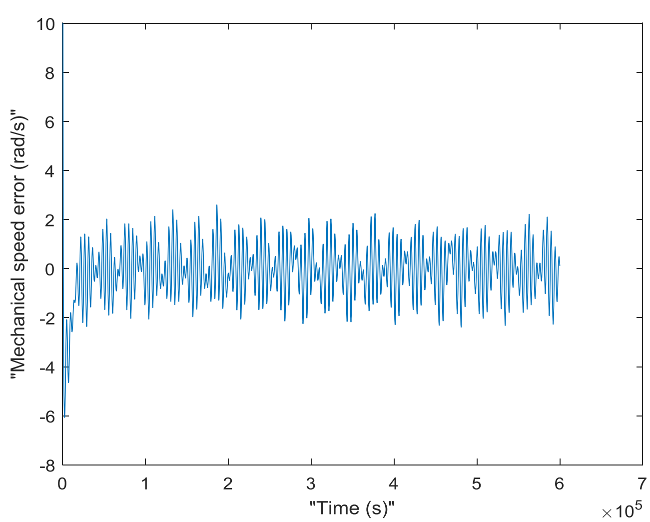


(d)

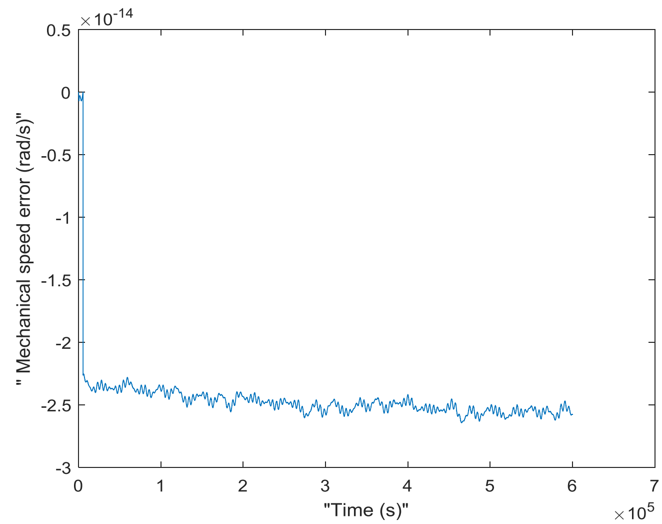


(e)

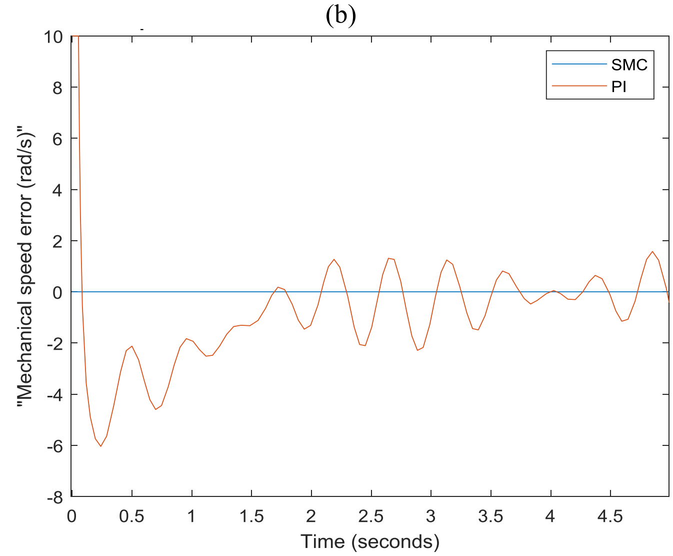
Fig. 7. The result of the system simulation with power control by sliding mode, (a) stator current, (b) rotor current, (c) torque, (d) active power, (e) reactive power.



(a)



(b)



(c)

Fig. 8. Simulation result of the mechanical speed error of the PI and SMC controllers, (a) mechanical speed error of the PI, (b) mechanical speed error of the SMC, (c) comparison between the mechanical error of PI and SMC.

8. CONCLUSION

This article presents the control of a doubly-fed induction generator wind system to control the active and reactive stator powers of a doubly-fed induction generator. Two types of controllers are synthesized and the active and reactive power of a DFIG wind turbine are compared to show that the performance has been adjusted and their performance analysed. The results demonstrate that the sliding-mode controller is more robust than the PI controller and enables independent control of the system's active and reactive power. It offers perfect reference tracking, zero static error and perfect decoupling. It also ensures zero power factor, and the electromagnetic torque is identical to the active power waveform. Moreover, the DFIG's three-phase stator and rotor currents are directly proportional to the active power input, and both currents have almost sinusoidal waveforms.

References

[1] D. Song, et al., "Maximum power extraction for wind turbines through a novel yaw control solution using predicted wind directions," *Energy Convers. Manag,* vol. 157, pp. 587–599, February 2018.

[2] M. E. Şahin, H. İ. Okumuş, "Comparison of different controllers and stability analysis for photovoltaic powered buck-boost DC-DC converter," *Electric Power Components and Systems*, 46(2), pp. 149-161, 2018.

