No-load And Blocked Rotor Test On An Induction Machine

Aim

- To estimate magnetization and leakage impedance parameters of induction machine using no-load and blocked rotor tests

Theory

An induction machine in its equivalent circuit form is akin to a transformer with 'slip' as an additional parameter. As a result, the equivalent circuit parameter estimation of induction machine proceeds on similar lines as that of a transformer's. The equivalent circuit for a single-cage induction machine is shown in Fig.(1). Here, $(R_r' + R_r'(\frac{1-s}{s})) + jX_{r1}'$ represents the rotor circuit impedance as a function of slip s.

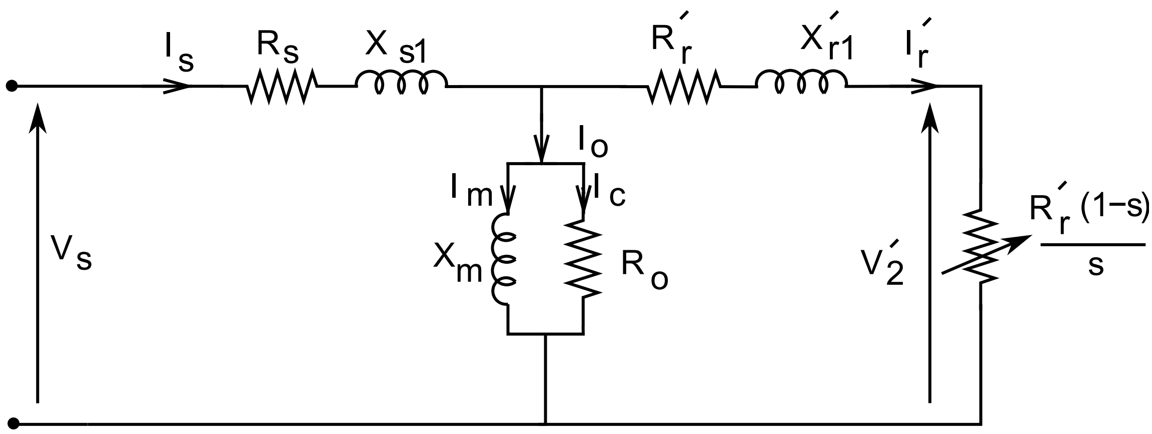

Figure 1: Per phase equivalent circuit of Induction Motor

No-load test

The no-load test approximates the stator circuit (R_s and X_{s1}) and magnetization branch parameters(X_m) of an induction machine. The machine is brought to its rated speed by applying rated three phase voltage at the stator (V_{nl}). Corresponding no-load current (I_{nl}) and no-load real power input(P_{nl}) are recorded.

When no mechanical load is driven by the machine, slip (s) is a very small value. As a result, referring to Fig.(1), the rotor circuit branch resistance quantity, $R_r'(\frac{1-s}{s})$ carries a large value. The impedance of rotor circuit branch is thus much higher compared to the magnetization branch impedance and their parallel combination would turn out to be close to jX_m (neglecting core conductance).

keeping this in mind, we have,

$$X_{nl} = X_{s1} + X_m \tag{1}$$

$$Z_{nl} = \frac{V_{nl}}{I_{nl}} \tag{2}$$

$$R_{nl} = \frac{P_{nl}}{I_{nl}^2} \tag{3}$$

where, Z_{nl} and R_{nl} are the no-load equivalent impedance and resistance respectively. Next, using (1-3), we get,

$$X_{nl} = \sqrt{Z_{nl}^2 - R_{nl}^2} \tag{4}$$

Also, as no load current is drawn, the losses that occur under these conditions would represent the only the rotational losses arising from friction, core loss. Hence,

$$P_{loss} = P_{nl} - I_{nl}^2 R_s \tag{5}$$

Blocked rotor test

The blocked rotor test is performed to estimate parameters that affect machine's performance under load such as its leakage impedance, similar to the short circuit test done for a transformer. In blocked rotor test, the machine shaft is locked or is prevented from rotating via external means. Blocking the shaft essentially amounts to making the slip equal unity ($n_r = 0$). If E_2' is the voltage appearing across the rotor circuit, we have

$$s = \frac{n_s - n_r}{n_s} \tag{6}$$

$$I_r = \frac{E_2'}{\frac{R_r'}{s} + jx_{r1}} \tag{7}$$

It can be observed that, the rotor resistance offered in this case is 'effectively' lowered by a fraction of $\frac{1}{s_0}$, where s_0 is the slip under rated operation (0.01-0.04). Rated stator currents can thus be established for much lower than rated values of stator terminal voltage.

