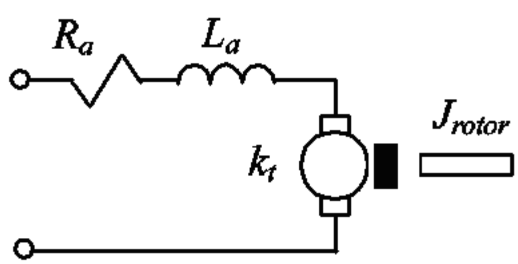
Lab-3: Permanent Magnet Brushed DC Motor

Objectives and Overview

The objectives for this sequence of laboratory experiments are:

- to experiment and fully characterize a small industrial ¼ HP 48V Permanent Magnet DC (PMDC) Motor by identifying its equivalent circuit parameters;
- to observe the load characteristics when the motor is supplied from a variable DC source;
- to observe the load and speed characteristics when the motor is supplied from a DC-DC converter with variable duty-cycle and variable frequency;
- to experiment with the four-quadrant DC-DC converter to operate the motor in forward and reverse directions.

By doing a set of measurements, the students will determine the motor torque/voltage constant k_t / k_v, the armature winding + brush resistance R_a, armature inductance L_a, combined friction/loss torque as a function of speed $T_{fric}(\omega_r)$, and the moment of inertia J_{rotor}. Based on the determined parameters, the students will develop a steady-state model (equivalent circuit) of the given motor, and then use the model to predict the torque-speed characteristics and compare them to the measured ones. The students will also use a DC-DC converter with PWM to control the motor by varying the duty-cycle d.



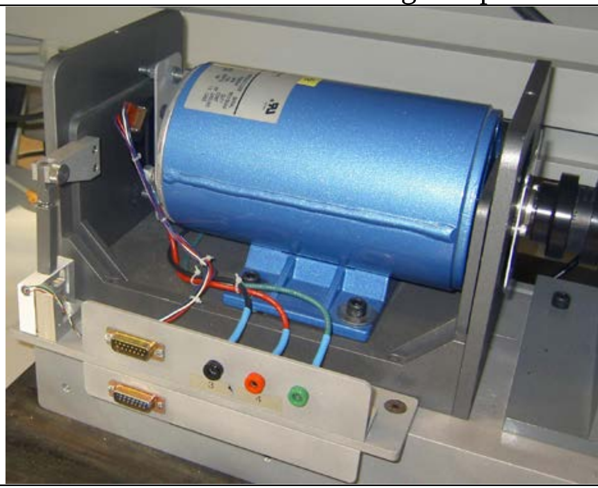
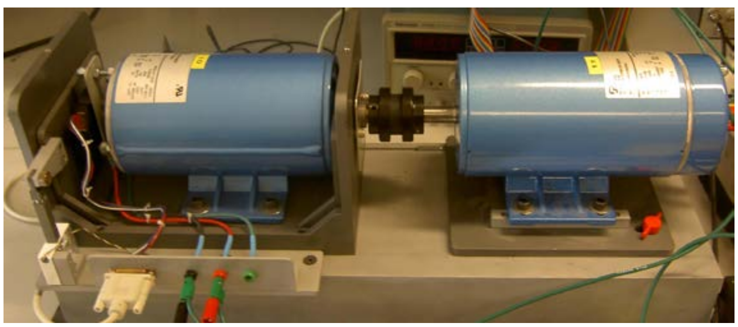
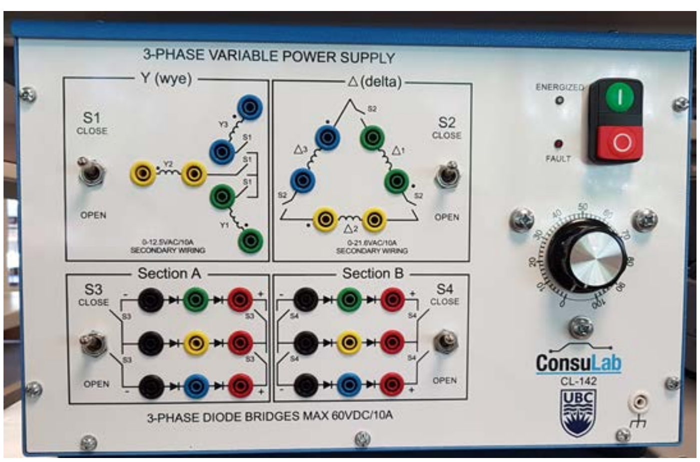
Preparation (Pre-Lab)

It is expected that the students have read and understood the corresponding chapter in the textbook and reviewed the lecture notes module corresponding to DC Motors. The students should be familiar with the theory and principle of DC machine operation and equivalent circuit. Also, make sure to review the DC-DC converter operation using PWM voltage control and the four quadrants of operation. 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.
- Assume the motor is operating in the first quadrant using DC-DC converter, and at a given speed, $E_a = k_t \omega_r$. Rewrite the equation $v_a = R_a i_a + L_a \dfrac{di_a}{dt} + E_a$ to find the expression for the armature inductance when the upper switch of the converter is ON (Hint: replace di_a with ΔI_a and dt with Δt, assuming you have two data points). Alternatively, you can also find the armature inductance using the OFF time interval. Also assume the value of the current ripple is $\Delta I_a = I_2 - I_1$.

