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Analysis of Induction Motor with Stator Winding Short-circuit Fault by Finite Element Model

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***Abstract*— The paper presents a finite element (FE) based efficient analysis procedure for induction machine (IM). The study based on finite element models (FEM) offers much more information on the phenomena characterizing the operation of electrical machines than the classical analytical models. This explains the increase of the interest for the finite element investigations in electrical machines.**

This paper attempts to present a dynamic model involving Finite Element Analysis and equivalent circuit simulation together for PWM inverter fed induction motor assisted based on Maxwell 2D and Simplorer. The nonlinear magnetization characteristics have been considered and calculated by FE software Maxwell. The circuits of the inverter are built by using the circuit components in Simplorer environnement.

Based on finite element models, this paper studies the influence of the stator winding short-circuit fault on the IM behavior under various conditions and severity. The comparison of the results obtained by simulation tests allowed verifying the precision of the proposed FEM model.

The presented fault model is used to study of the IM under fault conditions and seems to be well adapted for IM health monitoring and short-circuit fault diagnosis.

***Index Terms*—Finite element Method (FEM), Induction motor (IM), winding short-circuit fault, Maxwell, Simplorer.**

I. INTRODUCTION

A Lot of industrial, medical, aeronautical, military, etc. applications demand for high level safety operation. Therefore, it is impetuous to ensure the continuous work also of the electrical machines and drives included in it [1].

Squirrel-cage IM are widely used in small and large industries, such as electric power stations, oil refiners, and factories. Product lines will be stopped if these motors fail to operate. In addition to the disturbance of their operation, IM faults shorten their life-time. So, diagnosis of the faults is important from performance improvement and longer life-time points of view.

The interior faults of IM accounts for more than 70% in proportion of IM failures. Interior faults include stator and rotor of IM faults. Rotor faults are related to broken bars. They are caused by a combination of various stresses that act on the rotor and these stresses can be identified as electromagnetic, thermal, dynamic, environmental and mechanical. Therefore these leads to low-frequency torque harmonics, which increases noise and vibration [4], [10].

Inter turn fault cause a large circulating fault current in the shorted turns, leading to localized thermal overloading. This one can cause open-circuit failures (melting of conductors), and electrical fire. Voltage unbalance produces negative-sequence current, which decreases the motor efficiency and accelerates motor degradation due to increased thermal/mechanical stresses [8], [9]. In fact, a more precise model of the machine is necessary for an accurate analysis of the machine behavior in both healthy and faulty cases [6]. A detailed analysis of short circuit faults requires a precise model. The models of the induction machine, such as the multi winding model, multi-turns and the model of Park [7] are not practical to make changes in the electrical stator and rotor. They represent the electrical behavior of the equivalent induction machine. They do not take into account the electric or magnetic phenomena such as induced currents, magnetic saturation and the effect of complex geometry.

Inter turn fault cause a large circulating fault current in the shorted turn, leading to localized thermal overloading. This one can cause open-circuit failures (melting of conductors), short circuit faults (insulation damage) in the electrical circuit, and electrical fire [26].

In this paper, the transient analysis was done using 2D finite element electromagnetic field analysis. The designed geometric dimension is modeled in the FE using Ansys-Maxwell 14.

In this context, FEM can be successfully used, because it takes into account the non-linearity of the magnetic material being suitable for a detailed study of the IM behavior with faults, and in this case of the broken rotor bar fault type [2],

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[13]. 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 [11], [12]. 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 opening the machine, or experimenting in laboratories [7], [16]. The main idea is to understand the electric, magnetic and mechanical behavior of the machine in its healthy state and under fault conditions.

A new simulation scheme is proposed in this work. It is constituted by a new field-circuit coupled FEM by using Ansoft Simplorer and Ansoft Maxwell which is developed to compute the IM fed by PWM inverter. The magnetic fields distribution, the torque and the winding characteristics of the IM are presented.

