Adaptation of Power in Wind Turbine by Using the Comparison Between the Sliding Mode and Synergetic Control Method

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Abstract - The purpose of this paper is the Adaptation of Actives and reactive power generated by wind turbine system based on a doubly fed induction generator (DFIG) with a rotor feeding by electrical network. the adaptation power is applied through a comparison between two control methods. The first one presents a sliding mode control strategy. This technique finds its strongest justification in the problem of using a nonlinear control law robust to model uncertainties. The second one is the synergetic control method. The main principle of synergetic control is to push the system dynamics and any macro-variation of the system to operate at convergence towards the zero point and providing stability of the system. Finally, The Simulations were performed to confirm the reliability and efficacy of the methods proposed.

Keywords - Wind turbine; doubly fed induction generator; control stratigy; sliding mode; synergetic controller; active and reactive power.

I. INTRODUCTION

Nowadays, the double feed induction machines as generators (DFIG) is used on the most of wind turbines [1]. The DFIG has many advantages such as functioning in variable wind, maximum of power generation and low cost [2].

To control wind turbine systems many methods of control are proposed in literature. Adaptive control techniques are required for their high performance and accuracy [3].

The robust control strategy will be made on the importance of optimizing the desired parameters of the DFIG. In this perspective, active power and reactive power will be our two robustness evaluation parameters for the system [4].

Different nonlinear control strategies are proposed to control the power of DFIG by the rotor voltages [5][6]. This work consists of controlling the active and reactive power generated by DFIG, using the sliding mode and synergetic control . The performance of the Synergetic controller is approved and compared with the sliding mode controller.

The structure of the present paper is : A general introduction in the first part; modeling of the wind energy system is shown in the second part. The third part is dedicated to the control strategy of DFIG. The fourth part devoted to the design of sliding mode control method. fifth part dedicated to the synergetic control power strategy.

In the next part the Simulation results and analysis are shown. A conclusion is set towards the end.

II. MODELING OF THE WIND ENERGY SYSTEM

The diagram of a wind turbine energy system connected to the electricity network is described in Figure 1.

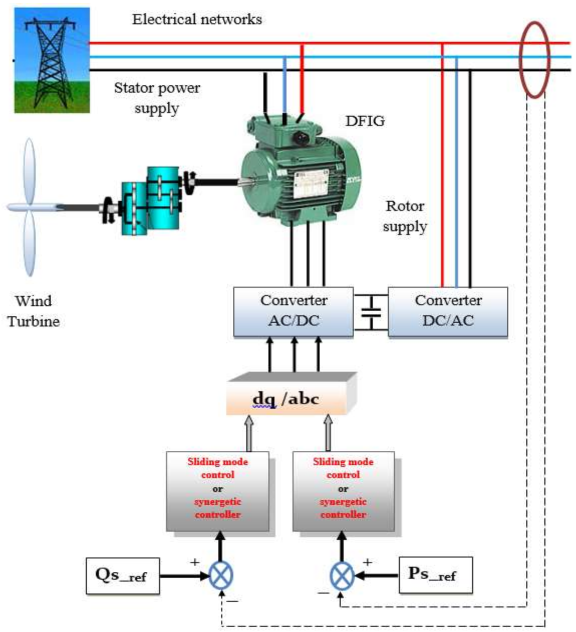


Fig. 1. Wind system considered.

III. MODELING OF WIND KINETIC POWER

The total power absorbed by the wind turbine from wind energy is given by [7, 8]:

$$P = \frac{1}{2}\rho S v^3 \quad (1)$$

but, only part of wind energy can be captured by the wind turbine [9]:

$$P = \frac{1}{2}\rho C_p S v^3 \quad (2)$$

For wind turbines, the energy extraction coefficient Cp which depends on the wind speed and the rotation speed of the turbine is generally defined in the [0.35- 0.5] interval.

