Stator faults in induction machine and its influence on the vector control

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Abstract –Although this machine is considered by its qualities of robustness and low cost of construction, it happens nevertheless that this one presents an electric or mechanical breakdown. Among these breakdowns, we quote turn-to turn t short circuit, stator phase breakdown, rotor bars breakdown… etc. In our article, we are interested in the study by simulation of the operation of an asynchronous machine presenting an electric breakdown which is the broke stator phase by modeling the machine in the two-phase reference mark. Another point is discussed in this article, it relates to the influence of this fault on the vector control. The results obtained are presented at the end of the article.

Key words: Induction machine, stator faults, phase breakdown, vector control, Park Model.

List of symbols

$R_s(R_r)$	Stator (Rotor)resistance
$L_s(L_r)$	Stator (Rotor)cyclic inductances
L_{sr}	Mutual inductance
$I_{abc}(I_{ABC})$	Stator (Rotor) current
$I_{ds}(I_{qs})$	d-axis (q-stator) stator current
$V_{ds}(V_{qs})$	d-axis (q-axis) stator voltage
$V_{abc}(V_{ABC})$	Stator (Rotor) voltages
$V_{1,2,3}$	Inverter voltages
$\psi_{abc}(\psi_{ABC})$	Rotor flux
ω_{gl}	slip frequency
ω_r	Rotor electric speed
ω_s	Synchronous speed
Ω_m	Mechanical speed
σ	Leakage coefficient
θ	electrical leading between the stator
and	rotor phases.
θ_s	electrical leading between the stator
phase	and the d axis.
T_r	Rotor time constant
p	Number of pairs of poles
C_{em}	Electromagnetic torque
C_r	Load torque
J	Moment of inertia
f	Viscous friction coefficient

1 Introduction

Rotating electrical machines play a very important role in the world's industry. Among them, the three squirrel cage induction machine is frequently used because of its relatively simple, robust construction and its low price.

Then, the power electronic and the different numerical controls permitted the use of this machine in most industrial applications at variable speed.
However, a very hard utilization conditions are in the beginning of the principle causes of stator or rotor failures.
Stator faults constitute a substantial portion of the faults related to squirrel cage induction motors [1].
Among these failures, we quote: Stator short-circuits that are the principal cause of electrical drives failures [2], stator phase breakdown, broken rotor bars …etc.

Several works are carried out in the field of modeling and the diagnostic of the faults in the electrical machines [3-4-5-6]. The majority of this work considered for their studies the three-phase mathematical model.

In this paper, an accurate model of squirrel cage induction motor under stator phase breakdown is presented. In general case, this model takes into account the resistance inequalities and a stator fault is modelized by inserting a higher resistance in the injured phase.

In our work, we interest also to the stator faults influence on the vector control. Except the Field weakening region, the vector control keeps the flux constant at its nominal value what makes it possible to obtain a maximum torque in variable speed electrical drives. We will see in follows the behavior of this method compared to a stator fault.
Simulation results are presented in the end of the paper.

2. MATHEMATICS MODELISATION

In the three phase system, stator and rotor voltage equations can be written under a matrix form as follows [7]:

$$[V_{abc}] = R_s[I_{abs}] + \frac{d}{dt}[\Psi_{abs}] \tag{1}$$

$$[V_{ABC}] = R_r[I_{ABC}] + \frac{d}{dt}[\Psi_{ABC}] \tag{2}$$

Magnetic equations to link fluxes currents are written:

$$[\Psi_{abc}] = [L_s]\cdot[i_{abc}] + [L_{sr}][i_{ABC}] \tag{3}$$

$$[\Psi_{ABC}] = [L_{sr}]^t\cdot[i_{abc}] + [L_r][i_{abc}] \tag{4}$$

In a machine that present inequalities in the stator resistances , the resistance R_s is replaced by a matrix $[R_{abc}]$ who can be written:

$$[R_{abc}] = \begin{bmatrix} R_a & 0 & 0 \\ 0 & R_b & 0 \\ 0 & 0 & R_c \end{bmatrix} \tag{5}$$

The stator and rotor inductance matrix inductance are given by :

In the stator

$$[L_s] = \begin{bmatrix} L_{aa} & L_{ab} & L_{ab} \\ L_{ab} & L_{aa} & L_{ab} \\ L_{ab} & L_{ab} & L_{aa} \end{bmatrix}$$

In the rotor

$$[L_r] = \begin{bmatrix} L_{AA} & L_{AB} & L_{AB} \\ L_{AB} & L_{AA} & L_{AB} \\ L_{AB} & L_{AB} & L_{AA} \end{bmatrix}$$

