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Fault Tolerant Control of Induction Motor Drives Subject to Rotor Resistance Adaptation

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Abstract: This paper describes the synthesis of a vector fault tolerant control of induction motor drives using an adaptive observer. This observer is used to detect the rotor resistance and flux components using the stator terminal voltages and currents. The rotor resistance is adapted using a new algorithm which does not imply a high computational load. Stability analysis based on Lyapunov theory is performed in order to guarantee the closed loop stability. The rotor resistance is used for the correction of the controllers and the rotor time constant. To verify the tolerance and the applicability of this control, we consider the stator inter-turn fault which is frequently encountered in practice. An analytical method for the modelling of this fault is presented. The equations which describe the transient as well as steady state behavior of unsymmetrical induction machine including the computation of machine inductances are presented. These inductances are calculated analytically using the magnetic field distribution through the machine air-gap. Simulation results are provided to evaluate the consistency and performance of the proposed fault tolerant control of induction motor based vector control.

Keywords— Adaptive observer; Fault tolerant control; Induction machine; Vector control.

I. INTRODUCTION

The induction machine (IM) is used in wide variety of applications as a mean of converting energy. Pumps, electrical vehicles and asynchronous generators are but few applications of large IM. The vector control has been recognized as the algorithm that gives the IM drives fast dynamic response. It provides the same performances as achieved by direct current machines. The IM are subject to different faults, due to a combination of thermal overloading, transient voltage stresses, mechanical stresses and environmental stresses [1-4]. From a number of surveys, it can be deduced that stator faults account approximately 40 % of all failures. An important problem is that the rotor resistance varies with respect to abnormal conditions. For vector controlled IM, the rotor resistance variation modifies the performances of the control system when we use a control law with fixed parameters [5-6]. Therefore, the fault tolerant control (FTC) is necessary to preserve some pre-specified performances: continuity, quality of services and stability. Some FTC schemes require explicit detection and estimation of the fault (active FTC), while some FTC schemes operate using robust controllers without such explicit detection (passive FTC) [7-9]. The proposed FTC is a combination between an active and passive FTC. The advantage of this combined FTC is that when the fault is not tolerant an alarm signal will indicate that the operator's intervention is necessary. The proposed approach consists to compensate the rotor resistance variation, due to faults, using a new algorithm for an online adaptation. Many researches have been done on adaptation of the rotor resistance [10-15]. In this paper, a new algorithm is proposed for the adaptation of the rotor resistance. This method is established using stability analysis based on Lyapunov theory. It is important to note that for low speed operation, the appropriate fault harmonics approach the fundamental frequency. In this condition, the distinction between the different harmonics is delicate and the classical spectral analysis of stator current is inconvenient for fault detection [16-17]. The observed rotor resistance is considered as a very interesting tool for this purpose. The research on condition monitoring and fault tolerant control of IM needs an accurate model. For this purpose, we have to elaborate a suitable model which enables us to predict the performances and to extract fault signatures on electromagnetic torque and stator current of unsymmetrical IM. The machine inductances are calculated analytically from the machine structure using the magnetic field distribution through the machine air-gap. The obtained faulty model provides a good compromise between modeling accuracy and simulation time. To verify the consistency and the applicability of the proposed approach, we consider the variation of rotor resistance due to temperature and the operation of IM with stator interturn fault. The contribution of this paper is that it provides an effective FTC strategy using a new and practical algorithm for the adaptation of rotor resistance. In addition, a new approach for the modelling of unsymmetrical IM is proposed.

II. VECTOR CONTROL TECHNIQUE

In order to obtain the machine inductances, firstly should be obtained the spatial distribution of magnetomotive force produced by a phase "j" of the stator windings. Using this distribution it is possible to get the harmonic components of magnetic flux linkage between the two phases "i" and "j". The principle of the vector control is that the torque and flux of the IM are controlled separately similarly to the direct current machine with separate excitation. The vector control is based on the orientation of the rotating frame d-q axis, as the d axis coincides with the rotor flux direction. The orientation of the magnetic flux along the d axis led to the annulation of the quadrature component, thus

$$\begin{aligned} \phi_{qr} &= 0 \\ \phi_{dr} &= \phi_r \end{aligned} \qquad (1)$$

