

Induction Machines – Review Sheet

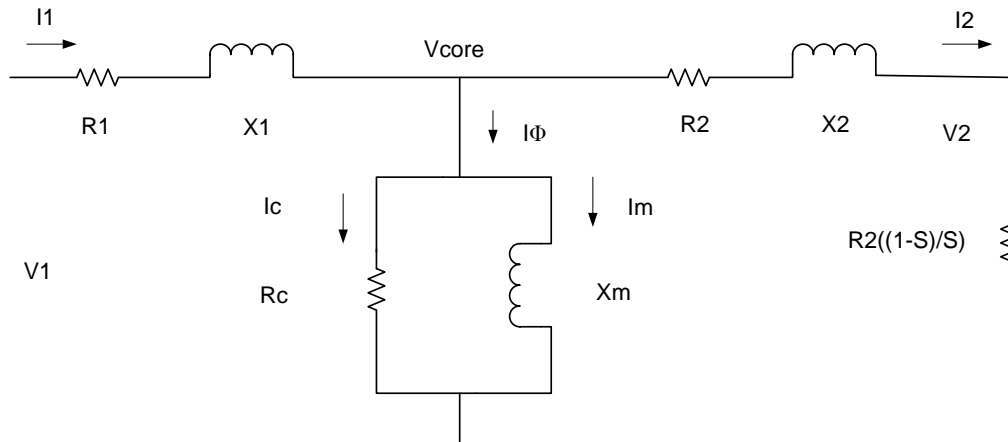
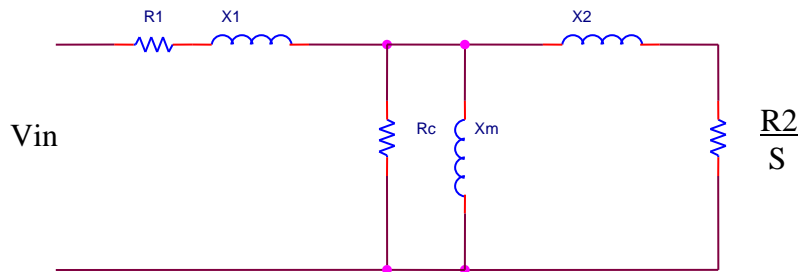
Basics of Induction Machine Operation:

An Induction machine operates a little bit differently from the Synchronous machines we looked at last week. They both have a similar stator, a series of winding designed in such a way that a rotating magnetic field is set up when AC current is applied. While a synchronous machine needs a DC excitation on the rotor to develop torque an induction machine relies completely on induction to generate the rotor magnetic field.

When AC current is applied to an induction machine the rotating magnetic field is set up in the stator. This rotating field is moving with respect to the rotor windings and thus induces a current flow in the rotor. The current flowing in the rotor windings sets up its own magnetic field. The interaction of the stator and rotor magnetic fields is what causes the machine to develop torque and begin to turn.

Induction Machine Equivalent Circuit and Slip:

The induction machine equivalent circuit will be derived in the first sections of this experiment. The equivalent circuit looks as follows:



An important thing to notice here is that this is very similar to the equivalent circuit model of a transformer with a shorted output side (see the transformer model review sheet). In fact the procedures we will use to determine the circuit parameters are very similar to the derivations in the transformer model lab. S is the slip of the machine, or how much the machine is lagging synchronous speed. Slip is defined as follows:

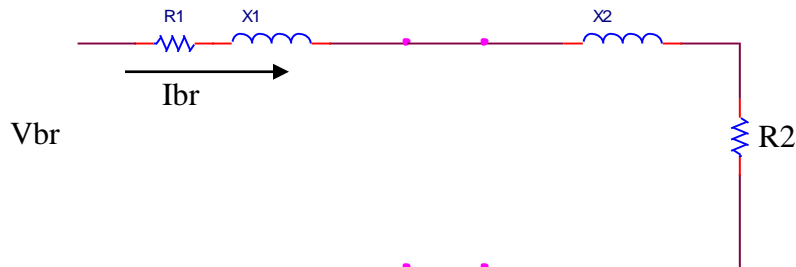
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$$S = \frac{N_s - N_M}{N_s} \quad \text{Where } N_s = \frac{120f}{p} \text{ is synchronous speed and } N_M \text{ is machine speed}$$

Once again we are using 4 pole machines in a 60 Hz environment so the synchronous speed is 1800 RPM.

