Lesson 15: Induction Motor Testing: Lock-Rotor and No-load Tests

ET 332b
Ac Motors, Generators and Power Systems

Learning Objectives

After this presentation you will be able to:

- Conduct locked rotor tests on 3-phase induction motors
- Conduct no-load tests on 3-phase induction motors
- Use measurements from lock rotor and no-load tests to find motor circuit parameters
Finding Induction Motor Parameters

**Dc Test** - finds $R_1$, the stator conductor resistance

Procedure:
1.) Apply dc voltage to stator
2.) Adjust dc source until rated current flows

Formulas

For wye connected stator

$$R_1 = \frac{V_{dc}}{I_{dc}}$$

For delta connected stator

$$R_1 = 1.5 \cdot R_{dc}$$

Finding Induction Motor Parameters

**Locked rotor test** - finds the rotor parameters ($R_2$, $x_2$) and stator reactance ($x_1$).

Locked-Rotor Test Procedure

1.) connect ammeters wattmeters and voltmeters as shown above
2.) mechanically lock the motor rotor
3.) adjust the supply voltage until rated current flows
4.) measure $V$, $P$, and $I$ (line-to-line voltage, line current and total active power)

Recommended practice is to perform test at 25% rated f (15 Hz)
Minimizes errors due to saturation ($X_1$) and skin effects ($R_2$)
Define Test Quantities

\[ I_{BR15} = \text{blocked rotor test current (15 Hz)} \]
\[ P_{BR15} = \text{blocked rotor test power (15 Hz)} \]
\[ V_{BR15} = \text{blocked rotor voltage (15 Hz)} \]

Calculations

Find total impedance at 15 Hz

\[ Z_{BR15} = \frac{V_{BR15}}{I_{BR15}} \]
\[ R_{BR15} = R_1 + R_2 \]
\[ R_2 = R_{BR15} - R_1 \]

Find rotor \( R \)

Locked-Rotor Test Calculations

Find the rotor and stator leakage reactances from locked rotor resistance and reactance

\[ X_{BR15} = \sqrt{Z_{BR15}^2 - R_{BR15}^2} \]

Change to 60 Hz

\[ X_{BR60} = \frac{60 \text{ Hz}}{15 \text{ Hz}} \cdot X_{BR15} \]
\[ X_{BR60} = x_1 + x_2 \]

Divide the leakage reactances based on the NEMA design types. Use the following table.

<table>
<thead>
<tr>
<th>Design Type</th>
<th>( A, D )</th>
<th>( B )</th>
<th>( C )</th>
<th>Wound Rotor</th>
</tr>
</thead>
<tbody>
<tr>
<td>( x_1 )</td>
<td>0.5( \cdot )( X_{BR60} )</td>
<td>0.4( \cdot )( X_{BR60} )</td>
<td>0.3( \cdot )( X_{BR60} )</td>
<td>0.5( \cdot )( X_{BR60} )</td>
</tr>
<tr>
<td>( x_2 )</td>
<td>0.5( \cdot )( X_{BR60} )</td>
<td>0.6( \cdot )( X_{BR60} )</td>
<td>0.7( \cdot )( X_{BR60} )</td>
<td>0.5( \cdot )( X_{BR60} )</td>
</tr>
</tbody>
</table>
Induction Motor No-Load Test

**No-load Test** - Finds magnetizing reactance and combined friction, core and windage power losses.

**No-Load Test Procedure**
1.) Apply rated voltage and frequency with no mechanical load.
2.) Measure current voltage and power.
3.) Uses same test instrument setup as locked-rotor test. Measure $I_L$, $V_L$ and $P_T$.

**Model for No-load test**

Since $I_M >> I_f$ it is neglected in this test so $R_{fe}$ omitted

**Measure**
- $P_{NL}$ = No-load power losses
- $I_{NL}$ = No-load current
- $V_{NL}$ = No-load voltage

**Induction Motor No-Load Test Formulas**

Find apparent and reactive power into unloaded motor

- $S_{NL} = V_{NL} \cdot I_{NL}$
- $Q_{NL} = \sqrt{S_{NL}^2 - P_{NL}^2}$

Use reactive power to find total reactance

- $X_{NL} = \frac{Q_{NL}}{I_{NL}}$

No-load reactance is the sum of the magnetizing reactance and stator leakage

- $X_{NL} = x_1 + x_M$
- $x_M = X_{NL} - x_1$

Use no-load power to find rotational losses

- $P_{NL} = I_{NL}^2 \cdot R_1 + P_{core} + P_{stator}$
Example 15-1: Following data is taken from no-load, locked rotor, and DC tests of a 3-phase, wye connected 40 HP, 60 Hz, 460 V, induction motor with a rated current of 57.8 A. The locked-rotor test is made at 15 Hz to minimize the errors due to saturation and skin effects. Determine the motor parameters and the total core, friction and windage losses. Draw the approximate equivalent circuit for the motor.