In a reference frame according to the rotating field, the voltage equations in the synchronously reference frame are

$$\begin{cases} \dfrac{di_{ds}}{dt} = -\dfrac{1}{\sigma L_s}\left(R_s + R_r\dfrac{L_m^2}{L_r^2}\right)i_{ds} + \omega_s i_{qs} + \dfrac{1}{\sigma L_s}\left(R_r\dfrac{L_m}{L_r^2}\right)\phi_{dr} + \dfrac{1}{\sigma L_s}v_{ds} \\ \dfrac{di_{qs}}{dt} = \omega_s i_{ds} - \dfrac{1}{\sigma L_s}\left(R_s + R_r\dfrac{L_m^2}{L_r^2}\right)i_{qs} - \dfrac{1}{\sigma L_s}\left(\dfrac{L_m}{L_r}\right)\omega\phi_{dr} + \dfrac{1}{\sigma L_s}v_{qs} \\ \dfrac{d\phi_{dr}}{dt} = R_r\dfrac{L_m}{L_r}i_{ds} - \dfrac{R_r}{L_r}\phi_{dr} \\ J\dfrac{d\Omega}{dt} = T_e - T_l - f_v\Omega \end{cases} \qquad \textbf{(2)}$$

v_{ds}, v_{qs} are the components of stator voltage vector, i_{ds}, i_{qs} are the components of stator current vector, Φ_{dr}, Φ_{qr} are the components of rotor flux vector, σ is the leakage factor, R_s and R_r are stator and rotor resistance, L_s and L_r represent the stator and rotor cyclic inductances and L_m is the stator-rotor cyclic mutual inductance. ω_s, ω are the stator and mechanical pulsation. J is the inertia of the rotor and the connected load, T_e the electromagnetic torque, T_l the load torque, Ω the mechanical angular speed and f_v is the viscose friction coefficient. For vector controlled IM. The block diagram of the proposed control scheme of induction motor is represented in Figure 4. The blocs SMC1, SMC2, and SMC3 are sliding mode controllers.

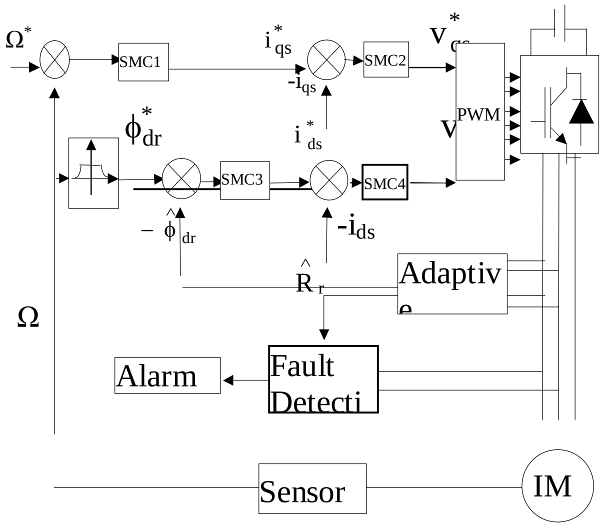


Fig. 1. Vector Fault tolerant Control scheme

III. ADAPTIVE OBSERVER

The objective is to determine the mechanism adaptation of the rotor resistance. The structure of the observer is based on the induction motor model in stator reference frame. The adaptive observer is represented in figure 2.

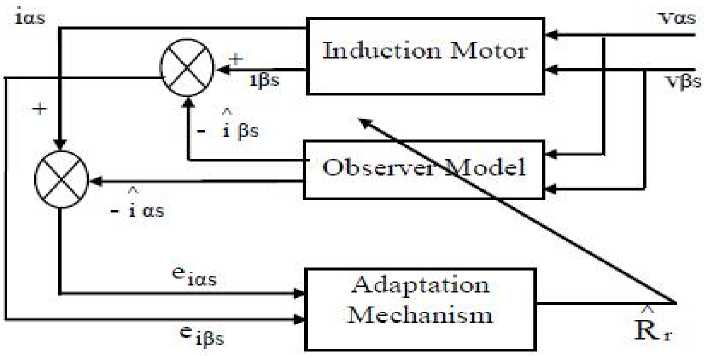


Fig. 2. Global adaptive observer.

