Lab-4: AC Squirrel-Cage Induction Motor

Objectives and Overview

The objectives for this sequence of laboratory experiments are:

- to experiment and fully characterize a small industrial ¼ HP 34V Induction Motor by identifying its equivalent circuit parameters;
- to observe the start up transient when the motor is directly connected to the fixed 60 Hz AC source and started from stall;
- to observe and measure the load characteristics when the motor is supplied from a fixed frequency 3-phase AC source;
- to experimentally control the motor speed by adjusting the source voltage magnitude at fixed 60 Hz frequency;
- to experiment and demonstrate the motor control using Variable Frequency Drive (VFD) in wide range of speeds, below and above the nominal speed;
- to get an idea on the energy conversion efficiency of different stages when the motor is driven by the VFD.

By doing a set of measurements, the students will determine parameters of the per-phase steady-state equivalent circuit for the conventional induction motor:

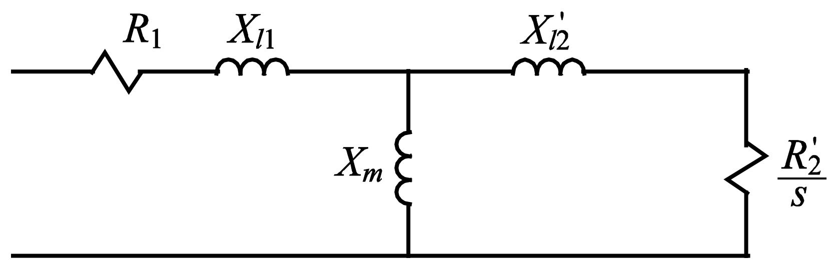


Fig. 1: Induction motor per-phase equivalent circuit.

This equivalent circuit and the equations discussed in class assume a symmetric Y-connected winding. The students will use this steady-state equivalent circuit as a model of the given motor to predict the torque-speed and load characteristics and compare them to the measured data.

Preparation (Pre-Lab)

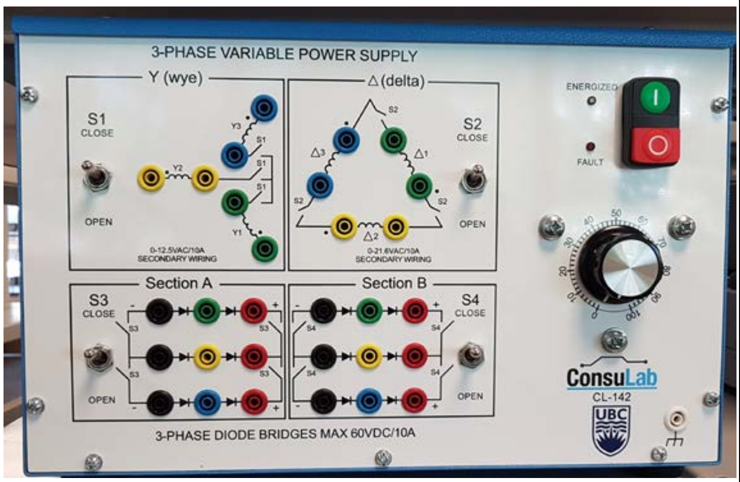
It is expected that the students have read and understood the textbook chapter and reviewed the lecture notes module corresponding to the AC Induction Machines. In particular, the students should be familiar with the theory and principle of rotating magnetic field, principle of operation of induction machines, procedures to determine the equivalent circuit parameters, and basic torque-speed characteristics. In addition, the students should review the material on motor control using the variable frequency 3-phase AC inverter. The Pre-Lab page should include the following:

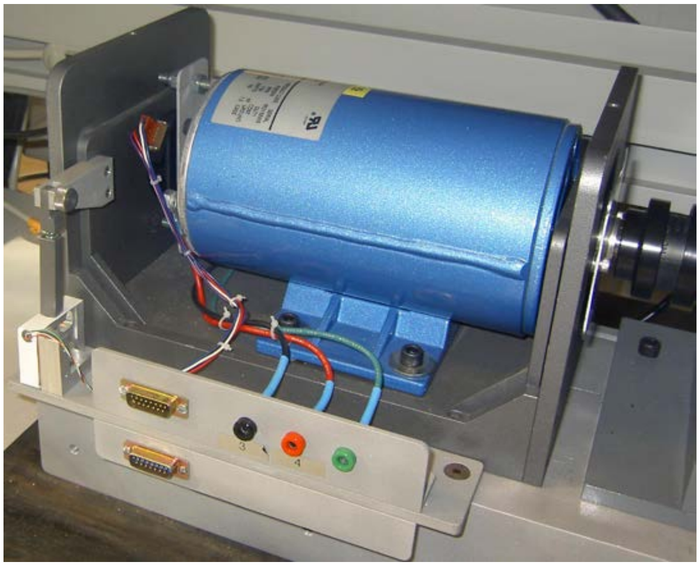
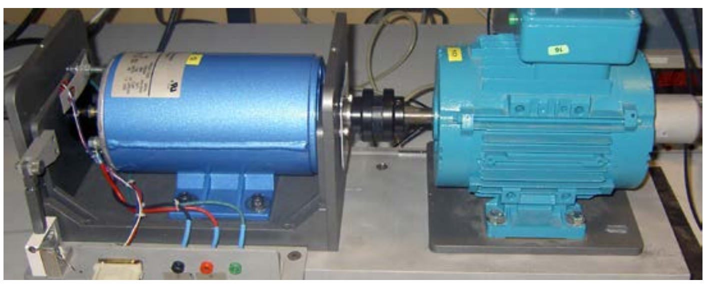
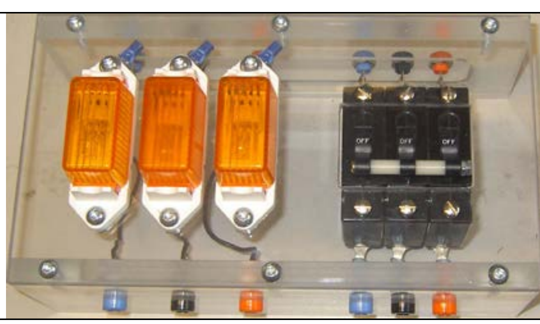
- Prepare a list of equations for calculating the equivalent circuit parameters using the Blocked-Rotor and No-Load Tests.
- Write down the expression for the torque-speed characteristic at 60 Hz fixed frequency and constant voltage magnitude.

