# FEM BASED TRANSIENT MOTION ANALYSIS OF INDUCTION MACHINES HAVING BROKEN ROTOR BARS

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## ABSTRACT

Rotating electrical machines play an important role in the world's industry. Hence there is a strong demand on their reliable and safe operation. Their faults and failures can lead to excessive downtimes and generate enormous costs due to reduced output, emergency maintenance and lost revenues. 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. In the FEM model the rotor fault was imposed by modifying the circuit model by connecting in series with the rotor bars considered broken a resistance of a great value.

## 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 [1]. In this paper some of the results of the FEM analysis of the squirrel-cage induction machine will be presented both in the case of healthy condition and when the machine has broken rotor bars.

## FEM MODEL OF THE INDUCTION MACHINE

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) analysis have been developed [2]. This method it is based on Maxwell's equations for magnetic and electric field [3]:

$$\nabla \times \overline{H} = \overline{J} \text{ and } \nabla \times \overline{E} = -\frac{d\overline{B}}{dt} \tag{1}$$

where $\overline{H}$ is the magnetic field strength [A/m], $\overline{E}$ is the electric field strength [V/m], $\overline{J}$ is the electric current density [A/m$^2$], $\overline{B}$ is the magnetic flux density [T].

Moreover the electric and magnetic filed quantities are related with the material properties expressed by the following relations:

$$\overline{J} = \sigma \cdot \overline{E} \text{ and } \overline{B} = \mu \cdot \overline{H} \tag{2}$$

where $\sigma$ is the electrical conductivity [S/m], $\mu$ 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 behavior of the machine due to any fault can be easily observed without the need of destroying a machine, or experimenting in laboratories machines with different fault types. The main idea was to understand the electric, magnetic and mechanical behavior of the machine in the healthy state and under fault condition.

To perform the FEM analysis of the induction machine Infolyitica's MagNet 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. MagNet is running under Microsoft Windows operation system and it is very easy to use due to its friendly interface.

As is mentioned in [4], to reduce computational time usually the electrical machine models are created on the smallest symmetrical part of the machine, in order to reduce de geometrical complexity and the number of finite element mesh nodes. These simplifications cannot be done in study of asymmetrical magnetic fields caused by machines faults, due to the fact that Neumann and Dirichlet boundary conditions are not matching pole-pair divisions as in the case of symmetrical magnetic excitations. In conclusion to obtain a correct result on changes in magnetic field distribution caused by rotor fault of induction machine, the calculation must be performed over the whole cross section of the machine.

To build any simulation model in MagNet, 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. There are three possibilities to visualize the magnetic flux distribution: using *Contour, Colored* or *Arrow Plots.*

The squirrel-cage induction machine in study was of 1.5 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.

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 model of the squirrel-cage induction machine in study contains two main parts: the three stator windings connected to three ac sinusoidal Y-connected voltage source (fig. 2.a) and the parallel connected rotor bars. Between both ends of two neighbored rotor coils modeling the rotor bars a series resistor-inductor assembly is connected. These are modeling the parts of the end rings short-circuiting two consecutive rotor bars (fig. 2.b).

