Abstract—This paper proposes the study of a robust control of the doubly fed induction generator (DFIG) used in a wind energy production. The proposed control is based on the linear active disturbance rejection control (ADRC) and it is applied to the control currents rotor of the DFIG, the DC bus voltage and active and reactive power exchanged between the DFIG and the network. The system under study and the proposed control are simulated using MATLAB/SIMULINK.

Keywords—Doubly fed induction generator DFIG, Active disturbance rejection control ADRC, Vector control, MPPT, Extended state observer, back to back converter, Wind turbine.

I. INTRODUCTION

SUSTAINABLE development and renewable energy today are of interest to several research teams. Thus, the development of wind represents a great investment in the field of technological research. The wind system that uses doubly fed induction generator and a back to back converter that connects the rotor of the generator to the grid has several advantages [1]. One advantage of this structure is that the power converters used are sized to pass a fraction of the total power of the system, which allows the reduction of losses in power electronics components [1], [14].

The system studied is a chain of wind conversion three-bladed horizontal axis using a double-fed asynchronous generator directly connected to the grid and driven by the rotor by means of the two power converters operating in PWM. These PWM converters are used to adjust the rotational speed of the generator to the wind speed to extract maximum power generated [2], [4]. (Fig. 1)

In this study, the control of the DFIG is based on three functions:
- The extraction of maximum power point tracking (MPPT)
- Vector control of DFIG with stator flux orientation according to the axis d.
- Control of PWM converters.

Performance of the wind system does not only depend on the DFIG but also the manner in which the two PWM converters are controlled [4], [15].

II. MODEL OF TURBINE AND CONTROL STRATEGY MPPT

A. Model of Turbine

The turbine captures kinetic energy of wind and converts it to a torque that makes rotate the rotor poles [7]. Aerodynamic power appearing at the turbine rotor is written as follows:

\[ P_{aero} = \frac{1}{2} C_p(\lambda, \beta) \rho \pi R^2 v^3 \]  

(1)

The aerodynamic torque is estimated by the following expression:

\[ T_{aero} = \frac{1}{2} C_p(\lambda, \beta) \rho \pi R^2 v^3 \frac{\Omega_t}{\Omega} \]  

(2)

\( \rho \) is the air density, \( R \) is the radius of the turbine, \( \Omega_t \) is the turbine speed, \( \beta \) is the pitch angle, \( \lambda \) is the speed ratio and \( v \) is the wind speed.

\[ \lambda = \frac{\Omega_t}{v} \]  

(3)

\( C_p \) is the power coefficient expressing the aerodynamic efficiency of the wind turbine. It depends on the speed ratio \( \lambda \) and the orientation angle of the blades \( \beta \). \( C_p \) is intrinsic to the
constitution of the wind and depends on profiles blades [2], [8]. It can be expressed by the following relationship:

\[ C_p = 0.22 \left( \frac{116}{\lambda} - 0.4\beta - 5 \right) e^{\frac{-125}{\lambda^2}} + 0.0068\lambda \]  

(4)

where

\[ \lambda = \frac{1}{\lambda + 0.008\beta - 0.035\beta^3 + 1} \]

Fig. 2 shows the curves of \( C_p \) as a function of \( \lambda \) for different values of \( \beta \).

The mechanical speed is related to the speed of rotation of the turbine by the multiplier coefficient \( G \). The torque on the slow axis is also related to the torque on the fast axis (generator side) by the coefficient multiplier \( G \).

The total inertia \( J \) is consisting of turbine inertia \( J_t \) reduced on the fast axis and the inertia of the generator \( J_g \).

\[ J = \frac{J_t}{\lambda^2} + J_g \]  

(5)

To determine the evolution of the mechanical speed from the total torque applied to the rotor of the DFIG, we apply the fundamental equation of dynamics:

\[ J \frac{d\omega_{mec}}{dt} = T_g - T_{em} - f\Omega_{mec} \]  

(6)

where,

\( T_g \): Torque from the multiplier is applied to the shaft of the generator

\( T_{em} \): The electromagnetic torque produced by the generator

\( f\Omega_{mec} \): Torque of viscous friction.

The previous equations allow determining the block diagram model of the turbine Fig. 3.

