King Fahd University of Petroleum & Minerals

Electrical Engineering Department

EE-360

Electric Energy Engineering

Laboratory Manual

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SAFETY GUIDELINES

To develop a healthy respect for electricity, it is important to understand how it acts, how it can be directed, what hazards it presents, and how these hazards can be minimized through safe laboratory procedures.

How Shock Occurs

Electricity can travel only in a closed or looped circuit. Normally, travel is through a conductor. Shock occurs when the body becomes a part of the electric circuit. The current must enter the body at one point and leave at another.

Shock may occur in one of three ways; the person must come in contact

1. With both wires of the electric circuit;
2. With one wire of an energized circuit and the ground or
3. With a metallic part that has become "hot" by itself being in contact with an energized wire, while the person is in contact with the circuit ground.

It is possible to receive a shock by touching only the energized wire, or an energized metallic part, and the ground because of the nature of an electric circuit. An electric circuit constitutes a completely continuous path. It starts at the generator, flows through wires (conductors) to the transformer, and back to the generator. In the transformer, the voltage is reduced (or increased) and flows into the building, where it is used to do useful work, and then back to the transformer. The generator and the transformer both have direct connections to the ground, and the current will use these paths if its normal path of return is broken and if it can get to the ground.

To receive a shock, a person must become part of an actual circuit; that is, the current must flow through his body as it would through a conductor. Under certain conditions, a person may be exposed to electricity but, unless his body becomes part of a circuit, no harm results. If, for instance, a person is standing on an insulating mat and touches only one wire of a 120-volt circuit, no

complete circuit is established and he will feel no shock. If, however, a person should touch both conductors of a circuit, even with the same finger, the finger becomes part of the circuit, current flowing through the finger from one side of the circuit to the other. For this reason, shock occurs when a finger is placed in a lamp socket (It is difficult to touch the base of the socket without also touching the side.)

Severity of The Shock

The severity of the shock received when a person becomes a part of an electrical circuit is affected by three primary factors. These factors are: (1) the rate of flow of current through the body, measured in amperes; (2) the path of the current through the body, and (3) the length of time the body is in the circuit. Other factors which may affect the degree of shock are: the frequency of the current phase of the heart cycle when shock occurs, and the physical and psychological condition of the person.

Remember that electric shock is no joke - for three reasons:

1. A shock, even a small one, is more harmful if it passes through the heart. Electrical leads should be handled with one hand only, while the other is safely out of the way.
2. Under certain conditions, electricity can produce a painful burn.
3. A sudden, unexpected shock causes a fast reaction and the reaction can result in injury, either to the person getting shocked, or a bystander. Be especially cautious when the circuit contains coils and capacitors. These can cause shocks after power has been turned off.

It is a good idea in any lab where electricity is used to learn where the master disconnects is in case of emergency. All students should be aware of elementary first aid and what to do if an accident occurs, either to themselves or another student.

Few suggestions are

- **DON’T** ever turn power on until the circuit is checked.
- **DO** be ready to turn the power off fast.
- **DON’T** ever clown around.
- **DO** make connections with one hand.
- **DO** turn the power off after every use.
- **DO** be prepared ahead.
- **DO** put everything carefully away after use.
- **DO** keep leads neat and area clean.
- **DO** follow instructions.
- Open and free wires shall be avoided before energizing the circuit.
- Do not energize any circuit until the instructor checks it.
- The supply voltage of the table is **220 VAC** only. Please check the voltage rating of any equipment before plugging into the table sockets. Use proper supply voltage for all the equipments in the lab. If a 110 VAC supply is needed then ask the technician to provide it
- The range of difference power equipments should be correctly selected in right time. **Do not overload any equipment / instrument**
- Seek help of your instructor for any doubt about the circuit connection.
- **Modification to the circuit may only be performed when the system is switched off (zero voltage/ zero current)**
- Always use the coupling and shaft end guards to protect against contact to rotating parts.
- **After finishing the experiment, turn off all the supply and bring them back to zero reading before dismantling the circuit. The first connections to be removed during dismantling the circuit are connections from all the voltage supplies.**
- Normally it is not required to open the device’s housing. However, if necessary to open the housing then it must be performed by lab technician

and under the condition only when the mains plug and all connecting leads have been disconnected.

- Attention should be given to the proper routing of the cables related to experiment when connecting the rotating machines. **Cables should never have a chance to come into contact with rotating components**
- Machines are to be positioned immediately adjacent to one another with their base please securely bolted together
- **Connect the thermal switch of the motor to the "TEMP CONTROL" on the control unit.**
- **Connect all the "PE" or ground connections present on the motor, generator and the tacho generator panels to the "PE "connection of the supply.**
- **Ground all the ground connections of isolation amplifier, CASSY and profi-CASSY units.**
- When a DC motor is removed from its power source then subsequently driven by at the cradle dynamometer it ca go into generator operation, thus producing voltage which will continue to be present at its terminals.
- Safety of working shall be strictly observed and maintained by one of the group member throughout the experiment time.
- **Push the emergency button "RED BUTTON" present on the experiment table in case of any emergency or safety related events.**

EE-Power Lab Regulations:

- Please adhere to the lab timings.
- **Safety shoes and clothing** is strictly enforced for any activities in the lab
- Keep good house keeping while working in the lab and place the wires and other accessories at their specified locations after finishing the work.

EXPERIMENT # 1: INTRODUCTION TO CASSY LAB

Objectives:

- To learn and experiment the measurement of electrical variables through the digital technology Cassy data acquisition in connection with Cassy Lab computer interface.
- To measure, display and record DC and AC quantities then extract subsequent quantities online and offline.
- To plot and analyze the results.

Apparatus:

- Variable DC Power Source 40….250V/10A .
- Three-phase AC Power supply. 0 – 400V/2.5A
- Adjustable Resistive Load.
- Fixed Inductive Load.
- 1 Profi-Cassy.
- 1 Sensor-Cassy.
- 1 Isolation Amplifier, Four Channels.
- 1 AC Adapter.
- 2 Professional Digital Multimeter.
- 1 Cassy Computer Data Acquisition and processing Interface package.
- 1 PC.
- 1 set of 32 safety connectors, black/blue/yellow.

Procedure:

A: Preliminary Measurements

1. Use the Professional Digital Multimeter to measure the load resistances and enter the relevant data in Table 1.

Table 1: Load Resistance measurements

Resistance control Position (%)	$Load_1(\Omega)$	$Load_2(\Omega)$	$Load_2(\Omega)$
Max (100%)			
Min (0%)			

2. Use the Professional Digital Multimeter to measure the inductance internal series resistances and enter the data in Table 2.

Table 2: Inductance internal series resistances measurements

Inductance Value(H), Current Rating (A)	$Load_1(\Omega)$	$Load_2(\Omega)$	$Load_2(\Omega)$
1.2 H, 0.5 A			

B: DC Measurements

3. Connect the circuit as shown in Figure 1 including Cassy measurement Connection for the indicated load Voltage and load Current and fix the rotating resistive curser at 100 % of R values.

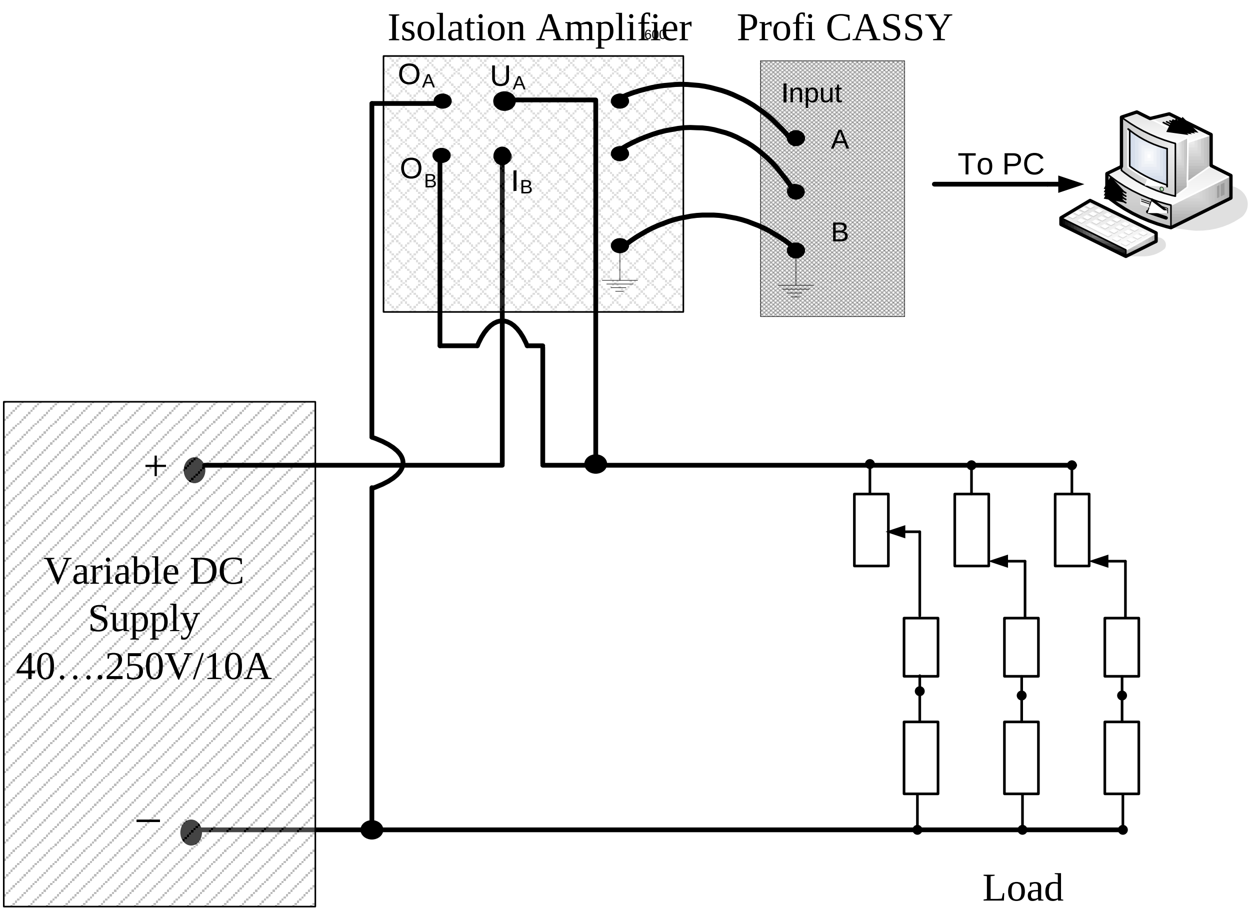
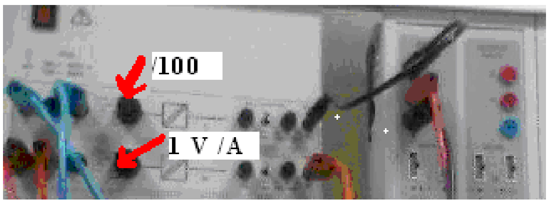


Figure 1: Wiring Diagram for DC Measurements Sep Up.

4. Use channel A of the Isolation Amplifier for voltage measurement with **/100 position** and connect the channel output to input A of Profi-Cassy as shown in icon 1:

5. Use channel B of the Isolation Amplifier for Current measurement with **1 V /A position** and connect the channel output to input B of Profi-Cassy as shown in icon 1.

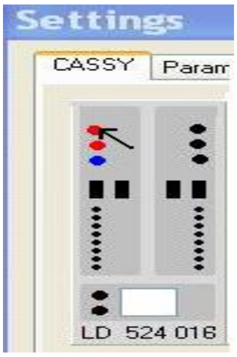
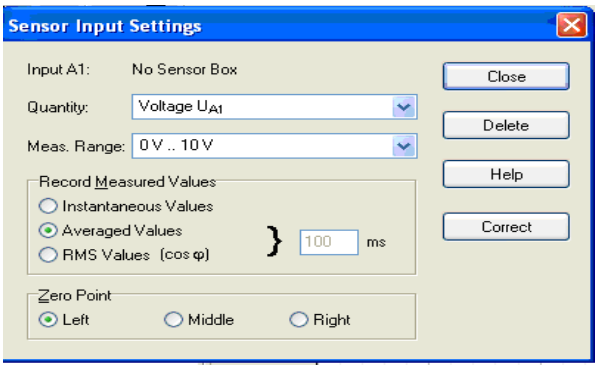
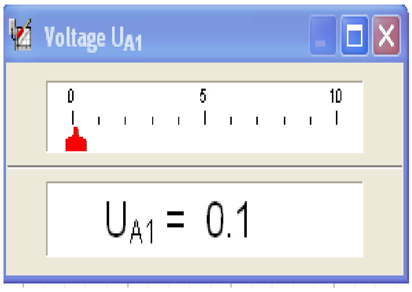


Icon 1

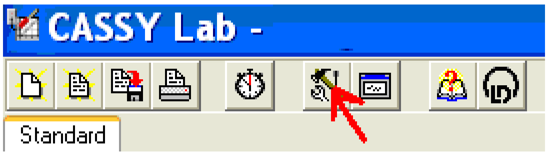
6. Run Cassy Lab which will automatically pop up the setting windows to activate both channels UA_1 and UB_1 of Profi-Cassy namely UA_1 and UB_1.

7. Click on the first red dot as shown on table 3 a), then Select the **Average Values** and **Zero point options** in the input settings of UA_1 as shown in table 3 b) below then note the pop up of the Voltage UA_1 meter appearing on the data plotting area of Cassy lab.

Table 3: Activation Sequence of UA_1

a) Activate Channel UA_1	b) Select the Average Values c) Select the Zero point options	d) Note the UA_1 Display meter
		

8. To activate channel UB_1 go on to Cassy lab menu and click on the **change settings** option as shown in icon 2 below.