IV. MODEL OF GENERATOR

The following equations describes the model of a doubly fed induction generator (DFIG) in the Park model. [7] [10]

$$\begin{cases} v_{ds} = R_s i_{ds} + \frac{d}{dt}\phi_{ds} - \omega_s \phi_{qs} \\ v_{qs} = R_s i_{qs} + \frac{d}{dt}\phi_{qs} + \omega_s \phi_{ds} \\ v_{dr} = R_r i_{dr} + \frac{d}{dt}\phi_{dr} - (\omega_s - \omega_r)\phi_{qr} \\ v_{qr} = R_r i_{qr} + \frac{d}{dt}\phi_{qr} + (\omega_s - \omega_r)\phi_{dr} \end{cases} \quad (3)$$

$$\begin{cases} \phi_{ds} = L_s i_{ds} + M_{sr} i_{dr} \\ \phi_{qs} = L_s i_{qs} + M_{sr} i_{qr} \\ \phi_{dr} = L_r i_{dr} + M_{sr} i_{ds} \\ \phi_{qr} = L_r i_{qr} + M_{sr} i_{qs} \end{cases} \quad (4)$$

$$C_{em} = p\frac{M_{sr}}{L_s}\left(\phi_{qs} i_{dr} - \phi_{ds} i_{qr}\right) \quad (5)$$

V. CONTROL STRATEGY OF DFIG

The control of the GADA must allow independent control of active and reactive powers by the rotor voltages generated by an inverter.

In the d-q frame of reference, the active and reactive stator powers of DFIG generator is defined by: [11]

$$\begin{cases} P_s = v_{ds} i_{ds} + v_{qs} i_{qs} \\ Q_s = v_{qs} i_{ds} + v_{ds} i_{qs} \end{cases} \quad (6)$$

So, the Adaptation of Eq. (6) from the hypotheses simplifying gives by:

$$P_s = -v_s \frac{M}{L_s} i_{qr} \quad (7)$$

$$Q_s = -v_s \frac{M}{L_s} i_{dr} + \frac{v_s^2}{L_s \omega_s} \quad (8)$$

For the control of DFIG generator, a new equation is established to show the relationship between the currents and the rotor voltages which will be applied to it [12].

$$v_{dr} = R_r i_{dr} + \left(L_r - \frac{M^2}{L_s}\right)\frac{di_{dr}}{dt} - g\left(L_r - \frac{M^2}{L_s}\right)\omega_s i_{qr} \quad (9)$$

$$v_{qr} = R_r i_{qr} + \left(L_r - \frac{M^2}{L_s}\right)\frac{di_{qr}}{dt} + g\left(L_r - \frac{M^2}{L_s}\right)\omega_s i_{dr} + g\frac{M v_s}{L_s} \quad (10)$$

VI. DESIGN OF SLIDING MODE CONTROL METHOD

To control the DFIG power we take n=1, so the expression of the active and reactive power control surface has the form : [13]

$$\begin{cases} S(P) = \left(P_s^{ref} - P_s\right) \\ S(Q) = \left(Q_s^{ref} - Q_s\right) \end{cases} \quad (11)$$

The derivatives of the surfaces are:

$$\begin{cases} \dot{S}(P) = \left(\dot{P}_s^{ref} - \dot{P}_s\right) \\ \dot{S}(Q) = \left(\dot{Q}_s^{ref} - \dot{Q}_s\right) \end{cases} \quad (12)$$

We replace the expressions for the power (Eq. 7 and Eq.8)

$$\begin{cases} \dot{S}(P) = \left(\dot{P}_s^{ref} + v_s \frac{M}{L_s}\dot{i}_{qr}\right) \\ \dot{S}(Q) = \left(\dot{Q}_s^{ref} + v_s \frac{M}{L_s}\dot{i}_{dr}\right) \end{cases}$$

(13)

Through the equations of the voltage *vqr* and *vdr* (Eq.10 and Eq.9), we can draw the current expressions *iqr* and *idr* :[14]

$$\begin{cases} \dot{S}(P) = \left(\dot{P}_s^{ref} + v_s \frac{M}{L_s L_r \sigma}\left(v_{qr} - R_r i_{qr}\right)\right) \\ \dot{S}(Q) = \left(\dot{Q}_s^{ref} + v_s \frac{M}{L_s L_r \sigma}\left(v_{dr} - R_r i_{dr}\right)\right) \end{cases}$$

(14)