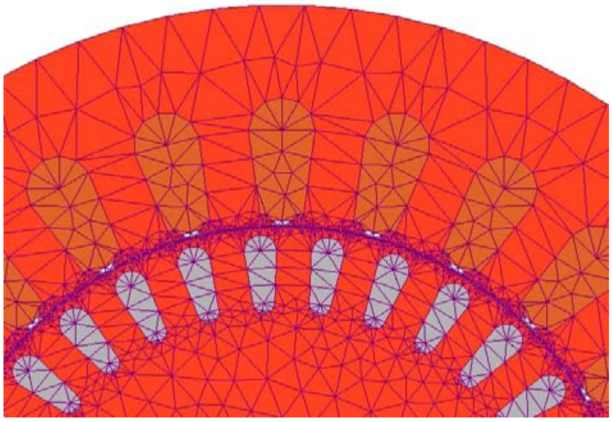
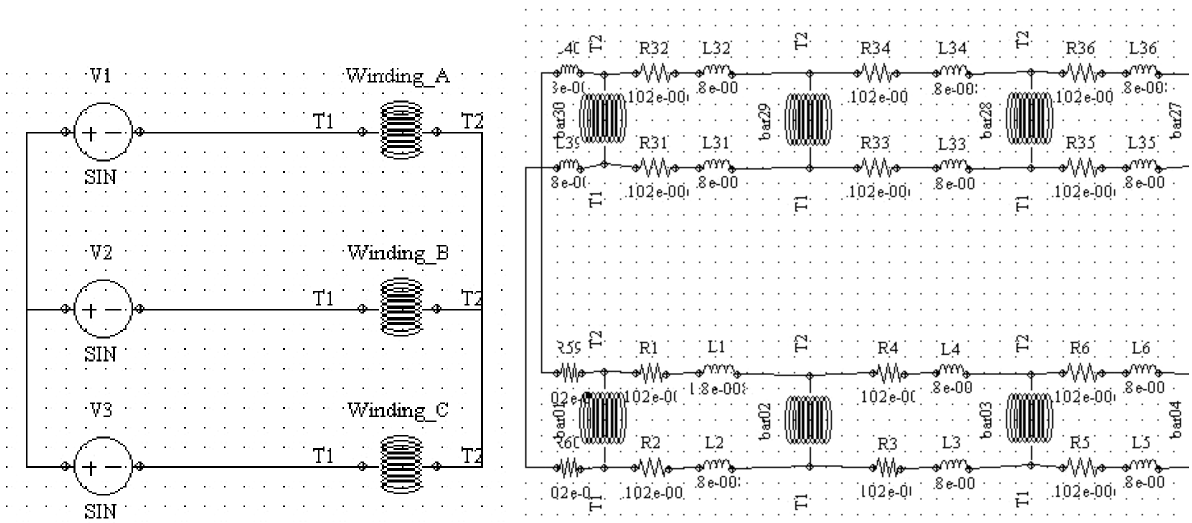


**Fig. 1.**
A part of the finite element mesh

In order to generate a rotor fault in the model of the induction machine the circuit model has to be modified by connecting in series with the solid rotor coil a resistance. Its value is 100 times the dc resistance of the whole bar [5].

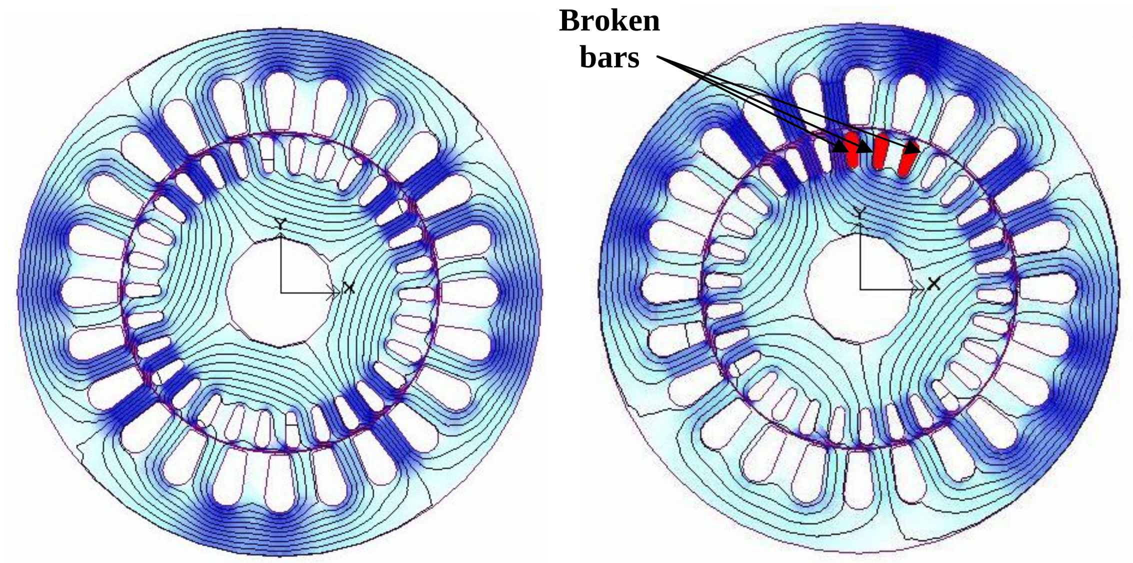



a) b)