Apparatus & Equipment

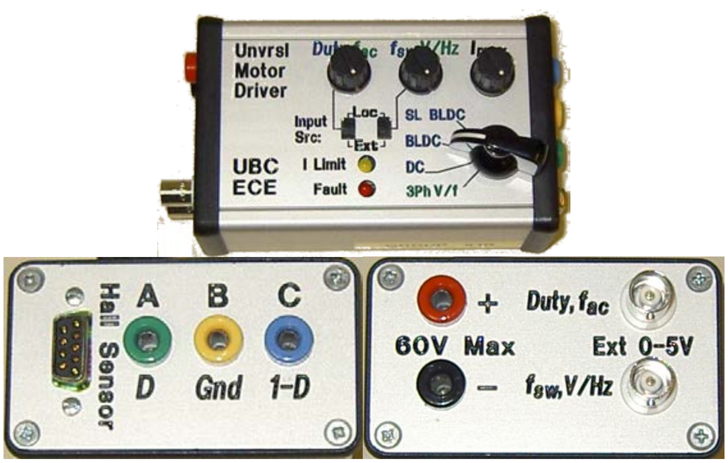
This lab includes the following components:

	**Motor Cradle:** The DC motor under investigation is mounted in a special cradle to permit measurements of the output torque. 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. Note though that internal friction and loss torque of the machine will not be coupled to the torque sensor.
	**Motor Bench:** Additional DC machine, identical to the one mounted on the Cradle, is used to emulate the mechanical load. This machine is mounted on the bench and is coupled through the shaft using rubber coupling. The torque and speed measurement signals are taken through the black multi-pin cable on the left side of the bench. This cable is then plugged in to the back of the Measurement Box.
	**3-Phase AC – DC 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.

DC Capacitor Box: The Box contains three electrolytic capacitors that can be switched ON and OFF in parallel. The terminal have polarity which should not be miswired! If use incorrectly, electrolytic capacitors can explode! In this experiment, you may be using a large capacitor (6800µF) to filter the DC voltage at the output of the rectifier.

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.

DC Power Supply: A flexible regulated Xantrex XHR6018 DC Power Supply will be used to supply the DC-DC Converter - Universal Inverter Box in the last task of this laboratory experiment. This power supply has adjustable output voltage 0-60V and current limit 0-18A, which is sufficient for most experiments in this laboratory.



Universal Inverter Box: A multi-purpose inverter was designed for driving various AC and DC motors. In this lab, you will use this Inverter to operate the DC Motor with Pulse-Width-Modulation (PWM) voltage control. For this mode, the mode switch should be in **DC** position (blue font). The inverter is also equipped with three knobs to control the duty cycle **D**, switching frequency $\mathbf{f_{sw}}$, and the current limit $\mathbf{I_{max}}$, respectively. Both **Input Src**. control switches should be **turned up for Local control**. This allows the user to operate the Inverter Box using the knobs (instead of external inputs)

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 connected 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 **DC Motor Analysis**. Double-click on the icon and start the program. A window shown in Fig. A should appear on your PC screen indicating that you are ready to start taking measurements. The **DC Motor Analysis** program interface is set up to display the two voltages (channels **V1** and **V2**) and two currents (channels **A1** and **A2**), **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 de-select the measurement of voltages and currents, but the first channel (V1 and A1) are always selected. For this lab, select all two 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 **AVERAGE** (not the RMS!) values of the voltages (in Volts) and currents (in Amps) are displayed. Both Channels also display the calculated instantaneous real power (Ch1 and Ch2) in Watts. The Channel 1 can also display the **PWM frequency** (**Ch1 kHz**) and the **duty cycle** (**Ch1 Duty**) of the switching voltage in channel V1.

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, and V2 with A2), 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.**

The Measurement Window period (in ms) can be adjusted during the process of taking measurements in order to better capture the desired waveforms and to see the details. The program can **PAUSE** and **SAVE** the measured data in a text file for further analysis in programs such as **EXCEL** or **MATLAB**. Once the measurement is **Paused**, the user can also zoom-in into any fragment of the recorded window by using the slide buttons **ZOOM** and **POSITION** on the bottom of the panel. Pushing the bottom **SAVE** brings the window for saving the data file. The user should name the file and save it into appropriate location/folder for future analysis.

Remember to press **Zero A1, Zero A2, Zero Torque, and Zero RPM** before each measurement to zero out any offset that might exist in these measurement channels.

Ask a TA and/or Technician responsible for the lab if you have any problem locating and/or running this program.