**B. MPPT Control Strategy**

To capture maximum of the incidental energy, we must continuously adjust the rotational speed of the turbine to the wind speed [2], [9], [15]. The principle of this command is to always have a rotation of the turbine which allows a speed ratio \( \lambda = \lambda_{opt} \).

In this article, the turbine is controlled without speed control (Fig. 4). The electromagnetic torque reference \( T_{em,\text{ref}} \) is determined from an estimate of the wind speed and the measurement of mechanical rotation speed [2], [7].

\[ T_{em,\text{ref}} = \frac{1}{2\pi}\lambda_{opt} C_{p\text{max}} \rho \pi R^2 \Omega_i^2 \]  

(7)

Fig. 3 Block diagram of the model turbine

**III. MODEL OF DFIG**

**A. Mathematical Model**

Electrical equations of DFIG in the Park reference \( dq \) are given by the following expressions [6]:

\[ V_{sd} = R_s i_{sd} + \frac{d\psi_{sd}}{dt} - \omega_s \psi_{sq} \]  

(8)

\[ V_{sq} = R_s i_{sq} + \frac{d\psi_{sq}}{dt} + \omega_s \psi_{sd} \]  

(9)

\[ V_{rd} = R_r i_{rd} + \frac{d\psi_{rd}}{dt} - \omega_r \psi_{rq} \]  

(10)

\[ V_{rq} = R_r i_{rq} + \frac{d\psi_{rq}}{dt} + \omega_r \psi_{rd} \]  

(11)

\[ \psi_{sd} = L_s i_{sd} + L_m i_{rd} \]  

(12)

\[ \psi_{sq} = L_s i_{sq} + L_m i_{rq} \]  

(13)

\[ \psi_{rd} = L_r i_{rd} + L_m i_{sq} \]  

(14)

\[ \psi_{rq} = L_r i_{rq} + L_m i_{sq} \]  

(15)

The expression of electromagnetic torque:

\[ T_{em} = \frac{3}{2} P \frac{L_m}{L_s} (i_{rq} \psi_{sq} - i_{sq} \psi_{rd}) \]  

(16)

\( L_s \) is the cyclic stator inductance, \( L_r \) is the cyclic rotor inductance, \( L_m \) is mutual inductance, \( R_s \) is stator resistance,
R_r is rotor resistance, p is number of pole pairs of the generator.

Active and reactive powers stator and rotor of the DFIG are written as follows:

\[ P_s = V_{sd}i_{sd} + v_{sq}i_{sq} \]  \hspace{1cm} (17)

\[ Q_s = v_{sq}i_{sd} - v_{sd}i_{sq} \]  \hspace{1cm} (18)

\[ P_r = v_{rd}i_{rd} + v_{rq}i_{rq} \]  \hspace{1cm} (19)

\[ Q_r = v_{rq}i_{rd} - v_{rd}i_{rq} \]  \hspace{1cm} (20)

B. Vector Control Strategy

For vector control of DFIG, we chose a Park reference linked to the rotating field. By adopting the hypothesis of a stator resistance R_s as negligible [4], [15] and the stator flux \( \Phi_s \) is constant and oriented along the axis d, the following equations can be deduced:

\[ \Phi_{sd} = \Phi_d = L_s i_{sd} + L_m i_{rd} \]  \hspace{1cm} (21)

\[ \Phi_{sq} = L_s i_{sq} + L_m i_{rq} = 0 \]  \hspace{1cm} (22)

\[ \Phi_{rd} = \sigma L_r i_{rd} + \frac{L_m}{L_s} \Phi_{sd} \]  \hspace{1cm} (23)

\[ \Phi_{rq} = \sigma L_r i_{rq} \]  \hspace{1cm} (24)

\[ V_{sd} = R_s i_{sd} + \frac{d\Phi_{sd}}{dt} = 0 \]  \hspace{1cm} (25)

\[ V_{sq} = R_s i_{sq} + \omega_s \Phi_{sq} = \omega_s \Phi_d \]  \hspace{1cm} (26)

\[ V_{rd} = R_r i_{rd} + \sigma L_r \frac{d\Phi_{rd}}{dt} = \omega_r \sigma L_r i_{rd} \]  \hspace{1cm} (27)

\[ V_{rq} = R_r i_{rq} + \sigma L_r \frac{d\Phi_{rq}}{dt} = \omega_r \sigma L_r i_{rd} + \omega_r \frac{L_m}{L_s} \Phi_s \]  \hspace{1cm} (28)

where \( \sigma = 1 - \frac{L_m}{L_s L_r} \) : dispersion coefficient between the coilings d and q.

