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Overview of Different Approaches in a Multiphysics Modelling of Induction Motor

Hacene Mellah

Department of Electrical Engineering, Faculty of Technologie University Ferhat Abbas Setif-1-, Cité Maabouda, Route de Béjaia / 19000 / Algérie.

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ABSTRACT

In this paper we interest to how we can make a multiphysics model of IM, the FEM currently represents the state-of-the-art in the numerical magnetic field computation relating to electrical machines. FEM is a numerical method to solve the partial differential equations that expresses the physical quantities of interest, in this case thermal transfer and Maxwell's equations. This approach is possible by using special simulation package frequently exploited bout in university and industry. A simple description of each one of this famous software is presented. In this moment, with the complicity of the problem, we made a decoupling between the thermal phenomena, electromagnetic and mechanics phenomena, in the first time we considers only the transient thermal and the other phenomena are in steady state, on the other hand in the second times the thermal behavior is ignored. FEM analysis is used for study state and transient mode, thermal transient, magnetic field calculation, the magnetic flux density and vector potential of machine is obtained. In this model we including, non linear material characteristics, eddy current effect, torque-speed characteristics, and magnetic analysis are investigated. Finally some simulation results of induction motor modeled by Motor-CAD and Maxwell software are given and commented.

Introduction

The design of electrical machines involves several fields of physics, such as electromagnetism, thermics, mechanics but also acoustics [1, 2], in the past, the thermal analysis of electric machines has received less attention than electromagnetic analysis. This is clear from the number of technical papers published relating to each of these particular subjects [3], but now the designer has therefore to predict the machine behavior in terms of electromagnetism, thermics, mechanics and acoustics [1].

For a multiphysics modeling of electrical machines there are three approaches [2]: the first is the analytical approaches: based on the analytical solution or equivalent circuit, quick and easy but the lowest in terms of accuracy [1, 2].

The second one is semi-analytical approaches: based on the nodal modeling or permeances network, the principle of nodal modeling method is to simplify the study of a system equivalent circuit. The most common formulation is one in which Kirchhoff's current law is used to establish a system of nodal equations [4], the second method based on a decomposition of the magnetic field of the machine into elements. permeances network less accurate and needs offline FEM results to evaluate the unknown air-gap permeances [5]. The last one represents the state-of-the-art in the numerical magnetic field computation relating to electrical machines, FEM 2D or 3D is a numerical method to solve the partial differential equations (PDE) that expresses the physical quantities of interest. Give a more accurate result compared to analytical modeling, which can be regarded as a simplification of the PDE [6].

The multiphysics model must respect certain criteria in its use and its execution speed. We then seek to obtain a good compromise between speed, precision and malleability [2].

This paper describes how we can make an induction motor multiphysics model of a computer-aided design (CAD); the specialised literature gives us several approaches by specialized engineering software, in the first section the different famous software used for multiphysics model of induction motor are presented and briefly explained. In the section II a thermal model of induction motor is created, solved and some results are given and commented for several duty types such as continuous duty (S1), intermittent periodic duty-type without starting (S3) and the two version of intermittent periodic duty with starting (S4) fast and slow. In section III an electromagnetic model of induction motor is given, solved, some simulation results are illustrate and commented.

Software Used for Multiphysics Model of Induction Motor

According to the literature we can distinguished many types:

ANSYS Software [7]

ANSYS electromagnetic solutions enable users to leverage best-in-class software technology to predict the behavior of high-performance electrical and electromechanical devices, ANSYS electromagnetic solutions allow the user to gain an understanding of:

- Device performance characteristics under applied loads/ excitations and boundary conditions.
- Visualization of the electromagnetic field in and around a device.
- Joule heating effects and resultant temperatures
- Force distribution and resulting deformation.

Tele:
E-mail addresses: has.mel@gmail.com

• Key design parameters: torque, force, resistance, inductance, capacitance, impedance, S parameters and radiated fields/emissions.

This software is very good and does not need any other software, but is a very expensive and it is not available in our university.

Flux2D & Flux/Portunus Co-Simulation

Flux 2d is largely used by the researchers [8], recently with version 10.3 of Flux; it is now possible to export finite element models into a system environment that will perform co-simulation. Co-simulation works for both 2D and 3D applications within Flux 10.3 and there is virtually no limit to the parameters that can be shared between the two programs. Because Portunus is multi-domain system simulation software, modeling within the same simulation sheet a complete mechatronic system is made easy [9-10].

