Implement Robust Nonlinear Control Techniques of a Wind System Based on a Dual Stator Induction Generator

Khaled Benzaoui, Abderrahmen Bouguerra, Samir Zeghlache, Mohammed Boukhari and Ayyoub Zeghlache

Implement Robust Nonlinear Control Techniques of a Wind System based on a Dual Stator Induction Generator

Khaled Benzaoui
dept. Electrical engineering
University of m'sila
M'sila, Algeria
khaled.benzaoui@univ-msila.dz

Abderrahmen Bouguerra
dept. Electrical engineering
University of m'sila
M'sila, Algeria
abderrahmen.bouguerra@univ-msila.dz

Samir Zeghlache
dept. Electrical engineering
University of m'sila
M'sila, Algeria
samir.zeghlache@univ-msila.dz

Mohammed Boukhari
dept. Electrical engineering
University of m'sila
M'sila, Algeria
mohammed.boukhari@univ-msila.dz

Ayyoub Zeghlache
dept. Electrical engineering
University of m'sila
M'sila, Algeria
ayyoub.zeghlache@univ-msila.dz

Abstract— **Wind energy is a source of energy that depends on the wind, is a kinetic energy of moving air masses around the globe, Wind energy is an indirect form of solar energy: the solar rays absorbed in the atmosphere lead to differences in temperature and pressure. The development of variable-speed wind technology and at constant frequency has today become a major area of interest in achieving a successful rapid and global migration towards this type of energy. The aim of this work is to implement robust nonlinear control techniques of a wind system based on a double star asynchronous generator, to independently control the active powers and reactive exchanged between the stator and the network. The objective is to assess the relevance and performance of advanced control techniques, such as (adaptive fuzzy control, Hybrid control, control by backstepping, control by sliding mode, etc. allows to achieve the desired performance. These nonlinear control techniques applied on this type of system ensuring convergence in finite time and robustness against parametric uncertainties and external disturbances, which is one of the main contributions of this work.**

Keywords— Nonlinear system, nonlinear control, wind energy, wind system, generator double star asynchronous, adaptive control.

I. INTRODUCTION

Energy demands are ever-increasing, sources of fossil fuels declining and concerns about pollution levels in the environment are the main motivations for the production of electricity based on energy sources renewable. Renewable energies, such as solar, wind, and tidal energies are clean, inexhaustible, and environmentally friendly energies. Because of all these factors, wind power generation has attracted great interest in recent years.

The proliferation of wind turbines has led electrical engineering researchers to carry out investigations in order to improve the efficiency of the electromechanical conversion and the quality of the energy supplied. The asynchronous machine in variable speed drives poses a certain number of difficulties making its control more complex compared to that of a direct current machine. Joint progress in power electronics and digital electronics now makes it possible to approach speed control variables in low, medium, and high-power applications. Jointly to these technological advances, the scientific community has developed various approaches to command (scalar command, command by state feedback, DTC command, vector control, etc.), to control the flow and torque of machines in real-time electric, by the advantages (high efficiency, low weight, small dimensions, fast operations, and very high-power density).

In this general conference, our study concerns the vector control of a self-excited double star asynchronous generator in wind energy conversion into electrical energy. We are also interested in studying and modeling the wind turbine and the double star asynchronous generator, in order to apply the control technique vector using conventional regulators, and on the other hand to evaluate the performance of the wind generator based on the DSIG connected to the isolated city [1,3,6,7].

II. WIND TURBINE AND GEARBOX MODELING

A. Turbine Model

Wind energy is the recoverable kinetic energy of air passing through a certain surface , the power is proportional to the cube of the wind speed [1]:

$$P_{wind} = \frac{E}{dt} = \frac{1}{2} * \rho * \pi * R^2 * V_{wind}^3 \qquad (1)$$

The relationship between wind speed and aerodynamic power extracted from the wind can be described as follows

$$P_{aer} = \frac{E}{dt} = \frac{1}{2} * \rho * \pi * R^2 * C_p(\lambda, \beta) * V_{wind}^3 \qquad (2)$$

with:

P_{wind}: wind power [W].

