

A website design in Green energy teaching

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Abstract–The paper presents a two-dimension (2-D), direct-coupled circuit-field-motion, time-stepping, finite element analysis for a wound-rotor induction motor with time-stepping method. With the accurate torque computation, the start up transient of the induction motor is investigated. The field results both at no load and at rated load are obtained. The steady and transient performance of varied mechanical load is studied. The slip ring induction analysis results can be used for website design for green energy teaching.

Keywords–Transient analysis, startup transients, slip ring induction motor, finite element method, transient behavior.

I. INTRODUCTION

Energy saving and environmental protection is a necessary concept for most of the electrical engineering subjects. This is also the common objective of most subjects. The squirrel cage motor transient performance has been studied [1]-[2]. The startup transient performance has been given with serial connected three-phase induction motor [3]. The paper presents a common used slip ring induction motor can be used into website design for green energy teaching. The stator and rotor parts of prototype three-phase, 1.8 Kw, 380 V, star-connected, rotor-wound induction motor are shown in Fig. 1. The rotor conductors are copper winding, instead of solid bars. Both the stator and the rotor winding are stranded coil, which make the eddy current loss of rotor is avoided in the conductors. The detailed parameters of machine are given in Table 1. The 2-D, direct coupled, circuit-field-electromechanical, time-stepping, field analysis method is applied to induction motor. The core loss and energy loss are fully considered in the computation. The field analysis results obtained for the induction motor give the visual, concise, accurate result in the startup and varied load process. The electrical circuit analysis results give a detailed performance induction motor. The analysis results can be used into green energy teaching with website design method.

II. ANALYSIS

1. Governor equations

Considering static and dynamic fields, Coulomb gauge is applied to ensure uniqueness of magnetic vector potential A, the field equations of slip-ring induction motor domains can be describes as [4] -[6].

$$\nabla \times (\nu \nabla \times A) - \nabla \nu_e \nabla \cdot A = \frac{i_s}{S} \quad (8)$$

in armature windings

$$\nabla \times (\nu \nabla \times A) - \nabla \nu_e \nabla \cdot A = \nabla \times \mu_0 \nu M_0 \quad (9)$$

in air gap, irons and Permanent magnets

where ν_e is one third of the trace of the reluctivity tensor, i_s armature phase current, S cross-sectional area of stranded winding respectively, ν the reluctivity, μ_0 permeability of the free space, M_0 the remanent intrinsic magnetization. Note A just has z component A_z for the 2-D analysis.



(a)



(b)

Fig. 1: The prototype slip ring induction machine: (a) stator; (b) wound-rotor.

Table 1: Parameters of slip ring motor

	Stator	Rotor
Rated current	4.5 A	10 A
Connected method	star	star
Voltage	380 V	120 V
Number of slots	36	24
Winding	single layer, concentric	single layer, full pitch
Turns per coils	48	24
Resistance per phase	2.6 Ω	0.4 Ω
Skew	no	no

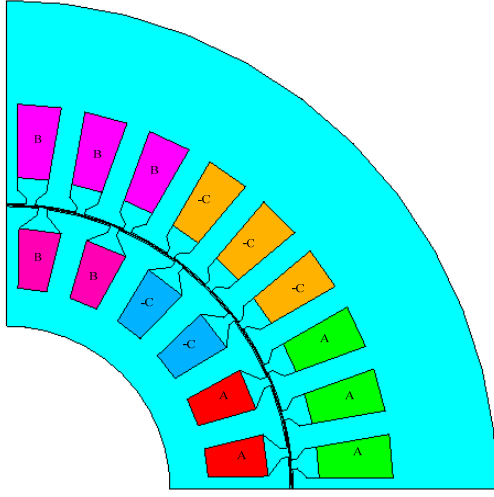


Fig. 2: Quarter of prototype slip ring induction machine.

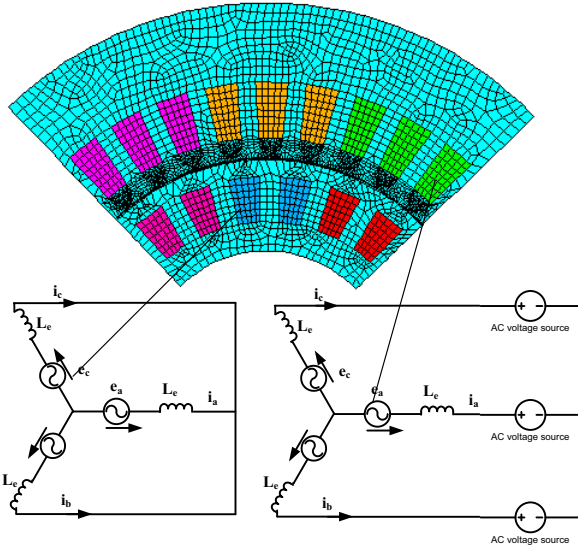


Fig. 3: Field and circuit coupled modeling of slip ring induction machine.