Thus, co-simulation between Flux and Portunus means that the designer is now able to combine all these modeling approaches with finite element models [9-10]. But this software is a commercial product and it isn't available in our university.

Motor-CAD has been developed to give the motor designer a fast method of analyzing design changes. In doing so, not only can the optimum design solution quickly be identified, but the user fully understands the consequences of such changes. Motor-CAD has been written such that the user need not be an expert in heat transfer [11]:

- All the difficult heat transfer parameters are calculated automatically by Motor-CAD.

Motor-CAD is advanced tools to analyze results, Motor-CAD has extensive options to help the user visualize and compare results [12]:

– Schematic diagram to identify the main heat transfer and identify constraint to cooling.

– Node temperatures plot to quickly view the distribution of temperatures over the cross-section.

– Transient temperature graphs to see the effect of duty cycle loads on the heating and cooling rates of different components in the construction.

– Sensitivity analysis to help identify the main constraints to cooling and for studying the effects of manufacturing options and tolerances on the cooling performance.

– Output data table of values to carry out advanced analysis Data can easily be exported to Excel or Matlab for later processing.

– Transient difference graph to highlights the degree to which the design changes effect the thermal performance

This software is developed at the department of Electronics and Electrical Engineering, University of Glasgow, where the losses and geometry data can be passed from SPEED to Motor-CAD and temperatures and geometry back [11-12].

This product is good in thermal modeling if we one does not take into account the effect of speed and electrical behaviors, in this context is largely used in literature [13-15], but to have results of close simulation to reality, it is necessary to take them into account by a Co-simulation with SpeedLab, this last is such a commercial product and is not available to our university.

Motor-CAD Co-simulation with SpeedLab

Maxwell Co-Simulation with Ephysics

The ePhysics is an interactive software package for analyzing thermal and structural deformation and stress, using ePhysics, you can compute the following [16]:

• Temperature and heat flow vector distributions.

• Average temperature, hot spot temperature, and cold spot temperature.

• Displacement, von Mises stress, principal stresses, and traction.

• RMS measure of stress, maximum von Mises stress, and maximum principal stress.

Thermal modeling of IM

The circuit, shown in Fig. 1, is a three-dimensional representation of the main heat transfer paths within an induction rotor. Thermal resistances for the conduction heat transfer paths are calculated from the dimensions and thermal conductivity of each component. Radiation is calculated using emissivity and view factor coefficients and component surface area. Convection thermal resistances (natural and forced) are calculated using proven empirical correlations, which are based on dimensional analysis [14].

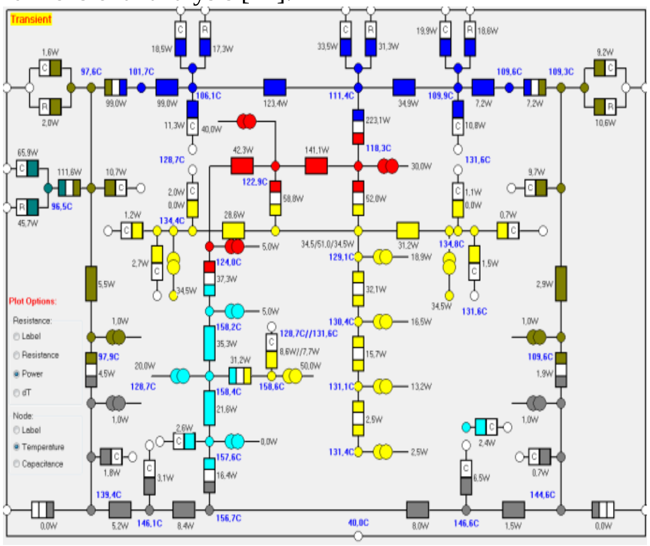

Fig. 1. Thermal network model of IM used in MOTOR-CAD

Duty type S1 (Continuous duty)

Duty type S1 (Continuous duty): characterized that the motor operation at a constant load maintained for sufficient time to allow the machine to reach thermal equilibrium [17-18].

In our application the necessary time for reach the steady state temperature is 25000s and the maximum temperature is 158.6c in rotor copper as shown in the figure.2 and the following tables.

We can see clearly that the rotor temperature is higher than the stator temperature; also we can say that the temperature of end winding is the most important winding temperatures (fig. 2).

