Induction Machine, Loss Modelling and Parameter Estimation

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Abstract—Induction machines (IMs) are today widely used in various applications. For example, it is by far the most used electrical motor in industry. Asynchronous motors, particularly the squirrel-cage induction motor, enjoy several inherent advantages like simplicity, reliability, low cost and virtually maintenance-free electrical drives. These facts are due to the induction motor advantages over the rest of motors. The main advantage is that induction motors do not require an electrical connection between stationary and brushes. Induction motor also has low weight and inertia, high efficiency and high overload capability. In addition, due to its practical importance, tremendous amounts of money are still spent today on research regarding its physics and operation. The range of possible research subjects pertaining to IMs is beyond belief. Covering all results and all references available in the literature could easily fill up a thesis all by itself.

Keywords—Induction Machine, Modelling, Thermal Rise, Parameters, Stator and Rotor Winding Resistance

I. INTRODUCTION

Induction machines (IMs) are today widely used in various applications. For example, it is by far the most used electrical motor in industry. Asynchronous motors, particularly the squirrel-cage induction motor, enjoy several inherent advantages like simplicity, reliability, low cost and virtually maintenance-free electrical drives. These facts are due to the induction motor advantages over the rest of motors. The main advantage is that induction motors do not require an electrical connection between stationary and brushes. Induction motor also has low weight and inertia, high efficiency and high overload capability. In addition, due to its practical importance, tremendous amounts of money are still spent today on research regarding its physics and operation. The range of possible research subjects pertaining to IMs is beyond belief. Covering all results and all references available in the literature could easily fill up a thesis all by itself.

Hybrid electric vehicles (HEVs), which combine the internal combustion engine of a conventional vehicle with the electric motor of an electric vehicle, are fuel efficient and environmentally friendly. The development of modern technology, including power electronic components, electric machines, computer control and software makes switching power between the gasoline engine and electric drive motor appear to be seamless to the driver. In comparison to the internal combustion engine, an electric motor is a relatively simple and far more efficient machine. The moving parts consist primarily of the armature (DC) or rotor (AC) and bearings, and the motoring efficiency is typically on the order of 80% to 95%. In addition, the electric motor torque characteristics are much more suited to the torque demand curve of a vehicle. Figure 1 depicts the basic classification of induction machine. The problems associated with existing control technique can only be reviewed and commented after the literature survey. Rotor resistance estimation and modelling of induction machine have been popular for past one decade in the research community. Moreover, fast and accurate control technique and evolutionary development in the digital control techniques opened a new area for research as model based predictive control, sliding mode control and switching transient control.

All these technique of sensorless or encoder-less control promises the faster and accurate control. In [1] have presented an article related to sensorless control of induction machine that includes the techniques that estimate the rotor speed based on non-ideal phenomena such as rotor slot harmonics and high frequency signal injection methods. Such methods require spectrum analyses which, besides being time-consuming procedures, allow a narrow band of speed control.

![Figure 1 Utilization of Electrical Machine in Different Application](image)

New techniques to evaluate faults have been given, in case of broken rotor bars of induction motors. Procedures are applied with closed-loop control. Electrical and mechanical variables are treated using fast Fourier transform (FFT), and discrete wavelet transform (DWT) at start-up and steady state. The wavelet transform has proven to be an excellent mathematical tool for the detection of the faults particularly broken rotor bars type [2]. The percentage of copper losses in the induction machine (IM) governs the performance and hence the efficiency of the machine.
The temperature dependence of stator resistance results in inaccurate performance prediction if temperature is not taken into account in advance [3]. Estimation of both stator and rotor resistances are dealt with, in order to monitor the thermal behavior of the induction machine in real time. For this, a reduced-order electrical model is presented and introduced in extended Kalman filters. [4] A new technique for stator-resistance (R/sub s/)-based thermal monitoring of small line-connected induction machines is proposed in this paper.

A simple device is developed for injecting a small DC signal into line-connected induction machines for estimation of Rsub s. The proposed DC injection device is capable of intermittently injecting a controllable DC bias into the motor with very low power dissipation [8].

II. INDUCTION MACHINE AND LOSS MODELLING
Figure 2 gives the definite arrangement of the induction machine with detailed assembly. It is very much obvious that the heat flow in the machine is part of the air and ventilation provided by the structure. There are several indian standards which are more prominent for the design of induction machine with definite heat flow to cool the machine for the ambient issue.