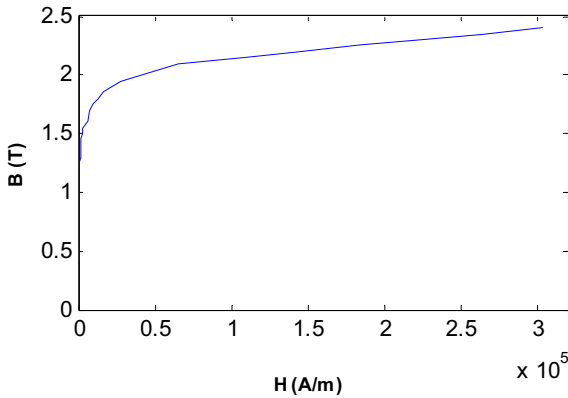


Fig. 4: Magnetization curve of iron.

The rotor movement is considered with standard discretization formulation in time domain of magnetic potential [7],

$$\{A_{n+1}\} = \{A_n\} + (1 - \theta)\Delta t \{\dot{A}_n\} + \theta\Delta t \{\dot{A}_{n+1}\} \quad (10)$$

where $\{A_n\}$ stands for nodal values of A at time step n and $\{\dot{A}_n\}$ for their time derivatives, Δt denotes the time

increment between two steps and θ the transient integration parameter. The θ value is chosen as 1 for the analysis, corresponding to backward difference. This means the initial ($n=0$) EMF DOF value must be 0, the next step ($n=1$) EMF DOF value can be obtained with previous step value of A_z . The standard Galerkin procedure is applied to 2-D rotor wound analysis.

2. Modeling of rotor-wound induction motor

With anti-period boundary condition, the electrical machined can be modeled with a pole-pitch region. Fig. 2 shows the quarter of prototype rotor wound induction motor. There are 3 slots per pole per phase for stator, and 2 slots per pole per phase for rotor.

The mesh of field of the machine and external armature circuits are shown in Fig. 3, the field element chosen to study is second order Quadrilatera element to get accurate computed result with limited element number. The current degrees of freedom (DOFs) are unified as phase current i_a , i_b and i_c , and corresponding EMF DOFs are unified as e_a , e_b and e_c in the field region of stranded coils. The three-phase armatures can be modeled as three current source elements, and each current source elements carry the field united current DOFs and EMF DOFs. The each phase internal resistance is considered in the circuit element [8], and each phase end winding flux leakage is take account as a leakage inductance L_{σ} . The stator external source is modeled as three independent phase voltage sources, with phase angle difference 120 degree. The field and circuit are direct coupled.

The B-H curve used to model nonlinear material magnetic property of iron is shown in Fig. 4. To avoid long iteration time for reluctivity of iron with simple chord method, the Newtown-Raphson method is used to get accurate saturated iron reluctivity [7].

There is not flux outside of the stator iron. So the magnetic flux parallel boundary condition should be applied to nodes located rotor inside edges and stator outside iron edges. The left edge and right edge of rotor is meshed with the same divisions, the same mesh scheme for the left edge and the right edge of stator. The anti-period boundary condition is assigned between the A_z DOFs of left side nodes and right sides nodes of rotor and stator respectively.

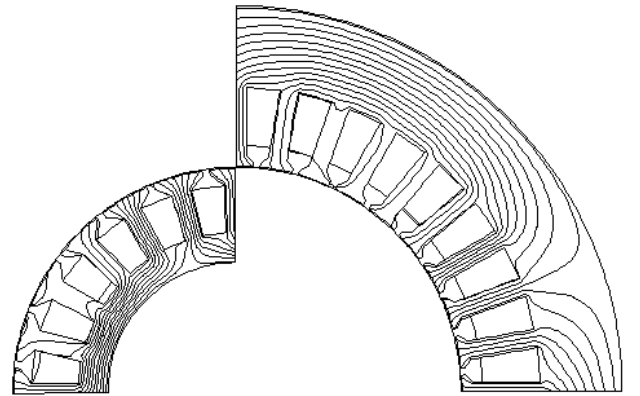


Fig. 5: Flux plot of induction motor after reach the steady states at no load condition.