Table 1. Temperature of some machine parts in steady state

Some Machine Parts	Temperature C^0
Ambient	40
Stator Lam (tooth)	122,9
Stator Lam (back iron)	118,3
Stator Surface	124
Rotor Surface	158,2
Rotor Tooth	158,4
Rotor Lamination	157,6
Rotor Copper	158,6
Shaft Center	156,7
Shaft front	139,4
Winding Average	131,5
Active Winding Average	130,2
End Winding Average	132,4
EWdg (R)	134,8

Table 2. Power loss of some parts of the machine in steady state

Some Machine Parts	Losses Watts
Stator Copper	120
Stator Tooth	40
Stator Back Iron	30
Rotor Coper	50
Rotor Tooth	20
Rotor Back Iron	0
Windage	10
Friction- R Bering	2
Friction- F Bering	2
Copper Layer = 1	44,39
Copper Layer = 2	38,76
Copper Layer = 3	31,01
Copper Layer = 4	5,838
Airgape Banding	0
Total	274

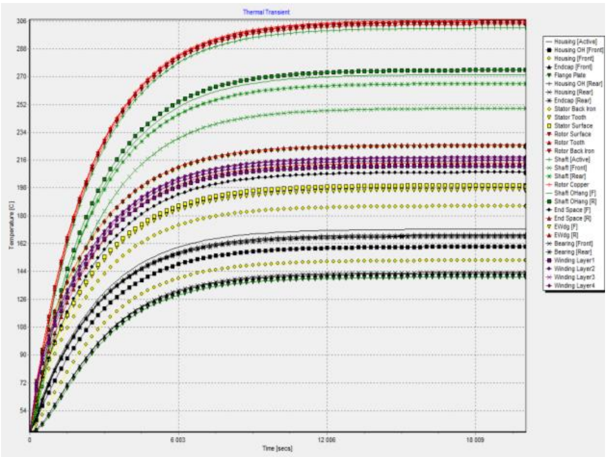

Fig. 2. Temperature of several party of IM operation with duty type S1 obtained by MOTOR-CAD.

3.2. S3 Intermittent periodic duty without starting

Operation as shown in Figure 3 which is composed of a sequence of similar duty cycles with cycle duration *tp* at constant load and an interval which is generally so short that thermal equilibrium is not reached and the starting current does not noticeably affect heating. This is the case when tp ≤ 3T (thermal time constant) [17-19].

This operation mode can be identification: by specification of the load period *tp*, cycle duration Te and power *P*, but also by the relative duty cycle *tr* in % rite like this:

$$tr\% = tp/Te*100 \qquad (1)$$

For our application Δ*tp* =2150s, Δ*tv*=2000*s and Te=4150s so tr*%=51.8%.

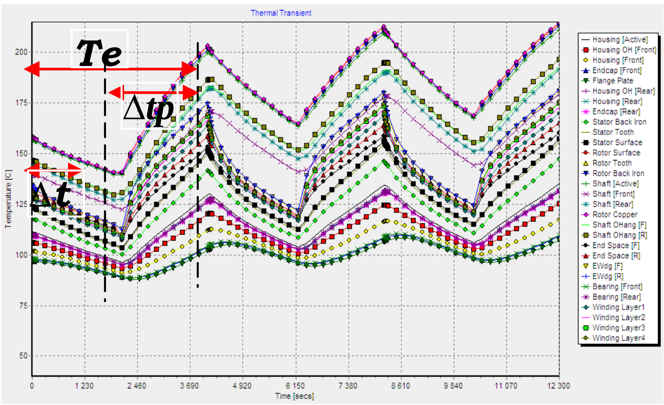

Fig. 3. Temperature of several party of IM operation with duty type S3 obtained by MOTOR-CAD

Continuous-operation periodic duty cycles:

The goals of these simulations are to see the effect of Δtp time of application load and Δtv non load (cooling) in the machine thermal state.