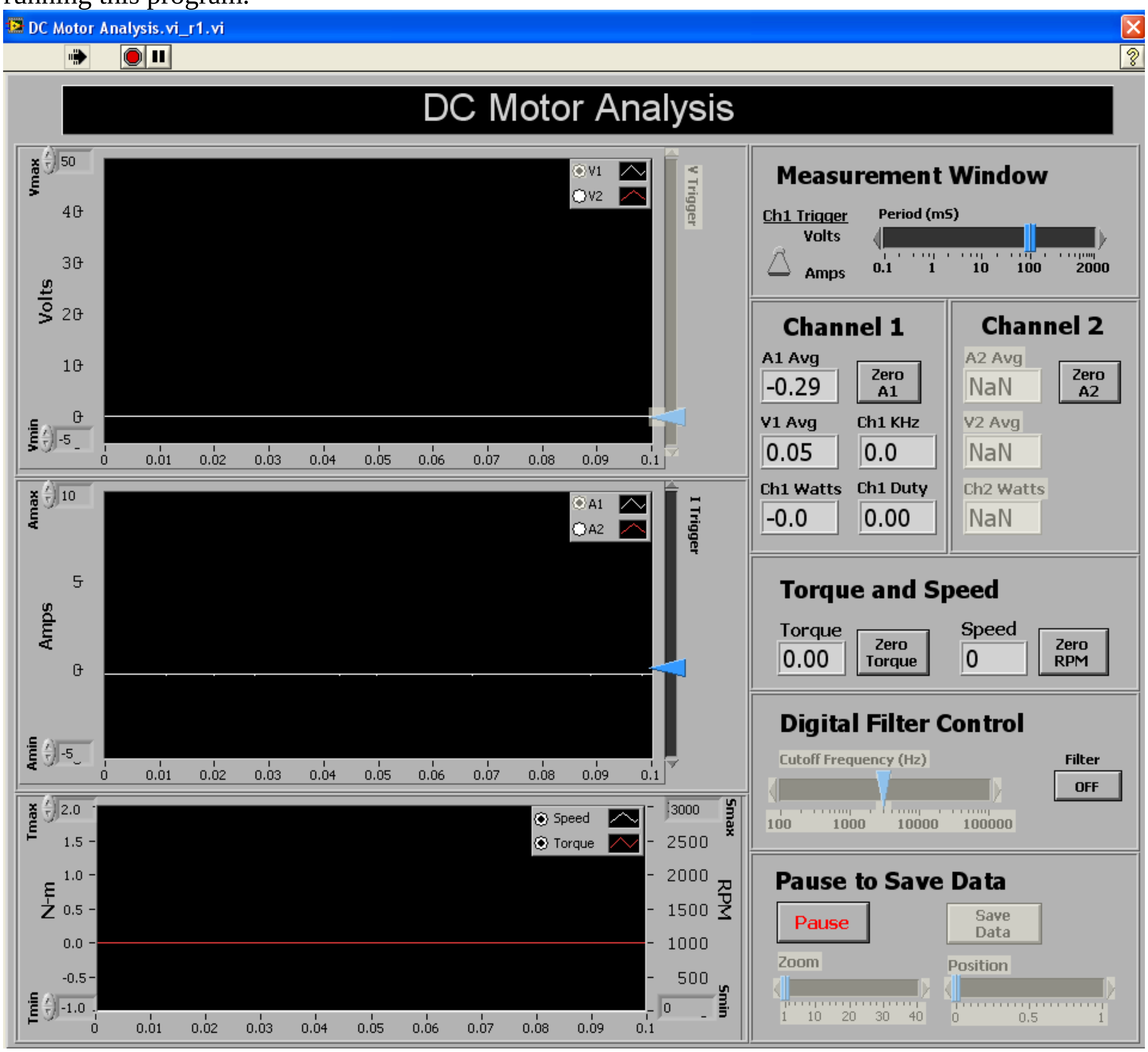


Fig. A: LabView program interface DC Motor Analysis.

Setting-Up the Experiment Using Variable DC Supply

In this part, the students will set up the multi-purpose **AC – DC Power Supply** in such a way that it will provide a variable DC voltage to drive the motor under study. The **Power Supply** has two sets on windings 'Y' (wye) and "Δ" (delta) the output voltage from which can be readily adjusted by the knob on the right side of the box. A low-ripple DC supply can be realized by connecting the transformer windings to the rectifiers as shown in Fig. 1 below. **All switches S1 through S4 must be closed.** Each 3-phase diode bridge results in a 6-pulse rectification. However, because the voltages from the 'Y' (wye) and "Δ" (delta) windings are shifted by 30 degrees, the 6-pulse ripple produced by each rectifier is also shifted by 30 degrees and is out-of-phase. By connecting the two rectifiers in series the overall ripple is reduced and the 12-pulse operation is achieved. You will then use the **Variac Knob** to adjust the voltage magnitude to the desired level. You will use this variable DC Supply to power the motor under study.

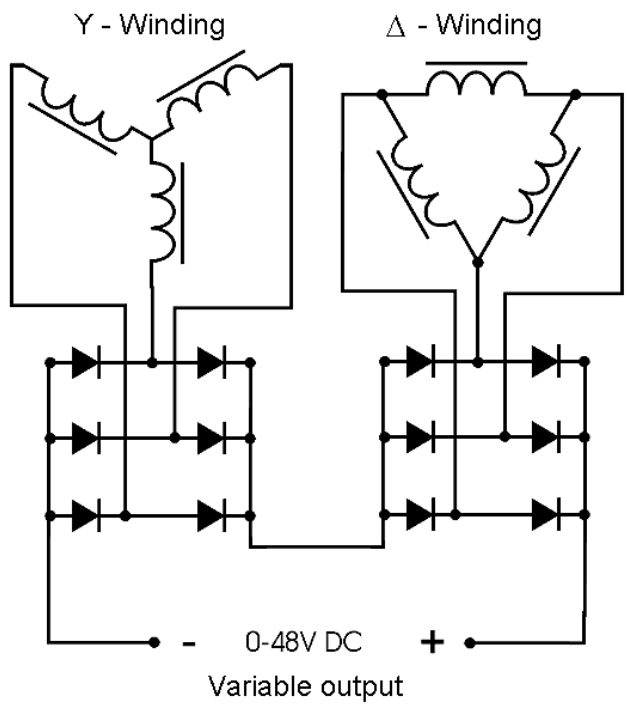


Fig. 1: Variable DC source with 12-pulse rectifier-bridge. An additional capacitor may be used at the output terminals to reduce voltage ripple.

