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Performance Analysis of Medium Voltage Induction Motor Using Stator Current Profile

W.Rajan Babu [1], Dr.C.S.Ravichandran[2], V.Matheswaran [3]

Assistant Professor, Department of EEE, Sri Eshwar College of Engineering, Coimbatore, Tamil Nadu, India[1]

Dean Electrical Science, Sri Ramakrishna Engineering College, Coimbatore, Tamil Nadu, India[2]

Design Engineer, The Riveraa Pumps India Private Limited, Coimbatore, Tamil Nadu, India[3]

ABSTRACT: Induction motor faults can be detected in an initial stage in order to prevent the complete failure of an induction motor and minimize the unexpected down time costs in production process. Accordingly, this paper presents three methods to detect induction motor faults. This paper analysis the fault diagnostic method that identifies the faults like inter-turn short circuits in stator windings, broken rotor bars that helps in identifying the motor fault's severity and air gap eccentricity occurring in the rotor. These types of faults represent 40 to 50% of all reported faults. The performance of the induction motors are analysed using its stator current profile.

KEYWORDS: Stator winding fault, rotor cage failure, air-gap irregularities, Medium Voltage Induction Motor

I.INTRODUCTION

MEDIUM-VOLTAGE (MV) induction motors are broadly used in the petrochemical, chemical, pulp, and paper industries, etc., and are typically essential to industrial processes. In many applications, these motors are operated under environmental stresses, such as high ambient temperature, high moisture, etc., which could lead to motor malfunction. Malfunction of these motors leads to not only high repair expense but also extraordinary financial loss due to unexpected downtime. Therefore, reliable monitoring and protection for MV motors is of great value to avoid catastrophic unscheduled downtime. IEEE Standard 841 motors are typical examples of MV large-sized induction machines used primarily in the petroleum and chemical industries.

TABLE I
COMPARISON OF IEEE, EPRI, AND ALLIANZ SURVEYS

MAJOR COMPONENTS	IEEE-IAS % OF FAILURES	EPRI % OF FAILURES	ALLIANZ % OF FAILURES
Bearing related	44	41	13
Stator related	26	36	66
Rotor related	8	9	13
Others	22	14	8

They are totally enclosed fan-cooled (TEFC) or naturally ventilated motors up to 4000 V and up to 500 hp.
Their electrical features are as follows:

- Motors rated for ambient temperature from −25 °C to +40 °C;
- starting output torque is about 40%–50% of the rated output torque;
- 2300-V and 4000-V designs use vacuum-pressure impregnated form windings;
- Rotor cage construction often uses copper or its alloy;
- Average temperature rise of the stator winding shall not exceed 80 °C at rated voltage, frequency, and power, 90 °C at 1.15 Service Factor

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Several alternatives have been used in industry to prevent severe damage to induction motors from the above mentioned faults and to avoid unexpected production shutdowns. Schedule of frequent maintenance is implemented to verify the integrity of the motors, as well as to verify abnormal vibration, lubrication problems, bearings conditions, and stator windings and rotor cage integrity. Most maintenance must be performed with the induction motor turned off, which also implies production shutdown.

Usually, large companies prefer yearly maintenance in which the production is stopped for full maintenance procedures. Redundancy is another way to prevent production shutdowns, but not induction motor failure. Employing redundancy requires two sets of equipment, including induction motors. The first set of equipment operates unless there is a failure, in which case the second set takes over. This solution is not feasible in many industrial applications due to high equipment cost and physical space limitations. Thus, in this thesis an alternative to these approaches is proposed.

Specifically, this paper addresses electrically detectable faults that occur in the stator windings and rotor cage, namely inter-turn short circuits in stator windings and broken rotor bars. The methods developed in this paper detect motor faults without the necessity of invasive tests or process shutdowns. Moreover, the presented methods monitor the operating induction motor continuously, so that human inspection is not required to detect motor faults.