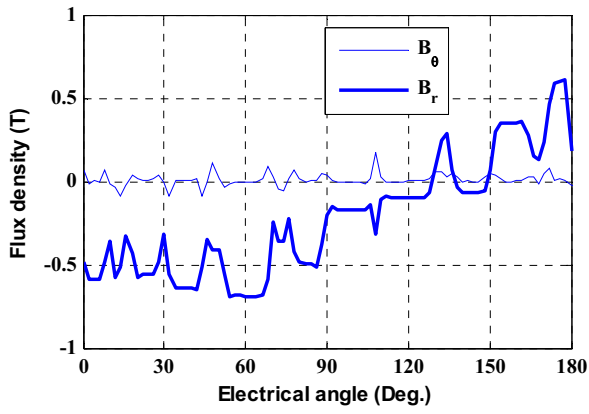


Fig. 6: Air gap flux density distribution at no load condition.

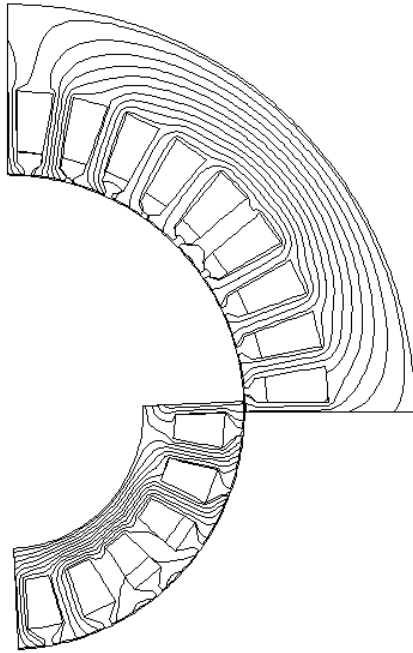


Fig. 7: Flux plot of induction motor after reach the steady states at rated load condition.

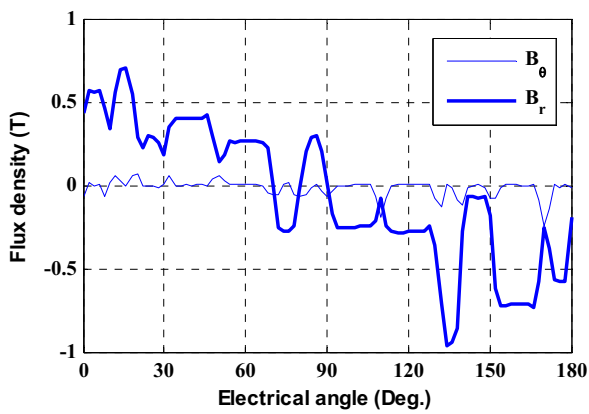


Fig. 8: Air gap flux density distribution at rated load condition.

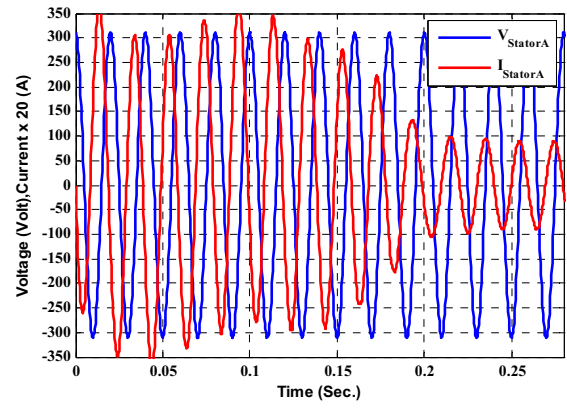


Fig. 9: Stator phase voltage and phase current induction motor at start up no load condition.

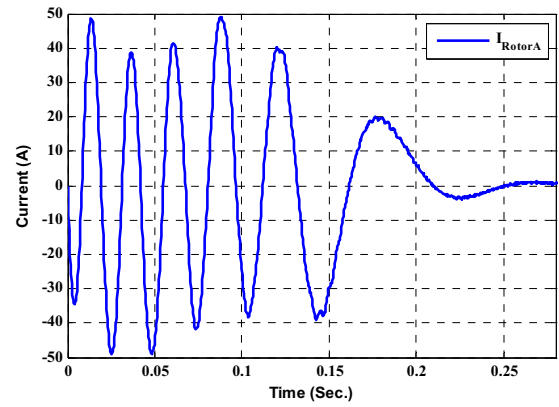


Fig. 10: Rotor phase current induction motor at start up no load condition.

