Asynchronous starting of synchronous motor with rotor faults using FEM

Joya Kappatou
University of Patras

ISEF 2011 - XV International Symposium on Electromagnetic Fields
in Mechatronics, Electrical and Electronic Engineering
Funchal, Madeira, September 1-3, 2011

ASYNCHRONOUS STARTING OF SYNCHRONOUS MOTOR WITH ROTOR FAULTS USING FEM

Konstantinos Ioannou and Joya Kappatou

University of Patras, Department of Electrical and Computer Engineering,
26500 Rion, Patras, Greece
E-mail: joya@ece.upatras.gr

Abstract ***– In this paper the numerical modeling of a large salient pole synchronous machine operating as a motor during asynchronous acceleration under healthy and faulty operation using time-stepping FEM is presented. Two rotor faults are simulated, broken bar and broken short circuit ring connector and the corresponding characteristics of the machine are calculated and compared to the ones of the healthy case.***

Introduction

During the periods of water pumping, a Synchronous salient pole machine operates as a motor and asynchronous starting is used in order to start the motor. Rotor faults are extremely rare in Synchronous pumped storage hydro generators, but can occur after many years of service and stringent starting cycles applying full voltage [1]. Though several contributions can be found in the literature regarding asynchronous starting of salient pole synchronous machines [2-5], there are quite few references concerning cage faults of salient pole synchronous machines [1]. In the present work our purpose is to get a deeper understanding of the behavior of the salient- poles synchronous motor during asynchronous acceleration and to study the effects of the cage faults on the characteristics of the motor. A synchronous machine with laminated poles equipped with damper windings in the rotor was simulated and three different conditions were studied, using 2-d time-stepping Finite Element analysis: with a healthy rotor, with one broken rotor bar and with a broken segment of the short-circuit ring.

The 2-d Finite Element Model

At starting the machine was lightly loaded and was supplied with nominal voltage, while the field circuit was short-circuited. In real conditions, a field discharger resistor is used to limit the field current and to reduce the oscillatory torque. When the motor reaches near synchronous speed, the excitation voltage is applied and the motor pulls into synchronism at 500 rpm. The 3-phase voltage supply of stator phases is connected to the circuits in the 2-d Finite Element Model via series of external resistances and inductances. Each circuit of the rotor is composed of two adjacent bars and the two short circuit ring connectors form an external short-circuited circuit. To simulate the broken bar, the resistance of one bar was given a value of 10^9 ohm and the same value was given to the resistance of one connector to the corresponding external circuit to simulate the fault of the s/c ring. The position of the fault on the slip ring is situated between two poles. The simulation of the faulty machine was performed using the entire cross-section of the machine. Due to the time consuming simulation of the entire startup, linear B-H curves of the ferromagnetic materials were used. The nominal data of the machine are: S_N= 200 MVA, U_N= 13 kV, I_N= 8882.3 A, f=50 Hz, p=6. The Stator winding has three parallel circuits. In Fig. 1 the cross-section of one pole and the yoke of the machine are presented.

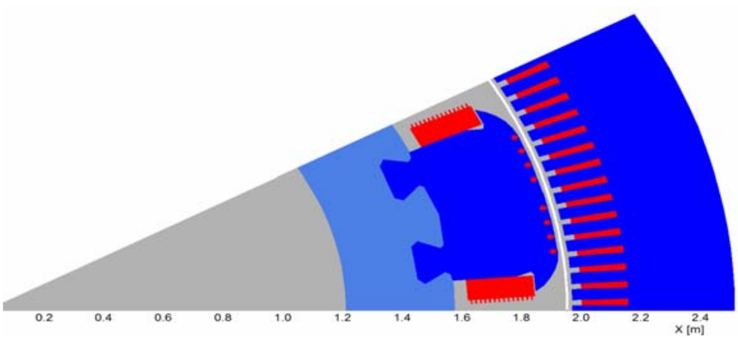

Fig. 1. Cross-section of one pole and the yoke of the machine

Simulation results

1. Healthy machine

Fig. 2 is the graphic representation of the flux lines during starting. As can be seen in Fig. 2, the armarure reaction causes the flux density to rise towards the leading edge of the pole. At steady state, the lines of the field are more evenly distributed. The above can be better obderved in Fig.3, where the distribution of the radial component of the air-gap flux density is shown for both cases, during starting and at steady state.
The characteristic of a phase current in one parallel section of the stator winding, is given in Fig. 4.