II.STATOR WINDING FAULT

Inter-turn short circuits in stator windings constitute a category of faults that is most common in induction motors. Typically, short circuits in stator windings occur between turns of one phase, or between turns of two phases, or between turns of all phases. Moreover, short circuits between winding conductors and the stator core also occur.
The different types of winding faults are summarizes below as follows

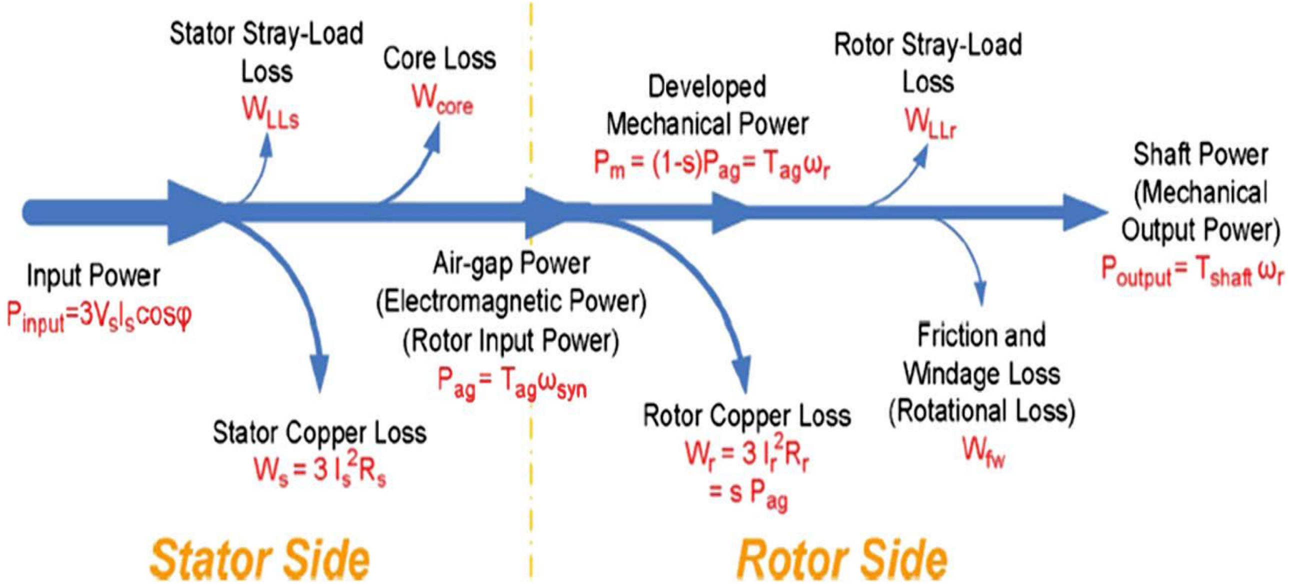
- Inter-turn short circuits between turns of the same phase winding short circuit, short circuits between winding and stator core, short circuits on the connections, and short circuits between phases are usually caused by stator voltage transients and abrasion.

- Burning of the winding insulation and consequent complete winding short circuits of all phase windings which are usually caused by motor overloads and blocked rotor, as well as stator energization by sub-rated voltage and over rated voltage power supplies. This type of fault can be caused by frequent starts and rotation reversals.

- Inter-turn short circuits are also due to voltage transients that can be caused by the successive reflection resulting from cable connection between motors and ac drives. Complete short circuits of one or more phases can occur because of phase loss, which is cause by an open fuse, contactor or breaker failure, connection failure, or power supply failure.

- Short circuits in one phase are usually due to an unbalanced stator voltage. An unbalanced voltage is caused by an unbalanced load in the power line, bad connection of the motor terminals, or bad connections in the power circuit. Moreover, an unbalanced voltage means that at least one of the three stator voltages is under or over the value of the other phase voltages.

- The Power flow in the Induction Motor is as shown below.



Although the stator winding of the MV motors are normally form-wound windings with more advanced insulation and are normally equipped with embedded thermal sensors for thermal protection, stator-related failures are still common in all MV motor failures, which is due to the higher electrical and thermal stresses on MV motors. Similarly, since the rotors of MV large motors are also under high stresses, including thermal stresses, mechanical stresses, and electrical stresses, the rotors of MV motors are typically more vulnerable compared to those of small motors.

TABLE II
LOSS SEGREGATION OF SMALL AND LARGE MOTORS

Losses Segregation of a 15 HP motor				
	W_{coper}	W_{core}	$W_{f\&w}$	W_{stray}
2 Pole	53	9	29	9
4 Pole	55	15	18	12
6 Pole	62	13	12	13

Losses Segregation of a 200 to 2000 HP motor				
	W_{coper}	W_{core}	$W_{f\&w}$	W_{stray}
2 Pole	29	15	36	20
4 Pole	35	18	24	23
6 Pole	37	23	18	22