From (21) and (22), the stator currents can be expressed as a function of the rotor currents as follows:

\[ i_{sd} = \frac{\Phi_d}{L_s} = \frac{L_m}{L_s} i_{rd} \]  \hspace{1cm} (29)

\[ i_{sq} = -\frac{L_m}{L_s} i_{rq} \]  \hspace{1cm} (30)

The terms of active and reactive stator power can be simplified as follows:

\[ P_s = -V_{sq} \frac{L_m}{L_s} i_{rq} \]  \hspace{1cm} (31)

\[ Q_s = V_{sq} \frac{L_m}{L_s} i_{rd} \]  \hspace{1cm} (32)

The simplified expression for the electromagnetic torque of the DFIG is written as follows:

\[ T_{em} = -\frac{3}{2} p \frac{L_m}{L_s} \Phi_s i_{rq} \]  \hspace{1cm} (33)

The block diagram showing the simplified mathematical model of DFIG is shown in Fig. 5.

IV. BACK TO BACK CONVERTER

The two converters of this wind turbine system (rotor side and grid side) are interconnected via a DC bus which allows for a transfer of between two sources at different frequencies. (Fig. 6)

These converters are bidirectional PWM control and they are composed of two switching cells, each is composed of two IGBT that are connected to two diode in anti-parallel.

A. Rotor Side Control (RSC)

The role of the converter PWM control is to provide adequate rotor voltages to ensure the necessary torque which is used to vary the speed of the mechanical DFIG to extract the maximum power generated [4], [14].

From (33), it is clear that the electromagnetic torque \( T_{em} \) can be controlled by the rotor currents \( i_{rq} \).

We deduce from (33):
\[ i_{q,ref} = \frac{2}{3} \frac{l_1}{n_{im} v_s} T_{em,ref} \] (34)

Substituting (7) into (34), we deduce:

\[ i_{q,ref} = \frac{1}{3} \frac{l_1}{n_{im} b_s q_{ap} c_p} R \Delta \phi^2 \] (35)

Similarly, the rotor current \( i_{d,r} \) is used to control the reactive power generated \( Q_r \). We deduce from (32):

\[ i_{d,r,ref} = \frac{q_s}{l_m} - \frac{l_1}{v_s l_m} Q_{r,ref} \] (36)

The simplified diagram of the control of the rotor side converter is shown in Fig. 7.

![Fig. 7 Simplified diagram of the rotor side converter control](image)

### B. Grid Side Control (GSC)

This converter PWM control ensures a regulation of the DC bus voltage \( U_{dc} \) and adjusts the power factor grid side [14]-[9].

The purpose of the control of this converter is to maintain constant voltage \( U_{dc} \) and ensuring unity power factor \( (Q_r = 0) \). Using the dq reference, electric filter equations \( (R_f, L_f) \) connected to the grid and the DC bus are expressed as follows:

\[ L_f \frac{d i_d}{dt} + R_f i_d = V_{af} - V_{af} \] (37)

\[ L_f \frac{d i_q}{dt} + R_f i_q = L_f \omega_s a_q = V_{af} - V_{af} \] (38)

\[ V_{af} = S_{dr} U_{dc} \] (39)

\[ V_{af} = S_{qr} U_{dc} \] (40)

\[ i_{m,f} = \frac{3}{2} (S_{dr} i_d + S_{qr} i_q) \] (41)

\[ C \frac{d u_{ac}}{dt} = i_{m,f} - i_{m,r} \] (42)

\( S_{dr} \) and \( S_{qr} \) are the functions of connection switches of the grid side converter in dq referential.