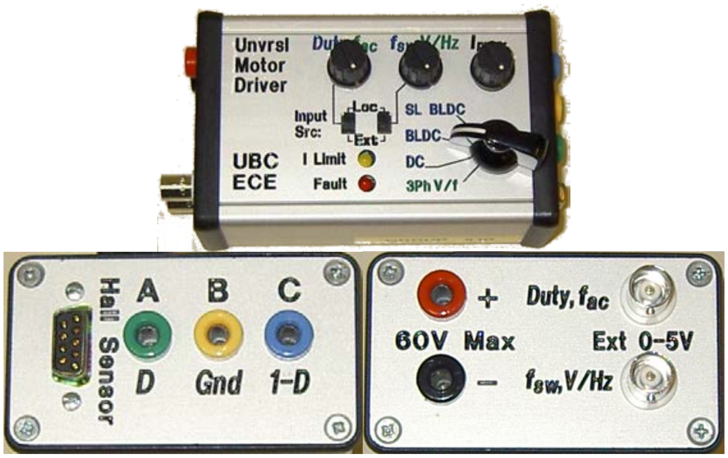
- Assume an inductor (a magnetizing branch of the induction machine or a transformer) under sinusoidal AC excitation. Write down an expression for the magnitude of the flux in terms of voltage and frequency. Write a sentence to rationalize why the voltage and frequency should be adjusted together for the Variable Frequency Drive applications.

Apparatus & Equipment

This lab includes the following components:

	**3-Phase AC Power Supply:** This flexible 3-phase Power Supply has two 3-phase transformers inside. The secondary windings can readily be configured into a 'Y' (wye) and "Δ" (delta) configurations. The front panel shows the transformer wiring and has several switches and connectors for configuring the output. It also has two 3-phase diode bridges for producing the DC output. The Power Supply transformers are fed from an internal 3-phase **Variac** (variable auto transformer) that can be used to adjust the output voltage. The Variac knob is located on the right of the front panel. By varying the Variac knob from 0 to 100%, the output AC voltages may be changed in the range from 0 to about 25 V (rms) per phase.
	**Induction Motor:** This is a small industrial ¼ HP Squirrel-Cage Induction Motor which you have to parameterize. The Stator winding is Y-connected with the access to the phase terminals. This motor should be mounted on the Motor Bench, wherein the motor shaft may be coupled to the Dynamometer for taking the measurements.

	**Dynamometer Cradle:** A DC machine is mounted in a special cradle to permit measurements of the torque and speed on the shaft. The motor housing is supported along its axis by ball bearings which enable it to move when the torque is developed on the shaft. The reaction torque is measured from the force acting on a load cell. This allows direct measurement of mechanical torque. The Dynamometer also has an optical position encoder mounted on the back of its shaft (left side) for measurement of speed. To reduce the effect of EMIs, connect the ground of the **DC Power Supply** (**green terminal**) with the ground of the **Motor Bench** (**also green terminal**).
	**Motor Bench:** The Induction Motor under test should be mounted on the Motor Bench as shown on the left. A DC machine mounted on the Cradle is used to emulate the mechanical load. This machine can be coupled to the Induction Motor through the shaft.
	**Load Resistor Box:** The Load Box contains several resistors from 100 to 50 Ohms, which can be switched on in parallel to each other. The box is equipped with a cooling fan to help dissipate the heat in case there is a significant power delivered to the load. Be careful! This box may get very hot, especially its heat-sink that is on the bottom. When the box dissipates more than 50W turn on the internal fan.
	**3-Phase Switch:** a 3-phase switch is mounted in a box together with synchronization lamps. This box is used to switch ON and OFF the Induction Motor under test in order to observe the start-up transient and record the voltage sag in the system due to a very high start-up current.



Universal Inverter: A multi-purpose inverter is designed for driving various AC and DC motors. In this lab, you will use this Inverter to operate the Induction Motor. For this mode, the mode switch should be in **3Ph V/f** position (**green**) corresponding to the Pulse-Width-Modulation (PWM) Volts-per-Hertz control. The Inverter is also equipped with two knobs to control the frequency **f_{ac}** (duty cycle) and the voltage/frequency ratio. The last knob on the right adjusts the current limit.

DC Power Supply: A flexible regulated Xantrex XHR6018 DC Power Supply will be used to supply the DC motors in this Lab experiment. This power supply has adjustable output voltage 0-60V and current limit 0-18A, which are sufficient for most experiments in this laboratory.

Measurement Box:

Each bench is equipped a multi-functional **Measurement Box** that can measure up to 3 voltages and up to 3 currents simultaneously with the sampling rate of 2.5 MS/sec (2.5MHz). The measured waveforms and their values can be displayed on the PC screen as well as recorded for possible post-processing. Its front panel has 3 current channels (**A1, A2, and A3**) and 3 voltage channels (**V1, V2, and V3**), respectively. The current channels are rated to measure and withstand a continuous current of up to 20 A (peak). The voltage channels are rated to measure and withstand the voltage of up to 50 V (peak). For special measurements only, the voltage measurement in each channel can be re-scaled by a factor of 10, thus raising the measurement limit to 500 V (peak). The **Measurement Box** is connects to the Data Acquisition (DAQ) card inside the PC. The **Measurement Box** has one power switch on its back panel on the right side. The power switch should be normally turned ON, and the three LEDs on the front panel should also be ON indicating its normal operation.