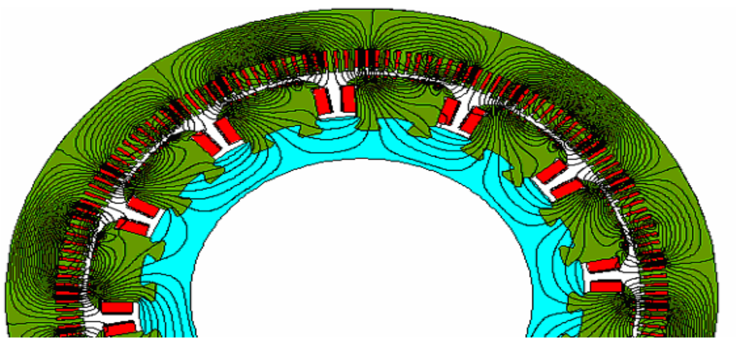

Fig. 2 Flux lines during asynchronous starting.

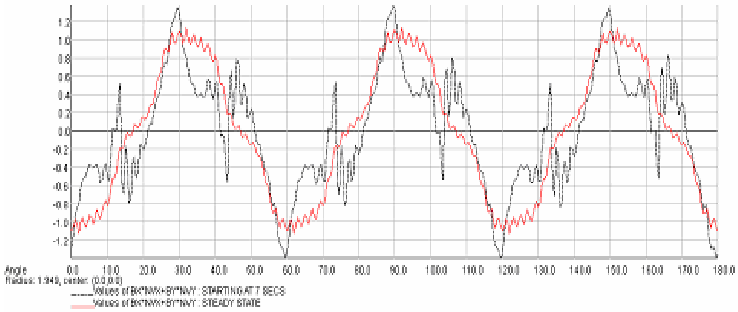

Fig. 3. Distribution of the radial air-gap flux density (in T) at: a) steady state, red line and b) acceleration, black line.

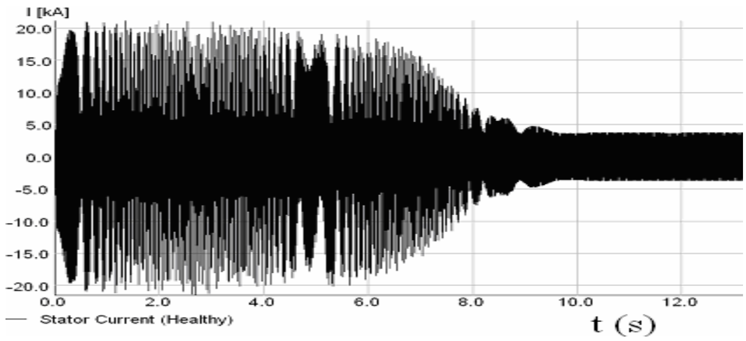

Fig. 4. Waveform of one parallel branch of the stator current

In Fig. 5 the waveforms of the electromagnetic torque and the speed of the rotor for the healthy case are depicted. Since the machine was lightly loaded, low torque is produced during steady state. At near half speed, at almost t=5 seconds, there is a dip in the speed characteristic, which is the result of the reduction of the average torque and is referred to as the Goerges effect. This sudden change of the electromagnetic torque is due to electrical and magnetic asymmetry and depends on the machine data [6]. The Goerges phenomenon is actually the operation of a 3-phase wound-rotor induction motor at half synchronous speed when the rotor circuit is unbalanced. As the synchronous motor is starting asynchronously, the asynchronous torque produced develops a sudden change near 50% of the synchronous speed. This is the consequence of a sudden change in the waveforms of the currents of the machine, as can be seen in Figs. 4, 6 and 7, where the stator current, a bar current and the field current are presented respectively.

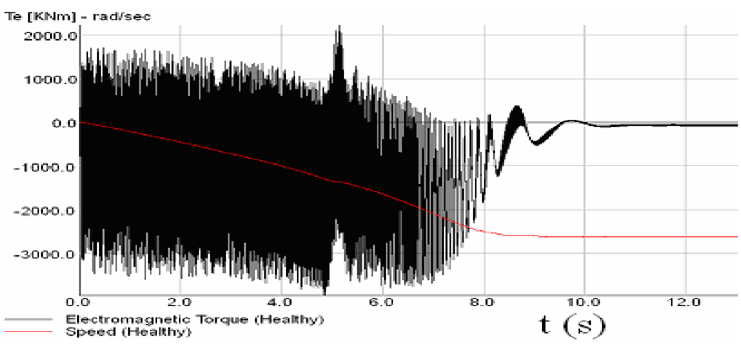

Fig. 5. Waveforms of the electromagnetic torque and the speed

In Fig. 6 the waveform of a damper bar current is depicted. The amplitude of the damper bars' currents reaches high values during asynchronous starting, as expected. A closer look shows that there is some current flow in the bar at the steady state of the synchronous motor, due to the air-gap asymmetry caused by the saliency.