In the stationary reference frame, the state equations of the induction motor are expressed.

$$\begin{cases} \dfrac{di_{\alpha s}}{dt} = -\dfrac{1}{\sigma L_s}\left(R_s + R_r\dfrac{L_m^2}{L_r^2}\right) i_{\alpha s} + \dfrac{1}{\sigma L_s} R_r \dfrac{L_m}{L_r^2}\Phi_{\alpha r} + \dfrac{1}{\sigma L_s}\omega\dfrac{L_m}{L_r}\Phi_{\beta r} + \dfrac{1}{\sigma L_s} v_{\alpha s} \\ \dfrac{di_{\beta s}}{dt} = -\dfrac{1}{\sigma L_s}\left(R_s + R_r\dfrac{L_m^2}{L_r^2}\right) i_{\beta s} - \dfrac{1}{\sigma L_s}\omega\dfrac{L_m}{L_r}\Phi_{\alpha r} + \dfrac{1}{\sigma L_s} R_r \dfrac{L_m}{L_r^2}\Phi_{\beta r} + \dfrac{1}{\sigma L_s} v_{\beta s} \\ \dfrac{d\Phi_{\alpha r}}{dt} = \dfrac{R_r L_m}{L_r} i_{\alpha s} - \dfrac{R_r}{L_r}\Phi_{\alpha r} - \omega\Phi_{\beta r} \\ \dfrac{d\Phi_{\beta r}}{dt} = \dfrac{R_r L_m}{L_r} i_{\beta s} - \dfrac{R_r}{L_r}\Phi_{\beta r} + \omega\Phi_{\alpha r} \end{cases} \quad (3)$$

$v_{\alpha s}$, $v_{\beta s}$ are the components of stator voltage vector, $i_{\alpha s}$, $i_{\beta s}$ are the components of stator current vector, $\Phi_{\alpha r}$, $\Phi_{\beta r}$ are the components of rotor flux vector.

The IM state model is expressed in the nonlinear form as follows.

$$\begin{cases} \dfrac{dX}{dt} = f(x,u) \\ y = h(x,u) \end{cases} \quad (4)$$

$$X^T = \left(i_{\alpha s}\ \ i_{\beta s}\ \ \Phi_{\alpha r}\ \ \Phi_{\beta r}\right),\ Y = \begin{pmatrix} i_{\alpha s} \\ i_{\beta s} \end{pmatrix},\ U = \begin{pmatrix} v_{\alpha s} \\ v_{\beta s} \end{pmatrix}$$

By linearizing the above state model, we can write:

$$\begin{cases} \dfrac{dX}{dt} = AX + BU \\ Y = CX \end{cases} \quad (5)$$

$$A = \frac{\partial f}{\partial x},\quad B = \frac{\partial f}{\partial u}$$
$$C_i = \frac{\partial h}{\partial x} \qquad (6)$$

The matrices are defined by

$$A=\begin{pmatrix} -a & 0 & \frac{R_r Lm}{L_r b} & \omega\frac{Lm}{b} \\ 0 & -a & -\omega\frac{Lm}{b} & \frac{R_r Lm}{L_r b} \\ \frac{R_r Lm}{Lr} & 0 & -\frac{Rr}{Lr} & -\omega \\ 0 & \frac{R_r Lm}{Lr} & +\omega & -\frac{Rr}{Lr} \end{pmatrix},\ B=\begin{pmatrix} \frac{1}{\sigma L_s} & 0 \\ 0 & \frac{1}{\sigma L_s} \\ 0 & 0 \\ 0 & 0 \end{pmatrix},\ C=\begin{pmatrix} 1 & 0 & 0 & 0 \\ 0 & 1 & 0 & 0 \end{pmatrix}$$

$$a=\frac{1}{\sigma Ls}\left(R_s + R_r\frac{L_m^2}{L_r^2}\right),\ b=\sigma L_s L_r,\quad \sigma = 1-\frac{L_m^2}{L_s L_r}$$

A linear state observer can then be derived by considering the mechanical speed as a constant parameter during the sampling time. This is considered because its variation is very slow comparing to the electrical variables. The model of the observer is expressed [18-19]

$$\begin{cases} \frac{d\hat{X}}{dt} = \hat{A}\hat{X} + BU + G\left(Y-\hat{Y}\right) \\ \hat{Y} = C\hat{X} \end{cases} \qquad (7)$$

The matrix of gain G is selected such as the eigenvalues of the matrix A-GC are in the left plane half of the complex plan and that the real part of the eigenvalues is larger in absolute value than the real part of the eigenvalues of the state matrix A [18-19].

The machine parameters are assumed to be perfectly known, the rotor resistance is unknown. We define

$$\delta Rr = Rr - \hat{R}r \qquad (8)$$

The symbol $\wedge$ denotes estimated values and G is the observer gain matrix.