**Fig. 2.**
Circuit model of the stator windings (a) and of the rotor cage (b)

## SIMULATION RESULTS

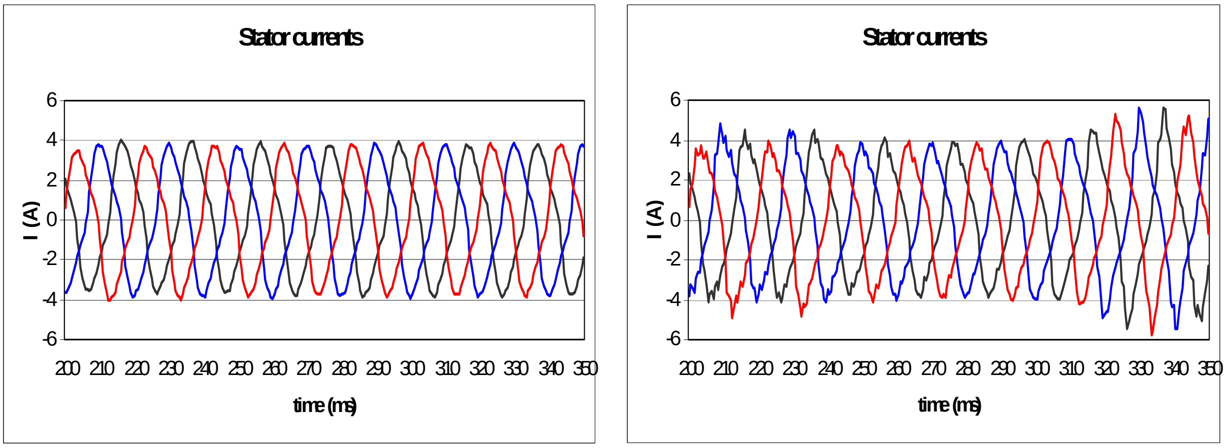
To perform the FEM based numerical field analysis of the machine in study the *Transient with motion* solver was selected. The simulation time was set up to 350 ms, and the step time to 0.5 ms. 50% of rated load was applied. First the healthy machine was simulated. Next the machine having 3 broken rotor bars was studied. The faults were simulated by the above mentioned modifications done in the circuit model.




a) b)

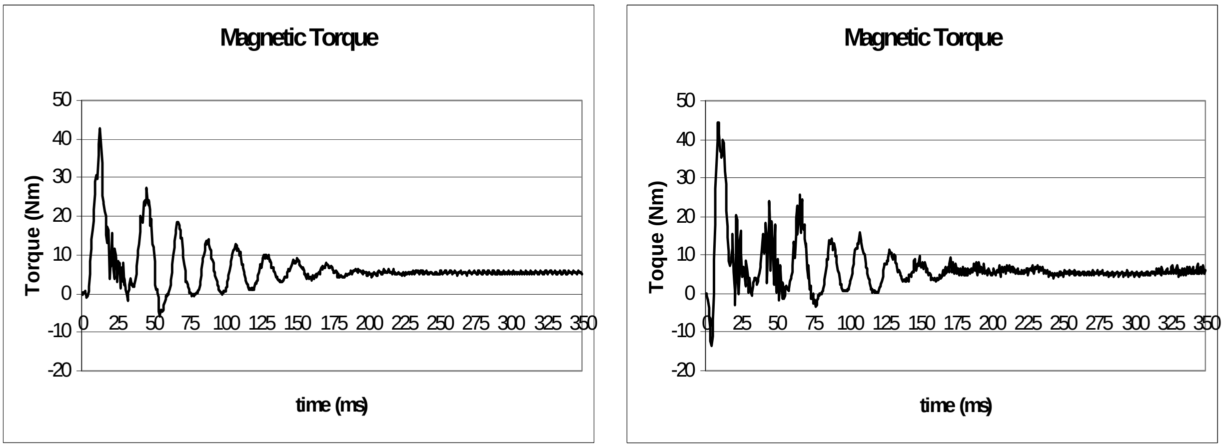
**Fig. 4.**
Magnetic flux plots in case the healthy motor (a) and that having 3 broken bars (b)