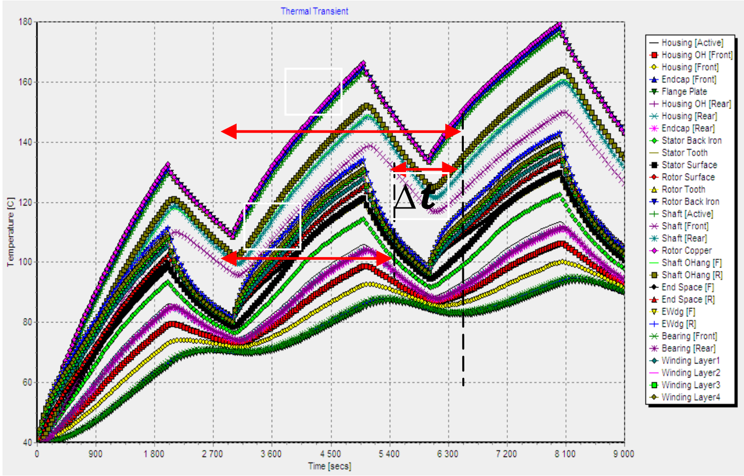

Fig. 4. Temperature of several party of IM operation with a fast continuous-operation periodic duty cycles obtained by MOTOR-CAD

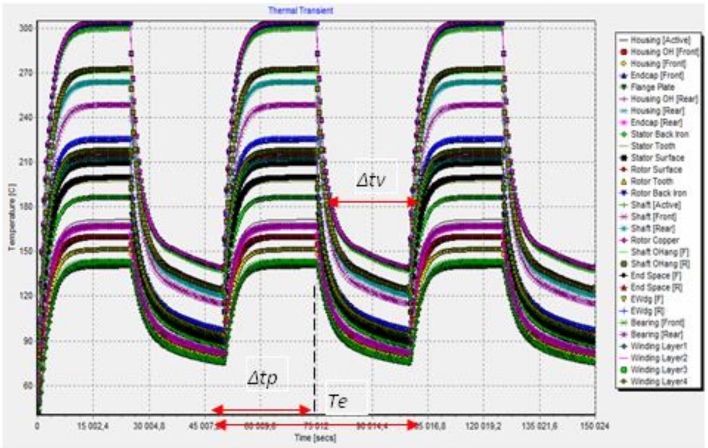

Fig. 5. Temperature of several party of IM operation with a slow continuous-operation periodic duty cycles obtained by MOTOR-CAD

Fig. 4. Show the temperature of several party of IM operation with a fast continuous-operation periodic duty cycles, in this case the operation mode is characterised by: Δtp =2000, Δtv=1000s, Te=3000s, tr= 33%, the ambient temperature is $40C^0$. A slow continuous-operation periodic duty cycles is showed in Fig. 5, this operation mode characterized by Δtp =Δtv=25000s, *tr* =50%.

By comparison between the tow same operation mode fast and slow, the duration time of the first one is 1/10 than the second one and the temperature reach not the thermal equilibrium but in the slow operation reach it.

We can see also the IM in the slow operation mode is naturally itself cooled at Δtv (25000s), but in the first mode the Δtv is small (1000s) so the IM can't cool naturally.

FEM of IM

The operation principle of electric machines is based on the interaction between the magnetic fields and the currents flowing in the windings of the machine.

Rotational Machine Expert (RMxprt) is an interactive software package used for designing and analyzing electrical machines, is a module of Ansoft Maxwell 12.1 20]. The structure of coil connection is shown in Fig. 7, Fig. 6

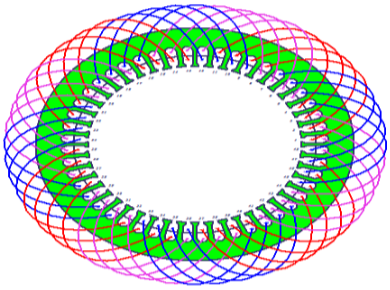

Fig.6. Stator and coil structure of the designed generator

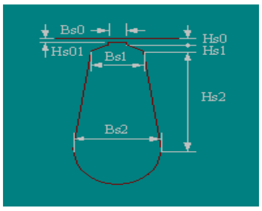

Fig 7. Slot type

The FEA model of electromagnetic field is built by Maxwe1l2D, This simulation is obtained by IBM ThinkPad pc (Core2 Duo CPU, 1.8 GHZ, 2 CPU, 3G RAM), and the simulation time is take some hours. Our model of IM used in Maxwell environment has 6038 triangles.

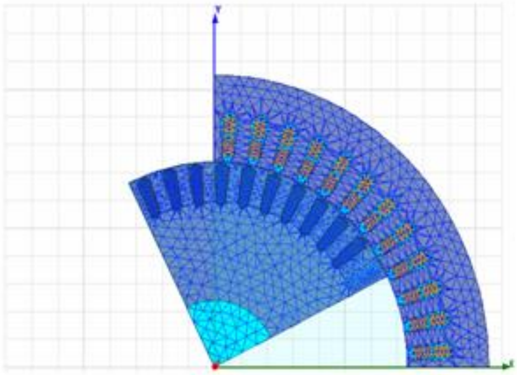

Fig. 8. Mesh of IM

Transient results

The IM stator current winding is shown in Fig. 9, the maximum transient magnitude is almost 230A, but in steady stat decrease to 25A and the frequency is 50Hz.