<table>
<thead>
<tr>
<th></th>
<th>No-load</th>
<th>DC Test</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>V_line</strong></td>
<td>460.0 V</td>
<td>V_dc = 12.0 V</td>
</tr>
<tr>
<td><strong>I_line</strong></td>
<td>32.7 A</td>
<td>I_dc = 59.0 A</td>
</tr>
<tr>
<td><strong>P_T</strong></td>
<td>4664.4 W</td>
<td></td>
</tr>
</tbody>
</table>

Example 15-1 Solution (1)

Convert line voltages, currents and total power to per phase quantities

\[
P_p = \frac{P_T}{3}
\]

Locked Rototor:

\[
P_{LR} = \frac{2573.4 \text{ W}}{3} = 857.8 \text{ W}
\]

No-Load:

\[
P_{NL} = \frac{4664.4 \text{ W}}{3} = 1554.8 \text{ W}
\]

\[
I_{LR} = 58.0 \text{ A} \quad \text{for wye connected} \quad I_L = I_p
\]

\[
V_{LR} = \frac{3 \times 460 \text{ V}}{\sqrt{3}} = 20.90 \text{ V}
\]

\[
V_{NL} = \frac{460 \text{ V}}{\sqrt{3}} = 265.4 \text{ V}
\]

\[
I_{NL} = 32.7 \text{ A}
\]
Example 15-1 Solution (2)

FIND \( R_1 \) FROM DC TEST VALUES

\[
R_{dc} = \frac{V_{dc}}{I_{dc}} = \frac{12.0V}{57.0A} = 0.2034 \Omega
\]

For a wye connected motor

\[
R_1 = \frac{R_{dc}}{2} = \frac{0.2034 \Omega}{2} = 0.1022 \Omega/\text{phase}
\]

Stator winding resistance

Example 15-1 Solution (3)

Use locked-rotor test values to find rotor resistance, \( R_1 \) and stator/rotor leakage reactance \( x_1, x_2 \)

\[
\begin{align*}
|Z_{BRIS}| &= \frac{V_{LR}}{I_{LR}} = \frac{20.9V}{58.0A} = 0.3603 \Omega \quad \text{TAKEN AT 15M2} \\
|R_{BRIS}| &= \frac{P_{LR}}{I_{LR}^2} = \frac{867.8W}{(58.0A)^2} = 0.2550 \Omega/\text{phase}
\end{align*}
\]

Find the rotor resistance

\[
R_2 = \frac{R_{BRIS} \cdot R_1}{R_2} = \frac{0.2550 \cdot 0.1022 \Omega}{0.1022 \Omega} = 0.1530 \Omega/\text{phase}
\]
Example 15-1 Solution (4)

Now find $X_{BR}$ at test frequency of 15 Hz

\[
X_{BR15} = \sqrt{2^2 - R_{BR15}^2}
\]

\[
X_{BR15} = \sqrt{0.360^2 - 0.255^2} = 0.2595 \text{ ohms}
\]

Convert this result to 60 Hz

\[
X_{BR60} = \frac{X_{BR15}}{2} \left( \frac{60}{15} \right) = 1.0182 \text{ ohms}
\]

Example 15-1 Solution (5)

Now find $X_m$ and power losses from no-load test data

\[
S_{NL} = V_{NL}I_{NL} \quad \text{ALL VALUES PER PHASE}
\]

\[
V_{NL} = 265.4 \text{ V} \quad I_{NL} = 32.7 \text{ A} \quad P_{NL} = 1559.8 \text{ W}
\]

\[
S_{NL} = (265.4 \text{ V})(32.7 \text{ A}) = 8694.5 \text{ VA}
\]

\[
Q_{NL} = \sqrt{S_{NL}^2 - P_{NL}^2} = \sqrt{8694.5^2 - 1559.8^2} = 8549.2 \text{ VAR}
\]

\[
X_{NL} = \frac{Q_{NL}}{I_{NL}} = \frac{8549.2 \text{ VA}}{(32.7 \text{ A})^2} = 7.99 \text{ ohms}
\]

\[
X_{NL} = X_1 + X_m \Rightarrow X_m = X_{NL} - X_1
\]
Example 15-1 Solution (6)

Need to find $x_1$ and $x_2$ to find the $x_m$ value. Assume the motor is NEMA design B

$$x_1 = 0.4X_{BL40} \quad x_2 = 0.6X_{BL60}$$

$$X_1 = 0.4(1.0182\Omega) = 0.4073\Omega/\text{phase}$$

$$X_2 = 0.6(1.0182\Omega) = 0.6110\Omega/\text{phase}$$

$$X_{m} = 7.992 - 0.9073\Omega$$

$$X_{m} = 7.58\Omega/\text{phase}$$

**TOTAL** $P_{fw} + P_{core}$

$$P_{NL} = I_{NL}^2R_1 + P_{core} + P_{fw}$$

$$P_{NL} = 1569.8\text{w}$$

$$I_{NL} = 32.7\text{A}$$

$$R_1 = 0.102\Omega$$

$$P_{NL} - I_{NL}^2R_1 = P_{core} + P_{fw}$$

$$1569.8\text{w} - (32.7\text{A})^2(0.102\Omega) = P_{core} + P_{fw}$$

$$1996\text{w/phase} = P_{core} + P_{fw}$$

Approximate Equivalent Circuit

[Diagram showing the approximate equivalent circuit with various impedances labeled (0.1020 Ω, j0.4073 Ω, j0.6110 Ω, j7.58 Ω, 0.1530/s Ω).]
END LESSON 15: INDUCTION MOTOR TESTING: LOCK-ROTOR AND NO-LOAD TESTS