Evaluation of Induction Motor Diagnosis by Finite Element Method Simulations

Zorig.a
Laboratoire d'Automatique de Sétif, LAS
Département d'Electrotechnique, Faculté de sciences de l'Ingénieur
Université Ferhat ABBAS de Sétif
zorig_assam@yahoo.fr

Radjeai.h
Laboratoire d'Automatique de Sétif, LAS
Département d'Electrotechnique, Faculté de sciences de l'Ingénieur
Université Ferhat ABBAS de Sétif
hradjeai@ yahoo.fr

Abstract. Induction motors play an important role in the world's industry. Hence there is a strong demand on their reliable and safe operation. Finite element method (FEM) is the most accurate technique for diagnosis and analysis of induction motor, because it can include all actual characteristics of the healthy and faulty induction motors. In this paper a FEM model of a three phase squirrel-cage induction machine is presented. It is used to analyze the behavior of the machine having broken rotor bars.

Keywords–Induction Motor, Finite Element Method, Flux2D, Diagnostics.

I. INTRODUCTION

Nowadays most of the motors used in industry are squirrel-cage induction motors because of their simple design, rugged construction, reliable operation, low initial cost, easy operation and maintenance, relatively high efficiency, etc. Hence numerous studies were presented in recent years in the field of fault detection of these machines. It is becoming a highly important issue to avoid any kind of failure of induction machine.

Moreover it is well known that unexpected failures on electrical drive system could result in many unpleasant events. In many applications induction machine's failures can shut down the entire industrial process. Such unplanned machines shut down cost both time and money. The one of the most inconvenient failure in squirrel-cage induction machine are the rotor failures, because these faults practically can not be repaired.

Generally, there are three major methods for fault analysis in induction motors. These are the magnetic equivalent circuit (MEC), winding function (WF) and finite element (FE) methods. In the MEC method, the equivalent magnetic circuit for each part of the motor is represented and these circuits are then connected to each others taking into account the direction of the magnetic flux.

It is noted that the complexity of precise mathematical models for induction motors is always the most difficult problem in the fault diagnosis. Simple models such as the MEC or d-q-o are unable to take into account the real fault cases [1]. The WF is a powerful technique that uses electrical circuits coupled to magnetic circuits and linking the relationship between the loop fluxes, stator winding currents, rotor bars current and voltages of the motor [2]. However, it is not possible to estimate the core losses of induction motor using this technique under faulty conditions. The FE method enables one to calculate the magnetic field distribution within the motor using its exact geometry and magnetic characteristics. Knowing the magnetic field distribution, other quantities of the motor such as induced voltage waveform, air gap magnetic flux density and different inductances can be obtained [3].

The finite element method has been used to analyze and diagnose a faulty induction motor [4]. Meanwhile, in this method, FEM is only used for inductance computations and the remaining calculations and analysis are carried out in a state-space environment.

II. FEM MODEL OF THE INDUCTION MACHINE

The finite element field-circuit model of the machine takes into account the non-linearity of the magnetic materials and is suitable for a deep study of squirrel cage induction machine behavior with rotor faults.

In recent years the Finite Element Method (FEM) become widely used in the design and analysis of electric machines and of her electromagnetic devices. So far a lot of program packages for computation of magnetic field, especially for two dimensional (2D) analyses have been developed. This method it is based on Maxwell's equations for magnetic and electric field [5]:

$$\nabla \times \vec{H} = \vec{J} \text{ And } \nabla \times \vec{E} = -\frac{d\vec{B}}{dt} \qquad (1)$$

Where $\vec{H}$ is the magnetic field strength [A/m], $\vec{E}$ is the electric field strength [V/m], $\vec{J}$ is the electric current density [A/m], $\vec{B}$ is the magnetic flux density [T]. Moreover the electric and magnetic field quantities are related with the material properties expressed by the following relations.

$$\vec{J} = \sigma \vec{E} \text{ and } \vec{B} = \mu \vec{H} \qquad (2)$$

Where σ the electrical conductivity [S/m], μ is the magnetic permeability [H/m].