The advantage of Ansoft/Simplorer is the ability to integrate FEA generated models within a system simulation. Many components that comprise nonlinear dynamic systems such as electrical machines must be modeled using FEA to accurately represent the performance of the device. The simulation results of the IM using the FEM analysis will be presented, both in the case of healthy and faulty condition.

Modeling of IM with internal faults is the first step in the design of the fault detection systems. For internal faults, the simulation is more complex, because the field picture totally changes. The finite element analysis can be used to model the IM under different internal faults [17].

II. Finite Element Method

FEM is a computer based numerical technique for calculating the parameters of electromagnetic devices. It can be used to calculate the flux density, flux linkages, inductance, torque; induced emf etc., in the FEM, the large electromagnetic device is broken down into many small elements. The behavior of an individual element can be described with a relatively simple set of equations [17]. The computer can solve this large set of simultaneous equations. From the solution, the computer extracts the behavior of the individual elements.

The FEM provides detailed information about the machine nonlinear effects (based on its geometry and material properties). This modeling approach is capable of obtaining an accurate and complete description of an electrical machine [15], [22]. The magnetic circuit is modeled by a mesh of small elements. The field values are then assumed to be a simple function of position within these elements, enabling interpolation of results. The time required to calculate the field distribution may be very long, depending on the number of elements considered [23]. A compromise must be reached between using finer meshes to achieve higher accuracy and the processing resources needed to achieve reasonable simulation times. The FEM is very flexible, especially for new designs incorporating new shapes. However long time simulation requirements reduce its attractiveness for a case when a control algorithm needs to be incorporated [5].

A. Finite Element Model of Induction Motor (AnsysMaxwell)

A model of the IM was constructed using Ansoft/Maxwell 14. The model of an IM is shown in Fig. 1. There are four steps involved in finite element analysis:

- Definition of geometrical parameters and construction of 2-D model.
- Definition of physical parameters such as regions, materials etc.
- Construction of electric circuit model.
- Meshing of the study domain and solving of problem.

Figure 1 shows the complete geometrical 2D model of the IM.

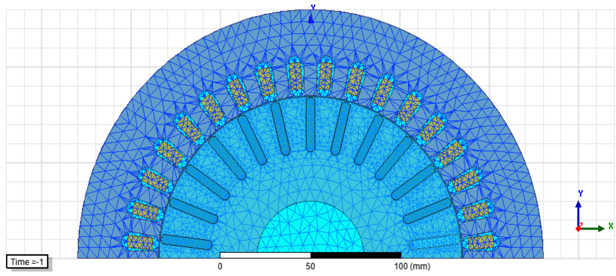

Fig. 1. Finite Element Model of 2 poles induction motor

One can build electric machines using Maxwell in different ways. However, the process is simplified by letting the RMxprt do the most of the job. RMxprt is a machine model whereby a software user can insert machine design parameters and related information. In the process of imputing the design data in the RMxprt, a user has to specify the dimensions of the stator and rotor of the machine and related parameters such as machine type, number of poles of the machine and control type. Furthermore, a user has to specify the rated parameters such as speed and voltage. A user has also to specify other parameters such as winding, slot, wire, conductors, insulation and some other related parameters [3].

B. Power Inverter (AnsysSimplorer)

Figure 3 shows the three-phase inverter of the simulation structure which implemented in Ansys/Simplorer. Here, ideal switches are used, but it is also possible to replace them with exact models of IGBTs. The PWM signals (S_a, S_b, S_c) can be generated from the control scheme in MATLAB and received through an interface and fed to the inverter switches S_1 to S_6 built up in Simplorer. In this work, the inverter is controlled by PWM signals generated with Simplorer.

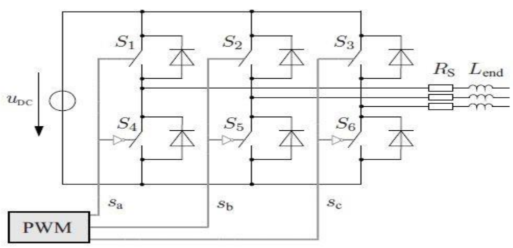

Fig. 2. A three phase Power Converter with additional resistance and end-winding inductance

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Besides the inverter, the model includes the concentrated phase end-winding inductances L_{end} and phase winding resistances R_s. These components are included in this model as it is not possible to integrate them in a two dimensional FEM based motor model. Fig. 3 and 4 give the PWM signals and the PWM output for one phase.

