Fault detection of variable speed wind generator

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Résumé

Cet article traite de la détection [illegible] des pannes des systèmes éoliens. Après explication de l'importance que revêtent la supervision et le diagnostic des pannes des systèmes [illegible]

Most wind turbines are now equipped with induction generators. These ma-

This paper is organized as follow. A brief description of the Doubly Fed Induction Generator is recalled and summarised in section 2. Section 3 presents the test bench. Preliminary results for observer design are specified in section 4. Section 5 is dedicated for the [illegible]

Stator and rotor voltages equations in frame are given by:

$$\begin{cases} u_s = R_s i_s + \dfrac{d\psi_s}{dt} \\ u_r = R_r i_r + \dfrac{d\psi_r}{dt} - j\omega_m \psi_r \end{cases} \quad (1)$$

with
$$\begin{cases} \psi_s = L_s i_s + L_h i_r \\ \psi_r = L_h i_s + L_r i_r \end{cases} \quad (2)$$

With (1) and (2), we get :
$$\begin{cases} u_s = R_s i_s - L_s \dfrac{di_s}{dt} + L_h \dfrac{di_r}{dt} \\ u_r = R_r i_r - L_h \dfrac{di_s}{dt} + L_r \dfrac{di_r}{dt} - j\omega_m L_h i_s - j\omega_m L_r i_r \end{cases} \quad (3)$$

Using the equation (3), we can rewrite it in a state representation form:

$$\frac{d}{dt}\begin{pmatrix} i_s \\ i_r \end{pmatrix} = \frac{1}{L_s L_r - L_h^2}\begin{pmatrix} -R_s L_r - j\omega_m L_h^2 & L_h R_r - j\omega_m L_h L_r \\ L_h R_s + j\omega_m L_s L_h & -R_r L_s + j\omega_m L_h L_r \end{pmatrix}\begin{pmatrix} i_s \\ i_r \end{pmatrix} + \frac{1}{L_s L_r - L_h^2}\begin{pmatrix} L_r & -L_h \\ -L_h & Ls \end{pmatrix}\begin{pmatrix} u_s \\ u_r \end{pmatrix} \quad (4)$$

Using (α,β) reference frame, we can write the state representation of our system:

$$\frac{d}{dt}\begin{pmatrix} i_{\alpha s} \\ i_{\beta s} \\ i_{\alpha r} \\ i_{\beta r} \end{pmatrix} = \frac{1}{L_s L_r - L_h^2}\begin{pmatrix} -R_s L_r & \omega_m L_h^2 & L_h R_r & \omega_m L_r L_h \\ \omega_m L_h^2 & R_s L_r & \omega_m L_r L_h & R_r L_h \\ R_s L_h & -\omega_m L_s L_h & -R_r L_s & -\omega_m L_s L_r \\ \omega_m L_s L_h & R_s L_h & \omega_m L_s L_r & R_r L_s \end{pmatrix}\begin{pmatrix} i_{\alpha s} \\ i_{\beta s} \\ i_{\alpha r} \\ i_{\beta r} \end{pmatrix} + \frac{1}{L_s L_r - L_h^2}\begin{pmatrix} L_r & 0 & -L_h & 0 \\ 0 & L_r & 0 & L_h \\ -L_h & 0 & L_s & 0 \\ 0 & L_h & 0 & L_s \end{pmatrix}\begin{pmatrix} u_{\alpha s} \\ u_{\beta s} \\ u_{\alpha r} \\ u_{\beta r} \end{pmatrix} \quad (5)$$

To get the complete model of our DFIG, the electromagnetic torque is expressed in (d,q) frame. In our (α,β) reference frame , we have :

$$T_{em} = k_t p L_h (i_{\alpha r} i_{\beta s} - i_{\beta r} i_{\alpha s}) \quad (6)$$

Where:

- iαs,βs , iαr,βr are respectively the currents of the stator and the rotor on the phases alpha and beta.
- uαs,βs , uαr,βr, are respectively the voltages of the stator and the rotor on the phases alpha and beta
- ωm is the rotational speed of the generator
- Ls, Lr, Lh are respectively the inductance of the stator, the rotor and the mutual inductance.
- Rs, Rr are respectively the resistance of the stator and the rotor.

(α, β) is the reference frame linked to the stator; changing from the classic (a, b, c) basis, which is corresponding to the stator and rotor windings of the generator, to the (α,β) basis.

ψ_s, ψ_r are stator and rotor fluxes.

k_l parameter of the type of Park Transformation.

p number of poles pair of the machine.

Experimental benchmark

Tests were performed using the experimental benchmark of the University of Mondragon. It consists of a DC machine of 25 kW emulating the aerodynamic and mechanical behaviour of a wind turbine, and a D.F.I.G of 15 kW emulating the electrical generator.