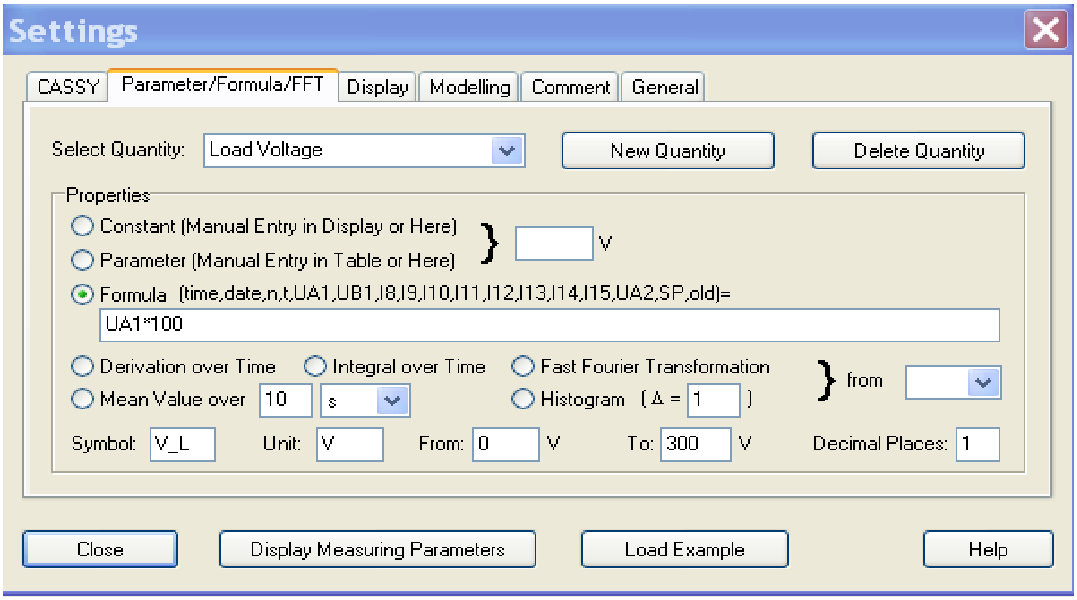


Icon 2

9. Repeat Step 7 for UB_1 (for second red dot).

10. To change the name and the scale for each meter in Cassy Lab double click on **change settings** option and select **Parameters/Formula/FFT**. Select the **New Quantity** feature to change the name of UA_1 to (Load Voltage),

then to change the value or the scale choose the **Formula option** and write the formula in the space below (UA_1*100) and continue with changing the relevant symbol and corresponding unit as well as the plotting range as shown in icon 3.



Icon 3

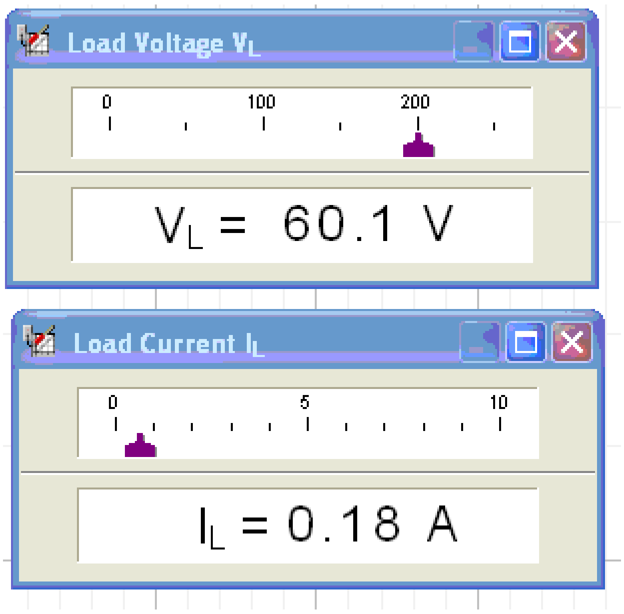
11. Click on the new appearing icon in Cassy lab menu up on the left which carry the symbol defined in step 10, a new display meter carrying the name of the new defined quantity (Load Voltage) pops up.

12. Repeat steps 10 and 11 to define the load current as UB_1.

13. **Ask your instructor to check your connections and CASSY Lab settings. Do not proceed to the next stage unless your connections and settings are completely examined by the instructor.**

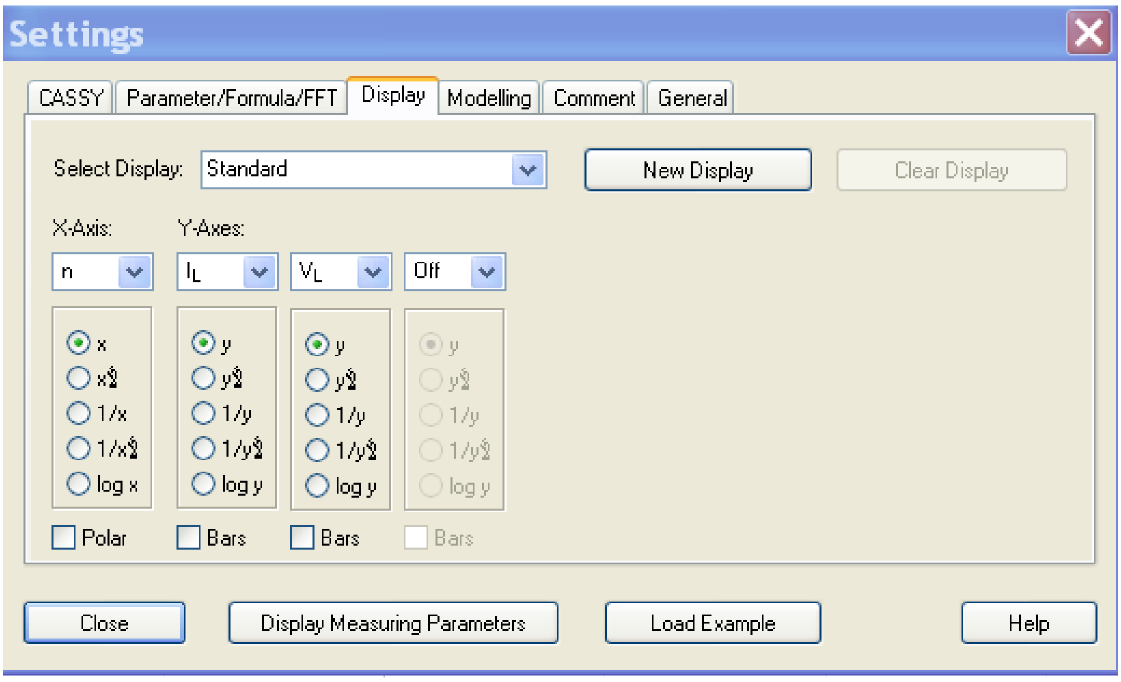
14. Turn ON the variable DC supply current control to maximum then increase the DC supply voltage gradually to 60 V DC while watching the newly

defined Cassy lab display meters for Load Voltage and Load Current as shown in icon 4, then reduce the supply voltage to zero then turn it OFF.



Icon 4

15. Click on the **change setting** option of Cassy and choose the **display** option. Select **n** for X axis, V_L and I_L for Y axes, and all other choices are set in Off position as shown in icon 5.

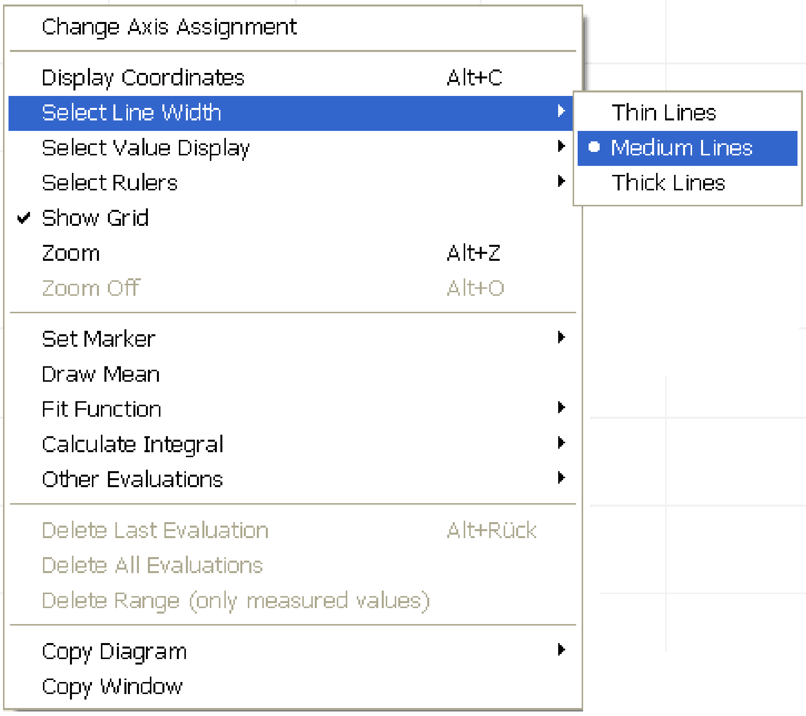


Icon 5

16. Double Click on the **change setting** option of Cassy and select the **Manual Recording** option as shown in icon 6.

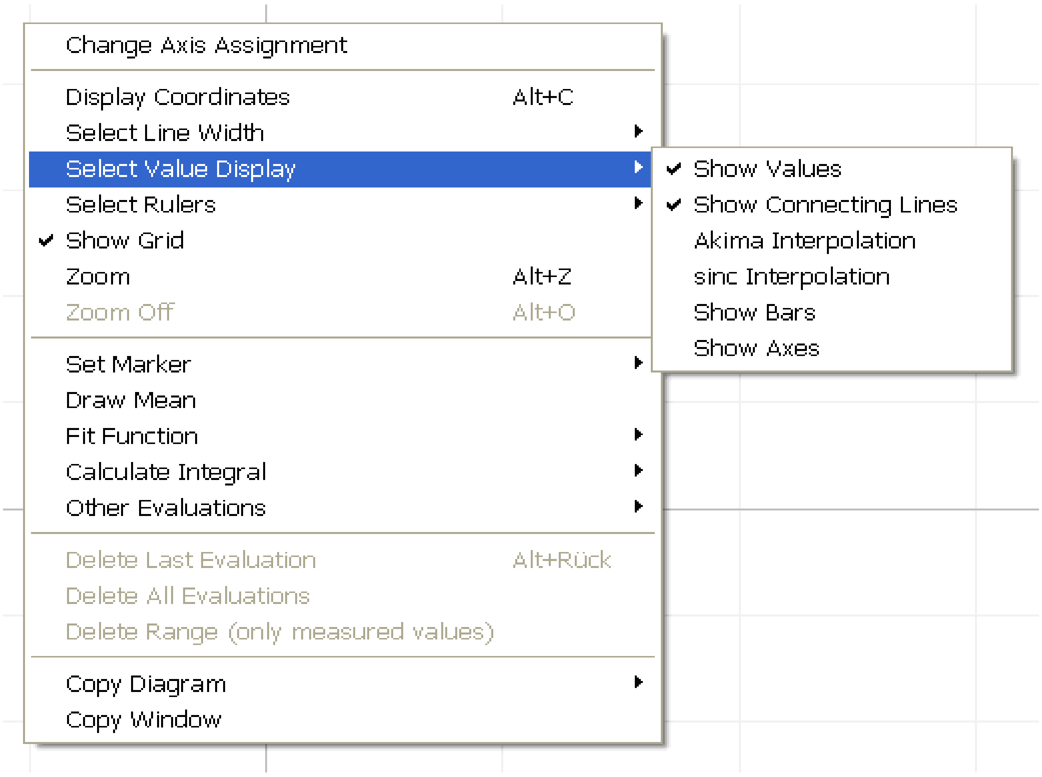
Icon 6:

17. Use the mouse right click in the central white area of Cassy lab and take the option of **Select Line With** and sub select the **Medium Lines** as shown in icon 7.



Icon 7

18. Use the mouse right click in the central white area of Cassy lab and take the option **Select Value Display** then go to the **Show Values** and sub select the **Show Connecting Lines** as shown in Icon 8.

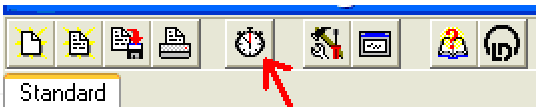


Icon 8

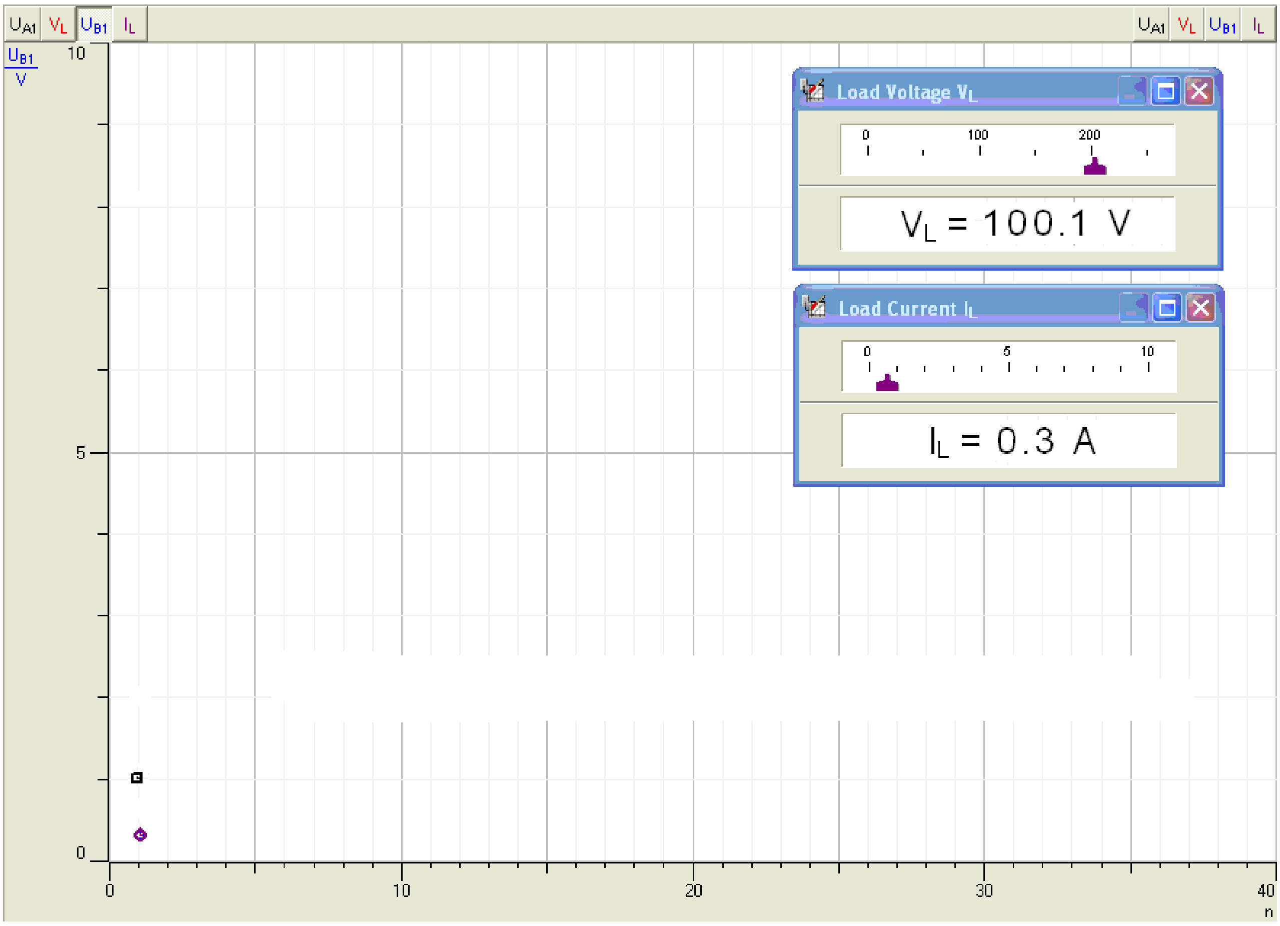
19. Set the load resistance to 100 % of R and **ask the instructor to check your connections and CASSY Lab settings. Do not proceed to the next stage unless your connections and settings are completely examined by the instructor.**

20. Turn ON the variable DC supply then increase the DC supply voltage gradually to 100 V DC. (the student is now ready to start data collection).