The magnetic field distribution is symmetrical in case of the healthy squirrel-cage induction machine (Fig. 4.a). When the rotor faults occur the magnetic field becomes asymmetrical due to the lack of currents in the broken bars. This leads to local saturation of the rotor and the stator core near the broken bars (Fig. 4.b). 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 [7]. The magnetic torque ripples are also increased in case the of faulty induction machine than in case of the machine without any rotor fault. Fig. 7 shows rotor currents for the case of no fault and three broken bars. One can easily notice that in the case of the machine having broken rotor bars the current has the highest value in the bars next to the broken ones. Hence it can be expected that the fault will soon propagate to these overloaded bars [8].



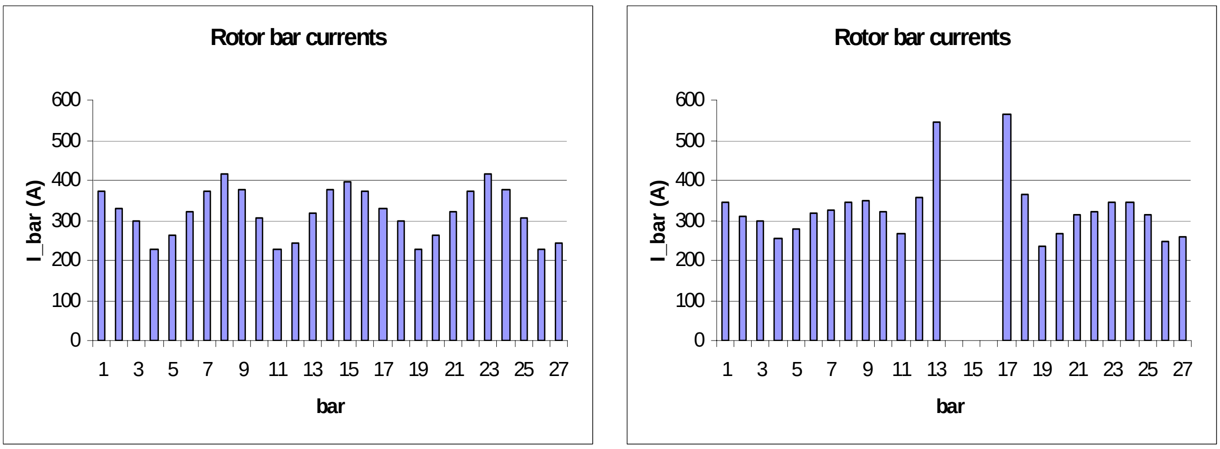

a) b)

**Fig. 5**.
Steady-state stator currents of the healthy machine (a)
and of the machine with broken rotor bars (b)




a) b)

**Fig 6.**
Magnetic torque of the healthy machine (a)
and of that having 3 broken rotor bars (b)




a) b)

**Fig 7**.
Rotor bar currents in the healthy machine (a)
and in the machine with broken rotor bars (b)

## CONCLUSUSION

Finite element method was used to determine the magnetic field distribution both in healthy induction machine and the machine having three broken rotor bars. 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.

This method also allows studying the effect of rotor faults on stator line currents, applicable on developing effective fault diagnostic tools. Once again it has been proved that the bars next to broken ones are the most exposed to future damage, due to the very high value bar currents.

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