But, in our case, we'll consider that the speed of the rotor of the generator ω_m is variable.

Our model (7) can be written in state representation:

$$\dot{x} = A(\omega_m)x + Bu$$
$$y = Cx \qquad (8)$$

Where

$A(\omega_m) = $ [illegible] and $B = $ [illegible]

$$\text{and } C = \begin{pmatrix} 1 & 0 & 0 & 0 \\ 0 & 1 & 0 & 0 \\ 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 1 \end{pmatrix}$$

[illegible]

The overseen conditions of observability and stability (9) and (10) allow us to write the observer like this:

$$\dot{\hat{x}} = \tilde{A}\hat{x} + \varphi(y,u) - K(C\hat{x} - y) = (\tilde{A} - KC)\hat{x} - \varphi(y,u) + KCx \qquad (11)$$

Where the form of $\tilde{A}$ is:

$$\tilde{A} = \lambda * \begin{pmatrix} -R_s L_r & 0 & R_r L_m & 0 \\ 0 & -R_s L_r & 0 & R_r L_m \\ R_s L_m & 0 & -R_r L_s & 0 \\ 0 & R_s L_m & 0 & -R_r L_s \end{pmatrix} \text{ and }$$

$$\varphi(y,u) = \lambda * \omega_m \begin{pmatrix} 0 & L_m^2 & 0 & L_r L_m \\ L_m^2 & 0 & L_r L_m & 0 \\ 0 & -L_s L_m & 0 & -L_s L_r \\ L_s L_m & 0 & L_s L_r & 0 \end{pmatrix} \begin{pmatrix} i_{s\alpha} \\ i_{s\beta} \\ i_{r\alpha} \\ i_{r\beta} \end{pmatrix} + \lambda * \begin{pmatrix} L_r & 0 & -L_m & 0 \\ 0 & L_r & 0 & -L_m \\ -L_m & 0 & L_s & 0 \\ 0 & -L_m & 0 & L_s \end{pmatrix} \begin{pmatrix} u_{s\alpha} \\ u_{s\beta} \\ u_{r\alpha} \\ u_{r\beta} \end{pmatrix}$$

with $\lambda = \dfrac{1}{L_s L_r - L_m^{\,2}}$ and $C = \begin{pmatrix} 1 & 0 & 0 & 0 \\ 0 & 1 & 0 & 0 \\ 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 1 \end{pmatrix}$

We can verify that our system is observable to fit conditions (9) and (10), and the choice of poles gives us the K matrix in order to get $\tilde{A} - KC$ Hurwitz.

With $\tilde{A}$, K, C constant matrix,

The error of state estimation is given by:

$$e = \hat{x} - x \qquad (12)$$

Then with the equations (8) and (10), we get,

$$\dot{e} = \dot{\hat{x}} - \dot{x} \Rightarrow$$

$$\dot{e} = (\tilde{A} - KC)(\hat{x} - x) = (\tilde{A} - KC)e \qquad (13)$$

The residue is chosen as $r = \hat{y} - y = Ce$ (14)

Note as said [9], that r possesses the characteristic features of a residual when the observer matrix K is so chosen that $(\tilde{A} - KC)$ is stable. In this case, $\hat{x}$ also provides an unbiased estimation for x, i.e.

$$\lim_{t \to \infty}(x(t) - \hat{x}(t)) = 0$$

Simulation results

Simulations without bias

We are only interested here to estimate currents which are sensitive to fault of the generator. Stator and rotor are connected to infinite grid, which is stable that's why voltages are constant or have very little variation. During test, speed of our generator varies between 2239 rpm and 2776 rpm, the sampling period is 0.0002 and the number of samples is 500 in each case.