With : $\sigma = 1 - \frac{M^2}{L_s L_r}$

By replacing of *vdr* and *vqr* expressions with $\left(v_{qr}^{eq} + v_{qr}^{n}\right)$ and $\left(v_{dr}^{eq} + v_{dr}^{n}\right)$ respectively, the derivative surface of active and reactive powers are written as follows:[14]

$$\begin{cases} \dot{S}(P) = \left(\dot{P}_s^{ref} + v_s \frac{M}{L_s L_r \sigma}\left(\left(v_{qr}^{eq} + v_{qr}^{n}\right) - R_r i_{qr}\right)\right) \\ \dot{S}(Q) = \left(\dot{Q}_s^{ref} + v_s \frac{M}{L_s L_r \sigma}\left(\left(v_{dr}^{eq} + v_{dr}^{n}\right) - R_r i_{dr}\right)\right) \end{cases} \quad (15)$$

In steady state of sliding mode, we have:

$$\begin{cases} S(P) = 0 \ , \ \dot{S}(P) = 0 \ , \ v_{qr}^{n} = 0 \\ S(Q) = 0 \ , \ \dot{S}(Q) = 0 \ , \ v_{dr}^{n} = 0 \end{cases} \quad (16)$$

From the expression of Eq. 16, the equivalent control equations (v_{qr}^{eq} and v_{dr}^{eq}) becomes:

$$\begin{cases} v_{qr}^{eq} = -\dot{P}_s^{ref}\frac{\sigma L_s L_r}{v_s M} + R_r i_{qr} \\ v_{dr}^{eq} = -\dot{Q}_s^{ref}\frac{\sigma L_s L_r}{v_s M} + R_r i_{dr} \end{cases} \quad (17)$$

So that the conditions $S(P)\dot{S}(P) \le 0$ and $S(Q)\dot{S}(Q) \le 0$ are verified, we put: [14]

$$\begin{cases} \dot{S}(P) = -v_s \frac{M}{\sigma L_s L_r} v_{qr}^{n} \\ \dot{S}(Q) = -v_s \frac{M}{\sigma L_s L_r} v_{dr}^{n} \end{cases} \quad (18)$$

therefore, the switching term is given by:

$$\begin{cases} v_{qr}^{n} = K v_{qr} \ sign\left(S(P)\right) \\ v_{dr}^{n} = K v_{dr} \ sign\left(S(Q)\right) \end{cases} \quad (19)$$

And limit tension is:

$$\begin{cases} v_{qr}^{\lim} = v_{qr}^{\max} sat(P) \\ v_{dr}^{\lim} = v_{dr}^{\max} sat(Q) \end{cases} \quad (20)$$

VII. SYNERGETIC CONTROL POWER STRATEGY

Synergetic control is considered a nonlinear control technique with first introduced in a general way by Kolesnikov team.

The objective of this controller is to force the system to evolve on the domain chosen beforehand φ=0 and providing stability of the system according to the following equation: [15]

$$T\frac{d\varphi}{dt}+\varphi=0 \tag{21}$$

And:

$$T_1\frac{d\varphi}{dt}+\varphi+T_2\int\varphi=0 \tag{22}$$

For improve he robustness control our design can be described through the model shown in figure 2

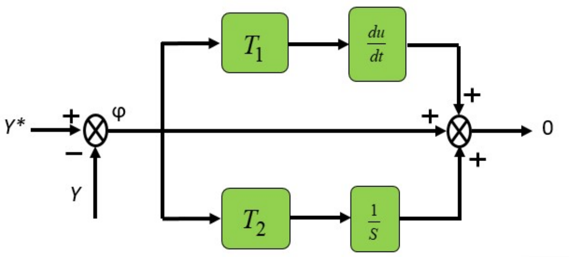


Fig. 2. Synergetic synthesis controller [16].

Where : Y^*: reference value, Y: measured value, φ: macro variable, T_1 et T_2: is coefficient time for derivative and integration respectively.

Through the equations Eq.7, Eq.8 and using the Rotor current *idr* and *iqr* respectively, we can control the active power and Reactive power of DFIG.

