A Control Method using Artificial Intelligence in Wind Energy Conversion System

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ABSTRACT

This work presents a field-oriented control (FOC) of active and reactive power applied on Doubly Fed Induction Machine (DFIM) integrated in wind energy conversion system (WECS). The main objective of this work is to compare the performances of energy produced by the use of two types of controllers (PI regulator and the neural network regulator (NN)) in order to control the wind power conversion system to compare their precision & robustness against the wind fluctuation and the impact on the quality of produced energy. A field oriented control of DEFIG stator is also presented to control the active and reactive power. To show the efficiency of the performances and the robustness of the two control methods those were analyzed and compared by simulation using Matlab/Simulink software. The results described the favoured method.

I. Introduction

The wind power is one of renewable energies which news fast growth in the world due to clean and nonpolluting nature [1]. Several machines were used in WECS, but the range of wind speed was limited in classical machines, the advanced technology created DFIM witch solves this problem and makes it more powerful [2]. Several control methods of the DFIM appeared, among them, the vector control [3]. The principle of this control is to make DFIM similar to separate excitation. DC machine. These last years, a big interest is given to the use of neural network in identification and control of the nonlinear systems; this is mainly due to their capacities of training and generalization [4]. This paper presents a comparison of performance in vector control using PI and controllers NN in WECS. The first regulator is PI which is simple and easy in implementation and gives acceptable performances [5], but it hasn't robustness in case of parameter variations. Then, a control device by neural network is used. This type of controller proved to be an interesting method for the design of controllers and was applied in many fields because of its excellent properties, such as insensitivity to external disturbances and variation of the parameters. It can present fast dynamic responses if the switching devices support a high frequency. The studied system is presented in (Fig. 1).

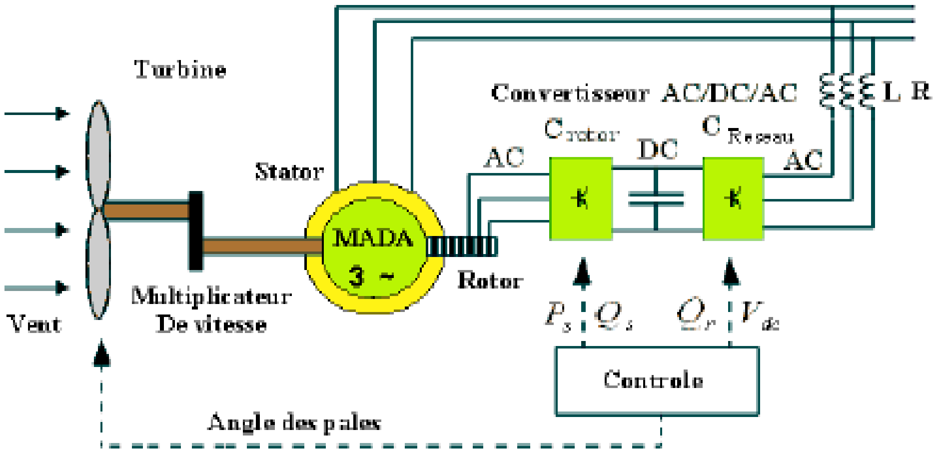

Figure 1. Scheme of the studied system.

II. Modeling and control of DFIM

II.1 Modeling of DFIM

The of Park transformation on electrical equations of DFIM in field reference frame gives the following equations [6][7][8]:

$$\begin{cases} V_{sd}=R_s i_{sd}+\frac{d\Phi_{sd}}{dt}-\omega_s\Phi_{sq} \\ V_{sq}=R_s i_{sq}+\frac{d\Phi_{sq}}{dt}+\omega_s\Phi_{sd} \\ V_{rd}=R_r i_{rd}+\frac{d\Phi_{rd}}{dt}-\omega_r\Phi_{rq} \\ V_{rq}=R_r i_{rq}+\frac{d\Phi_{rq}}{dt}+\omega_r\Phi_{rd} \end{cases} \quad (1)$$

The fields are given by:

$$\begin{cases} \Phi_{sd}=L_s i_{sd}+M_{sr} i_{rd} \\ \Phi_{sq}=L_s i_{sq}+M_{sr} i_{rq} \\ \Phi_{rd}=L_r i_{rd}+M_{sr} i_{sd} \\ \Phi_{rq}=L_r i_{rq}+M_{sr} i_{sq} \end{cases} \quad (2)$$