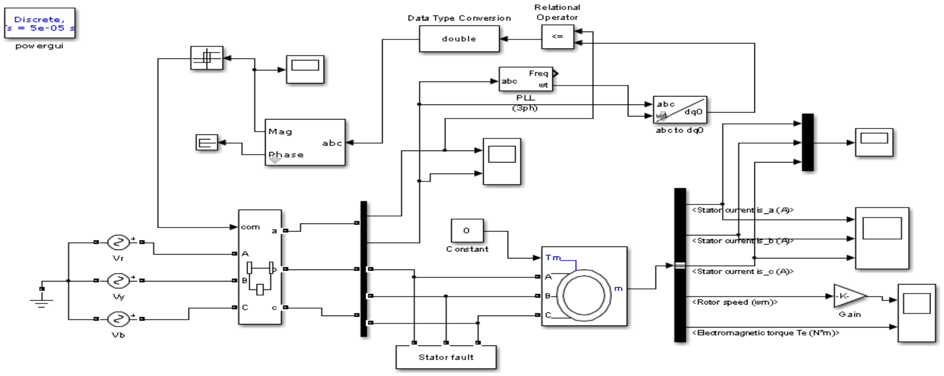


Fig 1. Simulink model of stator winding fault

The above figure 1 shows the Simulink model of stator winding fault works by giving the input supply is given to the stator through the three phase breaker and the voltage and current measurement block. Hence the direct voltage and current components and the components after converting from abc to dq components are compared using the relational operator and the output of it is again converted from abc to dq components to activate the relay function giving it as a feedback to the circuit breaker which trips the supply during the fault condition.

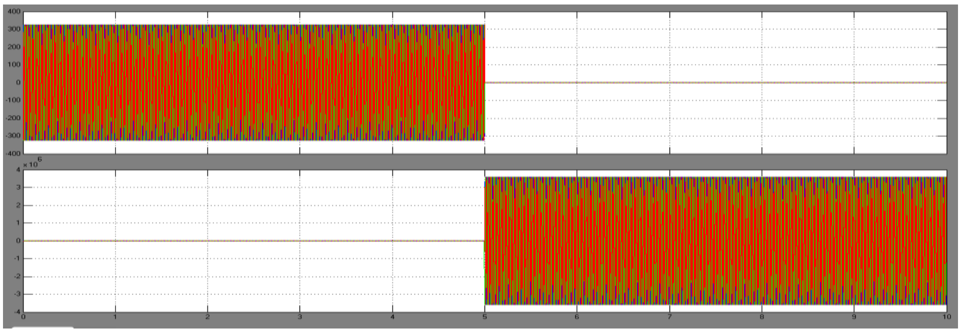


Fig 2 Simulink Output showing the voltage and current waveform

The above figure shows the voltage and current waveform for the Simulink model of figure 1 where the output will be normal till the fault occurs. At the time the fault occurs, the input trips off and the motor stops its operation.

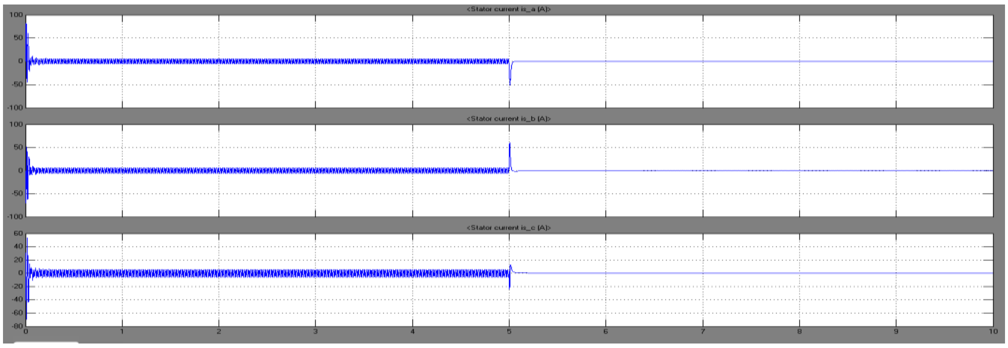


Fig 3. Simulink Output showing the three phase current waveforms

The above figure 3 shows the output waveform for three phase current which shows the normal flow of motor current till the fault occurs, when the fault occurs the motor operation stops.