With the rated current (I_{br}) flowing in the stator, we note the stator applied voltage (V_{br}) and the power input(P_{br}). It should be noted that the rotor position in blocked state affects the stator voltage (V_{br}) required for setting up I_{br}. Hence, an average calculated over different rotor positions can be taken. Assuming we have the stator circuit parameters R_s ready, the other machine parameters can be calculated as indicated below.

$$Z_{br} = \frac{V_{br}}{I_{br}} \tag{8}$$

$$R_{br} = \frac{P_{br}}{I_{br}} \tag{9}$$

$$X_{br} = \sqrt{Z_{br}^2 - R_{br}^2} \tag{10}$$

Here, $Z_{br} = R_{br} + jX_{br}$ is the equivalent impedance offered by the machine with rotor blocked. As the real power consumed during blocked rotor test is almost entirely the real power loss in the machine, we can use it to calculate the machine equivalent resistance as in (4). In other words, the applied stator voltage being low, the core loss component is quite a small fraction of rated core-loss.

To approximate X_{s1}, X'_{r1} and R'_r one needs to calculate the Thevenin equivalent impedance looking into the equivalent circuit of the machine from stator terminals.

$$
\begin{aligned}
Z_{br} &= R_{br} + jX_{br} && (11)\\
&= R_s + jX_{s1} + [(jX_m)||(R'_r + jX_{r1})] && (12)\\
&= R_s + jX_{s1} + \frac{jX_m[R'^2_r + jR'_rX_{r1} - jR'_r(X_{r1}+X_m) + X_{r1}(X_{r1}+X_m)]}{R'^2_r + (X_{r1}+X_m)^2} && (13)\\
&\text{Letting} \quad X_r = X_{r1} + X_m && (14)\\
&= R_s + jX_{s1} + \frac{jX_m[R'^2_r - jR'_rX_m + X_{r1}X_r]}{R'^2_r + X_r^2} && (15)
\end{aligned}
$$

Equating the real and imaginary parts in (10)

$$
\begin{aligned}
R_{br} &= R_s + R'_r\frac{X_m^2}{R'^2_r + X_r^2} && (16)\\
X_{br} &= X_{s1} + \frac{X_m[R'^2_r + X_{r1}X_r]}{R'^2_r + X_r^2} && (17)\\
&= X_{s1} + \frac{X_m[\frac{R'^2_r}{X_r} + X_r]}{\frac{R'^2_r}{X_r} + X_r} && (18)
\end{aligned}
$$

However,$X_r \gg R'_r$, the term $\frac{R'^2_r}{X_r}$ in (13) and R'^2_r in the denominator of (11) can be neglected.

$$
\begin{aligned}
R_{br} &= R_s + R'_r(\frac{X_m}{X_r})^2 && (19)\\
R'_r &\approx (R_{br} - R_s)(\frac{X_m}{X_r})^2 && (20)\\
\text{Also,} \quad X_{br} &= X_{s1} + \frac{X_mX_{r1}}{X_r} && (21)\\
&= X_{s1} + \frac{X_{r1}}{1 + \frac{X_{r1}}{X_m}} && (22)\\
& && (23)
\end{aligned}
$$

Again, in general, as $X_m \gg X_{r1}$, $\frac{X_{r1}}{X_m}$ can be neglected which yields,

$$X_{br} \approx X_{s1} + X_{r1} \quad (24)$$

For wound-rotor construction, one can assume that $X_{s1} \approx X_{r1}$ resulting in $X_{s1} = X_{r1} = 0.5 * X_{br}$. However, for squirrel cage induction machines, the distribution of X_{br} can be obtained from a look-up table indicating empirical distribution of leakage reactance for the machine type.

If X_{s1} is known, from the no-load test data, we have,

$$X_m = X_{noload} - X_{s1} \quad (25)$$

In this way, the machine parameters namely, $X_{s1}, X_m, R'_r, X'_{r1}$ can be calculated from the blocked rotor test using the above analysis.

Finally we note that, the blocked rotor test can be performed at different values of applied stator voltage frequencies. To obtain the leakage impedance parameters under rated conditions (where the rotor frequency is given by sF_s) with s being unity, the stator voltage frequency can be reduced to match the frequency of rotor currents during usual operation.