For this study we will consider the difference, between the measured and reference stator powers, as the variable. This variable represents the error. Can be written as follows: [15] [17] [18]

$$\begin{cases}\varphi_1 = P_{s\_ref} - P_s \\ \varphi_2 = Q_{s\_ref} - Q_s\end{cases} \tag{23}$$

By substituting the Eq. 23 in equation of synergetic synthesis theory (Eq. 22) we get:

$$\begin{cases}T_{qr1}\left[\dot{P}_{s\_ref}-\dot{P}_s\right]+P_{s\_ref}-P_s \\ +T_{qr2}\int P_{s\_ref}-P_s=0 \\ T_{dr1}\left[\dot{Q}_{s\_ref}-\dot{Q}_s\right]+Q_{s\_ref}-Q_s \\ +T_{dr2}\int Q_{s\_ref}-Q_s=0\end{cases} \tag{24}$$

By substituting the equations of power (Eq.7, Eq.8) after it is derived in (Eq. 24) we can write:

$$\begin{cases}T_{qr1}\left[\dot{P}_{s\_ref}+\frac{Mv_s}{L_s}i_{qr}\right]+P_{s\_ref}-P_s \\ +T_{qr2}\int P_{s\_ref}-P_s=0 \\ T_{dr1}\left[\dot{Q}_{s\_ref}+\frac{Mv_s}{L_s}i_{dr}\right]+Q_{s\_ref}-Q_s \\ +T_{dr2}\int Q_{s\_ref}-Q_s=0\end{cases} \tag{25}$$

And last we replace the equations of current (Eq.9, Eq.10) in Eq. 25 and write as follows:

$$\begin{cases}T_{qr1}\dot{P}_{s\_ref}+\frac{T_{qr1}Mv_s}{\sigma L_s}\left[v_{qr}-R_ri_{qr}-\frac{gMv_s}{L_s}-\omega_g\sigma i_{dr}\right] \\ +\varphi_1+T_{qr2}\int\varphi_1=0 \\ T_{dr1}\dot{Q}_{s\_ref}+\frac{T_{dr1}Mv_s}{\sigma L_s}\left[v_{dr}-R_ri_{dr}+\omega_g\sigma i_{qr}\right] \\ +\varphi_2+T_{qr2}\int\varphi_2=0\end{cases} \tag{26}$$

Through the equation (Eq. 26), the reference voltage equation for signal loop synergetic control can be extracted:

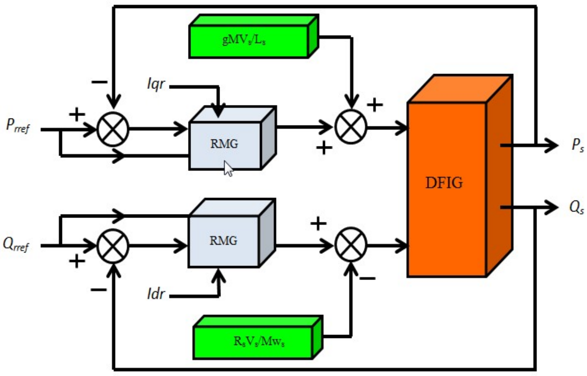
$$\begin{cases}v_{qr}=\frac{-\sigma L_s}{T_{qr1}Mv_s}\left[T_{qr1}\dot{P}_{s\_ref}+\varphi_1+T_{qr2}\int\varphi_1\right] \\ \quad +R_ri_{qr}+\frac{gMv_s}{L_s}+\omega_g\sigma i_{dr} \\ v_{qr}=\frac{-\sigma L_s}{T_{dr1}Mv_s}\left[T_{dr1}\dot{Q}_{s\_ref}+\varphi_2+T_{qr2}\int\varphi_2\right] \\ \quad +R_ri_{dr}-\omega_g\sigma i_{qr}\end{cases} \tag{27}$$

We put:

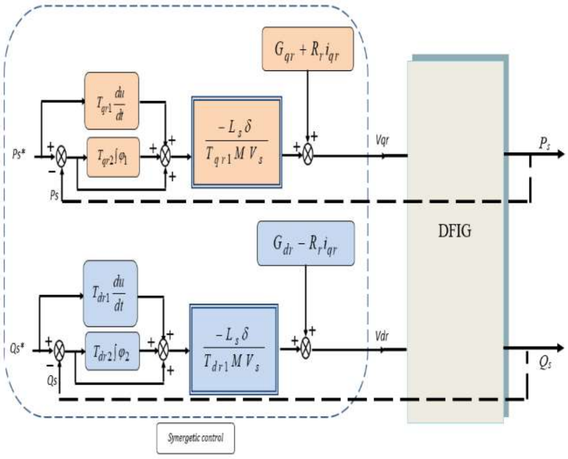
$$\begin{cases}G_{qr}=\frac{gMv_s}{L_s}+\omega_g\sigma i_{dr} \\ G_{dr}=\omega_g\sigma i_{qr} \\ G_Q=\frac{v_s^2}{L_s\omega_s}\end{cases} \tag{28}$$

VIII. SIMULATION AND RESULTS

To illustrate the control performance of the synergetic and sliding mode method applied to DFIG, a block diagram of the system is proposed in Figure 3.