The channels are color-coded. It is strongly recommended that you use appropriate and consistent color wires for each channel of measurements. This will make it easier for you to wire-up your circuits and subsequently check it and find any mistakes.

Setting-Up the DAQ System

Login to your local PC and locate the program **3 Phase Motor Analysis**. Double-click on the icon and start the program. A window shown in Fig. 1 should appear on your PC screen indicating that you are ready to start taking measurements. The **3 Phase Motor Analysis** program interface is set up to display the three voltages (channels **V1, V2,** and **V3**) and three currents (channels **A1, A2,** and **A3**), **Speed** and **Torque**, as will be needed in this lab. The measurement window can be triggered using either voltage or current signal of the first measuring channel (either **V1** or **A1**). The point of triggering also defines the relative angle of the measured signals. The user can select or un-select the measurement of voltages and currents, but the first channel (V1 and A1) are always selected. For this lab, select all the voltages and currents, Speed and Torque to be measured.

All measured signals (voltages, currents, speed, and torque) are displayed in two ways: On the left side of the panel, all selected variables are displayed as real-time instantaneous waveforms – just like in an oscilloscope. On the right side of the panel, the **RMS** values of the voltages (in Volts) and currents (in Amps) and their corresponding average values are displayed. All three Channels also display the calculated average real power in Watts.

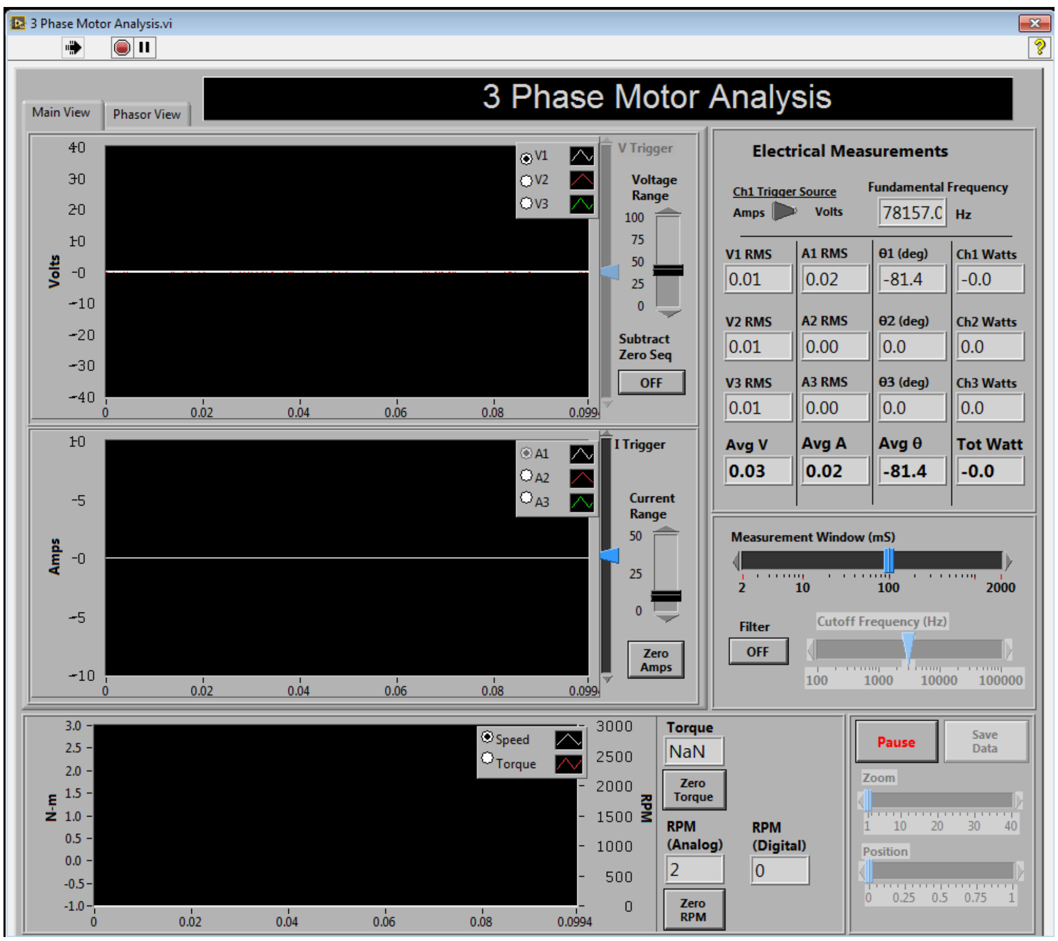


Fig. 2: LabView program interface 3-Phase Motor Analysis.

The **average real power** in each channel (in Watts) is calculated assuming the instantaneous voltage and current in that channel. The power is calculated by averaging the instantaneous power over the length of the measurement window. For this measurement to be correct, you have to make sure that the voltage and the current measurements are from the same Channel (V1 with A1, V2 with A2, and V3 is with A3, respectively), and that the polarities of both voltage and current channels are correctly wired.

Digital Filter: The program also has the capability to apply digital filtering to the measured voltages and currents. The user can turn the filter ON and OFF, as well as adjust the cut-off frequency. **For the purpose of this Lab, the filter should be OFF in all measurements.**

Note: In each task, you can use the Phasor View tab in the LabView program to observe the phasor diagram of three-phase voltages and currents.

Setting-Up the Experimental Part

1) Induction Motor Nameplate Information:

The **Induction Motor** must be mounted on the right side of the **Motor Bench**. For the first part of the experiment the **Induction Motor** shaft should be **de-coupled** from the Dynamometer so that the motor shaft is free to rotate. Look carefully at the **Induction Motor** and read the information that is written on its **Nameplate**. Using the Nameplate information, fill in Table 1 of your Lab Report. Note that since this motor was specially re-wound for reduced voltage (34/68 V), not all of the standard information is provided. So, complete as many entries of Table 1 as you can. The motor has two identical windings that are internally connected in parallel to operate at 34 V line-to-line. You will be able to complete Table 1 after you have completed this Lab Experiment. Calculate the nominal/rated values and write them down in Table 2 of your report.