P_{aer}: aerodynamic power of the wind turbine [W].

ρ: air density [kg/m3].

R: radius of the turbine in meters [m].

C_p: power coefficients.

λ: relative speed.

β: orientation angle of the blades in degrees [°].

V_{wind}: wind speed in [m/s]

*Corresponding author: Khaled Benzaoui
E-mail: khaled.benzaoui@univ-msila.dz.

The power coefficient can be defined by:

$$\begin{cases} C_p = c_1(\dfrac{c_2}{\lambda_i} - c_3\,\beta - c_4)e^{\dfrac{-c_5}{\lambda_i}} + c_6\lambda \\ \dfrac{1}{\lambda_i} = \dfrac{1}{\lambda + 0.08\beta} - \dfrac{0.035}{\beta^3 + 1} \end{cases} \quad (3)$$

where the chosen coefficient values of c1-c6 in this conference are:

TABLE I.   THE VALUES OF THE COEFFICIENTS OF C_P

C_1	C_2	C_3	C_4	C_5	C_6
0.1576	116	0.4	5	21	0.0068

The torque of the turbine is the ratio of the transmitted power to the shaft speed Ω_t. It is given by:

$$C_{aer} = \frac{P_t}{\Omega_t} \quad (4)$$

B. Gearbox Model

The optimum speed of the current turbines is in the vicinity of a few tens of revolutions per minute. This requires the introduction of a gearbox between the turbine and the electrical machine whose gear ratio G is chosen in order to set the generator shaft speed within the desired speed range. Neglecting the transmission losses, the torque T_t and shaft speed of the wind turbine Ω_t, referred to as the generator side of the gearbox, are given by [1]:

$$G = \frac{\Omega_{mec}}{\Omega_{turb}} \quad , G = \frac{T_t}{T_g} \quad (5)$$

with :

G: multiplier ratio.

T_t: turbine torque of the turbine [N.m].

T_g: generator torque [N.m].

Ω_{turb}: turbine speed [rad/s].

Ω_{mec}: Mechanical Speed Of The Generator [rad/s].

The mechanical equation can be expressed as:

$$J\frac{d\Omega_{mec}}{dt} = T_g - T_{em} - K_f\Omega_{mec} \quad (6)$$

The total inertia J_T is made up of the inertia of the turbine brought back to the fast axis J_{turb}, and the inertia of the generator J.

$$J_T = \frac{J_{turb}}{G} + J \quad (7)$$

with :

T_{em}: electromagnetic torque [N.m].

J_{turb}: inertia of the turbine [kg.m2].

J: generator inertia [kg.m2].

The block diagram of the turbine model with the control of the speed is represented in Fig.1
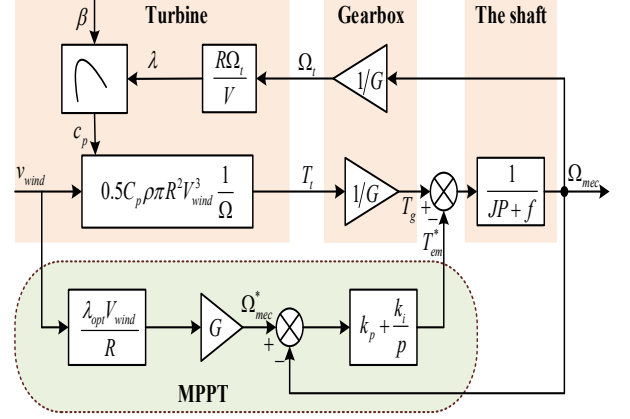

Fig. 1.   Block diagram of the turbine model with variable speed control [1].