Task 1: Characterization of the Motor under No-Load

Wire-up the circuit as shown in the Fig. 2 for taking the measurements on the **Motor in Cradle**. It is a good rule to connect the current-carrying circuit first, and then connected the voltmeter channel leads directly to the machine terminals. Please note that you will need to use a special red wire with a **Switch** to connect the **DC Source** to the current measurement channel. At this point, **do not** mount another DC machine on the bench! Make sure the Motor Cradle under test is not coupled to anything. Use the **Measurement Box** to measure and display the torque, speed, voltage, and current of the motor under test. Use Channel 1 voltage and Channel 1 current terminals, respectively.

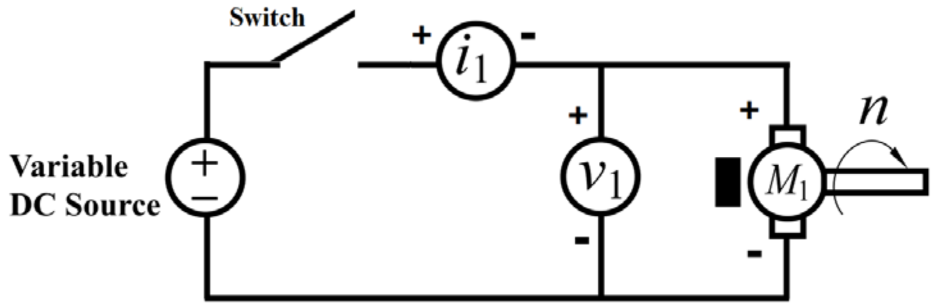


Fig. 2: Wiring diagram for the No-Load Test(s).

Task 1 A: Measuring the DC Resistance: Blocked-Rotor Test

While it is possible to use the bench top Multimeter for this task, a more accurate result is obtained by lightly powering the motor and measuring the voltage and current when the shaft is **not spinning** – Blocked-Rotor Test. First, the **DC Power Supply** should be off and turned to output zero volts. The **Switch** should be ON to supply the machine.

1) 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 lock plate and manually rotate the shaft to make sure that the lock clicks-in and locks properly.
2) Make sure that the program **DC Motor Analysis** is running on your PC. Press the **Zero** buttons on the **DC Motor** software interface to make sure that there is no offset in the current measurements. Turn on the **DC Power Supply** and keep monitoring the voltages and currents on the computer screen. You can adjust the measuring window size to get more stable readings.
3) Slowly increase the voltage v_1 until you start noticing that the current is increasing. Do not exceed the rated (5.1A) current of the Motor! Take three measurements at different current levels (from 0.5 to 5A) and record the values in Table I. Calculate the resistance R_a for each case as well as their average value. This value of resistance includes the resistance of the winding + resistance of the brushes.
4) Turn off the **DC Power Supply and remove the shaft lock.** You will **<u>not need</u>** to lock the shaft for any other tests. So, you can return the **Metal Lock** to the TA and/or Technician.

Task 1 B: Measuring No-Load Characteristic

1) Make sure the **Motor Cradle** under test is not coupled to anything.
2) Vary the applied voltage V_1 from 5V to about 40V DC and measure the armature current I_1, and speed $n_{no-load}$ in rpm. Take and record about 6 evenly-space data measurements. Record the measurements in Table 2. You will need these measurements to calculate the friction/loss torque as a function of speed $T_{fric}(\omega_r)$.

Task 1 C: Recording the Stopping Transient – Estimating Moment of Inertia

1) Apply 40V DC to the motor under test (**Motor in Cradle**). Make sure that the **DC Motor** software is set for the largest measurement window (approximately 2000ms) and that all measurements are stable.
2) Then, disconnect the **Power Supply** by turning OFF the **Switch** in the wires and quickly push the **PAUSE** button to save the stopping transient. You can also adjust the position and zoom into the recorded interval to better view the transient response. Then, push the **SAVE** button to save the data in a text file. You will use this data to calculate the moment of inertia for this motor in Task 5.

Task 1 D: Recording the Stopping Transient of two Machines – Estimating the Combined Moment of Inertia

1) Very carefully slide the Load-Motor (another identical PMDC Motor) into position and couple it to the **Motor in Cradle** under test using metal coupling. Secure the motor using the specially provided screws with red heads-handles. Now you have two machines coupled on the test-bench, which increased the total moment of inertia. Since the machines are very similar, their internal friction may be assumed the same.
2) Again apply 40V DC to the motor under test (**Motor in Cradle**). Make sure that all measurements are stable, and prepare to record deceleration transient.
3) Then, disconnect the **Power Supply** by turning OFF the **Switch** in the wires and quickly push the **PAUSE** button to save the stopping transient. You can also adjust the position and zoom into the recorded interval to better view the transient response. Then, push the **SAVE** button to save the data in a text file. You will use this data to calculate the combined moment of inertia for both machines in Task 5.