The voltage \( V_s \) is oriented along the q axis, the active and reactive power grids are thus written as follows:

\[ P_f = \frac{3}{2} V_{af} i_q \] (43)

\[ Q_f = \frac{3}{2} V_{af} i_d \] (44)

If we neglect losses in power converters, we obtain:

\[ P_{dc} = U_{dc} i_{m,f} = P_f \] (45)

Substituting (42) and (43) into (45), we obtain:

\[ C U_{dc} \frac{d u_{ac}}{dt} = \frac{3}{2} y_q i_q + U_{dc} i_{m,r} \] (46)

### V. CONTROL STRATEGY ADRC

#### A. Active Disturbance Rejection Control

Active disturbance rejection control is a robust command based on the extension of the model system by a state observer to estimate what the user can not master in the mathematical model of the system to control [3], [10]. This state observer dubbed « Extended State Observer (ESO) » allows to estimate all real disturbance and modeling uncertainties [3], [5]. This estimate is used in the generation of the control signal in order to decouple the system of the disturbance acting on the actual process [3], [5], [11], [10].

This disturbance rejection allows the user to treat the system as a simple model because the negative effects of external disturbances and modeling uncertainties are compensated for in real time [5], [12], [10], [13].

We consider the case of a first order system to illustrate the principle of the ADRC.

\[ \frac{dy(t)}{dt} = -\frac{1}{T} y(t) + bu(t) \] (47)

where \( b = \frac{K}{T} \) is the input, \( y(t) \) is the output, \( K \) is the gain and \( T \) is the constant of the system.

We substitute

\[ b = b_0 + \Delta b \]

where \( b_0 = \frac{K}{T} \) is the known part of \( b \), and \( \Delta b \) is the modeling error and/or variations in system parameters.

External disturbances are added, (47) of the system becomes:

\[ \frac{dy(t)}{dt} = -\frac{1}{T} y(t) + \frac{1}{T} d(t) + \Delta bu(t) + b_0 u(t) \]

\[ \frac{dy(t)}{dt} = f(y, d, t) + b_0 u(t) \] (48)

where \( f(y, d, t) = -\frac{1}{T} y(t) + \frac{1}{T} d(t) + \Delta bu(t) \) represents the total disturbance (internal and external).

The fundamental idea of the ADRC is to implement an extended state observer (ESO), which provides an estimate \( \hat{f} \) such that it can compensate for the effects of \( f(t) \) on the system [3], [5], [10], [12].

The description of the state space of the process described by (48) is given as follows:

\[
\begin{align*}
\dot{x}_1 &= x_2 + b_0 u \\
\dot{x}_2 &= f \\
y &= x_1
\end{align*}
\] (49)

In matrix form:
\[
\begin{align*}
\dot{x} &= Ax + Bu + D\dot{f} \\
y &= Cx \\
\end{align*}
\]

(50)

where \( A = \begin{pmatrix} 0 & 1 \\ 0 & 0 \end{pmatrix} \), \( B = \begin{pmatrix} b_2 \\ 0 \end{pmatrix} \), \( C = \begin{pmatrix} 1 \\ 0 \end{pmatrix} \) and \( D = \begin{pmatrix} 0 \\ 1 \end{pmatrix} \).

We cannot measure total disturbance \( f(t) \); we can only estimate using the extended state observer (ESO) built using the input \( u(t) \) and the output \( y(t) \) [3]-[5].

The equations of the extended state observer are:

\[
\dot{\hat{x}} = A\hat{x} + Bu + D(\hat{y} - \hat{y})
\]

\[
\hat{y} = Cx
\]

(51)

where \( D = \begin{pmatrix} \beta_1 \\ \beta_2 \end{pmatrix} \), \( \beta_1 \) and \( \beta_2 \) are the parameters of the observer.

The estimated variables \( \hat{x}(t) = \hat{\theta} \) and \( \hat{z}(t) = \hat{f}(t) \) are used to implement the disturbance rejection and control laws.

\[
\hat{x}(t) = (A - DC)\hat{x}(t) + Bu(t) + Dy(t)
\]

\[
u(t) = u_0(t) - \hat{f}(t)
\]

where

\[
u_0(t) = K_p(r(t) - \hat{y}(t))
\]

(53)

\( r(t) \) is the reference input signal to follow.

Fig. 8 shows the structure of the control loop by ADRC for a first order process [3], [5].

![ADRC topology](image)

To function correctly, the observation parameters \( \beta_1 \) and \( \beta_2 \), defined in (51), must also be determined.