The electromagnetic torque is given by:

$$C_{em} = P\frac{M_{sr}}{L_s}\left(\Phi_{sq} i_{rd}-\Phi_{sd} i_{rq}\right) \quad (3)$$

$$J\frac{d\Omega_{mec}}{dt} = C_{em} - C_r - f.\Omega_{mec} \quad (4)$$

II.2 Power Control

In order to control easily the electrical power produced by the WECS, we applied an independent control of the active and reactive powers by FOC of stator The principle consists in aligning stator field along the d axis of Park reference frame (Fig.2) [3][9]. This choice is to eliminate the coupling between powers.

We have: $\Phi_{sq} = 0$ then $\Phi sd = \Phi s$.

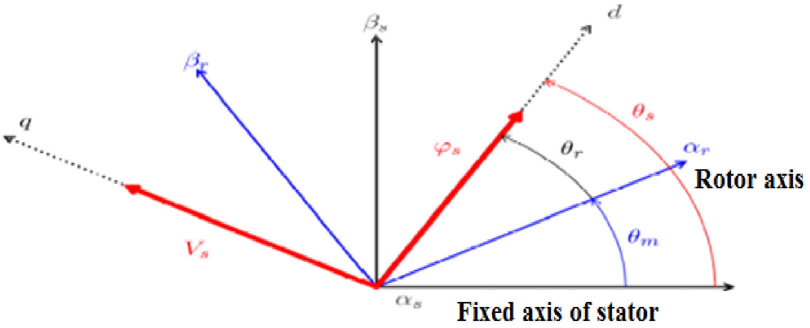

Figure 2. Position of the stator flux.

The systems of equation (1) and (2) can be simplified as the following form:

$$\begin{cases} V_{sd} = R_s i_{sd} \\ V_{sq} = R_s i_{sq} + \omega_s \Phi_s \\ V_{rd} = R_r i_{rd} + \dfrac{d\Phi_{rd}}{dt} - \omega_r \Phi_{rq} \\ V_{rq} = R_r i_{rq} + \dfrac{d\Phi_{rq}}{dt} + \omega_r \Phi_{rd} \end{cases} \quad (5)$$

For high power machines we can neglect the resistance of the stator windings, so:

$$\begin{cases} V_{sd} = 0 \\ V_{sq} = V_s = \omega_s \Phi_s \\ V_{rd} = R_r i_{rd} + \dfrac{d\Phi_{rd}}{dt} - \omega_r \Phi_{rq} \\ V_{rq} = R_r i_{rq} + \dfrac{d\Phi_{rq}}{dt} + \omega_r \Phi_{rd} \end{cases} \quad (6)$$

$$\begin{cases} \Phi_s = L_s i_{sd} + M_{sr} i_{rd} \\ 0 = L_s i_{sq} + M_{sr} i_{rq} \\ \Phi_{rd} = L_r i_{rd} + M_{sr} i_{sd} \\ \Phi_{rq} = L_r i_{rq} + M_{sr} i_{sq} \end{cases} \quad (7)$$

$$Cem = -P \frac{Msr}{Ls} \Phi s\, irq \quad (8)$$

The active and reactive stator power in the Park reference, are written:

$$\begin{cases} P = v_{sd} i_{sd} + v_{sq} i_{sq} \\ Q = v_{sq} i_{sd} - v_{sd} i_{sq} \end{cases} \quad (9)$$

According to FOC, this system of equations can be simplified as:

$$\begin{cases} P = v_s i_{sq} \\ Q = v_s i_{sd} \end{cases} \quad (10)$$

$$\begin{cases} i_{sd} = \dfrac{V_s}{\omega_s L_s} - \dfrac{Msr}{L_s} . i_{rd} \\ i_{sq} = -\dfrac{Msr}{L_s} . i_{rq} \end{cases} \quad (11)$$

$$\begin{cases} P = -\dfrac{V_s M_{sr}}{L_s} i_{rq} \\ Q = -\dfrac{V_s M_{sr}}{L_s} i_{rd} + \dfrac{V_s^2}{L_s \omega_s} \end{cases} \quad (12)$$

$$\begin{cases} \Phi_{rd} = \left(L_r - \dfrac{M_{sr}^2}{L_s} \right) i_{rd} + \dfrac{M_{sr} V_s}{\omega_s L_s} \\ \Phi_{rq} = \left(L_r - \dfrac{M_{sr}^2}{L_s} \right) i_{rq} \end{cases} \quad (13)$$