We will determine the differential system describing the evolution of the error

$$e = X - \hat{X} \qquad (9)$$

The state matrix of the observer can be written

$$\hat{A} = A + \delta A \qquad (10)$$

$$\delta A = \begin{pmatrix} +\frac{1}{\sigma Ls}\delta R_r & 0 & -\frac{Lm}{bLr}\delta R_r & 0 \\ 0 & +\frac{1}{\sigma Ls}\delta R_r & 0 & -\frac{Lm}{bLr}\delta R_r \\ -\frac{Lm}{Lr}\delta R_r & 0 & \frac{\delta R_r}{Lr} & +\delta\omega \\ 0 & -\frac{Lm}{Lr}\delta R_r & 0 & \frac{\delta R_r}{Lr} \end{pmatrix} \qquad (11)$$

Then, we can write

$$\frac{d\hat{X}}{dt} = \hat{A}\hat{X} + BU - GCe \tag{12}$$

Thus

$$\frac{de}{dt} = (A - GC)e - \delta A\hat{X} \tag{13}$$

We define the Lyapunov function

$$V = e^T e + \frac{(\delta R_r)^2}{\lambda} \tag{14}$$

λ is a positive scalar. The Lyapunov function should contain term of the difference δR_r to obtain mechanism adaptation. The stability of the observer is guaranteed for the condition [20-21]

$$\frac{dV}{dt} < 0 \tag{15}$$

The derivative of the Lyapunov function

$$\frac{dV}{dt} = 2e^T\frac{de}{dt} + 2\frac{\delta R_r}{\lambda}\frac{d\delta R_r}{dt} \tag{16}$$

The first term becomes

$$2e^T\frac{de}{dt} = 2e^T(A - GC)e - 2e^T\delta A\hat{X} \tag{17}$$

The rotor flux components cannot be measured. In addition, the flux dynamic is faster than the machine parameters dynamic. To obtain the adaptation mechanism of the rotor resistance, we accept that

$$\begin{aligned} \hat{\Phi}_{\alpha r} &= \Phi_{\alpha r} \\ \hat{\Phi}_{\beta r} &= \Phi_{\beta r} \end{aligned} \tag{18}$$

Thus

$$e^T\delta A\hat{X} = \frac{\delta R_r}{\sigma L_s}\delta R_r\left(\hat{i}_{\alpha s}\, e_{i\alpha s} + \hat{i}_{\beta s}\, e_{i\beta s}\right) - \frac{L_m}{bL_r}\delta R_r\left(\hat{\Phi}_{\alpha r}\, e_{i\alpha s} + \hat{\Phi}_{\beta r}\, e_{i\beta s}\right) \tag{19}$$

For the second term of (16), we can write

$$2\frac{\delta R_r}{\lambda}\frac{d\delta R_r}{dt} = 2\frac{\delta R_r}{\lambda}\frac{dR_r}{dt} - 2\frac{\delta R_r}{\lambda}\frac{d\hat{R}_r}{dt} \tag{20}$$

We consider the hypothesis of a slowly varying regime for the machine parameters, thus

$$\frac{dR_r}{dt} \approx 0 \tag{21}$$

Consequently

$$\frac{d\delta R_r}{dt} = -\frac{d\hat{R}_r}{dt} \tag{22}$$

Finlay, we obtain

$$\frac{dV}{dt} = 2e^T(A - GC)e - 2\frac{\delta R_r}{\lambda}\frac{d\hat{R}_r}{dt} + 2\delta R_r\left[\frac{L_m}{bL_r}\left(\hat{\Phi}_{\alpha r}\, e_{i\alpha s} + \hat{\Phi}_{\beta r}\, e_{i\beta s}\right) - \frac{1}{\sigma L_s}\left(\hat{i}_{\alpha s} e_{i\alpha s} + \hat{i}_{\beta s}\, e_{i\beta s}\right)\right] \quad (23)$$

If the term $2e^T(A - GC)e$ is negative, the condition $\frac{dV}{dt} < 0$ is verified for

$$2\delta R_r\left[\frac{L_m}{bL_r}\left(\hat{\Phi}_{\alpha r}\, e_{i\alpha s} + \hat{\Phi}_{\beta r}\, e_{i\beta s}\right) - \frac{1}{\sigma L_s}\left(\hat{i}_{\alpha s} e_{i\alpha s} + \hat{i}_{\beta s}\, e_{i\beta s}\right)\right] - 2\frac{\delta R_r}{\lambda}\frac{d\hat{R}_r}{dt} = 0 \quad (24)$$

