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Effect on Induction Motor Performance with Broken Rotor Bars Using Finite Element Method

Ray Hardik, Manish Sinha, Vijayaraj J
PG Scholar, Assistant Professor, Manager R&D

Abstract*— Three Phase Induction Motors are widely used for industrial and domestic applications. There are various faults that occur in induction motors like stator inter-turn fault, bearings faults and eccentricity fault. Out of these faults, the rotor broken bar fault is very specific in squirrel cage induction machines. Finite element method is more precise than the winding function approach method, as it is based in the actual geometry of the machine. This paper presents simulations of broken bars detection in a three phase squirrel cage induction motor under full load condition for healthy condition, two and four broken bars. This paper uses a CAD package called "Ansoft Maxwell" for the Transient 2D analysis. The various machine parameters like magnetic torque, winding current, losses etc, are calculated using this CAD package and their values are compared under healthy and faulty conditions.

***Index Terms*—Finite Element Method, Rotor Broken Bars, Three Phase Squirrel Cage Induction Motor, Torque**

I. INTRODUCTION

Induction motors are complex electro-mechanical devices utilized in most industrial application for the conversion of power from electrical to mechanical form. Induction motors are used as the workhorse in industrial applications. Such motors are robust machines used not only for general purposes, but also in hazardous locations and severe environments. However induction motors are susceptible to many types of fault in industrial application. Such as rotor fault (broken bars or end ring), stator inter-turn fault, eccentricity fault and bearing fault. A motor failure that is not identified at initial stage may become catastrophic and the induction motor suffers severe damage. Thus, undetected motor faults may cascade into motor failure, which in turn may cause production shutdowns. Such shutdowns are costly in terms of lost production time, maintenance costs, and wasted raw materials. A variety of conditions monitoring techniques and signature analysis methods have been developed[1]. Online fault diagnosis system increases industrial efficiency and reliability. Hence emerging commercial electromagnetic CAD packages like MagNet, FEMM, ANSOFT, etc, can be used for the fault detection of non-invasive methods. Finite element analysis, which is a computer based numerical technique, is used for calculation of the machine parameters like flux function, electromagnetic torque, etc, accurately [2].

Interior faults in induction motors like rotor damages are related to broken bars. Rotor failures are caused by a combination of various stresses can be identified as electromagnetic, thermal, dynamic, environmental and mechanical [3]. Therefore these leads to low frequency torque harmonics, which increases noise and vibration. The transient performance is predicated at the starting of the motor with full load. The geometry dimension of induction motor is modeled in the finite element domain. The modeling with finite element method represents a high fidelity electromagnetic behavior. This leads to more precise results than other models, as the actual geometry and winding layout of the machine are used [4]. The consideration of the behavior of the local electromagnetic induction machine provides a more accurate modeling. This paper presents the transient state modeling of squirrel cage induction motors using the 2D finite element electromagnetic analysis. The "Ansoft Maxwell" magnetic analysis software is used for calculating the magnetic field of an induction motor for the normal rotor, and for broken bars.

II. FINITE ELEMENT METHOD

A finite element method (abbreviated as FEM) is a numerical technique to obtain an approximate solution to a class of problems governed by elliptic partial differential equations. Such problems are called as boundary value problems as they consist of a partial differential equation and the boundary conditions. Finite element software accurately calculates magnetic fields and related motor design parameters for motors of complicated geometry with saturation armature reaction and with or without eddy currents [5]. In the finite element method, the large electromagnetic devices are broken down into many small elements. The equation describing the behavior of the individual elements are joined into an extremely large set of equations that describe the whole parameters. Finite element methods (FEM) of analysis have emerged in the past decades as the useful numerical methods for magnetic

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field analysis of electrical machines [6]. The ratings of the machine are presented in Table I. Each component of the field quantities is assumed to vary sinusoidal with time. From the design data the ratio of length to pole pitch ratio is 1.5. The slots per pole per phase are 4 and the air gap length is fixed to be 1.5 mm.

TABLE I. INDUCTION MACHINE DATA

Full Power	750 kW
Full Voltage	690 V
Full Frequency	50 Hz
Number of Poles	4
Number of Stator Slots	48
Number of Rotor Slots	58
Efficiency	0.95
Rated Speed	1486 rpm
Power Factor	0.85

A. Induction motor model

The model of an induction motor is shown in Fig. 1. There are four steps involved in finite element analysis. They are discretisation, shaping function, stiffness matrix and solution technique.