The speed variation of IM is showed in Fig 10 where the duration of the transient mode is 0.2s and study state mode occupies the remainder of the simulation time at the value of 1455rpm

Table 3. Some Rated Values, Geometric Parameters of the Designed Machines

Somme Electrical And Dimensional Parameters	Value
Rated output power (kW)	7.5
Rated voltage (V)	380
Given rated speed (rpm)	1450
Number of poles	4
Outer diameter of stator (mm)	210
Inner diameter of stator (mm)	148
Number of stator slots	48
Outer diameter of rotor (mm)	147.3
Inner diameter of rotor (mm)	48
Number of rotor slots	44
Length of stator core (rotor) (mm)	250
Stacking factor of stator core	0.92
Stacking factor of iron core	0.92
Frictional loss (W)	12
Operating temperature (0C)	75

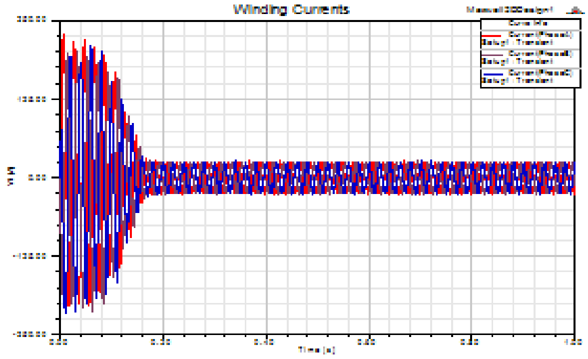

Fig. 9. IM stator current winding

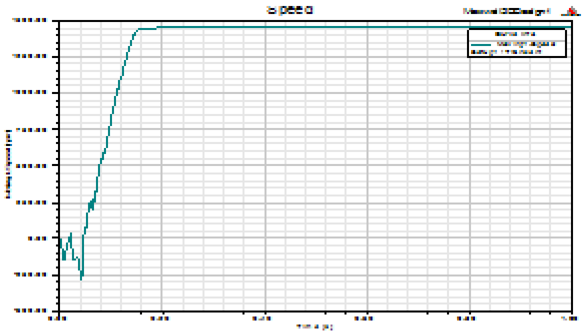

Fig. 10. Speed of IM

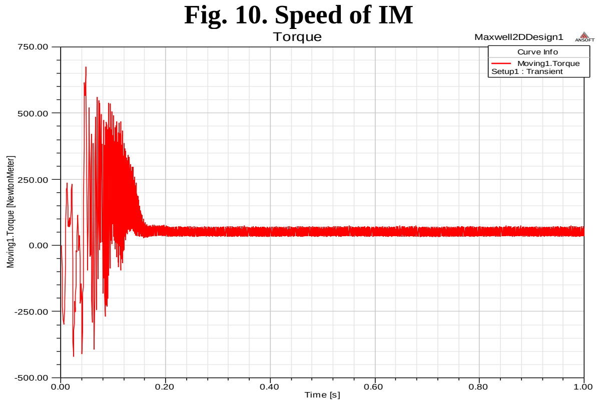

Fig. 11. Torque of IM

Fig. 11 shows the torque variation, the couple peak equal to 675Nm in the transient mode because of the increase in the inrush current and is stabilized with the value 50 Nm value of load torque in the steady state.

Stranded Loss: Stranded loss is calculated for Transient solution types. Stranded loss will be calculated for the following three cases:

Winding with voltage excitation and non-zero resistance:

$$S\_Loss = I^2 R \quad (2)$$

Stranded current excitation with conductivity:

$$S\_Loss = I^2 / \sigma A \quad (3)$$

External circuit, voltage source and non-zero resistance,

$$S\_Loss = I^2 R(dc) \quad (4)$$

Thus here the dc resistance (calculated with the conductivity of the material of the respective cross section A) is used to calculate the stranded loss but not used in the circuit equation where it doesn't impact the current calculation(current is calculated taking R into account but not R(dc)).