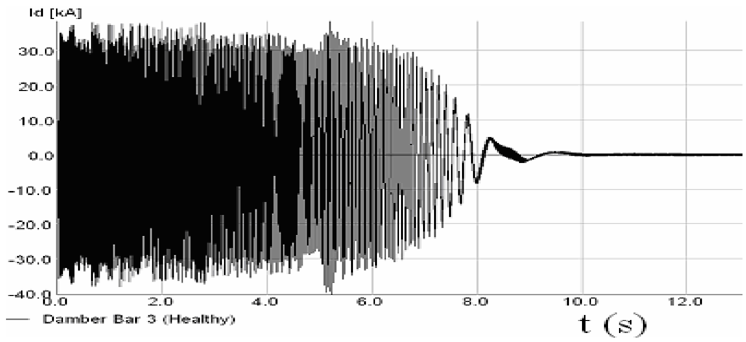

Fig. 6. Waveform of a damper bar current

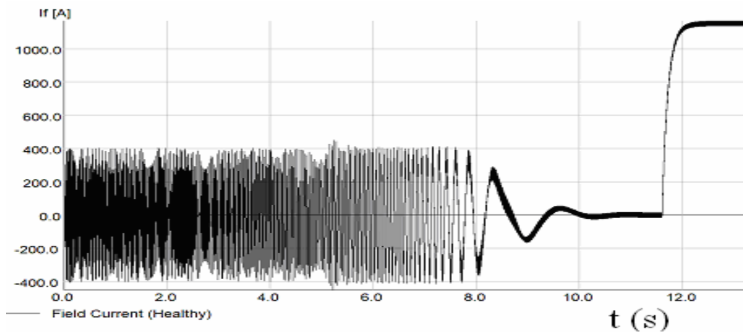

Fig. 7. Waveform of the field current

In Fig. 8 the distribution of the current density in the bars at a certain time during starting is depicted. This distribution is unequal and it depends on the time.

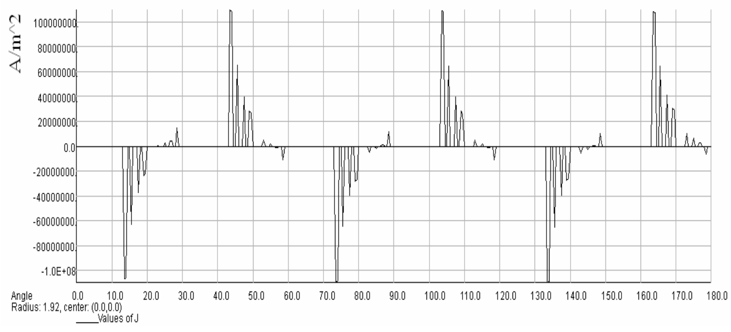

Fig. 8. Distribution of the current density in the damper bars at acceleration.

2. Faulty machine

Two different conditions were simulated, using 2-d time-stepping Finite Element analysis: with one broken rotor bar and with a broken segment of the short-circuit ring.
Some waveforms from these simulation results have been chosen to be presented. In Fig. 9 the waveforms of the rotor speed during starting for the healthy and the two faulty cases, are presented.

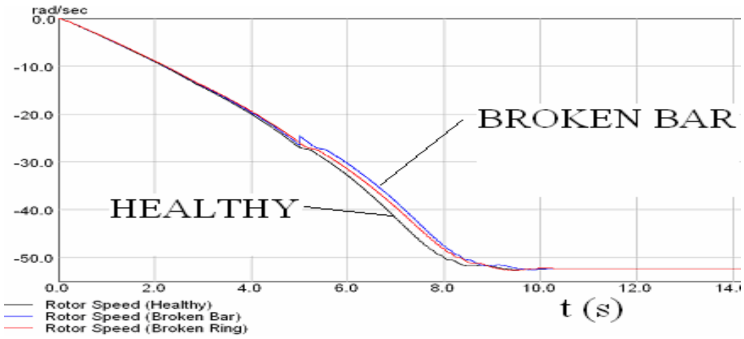

Fig. 9. Waveform of the speed during starting for the three models: black line for the healthy, blue line for the broken bar and red line for the broken sector case.

From the simulation results arises that the Gorge effect is more intense and the motor needs more time to pull into synchronism under faulty conditions compared to the healthy case. This is expected, because the asymmetry of the rotor is greater in the faulty machines.

The distribution along the periphery of the rotor of the current density in the bars is presented in Fig. 10 for the broken bar case. The assymetry of the current distribution is evident. Specifically, the bars next to the broken are charged with greater currents during start-up. This can be observed clearly in Fig. 11 and Fig. 12, where the waveform of the current of the same bar neighboring to the broken is depicted for both cases, healthy and broken bar. This extra charge of the neighboring bars makes them more vulnerable and expected to break next.