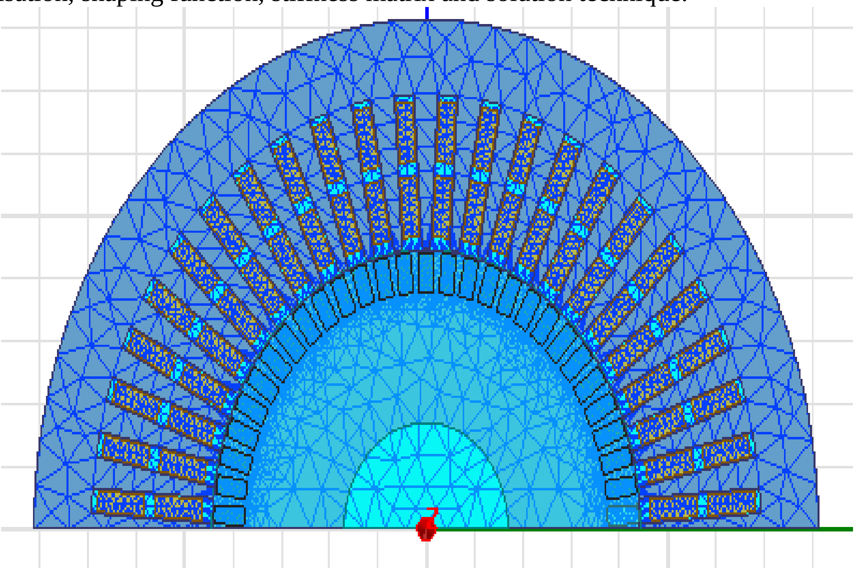


Fig - 1. Discretisation of Induction motor model

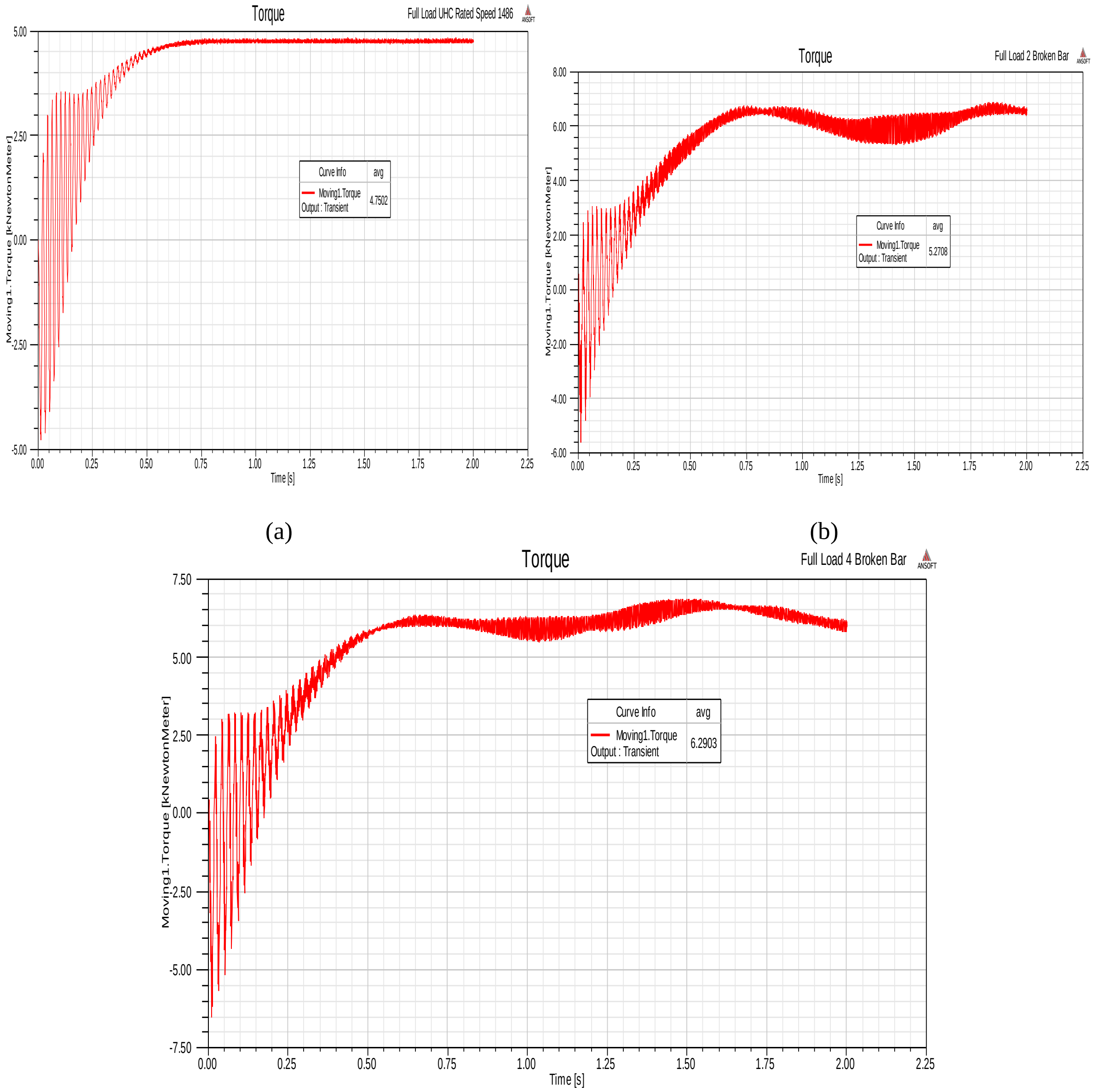
The steps involved in the CAD package are pre processing where the discretisation of model is done, solver and post processing [7]. First the original field problem domains are discretised into number of sub domains or elements. The shaping function is defined at each node. To achieve minimization, it is convenient to separate the global energy into its element components and to minimization one triangle at a time[8]. Then appropriate solution technique is used to solve the equations and obtain the necessary parameters like energy, flux function, current, torque etc.