The inductance mutual matrix is:

$$[L_{rr}] = m_{sr}\begin{bmatrix} \cos\theta & \cos\left(\theta + \frac{2\pi}{3}\right) & \cos\left(\theta - \frac{2\pi}{3}\right) \\ \cos\left(\theta - \frac{2\pi}{3}\right) & \cos\theta & \cos\left(\vartheta + \frac{2\pi}{3}\right) \\ \cos\left(\theta + \frac{2\pi}{3}\right) & \cos\left(\theta - \frac{2\pi}{3}\right) & \cos\theta \end{bmatrix}$$

The breakdown phase is represented by inserting a higher resistance in series with the phase which has undergoes the cut. What increases the total resistance of the phase in question.

3 PARK MODEL

In follows, we present the electric and magnetic equations of the machine in a two-phase reference frame of Park related to the rotating field. This machine presents stator resistances with different values.

3.1 Voltage equations

The stator and rotor voltage equations in the Park model are represented by the following system:

$$\begin{cases} V_{ds} = R_{dds}I_{ds} + R_{dqs}I_{qs} + \dfrac{d\Psi_{ds}}{dt} - (\omega_s - \omega_m)\Psi_{qs} \\ V_{qs} = R_{qqs}I_{qs} + R_{dqs}I_{ds} + \dfrac{d\Psi_{qs}}{dt} + (\omega_s - \omega_m)\Psi_{ds} \\ 0 = R_r I_{dr} + \dfrac{d\Psi_{dr}}{dt} - (\omega_s - \omega_m)\Psi_{qr} \\ 0 = R_r I_{qr} + \dfrac{d\Psi_{qr}}{dt} + (\omega_s - \omega_m)\Psi_{de} \end{cases} \tag{6}$$

$R_{dds}, R_{qqs}, R_{dqs}$ are expressed by the following relations:

$$\begin{cases} R_{dds} = \dfrac{2}{3}\left[R_a\cos^2\theta_s + R_b\cos^2(\theta_s - \dfrac{2\pi}{3}) + R_c\cos^2(\theta_s - \dfrac{4\pi}{3})\right] \\ R_{dqs} = -\dfrac{1}{3}\left[R_a\sin 2\theta_s + R_b\sin(2\theta_s - \dfrac{2\pi}{3}) + R_c\sin(2\theta_s - \dfrac{4\pi}{3})\right] \\ R_{qqs} = \dfrac{2}{3}\left[R_a\sin^2\theta_s + R_b\sin^2(\theta_s - \dfrac{2\pi}{3}) + R_c\sin^2(\theta_s - \dfrac{4\pi}{3})\right] \end{cases}$$

3.2 Flux equations

$$\begin{cases} \Psi_{ds} = L_s I_{ds} + L_m I_{dr} \\ \Psi_{qs} = L_s I_{qs} + L_m I_{qr} \\ \Psi_{dr} = L_r I_{dr} + L_m I_{ds} \\ \Psi_{qr} = L_s I_{qr} + L_m I_{qs} \end{cases} \quad (7)$$

4 STATE FORM REPRESENTATION

From the systems of equations (6) and (7) we deduce a state representation of equations in the following form:

$$\dot{X} = AX + BU \quad (8)$$

With:

$$[A] = \begin{bmatrix} -\frac{1}{\sigma L_s}(R_{dd}s + \frac{L_m^2}{L_r T_r}) & -\frac{1}{\sigma L_s}(R_{dqs} - \omega_s \sigma L_s) & (\frac{L_m}{L_r T_r}) & (\omega_r \frac{L_m}{L_r} \\ -(R_{qds} + \omega_s \sigma L_s) & -(R_{qqs} + \frac{L_m^2}{L_r T_r}) & -(\omega_r \frac{L_m}{L_r}) & (\frac{L_m}{L_r T_r}) \\ (\frac{L_m}{T_r}) & 0 & -(\frac{1}{T_r}) & \omega_{sl} \\ 0 & (\frac{L_m}{L_r}) & -\omega_{sl} & -(\frac{1}{T_r}) \end{bmatrix}$$

$$[B] = \frac{1}{\sigma Ls} \begin{bmatrix} 1 & 0 \\ 0 & 1 \\ 0 & 0 \\ 0 & 0 \end{bmatrix}$$

$$[U] = \begin{bmatrix} Vds \\ Vqs \end{bmatrix}$$

We add to that the mechanical equation:

$$J \frac{d\Omega}{dt} = C_{em} - C_r - K_f \Omega \quad (9)$$

The electromagnetic torque is written:

$$C_{em} = PL_m (I_{qs} I_{dr} - I_{ds} I_{qr}) \quad (10)$$

4. Breakdown phase

To model this defect it is not explicitly necessary to change the topology of the equivalent circuit of the machine. The insertion of a great resistance in the phase containing the defect is sufficient [3]. For simulation we considered the electric defect in the phase “a” of the stator. In this case, R_a ,takes a very large value, on the other hand resistances of the two other phases remain invariant. Thus we write:

$$R_b = R_c = R_s$$

During the failure, the phase voltages of the machine are expressed according to the network voltages by the relations:

$$V_a = \frac{U_{13} + U_{12}}{2}$$

$$V_b = -V_c = \frac{U_{23}}{2}$$

5 Indirect vector control

Among the existing methods to control an asynchronous machine, we use the method known as with oriented flux. This control law has the capacity to obtain asynchronous machine best the dynamic performance. This control strategy is based on decoupling between flux and torque so as to be able to act on the torque by the intermediary of a current; we thus have a vector control of the asynchronous machine which must intrinsically comprise certain characteristics:

- Precise control of the torque to the null speed at the nominal speed; Flux
- maintenance to its nominal value for speeds lower at the nominal speed
- Possibility of under excitation for an operation at over speed.

The equations system for a field orientation of en induction machine is written as follows:

$$\begin{cases} V_{ds} = R_s I_{ds} + \sigma L_s \frac{dI_{ds}}{dt} + \frac{L_m}{L_r} \frac{d\varphi_r}{dt} - \omega_s \sigma L_s I_{qs}. \\ V_{qs} = R_s I_{qs} + \sigma L_s \frac{dI_{qs}}{dt} + \frac{L_m}{L_r} \omega_s \varphi_r + \omega_s \sigma L_s I_{ds}. \\ \varphi_r + \frac{d\varphi_r}{dt} T_r = L_m I_{ds}. \\ \omega_{gl} = \omega_s - \omega_r = \frac{L_m}{T_r \varphi_r} I_{qs}. \\ Cem = p \frac{L_m}{L_r} \varphi_r I_{qs}. \\ J \frac{d\Omega_r}{dt} = Cem - Cr - f\Omega_r. \end{cases} \quad (11)$$

6 Effect of the stator fault on the vector control

The following figure represent machine with stator phase fault associated to the vector control

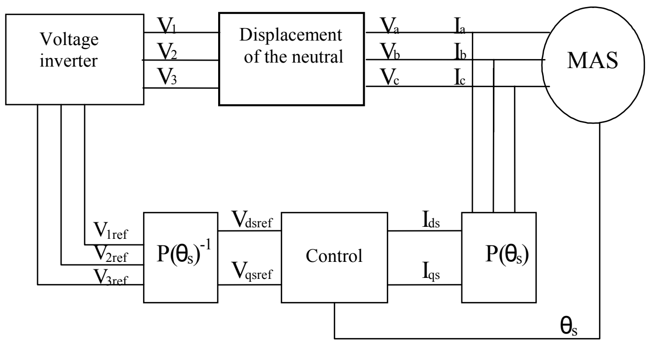

Fig.1: Principle scheme of the machine associated the control vector

The machine voltages expressed according to those of the inverter are given by:

$$\begin{aligned} V_a &= \frac{2V_1 - V_2 - V_3}{2} \\ V_b &= \frac{V_2 - V_3}{2} \\ V_c &= \frac{V_3 - V_2}{2} \end{aligned} \qquad (12)$$

The inverter is supposed to be ideal thus we write:

$$V_1 = V_{1ref}$$
$$V_2 = V_{2ref}$$
$$V_3 = V_{3ref}$$

With:

$$\begin{bmatrix} V_{1ref} \\ V_{2ref} \\ V_{3ref} \end{bmatrix} = P(\theta_s)^{-1} \begin{bmatrix} V_{dsref} \\ V_{qsref} \end{bmatrix}$$

$$\begin{bmatrix} V_{ds} \\ V_{qs} \end{bmatrix} = P(\theta) \begin{bmatrix} V_a \\ V_b \\ V_c \end{bmatrix}$$

7 Simulation results

Fig.2 present the simulation results in the case where the machine is fed by the network and Fig.3 when it is associated the vector control

This results represent respectively speed, the electromagnetic torque as well as the currents of the three stator phases.

The machine starts with no load then we applied a torque load at t=1s. The application of the faults takes place in the interval of time 3s-5s. We note that stator defect induced electromagnetic torque undulations which they same cause oscillations speed of the machine what thus generates mechanical vibrations an abnormal operation of the machine. As regards currents, that of the phase which has undergoes the defect is null on the other hand the currents Ib and Ic increased. Speed and torque follow their references perfectly.