Blocked Rotor Test:

This test is analogous to the transformer short circuit test and is used to find the values of R_1 , R_2 , X_1 , and X_2 . Locking the rotor in place forces the machine speed to zero so S becomes 1. Assuming the shunt branch values (R_c and X_m) are much larger than X_2 and R_2 the equivalent circuit reduces to:



Block Rotor circuit

Obtaining V_{br} , I_{br} and P_{br} the values of R_1 , R_2 , X_1 , and X_2 can be found using the following equations:

$$P_{BR} = I_{BR}^2 (R_{EQ})$$

$$R_{EQ} = P_{BR} / I_{BR}^2$$

$$R_1 = R_2 = R_{EQ} / 2$$

$$Q_{BR} = \sqrt{(V_{BR} * I_{BR})^2 - P_{BR}^2}$$

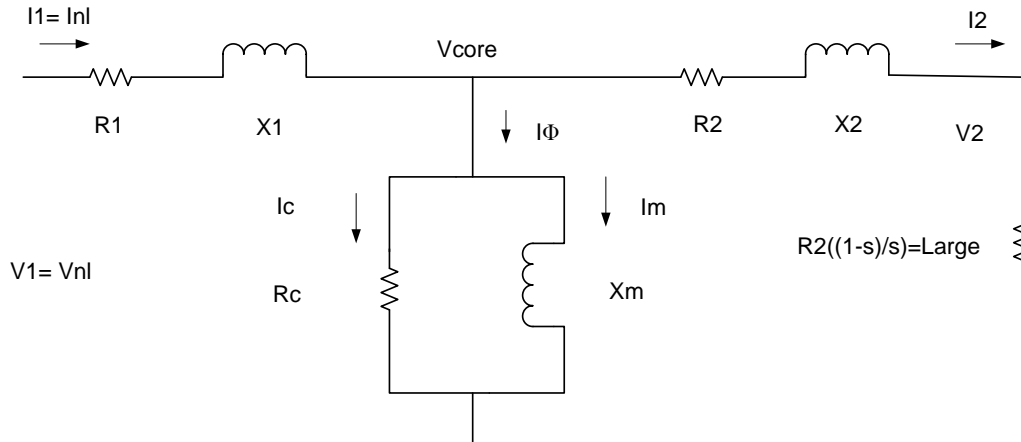
$$Q_{BR} = I_{BR}^2 (X_{EQ}) \Rightarrow X_{EQ} = \frac{Q_{BR}}{I_{BR}^2}$$

$$X_1 = X_2 = \frac{X_{EQ}}{2}$$

No-Load Test:

This test is analogous to the transformer open circuit test and is used to find the values of R_c , and X_m . Leaving the rotor free to spin the machine speed approaches synchronous speed so S becomes 0 and the R_2 resistance term goes very large. The equivalent circuit then reduces to:

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No load circuit

Obtaining V_{nl} , I_{nl} , P_{nl} and using the values of R_1 and X_1 from the previous section the values of R_c , and X_m can be found as follows:

$$\begin{aligned} \vec{V}_{NL} &= V_{NL} \angle 0^\circ \\ \vec{I}_{NL} &= I_{NL} \angle -\arccos\left(\frac{P_{NL}}{V_{NL} I_{NL}}\right) \\ \vec{V}_{CORE} &= \vec{V}_{NL} - \vec{I}_{NL}(R_1 + jX_1) \\ P_{NL} &= I_{NL}^2(R_1) + \frac{|V_{CORE}|^2}{R_c} \Rightarrow R_c = \frac{|V_{CORE}|^2}{P_{NL} - I_{NL}^2(R_1)} \\ Q_{NL} &= \sqrt{(V_{NL} * I_{NL})^2 - P_{NL}^2} \\ Q_{NL} &= I_{NL}^2(X_1) + \frac{|V_{CORE}|^2}{X_M} \Rightarrow X_M = \frac{|V_{CORE}|^2}{Q_{NL} - I_{NL}^2(X_1)} \end{aligned}$$

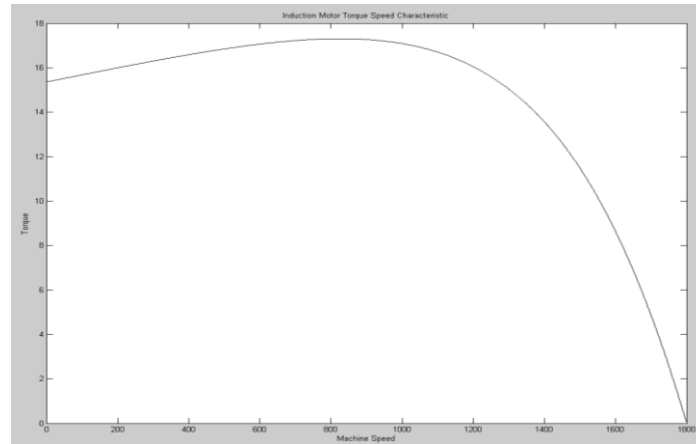
Induction Machine Torque Speed Characteristic:

The torque speed characteristic of an induction motor is as follows:

$$T_{DEV} = \frac{3 * I_2^2 \frac{R_2}{S} (1-S)}{\omega_m} \quad \text{where, } \omega_m = \frac{2\pi N_m}{60}, N_m = (\text{speed})RPM$$

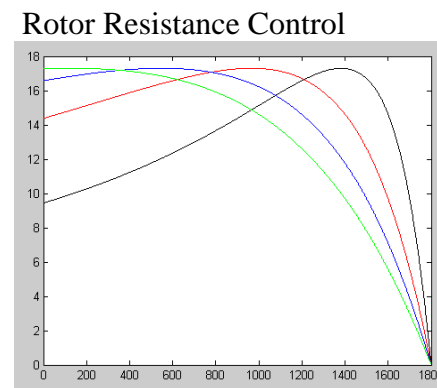
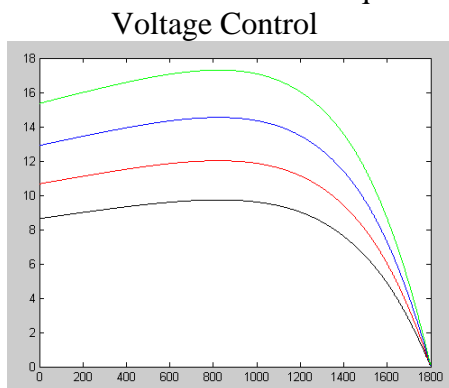
This equation describes the torque developed as a function of slip. I_2 is found from I_1 and I_Φ using current division. Since slip is linearly dependant on machine speed this torque equation give torque as a function of speed. Plotting torque versus speed we get the following curve.

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Rotor Resistance and Voltage Control:

There are 2 ways to modify the torque speed characteristic of an induction motor, through use of rotor resistance control or voltage control. From the torque speed characteristic it can be seen that the torque developed is proportional to the square of the terminal voltage (V_P). Thus increasing the voltage gives a higher torque at each speed. Using rotor resistance control shifts the speed value at which maximum torque occurs but does not affect the maximum torque value.



*note: Rotor Resistance control is not an option for squirrel cage induction motors