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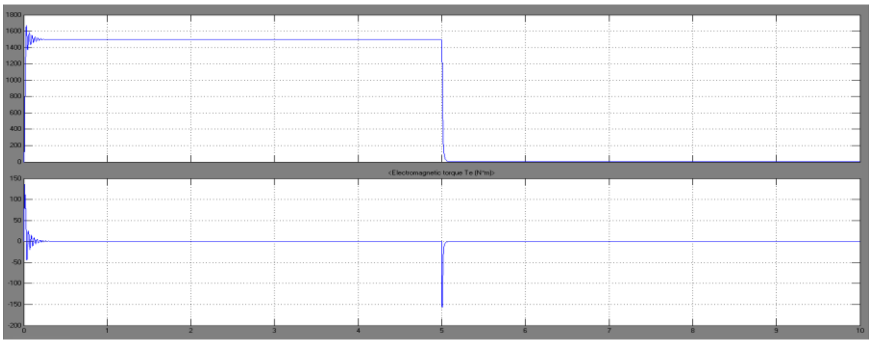

Fig 4. Simulink Output showing the speed and torque waveforms

The above figure 4 shows the speed and torque waveform which is normal and steady after few oscillations and when a fault occurs, the motor operation stops and hence the motor torque and speed comes zero.

III.ROTOR CAGE FAILURES

The squirrel cage of an induction motor consists of rotor bars and end rings. A broken bar can be partially or completely cracked. Such bars may break because of manufacturing defects, frequent starts at rated voltage, thermal stresses, and/or mechanical stress caused by bearing faults and metal fatigue.

Rotor cage fault (broken rotor bar/end-ring) accounts for approximately 5–10% of all induction motor failures. For MV motors, the rotor cage fault is even more common than that of small motors due to the extensive thermal stresses on the rotor. Normally, broken rotor bar can be caused by the following reasons:

1) Thermal stresses due to thermal overload; overheating of the rotor cage can cause thermal expansion and thus mechanical stresses;
2) Magnetic stresses caused by electromagnetic forces, unbalanced magnetic pull;
3) Dynamic stresses due to shaft torques;
4) Environmental stresses due to contamination, abrasion of rotor material;
5) Mechanical stresses due to lose laminations, etc.

A broken bar causes several effects in induction motors. A well-know effect of a broken bar is the appearance of the so-called sideband components. These sidebands are found in the power spectrum of the stator current on the left and right sides of the fundamental frequency component.

The frequencies of these sideband are given by:
$fb = (1 \pm 2s) f$,
where s is the slip in per unit and f is the fundamental frequency of the stator current.

Other electric effects of broken bars are used for motor fault classification purposes including speed oscillations , torque ripples, instantaneous stator power oscillations, and stator current envelopes. Here the fault monitoring method is based on torque ripples for broken bar detection, while the fault diagnostic method is based on the three-phase stator current envelope for classification of broken rotor bars and inter-turn short circuits.

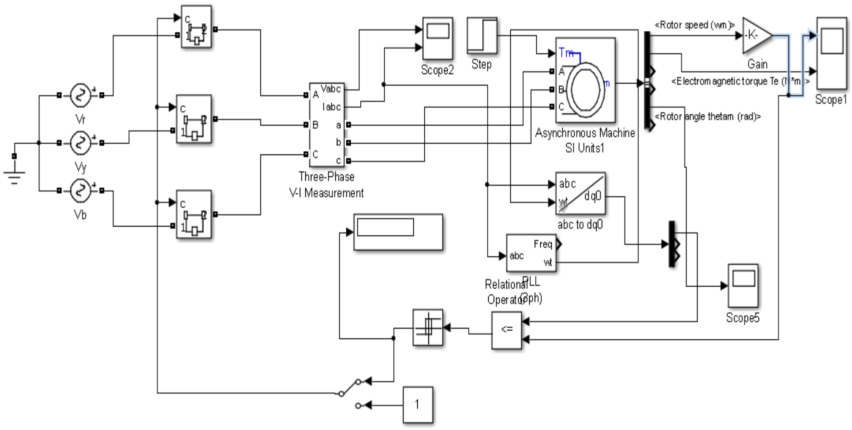

Fig 5. Simulink model of rotor cage failure

The above figure 5 shows the Simulink model of rotor cage failure where the relay is connected to the circuit breaker, If fault occurs in rotor the changes of motor operation from normal operating condition then the relay trips the circuit breaker.so that the motor becomes to rest.