This condition can be verified if

$$\frac{d\hat{R}_r}{dt} = +\lambda\left[\frac{L_m}{bL_r}\left(\hat{\Phi}_{\alpha r}\, e_{i\alpha s} + \hat{\Phi}_{\beta r}\, e_{i\beta s}\right) - \frac{1}{\sigma L_s}\left(\hat{i}_{\alpha s} e_{i\alpha s} + \hat{i}_{\beta s}\, e_{i\beta s}\right)\right] \quad (25)$$

We obtain the adaptation mechanism in the form

$$\hat{R}_r = \int_0^t \lambda\left[\frac{L_m}{bL_r}\left(\hat{\Phi}_{\alpha r}\, e_{i\alpha s} + \hat{\Phi}_{\beta r}\, e_{i\beta s}\right) - \frac{1}{\sigma L_s}\left(\hat{i}_{\alpha s} e_{i\alpha s} + \hat{i}_{\beta s}\, e_{i\beta s}\right)\right] dt \quad (26)$$

The estimated electromagnetic torque is expressed

$$\hat{C}_e = \frac{3}{2} p \frac{L_m}{L_r}\left(\hat{\Phi}_{\alpha r}\, \hat{i}_{\beta s} - \hat{\Phi}_{\beta r}\, \hat{i}_{\alpha s}\right) \quad (27)$$

IV. MODELING OF UNSYMETRICAL IM

A. Modeling of interturn fault

In IM, coils are insulated one from other in slots as in end winding region. The biggest probability for inter-turn fault is inter-turn between turns in the same coil. When an inter-turn fault occurs, the phase winding has less turns. As a result of the inter-turn fault, the mutual between the phase in which inter-turn is occurred and all of the circuits in machine are altered. Initially, we consider the sample example, where the coil U-V has four turns and occupied two slots. When, a short circuit occurred between the contact points c_1 and c2, three turns in series are obtained. In addition, a new short-circuited turn which we call the short circuited phase D is created and magnetically coupled with all the other circuits. It is evident that the phase current and the currents which follow in the short-circuited phase produce opposite MMFs.

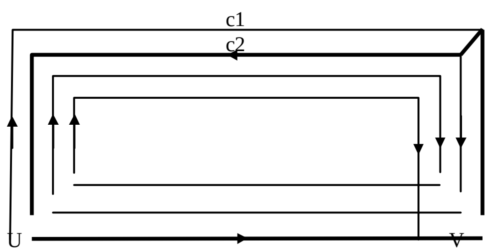


Fig. 3. Short-circuited coil.

The new phase D is described by the voltage equation

$$r_d i_d + \frac{d\Phi_d}{dt} = 0 \quad (28)$$

Φ_d , i_d and r_d are respectively the magnetizing flux, the current and the resistance of the new phase D.

Applying the following method for the calculation of machine inductances, we obtain the self and mutual inductance of the new phase and all the other circuits.

The equations describing the three phase induction machine with n rotor's bars can be written in the conventional vector-matrix form, wherein the machine parameters are calculated in the healthy and faulty modes.

B. Stator voltage equations

In the case of unsymmetrical conditions, we employ line to line voltages as inputs in simulation model. The stator voltage equation becomes

$$[u_{sf}] = [R_s][i_{sf}] + \frac{d[\Phi_{sf}]}{dt} \tag{29}$$

$$[u_{sf}] = [u_{ab}\ u_{bc}\ u_{ca}\ 0]^T$$

$$[i_{sf}] = [i_{as}\ i_{bs}\ i_{cs}\ i_d]^T$$

$$[R_s] = \begin{bmatrix} r_{as} & -r_{bs} & 0 & 0 \\ 0 & +r_{bs} & -r_{cs} & 0 \\ -r_{as} & 0 & +r_{cs} & 0 \\ 0 & 0 & 0 & +r_d \end{bmatrix} \tag{30}$$

u_{ab}, u_{bc} and u_{ca} are the line to line voltages.
i_{as}, i_{bs} and i_{cs} are the line currents.
r_{as}, r_{bs} and r_{cs} are the resistances of stator windings.