Solid Loss: solid loss represents the resistive loss in a 2D or 3D volume and is calculated by:

$$Solid\ Loss = \frac{1}{\sigma} \int_{vol} J^2 \quad (5)$$

Core Loss: core loss combines eddy current losses and hysteresis losses for a transient solution type. It is a post-processing calculation, based on already calculated transient magnetic field quantities. It is applicable for the evaluation of core losses in steel laminations (frequently used in applications such as electric machines, transformers) or in power ferrites.

Fig. 12 shows this three type of losses presented in IM Stranded Loss, Solid Loss and Core Loss, their value is 0.63Kw, 0.38 kW and 0.13kW respectively

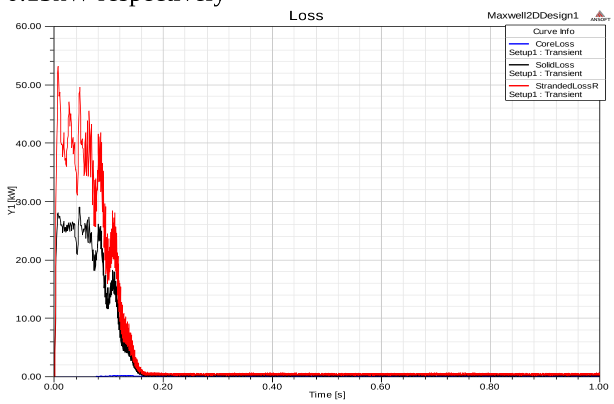

Fig. 12. Loss of IM

Fig. 13 illustrates the stator flux linkage of IM, where in study state the value is 0.95wb.

The stator induced voltage is illustrated in fig 14 their amplitude is equal to 315V.

Fig. 15 give the information of current and voltage of squirrel cage bar of induction machines, the induced voltage value is surroundings 0V and the current is sinusoidal, the amplitude is 300A.

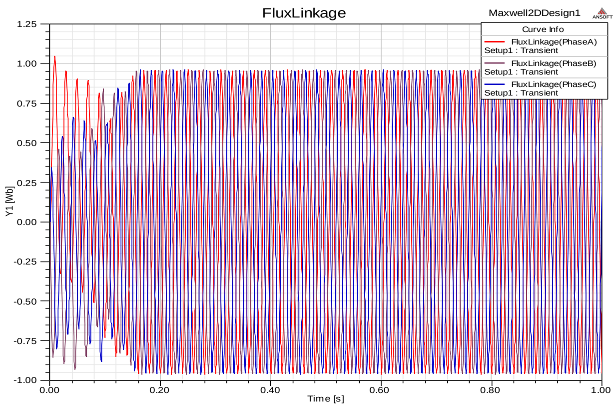

Fig. 13. Flux Linkage of IM.

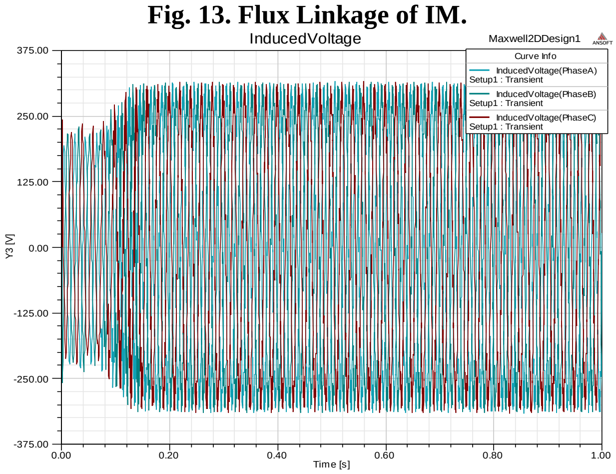

Fig. 14. Stator induced voltage of IM.

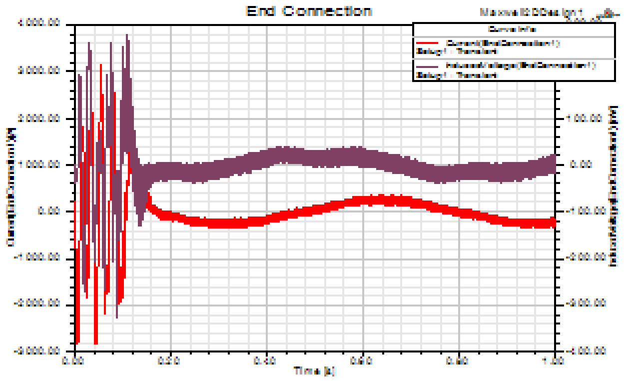

Fig. 15. End connection voltage and current of IM.