Based on these equations FEM based programs compute the magnetic field distribution of any electrical machine. In the case of the 2D analysis the computations are performed for a transversal plane to the axes of the machine. Well-developed fault detection of any electrical machine requires a well-grounded theoretical basis. The use of simulation tools helps the researchers to emphasis the effects caused by faults in an electrical machine and to develop efficient fault detection methods. Using FEM analysis the changes in electric, magnetic and mechanic behaviour of the machine due to any fault can be easily observed without the need of opening the machine, or experimenting in laboratories. The main idea is to understand the electric, magnetic and mechanical behaviour of the machine in its healthy state and under fault conditions ,[6].

To perform the FEM analysis of the induction machine Flux2D Simulation Software was used. This program is one of the best electromagnetic field simulation software worldwide used by hundreds of engineers and designers to design and analyze electromagnetic devices.

To build any simulation model in Flux2D, only a few steps have to be done. In the first step the geometrical model has to be created, on which the boundary conditions will be set up. Next the circuit model has to be created. The program automatically generates the mesh and start to solve the problem in concordance with the solver's parameters, which can be set up by the user. The field quantities can be visualized on the surface or a specified internal cross section of the component.

The squirrel-cage induction machine in study was of 7.5 kW rated power.

After the above-mentioned steps in creating the model, the automatic generated finite element mesh had to be corrected manually near the air-gap, where the magnetic flux has the highest gradient, in order to get the most accurate results in the area. A part of the corrected mesh is given in Fig. **1.**

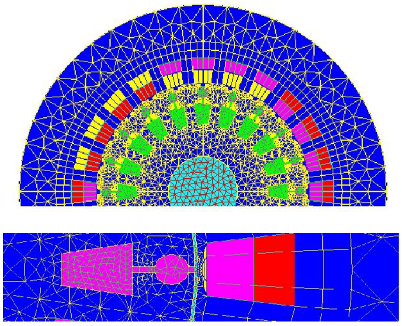


Fig.1. the solution meshes of the 2D FEM model of the induction machine.

Following a Circuit model has to be created, which permits to connect the coils to the source in order to properly simulate the voltage and current present at its terminals. In this way is possible to connect the coils to each other and to any other external circuit containing resistors, capacitors, inductors different types of current and voltage sources.

The circuit components presented in Fig.2 are as follows:

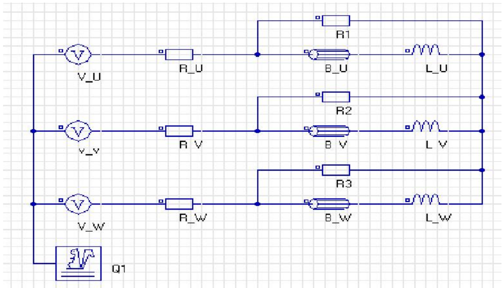


Fig.2. Circuit model of the squirrel cage induction machine.

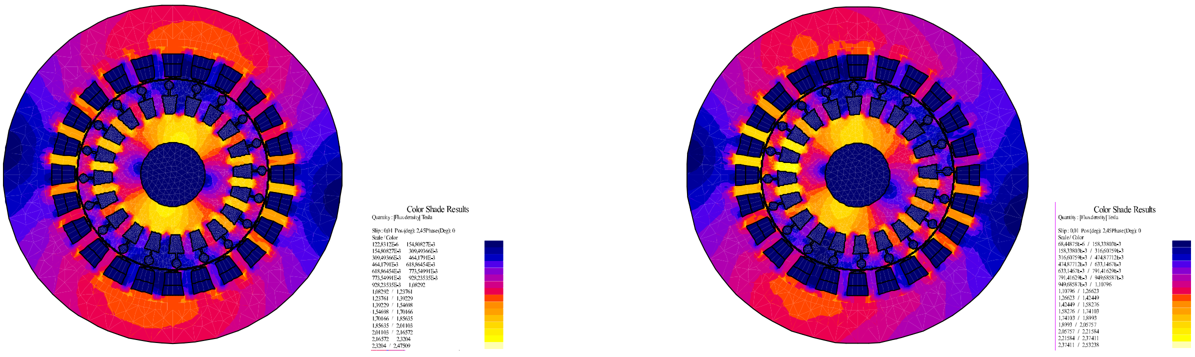
The circuit components "outside" the motor, for the applications with an imposed voltage source, Fig.2, are:

- Three voltage sources, V_U, V_V, V_W characterized by: RMS value $U_{1n} = 380$ V, frequency $f_{1n} = 50$ Hz.
- Three resistors, *R_U, R_V, R_W of 0.9 Ω* to model the voltage drop inside the power source network in the no-load motor start-up simulation and motor transient after the application of rated load. For the other magneto-dynamic and transient applications, these resistors have a very small resistance, 10^{-6} Ω.
- B_U, B_V, B_W represent the coils of the three-phase winding of the machine;
- L_U, L_V and L_W symbolize the stator end winding inductance per phase.
- a resistance of high value $R1 = R2 = R3 = 10^6$, modeling the voltmeters that measure the phase to null voltage at the stator winding terminals;
- Q1 is a macro-circuit (a feature of Flux software package) used to model the squirrel cage of the machine [7].

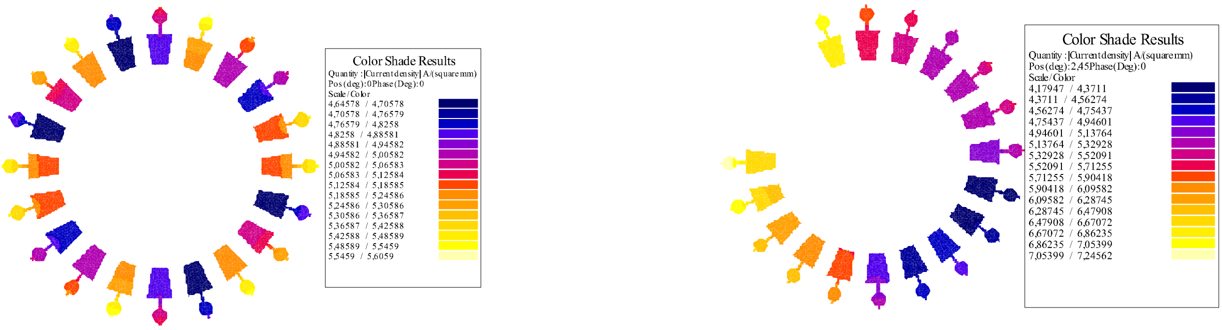
III. SIMULATION RESULTS

From the numerous results obtained using the FEM model for the healthy and for the machine having 3 broken bars only the most significant ones will be presented in Fig.3

a. Flux distribution.



b. Flux density.



c. electric current density

Fig.3. Results obtained by the FEM based model of the induction machine.

As it can be seen from Fig. 3 the broken bars has affects on the magnetic flux distribution in the machine, generating visible asymmetries. Due to the broken bars some neighboured rotor and stator teeth became saturated. The current densities in the neighboured rotor bars to those broken are significantly increased.

The table I represents the influence of the broken rotor bar on the motor efficiency. One notices the reduction in the motor efficiency and the cosφ according to broken bars number.

TABLE I. *Influence of increasing number of broken rotor bars* on *motor efficiency*

N° of broken rotor bars	M_{en} N.m	P_{2n} kW	P_{j1n} Watt	P_{j2n} Watt	cosφ	η
0	25.86	7.5	365 .1	277 .2	0.84	0.87
1	25.76	7.37	361.03	272.64	0.8403	0.85
2	25.24	7.12	357.77	263 .91	0.8292	0.846
3	24.98	6.81	348 .08	253.02	0.8014	0.843
4	23.68	6.38	332	237 .92	0.776	0.839
5	21 .94	5.89	316.73	220 .77	0.737	0.833

This degrades the steady-state torque characteristic of the induction motor progressively (Fig. 4).We have also investigated the dynamic response of induction motor with healthy and faulty rotor cage, which is important in high dynamic servo drives.

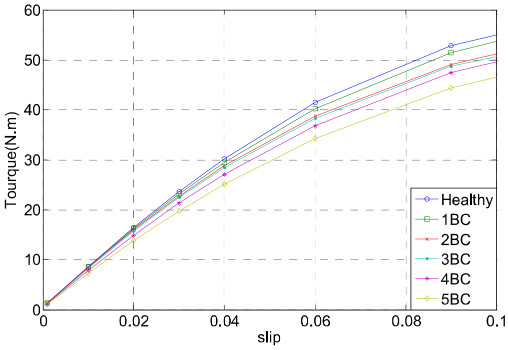


Fig.4. Influence of increasing number of broken rotor bars on induction motor performance— decreases of steady-state versus slip characteristic.

