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# DIAGNOSIS OF INDUCTION MOTOR FAULT BY PARAMETER ESTIMATION TECHNIQUE

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***Abstract-*** **This paper addresses a simple and reliable technique, based on parameter estimation methods, is introduced for rotor broken bar fault detection. Condition monitoring of electric motors avoids unexpected motor failures and greatly improves system reliability and maintainability. These are very important issues in motor-driven and power-electronics systems since they are very important issues in motor-driven and power-electronics systems since they can greatly improve the reliability, availability, and maintainability of the system. Induction motors are critical components in many industrial processes early fault diagnosis and Condition monitoring can increase machinery availability and performance, reduces consequential damage, prolong machine life, reduce spare parts and breakdown maintenance. A reliable parameter estimation technique for induction motors is critical for the development of high-performance drive systems, and it can also be utilized for condition monitoring applications as well. An accurate parameter estimation technique can also be used for motor condition monitoring purposes.**

***Keywords:*** **Condition Monitoring, Recursive Least Square, Rotor fault.**

## I. INTRODUCTION

The induction motor fault diagnosis is a modern scientific area. It concerns the industry seriously, while faults can lead to the production process shutdown and/or to the motor irreparable damage. Throughout the literature, the main faults which may occur are broken/cracked rotor bars and end-rings, eccentricity, and stator faults [1], [2]. Many diagnostic methods have been proposed during the years. The dominant method amongst them is the widely known Motor Current Signature Analysis (MCSA) method [3]. Other means such as the torque [4] the magnetic field [5], and the electrical power [6] have also been used extensively throughout the literature for prompt fault detection.

Three phase Induction motors are now a day widely used in all types of industry applications due to their simple construction, higher reliability and availability of power converters using efficient control strategies. A permanent condition monitoring of the electrical drive can increase the productivity, reliability and safety of the entire installation.

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Condition Monitoring (CM) is an important issue in many fields, including railways, power delivery, and electrical machines and motors. An Unexpected fault or shutdown can result in a serious accident and financial loss for the company. Energy companies must find ways to avoid failures, minimize downtime, reduce maintenance costs, and lengthen the lifetime of their equipment. With reliable condition monitoring, machines can be utilized in a more optimal fashion. It can be defined as a technique or process of monitoring the operating characteristics of a machine so that changes and trends of the monitored signal can be used to predict the need for maintenance before a breakdown or serious deterioration occurs, or to estimate the current condition of the machine. More than 95% of the induction motor used are squirrel cage motors.

The following are the major advantages of performing condition monitoring in induction machines.

- Increases Reliability of the machines.
- Increases machinery availability.
- Decreases loss of production due to faulty motors.
- Increases machinery performance.
- Reduces consequential damage due to faults in machines.
- It prolongs machine life.
- Reduces spare parts.
- Reduces breakdown maintenance.

Through Figure.1 shown below we might think in spite of all protective equipments in modern days what will be the reason for destruction of the motor. The end result in this picture is that the motor is completely destroyed, but what started it? Was it a bearing fault, excessive starts, or a poor ventilation system? In this example, the rotor was locked when it started and could not reach running speed. The resultant high currents overheated the rotor, stator, shaft and other components in the motor. Inspection later revealed that the overloads in the power circuit it had failed and did not trip the motor, resulting in complete destruction of the motor. There were multiple problems in this situation, which led to the destruction of the motor.

**Fig.1Typical fault in induction motor**

If condition monitoring has been carried out in this case complete destruction of the motor could have been avoided and hence a huge amount of cost might have been saved. Thus, CM is desirable for such cases. This motivates the need for developing new reliable and efficient CM methods to avoid such damages.

### A. CLASSIFICATION OF FAULTS

The most prevalent faults in Induction Motor are briefly categorized as


**Fig. 2 Classification of faults**

The surveys indicate that in general, failures in electrical machines are dominated by bearing and stator faults with rotor winding problems being less frequent. Fig. 2 shows the statistical spread in the various dominant mechanisms.