III. MODELING OF THE DSIG

The writing of the DSIG model in a two-phase frame (d, q) linked to the rotating field is obtained by using the normalized Park transformations in order to conserve power. By applying these transformations to the voltages as well as to the stator fluxes, we obtain the electric and magnetic models. The representation of the windings of the DSIG in the Park frame is given in Fig.2 [3]:
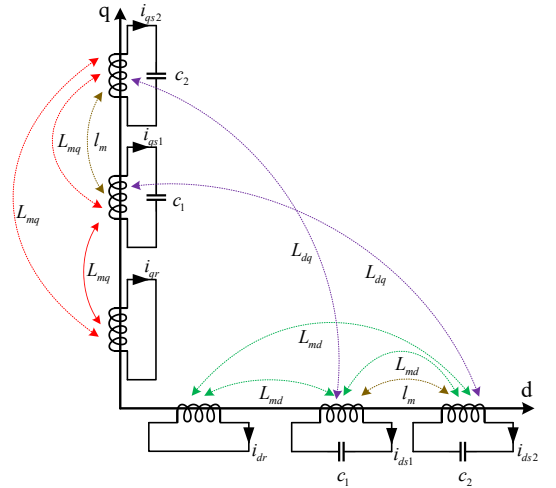

Fig. 2.   Representation of the DSIG model in (dq) frame [2].

A. Forming an Equation of State

$$\left[\dot{X}\right] = [L]^{-1}\left\{[B][V] - [C][X]\right\} \quad (8)$$

where: $\omega_{gl} = \omega_s - \omega_r \,, \omega_r = p * \Omega_{mec}$

with :

ω_s: Speed of the synchronous

ω_r: Rotor electrical angular speed

$$L_m = b_1 + b_2 I_m + b_3 I_m^2 + b_4 I_m^3 \qquad (9)$$

with :

L_m: Magnetizing inductance

I_m: Magnetizing current

where the values of b1; b2; b3; b4 are:

$$[X] = \begin{bmatrix} i_{ds1} & i_{qs1} & i_{ds2} & i_{qs2} & i_{dr} & i_{qr} \end{bmatrix}^T$$

$$[V] = \begin{bmatrix} v_{ds1} & v_{qs1} & v_{ds2} & v_{qs2} & v_{dr} & v_{qr} \end{bmatrix}^T$$

$$[B] = diag\begin{bmatrix} 1 & 1 & 1 & 1 & 0 & 0 \end{bmatrix}$$

$$[L] = \begin{bmatrix} -L_{ds1} & 0 & -L_{md}-l_m & -L_{dq} & L_{md} & 0 \\ 0 & -L_{qs1} & L_{dq} & -L_{mq}-l_m & 0 & L_{mq} \\ -L_{md}-l_m & L_{dq} & -L_{ds2} & 0 & L_{md} & 0 \\ -L_{dq} & -L_{mq}-l_m & 0 & -L_{qs2} & 0 & L_{mq} \\ -L_{md} & 0 & -L_{md} & 0 & L_{dr} & 0 \\ 0 & -L_{mq} & 0 & -L_{mq} & 0 & L_{qr} \end{bmatrix}$$

$$[C] = \begin{bmatrix} -R_{s1} & \omega_s L_{qs1} & -\omega_s L_{dq} & \omega_s(L_{mq}+l_m) & 0 & -\omega_s L_{mq} \\ -\omega_s L_{ds1} & -R_{s1} & -\omega_s(L_{md}+l_m) & -\omega_s L_{dq} & \omega_s L_{md} & 0 \\ \omega_s L_{dq} & \omega_s(L_{mq}+l_m) & -R_{s2} & \omega_s L_{qs2} & 0 & -\omega_s L_{mq} \\ -\omega_s(L_{md}+l_m) & \omega_s L_{dq} & -\omega_s L_{ds2} & -R_{s2} & \omega_s L_{md} & 0 \\ 0 & \omega_{gl} L_{mq} & 0 & \omega_{gl} L_{mq} & R_r & -\omega_{gl} L_{qr} \\ -\omega_{gl} L_{md} & 0 & -\omega_{gl} L_{md} & 0 & \omega_{gl} L_{dr} & R_r \end{bmatrix}$$

where $L_{ds1} = l_{s1} + L_{md} + l_m$, $L_{qs1} = l_{s1} + L_{mq} + l_m$, $L_{dr} = l_r + L_{md}$, $L_{qr} = l_r + L_{mq}$, $L_{ds2} = l_{s2} + L_{md} + l_m$

$L_{qs2} = l_{s2} + L_{mq} + l_m$, $L_m = L_{md} = L_{mq}$, $L_{dq} = 0$

IV. SIMULATION AND DISCUSSION OF RESULTS

A. Simulation

The following Fig. 5 presents the vector control of the DSIG, with estimator of the magnetization inductance.