21. Click ones on The Start/**Stop Measurement** icon as shown in icon 9 below to record your first data points as demonstrated in icon 10.



Icon 9



Icon 10

22. Carry on the measurement and data recording of step 21 by varying the resistive load from **100% to 30%** in steps as follows 100%, 90%, 80%, 70%, 60%, 50%, 40%, and 30%.

23. Bring the resistance rotating control back to 100% and save Cassy Lab file under a different name and exit Cassy Lab environment, reduce the DC supply voltage to zero and switch the power supply OFF.

C: AC RL Circuit Measurements

24. Connect the circuit as shown in figure 2; note that the AC power supply must be connected between line and neutral terminals.

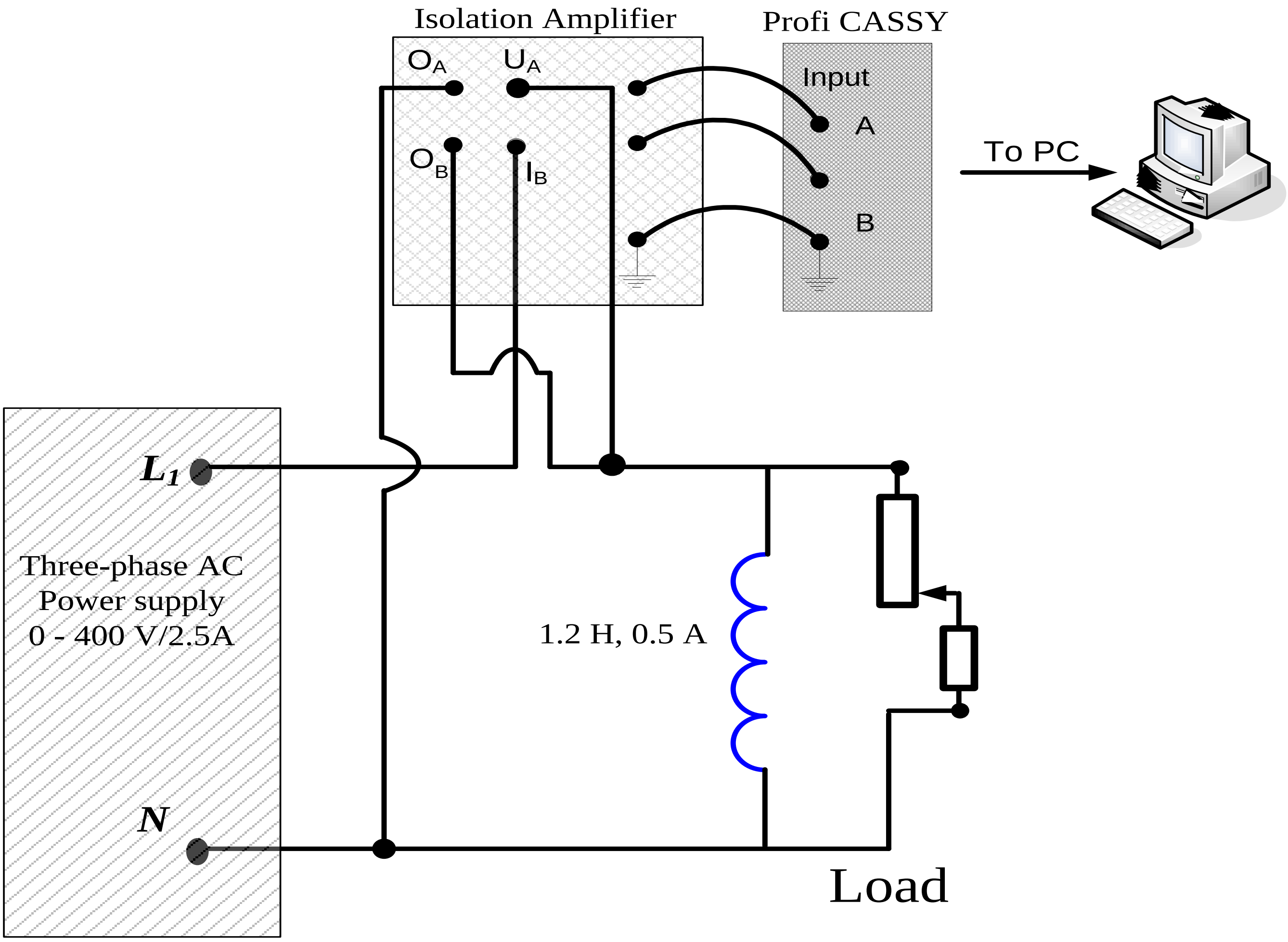


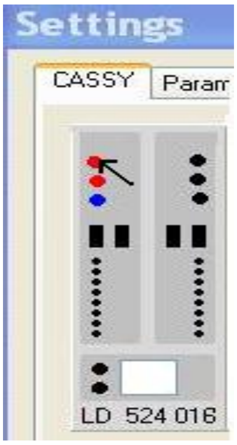
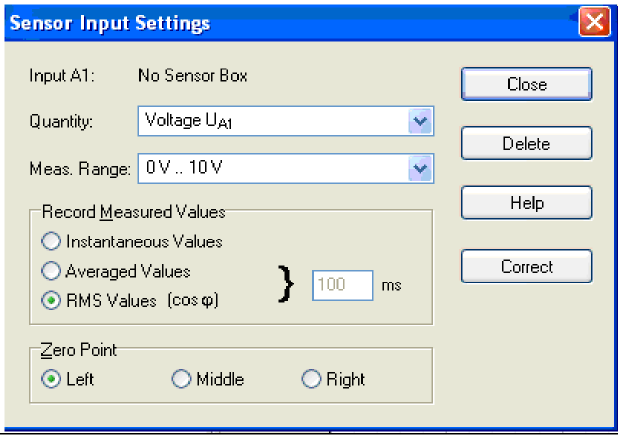
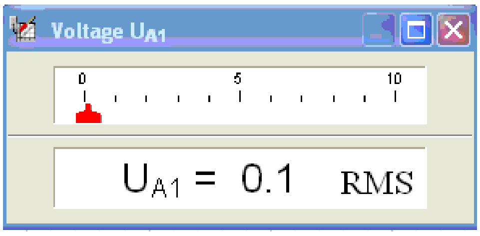
Figure 2: Wiring Diagram AC Measurements for Resistive Inductive Sep Up

25. Open a copy of the previous Cassy Lab file to activate both channels of Profi-Cassy namely UA_1 and UB_1, and then CASSY settings should pop up.

26. Click on the first red dot as shown on table 4 a), then Select the **RMS Values ($\cos\varphi_1$)** and **Zero point options** in the input settings of UA_1 as

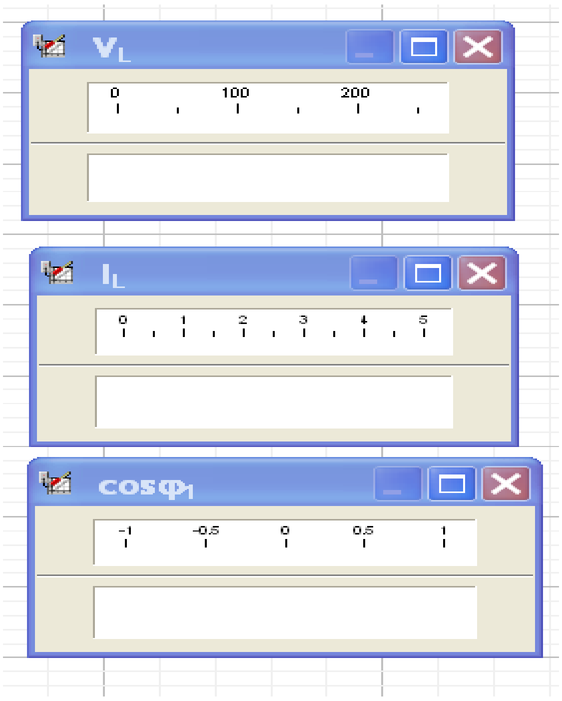
shown in table 4 b) below then note the pop up of the Voltage UA_1 meter appearing on the data plotting area of Cassy lab as shown in table 4 d).

Table 4: AC Activation Sequence of UA_1

<table>
<tr><th>a) Activate Channel UA_1</th><th>b) Select the RMS Values ($\cos\varphi_1$)
c) Select the Zero point options</th><th>d) Note the UA_1 Display meter</th></tr>
<tr><td>
</td><td>
</td><td>
</td></tr>
</table>

27. Repeat Step 26 for UB_1 AC activation (second red dot).

28. Make sure that three meters are popped up for AC measurements UA_1, UB_1, and for $\cos\varphi_1$ as shown in icon 11.



Icon 11

29. Click on the **change setting** option of Cassy and choose the **display** option. Select **n** for X axis, V_L, I_L and ($\cos\varphi_1$) for Y axes, and other choices are set in Off.

30. Repeat steps 16, 17, and 18.

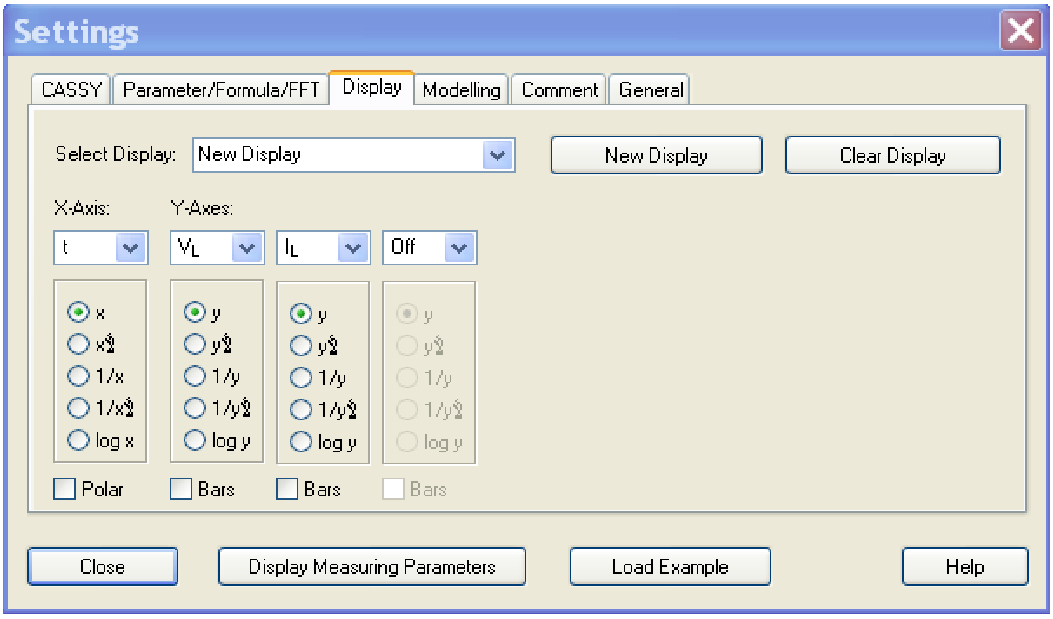
31. **Set the load resistance to 100 % of R and ask the instructor to check your connections and CASSY Lab settings. Do not proceed to the next stage unless your connections and settings are completely examined by the instructor.**

32. Turn ON the AC power supply and adjust the voltage to 100 V for **line to neutral voltage**.
33. Repeat steps 21 and 22.
34. Bring the resistance rotating control back to 100% and save Cassy Lab under different name.

35. In the actual Cassy lab file, double click on Cassy **Measuring Parameters** setting and select the **Automatic recording** for Cassy measuring parameters with the **measuring interval of 100 µsec** and the **xNumber to 500.** Tick √ trigger, UA_1, 0.00 V Rising as shown in icon 12

Icon 12

36. Click on the **change setting** option of Cassy and choose the **display** option. Select **t** for X axis, $\mathbf{V_L}$ and $\mathbf{I_L}$ for Y axes, and all other choices are set in Off position as shown in icon 13.

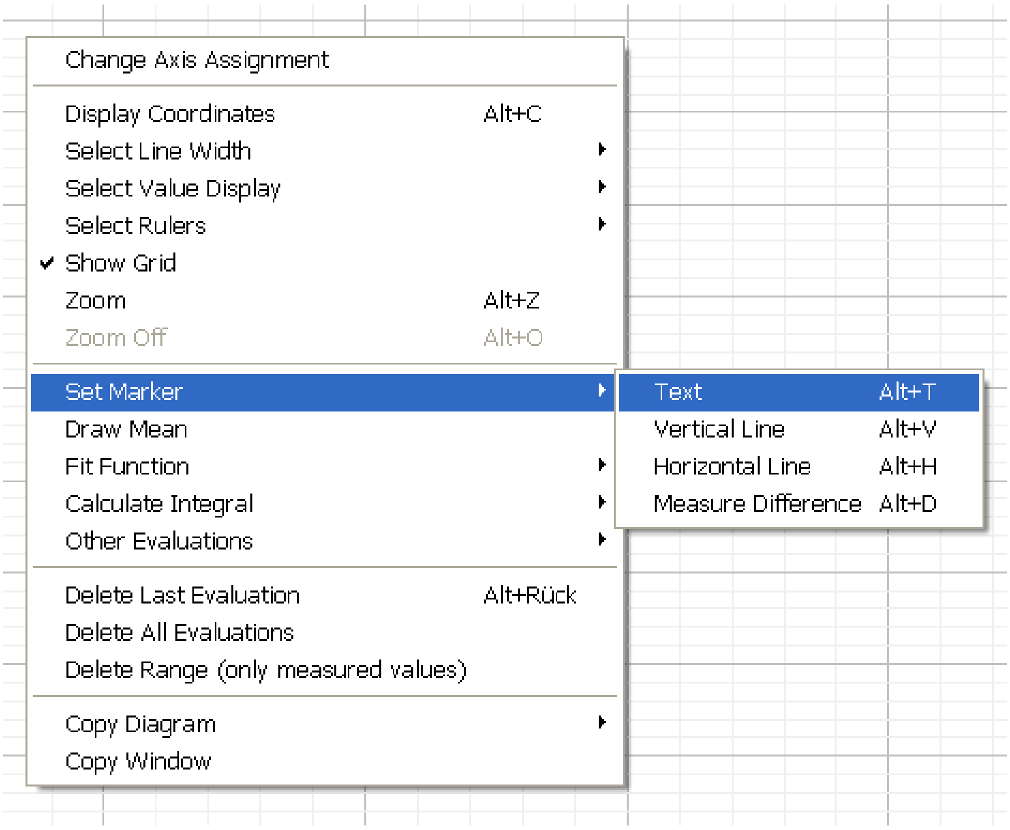


Icon 13

37. Click on **start the measurements** and record the RMS values for voltage and current as well as the corresponding power factor and save the time domain file under different name.
38. Change the resistance to 50% and repeat step 36.
39. Change the resistance to 10% and repeat step 36.

