Electrical Machines Laboratory
Department of Electrical Engineering, IIT Kharagpur
Session: Spring, 2021-22
Experiment # 2

Induction Machine Experiments

Objective

- To determine the equivalent circuit parameters of an induction motor by performing No load test and blocked rotor test
- Determination of the performance characteristics of induction machine with load test and by operating the machine in grid-connected mode

Procedure

1. No-Load Test on Three Phase Induction Machine

For better prediction of machine parameters; test needs to be conducted at synchronous speed, however with standalone induction machine setup one cannot operate the machine at synchronous speed. So use a mechanically coupled DC-motor to run the induction machine at synchronous speed. Below are the step-by-step instructions to conduct No-load test on three phase induction machine.

- Connect the given individual blocks as shown in figure-1
- Double click on induction machine block, change the mechanical input setting to Mechanical rotation port
- If required use additional blocks available in the simulink library browser to conduct the test
- Make sure that mechanical rotation ports of the DC-Machine and Induction machine are connected (Note: It will indicate both the machines are mechanically coupled)
- Do not give any power supply to the dc machine before starting the experiment
  - Keep the DC-Machine field rheostat in the minimum position

- Keep the input voltage slider of the induction machine at minimum position before starting the simulation
- Slowly vary the input voltage slider of the induction machine upto the rated voltage of the machine
- At this point machine speed is slightly lesser than the synchronous speed of the machine
- Now give power supply to the field winding of the DC-Machine
  - Observe the voltage generated across the armature terminals of the DC-Machine
  - Slowly vary the field rheostat position until the voltage across the armature terminals is same as the DC-grid voltage (Both magnitude and sign should be same)
  - Now close the switch between armature terminals and DC-grid (DC-Machine will work like a DC-Motor)
- Vary the field rheostat further to operate the induction machine close to synchronous speed but it should not cross synchronous speed or induction machine should not draw power from DC-machine
- Tabulate the required values as per the Table provided in the instruction set

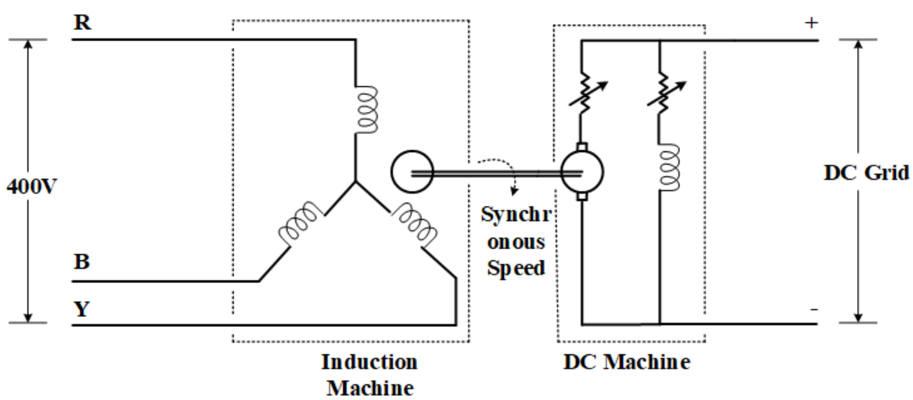

Figure 1: No-Load Test Connection Diagram

2. Blocked Rotor Test on Three Phase Induction Machine

- Connect the given individual blocks as shown in figure-2
- Double click on induction machine block, change the mechanical input setting to speed ω
- If required use additional blocks available in the simulink library browser to conduct the test
- Since the test needs to be conducted at zero speed, give mechanical input as zero using constant block, which will be available in the commonly used blocks section of simulink library browser
- Keep the input voltage slider at minimum position before starting the simulation and for better test results keep the input voltage frequency as 20Hz instead of rated frequency

- Slowly vary the input voltage slider upto the rated current of the machine
- Tabulate the required values as per the Table provided in the instruction set