Field results

The flux line distribution of half induction motor is shown in Fig. 16, the maximum value of the vector potential A at 1s is 0.19272 Wb/m.

Fig. 17 Illustrate the distribution of Flux density of a half-IM at 1s, we can read in this figure that the maximum of the magnetic flux density is 1.7926 Tesla.

In our application we have considered a lot of losses such as Eddy effect, hysteresis and the load losses, the Fig. 18. Show the total losses of a half-IM at 1s, the maximum of the total losses is 5818400 W/m2.

Table 4. Comparison between load and no load operation

Quantity	No load	Load 50Nm
A [e-1 wb/m]	1.9007	1.9272
B[Tesla]	1.6916	1.7926
H[e005Am]	7.70860	9.4150
Ohmic losses [e006 W/m2]	2.1797	134,8

The tables.4 shows the simulations results of a comparative study between a load and non load operations, we see clearly that the presence of load influent directly in the induction motor characteristics such us potential vector (A), magnetic flux density (B), magnetic field intensity (H), and the increasing load give an increasing of these quantity.

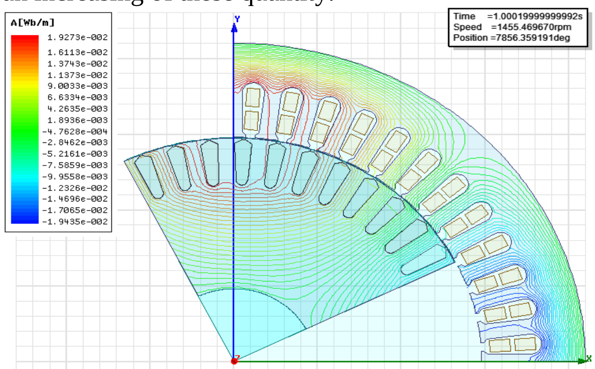

Fig. 16. Flux line distribution of the half-IM at 1s.

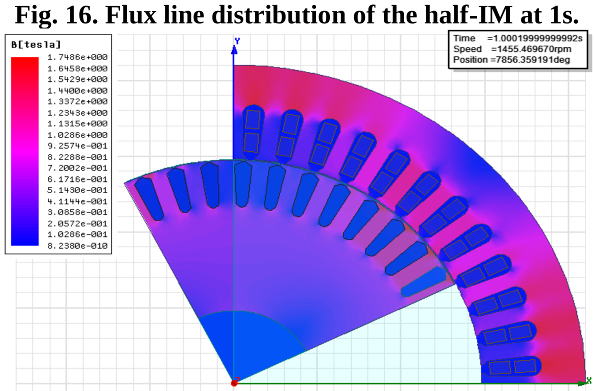

Fig. 17. Flux density of half-IM at 1s

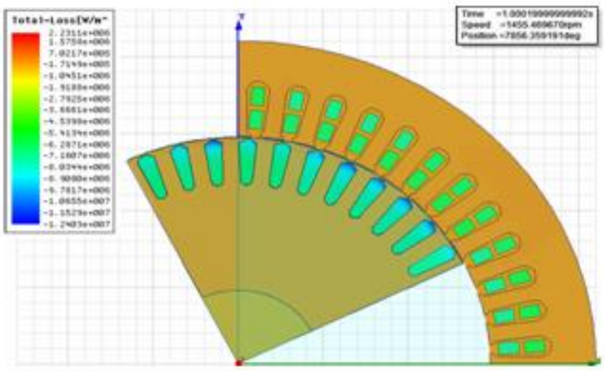

Fig. 18. Half-IM Total losses at 1s

Conclusion

In this paper, deferent approaches of multiphysics modeling of electrical machine are sited and discussed, the exactly behavior of induction motor is very complex and several field of physics exist such as electrics, magnetic, thermics and even acoustic; but pure that this, these phenomena its coupled between them, the work presented by [1] use a multiphysics model with analytical or semi-analytical approaches, these last are accurate but; less accurate compared with the numerical method, so our approaches is to use just the numerical method, in this context our preliminary study interest.

Finite element analysis (FEA) is a frequently used method for analysis of electromechanical converters. As a numerical analysis method, FEA allows for including any practical material, external excitation (voltage driven or current driven), inclusion of motion, and nonlinear effects such as magnetic saturation, eddy current effects, parametric variation, and environmental condition.