Report

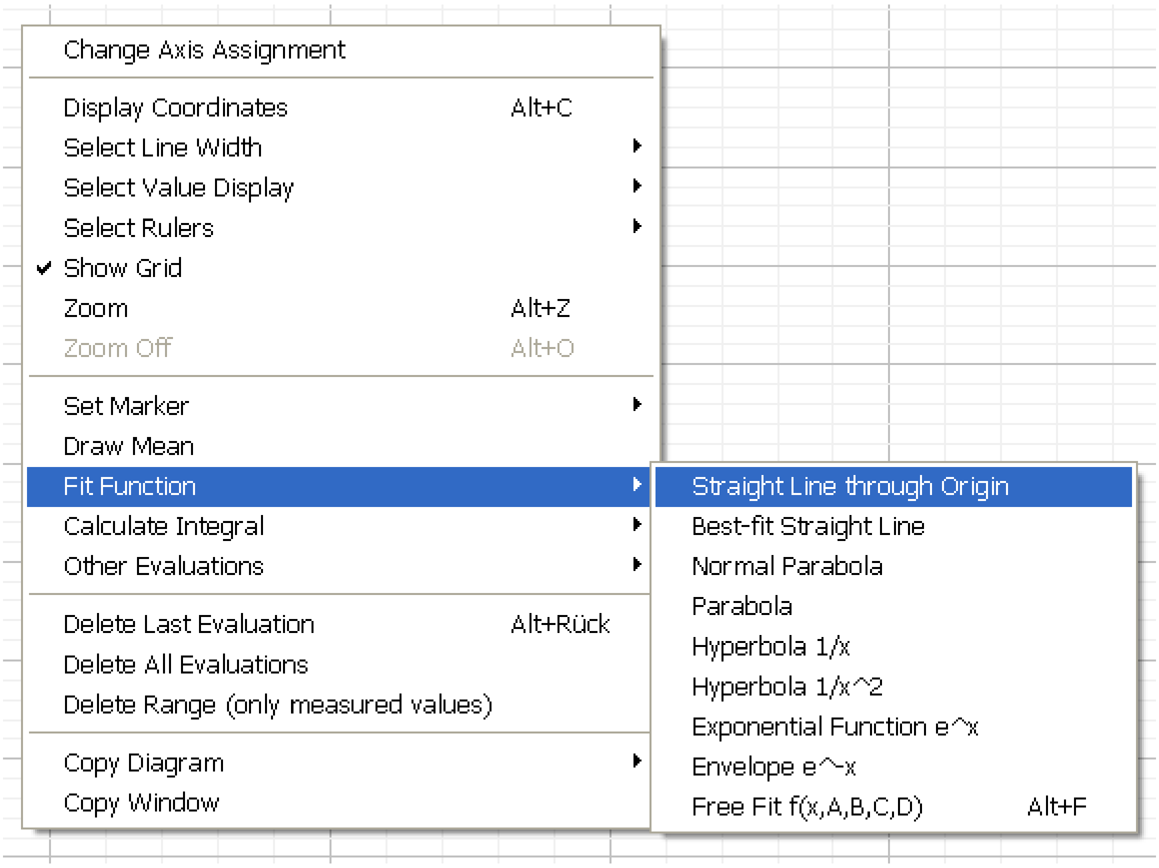
1. Display the recorded data of table 1 and table 2.
2. Display the plot of the recorded data from the circuit of Figure 1.
3. Use the first Cassy lab saved file to plot the load Power versus the load current.
4. Use Cassy Lab **Set Marker** feature as shown in icon 14 to find the slope of the relation between the load power and the load current and verify your result by using the mathematical relevant relation. Show your plot and results



Icon 14

5. Plot the load Power versus the load resistance then use Cassy Lab **Fit Function** as shown in icon 15 to find the relation between the load power and the load resistance by choosing the appropriate Cassy lab fitting function

and verify your result through using the mathematical relevant relation. Show your plot and results.



Icon 15

6. Display the plot recorded data from the circuit of Figure 2.
7. Use the recorded data from the RL circuit of figure 2 to plot the equivalent series impedance, the equivalent resistance, as well as the load real power versus the number of measurements n.

8. Use Cassy Lab **Set Marker** as shown in Icon 14 to find the measured power factor for each case of step 37, 38 and 39 and compare it with its corresponding recorded power factor by direct Cassy measurements. Show your time domain plot and results for each case.

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EXPERIMENT # 2:	**THREE PHASE CIRCUITS AND POWER MEASUREMENTS**

Objectives:

- To connect the three-phase loads as wye **(Y)** and delta **(Δ)** connections.
- To measure the power in three-phase circuits.
- To determine the power factor of three-phase circuits.

Apparatus:

- 1 AC power supply 400V.
- 1 Resistive load.
- 1 inductive load.
- 1 capacitive load.
- 1 set of 10 safety connectors, black.
- 1 set of 10 safety connectors, green/yellow.
- 1 set of 32 safety experiment cables.
- 1 set of 10 safety experiment cables, green/yellow.
- Isolation Amplifier, Profi-CASSY unit, Sensor-CASSY unit, and PC.

Theory :

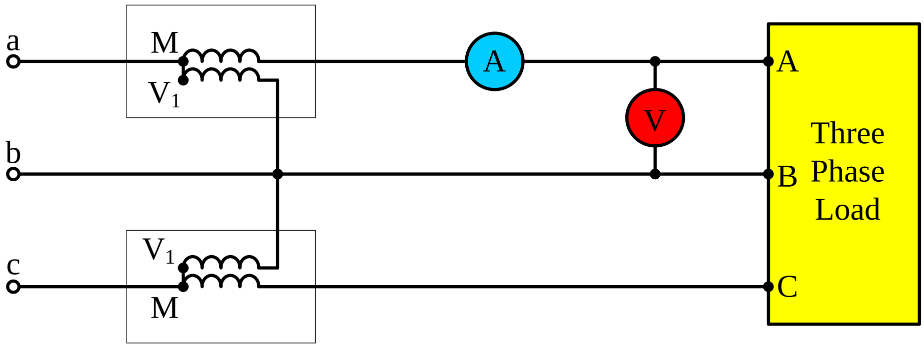

Figure 1: Two Wattmeter Connection

In a Y-connection, the line and the phase quantities are related by:

$V_p=V_L/\sqrt{3}$ (1)

$I_p=I_L$ (2)

Whereas the relationships for a Δ-connection are

$I_p=I_L/\sqrt{3}$ (3)

$V_p=V_L$ (4)

The real and reactive powers for a 3 Φ circuit (either Y or Δ connection) are given as

$P=\sqrt{3}\ V_L\ I_L \cos\theta$ (5)

$Q=\sqrt{3}\ V_L\ I_L \sin\theta$ (6)

Where θ is the power factor angle of the balanced load

If two wattmeters are connected to measure the power of any 3Φ load, it can be shown that the CASSY wattmeters will read V_{ab}, I_a, V_{cb}, and I_c.

$P_1 = V_L\ I_L \cos(30 + \theta)$ (7)

$P_2 = V_L\ I_L \cos(30 - \theta)$ (8)

Where θ the power factor angle of the load. From (7) and (8) we can show that the total power

$P_T = P_1 + P_2 = \sqrt{3}\ V_L\ I_L \cos\theta$ (9)

$Q_T = \sqrt{3}(P_2 - P_1) = \sqrt{3}\ V_L\ I_L \sin\theta$ (10)

$\tan\theta = \sqrt{3}(P_2 - P_1)/(P_1 + P_2)$ (11)

<u>Procedure:</u>

<u>Case A: Y – Connection, Inductive Load</u>

Connect the three phase Y-connected inductive load as shown in Figure 2, please follow the following steps carefully:

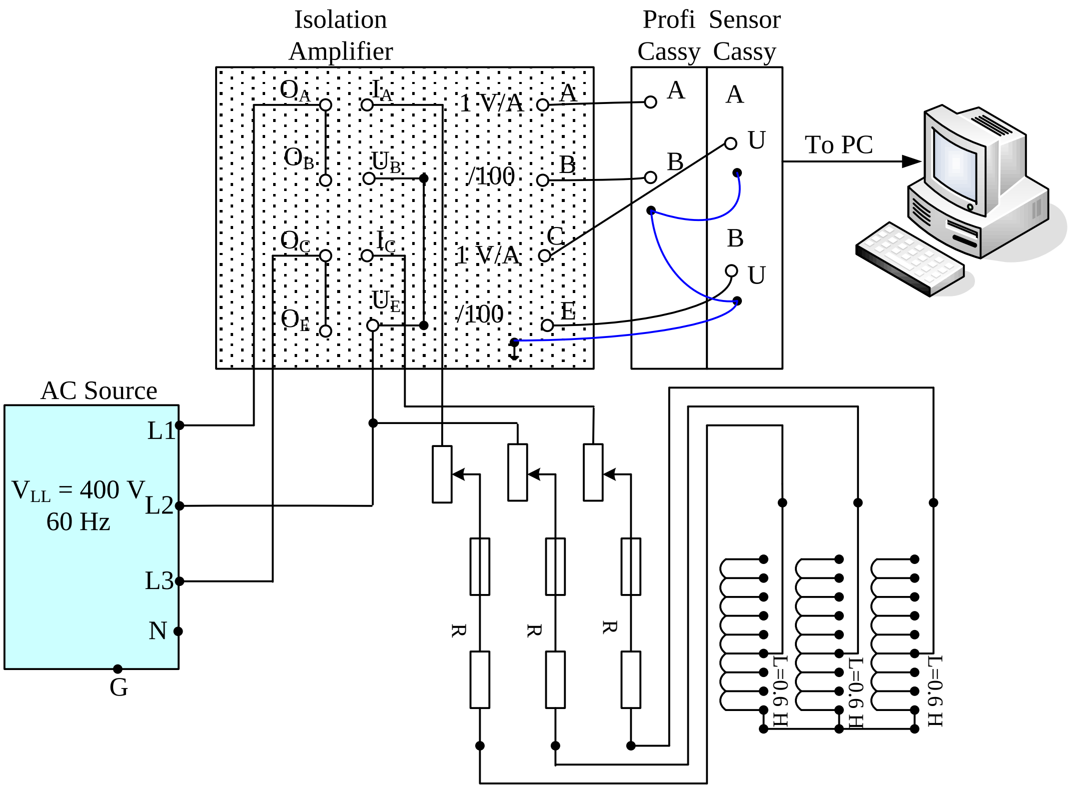

Figure 2 Y-Connected Inductive Load

NOTE: Any time you are using the isolation amplifier channel for current measurement, you should set the Range Selection Switch to "1 V/A"; and in the case you are using the isolation amplifier channel for voltage measurement, you should set the Range Selection Switch to "/100".

1. Make sure that AC source is OFF. Switch ON the Isolation Amplifier and Profi-CASSY. From the PC, run the CASSY lab Software.
2. From the “Profi-CASSY”, define channel A (UA1) and Channel B (UB1). From "Sensor-CASSY" define channel A (UA2) and Channel B (UB2). Select “RMS” value option for UA1, UB1, UA2, and UB2.

3. Click on **Tool Box Button** and from "**Parameter/Formula/FFT**" option, use new quantity to define I_a as UA1 from the "formula" option. Accordingly adjust the symbol, unit, range etc.
4. Repeat above step to define V_{ab} as UB1*100, I_c as UA2, and V_{cb} as UB2*100 respectively.
5. From the "**Display**" option, select X-axis as the time and I_a, V_{ab}, I_c, and V_{cb} as Y-axis. Switch off all other signals. You can be able to see the phase currents and the line voltage simultaneously with respect to time.
6. Double click on **Tool Box Button**, make sure the automatic box is checked and then change the sampling rate to 100 μs and select "trigger" option as UB1 rising.
7. **After you finish connecting the circuit please ask your instructor to check your connections.**
8. Turn the power supply ON.
9. Click on the **clock icon** to display the current and voltage waveforms. You will observe the waveforms like oscilloscope.
10. Save the file as **waveform**.
11. Double click on **Tool Box Button**, tick on the "**manual recording".**
12. Vary the load resistance as shown in Table 1 and record the line voltages, line currents, and the cosine by pressing F9 on the keyboard for each step.
13. After you finish the measurements and the recording, save your measurements in file as **YRL** and return the position of R to 100% and switch the power supply OFF.

Table 1: Results for Y-connection (Inductive Load L=0.6H)

R	V_{AB} (V)	I_A (A)	Cos(30+θ)	V_{CB} (V)	I_C (A)	Cos(30-θ)
100%						
60%						
30%						

Case B: Y – Connection, Capacitive Load

14. Now, replace the three phase inductors by three phase capacitors to the load as seen in Figure 3, then turn ON the power supply and repeat record the data (steps 9-12) as shown in Table 2.

15. After you finish the measurements and the recording, save your measurements in file as **YRC** and return the position of R to 100% and switch the power supply OFF.

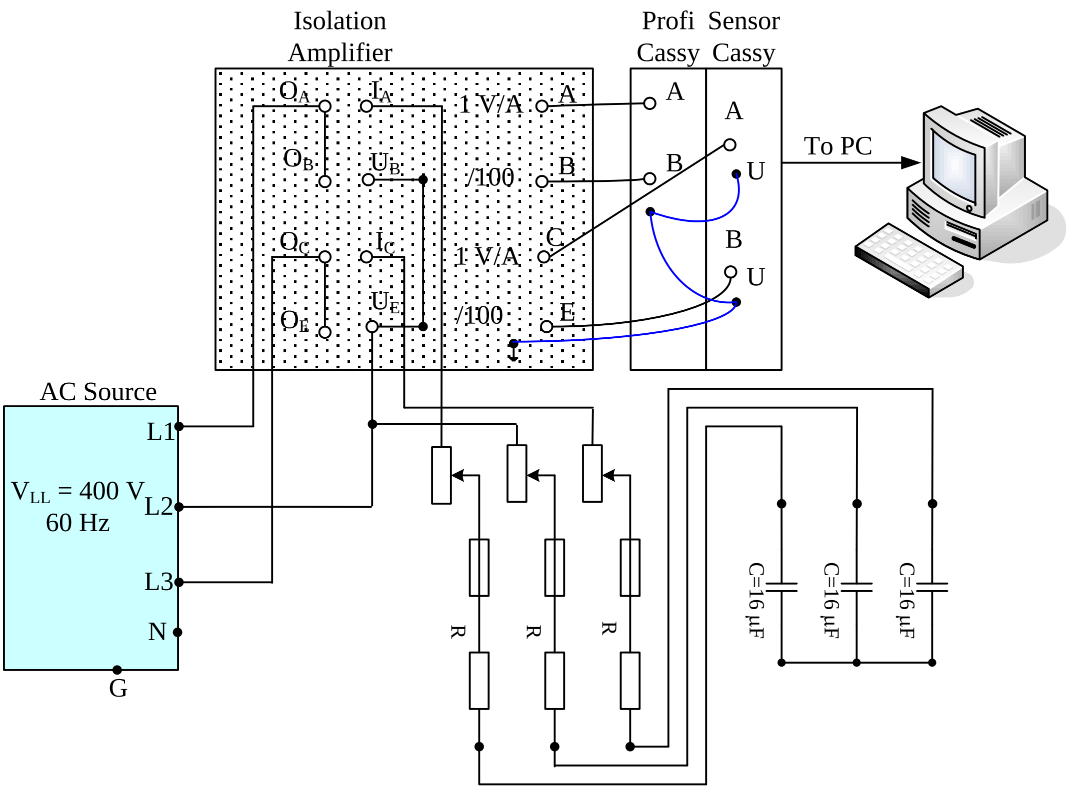

Figure 3 Y-Connected Capacitive Load

Table.2: Results for Y-connection (Capacitive Load C=16µF)

R	V_{AB} (V)	I_A (A)	Cos(30+θ)	V_{CB} (V)	I_C (A)	Cos(30-θ)
100%						
60%						
30%						

Case C: Δ – Connection, Inductive Load

16. Modify the circuit setup as shown in Fig. 4 for the inductive load as Δ-connection, and then turn ON the power supply and repeat record the data (steps 9-12) as shown in Table 3.