Reliable electrical motor performance is vital to profitable plant operation. Motor maintenance spending constitutes the largest component (50-70%) of electrical maintenance budgets. Based upon a study, 37% of electrical motor failures can be attributed to stator problems. The other 63% (rotating assemblies, including bearings) are susceptible to imbalance, misalignment, and other mechanical problems that can be diagnosed and mitigated through the proper application of vibration monitoring and other well-known practices [21].

To minimize the cost of motor ownership and optimize opportunity, it is essential to have a reasonable understanding of a motor's condition and its residual life. This can be accomplished using several different testing methods, ranging from on-line monitoring to off-line testing. This chapter focuses on describing the classification of various causes and faults of induction motors in detail.

### B. BROKEN ROTOR BAR FAULTS

These common faults occur on the movement part of cage rotor type or synchronous machine, which has damper bars. Cracking or breaking these bars arises due to manufacturing problem on the bar itself or due to high value of bar currents which induce through rotor circuits. These currents are caused by unbalanced, sudden or over loading of the machine. It had been shown that the broken bar may detect the material properties of the core and the current distribution of the adjacent rotor bars. Therefore, the adjacent bar is more susceptible to break than the nonadjacent bar.

### C. STATOR WINDING FAULTS

In this type of faults, a short circuit could occur between two adjacent turns, coils or even between phases. In advanced stage, faults may take place between the core and the stator windings. Harmonics components of the flux density in the air-gap region may be used to give an indication about the stator turn faults. As a result, the magnetic flux as well as flux density will be deformed, and stored magnetic energy will decrease in proportion to the degree of short circuit [9]. Therefore, it is possible to diagnose the faults of induction machines
by analyzing the magnetic field quantities.

### D. AIR-GAP ECCENTRICITY FAULTS

In this kind of faults, the air-gap of the machine has unequal spaces along the outer radius of rotor. Air-gap eccentricity faults may occur due to damage of the mechanical parts of the electric machine like the gearbox bearings. These misalignments of the shaft include static eccentricity, dynamic eccentricity or mixed eccentricity. In static eccentricity, although the axial axis of the rotor coincides with the axial axis of rotation, it does not coincide with stator axis, and the minimum air-gap position is mixed. In dynamic eccentricity, the rotor axial axis does not coincide with the axis of rotation, and the minimum air-gap position rotates along the internal boundary of the stator.

## II. CONDITION MONITORING USING PARAMETER ESTIMATION METHOD

There are many papers regarding rotor condition monitoring, and rotor fault detection. Some of these works have mainly used the frequency spectrum of the stator current for rotor condition monitoring. The rotor magnetic field orientation pendulous oscillation, due to broken bars, was recently presented as an index for rotor fault diagnostic purposes. There are other techniques which are based on the artificial intelligence and data mining methods as well as some investigations based on parameter estimation or parameter identification techniques.

A reliable parameter estimation technique for induction motors is critical for the development of high-performance drive systems, and it can also be utilized for condition monitoring applications as well. However, in the context of existing literature the main thrust of parameter estimation techniques in motor-drive control applications is its use to achieve fast and controlled torque response of an induction motor utilizing the principle of vector (field oriented) control. The widely-used squirrel-cage rotor aids in the robustness and economy of the drive, but rotor quantities are not accessible. However, the full advantage of vector control is available only if the instantaneous position of the rotor flux vector relative to a stationary reference frame can be indirectly obtained. Hence, knowledge of motor parameters is needed.

An accurate parameter estimation technique can also be used for motor condition monitoring purposes. Here in this paper, a simple and reliable technique, based on parameter estimation methods, is introduced for rotor broken bar fault detection. The main idea is that the apparent rotor resistance and leakage inductance of a squirrel-cage induction motor will increase when a rotor bar breaks. Meanwhile, the stator resistance, inductance and the magnetizing inductance will not be directly impacted by such rotor bar breakages. It is a wellestablished fact that a broken bar fault generates modulation envelops superposed on the amplitudes of stator currents over a slip cycle. This type of envelops cannot be observed under no-load condition because the squirrel-cage bars virtually conduct no current under such a condition. Accordingly, the rotor circuit's effects are hardly reflected on the stator side. This means that the stator parameters are not affected by a bar breakage. This is due to the fact that in a no-load situation only the electrical circuits of the stator windings carry the currents and the rotor circuit behaves like an open circuit secondary winding.