III. TRANSIENT ANALYSIS

In this section, the simulation results for the transient analysis of three phase induction motor for healthy motor, faulty motor with two, four broken bars under full load are presented.

A. Magnetic Torque Plot

The magnetic torque has been increased when the number of broken bars is increased. The value of magnetic torque is tabulated in Table II.



(a) (b)

(c)

Fig 2. Magnetic Torque Plot (a) Under Healthy Condition (b) 2 Broken Bar (c) 4 Broken Bar

It can be observed that under full load the magnetic torque obtained for healthy motor is 4.7502 kNm, for 2 broken bars is 5.2708 kNm, for 4 broken bars is 6.2903 kNm. The graphical representation for magnetic torque is shown in Fig. 2. When the number of rotor broken bar increases the resistance of the rotor will increase which in-turn leads to current increase and hence the torque.

TABLE II. MAGNETIC TORQUE

Condition		Magnetic Torque (kNm)	Percentage Change (%)
Full Load	Healthy	4.7502	-
	2 Broken Bar	5.2708	10.95
	4 Broken Bar	6.2903	32.42

Hence the above analysis shows that there is an increase in the percentage change when the broken bars increase.

B. Stator Phase Current Plot

The stator phase current plot healthy and faulty motor under full load is shown in Fig. 3. The time step is taken as 2 seconds.

