A Hybrid H∞-MRAS Observer of Wind Turbines Conversion Systems based on DFIG

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ABSTRACT

This study proposes the robust sensor-less advanced frequency control (robust H∞ control) of the system of wind turbine based on a doubly fed induction generator (DFIG), the power exchange between the machine stator and the network is achieved by applying the rotor of DFIG via a bidirectional converter. The purpose of the control is to regulate the stator active and reactive power produced by the DFIG using a robust H∞ controller. The Model reference and adaptive system (MRAS-Observer) uses the error between the actual and estimated values (voltage/current) to construct the observed mechanical parameters (speed and position) value, this technique uses two separate models: the first is the reference model, the second is the adjustable mode. The error between these models is used by the adaptive mechanism. The adjustment mechanism is mostly a PI controller, to improve the performance and robustness of the classical MRAS observer, we replace the classical PI controller with a robust H∞ controller. The results simulations confirm the robustness of the sensorless robust H∞ control using the H∞-MRAS observer compared to conventional MRAS, which improves the quality and quantity of generated power.

I. Introduction

The energy of wind is a free source that is accessible wherever in the globe, which makes it one of the sustainable energy sources and an excellent choice in contrast to the traditional energy sources that harm the climate [1], [2]. Variable speeds are increasingly being used in turbine chains due to many advantages. Today, the importance of wind power has prompted extensive research. These research goals are to improve the efficiency and quality of wind systems or power generation by choosing the optimal system architecture and developing robust controllers that can compensate for the effects of parameter changes and external disturbances [1], [3]. Most wind turbines installed today are equipped with Doubly Fed Induction Generators (DFIGs). In this configuration for variable power conversion, the DFIG rotor windings are powered by two static converters separated by continuous bus bars. This is the most popular configuration in recent years due to its many technical and economic advantages [3].

DFIG's robust sensor-less control provides essential position or speed rotor information. This can be obtained by using mechanical sensors (encoders), but these mechanical sensors multiple the global cost and machine size, and reduce the performance, and the system is sensitive to disturbances [3]. According to these points of view, the sensor-less strategies draw the consideration of specialists. In this way, numerous procedures are utilized for estimated and observed the speed/position (mechanical parameters) in the literatures [4], [5].

In this paper, we have presented the model of the mechanical, and electrical parts of the chain of wind turbine equipped with DFIG. In the following part, we have introduced the advanced frequency control (robust H∞ control) for regulate the active and reactive powers of stator. In next section, H∞-MRAS is utilized for observed the position/speed of the DFIG rotor. Finally, the simulation results and conclusion are presented the robustness of the sensor-less robust H∞ of a doubly fed induction generators DFIG based on H∞-MRAS compared with classical MRAS.

II. Chain of Wind Conversion Model

Figure 1 shows the system of wind energy based on doubly fed induction generator (DFIG) [5], [6]:

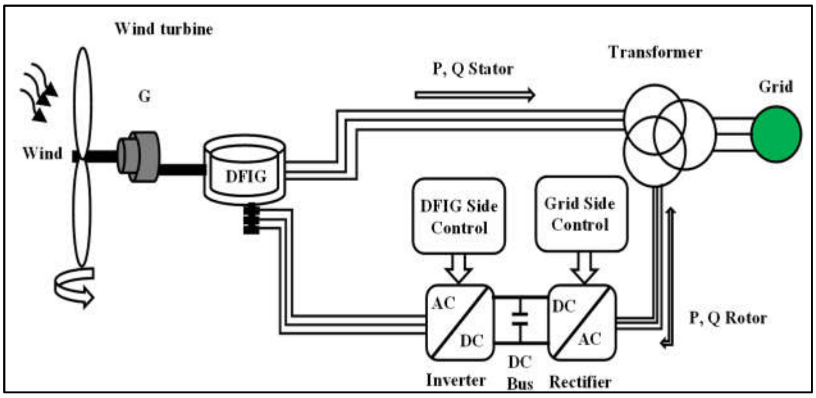

Figure 1. Global system of wind turbine based on DFIG.