Procedure

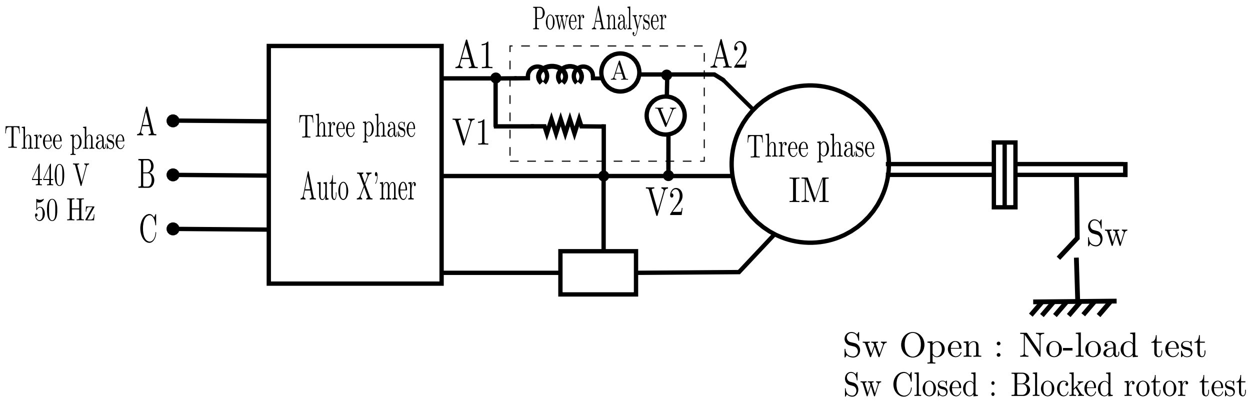

Figure 2: Circuit Diagram for no-load and blocked-rotor test on 3 Phase Induction Motor

A. Note down the machine ratings and calculate rated current of the machine

No-load test :

B. Disconnect any mechanical load connected to the induction motor.

C. Gradually apply three phase voltage across motor stator terminals via the autotransformer

D. As the stator voltage is increased, the machine speeds up. Make sure the voltage is applied such that the machine does not speed up too fast

E. Adjust the stator voltage to its rated value

F. Note down no-load quantities such as V_{nl}, I_{nl}, P_{nl}

G. Slowly decrease the stator voltage to zero and disconnect the supply.

Blocked rotor test :

B. Fasten the machine rotor shaft to the fixed disc with the help of screws provided. Make sure the rotor shaft is tightly held in position.

C. Slowly increase the three phase stator voltage from zero with the help of autotransformer

D. Stop when rated current is established in the machine stator

E. Record relevant quantities from the power analyzer

F. Slowly decrease the autotransformer voltage back to zero.

G. In case the blocked rotor test is to be performed at input voltage frequencies other than the power frequency(50 Hz), use a 'Variable Voltage Variable Frequency' (V.V.V.F) source in place of autotransformer.

Record

No-load test :

- Input stator voltage at rated stator current (V_{nl}), stator current (I_{nl}), input real power(P_{nl})
- Use (2-4) to calculate Z_{nl}, R_{nl} and X_{nl}
- Use (5) to calculate rotational losses

Blocked rotor test:

- Input stator voltage at rated stator current (V_{br}), stator current (I_{br}), input real power(P_{br})
- Use (4) and (5) to calculate R_{br} and X_{br}
- Further use (15),(19) and (20) to calculate machine parameters
- Use results of no-load test wherever necessary

Follow-up Questions

1. Compare and contrast the no-load and short circuit tests performed on transformers to the no-load and blocked rotor tests performed on induction machines
2. Refer to a table giving distribution of leakage reactance X_{br} between stator and rotor for different classes of machines
3. How can the blocked-rotor test be performed to obtain induction motor characteristics near synchronous speed? (Hint: Think about varying the supply frequency)
4. Calculate the equivalent circuit parameters with the following machine data
   Machine rating : 8 kW, 400 V, $R_{dc} = 0.6\ \Omega$ per phase
   No-load test: 400 V, 7 A, 250 W
   Blocked-rotor test: 90 V, 35 A, 1350 W

References

(1) M.G.Say, "Alternating Current Machines", 5th Ed., Ch.7-9

(2) P.S.Bimbhra, "Electrical Machinery", Ch.5

(3) A.E. Fitzgerald, C. Kingsley Jr., S.Umans, "Electric Machinery", 6th Ed., Ch.6

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