The complete wind conversion chain was simulated under the Matlab / Simulink environment. The performances of the vector control to maintain the voltage at the output of the two rectifiers constant whatever the driving speed in a range of feasibility, these performances will appear in the following; From the series of numerical simulation in which we have made simulation, will be with the control which shows its essence to make the tension constant whatever the driving speed.

To see the vector control performance, we trained the DSIG at several speeds, as shown in Fig. 6, Fig. 7, and Fig. 8. The reference voltage is fixed at the value Vdc* = 350 V
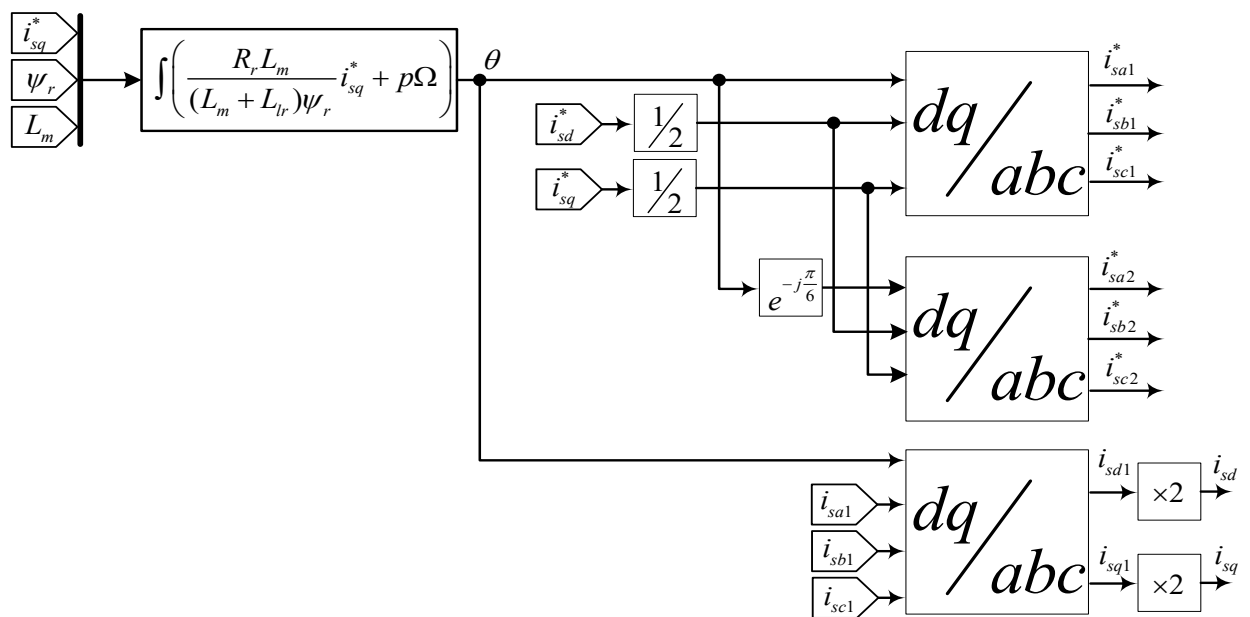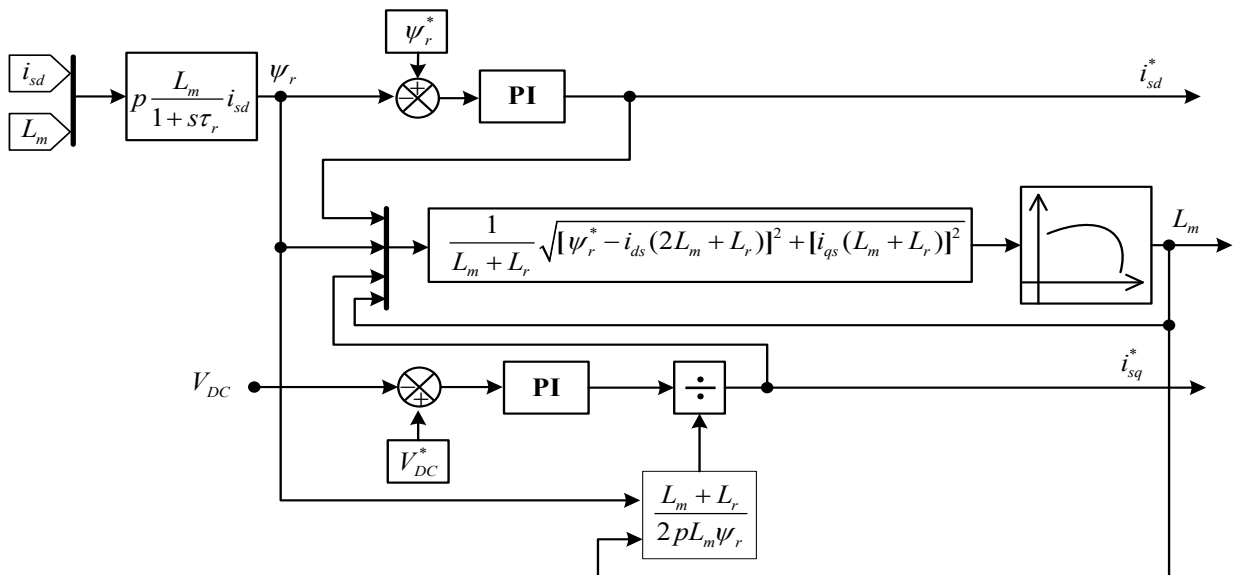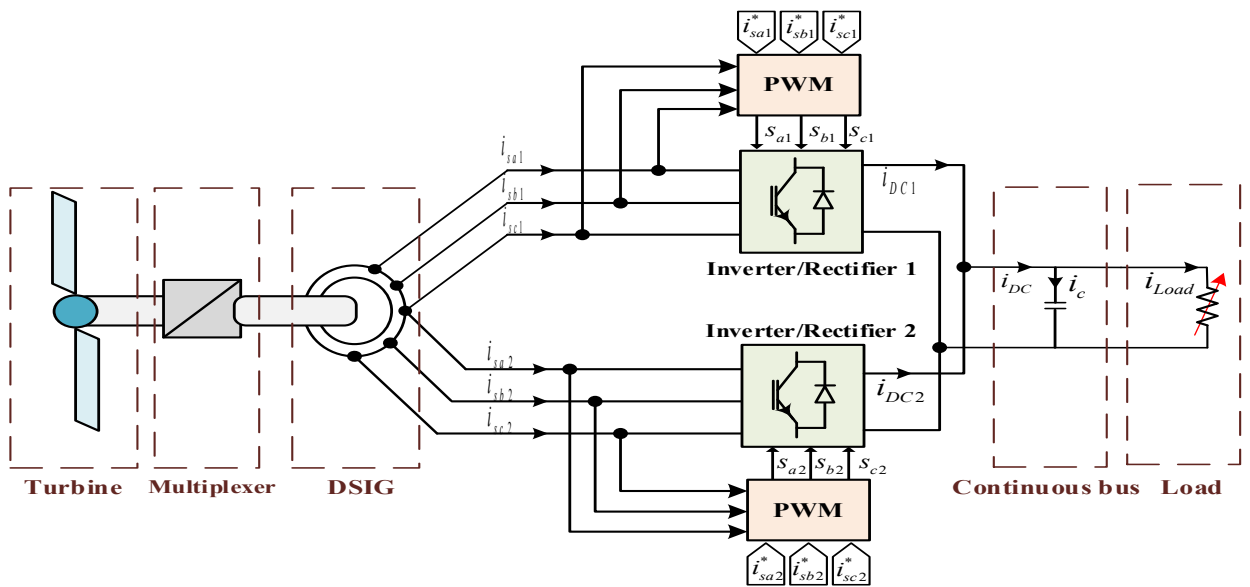
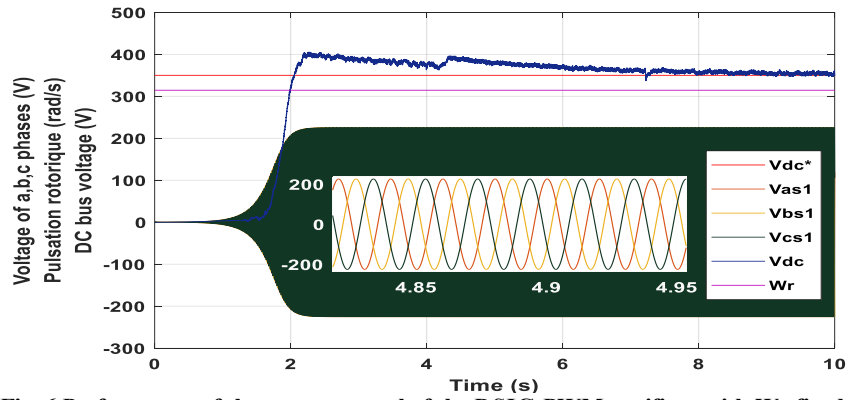Fig. 3.   Vector control algorithm of the double star asynchronous generator [3].