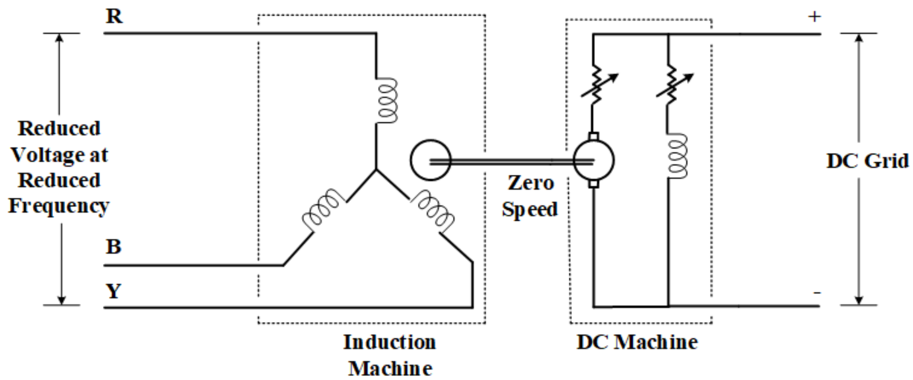

Figure 2: Blocked Rotor Test Connection Diagram

3. Load Test on Three Phase Induction Machine

- Connect the given individual blocks as shown in figure-1
- Double click on induction machine block, change the mechanical input setting to Mechanical rotation port
- If required use additional blocks available in the simulink library browser to conduct the test
- Keep the input voltage slider at minimum position before starting the simulation
- Slowly vary the input voltage slider upto the rated voltage of the machine
- At this point machine speed is slightly lesser than the synchronous speed of the machine
- Keep the DC machine field rheostat in minimum position, so that rated field current will flow in the DC machine
- Now turn on the loads connected across the armature terminals of the DC machine
- Tabulate the required values as per the Table provided in the instruction set

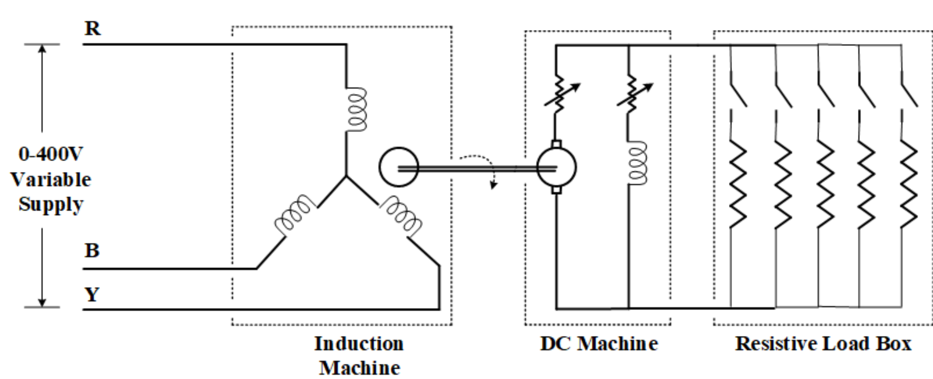

Figure 3: Load Test on Three Phase Induction Machine

4. Grid Connected Operation of Three Phase Induction Machine

Using load test one can verify the characteristics of induction machine in motoring mode but using grid connected operation, generating mode characteristics of induction machine are obtained. In motoring mode induction machine will draw power from the three phase supply and delivers power to the loads connected across DC-machine side. In generating mode induction machine will draw power from the DC-machine and delivers power to the three phase supply. Below are the instructions to perform grid connected operation of three phase induction machine.

- Connect the given individual blocks as shown in figure-4
- Steps to conduct the test are similar to No-Load test
- Fallow first nine steps of the No-Load test
- Vary the field rheostat further such that the speed of the machine is more than synchronous speed of the induction machine, make sure that the current delivered by the induction machine is with in the limits.
- Repeat above step and Tabulate the required values as per the Table provided in the instruction set
- Plot the relevant graphs as per the instruction set, For your reference below listed plots are included in the example section
- Both load test and grid connected operation results are plotted in same figure, in order to observe the machine performance below and above synchronous speeds
    - DC-Machine synchronization with DC-Grid
    - Output power vs slip characteristics of the induction machine
    - Torque vs slip characteristics of the induction machine
- For better resolution of the graphs, one is allowed to take the readings more than five operating conditions