(a)



(b)

Fig. 3. Block diagram of active and reactive power controlled by (a) sliding mode controller, (b) Synergetic controller

The sliding mode control and synergetic control technique are used to control the DFIG stator powers (P_s, Q_s).

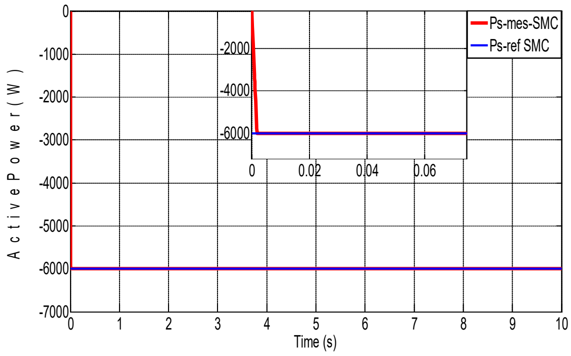


Fig. 4. Block diagram of active power controlled by sliding mode controller

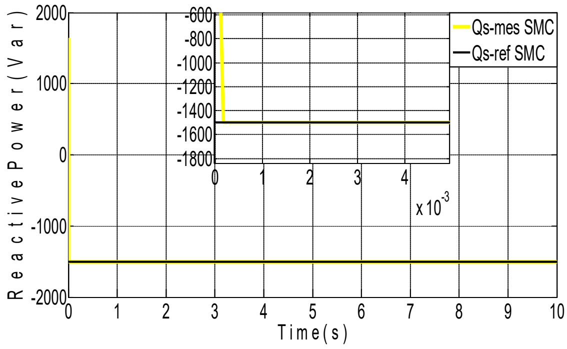


Fig. 5. Block diagram of reactive power controlled by sliding mode controller

Figures 4 and 5 show the control of active and reactive stator powers by sliding mode control method with value of 6 kW to active power and 1.5 kvar to the reactive power.

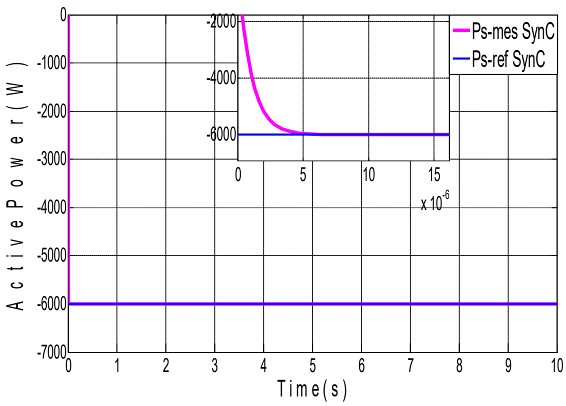


Fig. 6. Block diagram of active power controlled by synergetic controller

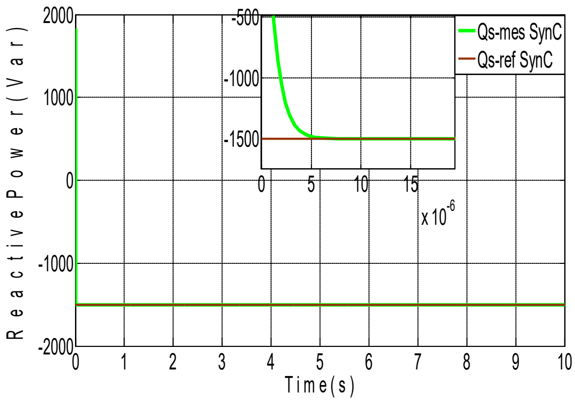


Fig. 7. Block diagram of reactive power controlled by synergetic controller

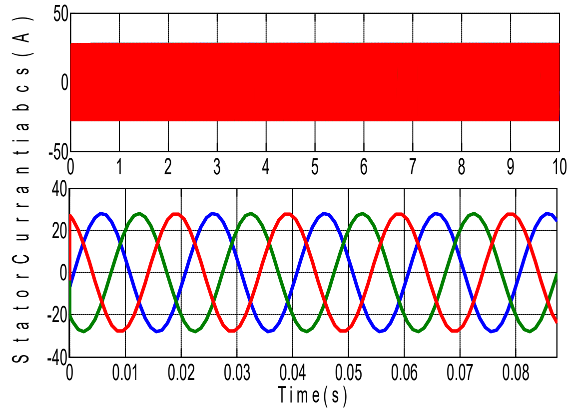


Fig. 8. Block diagram of stator current.