II.1. Model of Wind Turbine

The mechanical energy produced by wind power turbine [6], [7], [8]:

$$P_m = \frac{1}{2}\,\rho\, S\, v^3\, C_p \tag{1}$$

where ρ : air density; v : wind speed (m.s^{-1}); Sweep space for a turbo-blade $S = \pi R^2$ (m^2); C_p power coefficient is expressed by:

$$C_p\,(\lambda, \beta) = \frac{1}{2}\left(\frac{116}{\lambda_i} - 0.4\,\beta - 5\right) e^{-\left(\frac{21}{\lambda_i}\right)} \tag{2}$$

$$\lambda_i = \left(\frac{1}{\lambda + 0.08\,\beta} - \frac{0.035}{\beta^3 + 1}\right) \tag{3}$$

The speed ratio can be written as [8], [9]:

$$\lambda = \frac{R\,\Omega_t}{v} \tag{4}$$

with; Ω_t the mechanical speed of turbine of DFIG (rad/s).

II.2. Model of DFIG

By using the electrical/mechanical equations we give the DFIG model in Park reference (d − q) [10], [11]:

$$\begin{cases} v_{ds} = R_s i_{ds} + \frac{d\varphi_{ds}}{dt} - \omega_s\ \varphi_{qs} \\ v_{qs} = R_s i_{qs} + \frac{d\varphi_{qs}}{dt} + \omega_s\ \varphi_{ds} \\ v_{dr} = R_r i_{dr} + \frac{d\varphi_{dr}}{dt} - (\omega_s - \omega_r)\ \varphi_{qr} \\ v_{qr} = R_r i_{qr} + \frac{d\varphi_{qr}}{dt} - (\omega_s - \omega_r)\ \varphi_{dr} \end{cases} \tag{5}$$

with; $\varphi_{dr} = l_s i_{ds} + l_m i_{dr}$, $\varphi_{qs} = l_s i_{qs} + l_m i_{qr}$, $\varphi_{dr} = l_r i_{dr} + l_m i_{ds}$, $\varphi_{qr} = l_r i_{qr} + l_m i_{qs}$.

III. Advanced Frequency Control Strategy of DFIG

Advanced frequency control (Robust H∞ control) strategy has been examined widely in recent years [12], [13]. It is an important solution for system disturbances and uncertainties. The robust H∞ control (advanced frequency control) was proposed from the search for a better formalization of the specifications by mathematical criteria whose effective resolution makes it possible to synthesize a corrector answering these specifications [13], [14].

III.1. General Advanced Frequency Control Configuration with Uncertainty

The standard configuration of the robust H∞ controller with the plant and the weighting function is shown in Figure 2 [12].

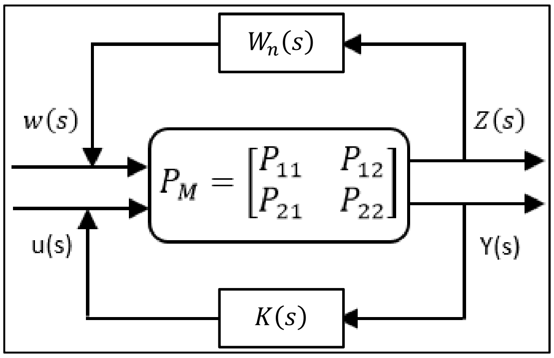

Figure 2. General Setup of the H∞ design problem.

with;

$x(t)$: Controlled outputs vector;

$z(t)$: Inputs vector of criterion H∞;

$y(t)$: Measured outputs vector;

$u(t)$: Inputs vector of control;

III.2. Synthesis of the Robust H∞ Controller

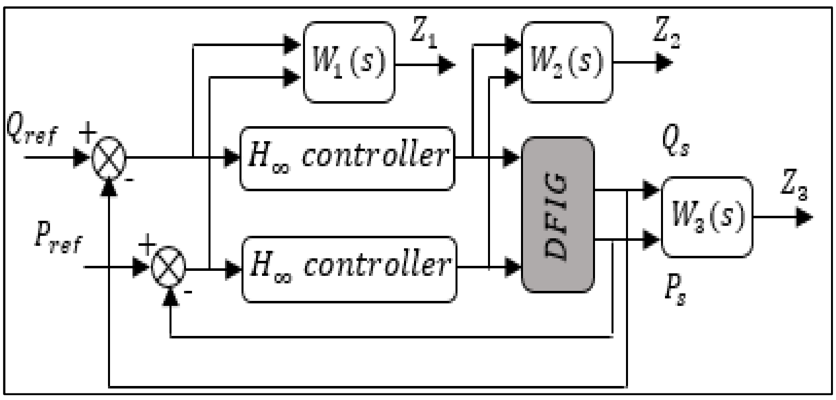

Figure 3. H∞ controller scheme.