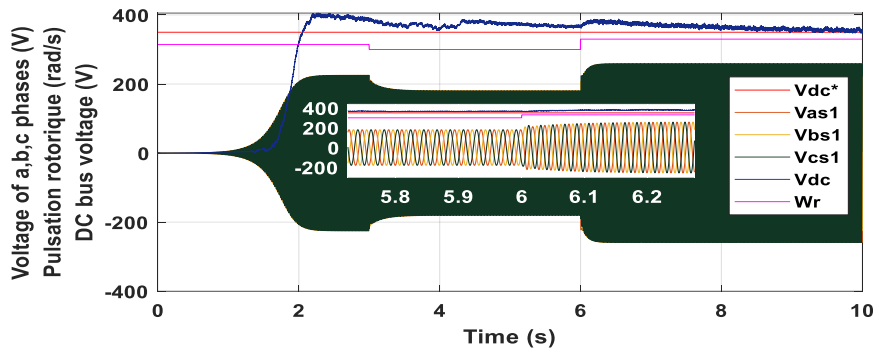**Fig. 6 Performance of the vector control of the DSIG-PWM rectifiers with Wr fixed.**

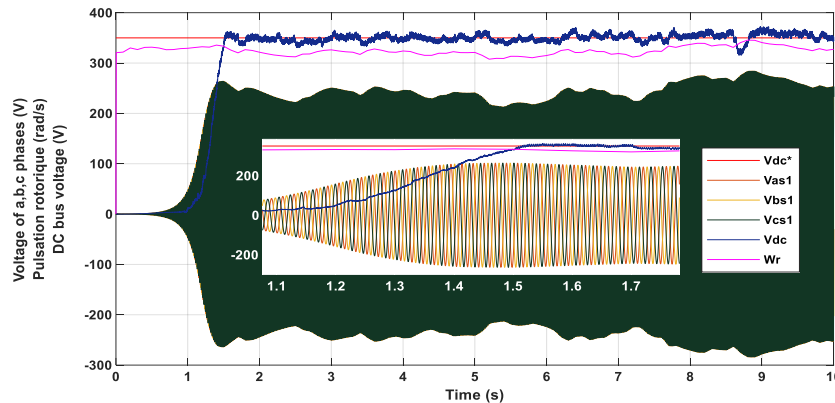**Fig. 7 Performance of the vector control of the DSIG-PWM rectifiers with Wr variable.**

Fig. 8 Performance of the vector control of the DSIG-PWM rectifiers with a Wr wind turbine

B. Discussion of Results

According to Figure. 6, we note that the DC bus voltage Vdc is perfectly controlled at its reference (Vdc*= 350V) at a response time of value tr = 8s.

Figure. 7, shows that the DC bus voltage is stable and robust in the presence of variations in drive speed.

In Figure. 8, we notice that the DC bus voltage (Vdc) generally follows its reference value with a response time of tr = 1.51s, with a remarkable static error.

