

# Induction Motor Simulation using Scilab

PRASAD MEHENDALE

## Abstract

Behaviour of an induction motor is simulated using Scilab. A variable frequency drive (VFD) is used to change the supply frequency. As a result, motor speed changes. For various frequencies; speed, output torque, power factor, efficiency are studied. Graphs also are generated to describe this behaviour.

## 1 The equivalent circuit of an induction motor

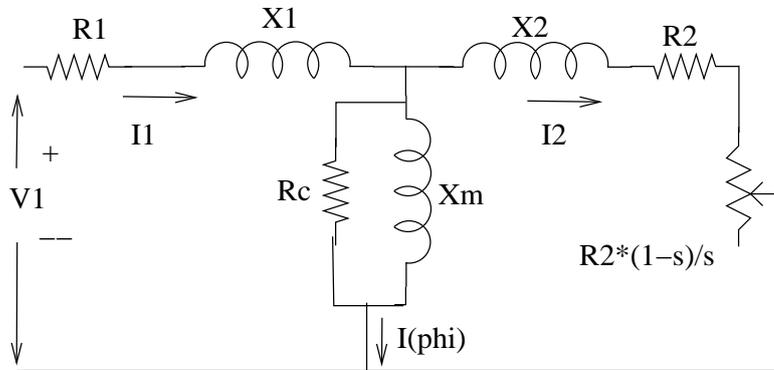
An induction motor can be considered like a transformer with an air-gap. The equivalent circuit can be used to form a mathematical model. In this simulation, the **motor of following specifications** is studied.

A three phase Y connected 220-V (line to line voltage) 7.5 kW, 60 Hz, 6 pole induction motor has the following values in  $\Omega$ /phase referred to the stator.

$r_1=0.294$ ,  $r_2=0.144$ ,  $x_1=0.503$ ,  $x_2 = 0.209$ ,  $x_m = 13.25$ . The total friction, windage and core losses may be assumed as 6.5% of the power input at any given load. At 2% slip (loading condition), the motor offers its best performance.

Figure 1 on the following page shows equivalent circuit of an induction motor. The equivalent circuit is drawn with stator as the reference. Various parameters described below can be found out by actual measurement and carrying No Load Test and Blocked Rotor test.

Fig. 1: Induction Motor Equivalent Ckt



$R1$  is stator resistance.

$X1$  is the stator leakage reactance.

$Xm$  is the mutual reactance.

$Rc$  is the resistance representing core heat loss.

$X2$  is rotor leakage reactance seen by the stator.

$R2$  is the rotor resistance seen by the stator.

$R2(1-s)/s$  load dependant rotor resistance component.

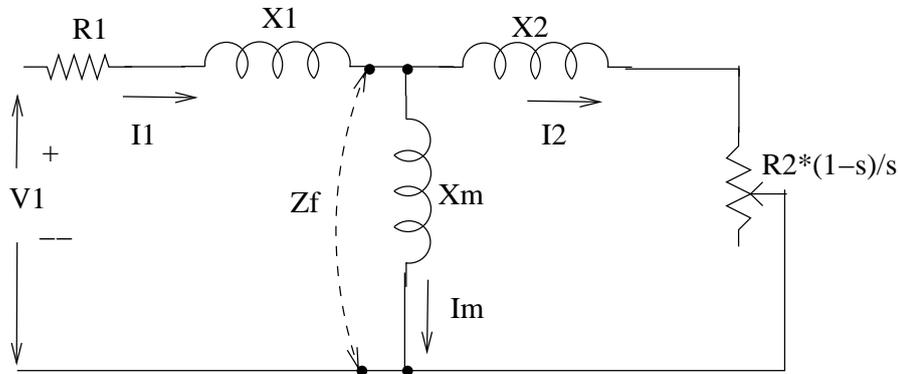
Note that slip represents the loading condition of the motor. More is the slip, more load is on the motor shaft. Less slip indicates that the motor is lightly loaded.