The main problem of the robust H∞ control technique is to find the controller function $K(s)$, which internally stabilizing the controlled dynamics closed-loop, and minimizing the H∞ norm of the transfer function as depicted in Figure 3, which express the relation between input and output [12], [13], [14]:

$$\left\| \begin{matrix} W_1(s)S(s) & W_1(s)W_3(s)S(s)G(s) \\ W_2(s)K(s)S(s) & W_2(s)K(s)W_3(s)S(s)G(s) \end{matrix} \right\|_\infty < \gamma \tag{6}$$

where; $z(t)$ is the criterion H∞ input vector, $y(t)$ is the measured output vector, $u(t)$ is the control Input vector, and $W_n(s)$ is the exogenous input vector (uncertainties), $K(s)$ is the H∞ controller, $G(s)$ is the plant [13], [14].

To control Z_1, Z_2, Z_3, we can write [12]:

$$\begin{cases} Z_1 = W_1(s)\begin{bmatrix} Q_{ref} - Q \\ P_{ref} - P \end{bmatrix} \\ Z_2 = W_2(s).u(s) \\ Z_3 = W_3(s)\begin{bmatrix} Q \\ P \end{bmatrix} \end{cases} \tag{7}$$

with; $W_1 = \begin{bmatrix} \frac{s/M_s+\omega_1}{s+\omega_1.\varepsilon} & 0 \\ 0 & \frac{s/M_s+\omega_1}{s+\omega_1.\varepsilon} \end{bmatrix}$; $W_2 = \begin{bmatrix} \frac{s+\omega_h/M_u}{s.\varepsilon_{us}+\omega_h} & 0 \\ 0 & \frac{s+\omega_h/M_u}{s.\varepsilon_{us}+\omega_h} \end{bmatrix}$; $W_3 = \begin{bmatrix} 0.42 & 0 \\ 0 & 0.021 \end{bmatrix}$.

We obtain $\gamma = 0.4249$, , $\gamma = 0.5387$ and the active power corrector of order 3 whose transfer function is given as follows :

$$K_P(s) = \frac{1.63e04\ s\hat{}2 + 5.109e07\ s + 3.53e09}{s\hat{}3 + 1.094e06\ s\hat{}2 + 3.341e09\ s + 4.469e06} \tag{8}$$

$$K_Q(s) = \frac{2.33e04\ s^2 + 1.9e07\ s + 2.3e09}{s^3 + 2.08e06\ s^2 + 5.2e09\ s + 4.9e06} \tag{9}$$

The proposed controller (robust H∞) for regulate the stator power (active and reactive) of DFIG is illustrated in Figure 4:

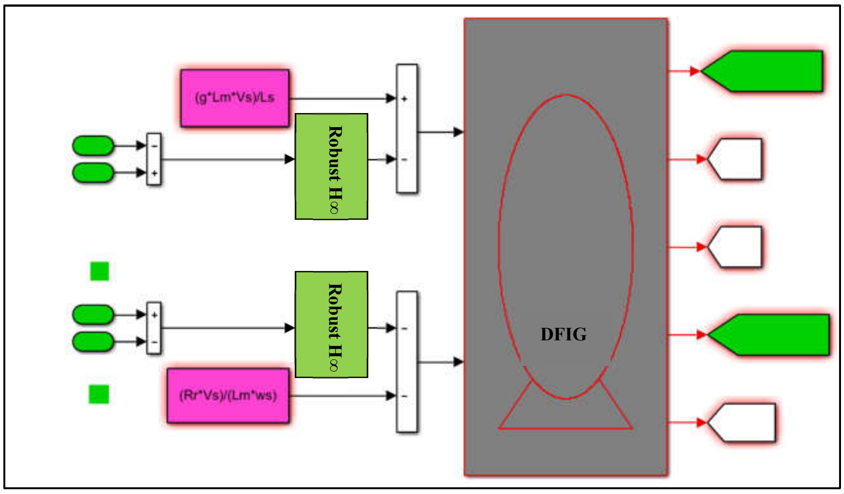

Figure 4. Block diagram of DFIG using the robust H∞ controller.