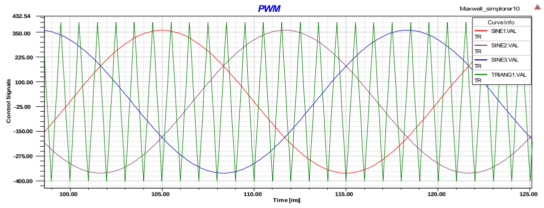

Fig. 3. 2-Level PWM Comparison Signals

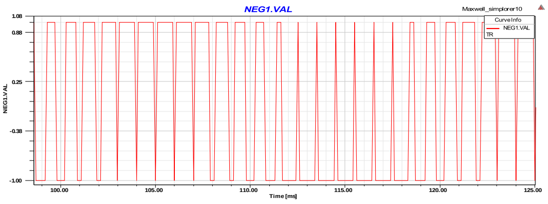

Fig .4. 2-Level PWM Output (Unfiltered)

C. System Model

In this section, we propose to feed the machine with a three-phase PWM inverter. The FEM model of the machine is developed on Maxwell and used for simulation with Ansys-Simplorer in order to have the simulation results of the complete system. Fig. 5 shows the principle diagram of the proposed co-simulation.

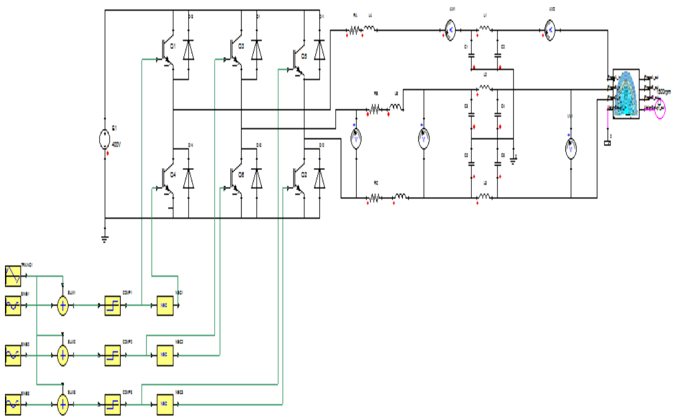

Fig. 5. Simulated system model

This IM is a three-phase and two-pole. The main dimension of the IM is shown in table I. The finite element simulation model of this motor with mesh division is shown in Fig.1.
The main circuit of PWM is built by the circuit component module in Simplorer, there are 6 IGBTs switches and 6 stream diode modules.
In PWM inverter control circuit, Triangular module serve as carrier wave generator and Sine module serve as modulation wave generator. Each sinusoidal signal is shiefted by 120 degrees based on a same frequency.
According to each module of all above built, the PWM inverter fed IM system can be composed of the entire systematic model. Figure 6 shows the simulated system model for the study of inverter fed induction motor. In the systematic model, Motor rotation speed is given rated speed 1500 rpm by V_ROTB1 module.

III. IM Model with Stator Winding Short-circuit Fault

In this paper, the simulation model of the machine is established by Ansoft Maxwell. The IM model was verified by the test results of the healthy machine. The no-load normal operation was simulated.

The electrical model representation of three phase squirrel cage connected to IM is shown in Fig. 2. The power source is considered as a voltage source connected with the series resistances and inductances of the stator windings in each phase. Fig. 6 shows the flux lines of the healthy machine.