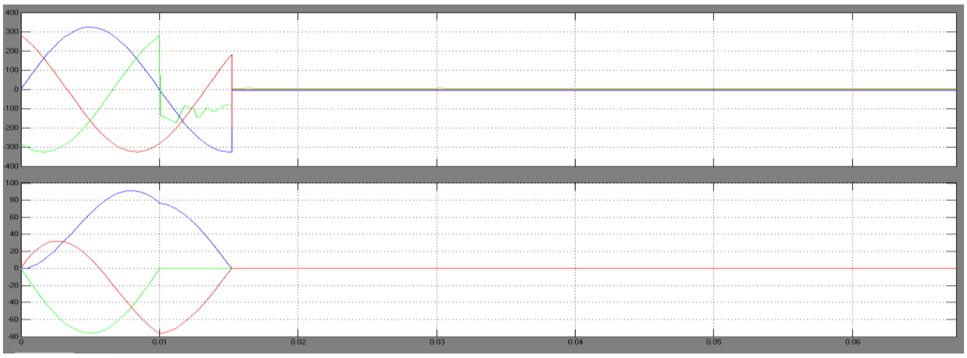

Fig 6. Simulink Output showing the voltage and current waveforms

The above figure 6 shows the output voltage and current waveform for the rotor cage failure, where the three phase voltages and currents will flow normally till the fault condition occurs. When the fault occurs, the motor stops and the voltage and current flow reduce to zero.

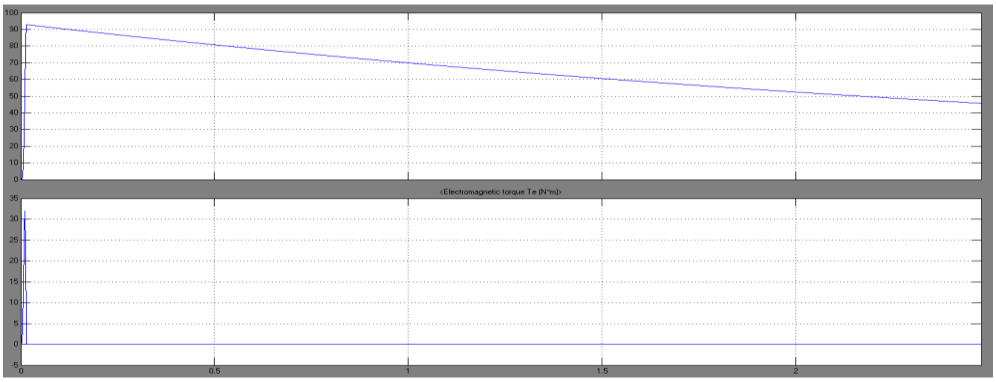

Fig 7. Simulink Output showing the Speed and torque response of induction motor

The above figure 7 shows the speed and torque curve for the rotor cage failure where it runs in its normal speed and torque till the rotor cage failure fault occurs. The value of the speed reduces from its normal value and the torque value reduces to zero at the time of fault.

IV.AIR GAP IRREGULARITIES

The air gap torque profile for the same case-study induction motor under the same operating conditions. It is important to observe the same envelope characteristic in both signals, i.e. the frequency of the envelope and the oscillations of air gap torque are the same. The amplitude of the envelope and of the air gap torque is proportional to the motor load. If the motor is loaded, the amplitude of the envelope and of the air gap torque increases. Thus, the profile modulations of the envelope and torque are more evident. For the no load case, the amplitude of the envelope and the torque oscillations are very low.

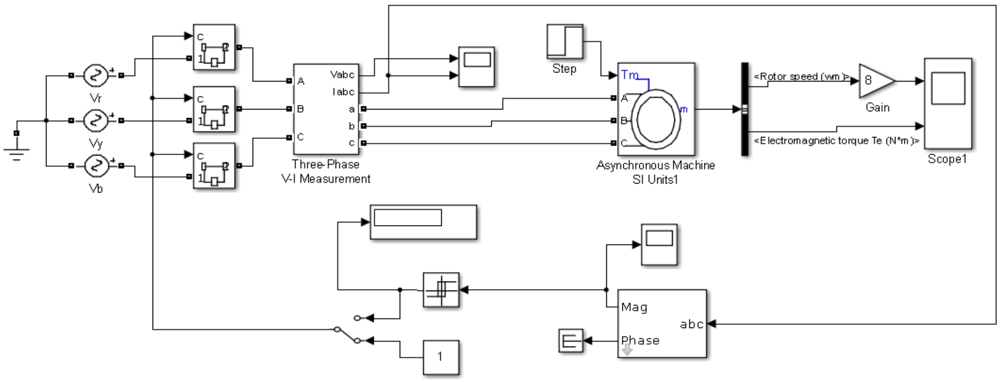

Fig 8. Simulink model of air gap irregularities

The above figure 8 shows the Simulink model of air gap irregularities. Here when the friction factor in the motor parameter block is increased, the air gap between the stator and the rotor reduces.