This paper addresses two issues, first it presents a new approach for rotor parameter estimation of induction motors, and second it presents the utilization of this parameter estimation approach for purposes of rotor condition monitoring of induction motors.

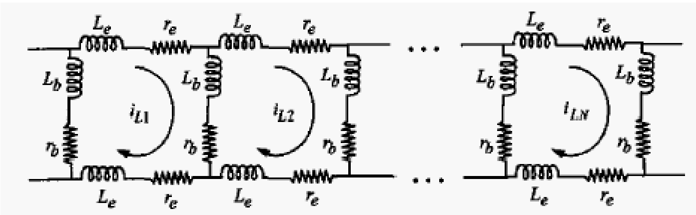

**Fig.3 Developed Squirrel Cage Rotor Model**

- Rotor Resistances & Inductance of a IM will increase when a rotor bar breakage occurs.
- If Rotor bar breaks the bar resistance $r_b$, will assume an infinite value.
- Consequently, increase in the overall equivalent resistance of the rotor cage is affected.

## III. METHODOLOGY

The present rotor parameter estimation approach constitutes a combination of signal processing and least squares techniques. In this approach, the motor terminal currents, voltages and motor speed are sampled over a specific period of time. The measured voltages and currents are transformed from an ABC frame of reference to a stationary dq0 reference frame. Then, the obtained voltages and currents are further broken down to their frequency components. Furthermore, those waveforms are mathematically expressed in a form of summation of sinusoidal waveforms with their associated frequencies. Consequently, the rotor currents, which are not physically accessible, can be calculated. Based on the measured stator quantities and obtained rotor currents, all represented in the stationary dq0 reference frame, a least squares method was implemented to calculated the rotor's inductance and resistance estimations.

The matrix equation of IM in dq0 reference frame is given by

$$\begin{pmatrix} V_{qs} \\ V_{ds} \\ 0 \\ 0 \end{pmatrix} = \begin{pmatrix} r_s+L_sD & \omega L_s & L_mD & \omega L_m \\ -\omega L_s & r_s+L_sD & -\omega L_m & L_mD \\ L_mD & (\omega-\omega r)\,L_m & r_r+L_rD & (\omega-\omega_r)\,L_r \\ -(\omega-\omega_r)\,L_m & L_mD & -(\omega-\omega_r)\,L_r & r_r+L_rD \end{pmatrix} \begin{pmatrix} i_{gs} \\ i_{ds} \\ i_{qr} \\ id_r \end{pmatrix} \quad \text{------- (1)}$$

where,

$R_s$ is Stator resistance.
$R_r$ is Rotor resistance.
$L_s$ is Stator inductance.
$L_r$ is Rotor inductance.
$L_m$ is Magnetizing inductance.
$\omega_r$ is Rotor speed.
$\omega$ is Speed of reference frame.
D is time differential operator.

This matrix equation can be represented in a dq0 reference frame fixed to the stator, by substituting the reference frame speed, $\omega = 0$ in equation **1**, which leads to the following

$$\begin{pmatrix} V_{qs} \\ V_{ds} \\ 0 \\ 0 \end{pmatrix} = \begin{pmatrix} r_s+L_sD & 0 & L_mD & 0 \\ 0 & r_s+L_sD & 0 & L_mD \\ L_mD & -\omega r\,L_m & r_r+L_rD & -\omega_rL_r \\ \omega_r\,L_m & L_mD & \omega_r\,L_r & r_r+L_rD \end{pmatrix} \begin{pmatrix} i_{gs} \\ i_{ds} \\ i_{qr} \\ id_r \end{pmatrix} \quad \text{----------- (2)}$$

The first two rows of (**2**), which express the stator differential equations, can be rewritten as follows

$$Di_{qr} = 1/L_m\,(v_{qs} - r_si_{qs} - L_sDi_{qs}) \quad \text{-------- (3)}$$

$$Di_{dr} = 1/L_m\,(v_{ds} - r_si_{ds} - L_sDi_{ds}) \quad \text{--------- (4)}$$