The dynamics of the observer must be fast, the poles of this observer must be placed to the left of the pole of the closed loop \( S_{CL} \). A simple rule suggests [5]:

\[S_{ESO1} = S_{ESO2} \approx (3 \ldots 10)S_{CL}\]

(57)

for the two concerned poles where \( S_{CL} = -\frac{1}{t_r}\).

From the matrix \((A - DC)\) in (52), we calculate the parameters of the observer so as to have a common pole \( S_{ESO}\) of its characteristic polynomial:

\[\det(sI - (A - DC)) = s^2 + \beta_1s + \beta_2 = (s - S_{ESO})^2\]

(58)

From this equation, we deduce:

\[\beta_1 = -2.\frac{S_{ESO}}{S_{CL}} \text{ and } \beta_2 = \left(\frac{S_{ESO}}{S_{CL}}\right)^2\]

(59)

where \( S_{ESO} \approx (3 \ldots 10)S_{CL}\).

B. Control of Rotor Currents by ADRC

From (27) and (28), the following expressions of rotor currents are deduced:

\[
\frac{di_{rd}}{dt} = -\frac{k_r}{\sigma_{se}}i_{rd} + \omega_r i_{rq} + \frac{1}{\sigma_{se}}V_{rd}
\]

(60)

\[
\frac{di_{rq}}{dt} = -\frac{k_r}{\sigma_{se}}i_{rq} - \omega_r i_{rd} + \omega_r\frac{L_m}{\sigma_{se}}\Phi_s + \frac{1}{\sigma_{se}}V_{rq}
\]

(61)

We put these expressions in the form:

\[
\frac{di_{rd}}{dt} = \frac{b_0}{\sigma_{se}}i_{rd} + \frac{1}{\sigma_{se}}V_{rd}
\]

(62)

where

\[
\begin{align*}
  f_{rd} &= \frac{b_0}{\sigma_{se}}i_{rd} + \omega_r i_{rq} + \frac{1}{\sigma_{se}}V_{rd} \\
u &= V_{rd} \\
b_0 &= \frac{1}{\sigma_{se}}
\end{align*}
\]

(63)

\[
\begin{align*}
  f_q &= \frac{b_0}{\sigma_{se}}i_{rq} - \omega_r i_{rd} - \omega_r\frac{L_m}{\sigma_{se}}\Phi_s + \frac{1}{\sigma_{se}}b_0V_{rq} \\
u &= V_{rq} \\
b_0 &= \frac{1}{\sigma_{se}}
\end{align*}
\]

(64)

\( f_{rd} \) and \( f_q \) are the total disturbance respectively affecting the rotor currents \( i_{rd} \) and \( i_{rq} \). \( u = V_{rd} \) and \( u = V_{rq} \) are respectively the control inputs of the currents loops \( i_{rd} \) and \( i_{rq} \). \( b_0 \) is the known part of the system parameters.

By choosing a suitable response time, we can easily determine the parameters \( k_p, \beta_1 \) and \( \beta_2 \) of the ADRC controllers, so that the rotor currents follow their reference \( i_{rd, ref} \) and \( i_{rq, ref} \) respectively given by (36) and (35).
C. Control of the DC Bus

The voltage \( U_{dc} \) across the capacitor \( C \) is given by (46).
We set \( w = U_{dc} / L \), (46) can therefore be written as follows:

\[
\frac{dw}{dt} = 3 \frac{V_c}{c} i_{af} - 2 \frac{\sqrt{2}}{c} i_{mr}
\]  

(64)

We put (64) in the canonical form of the ADRC regulator:

\[
\frac{dW}{dt} = f (W, d, t) + b_0 \cdot u
\]

where

\[
\begin{align*}
W &= -2 \frac{\sqrt{2}}{c} i_{mr} + (3 \frac{V_c}{c} - b_0) i_{af} \\
u &= i_{af} \quad b_0 = 3 \frac{V_c}{c}
\end{align*}
\]  

(65)

\( f_w \) represents the total disturbance, \( w \) and \( i_{af} \) are respectively the output and the control input of the control loop of the voltage \( U_{dc} \). \( b_0 \) is the known part of the system parameters.

We choose the controller parameters ADRC \( K_p, \beta_1 \) and \( \beta_2 \), to maintain constant voltage DC bus.