Figures 6 and 7 show the control of active and reactive stator powers by synergetic control method. In the period t = [0 10] s, the desired active power is 6 kW and the reactive power is 1.5 kvar. Additionally Figure 8 shows the adjusted stator value at 28A.

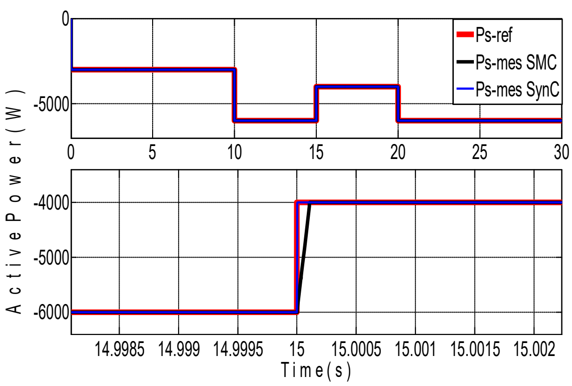


Fig. 9. Stator-active power after control and regulation

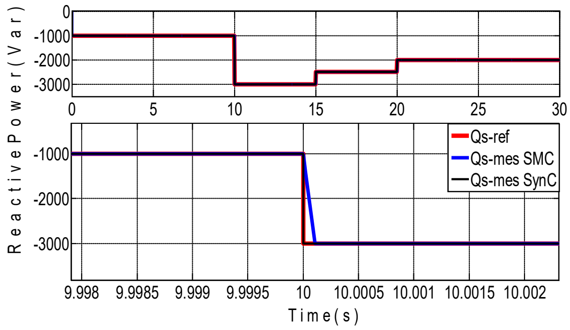


Fig. 10. Stator-reactive power after control and regulation

Figures 9 and 10 show that the control of the active and reactive powers by synergetic control technique is very fast (0.0002s) compared to the SMC technique with more precision. In period [10 15] s: $P_{s\text{-}SynC}$= 6KW, $P_{s\text{-}SMC}$=5.8KW and $Q_{s\text{-}SynC}$ = 3 kW, $Q_{s\text{-}SMC}$=2.85 kW. So the control by synergetic control method is robust compared to the sliding mode controller.

IX. CONCLUSION

In this paper, the control of a wind energy recovery system equipped by doubly fed induction generator (DFIG) is presented. Firstly, a model of the generator was proposed. Then, a sliding mode and synergetic control strategy of DFIG allowing independent power control have been proposed and tested.

The simulation results allowed us to judge the qualities of the control based on the sliding mode and synergetic control. Through the response characteristics, we observe a fast and good performance of synergetic control method compared to the sliding mode control in the presence of parametric variations.

After the simulation in the MATLAB-Simulink environment; the results found prove the effectiveness of the synergetic control method compared to the sliding mod control.

X. REFERENCES

[1] EL.O. Zouggar, S. Chaouch, O.A. Djaffar, and L. Abdelhamid, Sliding control with fuzzy type-2 controller of wind energy system based on doubly fed induction generator, *Instrumentation Mesure Metrologie, vol. 18, No. 2*, 2019, 137-146.

[2] S. Boubzizi, H. Abid, A. El hajjaji, and M. Chaabane, Comparative study of three types of controllers for

DFIG in wind energy conversion system, *Journal of Protection and Control of Modern Power Systems, vol. 21*, 2018, 1-12.

[3] J. Priyank, and Dr. M.J. Nigam, Design of a model reference adaptive controller using modified MIT rule for a second order system, *Advance in Electronic and Electric Engineering, vol. 3, No 4*, 2013, 477- 484.