Here, $v_{qs}$, $v_{dr}$, $i_{qs}$, $i_{ds}$, $i_{qr}$, and $i_{dr}$ are represented in the stationary frame of reference with the rotor currents referred to the stator side. Using the Fast Fourier Transformation (FFT), one can obtain all frequency components of any stator or rotor voltages and currents. From the obtained frequency components, the waveforms can be reconstructed in a time domain as the summation of the sinusoidal waveforms.

From equation **4**, the rotor differential equations can be rewritten as follows

$$i_{qr}r_r + (Di_{qr} - w_ri_{dr})L_r = W_rL_mi_{ds} - L_mDi_{qs} \quad \text{-------- (5)}$$

$$i_{dr}r_r + (Di_{dr} + w_ri_{qr})L_r = -w_rL_mi_{qs} - L_mDi_{ds} \quad \text{--------- (6)}$$

Where, the unknown parameters are the rotor resistance, $r_r$, and the rotor inductance, $L_r$. In order to estimate these parameters, either (**5**) or (**6**) can be used for implementing a Least Squares (LS) method. Here, equation (**5**) is considered for the remainder of the discussion on estimating the unknown parameters.

## IV. RECURSIVE LEAST SQUARE TECHNIQUE

Let vectors θ and X, and scalar Y be defined as follows

$$\theta = [\theta_1\ \theta_2]^T = [r_r\ \ L_r]^T \quad \text{-----(7)}$$

$$X = [x_1\ x_2]^T = [i_{qr}\ \ Di_{qr} - \omega_ri_{dr}]^T \quad \text{-----(8)}$$

$$Y = L_m(\omega\,_ri_{ds} - Di_{qs}) \quad \text{-----(9)}$$

Hence, (**8**) can be expressed based on the vectors of the unknown parameter, θ , X , and Y as follows

$$X^T \theta = Y \qquad \text{-------- (10)}$$

If we make N measurements, N > 2, we could minimize the squared error between the actual output, y $(t_k)$ and the predicted output, $\hat{y}(t_k) = \hat{\theta}^T X(t_k)$ , by minimizing

$$J(\hat{\theta}) = 1/N \{\sum_{K=1}^{N} \alpha[y(t_k) - \theta^T x(tk)]^2\} \qquad \text{-------- (11)}$$

where, α is known as the weighting factor

and typically (1/ α ) is set to a value just less than one. After further mathematical manipulation the following formulations are obtained.

$$\hat{\theta}(t_k) = \hat{\theta}(t_{k-1}) + P(t_k)x(t_k)\alpha[y(t_k) - (\hat{\theta}(t_{k-1}))^T x(t_k)] \qquad \text{--------- (12)}$$

where,

$$P(t_k) = P(t_{k-1}) - \frac{P(t_{k-1})x(t_k)(x(t_k))^T P(t_{k-1})}{(x(tk))^T P(tk-1)\, x(t_k) + (1/\alpha)} \qquad \text{--------- (13)}$$

It has to be pointed out that the denominator in equation (**13**) is a scalar, although x is a vector, and P is a matrix. Typically, $P(t_0) = CI_{2x2}$, where, C is a large constant number.

## V.SIMULATION RESULTS AND ANALYSIS

Parameter estimation approach based on recursive least square algorithm discussed in the previous chapter is validated for the following parameters using **MATLAB / SIMULINK** Software as shown in fig4.