IV. Sensor-less Speed Control Associated with MRAS Observer

IV.1. The Model Reference and Adaptive System

We execute this procedure, utilizing two autonomous models. The first is the reference model. It is utilized for the determination of the currents (direct and quadrature components) from the direct measurement of currents. The second, adjustable model is used to estimate two components of the currents from the direct measurement of currents and voltages [15]. By deleting the error between two models, we can observe the speed of rotor in dynamic mode. This error is used by PI controller (adaptive mechanism) [16], [17]. The presentation of the classical MRAS observer shows in Figure 5.

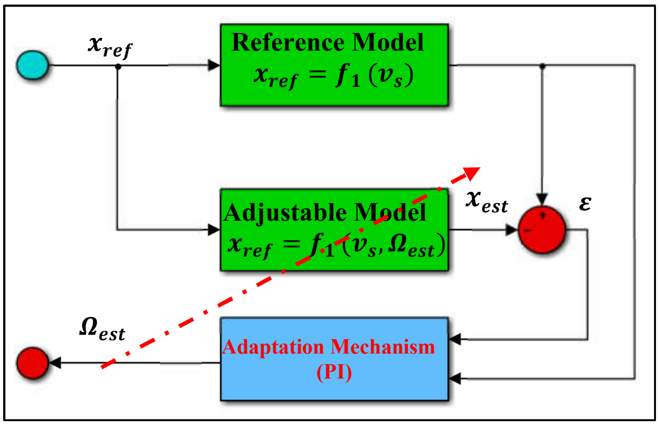

Figure 5. Global structure of the classical MRAS observer.

The disadvantages of classical MRAS observer is that the part of adaptive mechanism (PI controller). In order to improve this observer, we propose to replace the PI by advanced frequency control (Robust H∞ control).

IV.2. H∞-MRAS Obsever

In this section, we applied the observer of H∞-MRAS in different region of speed of wind (low, medium and high). The main drawback, when we applied the classical MRAS is bad estimation of wind speed/position. To improve the performance of the classical MRAS observer based on classical PI controller, we replace PI with advanced frequency control (Robust H∞ control) (Figure .6):

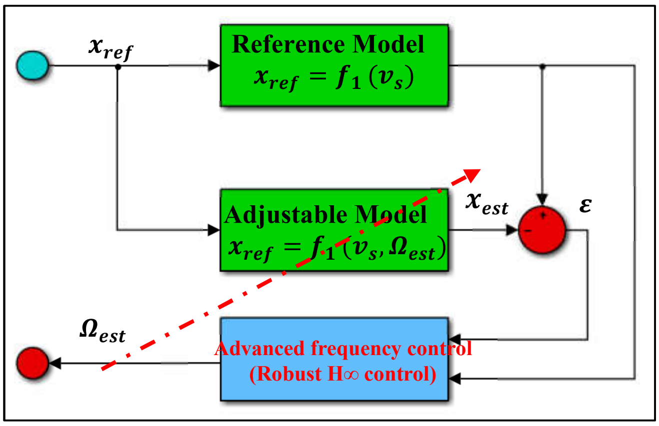

Figure 6. Block diagram of the H∞-MRAS observer.

IV.3. Global Sensor-less Robust H∞ controller Based on H∞-MRAS Observer

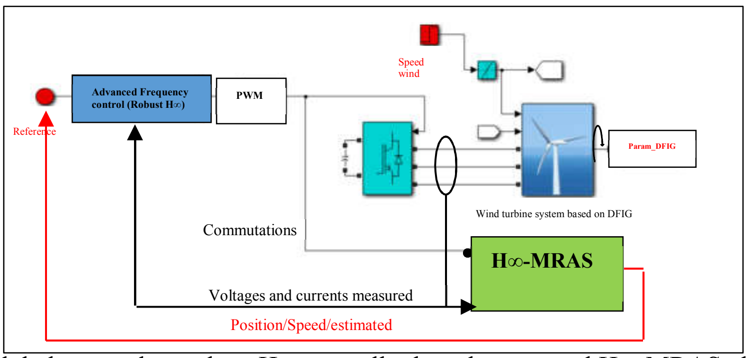

Figure 7. Global sensor-less robust H∞ controller based on a novel H∞-MRAS observer.