Task 2: Measuring Load Characteristics

You now should have both machines coupled on the test-bench. Wire-up the circuit as shown in the Fig. 3 for taking the measurements on both DC machines. Connect the **V1** voltmeter across the **M1** dc machine terminals (not to the dc power supply!). Use the **Measurement Box** to measure and display the torque, speed, voltages, and currents. The second DC Machine will be used as a Generator loaded by the variable resistor via the **Load Resistor Box.** During this test, the **Load Resistor Box** may get very hot! By adjusting the load of the DC Generator which emulates the mechanical load, you will be changing the mechanical torque applied to the **Motor in Cradle** under test.

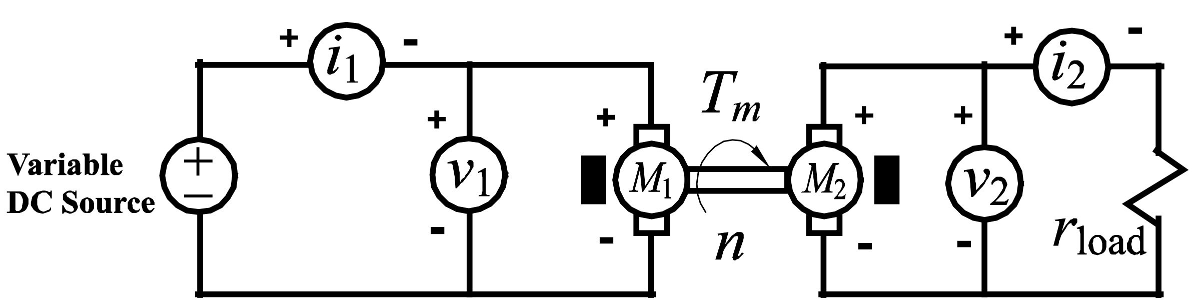


Fig. 3: Wiring diagram for the Load Characteristic(s).

Task 2 A: Load Characteristic – Speed Regulation

1) Switch OFF all load resistors in the **Load Resistor Box** and adjust the **Power Supply** to output about 40 - 45V. Record this set of measurements in the first column of Table 3. Remember, it may be necessary to adjust the V1 value to the same value when the voltage drops under load!
2) Then, switch on the resistors in the **Load Resistor Box** one at a time, thus increasing the load torque. Take about 6 measurements and record the values in Table 3. Make sure the last column corresponds to the case when **all** resistors are **ON**.

Task 2 B: Speed Control by Adjusting Voltage

1) Switch on **all** load resistors in the **Load Resistor Box**. This will correspond to a mechanical load with maximum torque.
2) Vary the **DC Power Supply** to output 5 - 45V and record about 6 evenly-spaced measurements from almost zero speed (slightly spinning) to the maximum speed. Write the measurements in Table 4.

Task 3: Speed Control Using DC-DC Converter (Inverter Box)

Keep the configuration of Task 2 (Fig. 3) with the **Measurement Box**, except now your Variable DC Source will be provided through the **Universal Inverter Box**. The **Inverter Box** takes the input DC voltage from the Power Supply (red for positive, and black for negative terminals, respectively), and outputs the Pulse-Width Modulated voltage (chopped voltage) with variable frequency and duty cycle. Connect the **Inverter Box** to the **Xantrex DC Power Supply** as depicted in Fig. 4. Pay attention to the polarity of the wires. Then, connect the motor circuit (circuit of Fig. 3) to the **Inverter Box** output as shown in the Fig. 4. Use the middle (yellow, **Gnd**) terminal for the negative (ground) and use the left (green, **D**) terminal for the positive output. You will be using only one "leg" of the inverter to control the DC Motor. So, you will be able to control the motor speed in one direction only (Quadrant I and II). The mode switch on the **Universal Inverter Box** should be in "**DC**" position indicating that you will be controlling a DC motor.

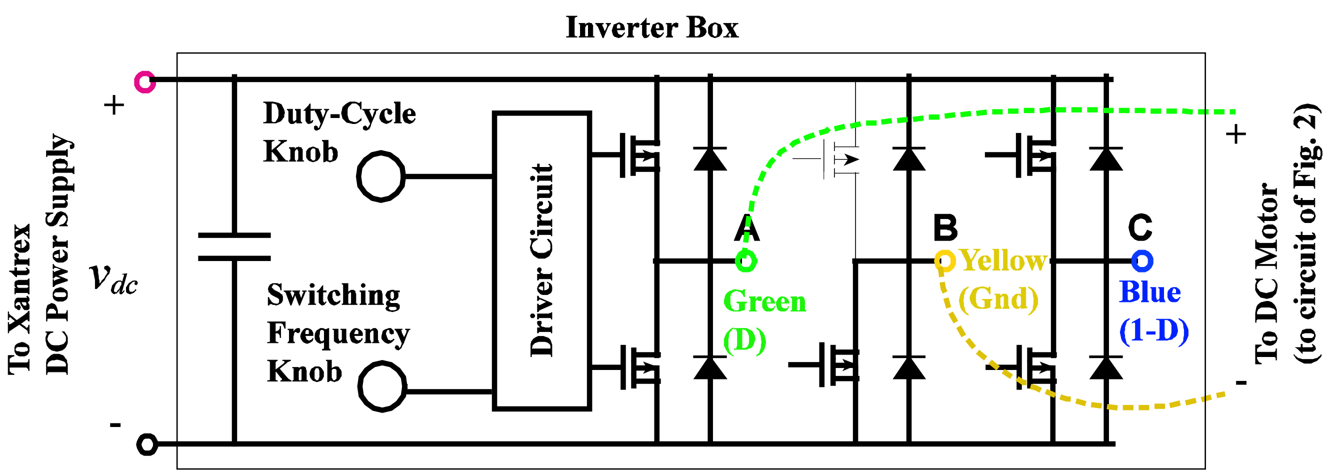


Fig. 4: Wiring diagram for the Variable DC Supply using the Universal Inverter Box.