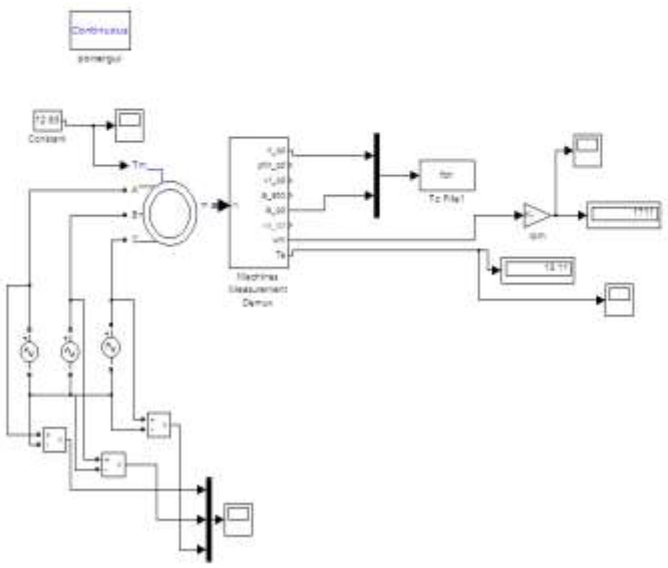

**Fig. 4 Simulation Circuit**

### A. SPECIFICATIONS OF MOTOR USED

| | |
|---|---|
| HP rating | = 3 hp |
| Voltage | = 220 (L-L) |
| Frequency | = 60 Hz |
| Stator Resistance | = 0.435 ohms |
| Stator Inductance | = 4 mH |
| Rotor Resistance | = 0.816 ohms |
| Rotor Inductance | = 2 mH |
| Mutual Inductance | = 69.31 mH |
| Moment of Inertia | =0.089 Kgm2 |
| Rated Speed | = 1725 rpm |
| No. of Poles | = 4 |
| Rated Torque | = 12.93 Nm |
| No. of Rotor bars | = 36 |

The induction motor model of MATLAB is simulated for various cases namely healthy, one bar broken, three bars broken and five bars broken conditions. Corresponding values of speed, current and voltages in dq0 frame is sampled and stored for further processing in least square algorithm. Then the M-file for the algorithm is run to estimate the values of rotor resistance and inductances.

### B. SIMULATION RESULTS

The simulation results for the various cases are listed below.

**TABLE I**
**Actual and Estimated Rotor Resistance**

| Case | Actual value | Estimated Value | %Error |
|---|---|---|---|
| **Healthy condition** | 0.816 | 0.7901 | 3.17 |
| **One bar broken** | 0.8387 | 0.813 | 3.06 |
| **Three bar broken** | 0.884 | 0.86 | 2.71 |
| **Five bar broken** | 0.929 | 0.9 | 3.15 |

**TABLE II**
**Actual and Estimated Rotor Inductance**

| Case | Actual value | Estimated Value | %Error |
|---|---|---|---|
| **Healthy condition** | 2 mH | 1.9811 mH | 0.945 |
| **One bar broken** | 2.0012 mH | 1.9831 mH | 0.904 |
| **Three bar broken** | 2.0036 mH | 1.9852 mH | 0.918 |
| **Five bar broken** | 2.00722 mH | 1.9885 mH | 0.929 |