17. After you finish the measurements and the recording, save your measurements in file as **DRL** and return the position of R to 100% and switch the power supply OFF.

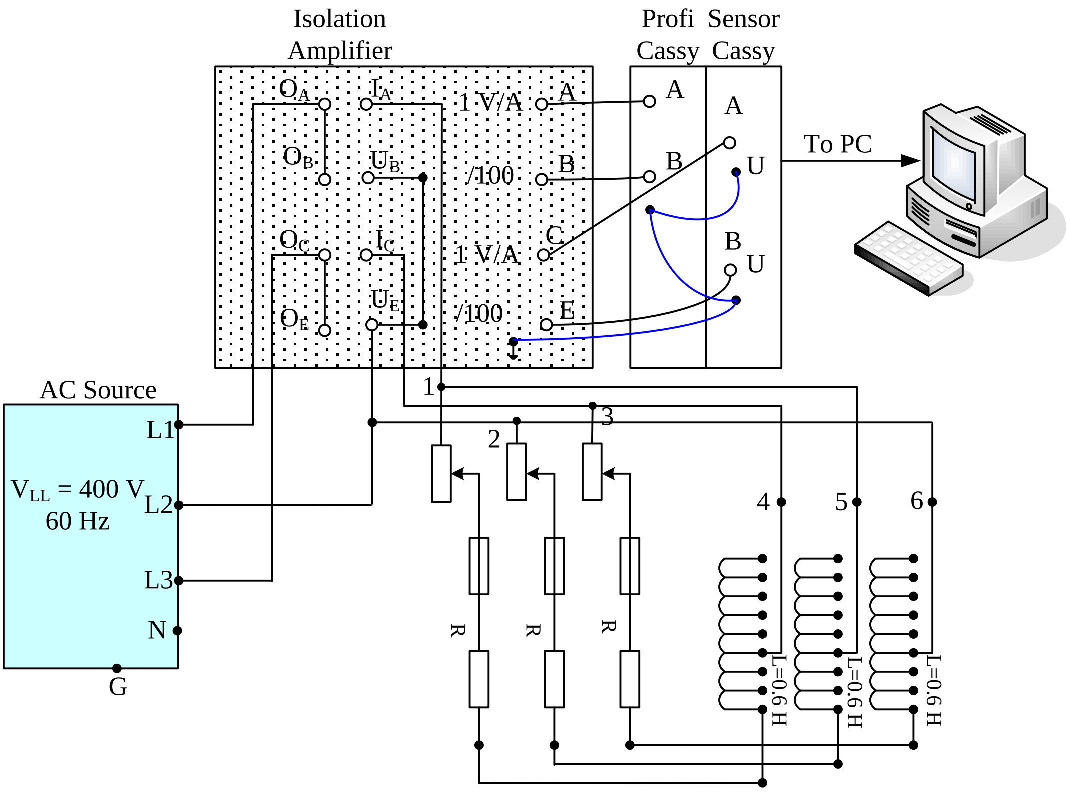

Figure 4 Δ-Connected Inductive Load

Table.3: Results for Δ-connection (Inductive Load L=0.6 H)

R	V_{AB} (V)	I_A (A)	Cos(30+θ)	V_{CB} (V)	I_C (A)	Cos(30-θ)
100%						
60%						
30%						

Case D: Δ – Connection, Capacitive Load

18. Now, replace the three phase inductors by three phase capacitors to the load as seen in Figure 3, then turn ON the power supply and repeat record the data (steps 9-12) as shown in Table 4.

19. After you finish the measurements and the recording, save your measurements in file as **DRC** and return the position of R to 100% and switch the power supply OFF.

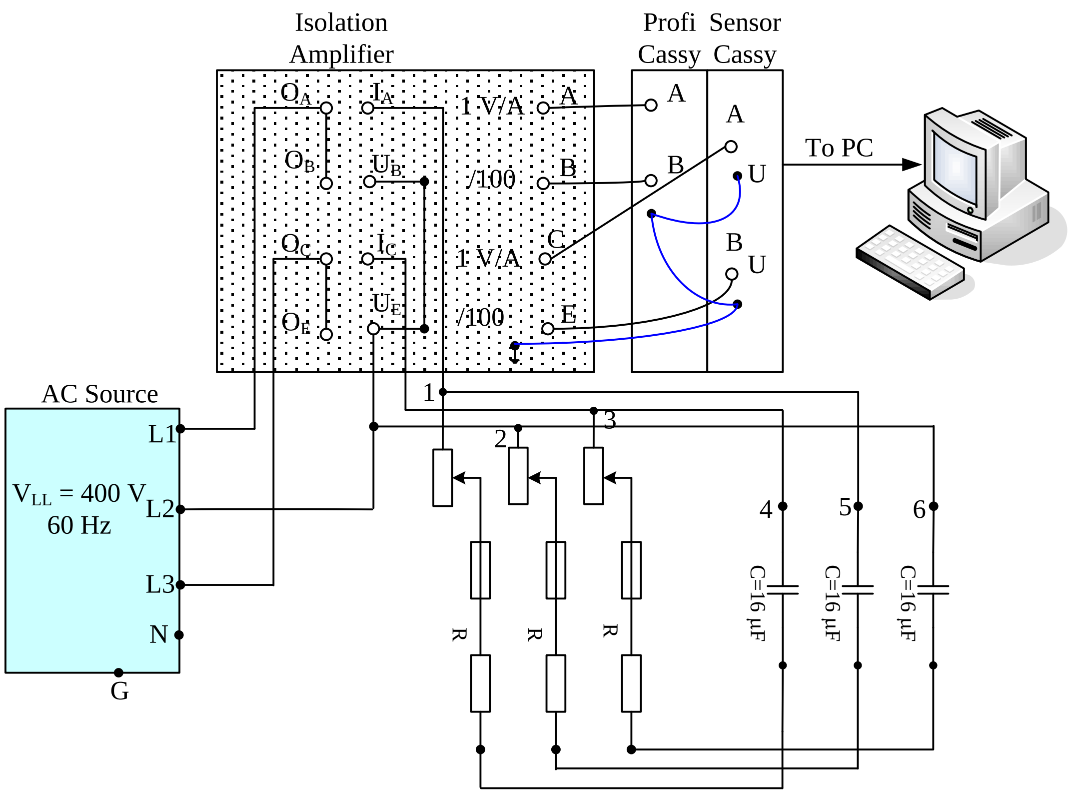

Figure 5 Δ-Connected Capacitive Load

Table.4: Results for Δ-connection (Capacitive Load C=16 μF)

R	V_{AB} (V)	I_A (A)	Cos(30+θ)	V_{CB} (V)	I_C (A)	Cos(30-θ)
100%						
60%						
30%						

Report

Using the recorded measurements of $\mathbf{I_a}$, $\mathbf{V_{ab}}$, $\mathbf{cos\varphi_1}$, $\mathbf{I_c}$, $\mathbf{V_{cb}}$, and $\mathbf{cos\varphi_2}$, run the CASSY-software and define a new quantity to calculate P1 and P2 as given in equations (7) and (8) using "**formula**" option.

Define a new quantity to calculate the total active power PT, reactive power QT, and the power factor angle θ as given in equations (9-11) using "**formula**" option.

Hint: Use arctan function to find θ**.**

For all cases A, B, C, and D, show by using CASSY software the relation between PT, QT, and θ versus three values of load resistance.

Your results should be presented like the table below for each case.

R %	**Vab**	**Ia**	**cosφ1**	**Vcb**	**Ic**	**cosφ2**	**P1**	**P2**	**PT**	**QT**	**θ**
100											
60											
30											

EXPERIMENT # 3:	MAGNETIC CIRCUIT CHARACTERISTICS

Objectives:

- To determine the B-H characteristics of an iron core
- To find the relative permeability of core material (μ_r)
- To calculate the iron core reluctance (R)

Apparatus:

- Laminated core
- Coil
- Single-phase variable AC supply 0…400 V / 2.5 A
- Isolation Amplifier, Profi-CASSY, and PC

Theory:

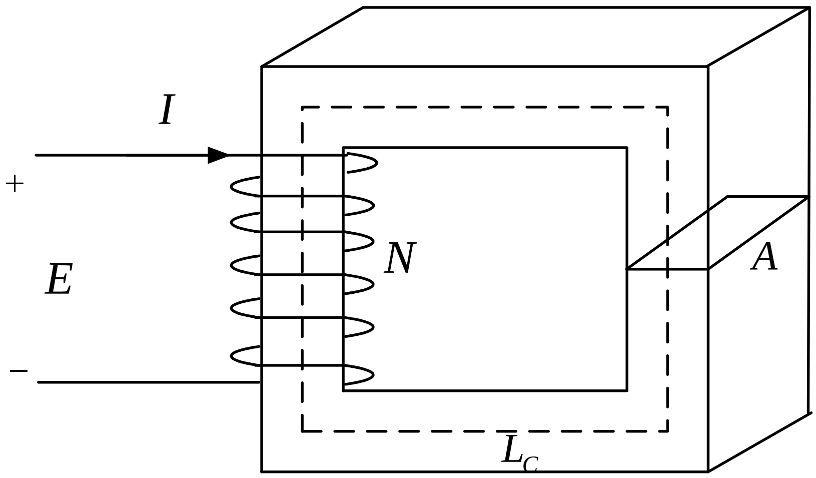

Fig. 1: A magnetic circuit

If a current of I A flows from a supply of E volts through a coil of N turns as shown in Fig. 1, the magnetic field intensity H can be written as:

$$H = \frac{NI}{L_C} \quad \text{(AT/m)} \tag{1}$$

where L_C is the mean length of the magnetic core in meters.

From faraday's law of electromagnetic induction, the rms values of the induced voltage across the coil E is

$$E = \omega N \Phi = \omega NAB \tag{2}$$

where $\omega = 2\pi f$ is the frequency in rad/s, A is the cross section area of the core in m^2, and B is the magnetic field density in Tesla. B can be expressed as

$$B = \mu H = \mu_0 \mu_r H \tag{3}$$

where, μ_r is the relative permeability of the core material and μ_o is the permeability of the air. Note: $\mu_o = 4\pi \times 10^{-7}$ (H/m).

From (1), (2) and (3), it is clear that $B \propto E$ and $H \propto I$. Therefore, E-I characteristic of the core is equivalent to the B-H characteristic. Further, it can be shown that

$$E = \frac{\omega N^2 A \mu_0 \mu_r I}{L_C} \tag{4}$$

Then μ_r can be determined as

$$\mu_r = \frac{EL_C}{\omega N^2 A \mu_0 I} \tag{5}$$

The reluctance of the magnetic core can be expressed as:

$$R = \frac{NI}{\Phi} = \frac{L_C}{\mu_0 \mu_r A} \quad \text{(At/Wb)} \tag{6}$$

Substituting from (2) or (5) in (6) gives

$$R = \frac{\omega N^2 I}{E} \quad (7)$$

Procedure:

Please follow the following steps carefully:

1. Read and take the coil nameplate data. Verify the following specifications: $L_C = 40$ cm, $N = 400$ turns, and $A = 9$ cm^2.
2. Make sure that the source is off.
3. Connect the circuit as shown in the wiring diagram of Fig. 2.
4. Switch on the Isolation Amplifier and the Profi-CASSY. Note that the channel A measures the voltage and channel B measures the current.
5. In the Isolation amplifier, adjust the scale of channel A as "/100" and the scale of channel B as "1 V/A".
6. From the PC, activate the CASSY Lab software and select "RMS Values" option for both channels. Note that UA1 and UB1 represent the voltage E and current I respectively.
7. From "Parameter/Formula/FFT" option, use new quantity to define E as UA1*100 from the "Formula" option. Accordingly, adjust the symbol, unit, range,…etc.
8. Repeat Step 7 to define I as UB1.
9. From the "Display" option, select I as X-axis and E as Y-axis. Switch off all other signals.
10. Adjust the scale of Y-axis from 0 to 200 V and X-axis from 0 to 4 A.
11. Double click on the "Setting" icon to activate the Measuring Parameters. Select the "Manual Recording" option.
12. **Ask the instructor to check your connections and CASSY Lab settings. Do not proceed to the next stage unless your connections and settings are completely examined by the instructor.**

13. Make sure that the supply voltage is set at 0 V position. Switch ON the supply.
14. Increase the voltage from 0 to 160 V in 10-15 steps. Record the measurements of *E* and *I* at each step by clicking on Clock icon or F9.
15. Reduce the voltage to 0 V, switch OFF the supply, and save your CASSY Lab file.