D. Control Grid Side Converter

From (37) and (38), we determine the currents \( i_{af} \) and \( i_{qf} \) by the following expressions:

\[
\frac{di_{af}}{dt} = \frac{1}{L_f} V_{sd} - \frac{R_f}{L_f} i_{af} - \omega s i_{qf} - \frac{1}{L_f} V_{af}
\]

(66)

\[
\frac{di_{qf}}{dt} = \frac{1}{L_f} V_{sq} - \frac{R_f}{L_f} i_{qf} - \omega s i_{af} - \frac{1}{L_f} V_{af}
\]

(67)

These equations can also be written as follows:

\[
\frac{di_{af}}{dt} = f_{af}(i_{af}, d, t) + b_0 u(t),
\]

where

\[
\begin{align*}
f_{af} &= \frac{1}{L_f} V_{sd} - \frac{R_f}{L_f} i_{af} + \omega s i_{qf} + \frac{1}{L_f} V_{af} \\
u &= V_{af} \quad b_0 = - \frac{1}{L_f} V_{af}
\end{align*}
\]

(68)

\[
\frac{di_{qf}}{dt} = f_{qf}(i_{qf}, d, t) + b_0 u(t),
\]

where

\[
\begin{align*}
f_{qf} &= \frac{1}{L_f} V_{sq} - \frac{R_f}{L_f} i_{qf} + \omega s i_{af} + \frac{1}{L_f} V_{af} \\
u &= V_{af} \quad b_0 = - \frac{1}{L_f} V_{af}
\end{align*}
\]

(69)

\( f_{af} \) and \( f_{qf} \) represent the total disturbance. \( V_{af} \) and \( V_{qf} \) are respectively the control input of the control loops of currents \( i_{af} \) and \( i_{qf} \). \( b_0 \) is the known part of the system parameters.

The reference current \( i_{af,ref} \) which can impose a zero grid side reactive power is deduced from (44):

\[
i_{af,ref} = \frac{2}{3} \frac{1}{V_{af}} Q_{ref} = 0
\]

(70)

The reference current \( i_{qf,ref} \) is deduced from (43) and (45):

\[
i_{qf,ref} = \frac{2}{3} \frac{1}{V_{af}} U_{dc,ref}
\]

(71)

Similarly, we determine the ADRC controller parameters so that the currents \( i_{af} \) and \( i_{qf} \) follow their references.

VI. SIMULATION AND RESULTS

The overall model of the wind system using the doubly fed induction generator was simulated in Matlab/Simulink environment. The system parameters are given in the appendix.

To illustrate the performances of the ADRC command used to control this wind system, we conducted several tests in different conditions.

A. Test Tracking and Control

Fig. 9 shows the profile of the mechanical speed of the generator shaft driven in rotation by wind. The generator parameters are fixed and given in the appendix. Mechanical rotor speed varies between 1000 rpm and 1800 rpm.

Figs. 10-12 show that the rotor currents \( i_{rd} \) and \( i_{rq} \) perfectly follow their reference. The current \( i_{rq} \), which controls the electromagnetic torque of the generator, varies in the same shape as the wind speed to extract the maximum power. The current \( i_{rd} \), which controls reactive power \( Q_a \), is kept constant to have a unity power factor on the stator side.

Figs. 13 and 14 show the total disturbances of the control loops of rotor currents. These disturbances are estimated and perfectly compensated by the regulator ADRC which allowed having a very good performance. We also note from these results, thanks to the ADRC, coupling between the two currents \( i_{rd} \) and \( i_{rq} \) disappeared.

![Fig. 9 Mechanical Rotor Speed](image)

![Fig. 10 Rotor Current i_r and its Reference](image)
Figs. 15 and 16 show that the DC bus voltage $U_{dc}$ is kept constant by the ADRC regulator. The fluctuations of such a voltage vis-à-vis the reference value of 700V are around 0.28%.

Figs. 17-20 show the simulation results of currents $i_{df}$ and $i_{qf}$ of the filter ($R_f$ $L_f$), reactive and active power on grid side.

The current $i_{df}$ perfectly follows its zero reference which enables to have a zero reactive power on grid side.