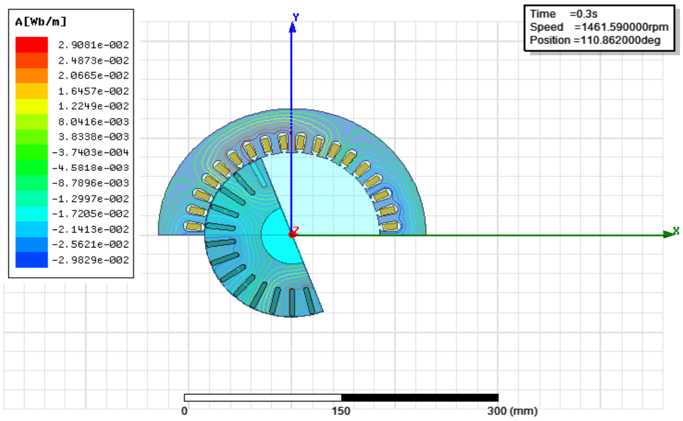

Fig. 6. Flux lines of healthy induction motor

Table I shows nominal values of the simulated machine. A draw of 2D model is not necessary because RMXprt makes possible to export 2D model to the Ansys Maxwell program.

A. IM inter-Turn Fault dynamic Model

One of the most common faults in the electrical motors is the inter-turn short circuit in the one of stator coils [14], [15]. The increased heat due to this short circuit may also lead to turn-turn and turn to ground faults. The inter turn fault is mostly caused by mechanical stress, moisture and partial discharge, which is accelerated for electrical machines supplied by inverters [20].

Most of dynamic fault models, presented in different works, are based on healthy machine circuit model with an additional fault circuit. However, when a fault occurs the current and flux density distribution is more or less modified as a function of fault severity [21], [24], [25]. Therefore, it is necessary to verify these dynamic models precision. The behavior study of electrical machines in steady state, transient and fault

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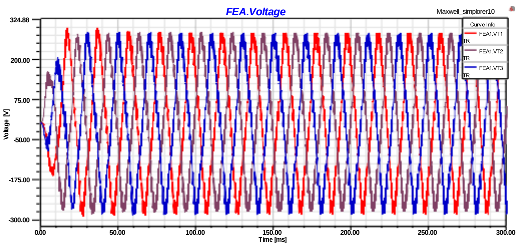
conditions requires accurate knowledge of the equivalent circuit parameters. Some authors have validated their proposed model experimentally by measuring the machine external variables (stator voltages and currents) [19]. However, experimental tests for parameter identification can be replaced by digital simulation using finite element method (FEM) [16], [18].

The validated finite element model is used to simulate the IM with stator short-circuit fault. In this paper, Co-simulation of IM fed by the PWM inverter with different degrees of stator short circuit using Ansoft Maxwell and Simplorer.

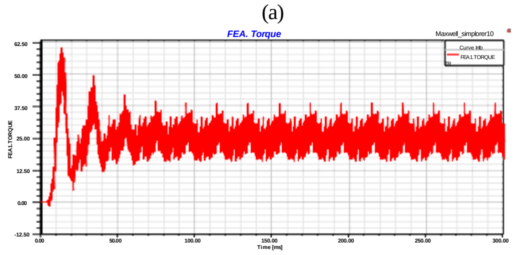
In order to analyze the characteristic on stator short circuit, different levels of this fault are tested in which 8.33% et 50% of the whole stator windings are investigated. Shorted turns was assign in three phases belonged in A phase winding such as winding in phase 1, phase 2 and phase 3. Precisely, 14 turns shorted in winding No.1, No.2, No.3 respectively means 14 turns shorted and 50% and 84 turns shorted in each winding. Simulation results for healthy and faulty machine are given in Fig. 7, 8 and 9.

