Investigation of the equivalent circuit of an induction machine.

EQUIPMENT: Squirrel Cage Induction Motor (MV1009)
DC Machine (MV 1005-225)
Shunt Regulator (MV1905)
Load Resistor (MV1100)
Torque Measuring Unit (MV1051)
Three-phase variable supply
Power factor meter
DC and AC ammeters
DC and AC voltmeters

THEORY:

The approximate (per-phase) equivalent circuit of a three-phase induction motor as shown in **Figure 1**. The circuit parameters are as follows:

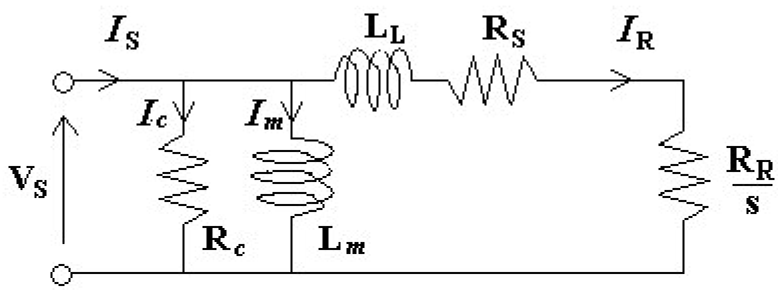

Figure 1 Approximate Equivalent Circuit of Three-phase Induction Motor

R_S is the stator winding resistance;
R_R is the rotor resistance;
X_L is the leakage reactance;
R_c is the iron core loss and the windage and friction losses;
L_m is the magnetising inductance;
s is the motor slip.

The motor slip is defined as:

$$s = \frac{N_S - N_R}{N_S}$$

where N_S is the synchronous speed of the rotor and N_R is the rotor speed. Both are measured in revolutions per minute (rpm). The synchronous speed for a machine connected to a 50Hz supply is:

$$N_S = \frac{6000}{p}$$

where *p* is the number of poles. Thus, for an induction motor with four poles, *p* = 4 and the synchronous speed is 1500rpm.

To determine the elements of the equivalent circuit, two tests are carried out: the No-Load Test and the Locked Rotor Test.

No-Load Test

This test is carried out with the motor unloaded and with rated voltage applied to the stator windings. As the no-load speed of the motor will be slightly less than the synchronous speed, the slip s will be approximately zero:

$$s \approx 0, \text{ so } \frac{R_R}{s} \text{ is very large}$$

As a consequence of this, $\boldsymbol{I_R}$ is very small and the branch carrying $\boldsymbol{I_R}$ can be ignored. The simplified equivalent circuit shown in **Figure 2** can be used.

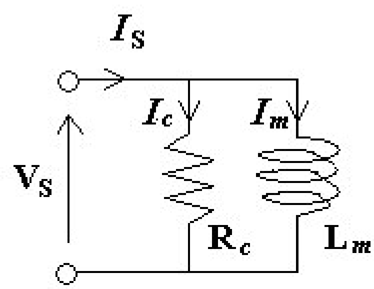

Figure 2 Equivalent Circuit during No-Load Test

If the phase voltage, current and power factor are measured, the circuit parameters of the magnetising branch can be determined as follows:

$$I_C = I_S \times p.f. \qquad \text{and} \qquad I_m = \sqrt{I_S^2 - I_c^2}$$

$$R_c = \frac{V_S}{I_c} \qquad \text{and} \qquad X_m = \frac{V_S}{I_m}$$

Locked Rotor Test

In this test the rotor is locked to prevent rotation, hence the slip is one. The supply voltage is increased from zero until rated current flows in the motor stator winding. This occurs at a relatively low voltage (between 10% and 30% of the rated voltage). At this low voltage $\boldsymbol{I_c}$ and $\boldsymbol{I_m}$ are negligible compared to $\boldsymbol{I_R}$ and the equivalent circuit may be re-drawn as shown in **Figure 3**.

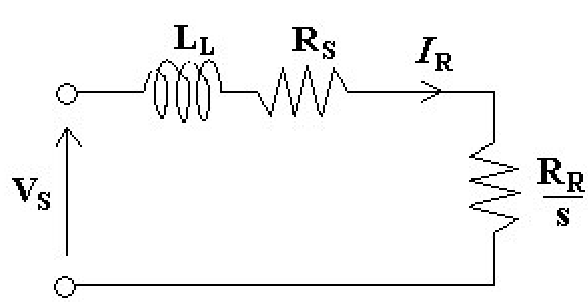

Figure 3 Equivalent Circuit during Locked Rotor Test

If the phase voltage, current and power factor are measured, the circuit elements R_S, R_R, and L_L can be determined as follows:

$$\left|Z\right| = \frac{V_S}{I_R}$$

$$R_{total} = R_S + R_R = \left|Z\right| \times p.f.$$

$$X_L = \omega L_L = \sqrt{\left|Z\right|^2 - R_{total}{}^2}$$

The stator (per phase) dc winding resistance R_S is measured using an ohmmeter. For example, this measurement can be taken between points A and B in **Figure 4** below. Note that the machine winding is connected in delta and the above calculations are based on a star connected machine, hence a star equivalent circuit is required for the machine. This is easily achieved by carrying out a delta-star transformation. Since the rotor windings are balanced, this involves dividing the delta impedance by 3 to obtain the star equivalent impedance.