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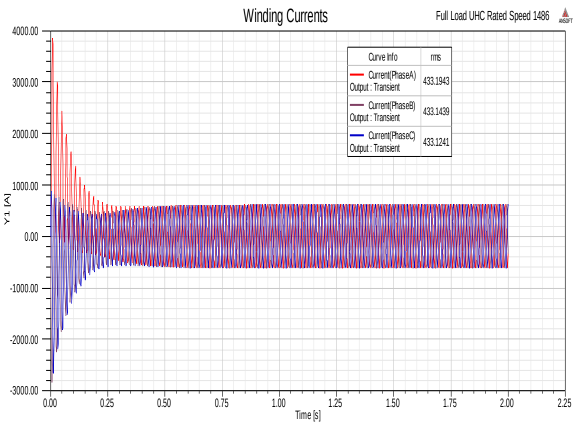
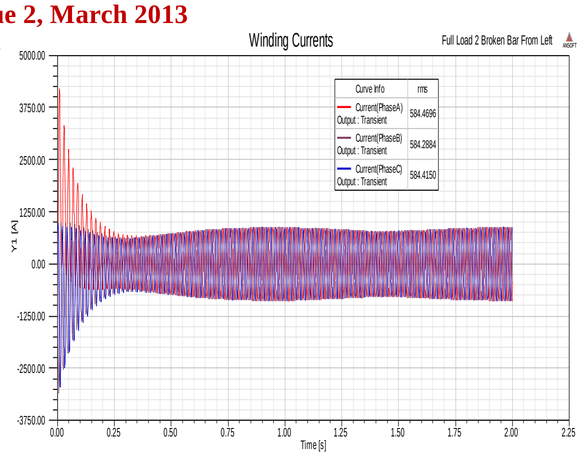
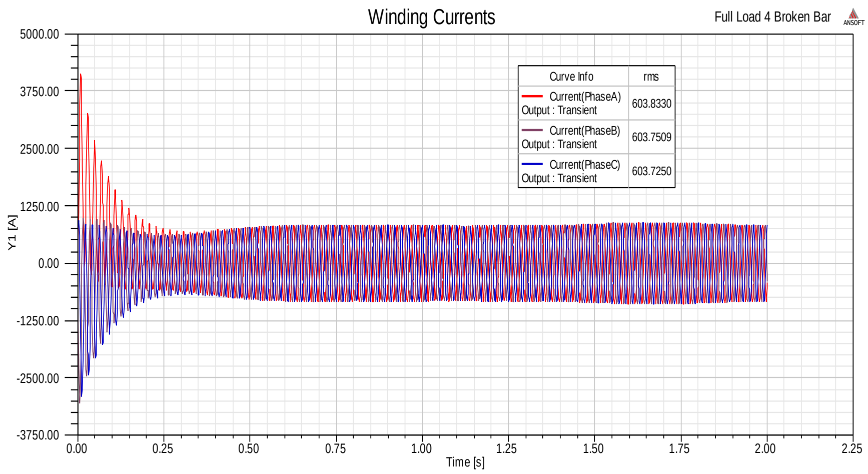


(a)



(b)



(c)

Fig 3. Stator Phase Current Plot (a) Healthy (b) 2 Broken Bar (c) 4 Broken Bar

The stator phase current values under various loads are tabulated in Table III.

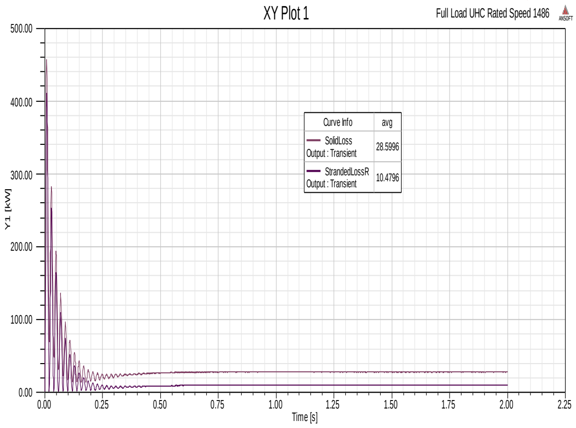
TABLE III. STATOR PHASE CURRENT

Condition		Stator Phase Current (A) RMS			Percentage Change (%)		
		Phase A	Phase B	Phase C	Phase A	Phase B	Phase C
Full Load	Healthy	433.1943	433.1439	433.1241	-	-	-
	2 Broken Bar	584.4696	584.2884	584.4150	34.92	34.89	34.93
	4 Broken Bar	603.8330	603.7250	603.7250	39.39	39.38	39.38

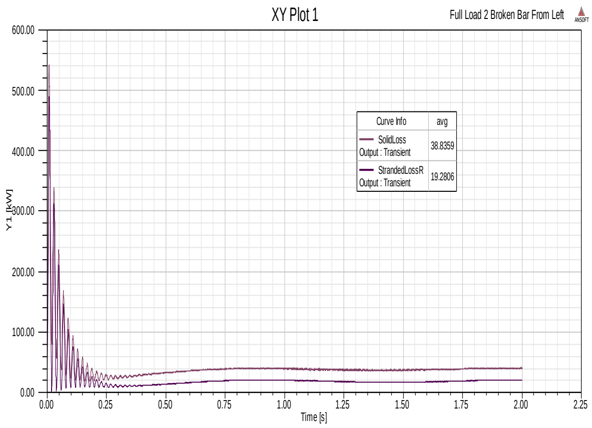
Under full load, the current obtained for healthy (Phase A) is 433.1943 A, for 2 broken bar 584.4696 A, for 4 broken bar 603.8330 A. Similarly it is continued for Phase B and Phase C. The stator phase current value has been increased when the number of broken bars increased. Hence the above analysis shows that there is an increase in the percentage change when the broken bars increase.