B. Simulation Results

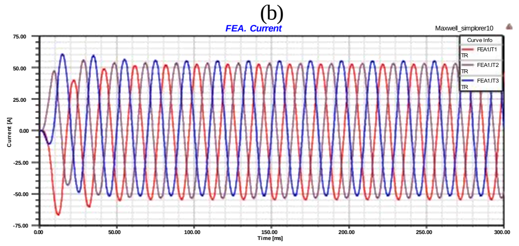
- Healthy machine



(a)



(b)

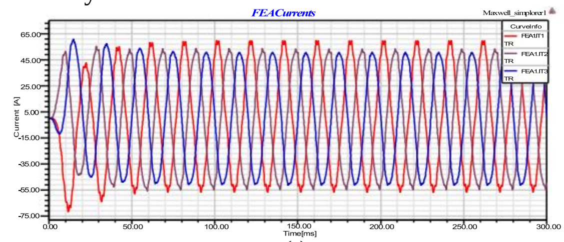


(c)

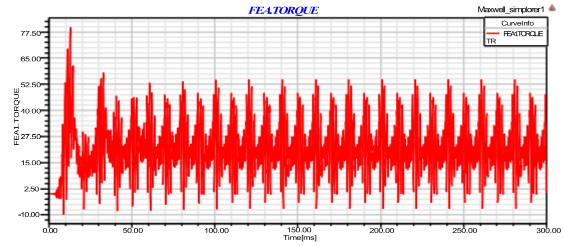
Fig. 7. Results obtained by Simplorer for healthy machine (a) phases voltage (b) electromagnetic torque (c) phases current

An inter-turn fault denotes an insulation failure between two windings in the same phase of the stator. The insulation failure is modeled by a resistance, where its value depends on the fault severity [23]. The stator winding of an IM with inter-turn fault is represented in Fig. 4.

- Faulty machine



(a)



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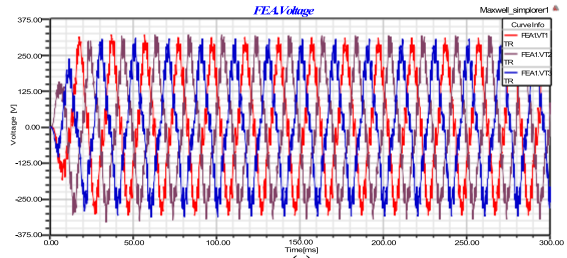
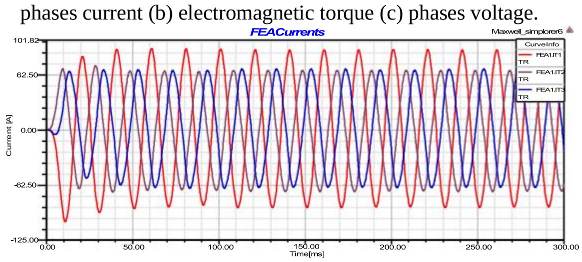
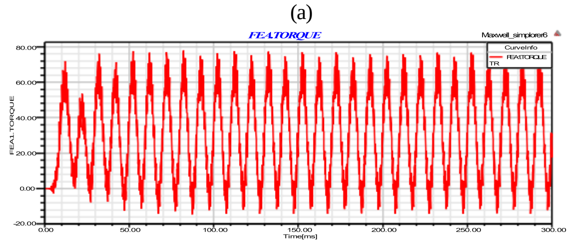


(c)

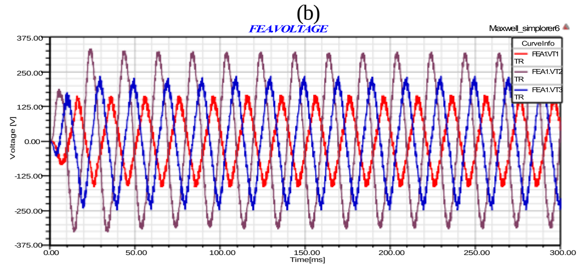
Fig. 8. Results obtained by Simplorer with 8.83% short circuit fault (a) phases current (b) electromagnetic torque (c) phases voltage.



(a)



(b)



(c)

Fig. 9. Results obtained by Simplorer with 50% short circuit fault (a) phases current (b) electromagnetic torque (c) phases voltage.

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Figure 9 and 10 show the simulation result of the electromagnetic torque, the stator current and the stator voltage with 8,33% and 50% of short circuit fault. We note that when increasing the number of shorted turns, the torque and the stator current is more affected. In fact, the bars destruction increases the current amplitude of the affected phase and increases the oscillations. These cause oscillations of the rotational speed, which generates mechanical vibrations and thus, an abnormal operation of the machine.
A finite element model is established for induction machine simulation of stator short circuit fault taking magnetic phenomena into account. The simulation results under normal and abnormal operation of the IM are verified.