![Figure 2 Part of the Induction Machine](image)

Figure 2 is more elaborate as part of induction machine is given where as the insulation in between the contact is provided in the machine. The insulation in the system is given in the classes and categorized with the highest and average heat with the operation.

<table>
<thead>
<tr>
<th>Class of Insulation</th>
<th>Temperature [°C]</th>
<th>Level</th>
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<tbody>
<tr>
<td>Y</td>
<td>90</td>
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<tr>
<td>A</td>
<td>105</td>
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<td>E</td>
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<td>H</td>
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<tr>
<td>C</td>
<td>&gt;180</td>
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Table 1 Level of allowable temperature for Various Insulation Class

![Figure 3 Separation of Losses](image)

Losses are produced by magnetic fluxes and electric currents in machines which have complicated distribution such that the sources of losses are often ambiguous. In addition, when heat is generated its dissipation follows yet another complicated thermal pattern.

![Figure 4 Stator and Rotor winding of Electrical Machine](image)

The d-q Transformation
For induction machine the very preferred reference frame is one with the axes rotating at synchronous speed. In d-q axis it is assumed to be 90 phase displacement between the d and q axis. The d-q variable transformation is given as:
\[ i_a = \frac{2}{3} \left[ i_3 \cos(\omega t) + i_2 \cos(\omega t - \frac{2\pi}{3}) + i_1 \cos(\omega t + \frac{2\pi}{3}) \right] \] (3.1)

\[ i_3 = \frac{2}{3} \left[ i_2 \sin(\omega t) + i_1 \sin(\omega t - \frac{2\pi}{3}) + i_0 \sin(\omega t + \frac{2\pi}{3}) \right] \] (3.2)

And the inverse transformation is given as;

\[ i_r = i_3 \cos(\omega t) - i_2 \sin(\omega t) \]
\[ i_2 = i_3 \cos(\omega t - \frac{2\pi}{3}) - i_1 \sin(\omega t - \frac{2\pi}{3}) \]
\[ i_1 = i_3 \cos(\omega t + \frac{2\pi}{3}) - i_0 \sin(\omega t + \frac{2\pi}{3}) \]

Similarly, all the transformation can be applied for voltage and flux linkages of the induction machine for 3-phase to 2-phase conversion. However, for the rotor quantities in relation to synchronously rotated d-q axes need to be determined. Let us assume that the \( \theta \) is the angle by which d-axis leads phase A axis of rotor.

The equations are an exception to the prescribed specifications of this template. You will need to determine whether or not your equation should be typed using either the Times New Roman or the Symbol font (please no other font). To create multileveled equations, it may be necessary to treat the equation as a graphic and insert it into the text after your paper is styled.

III. LOSSES IN INDUCTION MACHINE

Iron Loss

Iron loss is more prominent and it is consequences of an alternating magnetic field. The losses comprise hysteresis and eddy currents are comprised and result of induction of current which circulate within the conducting material. The iron losses mainly occur in stator magnetic section, since under normal operating conditions the frequency of the rotor flux is low, resulting in small rotor losses.

Friction and Windage Loss

A loss caused by the resistance to the motion within the bearing is classed as friction loss. Whereas, in fan cooled machine power required to drive the fan and to overcome the resistance offered by air is called the Windage loss. In practical machine it is not possible to segregate these two losses in the machine as both are associated with rotational speed. Generally, friction and Windage loss is proportional to the square root of the speed. In practice, the measurement of iron, friction and windage losses are straightforward using a series of no load tests despite all the complexities involved in their prediction. In the no load test, the machine is run at rated voltage and frequency without any connected load until the power input becomes constant. The power input at the rated voltage will therefore be the sum of the friction and windage, core, and no load primary copper losses. Subtracting the calculated copper losses at the test temperature from the power input gives the sum of the friction and windage, and core losses.

ACKNOWLEDGMENT

This paper is part work of the master of technology under the guidance of the Mr. Abhijit Mandal at Disha Institute of Management and Technology, Raipur affiliated to the Chhattisgarh Swami Vivekananda Technical University, Bhilai.
REFERENCES


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