2) Measuring Stator Winding Resistance:

For calculating the parameters of equivalent circuit you will also need to measure the resistance of the stator winding at DC. It is convenient to take this measurement before the motor is connected to the AC source. The simplest way to measure the winding resistance is to use the Multimeter that is available on your bench top. This will measure the resistance at low current. You may apply a variable DC source and measure the current and voltage applied to the winding (similarly to the DC Machine Lab). Use long wires and the bench **DC Power Supply**. Make sure to apply very low voltage and low current between 2 and 3 A. **Do not exceed 5 A for the DC measurement!** Write your results in Table 3 of the Lab Report.

3) Wiring the 3-Phase AC Power Supply:

In this part, the students will set up the multi-purpose **3-Phase AC Power Supply** in such a way that it will provide a variable 3-phase AC voltage to drive the motor under study. The **3-Phase AC Power Supply** has two sets on windings 'Y' (wye) and "Δ" (delta). For this test, you will need to reconfigure the "Δ" (delta) winding, which is on the right side, into the 'Y' (wye) configuration in order to provide the sufficient voltage to supply the motor. **The switch S2 must be open.** Use three **short red wires** to make neutral point as shown in Fig. 3. **Please pay a**

particular attention to the windings polarity, which is required to properly add up the voltages. The arrangement in Fig. 4 will give up to about 21 V (phase voltage) and 37V (line-to-line voltage) at the output terminals A-B-C. This should be more then sufficient to supply the Induction Motor under test. The terminals A-B-C are then used to provide the variable AC voltages to supply the **Induction Motor**. The Variac know on the right side of the Power Supply is used to adjust the output voltage.

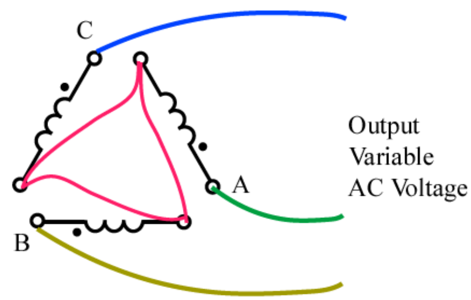


Fig. 3: 3-Phase AC Power Supply wiring diagram.

4) Wiring the Induction Motor:

In your experiment you will be monitoring the phase voltages and currents. Wire up the circuit as shown in Fig. 4 so that you can measure current and voltage in each phase. First connect the current-carrying circuit and the **3-Phase Switch**. Then connect the voltmeter wires directly on the AC Power Supply panel. Use **color wires** to distinguish among the phases (For example, Green, Yellow, and Blue). **Make sure that the polarity of each current and voltage channel are connected as shown in Fig. 4 and that the channels are ordered consistently**, e.g., Ch.1 current and Ch. 1 voltage are connected to the same phase (same applies to the other channels). Mismatching the channels will result in incorrect measurements. Note that in Fig. 4 the Voltmeter Channels form a neutral point. This neutral point is used to measure the phase voltages that will be supplied to the motor. Although the motor winding is Y-connected, its actual neutral point is not available at the motor terminals! The rest of the wiring is described in each Task.

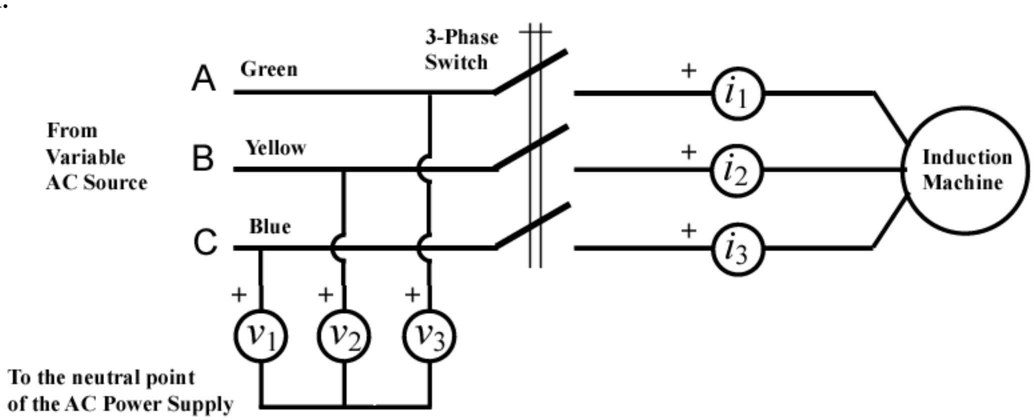


Fig. 4: Wiring diagram for taking the no-load phase voltage and current measurements.

Task 1: No-Load Motor Characteristics

Verify your circuit according to Fig. 4 and make sure that the **Induction Motor** is decoupled from the Dynamometer Cradle (Load-Motor). Use the **Measurement Box** to display the voltages, currents, and power of the motor under test.

Task 1 A: Measuring No-Load Rotational Losses

1) Turn ON the 3-Phase AC Power Supply and slowly increase the applied voltage from 0V to the nominal value of the line-to-neutral voltage recorded in Table 2 (about 19 to 20 V rms for phase voltages). Turn ON the 3-Phase Switch to power up the motor. The software program should display the voltage and current measurements for each phase individually as well as averaged among the three phases. The readings should be roughly balanced among the phases with pronounced lagging current. Record the average phase voltage, phase current, average angle, and the total real power in Table 4. You will have to calculate the combined rotational losses as the total input electrical power less the power dissipated on the stator resistances. That is $P_{rot-loss} = P_{nl} - 3R_1 I_{s,average}^2$.
2) Turn **OFF** the Power Supply by pushing the red **Stop** button. The Variac knob should remain in the maximum voltage position.