V. Results of Simulations

The proposed sensor-less robust H∞ controller of the system of wind energy equipped with DFIG using H∞-MRAS observer has been evaluated via simulation tests through Matlab/Simulink. The DFIG nominal power used in the simulation is 1.5 MW. Figure 8 shows the profile of wind speed applied on turbine (mechanical part).

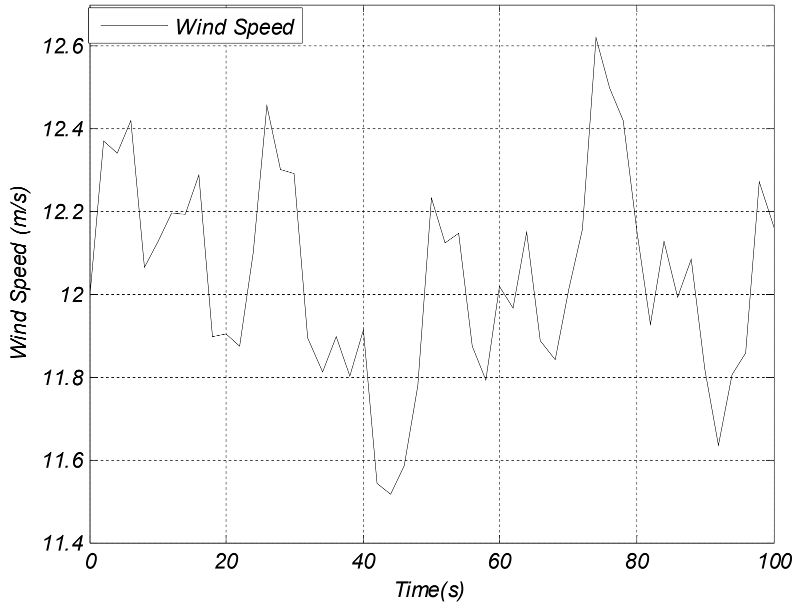

Figure 8. profile of wind speed.

Figure 9 illustrates the dynamic of stator power (active/reactive), and Figure 10 shows the currents of stator (proper sinusoidal form), and torque of electromagnetic by using the sensor-less robust H∞ controller.

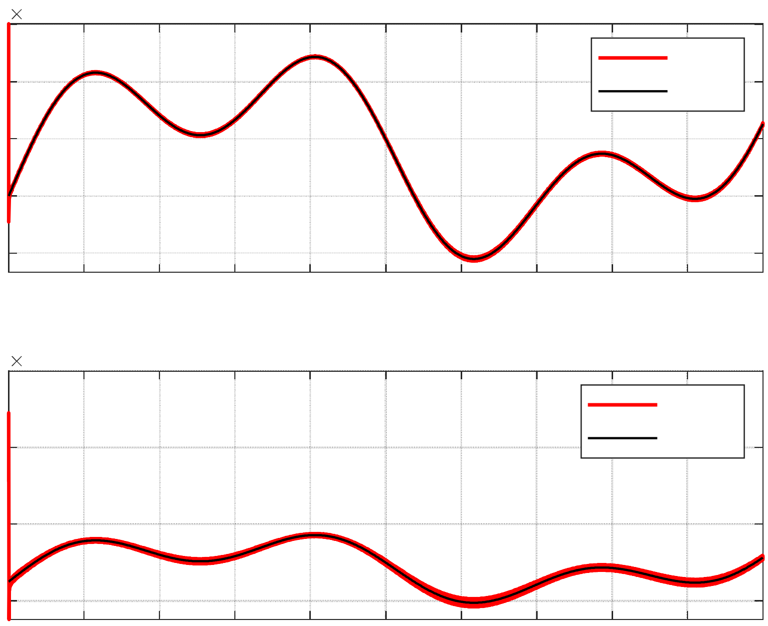

Figure 9. Stator powers of DFIG.