The flux equations are expressed

$$[\Phi_{sf}] = [A_f][\Phi_s] \tag{31}$$

$$[\Phi_s] = [L_{ss}][i_s] + [L_{sr}][i_r] \tag{32}$$

$$[A_f] = \begin{bmatrix} +1 & -1 & 0 & 0 \\ 0 & +1 & -1 & 0 \\ -1 & 0 & +1 & 0 \\ 0 & 0 & 0 & +1 \end{bmatrix} \tag{33}$$

L_{ss} , and L_{sr} are the matrices of the stator, and the stator-rotor mutual inductances. i_r is the rotor vector current.

When lots of short-circuited turns are created. They will be identical and have no conductive contact with other phases. They can be analyzed with the same manner as the case of one short-circuited turn.

C. Rotor voltage equations

The rotor cage is composed of n bars and the end ring circuit. It is modeled by an equivalent circuit containing n magnetically coupled circuits. Each rotor loop consists of two adjacent bars and the two portions of the end ring connect them as follows.

The rotor voltage equation is expressed

$$0 = [R_r][i_r] + \frac{d[\Phi_r]}{dt} \tag{34}$$

With

$$[\Phi_r] = [L_{rs}][i_s] + [L_{rr}][i_r] \tag{35}$$

$$[L_{rs}] = [L_{sr}]^T \tag{36}$$

$[i_r]$ is the rotor vector current;

$[R_r]$ is the n by n symmetric matrix of the rotor resistances;

$[L_{rs}]$ is the matrix of rotor-stator mutual inductances;

n is the number of bars.

In the case of healthy rotor, it can be demonstrated that [22-23]

$$[R_r] = \begin{bmatrix} R_0 & -r_b & 0 & . & . & 0 & -r_b \\ -r_b & R_0 & -r_b & . & . & 0 & 0 \\ . & . & . & . & . & . & . \\ . & . & . & . & . & . & . \\ . & . & . & . & . & . & . \\ 0 & 0 & . & . & -r_b & R_0 & -r_b \\ -r_b & 0 & . & . & . & -r_b & R_0 \end{bmatrix} \quad (37)$$

$$R_0 = 2(r_b + r_e) \quad (38)$$

r_e is the end ring segment resistance and r_b is the total bar resistance.

L_{rr} is the n by n symmetric matrix of the rotor inductances. In the case of healthy rotor, it can be verified that [22-23]

$$[L_{rr}] = \begin{bmatrix} L_{kk}+L_0 & L_{km}-l_b & L_{km} & . & L_{km} & L_{km} & L_{km}-l_b \\ L_{km}-l_b & L_{kk}+L_0 & L_{km}-l_b & . & L_{km} & L_{km} & L_{km} \\ . & . & . & . & . & . & . \\ . & . & . & . & . & . & . \\ & & . & & & & \\ L_{km} & L_{km} & . & . & L_{km}-l_b & L_{kk}+L_0 & L_{km}-l_b \\ L_{km}-l_b & L_{kj} & . & . & . & L_{km}-l_b & L_{kk}+L_0 \end{bmatrix} \quad (39)$$

$$L_0 = 2(l_b + l_e) \quad (40)$$

L_{kk} is the magnetizing inductance of each rotor loop, l_b is the rotor bar leakage inductance and l_e is the rotor end ring leakage inductance. L_{km} is the mutual inductance between two rotor loops.

D. Electromagnetic torque

The mechanical equation is

$$J \frac{d\Omega}{dt} = T_e - T_l - f_v \Omega \quad (41)$$

The electromagnetic torque can be obtained by the magnetic co-energy variation of the machine relative to the electrical displacement. It can be expressed [24]

$$T_e = \frac{P}{2} [i_s]^t \frac{\partial [L_{sr}]}{\partial \theta} [i_r] \quad (42)$$

p is the number of poles pairs and θ is the electrical angular displacement of the rotor.

V. SIMULATION RESULTS

The technique presented in the previous sections, has been implemented in the MATLAB environment. To illustrate performances of the proposed control, particularly at low speeds, we simulated the symmetrical and unsymmetrical operations.

A. Symmetrical operation

We simulated a loadless starting up mode with reference speed of -250 rpm; at t = 0.5 s, the reference speed is inversed and becomes +250 rpm, then at t = 1 s, nominal torque of 13.5 J/rad is applied on the shaft. At t = 1 sec, the rotor resistance increases of 100 %. The simulation results are shown in figure 8.