Task 1 B: Recording the No-Load Start-Up Transient

A typical **Induction Motor** may draw a very significant current during its starting from a line fixed-frequency AC source. This transient starting current may be 5 to 8 times larger than its nominal operating stator current, which causes the voltage sag (drop) and may represent a problem especially for large motors. The starting torque is not very high (compared with the very high starting current). Therefore, adding mechanical inertia (mechanical load) may significantly prolong the starting transient. In this task you will observe this phenomenon.

1) Make sure that **3-Phase Switch** is OFF and the motor is not spinning. Turn ON the 3-Phase AC Power Supply and check the Variac knob to supply to the **nominal** output voltage.
2) The program should be prepared to SAVE the measurements. For that, you will need to increase the measurement window size to its maximum time length (2 sec). Your screen will be updated at longer time intervals (2 sec).
3) Move your computer Mouse to the **PAUSE** button and be prepared to click on it. Then, turn ON the **3-Phase Switch** to start the Induction Motor. As soon as the transient appear on the screen click on the **PAUSE** button on the program interface. Once the transient is captured on the PC screen you may be able to zoom into the representative part of the transient that includes only few cycles before the transient and after the steady-state is reached. Then save the data file by clicking on the **SAVE** button. The saved file is in the text format and can be used for plotting the data in the software of your preference (Matlab, Excel, etc.)
4) Turn off the Power Supply by pushing the red **Stop** button.

Task 1 C: Recording the Start-Up Transient under Mechanical Load

1) Now couple the **Induction Motor** shaft to the Dynamometer (DC Machine). Make sure that the metal coupling is in place and that the Induction Motor is tightly fixed using the finger screws (at least one of them).
2) Repeat Step 3) of Task 1 B, record and **SAVE** the start-up transient. Note that now your motor is loaded with additional inertia as well as the friction from the Dynamometer DC Machine. The observed transient will be somewhat different – it should be longer. Save the captured data for the future comparison.
3) Reduce the voltage to zero and turn off the Power Supply. You will then need to plot and compare the results from Task 1 B and C.

Task 2: Blocked-Rotor Test

The Induction Motor shaft should be coupled to the Dynamometer (DC Machine). The wiring remains the same as it was in Task 2. For this measurement only, you will need to lock the Machine shaft. Ask your Lab TA and/or technician for a **Metal Lock** that can be inserted in a special slot on the top of the Motor Cradle to lock the shaft. Slide in the **Metal Lock** plate and manually rotate the shaft to make sure that the lock clicks-in and locks properly.

1) Make sure that 3-Phase AC Power Supply is OFF and the Variac knob is in the position corresponding to the **minimum** output voltage. Also make sure you zero the torque measurement before closing the 3-Phase Switch.
2) Turn ON the 3-Phase Switch and the AC Power Supply. Slowly increase the voltage until you reach the rated/nominal phase current recorded in Table 2. Observe that the motor shaft is not (or should not be) spinning. Note that developed starting torque is quite small. Recall that you can change the direction of rotation by swapping any two phases on the motor terminals. If your torque measurement is in the negative direction, you can simply swap any two phases on the motor terminals to get the correct direction of rotation! Record the measurements in Table 5.

Task 3: Measuring Load Characteristics of the Motor

For this Task, you can simplify the circuit and remove the 3-Phase switch as shown in Fig. 5. Re-Connect the voltmeter wires directly to the Induction Motor terminals, whereas the neutral point can now be floating. Connect the **Load Resistor Box** to the Dynamometer DC Machine as shown in the Fig. 5. The loaded Dynamometer will be used to emulate a mechanical load torque for the **Induction Motor**. There is no need to measure any electrical variable on the DC side since we are only interested in the resulting mechanical torque. By adjusting the load of the DC Machine you will be changing the mechanical torque applied to the **Induction Motor** under test.

Make sure that the **Resistor Box** fan switch is turned **ON** to allow the fan operation for cooling the resistors. Otherwise, the box will get very hot!

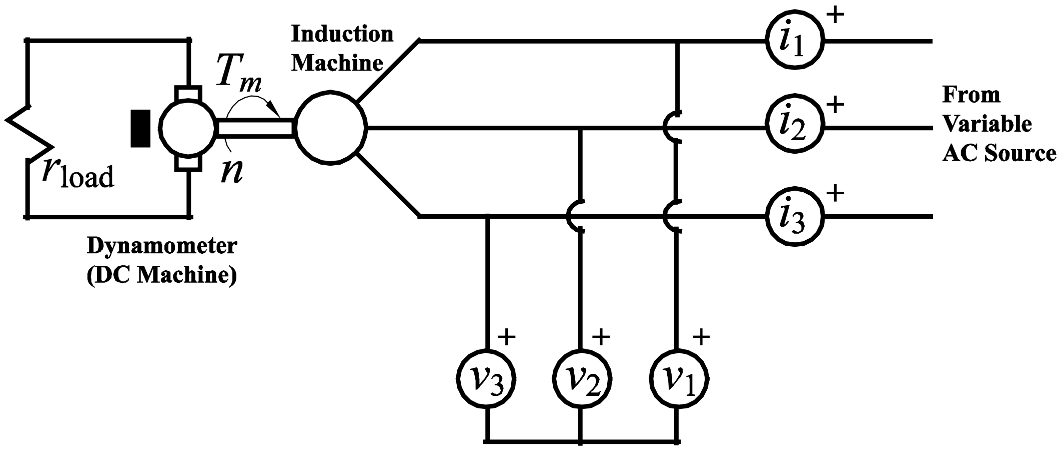


Fig. 5: Wiring diagram for measuring the Load Characteristics.