The current $i_{qf}$ is maintained, by ADRC regulator, at its reference value, which allows having an evolution of the active power on grid side similar to wind profile.
B. Robustness Test

The test of robustness is to vary the parameters of the model of DFIG. In fact, the calculations of regulators are based on functions whose parameters are assumed to be fixed. However, in a real system, these parameters are subject to variations caused by different physical phenomena. Figs. 21-26 show the evolution of the current rotor after a 100% variation of the value of the rotor resistance $R_r$ and a 150% rotor inductance $L_r$. These variations in $R_r$ and $L_r$ have almost no influence on the operation of the generator because ADRC regulators allow automatically compensate for the disturbance due to these variations. The tracking of setpoints is always ensured and the stability is not affected by variations of these parameters.
Fig. 25 Zoom on the Current $i_{rd}$ and its Reference after a 150% variation of $L_r$

Fig. 26 Current $i_{q}$ and its Reference after a 150% variation of $L_r$

Figs. 27 and 28 show that after a 100% variation of the capacity of the DC bus, voltage $U_{dc}$ always perfectly follows its setpoints and the voltage fluctuations do not exceed 0.4%.

Fig. 27 Voltage $U_{dc}$ and its Reference after a 100% variation of $C$

Fig. 28 Zoom on Voltage $U_{dc}$ and its Reference after a 100% variation of $C$

Figs. 29 and 30 also show robustness of the ADRC regulators of the loops currents $i_{df}$ and $i_{qf}$. The two currents perfectly follow their setpoints despite variation of the resistance $R_f$ at 100%.

Fig. 29 Current $i_{qf}$ and its Reference after a 100% variation of $R_f$

Fig. 30 Current $i_{df}$ and its Reference after a 100% variation of $R_f$

VII. CONCLUSION

This article has been devoted to modeling of a wind turbine based on a doubly fed induction generator, and developing an ADRC control which compensates the errors modeling and parametric variations of the system.

We could see through the results obtained in this paper, that the active disturbance rejection control is more efficient and allows for a better operation by eliminating the effect of external and internal disturbance, which represent the main problem in the electric power system.

The ADRC allows increasing system reliability and improving its energy efficiency.

APPENDIX

**Doubly Fed Induction Generator Parameters:**
- Rated power: 300 KW
- Stator and rotor resistance: $R_s = 8.9\,\text{m\Omega}$, $R_r = 13.7\,\text{m\Omega}$
- Stator and rotor inductance: $L_s = 12.9\,\text{mH}$, $L_r = 12.7\,\text{mH}$
- Mutual inductance: $L_{sr} = 12.672\,\text{mH}$
- Number of pole pairs: $p = 2$

**Turbine Parameters:**
- Radius of the turbine: $R = 13.5\,\text{m}$
- Gain multiplier: $G = 65$
- Inertia total moment: $J = 10\,\text{kg.m}^2$
- Air density: $\rho = 1.22\,\text{kg/m}^2$
- Coefficient of viscous friction: $f = 0.0001$
- Optimal tip speed ratio: $\lambda_{opt} = 8.1$
- Maximal power coefficient: $C_{p_{max}} = 0.45$
Connecting to the Grid Parameters:

Filter inductance: \( L_f = 2.5mH \)

Filter resistance: \( R_f = 75m\Omega \)

DC link capacity: \( C = 4400\mu F \)

Adrc Controller Parameters

Rotor currents controller gain: \( K_{p.r} = 133.33 \)

Rotor currents parameter: \( b_{r2} = 4069.3 \)

Observation parameters of the loop currents rotor: \( \beta_{1r} = 1066.7, \beta_{2r} = 284.44e^3 \)

Filter currents controller gain: \( K_{p.f} = 200 \)

Filter currents parameter: \( b_{f0} = -400 \)

Observation parameters of the loop currents filter: \( \beta_{1f} = 2000, \beta_{2f} = 10^6 \)

DC link voltage controller gain: \( K_{p.v} = 400 \)

DC link voltage parameter: \( b_{v0} = 385e^3 \)

Observation parameters of the loop DC link voltage: \( \beta_{1c} = 256e^4 \)

DC link voltage parameter: \( b_{v2} = 3200, \beta_{2c} = 256e^4 \)

REFERENCES


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