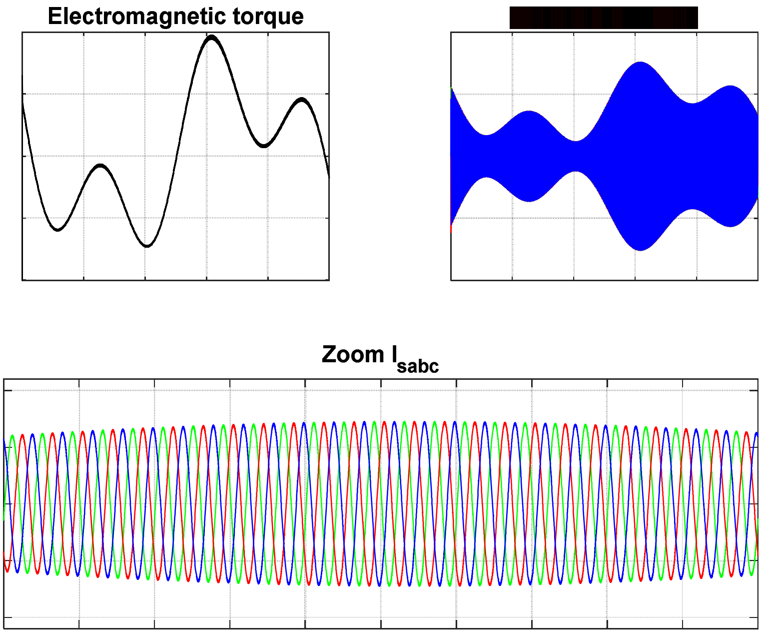

Figure 10. Currents stator, and torque of electromagnetic.

These results of simulation demonstrate a high tracking, absolute decoupling, no transients state, zero static error, and a strictly sinusoidal current, so power quality improves when we use a robust H∞ controller.

In the section on sensor-less control, the system of wind turbines based on DFIG will be evaluated by using an industrial benchmark shown in Figure 11, with variable speed range between [+120 +9] (rad/s), to test the robustness and performance of the proposed observer (H∞-MRAS) compared with a conventional MRAS observer.

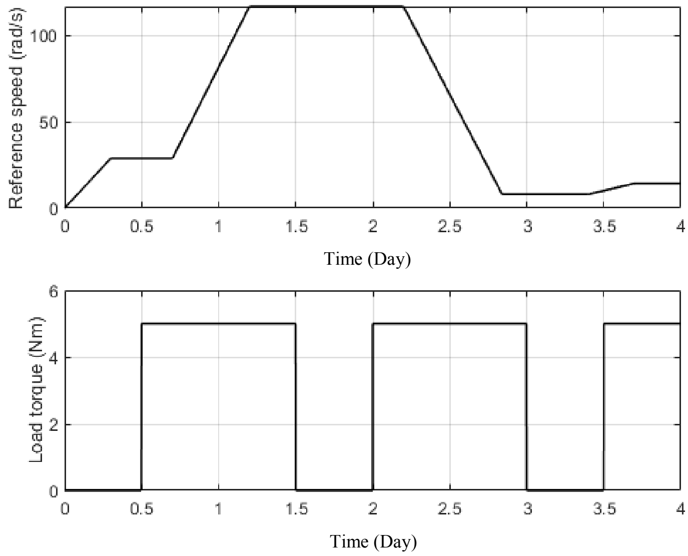

Figure 11. Industrial Benchmark.

Figure 12 shows the speed estimation when we use the novel H∞-MRAS and conventionnel MRAS observers. We find that the dynamics of the velocity estimation are the same as the measured and reference velocities, with almost negligible errors in H∞ MRAS compared to conventional MRAS observers. This result confirms the robustness and performance of the proposed sensor-less control provided with a novel H∞-MRAS observer.