Task 3 A: Load Characteristic – Speed Regulation under Nominal Voltage

1) Switch off all load resistors in the **Load Resistor Box** and turn on the **Power Supply**.
2) Quickly increase the source voltage to its maximum. If you do not do this fast enough, too much current will be flowing in the machine windings, which can damage the machine. Once the machine is rotating around nominal speed, slowly decrease the voltage of the **Power Supply** to output about **19 – 20V** rms per-phase. Because the supply is unregulated, it will be **necessary to adjust the output to the same value** when the voltage drops under load. Record this measurement in the first column of Table 6.
3) Then, one at a time, start switching ON the resistors in the **Load Resistor Box** and record the measurements in Table 6. Your last measurement should be at the maximum mechanical load that is achieved when all the resistors in the **Load Resistor Box** are turned ON. The last measurement should be in the range 200 – 290W.

Task 3 B: Speed Control by Adjusting Voltage

1) Continue from the previous test Task 3 A. Check that the phase voltage is **19 - 20V** rms per-phase. The dissipated real power should be high corresponding to the last point in Task 3 A part 3). Do not change the switches of the **Load Resistor Box**. Record this measurement in the first column of Table 7.
2) Slowly decrease the voltage by 3 volts at a time and record the values in Table 7. The machine speed should be decreasing but not as nicely as you had experienced in DC Machines. After taking several measurements, the **Induction Motor** will slowly stall! When it happens, turn OFF the AC Power Supply. You will have to explain why it happened in your Lab Report. Note that when the voltage is decreasing, the current will be rapidly increasing!

Task 3 C: Load Characteristic – Speed Regulation under Low Voltage

1) Switch OFF all load resistors in the **Load Resistor Box** and turn ON the **Power Supply**. Adjust the Variac knob to reduce the phase voltage to **12 – 14V** rms per-phase. This will emulate an abnormal low voltage in the system. The motor should still be spinning. Because the supply is unregulated, it will be **necessary to adjust the output to the same value** when the voltage drops under load. Record this first value in the first column of Table 8.
2) Then, one at a time, start switching ON the resistors in the **Load Resistor Box** and record the measurements in Table 8. Your last measurement should be at the maximum mechanical load that is achieved when all the resistors in the **Load Resistor Box** are turned ON. Monitor the phase current and the speed. The current may be very high, which is likely to cause overheat and the trip the current protection of the AC Power Supply. When it happens, turn OFF the Power Supply.

Task 4: Operation with Variable Frequency Drive (VFD)

In this Task, you will operate the **Induction Motor** under test using the **Universal Inverter Box** that is capable of producing/modulating output voltages with variable frequency and amplitude. Most of the AC circuit remains the same as in previous task as depicted in Fig. 5; however, the AC Source used in the previous tasks will be replace by the **Inverter Box**. So, remove the three wires from the 3-Phase AC Power Supply and connect them to the **Universal Inverter** output terminals A-B-C as shown in Fig. 6.

Configure the Universal Inverter:

Attention: Since the **Inverter** switches at high frequency (20kHz), they emit electromagnetic waves that could cause electromagnetic interference (EMI). To reduce the effect of EMIs on the accuracy of measurements, you will also need to connect the ground of the **DC Power Supply** (**green terminal**) with the ground of the **Motor Bench** (**also green terminal**).

a) The **Universal Inverter** mode switch should be in **3Ph V/f** position (**green**) corresponding to the Volts-per-Hertz control Pulse-Width-Modulation (PWM).
b) The Inverter is also equipped with knobs to control the frequency $\mathbf{f_{ac}}$ (duty cycle) and the voltage/frequency **V/Hz** ratio. **Initially, the left-most knob should be turned to minimum position corresponding to minimum frequency and output voltage**. The second knob controlling the **V/Hz** ratio should be turned to approximately 1/3.
c) The third knob is for setting the current limit and it should be set to maximum (which corresponds to about 30A). The DC terminals should be connected to the Xantrex **DC Power Supply**.

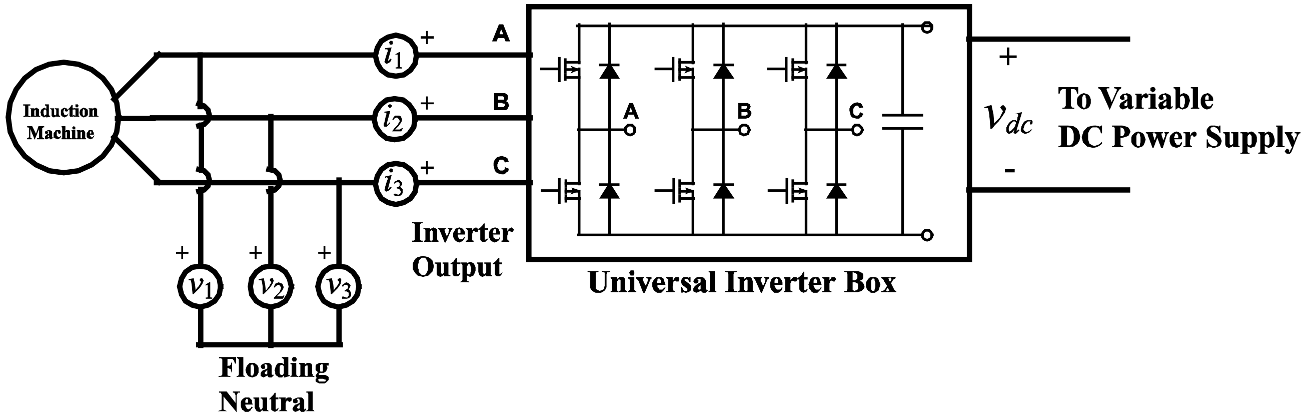


Fig. 6: Wiring diagram for operation of Induction Motor with Variable Frequency Drive.