IV. Conclusion

In this paper, the FEM analysis is performed for the study of a rotor surface mounted IM with broken bar failure. FEM is used for magnetic field study and determining the machine parameters under various fault conditions.
In this work, a dynamic model coupling 2D finite element method in Maxwell and equivalent circuit simulation in Simplorer is proposed to compute the performances of an IM fed by PWM inverter. The nonlinear magnetization characteristics have been considered and calculated by FEM. The circuits of the inverter are built by using the circuit components in Simplorer. The magnetic fields, the winding characteristics and the torque of the IM are presented. The performances of the IM fed by sinusoidal voltage are computed as comparison with that of fed by PWM inverter. All results of the two simulation methods are compared for revealing the effect of PWM inverter.

In order to highlight the effect of short circuit fault, the harmonic spectral analysis and symmetrical components for phase current and electromagnetic torque is carried out. The electromagnetic torque and its harmonics are studied for the IM machine with broken bar fault. It is revealed that current sequences and harmonic of torque ripples is an indicator for detecting this fault

TABLE I. Specifications Adopted For The Induction Machine

Induction Machine parameters	
Parameters	***values***
Out Put Power	11KW
Rated Voltage	380V
Number of poles	2
Speed	1462rpm
Frequency	50Hz
Number of stator slots	36
Number or rotor slots	26

References

[1] L.Saidi, F. Fnaiech, H. Henao, G-A. Capolino, G. Cirrincine, " Diagnosis of broken-bars fault in induction machines using higher order spectral analysis", ISA Transactions, vol. 52, pp: 140-148, 2013.

[2] Jawad Faiz, B.M. Ebrahimi, "Locating rotor broken bars in induction motors using finite element method", Energy conversion and Management, vol. 50, pp: 125-131, 2009.

[3] S. Nagarajman, S. Rama Reddy, " Modeling and simulation of faulty squirrel cage induction motor using Magnet", vol. 2, No. 5, pp: 1793-1800, 2010.

[4] Xie Ying, "Performance Evaluation and Thermal Fields Analysis of Induction Motor with broken bars located at different relative positions", IEEE Transaction on magnetic, vol. 46, No. 5, pp: 1243-1250, 2010.

[5] Sprooten, Jean-Claude Maun, "Influence of saturation level on the effect of broken bars in induction motors using fundamental electromagnetic laws and finite element simulations", IEEE Transactions on Energy Conversion, vol. 24, No. 3, 2009.

[6] M. Rezazadeh Mehrjou, N. Marium, M. H. Marhaban, N. Misron, "Fourier analysis of motor current bars in squirrel-cage induction machines", Proceedings of IEEE Student on Research and Development (SCORed 2010), Putrajaya, Malaysia, 2010.

[7] A. Ceban, R. Pusca, R. Romary, "Study of rotor faults in induction motors using external magnetic field analysis", IEEE Transactions on Industrial Electronics, vol. 59, No. 5, pp: 2082-2093, 2012.

[8] B.L. Rajalakhmi Samaga, K.P. Vital, "Comprehensive study of mixed eccentricity fault diagnosis in induction motors using signature analysis", Electrical Power and Energy Systems, vol. 35, pp: 180-185, 2012.

[9] G.P. Mehta, B. Singh, M. s. Manna, "Performance Analysis of rotating induction machines for Air-Gap eccentricity & Rotor bar faults using finite element method", International Journal of Research in Computer and communication technology", vol. 2, No. 5, pp: 267-272, 2013.

[10] A. Gandhi, T. Corrigan, L. Parsa, « Recent advances in Modeling and online detection of stator interturn faults in electrical motors », IEEE Transactions on Industrial Electronics, vol. 58, No. 5, 1564-1575, 2011.