$$\begin{cases} V_{rd} = R_r i_{rd} + \left(L_r - \frac{M_{sr}^2}{L_s} \right) \frac{di_{rd}}{dt} - g\omega_s \left(L_r - \frac{M_{sr}^2}{L_s} \right) i_{rq} \\ V_{rq} = R_r i_{rq} + \left(L_r - \frac{M_{sr}^2}{L_s} \right) \frac{di_{rq}}{dt} + g\omega_s \left(L_r - \frac{M_{sr}^2}{L_s} \right) i_{rd} + g \frac{M_{sr} V_s}{L_s} \end{cases} \tag{14}$$

III. Control of Active and Reactive Power of DFIM

In this FOC in open loop we neither measured nor estimated. The decoupling is due to voltages and currents which are evaluated using transient equations of the machine [5][6]. This method is favored with microprocessors, but it is very sensitive to parameter variations of the machine.

This method in DFIM, the voltages are calculated by using power equations according to the following equations [5].

$$\begin{cases} V_{dr} = g\omega_s \frac{\left(L_r - \frac{L_m^2}{L_s} \right)}{\frac{V_s L_m}{L_s}} * P - \left(\frac{R_r \left(L_r - \frac{L_m^2}{L_s} \right)}{\frac{V_s L_m}{L_s}} p \right) * Q + \left(\frac{R_r V_s}{\omega_s L_m} + \left(L_r - \frac{L_m^2}{L_s} \right) \frac{V_s}{\omega_s L_m} p \right) \\ V_{qr} = -\left(\frac{R_r + \left(L_r - \frac{L_m^2}{L_s} \right)}{\frac{V_s L_m}{L_s}} p \right) * P - g\omega_s \frac{\left(L_r - \frac{L_m^2}{L_s} \right)}{\frac{V_s L_m}{L_s}} * Q + g\omega_s \left(L_r - \frac{L_m^2}{L_s} \right) \frac{V_s}{\omega_s L_m} \end{cases} \tag{15}$$

In this method, we power is controlled using two cascade controllers, te first is for power control, the second is for current control, the coupling terms appeared after this last, fig.3.

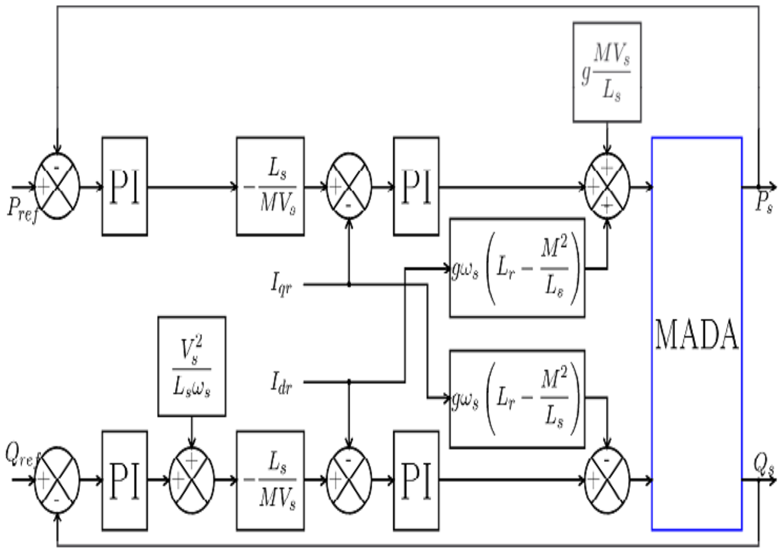

Figure 3. Control scheme of DFIM

IV. Neural network control

The use of an analogical controller leads to performance degradation in nonlinear and uncertain process or parametric variation of the system [10] [11]. Many intelligent controls have been applied on DFIM. Fuzzy control, neural networks [12]. The use of neural networks is a technique for controlling complex systems can be justified by its simplicity of implementation (some preliminary mathematical analysis) [13]. Considering the process as a black box and the ability to control the minimum of process information [14]. The use of neural networks is valid to control DFIM.

The idea is to replace the four PI regulators of FOC by neural regulators (RN) simple. For the training of the neural weights from PI regulators we use an algorithm of back-propagation called the algorithm of Levenberg-Marquardt (LM) [15] [16].