Task 4 A: Speed Control by Varying the Frequency

1) Double check to make sure that the $\mathbf{f_{ac}}$ knob of the **Inverter** has been turned to minimum position corresponding to minimum frequency and output voltage. Then, turn on the **DC Power Supply** and adjust the DC voltage to 45 V. Initially, the motor should not be spinning.
2) Slowly turn on the $\mathbf{f_{ac}}$ knob on the Inverter and increase the frequency. You should observe that the motor is now starting to rotate and that you can easily control its speed by changing the electrical frequency $\mathbf{f_{ac}}$. Observe the frequency on the **3-Phase Motor Analysis** LabView interface (make sure that the triggering is set on current!). Set the frequency to about 60 Hz and observe the waveforms of currents and voltages. Turn on the **Filter** located in the middle of the **3-Phase Motor Analysis** LabView interface and observe the difference between the filtered and unfiltered voltages. Adjust the **V/Hz** ratio knob so that the output voltage is about 19 V rms per phase at the frequency of 60 Hz. This should result in the current and voltage waveforms that are very close to ideal sinusoids.
3) Adjust the **Load Resistor Box** so that you have about 150 W coming into the **Induction Motor**.
4) Decrease the frequency to 10 Hz and do not change the **Load Resistor Box**. Then start increasing the frequency from 10 up to 95 Hz and record several measurements in Table 9. You should observe that you can readily control the motor speed which can easily exceed the 1800 rpm limit for 60 Hz! You may need to adjust the V/Hz ratio in order to keep the current waveforms close to sinusoidal.

Task 4 B: Efficiency of Energy Conversion

5) Complete the calculations of power and efficiency in Table 9.

Task 5: Calculations and Analysis

This part must be included with your Lab Report. You are very strongly encouraged to use **MATLAB** (or equivalent powerful tool) for performing the calculations.

Task 5 A: Determining Motor Parameters

1) Calculate the equivalent circuit parameters (write them down in Fig. A, all except the rotor resistance R_2'**)**. Complete Table 1 for the condition when the motor was loaded to the nominal output power defined by the mechanical speed and torque.
2) The rotor resistance can also be estimated from the measured load torque-speed characteristic. In particular, using the equation $T_e = 3\dfrac{V_1^2}{\omega_{syn}} \cdot \dfrac{(R_2'/s)}{(R_{1,th} + R_2'/s)^2 + (X_{1,th} + X_2')^2}$, it can be noted that at very small values of slip the torque is almost linearly/proportional to slip and may be approximated as $T_e \approx 3\dfrac{V_1^2}{\omega_{syn}} \cdot \dfrac{(R_2'/s)}{(R_2'/s)^2} = 3\dfrac{V_1^2}{\omega_{syn}} \cdot \dfrac{s}{R_2'}$. Based on this approximation, a new value for R_2' can be calculated using several points from the measured load torque-speed characteristic. Calculate this value and compare it to the value found in part 1). Choose one that in you opinion is more accurate, state and justify your choice and write it in Fig. A.

Task 5 B: Equivalent Circuit vs. Measured Comparison

1) Use the per-phase equivalent circuit of Induction Machine (Fig. A) and calculate the torque-speed characteristic $T_e(n)$ using the voltage from Table 6. Use about 15 to 25 equally-spaced (from 0 to 1800 rpm) points and superimpose on the same plot both calculated (theoretical) characteristic, as well as the measured characteristic from Table 6. Provide two plots: one with the scale from 0 to 1800 rpm, and the second one where you zoom-in to show all the measured points. Comment on the results.
2) Using the data in Table 6, calculate the motor efficiency as a function of the torque $\eta(T_m)$. Then, calculate the same characteristic using the equivalent circuit. Plot/superimpose the two curves: one calculated using the measured data, and one calculated using the equivalent circuit. Comment on the results.
3) Using the data in Table 6, plot the motor power factor as a function of the torque $PF(T_m)$. Show two curves: one calculated using the measured data, and one calculated using the equivalent circuit. Comment on the results.
4) Find the maximum and the minimum voltages for which you took measurements in Table 7. For these two voltages, plot two theoretical torque-speed characteristics using equation $T_e = 3\dfrac{V_1^2}{\omega_{syn}} \cdot \dfrac{(R_2'/s)}{(R_{1,th} + R_2'/s)^2 + (X_{1,th} + X_2')^2}$ and the equivalent circuit parameters. Use about 15 to 25 equally-spaced (from 0 to 1800 rpm) points and superimpose both plots on the

same graph. Also, superimpose on the same plot the data points corresponding to the measured speed and torque in Table 7. Make comments on the speed regulation.

5) What can you say and conclude about the accuracy of equivalent circuit compared to your measurements?

Task 5 C: Starting Transients

1) First, on one graph (using two subplots) plot the voltage and current (only for one of the phases) saved in Task 1 B. Then, plot on another graph the phase voltage and current recorder in Task 1C. In both cases, select the time interval that clearly shows the duration of the start-up transient, and then use the same relative time scale for both cases.
2) Show how long the transient lasts in each case. Write your conclusion to why this may represent a problem for the remaining power network. Extrapolate your conclusions to large induction motors on industrial sites.
3) Based on the equivalent circuit parameters that you have determined (see Fig. A) and the recorded voltage and current transients in Task B and C, determine/estimate the impedance Z of the AC power supply.

Task 5 D: Variable Speed Operation

1) What are the advantages and disadvantages of controlling the Induction Motor speed using the method of Task 3B? Briefly explain.
2) What are the advantages and disadvantages of controlling the Induction Motor using the VFDs based on your experience in Task 4?
3) Consider the chain of the components that you had in Task 4 including the following:

AC Source, VFD, Induction Machine, Mechanical Coupling, Mechanical Load.

Take one measurement in Task 4 and assign the energy conversion efficiency at each energy conversion stage in the above chain (Complete Table 9). Comment on where most of the energy is being lost and how the efficiency changes with motor speed and frequency.