The **Input Src**. control switches should be **turned up for Local control** using the knobs. Initially, set the switching frequency to a minimum which is around 2.4 kHz, and turn the duty cycle to minimum as well. The knob controlling the current limit should be approximately turned to a middle position. If needed, ask a TA for help to configure your circuit and the **Universal Inverter Box**.

Task 3 A: Speed Control by Adjusting the Duty-Cycle (2.4 kHz)

1) Switch **ON** all load resistors in the **Load Resistor Box**. This will correspond to a mechanical load with maximum torque. Turn on the **DC Power Supply** and slowly increase the output voltage from 0 to about 50 V dc.
2) Vary the **PWM Voltage Controller** duty-cycle ***d*** output in the range 0.1 – 0.9 and record about 5 evenly-spaced measurements from low speed to the maximum speed. Write the measurements in Table 5.
3) Set the duty-cycle ***d*** to 0.5. Observe and **PAUSE / SAVE** the waveforms. You will use this data for determining the current ripple and estimating the inductance. For your record, you can also do the **Print Screen** and save the bitmap image for later comparison.

Task 3 B: Speed Control by Adjusting the Duty-Cycle (10 kHz)

1) Continue from configuration of Task 3 A, step 3) with the duty-cycle ***d*** set to 0.5. Increase the switching frequency to 10 kHz. You should notice that the current ripple is much smaller than it was at switching frequency of 2 kHz. Observe and **SAVE** the waveforms. You will use this data for determining the current ripple. For your record, you can also do the **Print Screen** and save the bitmap image for later comparison.
2) Vary the **PWM Voltage Controller** duty-cycle ***d*** output in the range 0.1 – 0.9 and make sure they are similar to the values you used in Task 3 A. Write the measurements in Table 6. Comment on some possible differences between this and the previous case. You should notice the difference in current ripple ΔI_1.

Task 4: Efficiency of Converter and Bi-directional Operation

Keep the configuration as in Task 3 (Fig. 3 and Fig. 4) with the **Universal Inverter Box**. Set the switching frequency to 2.5 kHz, and turn the duty cycle to minimum as well. The knob controlling the current limit should be approximately turned to a middle position. If needed, ask a TA for help to configure your circuit and the **Universal Inverter Box**.

Task 4 A: Speed Control by Adjusting the Duty-Cycle at 2.5 kHz

1) Switch **ON all load resistors** in the **Load Resistor Box**. This will correspond to a mechanical load with maximum torque. The fan switch should be ON to provide the cooling. Turn on the **DC Power Supply** and slowly increase the output to 50 V dc.
2) Vary the duty-cycle ***D*** in the range 0.1 – 0.9 and observe the changes in speed and torque, similar to Task 3.

3) Choose any duty-cycle ***D*** between 0.1 and 0.9 you like, record only one set of measurement in Table 7. You will need this to calculate the energy conversion efficiency of the system. This will be used for calculating the efficiency of all energy conversion stages in Table 7.
4) Turn **OFF** the Power Supply.

Task 4 B: Bi-Directional Speed Control by Adjusting the Duty-Cycle (Mandatory!)

1) The same **Inverter Box** can also be used to operate the **DC Motor** in all four quadrants by using two of its "Legs." So, instead of using A (green, **D**) and B (yellow, **Gnd**) inverter terminals, now supply the motor from A (green, **D**) and C (blue, **1-D**) terminals, respectively. **Put the duty cycle knob in its middle position** and turn ON the **DC Power Supply**. Observe that the motor may start to spin slowly.
2) Observe the waveforms of voltages and currents of the motor under test, and **slowly** change the duty cycle ***D*** in the range 0.1 – 0.9. You should observe that the motor can be made to spin in forward and reverse directions. Note that changing the duty cycle very fast may cause the motor to operate in a regenerative breaking mode, which will reverse the energy flow from the spinning (decelerating) motor back to the Power Supply. Please avoid this mode and change the speed and direction **slowly**! Since the DC Power Supply used in the lab **cannot** absorb that energy back, it may shut off itself automatically for protection against over-voltage. If this happens, you will need to **re-start the DC Power Supply**. Observe and **SAVE** the waveforms for forward operation and then for reverse operation, for your future analysis.