V. TRANSIENT ANALYSIS OF A FAULTY INDUCTION MOTOR

It is also possible to analyze the transient behavior of induction motor by the FEM. This is required in the control of induction motor in order to obtain the optimal time response. Meanwhile, the transient analysis of the motor is required for on-line fault diagnosis of the motor.

The fault also modifies the shape of the steady-state stator line current of the machine. It can be easily observed in Fig. 5 that in the case of the faulty machine the current is more unbalanced and it has a pronounced fluctuation, due to the backward rotating magnetic field produced due to rotor faults. This is rotating at the slip speed, $n_2 = n_1 (2s -1)$ with respect to the stator, [8].

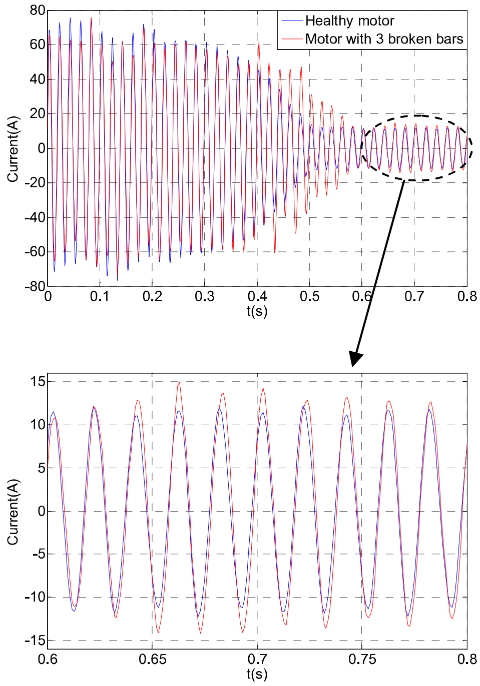


Fig.5. Phase current for healthy and faulty motor.

the magnetic torque(fig.7) ripples are also increased in case the of faulty induction machine than in case of the machine without any rotor fault.

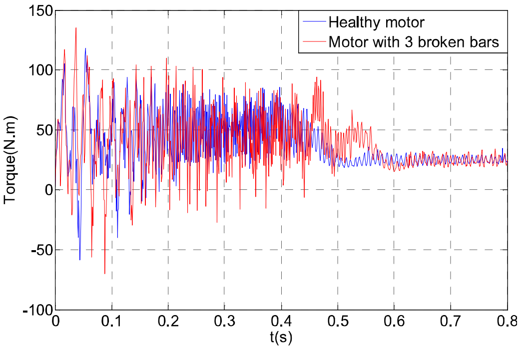


Fig.6. Time variations of electromagnetic torque.

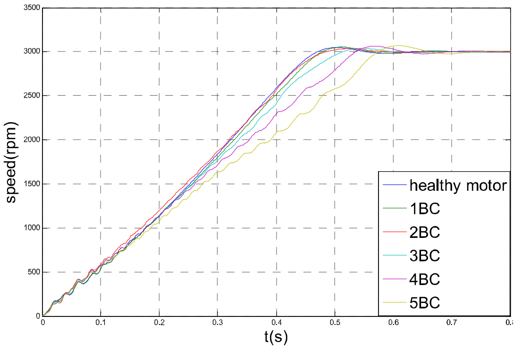


Fig.7. Time variations of speed of healthy and faulty induction motor.

The speed is less at the same load in the case of faulty rotor and it is visibly oscillating (Fig.7).

Fig. 8 shows the variations of the developed torque versus speed for healthy induction motor and motor with 3 broken bars.

A comparison of these results indicates that the rate of torque variations of the faulty motor is higher. The reason is the fault injects large harmonic components to the stator current which increase the amplitudes of the harmonic components. Therefore, the torque and speed of the faulty induction motor fluctuate and the rate of the faulty motor torque variations increases. So a higher noise and lower performance are expected from the faulty motor.