Reporting

Prepare the Lab Report that includes:
1) Title Page (all filled-in, with electronic signatures).
2) Pre-lab (scanned or pictures of pages).
3) Pages with the measured data and figures (pages 16 – 19).
4) Pages with **Calculations and Analysis**, discussions, and/or answers to questions in Task 5.
5) Brief **Conclusion/Summary** stating what you and your lab partner have learned in this Lab.
6) Appendix: Please include any additional Matlab code or windows of Simulink models that you have used for this lab.

Note: All reports must be typed. No exception.

ELEC 342

Lab Experiment: ___

Section: ___

Bench #: ___

Partners	Student ID #:	% participation	Signatures

Date Performed:

Date Submitted:

Table 1: Motor Nameplate Information and Nominal Characteristics

Info/Parameter	Nominal/Rated Value	Comments
NEMA Class		
Horse Power		
Speed		
Number of Poles		
Line Current		
Line Voltage		
Calculations corresponding to full load		
Efficiency		
Power Factor		

How can you explain the voltage and current information? Briefly explain why the motor has two sets of values.

Table 2: Nominal/rated phase voltage and current assuming Y-connected winding

$V_1(rms), V$	$I_1(rms), A$

Table 3: Stator winding DC resistance measurement (Do not exceed 5 A dc current!)

	Measurements (line-to-line)		**Calculation**
Using DC Source	V_{dc}, V	I_{dc}, A	$R_{1,dc} = 0.5V_{dc}/I_{dc}, \Omega$
Using Multimeter	R_{total}, Ω		$R_{1,dc} = 0.5R_{total}, \Omega$

Table 4: No-load measurement (motor is free spinning)

Average phase voltage $V_{nl}(rms), V$	Average phase current $I_{nl}(rms), A$	Average phase power-factor angle φ_{nl} (deg)	Total real power P_{nl}, W	**Calculate** rotational losses P_{rot}, W

Table 5: Blocked-rotor measurement (motor is not spinning)

Average phase voltage $V_{br}(rms), V$	Average phase current $I_{br}(rms), A$	Average phase power-factor angle φ_{br} (deg)	Total real power P_{br}, W	Stall Torque T_{br}, Nm

Table 6: Load test measurement: (under nominal voltage, 20 – 23V)

Measurement #	1	2	3	4	5	6	7
$V_{ph}(ave, rms), V$ keep it constant							
$I_{ph}(ave, rms), A$							
$\varphi_{pf}(ave, \deg)$							
$P_{in}(total), W$							
n, rpm							
T_m, Nm							
Calculation							
P_m, W							
Slip s							
Using last measurement, calculate SR $SR = \left(n_1 - n_{7,load}\right) / n_{7,load}$							
Using last measurement, calculate efficiency of the Motor, % P_m / P_{in}							

Table 7: Motor speed control by varying voltage (Motor may stall at low voltages)

Measurement #	1	2	3	4	5	6
$V_{ph}(ave, rms), V$						
$I_{ph}(ave, rms), A$						
$\varphi_{pf}\ (ave, \deg)$						
$P_{in}(total), W$						
n, rpm						
T_m, Nm						
Calculation						
P_m, W						
Slip s						
Using last measurement, calculate SR $SR = \left(n_1 - n_{last,load}\right) / n_{last,load}$						

Table 8: Load test measurement: (under low voltage, 12 – 14V)

Measurement #	1	2	3	4	5	6	7
$V_{ph}(ave, rms), V$ keep it constant							
$I_{ph}(ave, rms), A$							
$\varphi_{pf}\ (ave, \deg)$							
$P_{in}(total), W$							
n, rpm							
T_m, Nm							
Calculation							
P_m, W							
Slip s							

Table 9: VFD: Motor speed control by varying frequency at Vdc =45 V

Measurement #	1	2	3	4	5	6
f_{ac}, Hz	10	20	40	60	80	95
Inverter input DC current $I_{inv,dc}, A$						
$V_{ph}(ave, rms), V$						
$I_{ph}(ave, rms), A$						
$\varphi_{pf}\ (ave, \deg)$						
$P_{in-ac}(total), W$						
n, rpm						
T_m, Nm						
Calculate Slip s						

Calculate these values corresponding to different frequencies	Inverter input power P_{in-dc}, W	Input power at the Induction Motor terminals P_{in-ac}, W	Output mechanical power P_m, W	Efficiency of the Inverter, % P_{in-ac}/P_{in-dc}	Efficiency of the Motor, % P_m/P_{in-ac}
$f_{ac} = 10 Hz$					
$f_{ac} = 60 Hz$					
$f_{ac} = 95 Hz$					

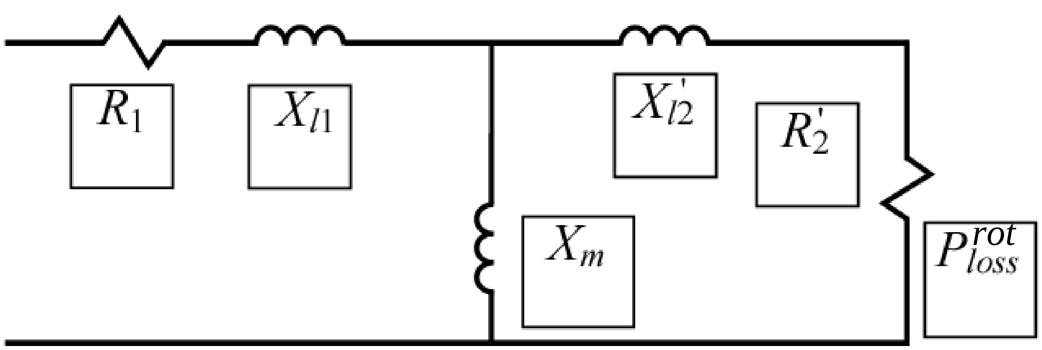


Fig. A. Induction Machine Equivalent Circuit. Fill-in the corresponding boxes with machine parameters. Make sure to include the units.