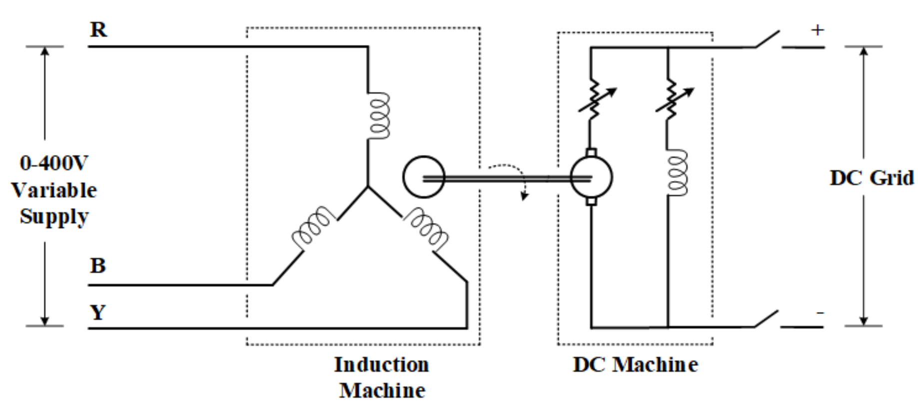

Figure 4: Grid Connected Operation of Three Phase Induction Machine

5. Examples

- The Simulink models considered to perform the tests are listed below
  - **Specifications of Squirrel-cage machine : 5.4HP (4kw) 400V 50Hz 1430Rpm**
  - **Specifications of DC machine : Armature :7HP 350V 1500Rpm, Field :350V 1.7A**

No-Load Test

- Unlike in physical induction machine, the simulink based machine will not contain the core loss component resistor, So the relevant machine parameters are calculated using No-Load test data as per the equivalent circuit shown in figure-5

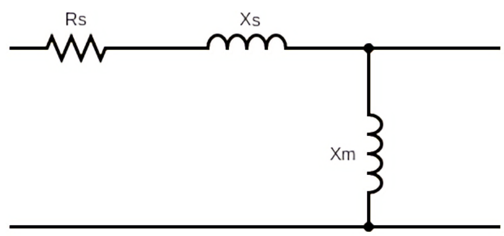

Figure 5: No-Load test equivalent circuit

- Below data is obtained while performing No-Load test on the induction machine

$V_{S,line}$	$I_{S,line}$	$P_{in}(3-\phi)$	$Q_{in}(3-\phi)$	N_r	T_e
400 V	4.128 A	142.4 W	2856 VAR	1499 rpm	0.4493 Nm

$$X_{nl} = \frac{Q_{nl}}{3}\frac{1}{I_{nl}^2} = 55.96\Omega$$

- Assume $X_l << X_m$

$$X_m = X_{nl} = 55.87\Omega$$

$$L_m = \frac{X_m}{2\pi * 50} = 0.1778H$$

- Stator copper losses obtained by subtracting the rotational losses from the total power during No-Load test

$$P_{cu_{nl}} = P_{in} - P_{Rotatoinal}$$

$$\Rightarrow P_{Rotatoinal} = T_e * \omega = 70.52W$$

$$\Rightarrow P_{cu_{nl}} = 142.4 - 70.52 = 71.88$$

$$P_{cu_{nl}} = 3I_{nl}^2 R_s$$

$$\Rightarrow R_s = 1.4061\Omega$$

Note: The calculated values ($R_s = 1.4061\Omega$ & $L_m = 0.1778H$) are matched with given parameters for the model ($R_s = 1.405\Omega$ & $L_m = 0.1722H$)

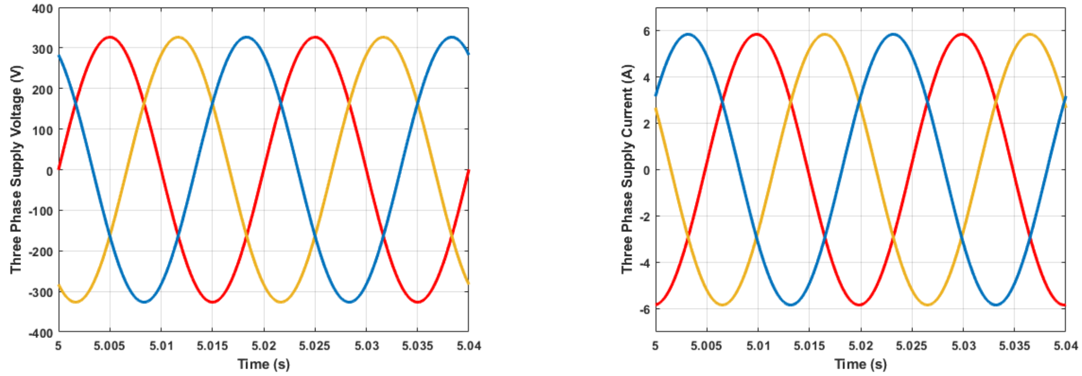

Figure 6: No-Load test wave forms

Blocked Rotor Test

- L_m and R_s are calculated from the no-load test data, The remaining equivalent circuit parameters are calculated using the blocked rotor test data and by considering the equivalent circuit shown in figure-7

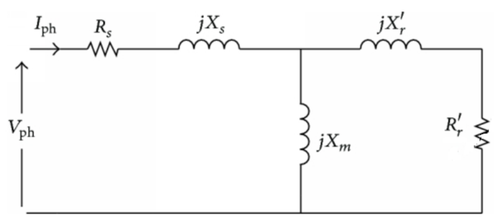

Figure 7: Blocked rotor test equivalent circuit

- Below data is obtained while performing the blocked rotor test on the induction machine