In the first time we take only the thermal and motion transient behaviors and the other phenomena are in steady state, a thermal model of induction motor is created, solved and some results are given and commented for several duty types.

In the second part we ignore just the thermal behavior, an electromagnetic model of induction motor is created, solved and some simulation results are given and commented.

In the future work, we want to do the same thing but with an induction motor multiphysics model based on numerical methods without simplification said before.

References

J. Le Besnerais, A. Fasquelle, M. Hecquet, J. Pellé, V. Lanfranchi, S. Harmand, P. Brochet, and A. Randria, " Multiphysics Modeling: Electro-Vibro-Acoustics and Heat Transfer of PWM-Fed Induction Machines," IEEE Trans on Industrial Electronics, vol. 57, no. 4, pp. 1279–1289, April 2010.

A. Fasquelle," contribution a la modélisation multi-physique : électro-vibro-acoustique et aérothermique de machines de traction," thèse de doctorat l'école centrale de Lille, 2007.

A. Boglietti, A. Cavagnino, D. Staton, M. Shanel, M. Mueller, and C. Mejuto, "Evolution and Modern Approaches for Thermal Analysis of Electrical Machines," IEEE Trans on Industrial Electronics, vol. 56, no. 3, pp. 871–882, march 2009.

W. D. Hamza, M.W. Joshua, C.K. Andreas, and D.P. Steven, "A Comparison of Nodal-and Mesh-Based Magnetic Equivalent Circuit Models," IEEE transactions on energy conversion, vol. 24, no. 2, pp. 388–396, June 2009.

S. Touati, R. Ibtiouen, O. Touhami and A. Djerdir, " Experimental investigation and optimization of permanent magnet motor based on coupling boundary element method with permeances network," Progress In Electromagnetics Research, Vol. 111, pp. 71- 90, 2011

H. Mellah, K.E. Hemsas, "Design and simulation analysis of outer stator inner rotor DFIG by 2d and 3d finite element methods," International Journal of Electrical Engineering and Technology (IJEET), ISSN 0976 –6545(Print), ISSN 0976 – 6553(Online) Volume 3, Issue 2, pp. 457-470, July- September 2012.

ANSYS Electromagnetic 12. Release, www.ansys.com,2009.

L. Chong, M.F. Rahman, "Saliency ratio derivation and optimisation for an interior permanent magnet machine with concentrated windings using finite-element analysis," IET, Electric Power Applications, pp. 249 – 258, 2010.

Flux Solution & Mechatronic products, Cedrat Group May 2009.

Flux2D help V10.3, CEDERAT Corporation 2010.

Motor-CAD Manual, Version 3.1(1), Motor Design Limited, 7 April 2006.

Motor-CAD Software for Thermal Analysis of Electric Motors," Motor-Design.com, January 2008.

A. Boglietti, A. Cavagnino, D.A.Staton, "Thermal Analysis of TEFC Induction Motors," IEEE Conference Publications Industry Applications Conference, 38th IAS Annual Meeting, vol. 2, pp. 849 - 856, 12-16 Oct. 2003.

A. Boglietti, A. Cavagnino, D. A. Staton, "TEFC Induction Motors Thermal Models: A Parameter Sensitivity Analysis," IEEE Trans on Industry Applications, vol. 41, no. 3, pp. 756–763, may/June 2005.

A. Boglietti, A. Cavagnino, D. A. Staton, M. Popescu, C. Cossar, and M. I. McGilp, "End Space Heat Transfer Coefficient Determination for Different Induction Motor Enclosure Types," IEEE transactions on industry applications, vol. 45, no. 3, pp. 929–937, may/June 2009.

Help of ePhysics V3®, Ansoft Corporation 2010.

International Standard, IEC 60034-1Eleventh edition, 2004-04.

Z. Gao, T. G. Habetler, R. G. Harley, and R. S. Colby, "A Sensorless Adaptive Stator Winding Temperature Estimator for Mains-Fed Induction Machines with Continuous Operation Periodic Duty Cycles," IEEE transactions on industry applications, vol. 44, NO. 5, pp. 1533–1542 September/October 2008.

Application basics of operation of three-phase induction motors, design duty types selection dimensioning, publication wp-motors," nov.1996.

Help of Ansoft Maxwell V12®, Ansoft Corporation 2010.