[3] J. M. Adánez, B. M. Al-Hadithi, A. Jiménez, "Wind turbine multivariable optimal control based on incremental state model," *Asian J. Control,* vol. 20, pp. 1–13, December 2018.

[4] S. Jie, A. Qian, " Research on several key technical problems in realization of smart grid. Power Syst," *Prot. Control,* 37(19), pp. 1-4, 2009.

[5] A. Z. Mohamed, M. N. Eskander, F. A . Ghali, "Fuzzy logic control based maximum power tracking of a wind energy system," *Renew. Energy,* vol. 23, pp. 235–245, 2001.

[6]S. H. Lee, Y.J. Joo, J. Back, J.H. Seo, " Sliding mode controller for torque and pitch control of wind power system based on PMSG," *In: International Conference on Control, Automation and Systems, ICCAS,* pp. 1079–1084, December 2010.

[7] G. Balta, Ç. Hisar, N. Altin, "Artificial intelligence based switching frequency regulation with fast terminal sliding mode control for DC–DC step-down converters," *Expert Systems with Applications,* vol. 228, pp. 12033, October 2023.

[8] M. Martinez-Lopez, J. Moreno-Valenzuela, W. He, "A robust nonlinear PI-type controller for the DC–DC buck–boost power converter," *Isa transactions*, vol. 129, pp.687-700, October 2022.

[9] M.E. Şahın, H.I Okumuş, H. Kahvecı, "Sliding mode control of PV powered DC/DC Buck-Boost converter with digital signal processor". *In: 17th European Conference on Power Electronics and Applications, EPE'15 ECCE Europe*, pp.1-8, September 2015.

[10] H. Afghoul, F. Krim, D. Chikouche, A. Beddar, "Design and real-time implementation of a fuzzy-switched controller for single phase active power filter," *ISA Trans,* vol. 58, pp. 614–621, 2015.

[11] Y. Daili, J. P. Gaubert, L. Rahmani, A. Harrag, "Quantitativ feedback theory design of robust MPPT controller for small wind energy conversion systems: Design, analysis, and experimental study," *Sustainable Energy Technologies and Assessments,* vol. 35, pp 308-320, October 2019.

[12] G. Balta, N. Altin, and A. Nasiri, "Interval type-2 fuzzy-logic-based constant switching frequency control of a sliding-mode-controlled DC–DC Boost Converter," *Appl. Sci,* vol. 13, pp. 3239, March 2023.

[13] G. Balta, N. Güler, and N. Altin, "Modified fast terminal sliding mode control for DC-DC buck power converter with switching frequency regulation" *International Transactions on Electrical Energy Systems,* vol. 17, pp. 5076611, October 2022.

[14] M. Zadehbagheri, R. Ildarabadi, M. B. Nejad, "Sliding mode control of a doubly-fed induction generator (DFIG) for wind energy conversion system". *Int. J. Sci. Eng. Res,* 4(11), pp. 1573, 2013.

[15] X. Liu, X. Kong, "Nonlinear model predictive control for DFIG-based wind power generation," *IEEE Trans. Autom. Sci. Eng,* 11(4), pp. 1046–1055, 2014.

[16] A. Beddar, H. Bouzekri, B. Babes, A. Afghoul, "Experimental enhancement of fuzzy fractional order PI+I controller of grid-connected variable speed wind energy conversion system," *Energy Convers. Manag,* vol.123, pp. 569–580, September 2016.

[17] H. Afghoul, F Krim, B Babes, A. Beddar, A. Kihal, "Design and real-time implementation of sliding mode supervised fractional controller for wind energy conversion system under severe working conditions," *Energy Convers. Manag*, vol. 167, pp. 91–101, November 2018.

[18] H. E. M. Lopez, "Maximum power tracking control scheme for wind generator systems," Agricultural and Mechanical College of Texas, PhD Thesis, Texas, United States, *2007.*

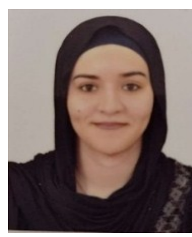
[19] K. Belgacem, A. Mezouar, A. Massoum, "Sliding mode control of a doubly-fed induction generator for wind energy conversion," *Int. J. Energy Eng,* 3(1), pp. 30–36, 2013.

[20] M. Zadehbagheri, R. Ildarabadi, M.B. Nejad, "Sliding mode control of a doubly- fed induction generator (DFIG) for wind energy conversion system," *Int. J. Sci. Eng. Res*, 4(11), 2013.

[21] X. Liu, X. Kong, "Nonlinear model predictive control for DFIG based wind power generation." *IEEE Trans. Autom. Sci. Eng,* 11(4), pp. 1046– 1055, 2014.

[22] X. Pinghua, S. Dan, "Backstepping-based DPC strategy of a wind turbine-driven DFIG under normal and harmonic grid voltage," *IEEE Trans. on P. Electron.,* 31(6), pp. 4216–25, 2016.

Biographies



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