$V_{S,line}$	$I_{S,line}$	$P_{in}(3-\phi)$	$Q_{in}(3-\phi)$
31 V	5.764 A	268.6 W	153.6 VAR

$$X_b = \frac{Q_b}{3 * I_b^2} = 1.5249\Omega; R_b = \frac{P_b}{3 * I_b^2} = 2.7052\Omega$$

$$Z_b = R_s + jX_s + (R_r' + jX_r') \| jX_m = R_b + jX_b$$

- After separating real and imaginary parts

$$X_b = X_s + X_r' \left(\frac{X_m}{X_r' + X_m} \right); R_r' = R_b - R_s \left(\frac{X_r' + X_m}{X_m} \right)^2$$

- Let $X_s = X_r' = K$, and by rearranging X_b

$$K^2 + K(2X_m - X_b) - X_m X_b = 0$$

- After substituting $X_m \& X_b$ values in the above equation $\Rightarrow K = 0.7838$
  $\Rightarrow L_s = L_r' = \dfrac{K}{2\pi 20} = 0.0062H$
  $\Rightarrow R_r' = 1.3808$
  Note: The calculated values ($R_r' = 1.3808\Omega$ & $L_s = L_r' = 0.0062H$) are matched with given parameters for the model ($R_r' = 1.395\Omega$ & $L_s = L_r' = 0.00584H$)

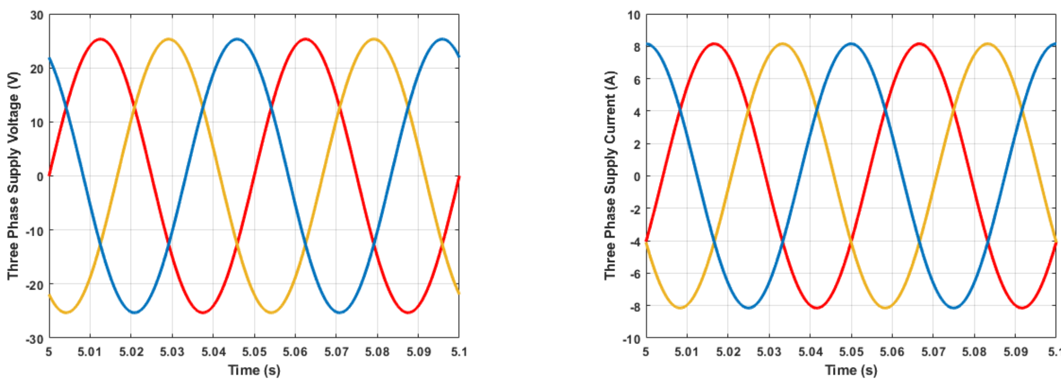

Figure 8: Blocked rotor test wave forms

Grid Connected Operation of Induction Machine

Figure-9 describe the DC-grid synchronization process, The synchronization process is described below

- At Starting voltage across the armature terminals of the DC-machine is 321 V
- By Varying the field resistance of the dc machine, armature terminal voltage increased gradually
- At time $t = T_s$ voltage across dc machine armature terminals is same as DC-grid voltage (350V)
- Switch is closed after T_s, after T_s voltage across DC machine armature terminals is constant as shown in figure-9

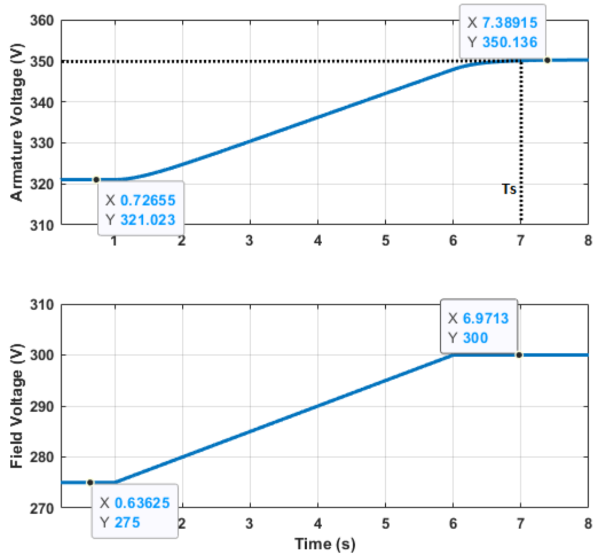

Figure 9: Waveform of armature terminal voltage of the DC machine for DC grid synchronization (Ts: time for synchronization)