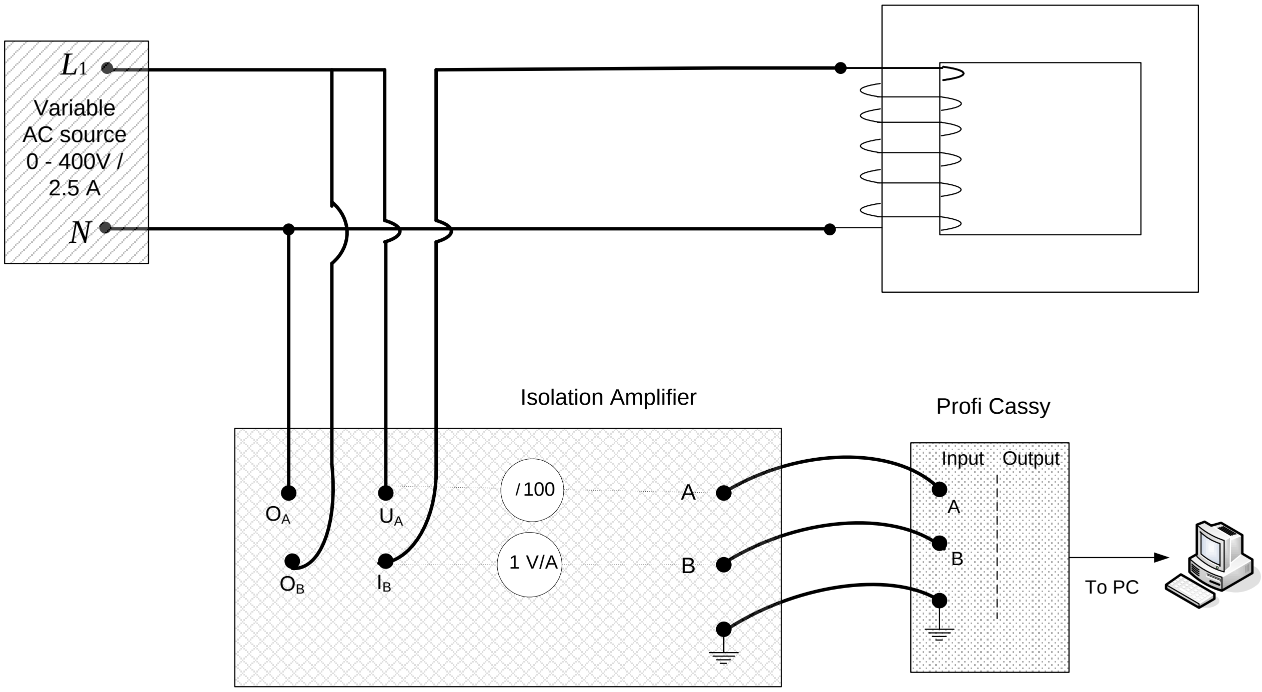

Fig. 2: Wiring diagram for magnetic circuit measurements

Report:

1. If B, H, μ_r and R are expressed in terms of E and I as follows. $H = K_1 \times I$, $B = K_2 \times E$, $\mu_r = K_3 \times E / I$, *and* $R = K_4 \times I / E$, calculate K_1 - K_4 and complete the following.

   $K_1 =$

   $K_2 =$

   $K_3 =$

   $K_4 =$

Hint: use Equations (1)-(7) along with the coil and core specifications given above, for example from (1), $K_1 = \frac{N}{L_C}$.

2. Based on the recorded values of E and I, define H, B, μ_r and R as new quantities in CASSY Lab.
3. Plot E vs. I, B vs. H, μ_r vs. H, and R vs. H.
4. Write a formal report that includes all measurements and calculations as given in the following Table along with all plots.
5. Comment on similarity and report the differences, if any, between E vs. I and B vs. H plots.
6. Comment on variation of μ_r and R as H increases.
7. Conclude on your results.

Magnetic circuit measurements and calculations

E	I	H	B	μ_r	R

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EXPERIMENT # 4: EQUIVALENT CIRCUIT AND PERFORMANCE EVALUATION OF 1-PHASE TRANSFORMER

Objectives:

1. To determine the equivalent circuit of a single phase transformer
2. To verify the voltages and currents transformer ratio.
3. To determine the voltage regulation of a transformer
4. To determine the efficiency of a transformer

Apparatus:

- 1 Single-phase transformer. (**N_1 = 847, N_2 = 456, N_3 = 456**)
- 1 Variable AC power supply 0 – 400V/2.5A.
- 1 Resistive load.
- 1 inductive load.
- 1 capacitive load.
- 1 set of 10 safety connectors, black.
- 1 set of 10 safety connectors, green/yellow.
- 1 set of 32 safety experiment cables.
- 1 set of 10 safety experiment cables, green/yellow.
- 2 Professional Digital Multimeter
- Isolation Amplifier, Profi-CASSY unit, Sensor-CASSY unit, and PC.

Theory

Equivalent Circuit Parameters:

The approximate equivalent circuit referred to primary of a transformer is given in Figure 1.

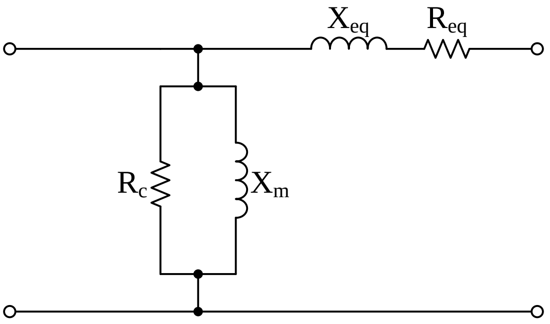


Figure 1 Equivalent Circuit of Single Phase Transformer

Where, R_c =1/g and x_m =1/b. These quantities are obtained from the open circuit power, voltage and current measurements. These are

$$R_c = \frac{V_1^2}{P_0} \quad (1)$$

$$I_c = \frac{V_1}{R_c} \quad (2)$$

$$I_m = \sqrt{I_0^2 - I_c^2} \quad (3)$$

and,

$$X_m = \frac{V_1}{I_m} \quad (4)$$

The equivalent resistances and reactances (R_{eq}, X_{eq}) are obtained from the current, voltage and power measurements in the primary winding when the secondary is shorted. These are written as

$$R_{eq} = P_{sc} / I^2_{sc} \quad (5)$$

$$|Z_{eq}| = V_{sc} / I_{sc} \quad (6)$$

$$X_{eq} = \sqrt{|Z_{eq}|^2 - R_{eq}^2} \quad (7)$$

Voltage Regulation and Efficiency:

The voltage regulation of transformer at rated load is defined as:

$V_R = (V_{no\ load} - V_{rated}) / V_{rated}$ (8)

If the approximate equivalent circuit of a transformer is used then for a lagging pf load

$$V_1 = V_{no-load} = V_{rated}\angle 0^o + I\cdot(\cos\theta - j\cdot\sin\theta)(R_{eq} + j\cdot X_{eq}) = \\ V_{rated}\angle 0^o + I\cdot(R_{eq}\cdot\cos\theta + X_{eq}\cdot\sin\theta) + j\cdot I\cdot(-R_{eq}\cdot\sin\theta + X_{eq}\cdot\cos\theta) \quad (9)$$

Neglecting the imaginary part on the right hand side,

$$VR = \frac{I\cdot(R_{eq}\cdot\cos\theta + X_{eq}\cdot\sin\theta)}{V_{rated}} \quad (10)$$

The efficiency of the transformer can be written as

η = Power Output / Power Input (11)

Or

$$\eta = \frac{Power\ Output}{Power\ Output + Loses}$$

The losses are,

Core loss = No load power input – No load copper loss

Copper loss = $I_2^2\ R_{eq}$

Note: the efficiency η_{max} will occur when $\frac{I_2}{I_{rated}} = \sqrt{\frac{P_0}{P_{sc}}}$

Procedure

Check the single phase transformer and record the number of turns for the primary and secondary and then calculate the turn ration **a** as shown in Table 1.

N1	
N2	
a	

Record rated value of I_2, find the I_1 rated and record the value of V_2 and then find the V_1 rated.

A. NO Load Test

Figure 2 shows open circuit single phase transformer, connect the circuit as seen in the Fig. 2.

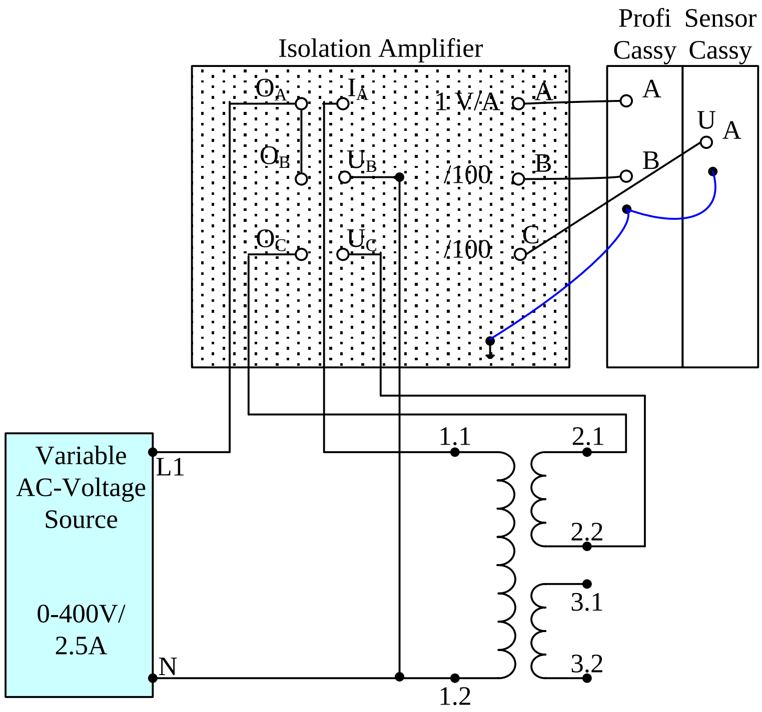


Figure 2 Circuit for measuring voltage transformation in a single-phase transformer

NOTE: The transformer to be investigated is to be operated with no-load (open secondary circuit).

NOTE: Any time you are using the isolation amplifier channel for current measurement, you should set the Range Selection Switch to "1 V/A"; and in the case you are using the isolation amplifier channel for voltage measurement, you should set the Range Selection Switch to "/100".

1. From the PC, run the CASSY lab Software.
2. From the “Profi-CASSY”, define channel A (UA1), Channel B (UB1), and from "Sensor-CASSY" channel A (UA2).
3. Select “RMS” value option for UA1, UB1, and UA2.
4. Click on **Tool Box Button** and from “**Parameter/Formula/FFT**” option, use new quantity to define I_0 as UA1 from the formula option. Accordingly adjust the symbol, unit, range etc.
5. Click on **Tool Box Button** and from “**Parameter/Formula/FFT**” option, use new quantity to define P_0 as 100*UA1*UB1*cos&j1 from the formula option. Accordingly adjust the symbol, unit, range etc.
6. Repeat above step to define V_1 as UB1*100 and V_2 as UA2*100, respectively.
7. **After you finish connecting the circuit and software setup, please ask your instructor to check your connections and setup.**
8. Turn **ON** the circuit and select voltage $V_1 \cong 230$V on the variable AC-source that powers the circuit.
9. Measure the no-load current I_0 of the test object, P_0, V_1, and the voltage across each of secondary V_2 (between terminals 2.1 and 2.2).
10. Compare the turn ration **a** calculated from the V_1 and V_2 with the ratio of N_1/N_2.
11. **Reduce the variable voltage source to 0, then turn the power OFF.**

Result:

V_1		V_2		**a**	
P_0		I_0			

B. Short-Circuit Voltage and Sustained Short-Circuit Current

12. Connect the circuit as shown in Fig. 3.

13. Click on **Tool Box Button** and from "**Parameter/Formula/FFT**" option, use new quantity to define P_{sc} as 100*UA1*UB1*cos&j1 from the formula option. Accordingly adjust the symbol, unit, range etc.

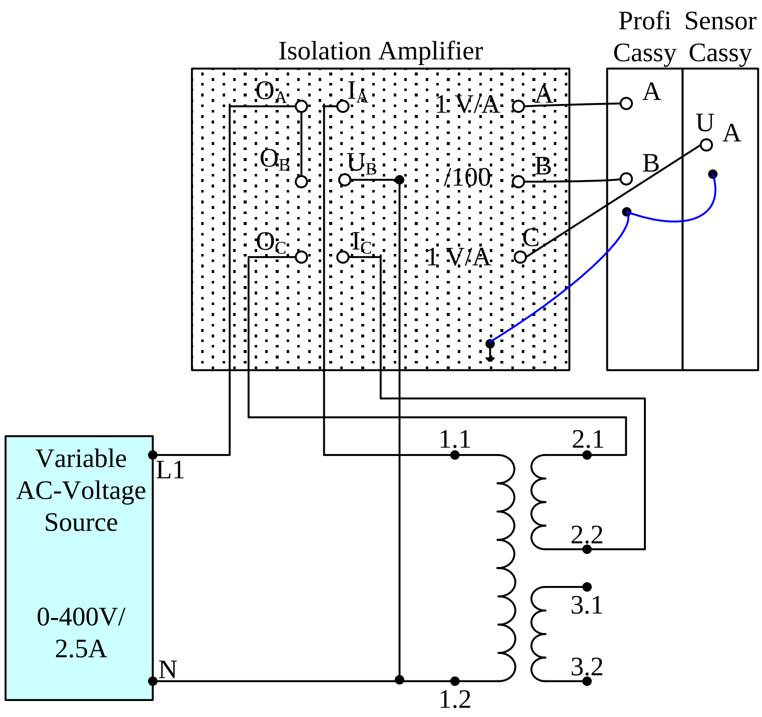


Figure 3 Circuit for measuring short-circuit voltage

14. Turn ON the variable voltage source, beginning from zero, slowly increase the voltage of the variable transformer until the current flowing in the primary side reaches its rated value; then read the corresponding voltage I_1sc, I_{2rated}, and V_{sc}. **Be careful that applying less than 5% input voltage will give the rated current in the secondary transformer. (≅7V)**.

15. Record your data in the similar table below and verify the turn ratio **a** from the current values.

V_{sc}		I_{sc}		P_{sc}		**a**	

16. Reduce the variable voltage source to 0, then turn the power OFF.

C. Voltage Behavior with Resistive Load, Evaluating Efficiency

17. Change the circuit to match Fig. 4.

Note: Three separate resistors are to be connected in parallel to increase current handling capability.