Task 5: Calculations and Analysis

This part must be included with your Lab Report:

Task 5 A: Determining Motor Parameters

1) Calculate the armature resistance R_a and record the value in Table 1.
2) Calculate the motor constant from the no-load data obtained in Table 2, Task 1. This is readily done by generating the value of $k_t = \dfrac{V_a - I_a R_a}{\omega_r}$ for each measured point and averaging the result. Also, calculate the voltage constant k_v for the second DC Machine that was used as a generator and record this number in Table 3. You have to use the open-circuit voltage (before you connected the load resistor). What can you say about these two constants and their values?
3) Calculate the friction torque T_{fric} in Table 2. Plot $T_{fric}(n)$ as a function of rotor speed n. This will require using the recently found motor constant k_t. What can you say about the curve? Is the loss predominantly from sliding friction, viscous damping, or windage (turbulent airflow)?
4) Given that you now know the friction torque at all speeds, you now can estimate with reasonable accuracy the system moment of inertia based on the rate of deceleration inferred

from your $\frac{dE_a}{dt}$ measurement in Task 1 C. Calculate the moment of inertial J_{rotor} using your best estimate of the friction torque at the speed where $\frac{dE_a}{dt}$ was measured. In particular, you will have to use $J_{rotor}\frac{d\omega_r}{dt} = \frac{J_{rotor}}{k_t}\frac{dE_a}{dt} = T_{fric}(\omega_r)$.

5) Based on the recorded stopping transient in Task 1D, calculate the combined moment of inertia of both machines $J_{combined}$ (when they are coupled), and compare the result with J_{rotor} obtained in step 4) above.
6) Based on the recorded data from Task 3, estimate the armature inductance L_a. You will need to use the current ripple and voltage information from Task 3 A or B. First, for a less accurate estimate, you can neglect the resistance R_a and use the equation: $v_a = L_a \frac{\Delta i_a}{\Delta t} + E_a$. Then, you should use more accurate equations that you have derived in your Pre-Lab assuming that you know the value of R_a. Compare these two results and use a more accurate on in Fig. A.
7) Complete Fig. A by filling-in all remaining machine parameters.
8) Based on your measurements in Task 2 Table 4, establish the equivalent mechanical load torque vs speed characteristic of the DC machine loaded with Resistor Box (with all resistors connected), $T_{m-load}(n)$, and plot it. Generally, load torque should increase with the speed. Comment on or explain the shape of this characteristic. It is linear or not, and why? You will also need this for other calculations using your model or equivalent circuit.

Task 5 B: Equivalent Circuit vs. Measured Comparison

1) Use the equivalent circuit of the DC machine, and calculate and plot the speed-torque characteristic $n(T_m)$ corresponding to the input voltage in your Task 2A, Table 3. Do not forget to include the effects of friction in your predicted curve (T_e vs. T_m)! Superimpose on the same plot the measured and the predicted characteristics. Comment on the results and the expected vs measured speed-voltage regulation.
2) Use the equivalent circuit of the DC machine and calculate the speed-voltage characteristic $n(V_1)$ of the loaded machine (use $T_{m-load}(n)$ that you have established before). Do not forget to include the effects of friction in your predicted curve. Superimpose on the same plot the characteristic measured in Task 2 B, Table 4, and the predicted characteristic. Comment on the results.
3) Calculate and plot the motor efficiency vs. current $\eta(I_1)$ characteristics based machine equivalent circuit (plus the measured friction). On the same plot, also show the efficiency of the single machine established from the measured date in Task 2 A, Table 3. Compare the results. Calculate/note at what current the motor has maximum efficiency.

Task 5 C: Comparison with Simulink Model

Use the parameters as you have determined for this PM DC motor for the Simulink Model described in Lectures Module 4. Implement this model using MATLAB/Simulink. Implement the Voltage Source with variable duty cycle operation (you can use a pulse generator block or improvise your own way to implement the PWM). Simulate and plot the current waveforms for the 2kHz and 10kHz operation corresponding to the duty cycle of 0.5 at the same mechanical load torque $T_{m-load}(n)$ as you had in your lab. Compare these simulated waveforms with the recorded waveforms of the current in Task 3 and Task 4. Comment how good your match is in terms of predicting the current ripple. This should verify how accurately you have determined the machine's armature inductance! Include the Simulink model and plots/results in your report.

Task 5 D: General Questions

1) What can you say about the accuracy of equivalent circuit compared to your measurements?
2) Which method of the speed control (Task 2 or Task 3/4) in your opinion is more practical for large motors and/or automotive/robotics applications? Briefly explain.
3) Also, plot on different plots the armature current and voltage (3 to 6 cycles) for the Task 3 A 3) and Task 3 B 1). What can you say about the effect of switching frequency?
4) In the energy conversion chain presented in Table 7, which element appears to be the least efficient and why?
5) Compare and discuss the captured waveforms of voltages and currents for the bi-directional operation in Task 4 B, with what you discussed in your lecture notes?

Task 6: 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 your comments (pages 15 – 19).
4) Additional pages with **Calculations and Analysis**, discussions, and/or answers to questions in Task 5.
5) Printouts of your Simulink model and its results.
6) Brief **Conclusion/Summary** stating what you and your lab partner have learned in this Lab.
7) **Appendix:** Please include any additional Matlab code or windows of Simulink models that you have used for this lab.

Note: The lab reports must be typed. No exception!