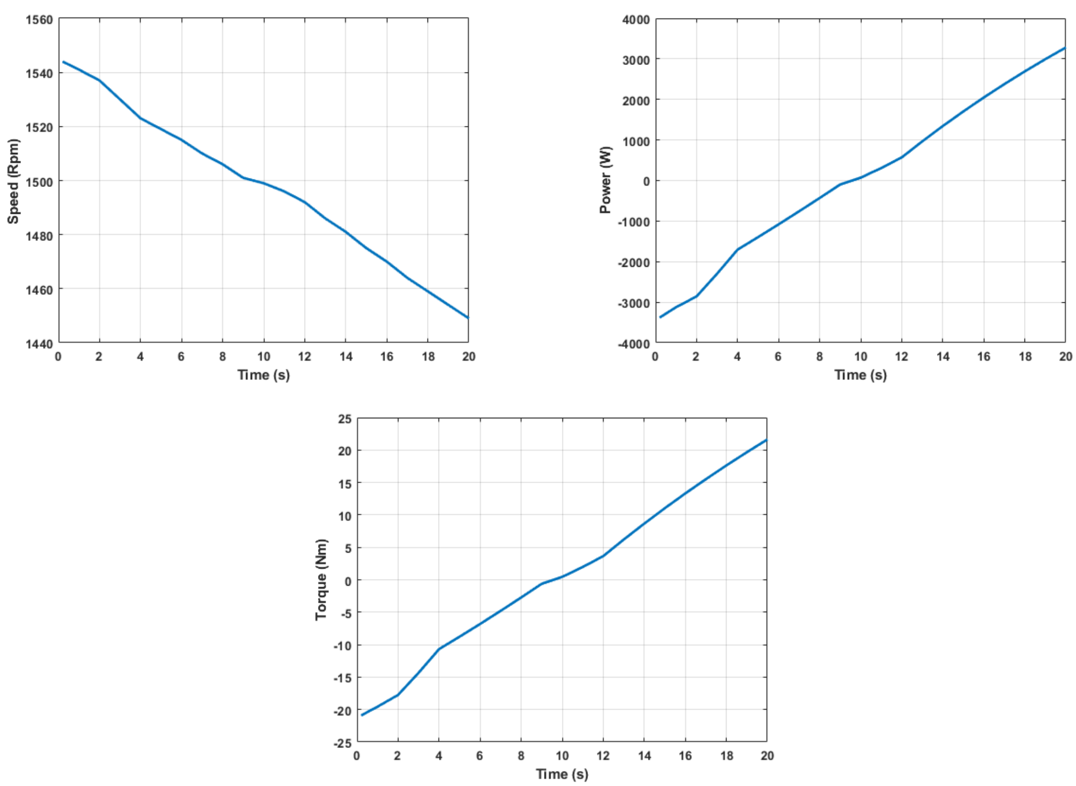

Figure 10: Induction machine wave forms with respect to time

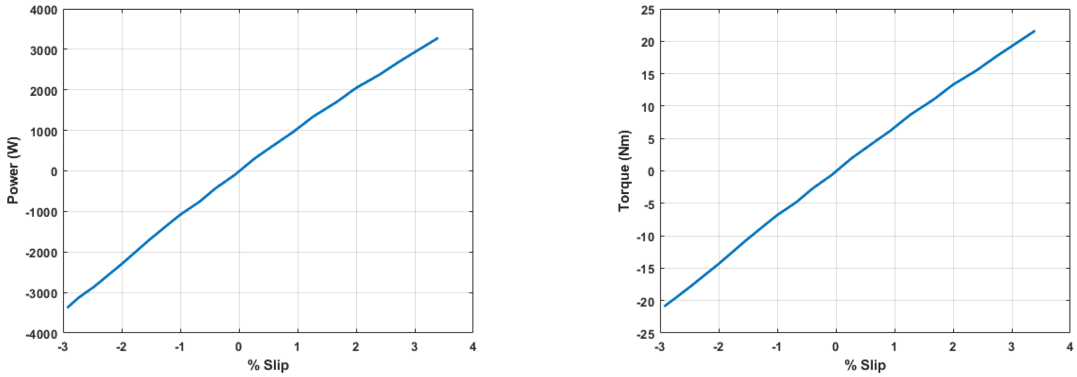

Figure 11: Induction machine wave forms with respect to slip

Note : As consistent from the theory, Power & Te are proportional to slip. The Obtained experimental graph corresponds to the linear region.