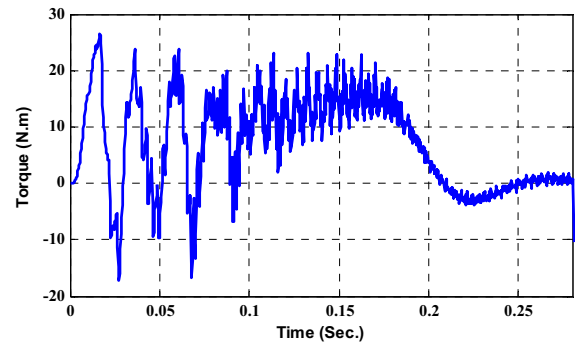


Fig. 11: Torque of induction motor at start up no load condition.

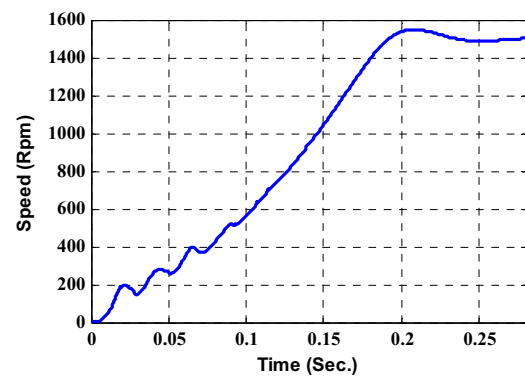


Fig. 12: Speed of induction motor at start up no load condition.

III. RESULTS

There are total 5125 elements and 14557 nodes in the 2D finite element analysis, the node number that falls on the magnetic flux parallel boundary is 87, the node number that falls on the anti-period boundary is 184, and the total variables number is $14557 - 87 - 184 / 2 + 3 \times 2 = 14384$. The time step is 0.3 ms. On a Sun Microsystems Sun-fire E6900 CPU 4 900 MHz 64 bits processor memory 4 GB, the computing time for a typical load is about 18 hours. The stator end-winding leakage inductance of the prototype induction motor is 17.57 mH, and 1.25 mH for rotor end-winding, determined using an analytical method [9]. To avoid time-consuming shortcoming of Iteration of equation solver, the Directed Sparse equation solver [7], which maximum in-core memory used in the solution process, is chosen for the analysis.

1. Field result

The induction motor startup at no load condition, it reaches steady states after the transient period pass. The field plot at no load is shown in Fig. 5. With no load condition, the current of rotor armature is near to zero, the field comes from excited current density of the stator armatures. The flux density distribution at mean air gap is depicted in Fig. 6, it can be observed the slot effect is really obvious. The flux plot of induction motor is shown in Fig. 7 at rated load condition 12.4 N.m. The flux density distribution at mean air gap is depicted in Fig. 8.

2. Startup transient performance of motor

Fig. 9 shows stator armature phase A voltage waveform and current waveform when the induction motor startup from standstill to rated speed at no load condition. The startup current is about 12.38 A (about 2.75 times of rated current). The phase current is lagged to phase voltage with induction motor has internal inductive load property. The rotor phase current waveform is depicted in Fig. 10. Its start up current is approximate 35 A (about 3 times of rated current). Fig. 11 shows torque profile of the induction motor startup with no load condition. It can be observed the reversed direction torque exist until to 0.09 second, then the positive torque domains the startup process. The rotor speed is shown in Fig. 12. It can be seen the motor reaches rated speed within 0.25 second at no load condition.

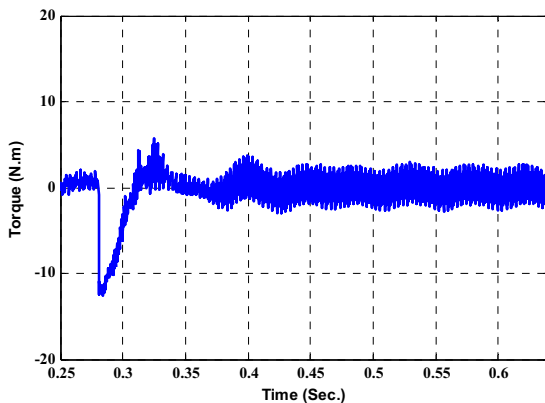


Fig. 13: Torque of induction motor at rated load condition.

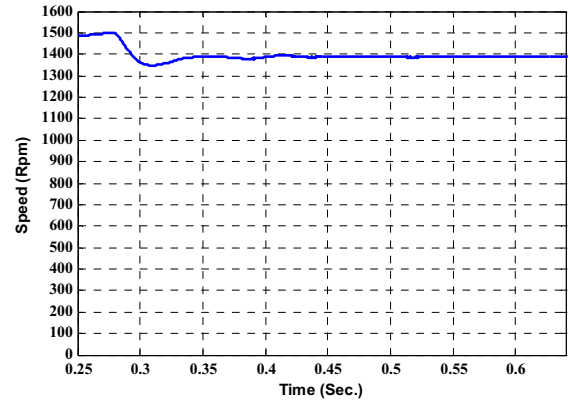


Fig. 14: Speed of induction motor response at rated load condition.