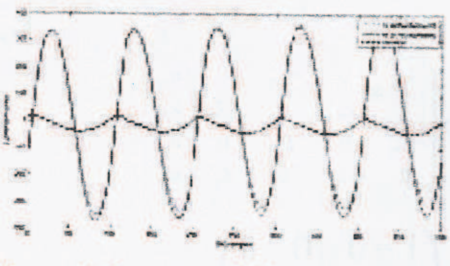

***Figure 4**: Current is alpha estimated, mea sured and the residual*

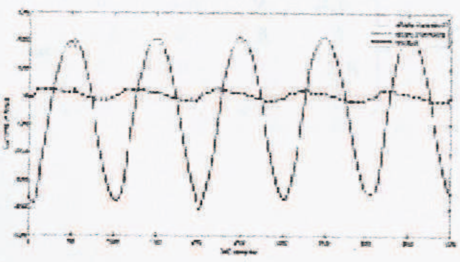

***Figure 5**: Current is beta estimated, measu-red and the residual*

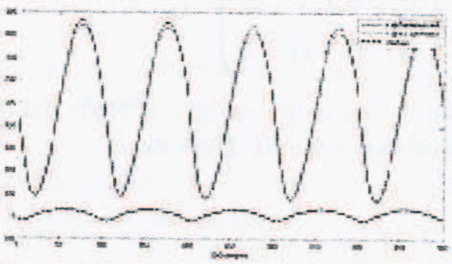

***Figure 6**: Current ir alpha estimated, mea sured and the residual*

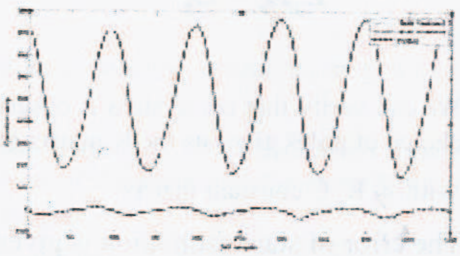

***Figure 7:** Current ir beta estimated, measu-red and the residual*

In Figure 4, 5, 6 and 7, we have the measured and estimated values of "is alpha", "is beta", "ir alpha", "ir beta" ,and the residue which is the difference between the measured value and estimated value for each of them.

We note here, that estimated and measured value have similarities and are close to each other.

We also see that the residues are not far from zero.

Simulation with bias

In this case, we will detect an additional fault on currents. Usually, these sorts of fault are due to sensor. To execute this test, in our simulation, we add an abrupt signal to measured currents. Speed of our generator varies between 2239 rpm and 2776 rpm, the sampling period is 0.2ms and the number of samples is 500 in each case. We have introduced abrupt signal in 100 samples.

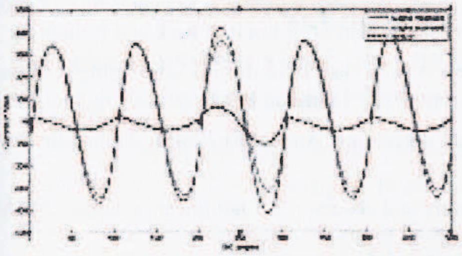

***Figure 8**: Current is alpha estimated, measured and the residual*

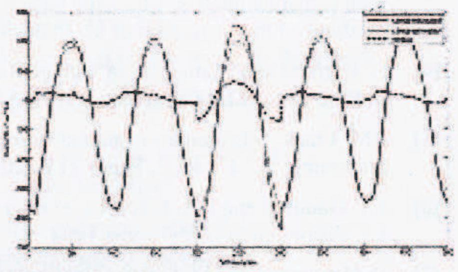

***Figure 9**: Current is beta estimated, mea sured and the residual*

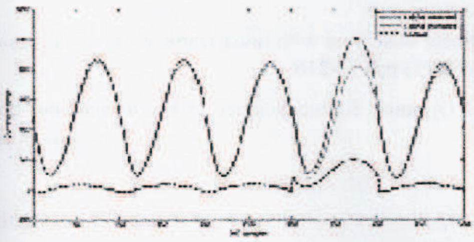

***Figure 10**: Current ir alpha estimated, measured and the residual*

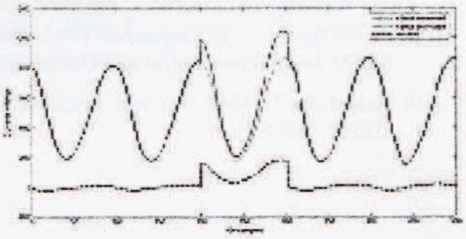

***Figure 11**: Current ir beta estimated, mea sured and the residual*

In Figure 8,9,10 and 11, we have the measured and estimated values of each component of the current i (is alpha, is beta, ir alpha and ir beta), and the residue which is the difference between the measured value and estimated value each of current. Here, we detect the fault signal; because the residue is not zero. The detected fault is an additive fault signal in 100 samples. The blue curves in dash show well the error amplitude.We isolate the error with good sensibility.

Conclusion

In this paper, we presented a nonlinear observer to solve fault detection and isolation of a wind generator especially the DFIG which is most used generator nowadays. Our system is totally observable. Estimate values of the stator and rotor current converge rapidly to our measured values if we increase our gain K. The methodology is only to estimate state using nonlinear observer. After injection of an abrupt signal in few points (100), we detect and isolate the error. We can also [illegible]

fault signature analysis of a wind turbine at a variable speed » Editorial Manager(tm) for Proceedings of the Institution of Mechanical Engineers, Part O, Journal of Risk and Reliability

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