[11] M. Bouzid, G. Champenois, "An efficient, simplified multiple-coupled circuit model of the induction motor aimed to simulate different types of stator faults", Mathematics and computers in simulation, vol. 90, pp: 98-115, 2013.

[12] P. Arumugam, T. Hamti, C. Gerada, "Modeling of different winding configurations for fault-tolerant permanent magnet machines to restrain interturn short-circuit current", IEEE Transactions on Energy Conversion, vol. 27, No. 2; 2012.

[13] T. Boileau, N. Leboeuf, B. Nahid-Mobarakeh, F. Meibody-Tabar, « Synchronous Demodulation of control voltages for stator interturn fault detection in PMSM », IEEE Transactions On Power Electronics, vol. 28, No. 12, pp: 5647-5654, 2013.

[14] B. Vaseghi, N. Takorabet, F. Neibody-Tahar, « Fault analysis and parameter identification of permanent-Magnet Motors by the finite-element method », IEEE Transactions, vol.9, pp: 3290-3295, 2009.

[15] O. A. Mohammed, N. Y. Abed, S. Ganou, "Modeling and characterization of induction motor internal faults using finite-element and discrete wavelet transforms", IEEE Transactions on Magnetics, vol. 42, No. 10, pp. 3434-3436, October 2006.

[16] C. Schulte, J. Bocker, "Co-simulation of an Electric traction drive", IEEE International Electric Machines & Drives Conference (IEMDC), pp. 974-978, May 2013.

ISSN: 2356-5608

[17] X. Zhao, H. Liu, Z. Z. Zuo, H. Zhang, Y. Chen, "Co-simulation of 600KW Traction Induction Motor Fed by PWM Inverter", 2nd International Conference on Electronic & Mechnanical Engineering and Information Technology, France, pp. 1680-1683, 2012.

[18] N.m. Elkasabgy and A.R. Eastham, « Detection of broken bars in the cage rotor on an induction machine », IEEE Trans, Ind. Appl, vol. 28, pp. 165-171, Janvier 1992.

[19] A. M. da Silva, R. J. Povineli, and N. A. O. Demerdash, " Induction machine broken bar and stator short-circuit fault diagnostics based on three-phase stator current envelopes", IEEE Trans. Ind. Electron., vol. 55, no. 3, pp. 1310-118, Mars 2008.

[20] X. Ying, "characteristic performance analysis of squirrel cage induction motor with broken bars", IEEE Trans. Magn., vol. 45, no. 2, pp. 759-766, febrary 2009.

[21] M. A. Mueller, S. Williamson, and T. J. Flack et al., "Calculation of iron losses from time-stepped finite element model of cage induction machines", in IEE conf. Pub., No.412, pp. 88-92, 1995

[22] H. Ma, R. Fang, P. Ju, and L. Zhang, « Research on the effect of rotor broken bar position in induction machine », in Power Engineering Conf., pp. 282-286, Dec. 2007

[23] J. Faiz and B. M. Ebrahimi, "A new pattern for detecting broken rotor bars in induction motors during start-up", IEEE Trans. Magn., vol. 44, no. 12, pp. 4637-4683, December 2008.

[24] O. A. Mohammed, N. Y. Abed, and S. Ganu, "Madeling and characterization on induction motor internal faults using finite-element and discrete wavelet transforms", IEEE trans. Magn., vol. 42, no. 10, pp. 3434-3436, October 2006.

[25] C. C. Yeh, G. Y. Sizov, A. Sayed-Ahmed, N. A. O. Demerdash, R.J. Povinelli, E. E. yaz, and M. lonel, " A reconfigurable motor for experimental emulation of stator winding interturn and broken bar faults in plyphase induction machines", IEEE Trans. Energy Convers., vol. 23, pp. 1005-1014, December 2008.

[26] A. Lebaroud, A. Medoued, C. Guy, "Analysis of inter-turn short circuit in slots by finite element model", 10th International Conference on Environnement and Electrical Engineering (EEEIC), pp.1-4, May 2011.

ISSN: 2356-5608