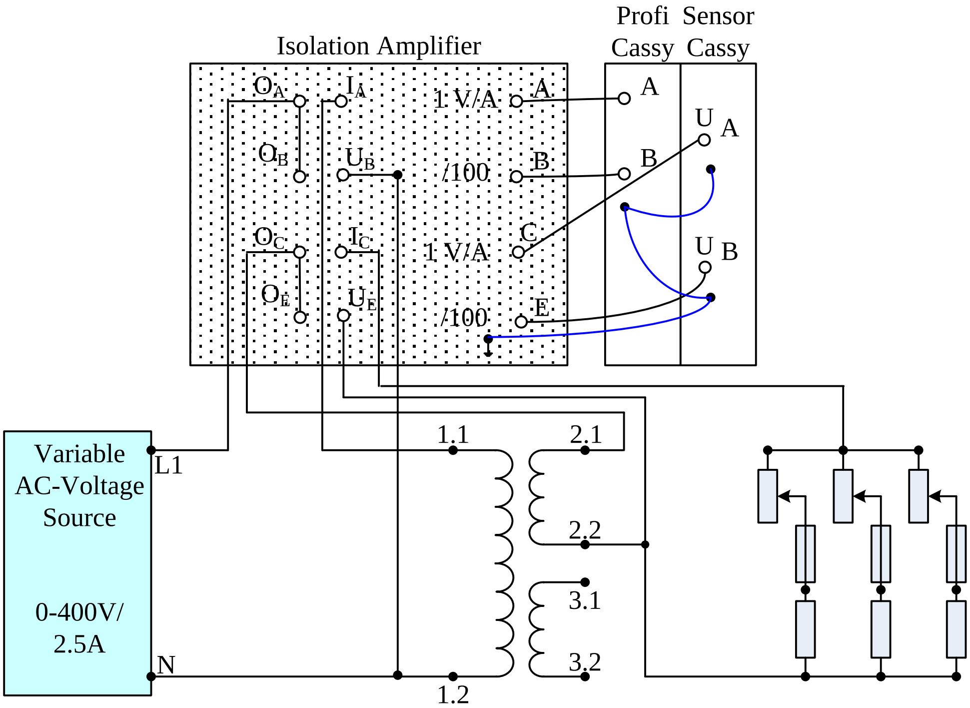


Figure 4 Circuit for investigating voltage behavior with resistive load and for evaluating efficiency

NOTE: Any time you are using the isolation amplifier channel for current measurement, you should set the Range Selection Switch to "1 V/A"; and in the case you are using the isolation amplifier channel for voltage measurement, you should set the Range Selection Switch to "/100".

18. From the PC, run the CASSY lab Software.
19. From the “Profi-CASSY”, define channel A (UA1), Channel B (UB1), and from "Sensor-CASSY" channel A (UA2), Channel B (UB2).
20. Select “RMS” value option for UA1, UB1, UA2, and UB2.

21. Click on **Tool Box Button** and from "**Parameter/Formula/FFT**" option, use new quantity to define $\boldsymbol{I_1}$ as UA1 from the formula option. Accordingly adjust the symbol, unit, range etc.
22. Repeat above step to define $\boldsymbol{V_1}$ as UB1*100 and $\boldsymbol{I_2}$ as UA2, and $\boldsymbol{V_2}$ as UB2*100 respectively.
23. Click on **Tool Box Button** and from "**Parameter/Formula/FFT**" option, use new quantity to define $\boldsymbol{P_1}$ as 100*UA1*UB1*cos&j1 from the formula option. Accordingly adjust the symbol, unit, range etc.
24. **After you finish connecting the circuit and setting up formulas, please ask your instructor to check your connections and setup.**
25. Turn the power supply ON.
26. Double click on **Tool Box Button**, tick on the **manual recording.**
27. First set the resistive load to a value of 100% and turn the circuit on. Set the variable voltage source to maintain a voltage of 230V.
28. Reduce the load R from 100% to 30% in 10-15 steps, for each setting, measure the corresponding values for voltage V_1, current I_1 and power factor $\cos\varphi_1$ on the primary side as well as voltage V_2 and current I_2, and $\cos\varphi_2$ on the secondary side as well as P_1 as shown in Table 1.
29. When load current I_2 is over 1.4A, these measurements should be made expeditiously in order to avoid overloading the transformer!
30. **Reduce the variable voltage source to 0, then turn the power OFF.**

D. Voltage Behavior with Inductive or Capacitive Load

31. Replace the resistive load with an inductive load and change the circuit to match Fig. 5. Here too, the inductive load elements are to be connected in parallel to increase current handling capability.

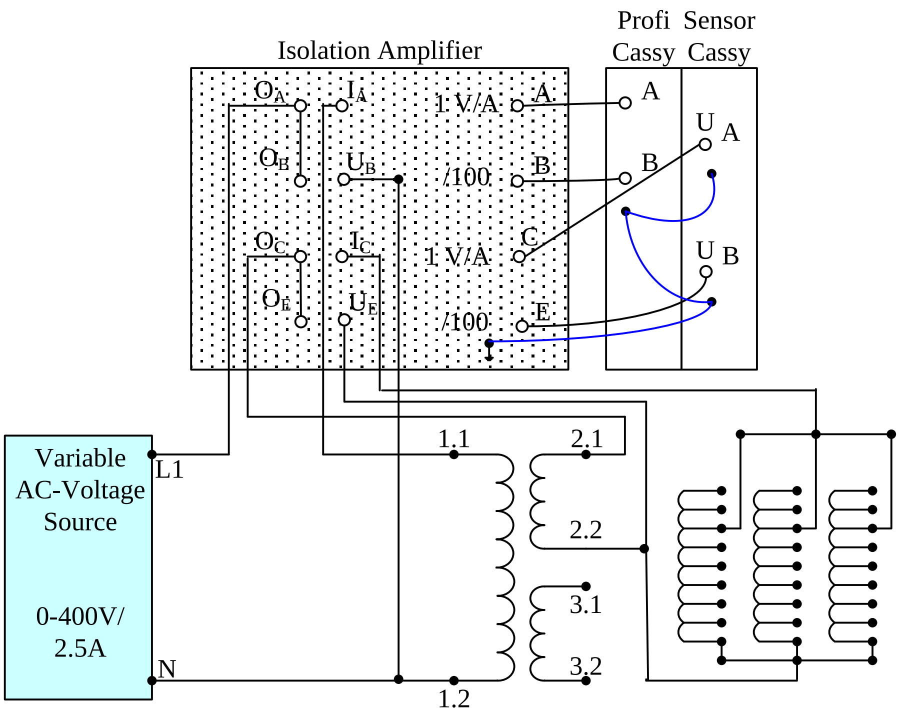


Figure 5 Circuit for investigating voltage behavior with inductive load

32. Set the transformer powering the circuit for 230V and maintain this value during the measurement.
33. First measure no-load voltage in the secondary side.
34. Take measurements for secondary current and secondary voltage with inductive loads set to the values prescribed by Table 2.
35. Perform the measurement expeditiously, particularly when small inductive load values are used, as these cause a rather high current load! **Furthermore, the circuit's supply voltage should be turned off prior to making each change to the inductive load. This is done to prevent large voltage surges when the secondary circuit is opened.**

Table 2 Voltage behavior for an inductively loaded single-phase transformer

$L_{indiv.}$ / H	6.0	4.8	2.4	1.2	1.0
L_{total} / H	2.0	1.6	0.8	0.4	0.333

I_2 / A					
V_2 / V					

36. Replace the inductive load with a capacitive load as shown in Fig. 6 and then repeat the above measurement series appropriately for values of capacitive load as specified in Table 3. These values of capacitance are to be created by connecting appropriate capacitors together in parallel. Begin the measurements with no-load on the secondary side and maintain a supply voltage of 230V.

37. **The circuit's supply voltage should be turned off prior to making each change to the capacitive load. This is done to prevent large voltage surges when the secondary circuit is opened.**

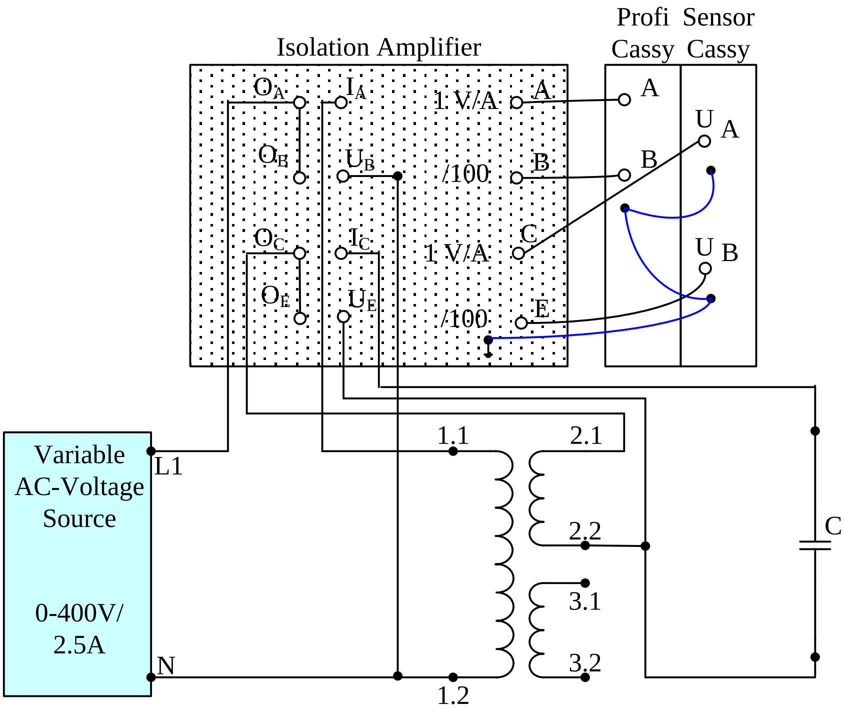


Figure 6 Circuit for investigating voltage behavior with capacitive load

Table 3 Voltage behavior for a capacitively loaded single-phase transformer

C / µF	4	8	12	16	20
I_2 / A					
V_2 / V					

What characteristic differences does a transformer exhibit as load current is increased when it is connected to a resistive, inductive, or capacitive load?

Report

After the measurements have been taken, calculate the effective power on the Effective power on the secondary side with the equation

$$P_2 = V_2 \cdot I_2 \cdot \cos\varphi_2$$

From the results are taken, derive a value for efficiency with

$$\eta = 100 \times \frac{P_2}{P_1}$$

The voltage regulation VR:

$$VR = 100 \times \frac{V_{NL} - V_L}{V_{NL}}$$

And complete the Table 1. Be careful about the current handling capabilities of the secondary winding!

Table 1 Voltage behavior and Efficiency for a Resistively Loaded Single-Phase Transformer.

	Measured							Calculated		
R/%	V_1	I_1	$\cos\varphi_1$	V_2	I_2	$\cos\varphi_2$	P_1	P_2	η%	VR%

1. Calculate R_c, X_m, R_{eq} and X_{eq} from the open circuit and short circuit tests.
2. Calculate the output power P_2, efficiency, and voltage regulation VR from your test results.
3. Plot efficiency, output voltage V_2, and VR as function of load current I_2.
4. Verify the maximum efficiency condition based on your measurement.
5. Plot a single graph containing the measured voltage output V_2 for inductive and capacitive load as a function of the output load current I_2.

EXPERIMENT # 5:	THREE PHASE TRANSFORMERS

<u>Objectives:</u>

1. To learn how to connect a three phase transformer in various types of circuits (connection symbols) and then determining their prospective values for voltage transformation and current transformation.
2. To investigate the behavior of the transformer when connected in various connection symbols to balanced load.

<u>Apparatus:</u>

- 1 three-phase transformer.
- 3-phase AC source voltage 400/2.5A.
- 1 resistive load.
- 1 set of 10 safety connectors, black.
- 1 set of 10 safety connectors, green/yellow.
- 1 set of 32 safety experiment cables.
- 1 set of 10 safety experiment cables, green/yellow
- 1 four channel isolation amplifier.
- 3 Multi meters.
- Isolation Amplifier, Profi-CASSY unit, Sensor-CASSY unit, and PC.

Theory :

In a Y-connection, the line and the phase quantities are related by:

$V_p = V_L/\sqrt{3}$ (1)

$I_p = I_L$ (2)

Whereas the relationships for a delta connection are

$I_p = I_L/\sqrt{3}$ (3)

$V_p=V_L$ (4)

The real and reactive powers for a 3 Φ circuit (either Y or Δ connection) are given as

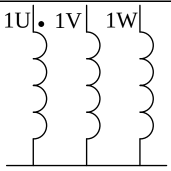
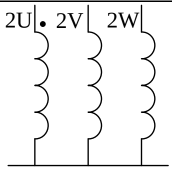
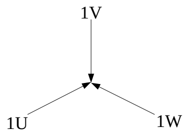
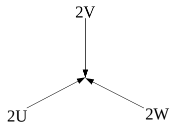
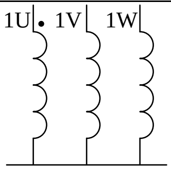
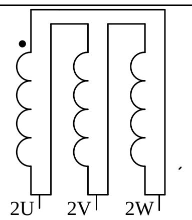
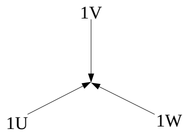
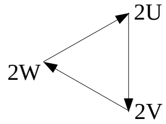
$P=\sqrt{3}\ V_L\ I_L \cos\theta$ (5)

$Q=\sqrt{3}\ V_L\ I_L \sin\theta$ (6)

Where θ is the power factor angle of the balanced load

The most frequently used connection symbols for three-phase transformers and their respective voltage transformation ratios are presented in Table 1.

Table 1 conventional connection symbols for three-phase transformers and their respective phase-to-phase transformation ratios. The dot in the schematic symbols indicated the respective winding's line end.

Connection Symbol	Schematic Symbol		Phasor Diagram		Transformation Ratio $\frac{V_1}{V_2}$
	Side 1	Side 2	Side 1	Side 2	
Y-Y					$\frac{N_1}{N_2}$ $N_1=876$ $N_2=266$
Y-Δ					$\frac{\sqrt{3}N_1}{N_2}$

Procedure:

A: Transformer in Y –Y Connection with Resistive Load

1. Connect the circuit as shown in Fig. 1, whereby only one secondary winding is needed.

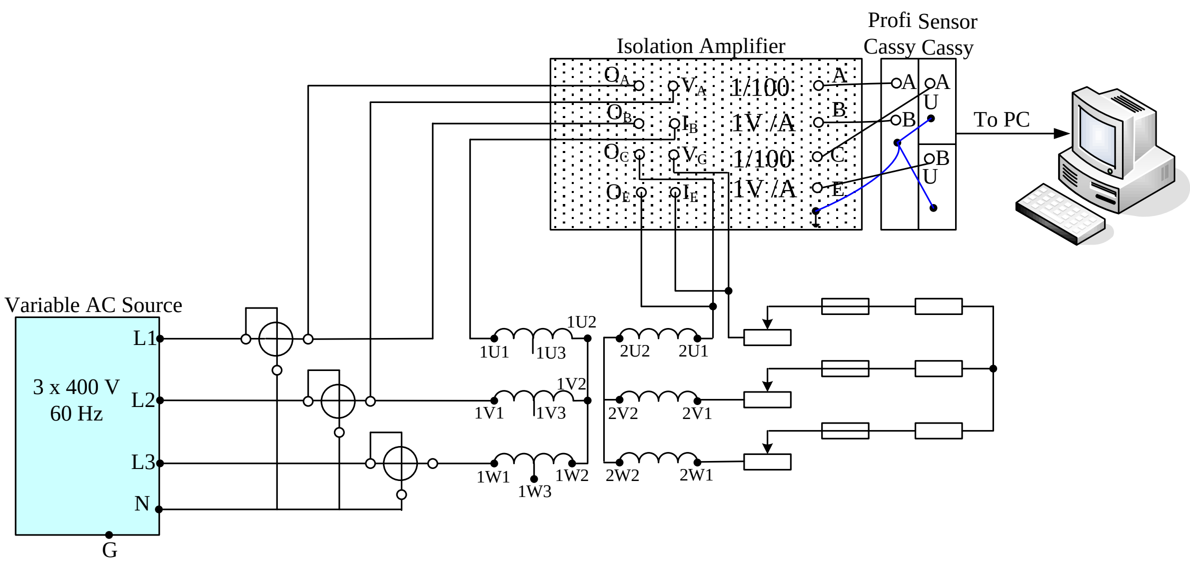


Figure 1 Circuit for investigating the three-phase transformer in Y-Y circuit

NOTE: Any time you are using the isolation amplifier channel for current measurement, you should set the Range Selection Switch to "1 V/A"; and in the case you are using the isolation amplifier channel for voltage measurement, you should set the Range Selection Switch to "/100".