Direct and quadrature current and flux are presented in Fig. 4. The currents Ids and Iqs answer this failure by an increase. Fluxes present small oscillations during the defect. These oscillations disappear just after this phenomenon. We note that the quadrature current Iqs with the same form as the torque and the direct current ids with the same form as the flux of axis.We can say that the vector control is practically not affected by the breakdown phase; decoupling is always kept.

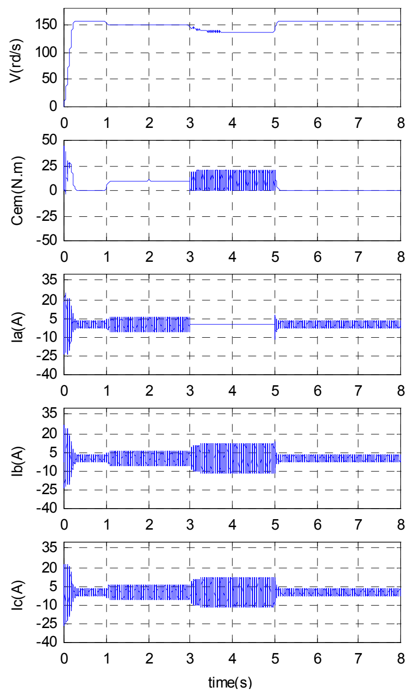

Fig. 2 : Representation of mechanic and electric quantities(machine fed by the network)

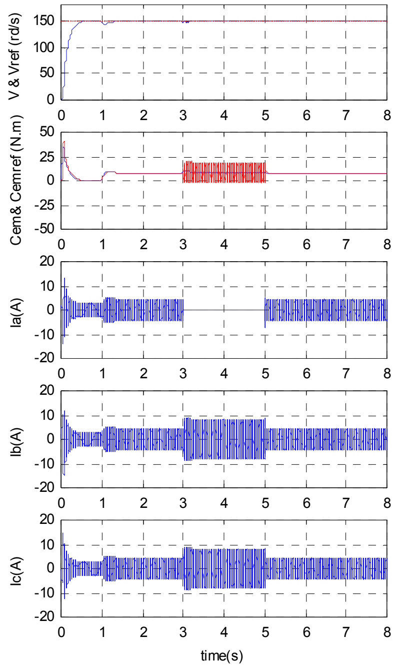

Fig. 3 : : Representation of mechanic and electric quantities(machine associated vector control)

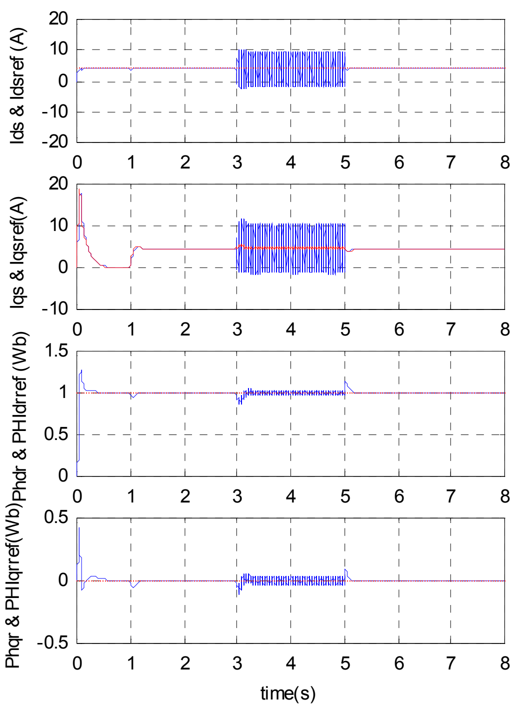

Fig. 4: Representation of direct and quadrature currents and flux respectively (Machine fed by the network)

8 Conclusion

We gave a report on a method allowing describing a stator rupture of phase in an asynchronous machine. We developed a model using the transformation of Park, which makes it possible to study this phenomenon. The results obtained show that the rupture of phase influences considerably the electric quantities and mechanical. This defect induced oscillations of the couple and consequently speed what results in vibrations of the machine. The rupture of phase is represented by the cancellation of the current and the increase in the resistance of the phase into question. In the vector control, currents Ids and Iqs answer this failure by an increase. Fluxes present small oscillations during the defect. These oscillations disappear just after this phenomenon. We note that the quadrature current Iqs with the same form as the torque and the direct current ids with the same form as the flux of axis.We can say that the vector control is practically not affected by the breakdown phase; decoupling is always kept.

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