Each neural network has a well-defined function depending on selected architecture (hidden layers' number and neural number in each hidden layer). The problem is to find that which gives better results. In our case we take a structure of neural network with only one hidden layer containing three neurals using the sigmoid transfer function of.

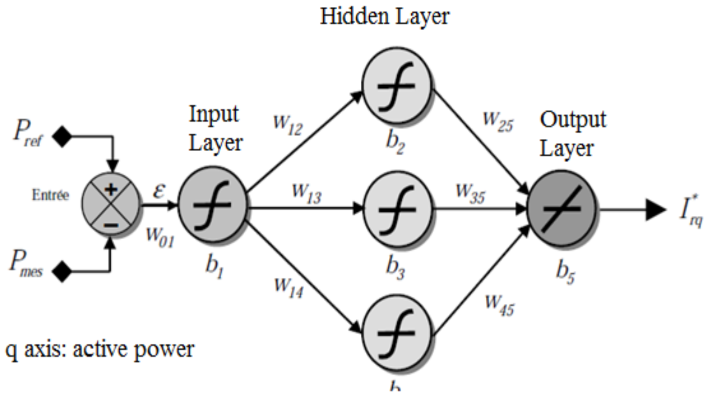

Figure 4. Multilevel perceptrons: (1-3-1) configuration.

The total diagram of FOC control with neural regulators is presented in (Fig.5).

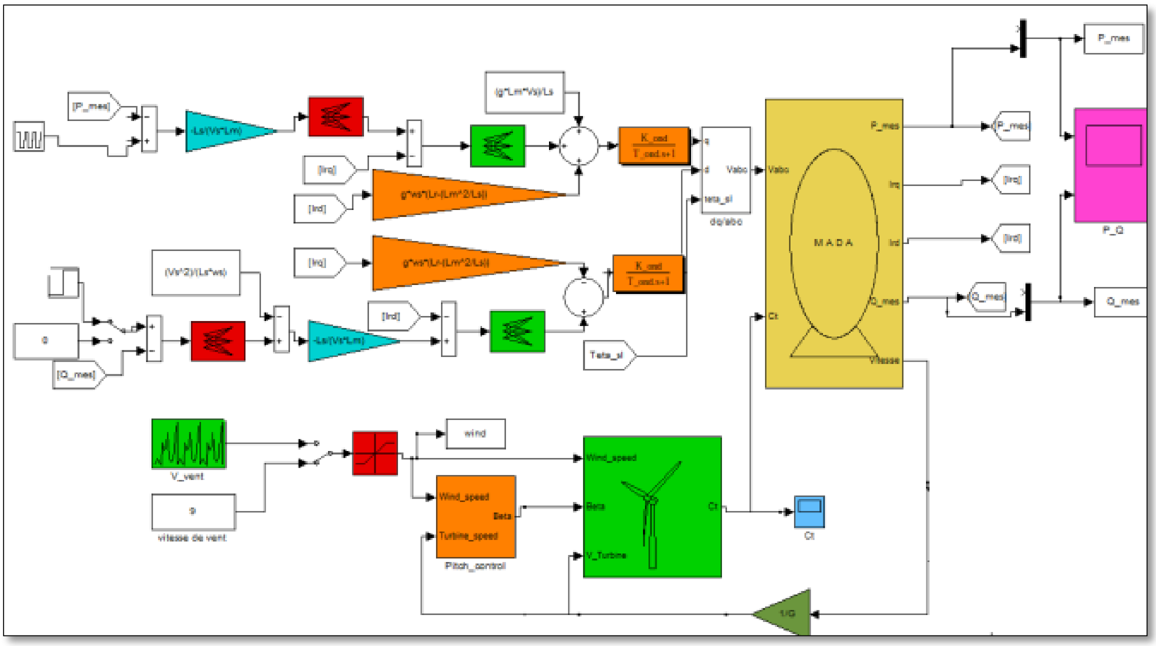

Figure 5. Global scheme of FOC control with neural regulators.

V. Simulation results

To analyze the system and the efficiennсy of proposed controller, some simulation tests were done at 0,8 s, using Matlab/Simulink. PWM Inverter control the rotor of DFIM. PI and NN Regulators are tested by two different ways, the following of the reference, and the robustness while varying the parameters of DFIM used in simulation those are presented in (table. I).