This motor simulation is done when slip is 2%. This is the best performance load condition of the motor at 60 Hz rated frequency. However during the simulation, you can change the slip percentile and hence change the loading condition. Normally the slip range is between 0 to 0.5 (no load to overload). Check the performance of the motor for various slip values.

## 2 Modified equivalent circuit

Main aim of this simulation is to predict the behaviour of the motor at various loading conditions when a VFD (variable frequency drive) is supplying

Fig. 2: Modified equivalent circuit



power to the motor at different frequencies. If we consider that the core heat component ( $R_c$  component) is a fixed proportion (6.5%) of the input power, the circuit becomes simpler.

Figure 2 shows the modified equivalent circuit. Note that the  $R_c$  component is absent. Thus  $Z_f$  is a parallel combination of  $jX_m$  and  $(R_2*(1-s)/s + jX_2)$ . This adjustment results in the total impedance of  $(Z_f + R_1 + jX_1)$  appearing across the input voltage  $V_1$ .

### 3 The Scilab Script

It is assumed that the motor is tested for No Load and Blocked rotor tests at 60 Hz, because the motor is designed for this frequency and rated line voltage 220V. We are interested in predicting its behaviour at various supply frequencies from a variable frequency drive. The range of frequencies will be 30 Hz to 90 Hz. **For simplicity, we assume that the waveshape is a pure sinusoid.** The user can select the loading condition (no load to overload) by mentioning the slip in the range 0 to 0.1. The best performance is obtained at slip = 0.02.

From the No load and Blocked rotor tests, the user finds  $X_1, X_2, R_2$  and  $X_m$ .  $R_1$  can be measured using an ohm-meter. The reactance values are for 60 Hz. From the reactances we can find the inductances  $L_1, L_2, M$ . This helps to calculate the values of reactances at different frequencies.

Following formulae and concepts play vital role in the script.

- $P_{gap} = 3 * I_2^2 * \left(\frac{R_2}{s}\right)$  = Total power transferred across the air gap from the stator.
- $P_{rotor} = 3 * I_2^2 R_2 = s * P_{gap}$
- Mechanical Power output =  $P_{mech} = P_{gap} - P_{rotor} = 3 * I_2^2 * \frac{R_2}{s} - 3 * I_2^2 R_2 = 3 * I_2^2 R_2 * \frac{1-s}{s} = (1-s) * P_{gap}$
- $T_{mech} = \frac{P_{mech}}{\Omega_{mech}} = \frac{P_{gap}}{\Omega_{gs}} = 3 * I_2^2 * \frac{R_2}{s * \Omega_{gs}}$
- $P_{shaft} = P_{mech} - P_{rotor}$
- $T_{shaft} = \frac{P_{shaft}}{\Omega_{mech}} = T_{mech} - T_{rotor}$
- Stator input power -  $P_{in} = 3 * Re [V_1 * I_1]$
- Efficiency -  $\eta = \frac{P_{shaft}}{P_{in}}$

## 4 Using the Scilab Script

1. Start scilab console.
2. Go to the directory where you have stored the “indmot.sce” script file.
3. Give the command: `exec (“indmot.sce”, -1)`
4. The script asks you some questions about your motor. Provide the necessary data. The data of the motor under study on page 1 is as below:
  - (a)  $R_1=0.294$
  - (b)  $R_2=0.144$
  - (c)  $L_1= 0.001334$  H
  - (d)  $L_2=0.000554$  H
  - (e)  $M=0.03514$  H

- (f) poles=6
- (g) line voltage=220V
- (h) Percentile slip=0.02
- (i) Rated Power in watt = 7500 W

All the above parameters are fixed except the **slip**. You can change the slip value within the range 0 to 0.1 (no load to overload) and see the behaviour of the motor reflected in the graphs. If you provide the data correctly, Scilab script will produce 4 graphs in the same window. The graphs are:

1. Frequency V/s Power Factor
2. Frequency V/s Output torque
3. Frequency V/s Rotror speed in rpm
4. Frequency V/s Motor Efficiency

## **References**

- [1] AC electrical machines - By Alexander S. Langsdorf
- [2] Electrical Machinery - By Fitzgerald, Kingsley & Umans