C. Solid and Stranded Losses

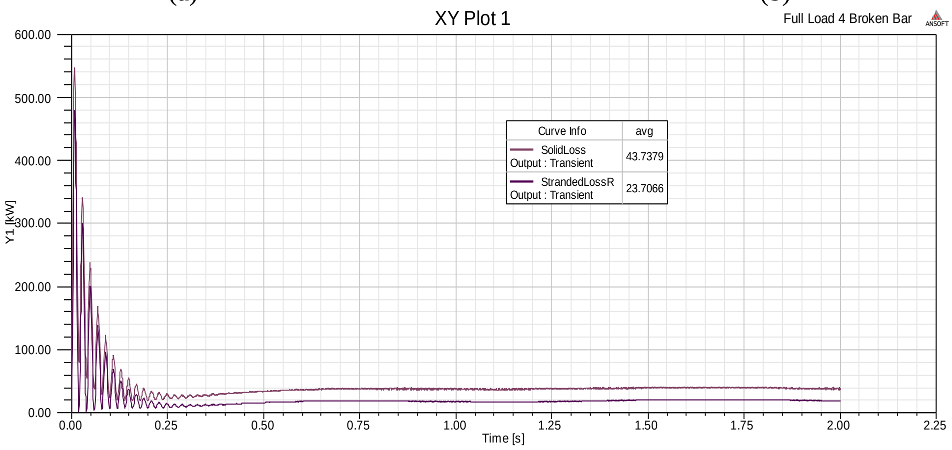
The solid and stranded loss has been increased when the number of broken bars is increased. The value for solid and stranded loss is tabulated in Table IV.



(a)



(b)



(C)

Fig 4. Solid and Stranded Loss (a) Healthy (b) 2 Broken Bar (c) 4 Broken Bar

It can be observed that under full load the solid and stranded loss obtained for healthy motor is 28.5996 kW, 10.4796 kW respectively. Similarly it is obtained for 2 and 4 broken bars.

TABLE IV. SOLID AND STRANDED LOSS

Condition		Losses (kW)		Percentage Change (%)	
		Solid	Stranded	Solid	Stranded
Full Load	Healthy	28.5996	10.4796	-	-
	2 Broken Bar	38.8359	19.2806	35.79	83.98
	4 Broken Bar	43.7379	23.7066	52.93	126.2

The graphical representation for solid and stranded loss is shown in Fig. 4. Hence the above analysis shows that there is an increase in the percentage when the broken bars increase.

IV. CONCLUSION

In this paper, a three phase squirrel cage induction motor is modeled on the basis of finite element method and the magnetic toque, stator phase current, solid and stranded loss is presented using Ansoft Maxwell. Comparisons are made with the healthy motor condition and the result is tabulated. In the transient analysis, it is found that the value of magnetic torque, stator phase current and solid and stranded losses increased when the numbers of broken bars are increased.

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AUTHOR BIOGRAPHY

Ray Hardik received her B.E degree in Electrical Engineering from G.H Patel College of Engineering and Technology, Vallabh Vidhyanagar, Gujarat, India 2010. He is presently a PG scholar in Electrical Power System, Electrical Department, Birla Vishwakarma Mahavidyalaya Engineering College. His research interest is on fault detection of squirrel cage induction motor.

Manish N. Sinha received his B.E degree in Electrical Engineering from Lukhdhirji Engineering College, Morbi, Gujarat, India. Master of Engineering in Electrical Power System from Birla Vishwakarma Mahavidyalaya Engineering College (ISTAR), Vallabh Vidyanagar, Anand, Gujarat, India. He has one year industry and 14 years teaching experience. He is presently a Assistant Professor in Electrical Department, Birla Vishwakarma Mahavidyalaya Engineering College. He has published around 20 technical papers in national and international conference proceedings/journals. His research interest is on Electrical Machines. He is a member of Institute of Engineers (India).

Vijayaraj J received his Diploma degree in Electronics and Communication Engineering from Sri Venkateswara Polytechnic, Vellore, B.E degree in Electrical Engineering from Jerusalem College of Engineering, Chennai, Master degree from Sri Venkateswara College of Engineering, Chennai and presently pursuing his Doctoral Degree from Indian Institute of Technology, Delhi. He has over 7 years of industrial experience. He has published two technical papers in national journals. His research interest is in Electric machine, permanent magnet and finite element method. He is a member of IEEE.