ELEC 343

Lab Experiment: ___

Section: ___

Bench #: ___

Partners	Student ID #:	% participation	Signatures

Date Performed:

Date Submitted:

Task 1A, Table 1: Armature + Brush Resistance Measurement

V_1, V			I_1, A			**Calculate** R_a, Ω		
						Average		

Task 1B, Table 2: No-Load Measurement

Measurement	**1**	**2**	**3**	**4**	**5**	**6**
$V_1(ave), V$						
$I_1(ave), A$						
$n_1(ave), rpm$						
Calculation						
k_t, $[V \cdot \sec/rad]$						
Average k_t						
T_{fric}, Nm						

Task 2A, Table 3: Load Test Measurement: (up to 6 measurement points)

Measurement #	1	2	3	4	5	6
$V_1(ave), V$						
$I_1(ave), A$						
$P_1(ave), W$						
$V_2(ave), V$						
$I_2(ave), A$						
$P_2(ave), W$						
n, rpm						
T_m, Nm						
P_2 / P_1						
$SR = \left(n_1 - n_{6,load}\right) / n_{6,load}$						
DC Machine (Generator) Voltage Constant $k_v = V_{2,oc} / \omega_r$						

Task 2B, Table 4: Motor Speed Control by Adjusting Voltage

Measurement #	1	2	3	4	5	6
$V_1(ave), V$						
$I_1(ave), A$						
$P_1(ave), W$						
$V_2(ave), V$						
$I_2(ave), A$						
$P_2(ave), W$						
n, rpm						
T_m, Nm						
P_2 / P_1						

Task 3A, Table 5: Motor Speed Control by Duty-Cycle (2 kHz): Vdc =

Measurement #	1	2	3	4	5
Duty-Cycle, ***d***					
$V_1(ave), V$					
$I_1(ave), A$					
Current Ripple $\Delta I_1, A$					
$P_1(ave), W$					
$V_2(ave), V$					
$I_2(ave), A$					
$P_2(ave), W$					
n, rpm					
T_m, Nm					
P_2 / P_1					

Task 3B, Table 6: Motor Speed Control by Duty-Cycle (10 kHz): Vdc =

Measurement #	1	2	3	4	5
Duty-Cycle, ***d***					
$V_1(ave), V$					
$I_1(ave), A$					
Current Ripple $\Delta I_1, A$					
$P_1(ave), W$					
$V_2(ave), V$					
$I_2(ave), A$					
$P_2(ave), W$					
n, rpm					
T_m, Nm					
P_2 / P_1					

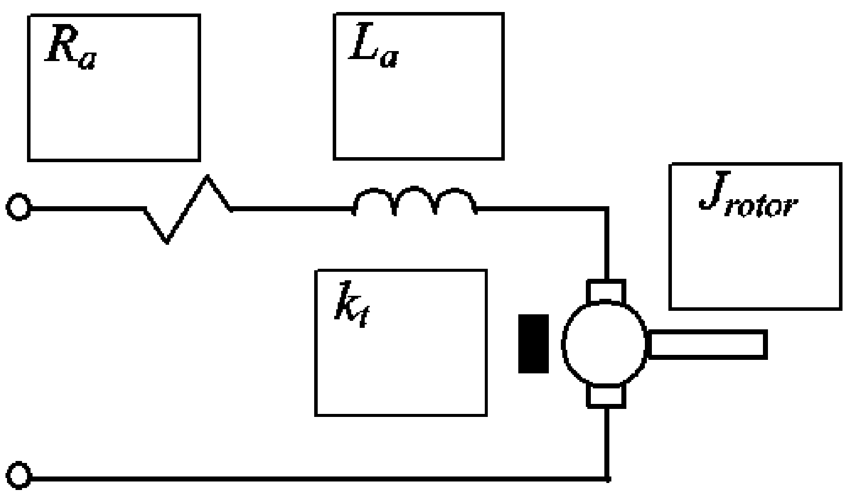


Fig. A. DC Machine Equivalent Circuit. Fill-in the corresponding boxes with machine parameters. Make sure to include the units.

Task 4, Table 7: Motor Speed Control using Universal Inverter Box (at 2.5 kHz)

Measurement #	1
Duty-Cycle, ***d***	
$V_1(ave), V$	
$I_1(ave), A$	
$P_1(ave), W$	
$V_2(ave), V$	
$I_2(ave), A$	
$P_2(ave), W$	
n, rpm	
T_m, Nm	

<table>
<tr><td colspan="7">Use the set of measurements complete the following section of the Table</td></tr>
<tr><td colspan="2">Input to Inverter Box</td><td rowspan="4">Input power at the DC Motor terminals
P_{dc-mot}, W</td><td rowspan="4">Output mechanical power
P_m, W</td><td rowspan="4">Efficiency of the Inverter, %
P_{dc-mot}/P_{inv}</td><td rowspan="4">Efficiency of the Motor, %
P_m/P_{dc-mot}</td><td rowspan="4">Efficiency of Inverter-Motor combined, %
P_m/P_{invt}</td></tr>
<tr><td>Voltage, Vdc</td><td>Current, A</td></tr>
<tr><td></td><td></td></tr>
<tr><td colspan="2">Total input power to the Inverter Box
P_{inv}, W</td></tr>
<tr><td colspan="2"></td><td></td><td></td><td></td><td></td><td></td></tr>
</table>

Consider the chain of the components that you had in this lab including the following:

DC Source, **DC-DC Converter**, **DC Machine 1**, **DC Machine 2**, and **Load Resistors Box**.

Using the data you recorded in Table 7, calculate and fill in the energy conversion efficiency at each energy conversion stage in the above chain. Comment on the efficiency of these stages to deliver the energy to the final resistor load.