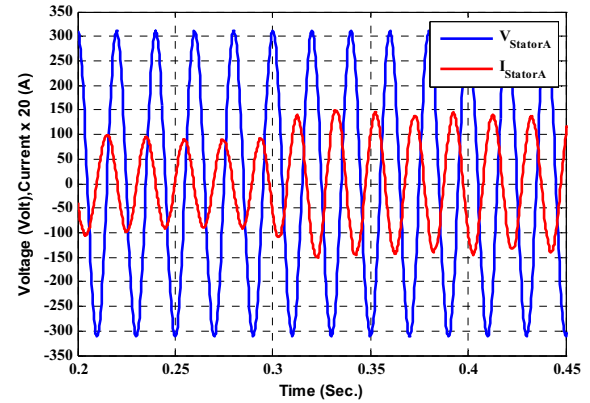


Fig. 15: Stator phase voltage and phase current induction motor at rated load condition.

3. Transient performance of motor with verified load

Fig. 13 shows the sum rotor torque rated load is applied the induction motor suddenly, while the induction motor is running with rated speed at no load condition. It can be seen the motor circuit can reach another steady states within 0.05 second. The speed response of the induction motor is depicted in Fig. 14 with rated load applied. It can be observed the motor reaches the rated speed 1390 rpm. Fig. 15 shows the stator phase A voltage and phase current waveforms with the rated load applied. It can be seen the stator current increases to about 4.6 A at rated load condition.

IV. CONCLUSION

The 2-D direct coupled circuit-field-motion time-stepping method has been applied the rotor wound induction machine. The eddy current can be neglected with rotor wound structure in the field element analysis. The field and flux density distribution for the motor is investigated at no load and at rated load condition. The start up transient performance of torque, speed and circuit is studied. The transient performance of rated load applied is also investigated. The detailed analysis results can be used for green energy teaching.

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REFERENCES

- [1] J. Bacher and C. Grabner, "Implemented Finite Element Routines for the Calculation of Quasi-Steady and Transient Characteristics of a Squirrel Cage Induction Machine", Proceedings of the World Congress on Engineering and Computer Science (WCECS), 22-24 Oct, 2008.
- [2] T.H. Pham, P.F. Wendling, S.J. Salon and H. Acikgoz, "Transient Finite Element Analysis of an Induction Motor with External Circuit Connections and Electomechanical Coupling", IEEE Tran. on Energy Conversion, Vol.14, No.4, pp. 1407-1412, 1999.
- [3] M.A. Badr, A.A. Alolah and A.F. Almarshood, "Transient Performance of Series Connected Three Phase Slip-ring Induction Motors", IEEE Tran. on Energy Conversion, Vol.13, No.4, pp. 305-310, 1997.
- [4] O. Biro and K. Preis, "On the Use of the Magnetic Vector Potential in the Finite Element Analysis of Three-Dimensional Eddy Currents", IEEE Tran. on Magn., Vol.25, No.4, pp. 3145-3159, 1989.
- [5] Theory Reference for the Mechanical APDL and Mechanical Application-release 12.1. ANSYS, Inc. 2009.
- [6] D.K. Cheng, 'Field and Wave Electromagnetics, 2nd ed.' (Addison Wesley, 1989).
- [7] M.V.K. Chari and S.J. Salon, 'Numerical methods in Electromagnetism' (Academic Press, 1999).
- [8] J. Wang, "A Nodal Analysis Approach for 2D and 3D Magnetic-circuit Coupled Problems", IEEE Tran. on Magn., Vol.32, No.3, pp. 1074-1077, 1996.
- [9] J.F. Gieras, 'Permanent-Magnet Motor Technology, 2nd ed.' (Marcel Dekker, 2002).

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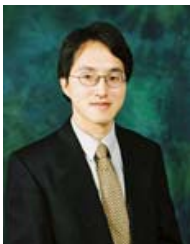
BIOGRAPHY



Weimin Wang was born in China. He received the B.Eng. and M.Eng degrees from Sichuan University, Chengdu, China, in 1994 and 1997, respectively, and the D.Eng. degree in mechanical engineering from South China University of Technology, Guangzhou, China, in 2000.

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