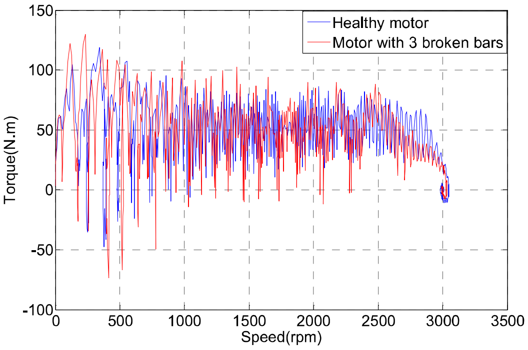


Fig. 8. Variations of torque versus speed for no-load.

It is of real interest to see what is happening in the rotor of the machine when broken bars appear. In Fig. 9 the currents through the rotor bar 4 (the next bar to those broken) are given. As it can be seen, the current in the neighbored bar of those broken is increased significantly.

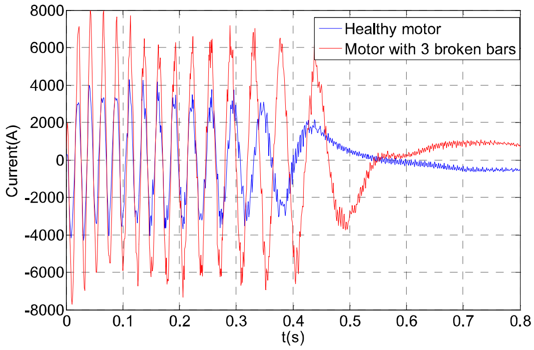


Fig.9. Current in rotor bar 4.

VI. CONCLUSION

This paper analyzed a broken-bar voltage-fed three phase squirrel-cage induction motor in magneto harmonic and transient case.

FE computation was used for diagnosis and analysis of the broken rotor bars induction motor. The method has minimum simplifying assumptions and very high accuracy compared with other fault diagnosis methods.

It has been shown that in broken bars motor the stator current characteristics and the torque are sensibility varied, the speed profiles oscillate.

The presented FEM analysis is one effective and inexpensive method for studying the influence of rotor faults on behavior of three phase squirrel-cage induction machines. The method has proved a significant applicability in the process of fault diagnosis of induction motors.

NOMENCLATURE

BC: broken bar.
P_{j1n}*: Joule losses in the stator windings,*
P_{j2n}*: Joule losses in the rotor cage.*
P_{2n} *: output power of the motor.*
M_{en} *: electromagnetic torque*
.

REFERENCES

[1] J.Faiz, B.M. Ebrahimi, Bilal Akin, H.A. Toliyat Finite-element transient analysis of induction motors under mixed eccentricity fault. *IEEE Trans Magn 2008;44(1):*66–74.

[2] J.Faiz, B.M. Ebrahimi, H.A. Toliyat ,W.S. Abu- Elhaija. Mixed-fault diagnosis in induction motors considering varying load and broken bars location. *J.Energy Conversion and Management.2010.*

[3] J.Faiz, B.M. Ebrahimi, Bilal Akin, H.A.Toliyat. Comprehensive eccentricity fault diagnosis in induction motors using finite element. Trans Magn 2009;45(3).

[4] JF.Bangura,RJ. Povinelli, NAO. Demerdash, RH.Brown: Diagnostics of eccentricities and bar/end-ring connector

breakages in poly phase induction motors through a combination of time series data mining and time-stepping coupled FE-state-space techniques industry applications. *IEEE Trans Ind Appl 2003;39(4):*1005–13.

[5] L.SZABÓ, J.B. DOBAI, and K.A. BIRÓ: FEM based transient motion analysis of induction machines having broken rotor bars, Proceedings of 2007 IEEE-TTTC International Conference on Automation, Quality and Testing, Robotics, Cluj (Romania), 2007, pp 353-358.

[6] L.SZABÓ, J.B. DOBAI, K.A. BIRÓ, F. Tóth. Fodor: study on squirrel cage faults of induction machines by means of advanced FEM based simulations.

[7] T. Tudorache, L. Melcescu and V. Petre: High Efficiency Squirrel Cage Induction Machines. International Conference on Renewable Energies and Power Quality (ICREPQ'09) ,Valencia (Spain), 15th to 17th April, 2009.

[8] L.SZABÓ,J.B.DOBAI,K.Á.BIRÓ,:Virtual Instruments for detecting rotor faults in induction motors, Advances in Electrical and Electronic Engineering, no. 2, vol. 3 (2004), Žilina (Slovakia), pp. 119-122.