Here the three phase voltage and current values are changed from abc components to dq components in which the d component specifies the magnitude and q component specifies the phasor value. If the magnitude value is more, then it represents the fault condition.

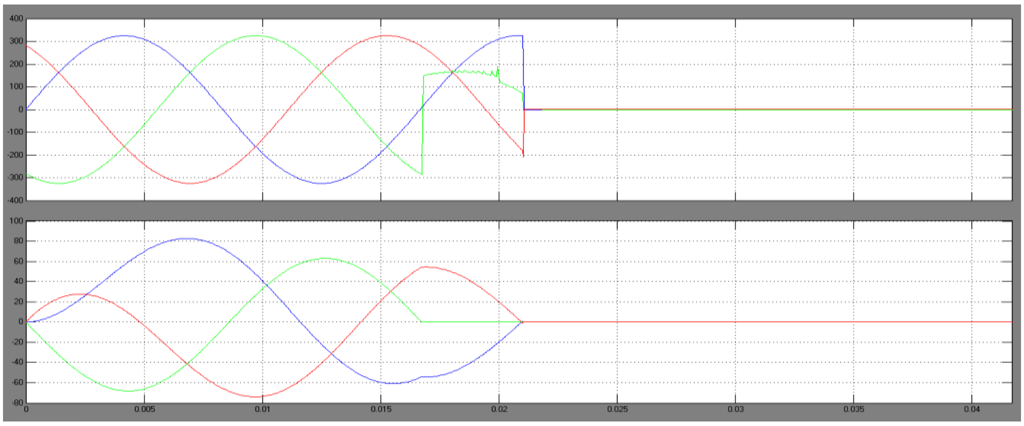

Fig 9. Simulink Output showing the voltage and current waveforms of motor

The above figure 9 shows the voltage and current waveforms for the air gap irregularities. The motor operates in normal condition, once there is a change in air gap due to friction or heavy load then the value of voltage and current becomes to zero.

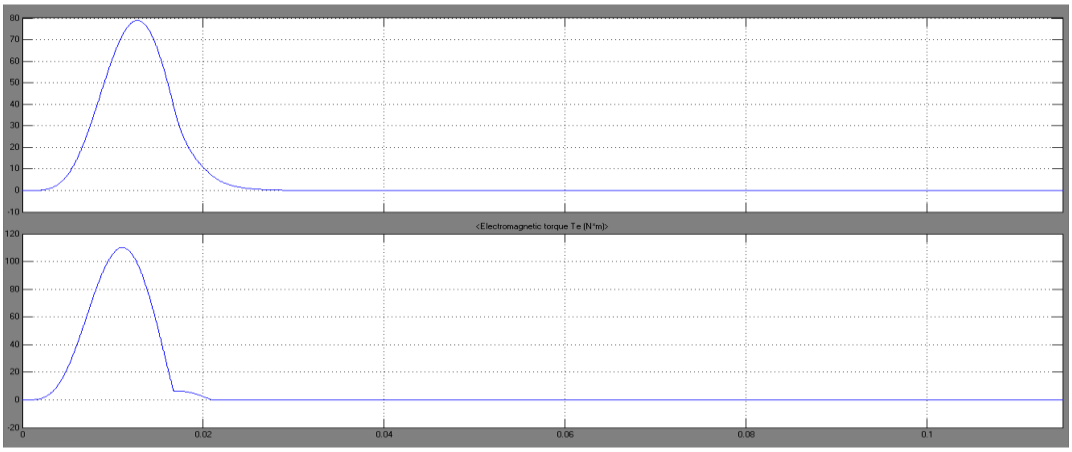

Fig 10. Simulink Output showing the Speed and torque response of induction motor

The above figure 10 shows the speed and torque response of the motor during the air gap irregularities fault condition. In case of drop in voltage and current automatically the speed and torque gets to zero. Then the motor comes to rest.

V.CONCLUSION

This paper presents a comprehensive method of the condition monitoring of induction motors. Detection of faults like stator inter turn fault, bearing failure detection, broken rotor bar/end-ring detection, and air gap eccentricity detection are done. For each type of fault the performance of the motor is is predicted using its current profile by which the type of fault is easily predictable. This technique is easier and reliable.

Moreover, the physical phenomenon associated with each of these faults was described, and the features of the induction motor performance resulting from these faults were presented using the simulink model for each of these faults.

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