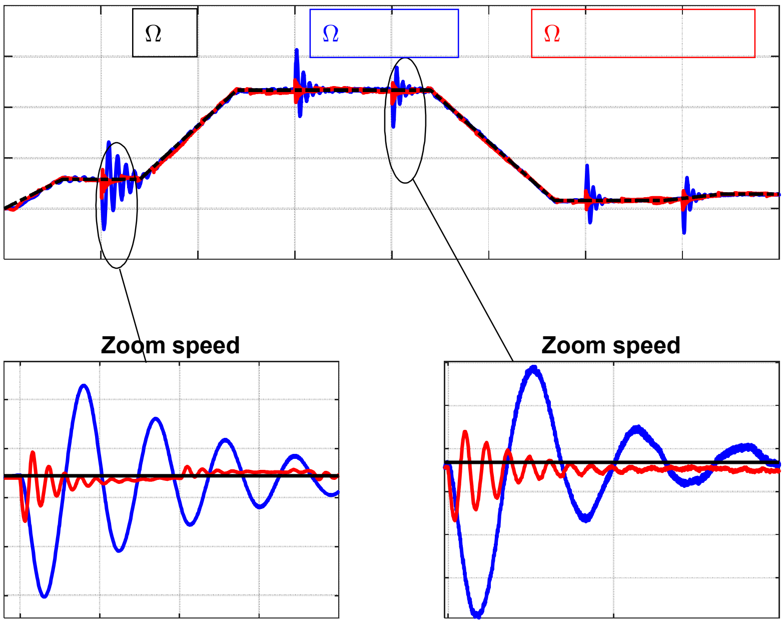

Figure 12. The rotational speed based on classical MRAS and H∞-MRAS.

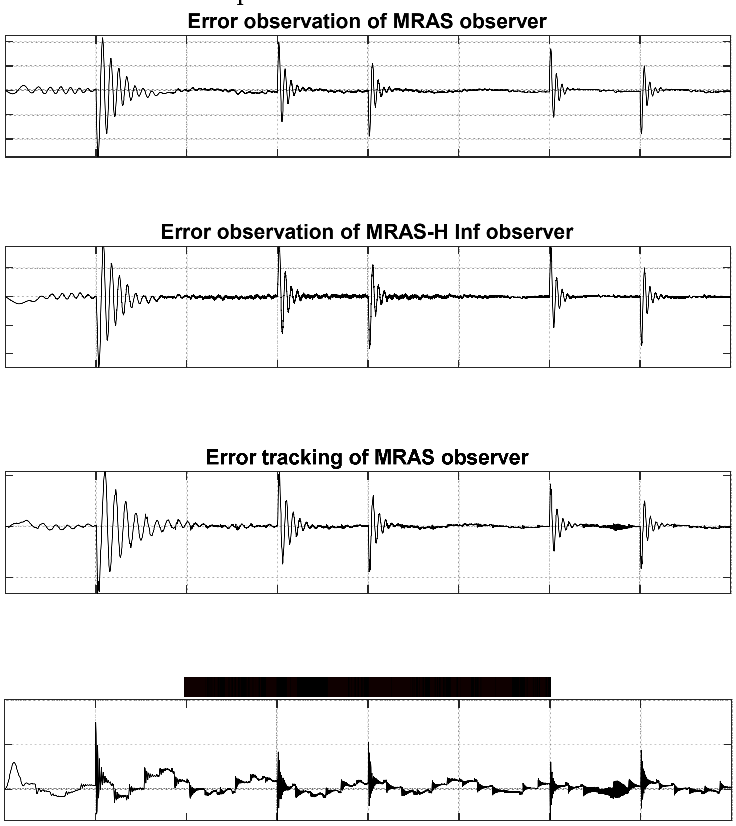

Figure 13. The error of observation and the tracking of the MRAS and H∞-MRAS observer.

Figure 13 shows an error of observation, and tracking, the load torque is applicate at t = 0.5 s, t = 2s, and t = 3.5s and cancels in t = 1.5s, and in t = 3s. This figure confirms the high robustness, and performance of the proposed observer (H∞-MRAS) compared with the conventionnel MRAS observer.

Note: Error of observation=Vmes-Vest, and error of tracking =Vmes-Vref.

VI. Conclusion

This paper enables us to present the performance of the sensorless robust H∞ controller, which is applied to the chain of wind turbines based on the DFIG using an H∞-MRAS observer, robust H∞ controller based on the minimization of the H∞ standard, using frequency concepts is used to regulate the powers of the stator (active/reactive), and In order to improve the performance and robustness of the classical MRAS based on the PI controller (adaption mechanism), replacing this part with the robust H∞ controller.

The primary motivation behind this study is to decrease machine cost and size (DFIG) by using an H∞-MRAS observer instead of encoder (mechanical sensor). The simulation results confirmed the robustness, a high observation (estimation) of the speed dynamic of the DFIG rotor in different regions (low medium, high), and low sensitivity (good disturbance rejection) of the proposed observer H∞-MRAS compared with the classical MRAS observer.

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