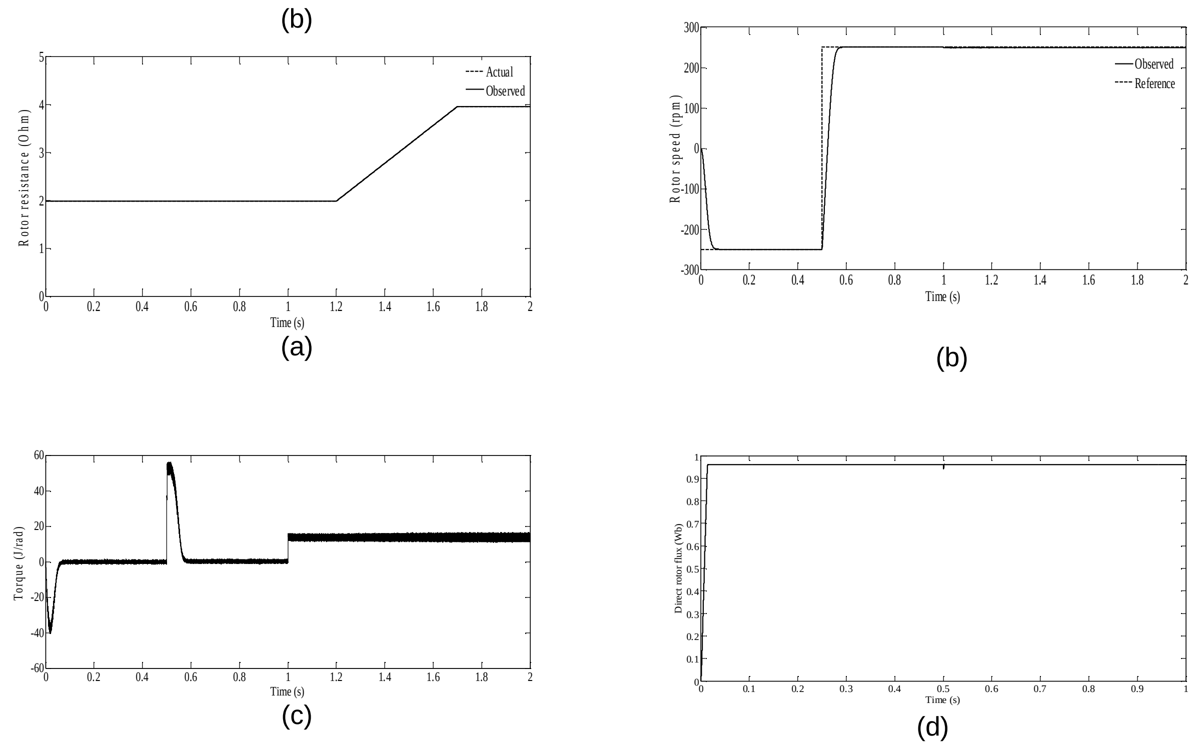
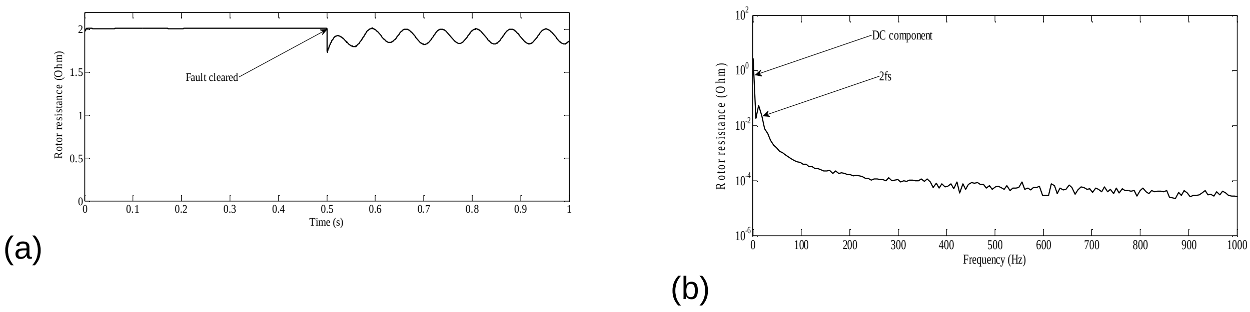


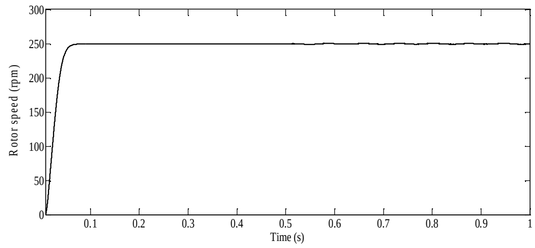
Fig. 8. Simulation results of DFOC controlled IM with rotor resistance variation: (a) rotor resistance, (b) rotor speed, (c) electromagnetic torque, and (d) direct component of rotor flux.