V.1 The following of reference

In this test, simulation was made with keeping the same parameters of the DFIM. We apply steps of active and reactivate power in order to observe well the behavior of this control. The obtained results are illustrated in (fig.6) .

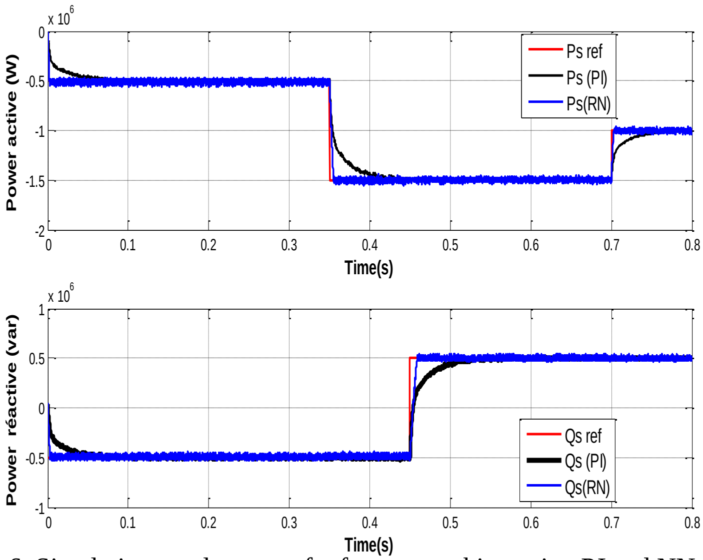

Figure 6. Simulation results tests of reference tracking using PI and NN regulators.

The simulation results obtained show good performances in following the active and reactive power. When the reference when changes, it is noticed that the oscillations decrease and the response time is smaller in the case of neural networks regulator.

V.2 Robustness

In order to test the robustness of PI and NN regulators, the value of the resistor of rotor is 1.5 of its nominal value, the stator and rotor winding values increased by 10% of their nominal values, the value of the mutual is decreased by 10 % of its nominal value.¶

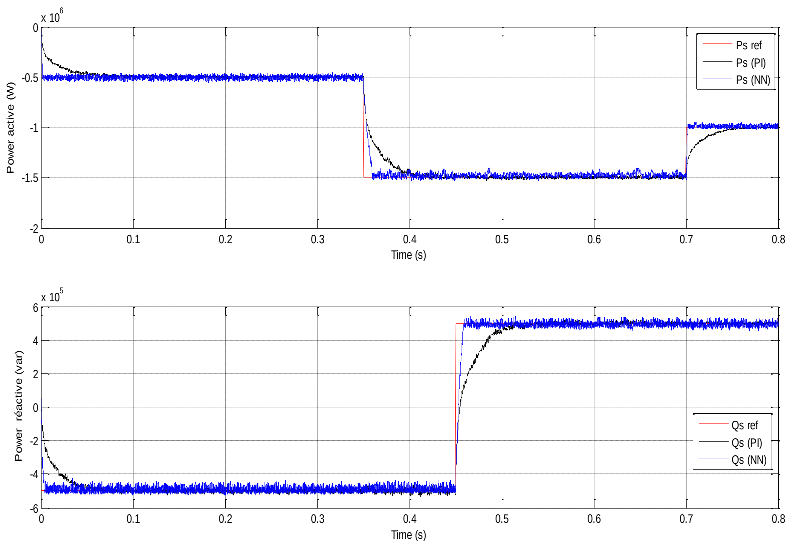

Figure 7. Influence of rotor resistor variation *Rr* of +50 %.

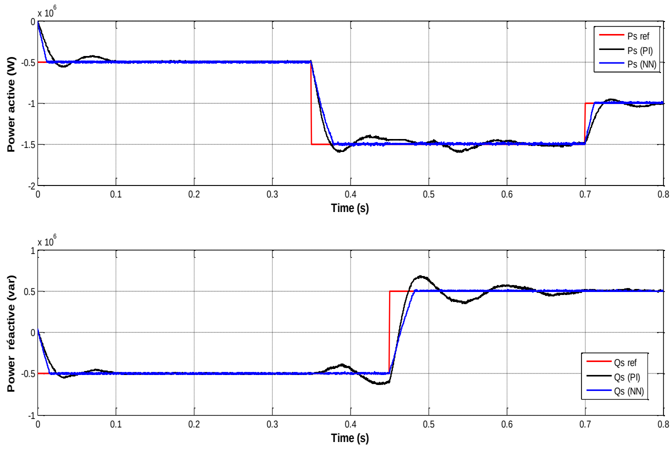

Figure 8. Influence of stator winding variation *Ls* of +10 %.