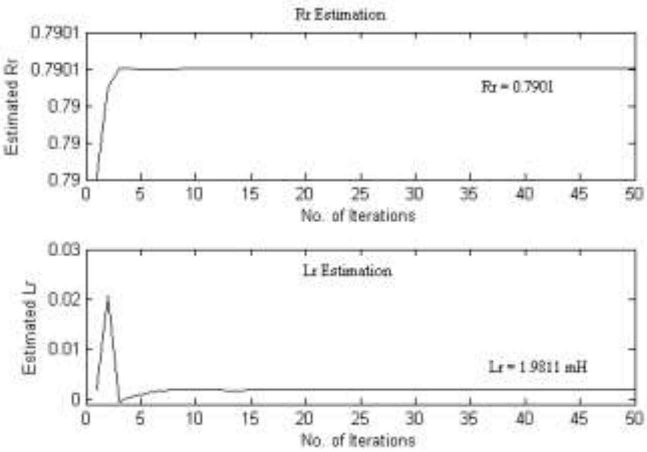


**Fig 4 Estimated values of rotor resistance & inductance (Healthy case)**

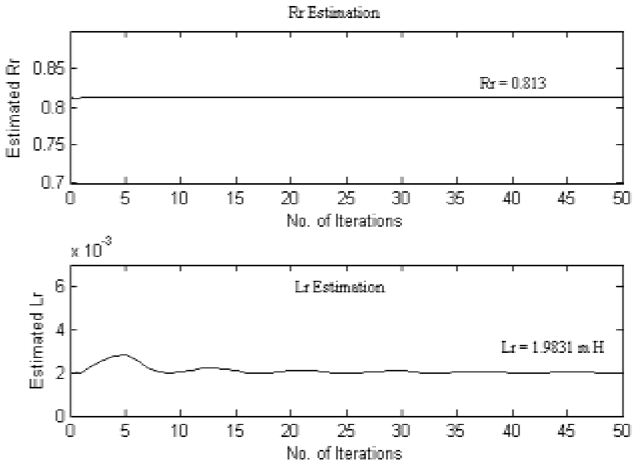


**Fig 5 Estimated values of rotor resistance & inductance (One bar Broken case)**

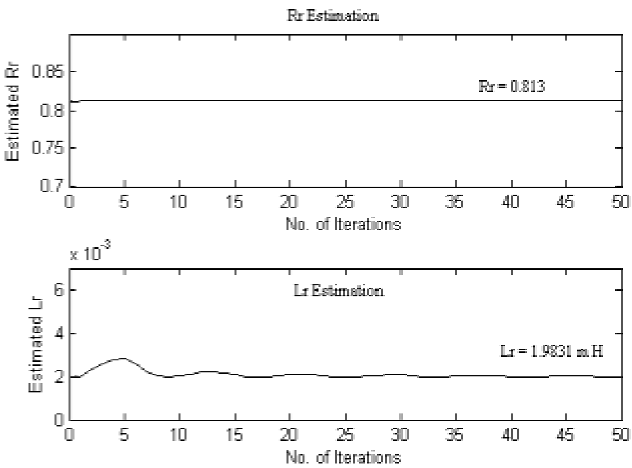


**Fig 6 Estimated values of rotor resistance & inductance (Three bar Broken case)**

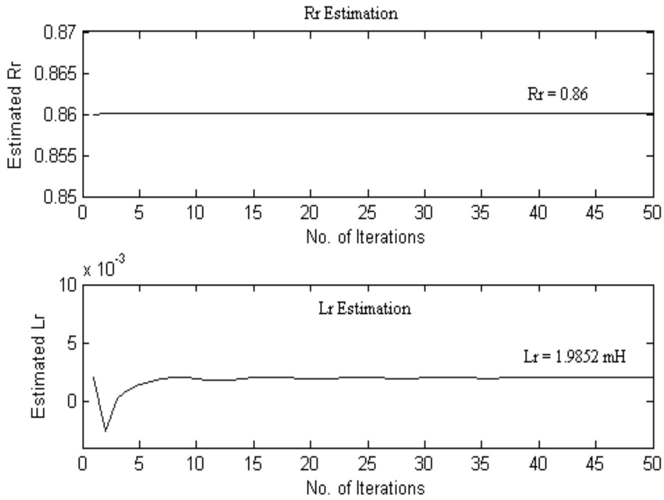


**Fig 7 Estimated values of rotor resistance &inductance (Five bar Broken case)**

## D. ANALYSIS

Simulation results are shown in the previous section. Table 1 gives the estimated values of rotor resistance for all the four cases. We can see that that resistance value increases for every case which is according the basic principle of the methodology. Also, it can be noted that error also remains near 3 %. Table 2 gives the estimated values of rotor inductance for all the four cases. Similarly hear also there is slight increase in the value of the inductance for each case. But it can be noted that the change is not as much as the change in the resistance value.

## VI. CONCLUSION

It has been shown that a simple and reliable rotor parameter estimation approach presented here used for the rotor condition monitoring purposes. The proposed methodology has been validated through simulation for one, three and five bars broken conditions. The estimated rotor resistance and inductance indicates that these parameters increase in value with an increase in the number of broken bars. Moreover, from the simulation results, it has been found that estimation of the rotor inductance is more reliable than the rotor resistance, because the error is less when compared to the resistance.

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