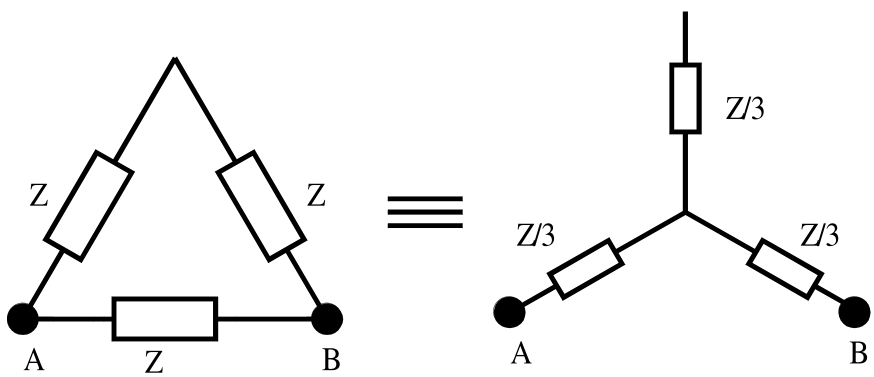

Figure 4 Delta-Star Transformation

In this case we are measuring the per-phase, star equivalent, stator resistance R_s. This is given by:

$$R_S = R_{\text{star}} = \frac{R_{delta}}{3}$$

The measured resistance is given by:

$$R_{AB} = R_{delta} \| 2R_{delta} = \frac{R_{delta} \times 2R_{delta}}{R_{delta} + 2R_{delta}} = \frac{2}{3} R_{delta}$$

i.e.

$$R_{delta} = \frac{3}{2} R_{AB}$$

hence:

$$R_{\text{S}} = \frac{R_{AB}}{2}$$

This is the dc star-equivalent resistance. The actual resistance when the motor is operating will be higher due to the skin effect (since the current will be AC) and because of the increase in resistance due to the higher temperature of the winding. To account for these effects, the dc resistance is multiplied by a factor of approximately 1.1. Hence the rotor resistance is given by:

$$R_R = R_{total} - \left(1.1 \times R_S\right)$$

PROCEDURE:

1. Examine the machine set and record a detailed description of the induction motor including its nameplate data.

No-load Test

2. Connect the induction motor test circuit as shown in **Figure 5**. Note the three-phase variac provides a reduced voltage at starting and also for the locked rotor test.

3. Switch on the induction motor and gradually increase the output voltage of the variac until the motor is running with rated voltage applied and under no-load conditions.

4. Read and record the motor voltage, current, power factor and speed. Switch off the induction motor and reduce the variac output to zero. Use these results to determine R_c and X_m as described in the theory section above. Also calculate the slip and verify that $s \approx 0$.

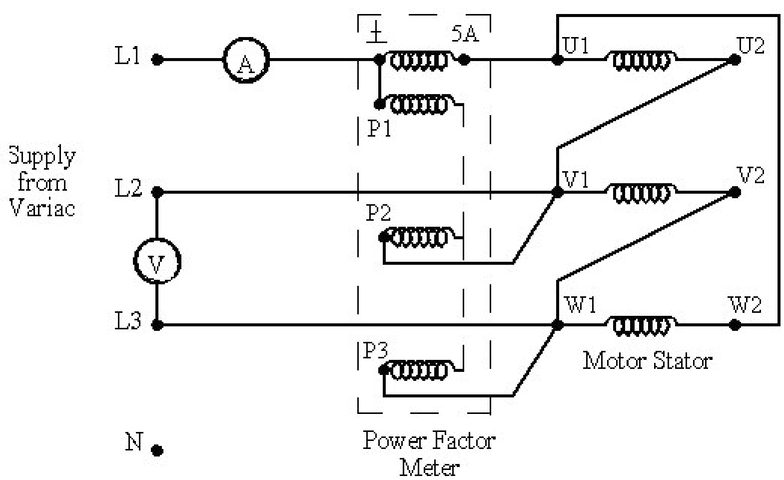

Figure 5 Circuit for Induction Motor Stator

Locked Rotor Test

5. Lock the rotor of the motor using the disc break.

6. With the circuit unchanged, switch on the induction motor and gradually increase the output voltage of the variac until rated current flows in the stator. Note that this condition will occur when the phase voltage is about 50V.

7. Read and record the motor voltage, current and power factor. Switch off the induction motor and reduce the variac output to zero.

8. Measure the dc resistance of the stator winding using the ohmmeter.

9. Use the above results to determine R_S, R_R and L_L.