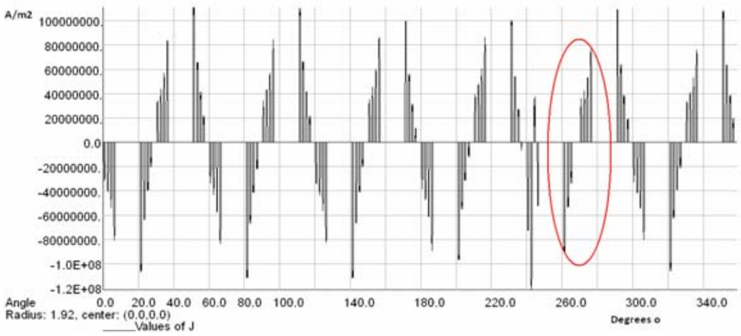

Fig. 10. Distribution of the current density in the damper bars at acceleration.

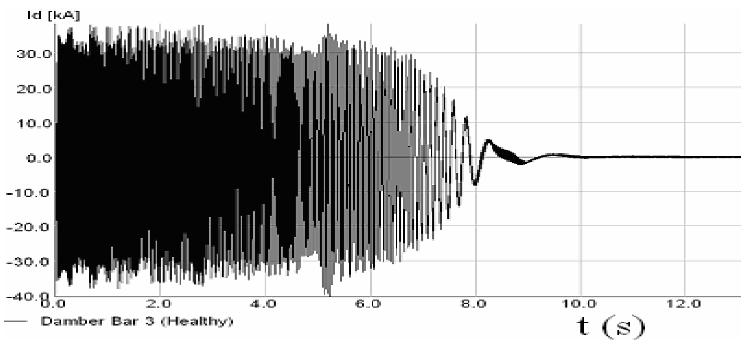

Fig. 11. Healthy machine. Waveform of the current of a specific rotor bar.

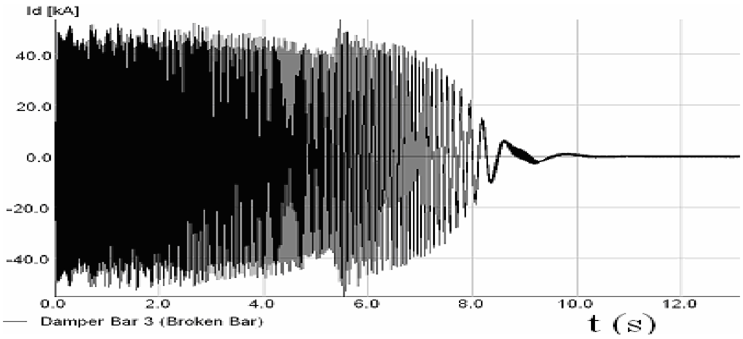

Fig. 12. Broken bar case. Waveform of the current of the rotor bar neighboring to the broken one, same bar as in Fig. 11.

Conclusions

A large salient pole synchronous machine operating as a motor during asynchronous acceleration, under healthy and faulty rotor operation using time-stepping FEM was simulated and studied.
A sudden change, near half synchronous speed, of the values of currents, torque and speed of the machine were observed, the Goerges effect, which is more intense in the cases of broken rotor bar or broken short-circuit ring connector. The broken bar or broken short-circuit ring connector causes lengthening of the acceleration time of the synchronous motor. The breaking of a bar causes disturbances in the electromagnetic characteristics of the machine and makes the neighboring bars more vulnerable and expected to break next.

References

[1] H. C. Karmaker, Broken Damper Bar Detection Studies Using Flux Probe Measurements and Time – Stepping Finite Element Analysis for Salient –Pole Synchronous Machines, Symposium on Diagnostics for Electric Machines, Power Electronics and Drives (SDEMPED 2003), Atlanta, USA, August 2003.

[2] Jaime de la Ree Lopez, Howard B. Hamilton, Torque Oscillations of Synchronous Motors Under Starting Conditions, IEEE Trans. On Industry Applications, Vol. IA-23, No. 3, pp 512-519, May-June 1987.

[3] Z. Maljkovic, M. Sundrica, B. Tomicic, Asynchronous Starting Process of Hydro-Generator, Proceedings of the International Conference on Electrical Machines (ICEM 2008), Vilamoura, Portugal, 2008.

[4] J. O. Ojo, V. Ostovic, T.A. Lipo, J.C. White, Measurement and computation of starting torque pulsations of salient pole synchronous motors, IEEE Trans. on Energy Conversion, Vol. 5, No 1, pp 176-182, March 1990.

[5] Fritz Neumayer, Erwin Schlemmer and Franz Ramsauer, “Finite Element Analysis of the Starting Behaviour of Large Salient Pole Machines”, Proc. International Symposium on Power Electronics, Electrical Drives, Automation and Motion, SPEEDAM 2006, 23-26 May 2006, Taormina, Italy.

[6] J. C. Das and J. Casey, “Characteristics and analysis of starting of large synchronous motors,” Proc. 1999 IEEE Industrial and Commercial Power Systems, 2-6 May 1999.