It is clear that the internal or external disturbances like changes in load torque, reference speed or rotor resistance variation don't allocate the performances of the proposed control. The flux tracks its reference value. The rotor speed response is also insensitive to parameters variation. Consequently, the global control scheme introduces good performances of robustness, stability and precision, particularly, under disturbance caused by parameter variation.

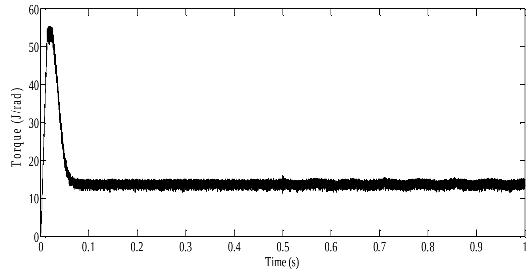
B. Unsymmetrical operation

We simulated a load starting up mode with a reference speed of +250 rpm. An interturn fault of 5 % is occurred on the first winding at t = 0.5 s. The simulation results are shown in figure 9.





(c)



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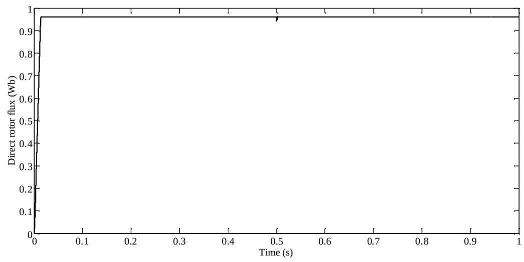

(e)

Fig. 9. Simulation results of DFOC controlled IM under stator interturn fault: (a) rotor resistance, (b) spectrum analysis of the observed rotor resistance, (c) rotor speed, (d) electromagnetic torque and, and (e) direct component of rotor flux.

For faulty condition, the rotor speed and flux still equal to their reference values. For the electromagnetic torque, pulsating component is generated to compensate the fault effect which is considered as internal disturbance. The observed rotor resistance decreases and oscillates below its nominal value with the frequency of $2f_s$. Such value of rotor resistance is considered as a fictitious quantity which only serves to superpose the Clarck model to the faulty one in unsymmetrical operation.

VI. CONCLUSION

In this paper a new approach for vector fault tolerant control has been developed. For this purpose, an adaptive observer, based on the rotor resistance adaptation, has been synthetized. The estimated rotor resistance is used for the correction of the rotor time constant, decoupling terms and the controllers. At low speeds, the observed rotor resistance can be used as a very interesting tool for fault detection purpose. An on line adaptation of the rotor resistance made more robust and more stable the adaptive observer. In faulty conditions, the machine is unbalanced and significant variation of rotor resistance is produced. Using the proposed FTC, the rotor speed and flux remain equal to their reference values. On the other hand, a pulsating torque is generated. If the stator current is not exceeding the acceptable level, the machine continues to operate with degraded performances until its repair or exchange. So, it’s always necessary to execute early fault detection for less damage. The obtained algorithm of the rotor resistance has the advantage to be easily implantable in a calculator. The proposed approach has well made more robust and more stable the IM based DFOC.

VII. Appendix

MACHINE PARAMETERS

Stator phase resistance	rs =1.5950 Ω
Rotor phase resistance	rr =1.3053 Ω
Effective air-gap	g = 0.35 mm
Stack length	L =125 mm
Rotor radius	r = 37.35 mm

Stator phase leakage inductance	Lls = 0.0040 H
Rotor phase leakage inductance	Llr = 0.0033 H
Drive inertia	J = 0.045 kg.m^2
Friction coefficient	fv = 0.0038 kg. $m^2.s^{-1}$
Stator phase turns	Ns =124
Rotor bar resistance	rb = 3.04E−4 Ω
Rotor end ring segment resistance	re = 8.75E−7 Ω
Rotor bar leakage inductance	lb = 5.16E−7 H
End ring segment leakage inductance	le = 1.59E−9 H

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