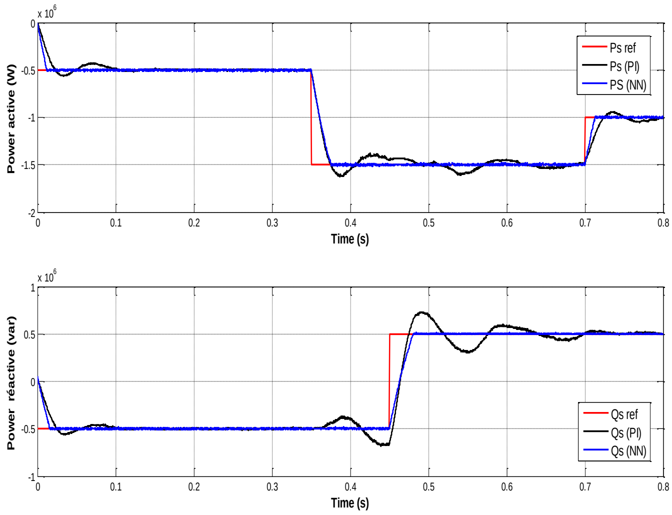

Figure 9. Influence of rotor winding variation *Lr* of +10 %.

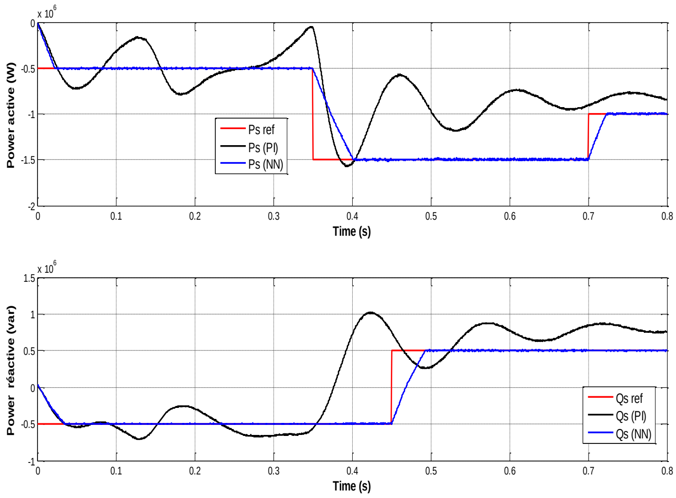

Figure 10. Influence of mutual winding variation *Lm* of -10 %.

The comparisons between the two controllers' show that the neural network presents good performances, but PI controller performances are deteriorating.

VI. Conclusion

This work enabled us to study FOC of DFIM which makes it possible to have a decoupling and an independent control of the active and reactive power. Then we studied the WECS. Firstly, the regulation is made with PI regulators. Secondly, is with neural networks.

The architecture of the neural network corrector retained is 1-3-1. It enabled us to improve the dynamic and static performances of the DFIM.

The simulation results obtained leads us to conclude that the neural network regulator, is better in robustness with a fast response time, a good following to reference and it does not present oscillation or goings beyond at the time of the transient state.

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Appendix

PARAMETERS OF DFIM

Symbol	*Value*
Rated Power P_N	1.5 W
Stator resistance R_s	0.012 Ω
Rotor resistance R_r	0.021Ω
Stator inductance L_s	0.0137 H
Rotor inductance L_r	0.0136 H
Mutual inductance L_m	0.0135 H
The friction coefficient f_r	0.0024 N.m.s[1]
Slip g	0.03
Pole Pairs p	2

PARAMETERS OF TURBINE

Symbol	*Value*
Radius of the wind turbine R	35.25 m
Gear box G	90
inertia J	1000 kg.m 2
Surface swept by ¶rotor S	$\pi \cdot R^2$ m 2
Air density ρ	1.22 kg/ m 3

PARAMETERS OF FEED

Symbol	*Value*
Stator rated voltage Vs	398 / 690 V
Rated frequency stator f	50 Hz
Rotor rated voltage V_r	225 / 389 V
Rated frequency rotor f_2	14 Hz

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