V. CONCLUSIONS

The objective of this conference is to present the oriented rotor flux vector control of a DSIG. Two conventional PI correctors are introduced to control the flux and the DC bus voltage. A magnetizing inductance estimator is used. The control system is subject to variations in the drive speed (wind turbine). The analysis of the different results obtained shows the acceptable performance of this wind generator in general terms. Always with the aim of seeking to improve the quality of the electrical energy generated by the wind generator based on the DSIG, it is proposed to replace the PI regulators with other regulators such as: regulators based on the techniques of artificial intelligence (fuzzy, neuron, etc.) [2].

Appendix A. DSIG parameters

no-load voltage	$V_n = 225V$
no-load current	$I_n = 2.83$ A
First stator winding resistance	$R_{s1} = 1.9\ \Omega$
Resistance of the second stator winding	$R_{s2} = 1.9\ \Omega$
Rotor resistance	$R_r = 2.1\ \Omega$
Leakage inductance of the first stator winding	$l_{s1} = 0.0132\ H$
Leakage inductance of the second stator winding	$l_{s2} = 0.0132\ H$
Rotor leakage inductance	$l_r = 0.0132$ H
Mutual leakage inductance	$l_m = 0.011$ H
Moment of inertia	$J = 0.038$ kg.m^2
coefficient of friction	$K_f = 0$ N.m.s/rad
Rated frequency	$f = 50$ Hz
Number of pole pairs	$p = 2$

Appendix B. Turbine parameters

Nominal power	$P_n = 7.5 KW$
Wind radius	R = 3.24 m
Shaft inertia	$J_T = 2 Kg.m^2$
viscous coefficient of friction	$K_f = 0 N.m.S^{-1}$
Time constant value	$\tau = 4$ s
Area density	$\rho = 1.25$ Kg.m^{-3}
Number of blades	
Speed multiplier gain	G = 8.3
Pitch angle	$\beta = 2°$

REFERENCES

[1] Benakcha, M., Benalia, L., Ammar, A., & Bourek, A. (2019). Wind energy conversion system based on dual stator induction generator controlled by nonlinear backstepping and pi controllers. International Journal of System Assurance Engineering and Management, 10(4), 499-509.

[2] Bendjeddou, Y., Abdessemed, R., & Merabet, E. (2020). Improved field-oriented control for standalone dual star induction generator used in wind energy conversion. Engineering Review: Međunarodni časopis namijenjen publiciranju originalnih istraživanja s aspekta analize konstrukcija, materijala i novih tehnologija u području strojarstva, brodogradnje, temeljnih tehničkih znanosti, elektrotehnike, računarstva i građevinarstva, 40(2), 34-46.

[3] Bendjeddou, Y. A. C. I. N. E., Abdessemed, R., Merabet, E., & Bentouhami, L. A. R. A. F. I. (2018). Fuzzy controller for self-excited dual star induction generator with online estimation of magnetizing inductance used in wind energy conversion. Revue Roumaine des Sciences Techniques-Serie Électrotechnique et Énergétique, 63(4), 417-422.

[4] Bendjeddou, Y., Abdessemed, R., Merabet, E., & Bentouhami, L. (2016). Fuzzy logic control of squirrel cage induction generator for wind energy conversion. Journal of Electrical Engineering, 16(3), 6-6.

[5] Bendjeddou, Y., Abdessemed, R., & Merabet, E. Commande A Flux Virtuel Oriente De La Generatrice Asynchrone A Cage Double Etoile.

[6] Bendjeddou, Y., Deboucha, A., Bentouhami, L., Merabet, E., & Abdessemed, R. (2021). Super twisting sliding mode approach applied to voltage orientated control of a stand-alone induction generator. Protection and Control of Modern Power Systems, 6(1), 1-9.

[7] Kahal, H., Taleb, R., Boudjema, Z. E., & Bouyekni, A. (2018). Commande par mode glissant d'ordre supérieur d'une GASDE intégrée dans un système éolien à double rotor. Journal of Renewable Energies, 21(1), 111-119.