[4] B. Fatnassi, B. Torchani, A. Sellami, and G. Garcia, , Sliding Mode Control of DFIG for a Variable Speed Wind Turbine, *International Conference on Control, Automation and Diagnosis (ICCAD),* 2022, DOI:10.1109/ICCAD55197.2022.9854007.

[5] M. Bourdoulis, and A. Alexandridis A, Rotor-side PI controller design of DFIG wind turbines based on direct power flow modeling, *2nd Int Conf on Renewable Energy Research and Applications (ICRERA)*, Madrid, Spain.,2013.

[6] A. Wiam, M. Ourahou, and H. Ali, Fuzzy logic rotor currents control of a DFIG-based wind turbine, *International Conference on Automation, Control Engineering and Computer Science (ACECS)Proceedings of Engineering and Technology – PET*, 2021, 3-8.

[7] M. Kendzi, and A. Aissaoui, Comparison between the MIT rule and fuzzy logic controller to adapting the power generated by a doubly fed induction generator integrated in a wind system, *10th IEEE International Conference on Smart Grid,* TURKEY, 2022, DOI:10.1109/icSmartGrid55722.2022.9848520,

[8] B. Hamane, M.L. Doumbia, M. Bouhamida, And M. Benghanem, Control of wind turbine based on DFIG using fuzzy-PI and sliding mode controllers, *Ninth International Conference on Ecological Vehicles and Renewable Energies (EVER),* 2014, DOI: 10.1109/EVER.2014.6844060.

[9] M. Kendzi, A. Aissaoui, M. Abid, and A. Tahour, Control of the photoelectric generator for used in feeding of the independent wind turbine system, *International Journal of Power Electronics and Drive System (IJPEDS), vol. 10, No. 3*, 2019, 1613-1627.

[10] Z. Zeghdi, L. Barazane, Y. Bekakra, and A.Larabi, Improved backstepping control of a DFIG based wind energy conversion system using ant lion optimizer algorithm, *Periodica Polytechnica Electrical Engineering and Computer Science, vol 66, No. 1*, 2022, 43–59.

[11] C. Mohssine, A. Essadki, and T. Nasser, A comparative study of PI, RST and ADRC control strategies of a doubly fed induction generator based wind energy conversion system, *International Journal of Renewable Energy Research-IJRER, vol.8, No.2*, 2018, 1174–1184.

[12] M. Kendzi, A. Aissaoui, Y. Dris, A. Bouiri, and M. Haddar, Management power of renewable energy in multiple sources system to feeding the rotor of a doubly-fed induction generator, *Bulletin of Electrical Engineering and Informatics, vol.12, No.2*, 2023, 619–632.

[13] M. Allam, Y. Djeriri, H. Mesai Ahmed, and I. Dehiba, Sliding mode control of a doubly fed induction generator for wind energy conversion systems, *International Symposium On Technology Sustainable Industry Development, ISTSID'19*, Algeria, 2019.

[14] O. El qouarti, A. Essadki, and T. Nasser , High order sliding mode control of active and reactive powers for DFIG based Wind turbine, *10th International Conference on Innovation, Modern Applied Science & Environmental Studies (ICIES'2022)*, 2022, https://doi.org/10.1051/e3sconf/202235101008

[15] A. Bouiri, C. Banoudjafer, and O. Boughazi, Cascade synergetic robust control power for wind speed variation based-on doubly-fed induction generator, *Journal of Electrical and Electronics Engineering, vol 13, No. 2*, 2020, 39-44.

[16] Y. Xunwei, J. Zhenhua, and Z. Yu, A synergetic control approach to grid-connected, wind-turbine doubly-fed induction generators, *IEEE Power Electronics Specialists Conference,* DOI:10.1109/PESC.2008.4592248, 2008.

[17] A. Fayssal, C. Azeddin, B.E. badr, and M. saad, Design and implementation of high performance field oriented control for grid-connected doubly fed induction generation viahysteresis rotor current controller, *Rev. Roum. Sci. Techn. – Électrotechn. et Énerg, vol. 61, No. 4*, 2016, 319–324.

[18] A. Ardjal, M. Bettayeb, R. Mansouri, and A. Mehiri, Nonlinear synergetic control approach for dc-link voltage regulator of wind turbine DFIG connected to the grid, *5th International Conference on Renewable Energy: Generation and Applications (ICREGA)*, 2018.