2. From the PC, run the CASSY lab Software.
3. From the “Profi-CASSY”, define channel A (UA1), Channel B (UB1).
4. From the "Sensor-CASSY", define channel A (UA2) & Channel B (UB2)
5. Select “RMS” value option for UA1, UB1, UA2, & UB2.
6. Double click on **Tool Box Button**, change the sampling rate to 100 μs and then close the window menu. Select triggering UA1 as rising edge.
7. Click on **Tool Box Button** and from “**Parameter/Formula/FFT**” option, use new quantity to define V_{abp} as UA1*100 from the formula option. Accordingly adjust the symbol, unit, range etc.
8. Repeat above step to define I_{ap} as UB1, V_{abs} as UA2*100, and I_{as} as UB2.
9. From the “**Display**” option, select X-axis as the time and V_{abp}, I_{ap}, V_{abs} and I_{as} as Y-axis. Switch off all other signals. You can be able to see the line voltages simultaneously with respect to time.
10. After you finish connecting the circuit please ask your instructor to check your connections.
11. Make sure the load resistance is at 100% and the power supply nope is at 0 V.
12. Turn the power supply ON.
13. Apply nominal voltage to the test object's primary and simultaneously display the primary and secondary voltages.
14. Reduce the load resistance until you read I_{2N} = 1.52A. (Hint: 3% of R)
15. Records all RMS voltages and currents from primary and secondary sides.

16. Display the phase shift between the primary and secondary voltages, primary and secondary currents, and voltage and current on the primary and voltage and current on secondary by the time delay between their zero crossover points.
17. Save all waveforms in different files.
18. After you finish, return load resistance back to 100% and then reduce the voltage supply to 0 V.

B: Transformer in Y-Δ Connection with Resistive Load

19. Set up the experimental circuit as shown in Fig. 2 where only one secondary winding is needed.

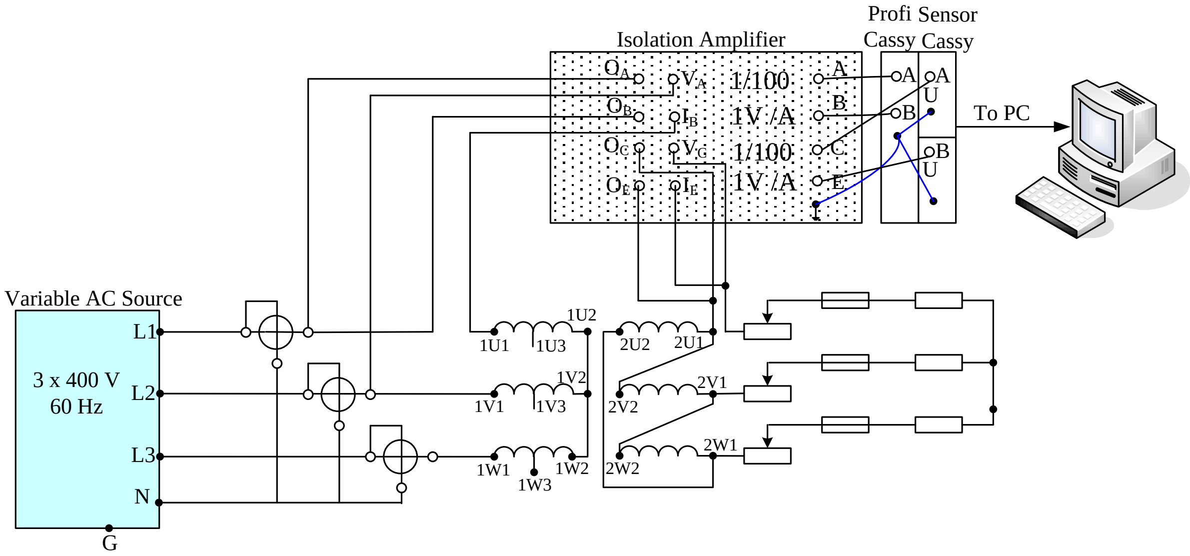


Figure 2 Circuit for investigating the three-phase transformer in a Y-Δ circuit

NOTE: Any time you are using the isolation amplifier channel for current measurement, you should set the Range Selection Switch to "1 V/A"; and in the case you are using the isolation amplifier channel for voltage measurement, you should set the Range Selection Switch to "/100".

20 Repeat steps 2-18.

21 Note that in Y-Δ connection case, the secondary current will be less than 0.9 A for the same load resistance is used in Y-Y connection.

<u>IMPOERTANT NOTICE:</u>

PLEASE DISCONNET YOUR CIRCUIT & HANG UP ALL WIRES IN THE PROPER LOCARION. ANY GROUP FAIL TO DO SO WILL LOSE 30% FROM THEIR LAB GRADE.

<u>Report</u>

1. Records waveforms, rms voltages, rms currents, P, Q, and PF and tabulate them.
2. Calculate the turn ratio "a" for both measured voltages and currents and verify your measurement by comparing the results of using N1 & N2 of the three phase transformer connections.
3. Determine the phase shift for the following:
    a. between primary and secondary voltages for each case,
    b. primary and secondary currents for each case,
    c. voltage and current on the primary side for each case,
    d. voltage and current on the secondary side for each case.
4. Draw phasor diagrams showing the line and phase voltages and currents for both Y and Δ connections.
5. Verify the relationships for the phase and the line voltages and currents and state reasons for any errors.

EXPERIMENT # 6: DC GENERATOR CHARACTERISTICS

Objectives:

- To experiment the open circuit characteristics of a separately excited DC generator with the field variation at different speed.
- To study load characteristics of a DC Shunt Generator.
- To observe and record the behavior the DC Compound generator for both cumulative and differential version under loading conditions.
- To conduct a comparative study for load characteristics of all tested generators versions and to evaluate the performance of the machine.

Apparatus:

- DC generator
- DC Motor

- Variable DC Power Source 40….250V/10A
- Variable DC Field Supply 0….250V/2.5A
- Tachogenerator
- 1 Profi-Cassy
- 1 Sensor-Cassy
- 1 Isolation Amplifier, Four Channel
- 1 AC Adapter
- 1Professional Digital Multimeter
- 1 Cassy Computer Data Acquisition and processing Interface package
- 1 set of 32 safety connectors, black/blue/yellow.

Theory :

The terminal voltage of a shunt generator is written as:

$V_t = E_a - I_a R_a$ (1)

Where

$I_a = I_f + I_L$ (2)

I_f is the shunt current and

I_L is the load current

For a short shunt compound generator, the terminal equation is modified to

$$V_t = Ea - I_a R_a - I_L R_s \quad (3)$$

Where Rs is the resistance of the series winding.

Procedure:

A: Preliminary Measurements

1. First read and enter the rating plate data of the DC Generator in Table 1.

Table 1: Generator Plate Data

Nominal Voltage (V)	
Nominal Current (Armature and Series Winding) (A)	
Nominal Current field (Shunt Winding) (A)	
Nominal Speed (RPM)	
Nominal Power (W)	

2. Use the Professional Digital Multimeter to measure the Generator resistances to be entered in Table 2.

Table 2: Generator Winding Resistances

$R_{A1,A2}$	$R_{B1,B2}$	$R_{C1,C2}$	$R_{D1,D2}$	$R_{D1,D3}$	$R_{D2,D3}$	$R_{E1,E2}$	$R_{E1,E3}$	$R_{E2,E3}$

3. Read and enter the rating plate data of the DC Motor in Table 3.

Table 3: Motor Plate Data

Nominal Voltage (V)	
Nominal Current (Armature and Series Winding) (A)	
Nominal Armature Current (Shunt Winding) (A)	
Nominal Speed (RPM)	
Nominal Power (W)	

4. Use the Professional Digital Multimeter to measure the Universal Motor resistances to be entered in Table 4.

Table 4: DC Motor Winding Resistances

$R_{A1,A2}$	$R_{B1,B2}$	$R_{C1,C2}$	$R_{D1,D2}$	$R_{D1,D3}$	$R_{D2,D3}$	$R_{E1,E2}$	$R_{E1,E3}$	$R_{E2,E3}$

B: Generator Open Circuit Charactiristics

5. Connect the circuit as shown in Figure 1 using Cassy measurement Connection for the indicated field current, open circuit voltage, and rotor speed.

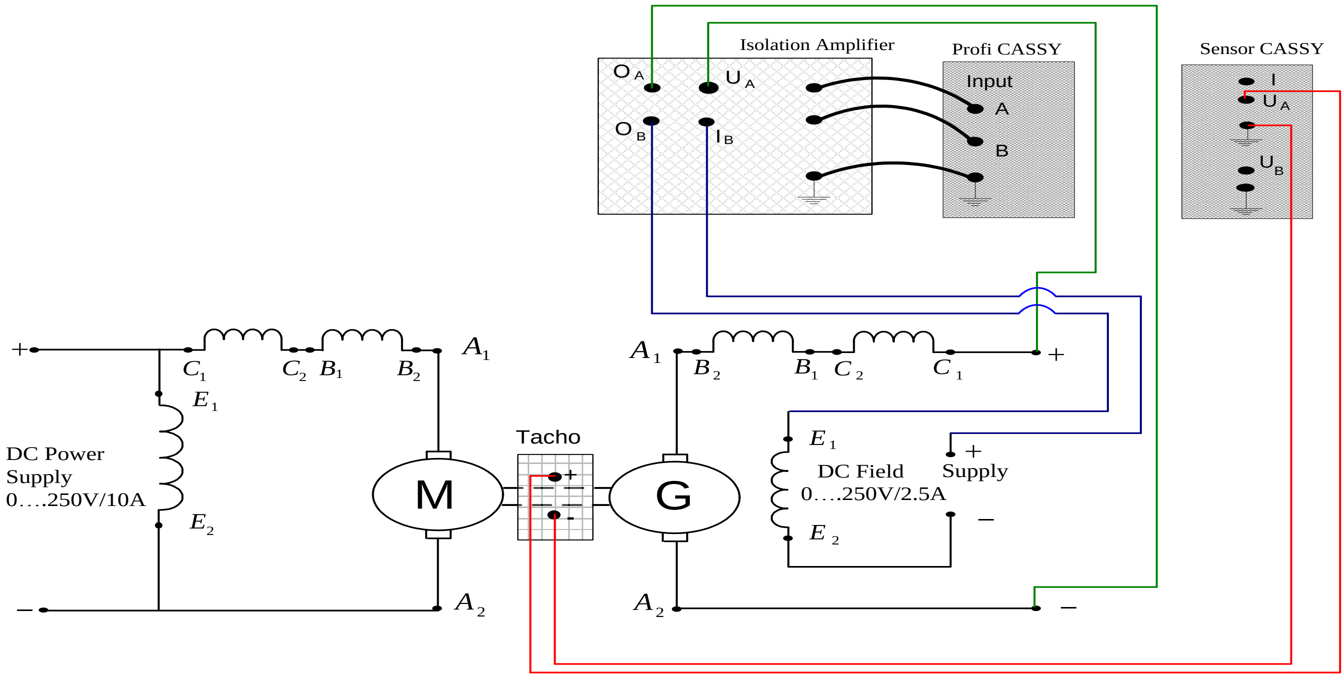


Figure 1: OCC DC Generator Set Up

6. Activate Cassy lab for Open circuit voltage as UA_1, field current as UB_1 and rotor speed as UA_2. For the quantity UA_1, UB_1, and UA_2, select the **Averaged Values** and the **Zero point left** options for the sensor input setting.

7. Adjust channel A of the Isolation Amplifier for **/100 position** and channel B for **1 V /A position**.

8. Select the **New Quantity** feature to define the no Load Voltage, as (UA_1*100 V), to define the field current as (UB_1 A) and to define rotor speed as (UA_2*1000 rpm).

9. Fix the **Manual Recording option** in Cassy lab Measurement parameters settings.

10. Go to Cassy lab **display** option and adjust it to conduct the online plotting for Open circuit voltage versus field current.

11. **Ask your instructor to check your connections and CASSY Lab settings. Do not proceed to the next stage unless your connections and settings are completely examined by the instructor.**

12. Make sure that the DC Motor power supply is OFF and the voltage control knob is at zero position

13. Make sure that the current control knob of the DC Motor power supply is set at maximum position (10 A). Gradually apply the DC Motor power supply voltage to start the motor till reaching a speed of 1400 rpm. (The student is now ready for online data recording and plotting).
14. It is required to vary the field excitation from zero till reaching a field current of 0.32 by a step of 0.02 A using the field supply voltage control. At every step the rotor speed has to be fixed at 1400 rpm by slightly adjusting the motor DC power supply voltage before taking the measurement.
15. Start the record of measurements and Conduct an online plotting of the open circuit voltage versus the field excitation current for every step (15 to 18 point).
16. Once you reach the data of a field current of 0.32 A, bring the excitation voltage and the motor DC supply voltage back to zero and save Cassy lab file. (keep the same file ON)
17. The same file of step 16 is still open, go to Cassy lab Measurement parameters settings; choose both the **Manual Recording** and **Append new Measurement Series** options.
18. Gradually apply the DC motor power supply voltage to start the motor till reaching a speed of 1700 rpm.
19. Repeat 14 and watch that at every step the rotor speed has to be fixed at 1700 rpm by slightly adjusting the motor DC power supply voltage before taking the measurement.
20. Repeat step 15 for 1700 rpm
21. Save your Cassy Lab file.
22. Reduce all source voltage to zero then turn then all OFF.

C: Separitly Excited DC Generator Load Characteristic

23. Connect the circuit as shown in Figure 2 using Cassy measurement Connection load voltage, for the load current, and for rotor speed. Note that at this stage the load resistance value has to be at 100%.
24. Open a new Cassy lab file and repeat steps 6,7,8,9.
25. Go to Cassy lab **display** option and adjust it to conduct the online plotting for **load voltage** versus **load Current**.
26. **Ask your instructor to check your connections and CASSY Lab settings. Do not proceed to the next stage unless your connections and settings are completely examined by the instructor.**
27. Disconnect the load from the circuit temporarily then apply and increase the field voltage till reaching the rated field current of 0.24 A.

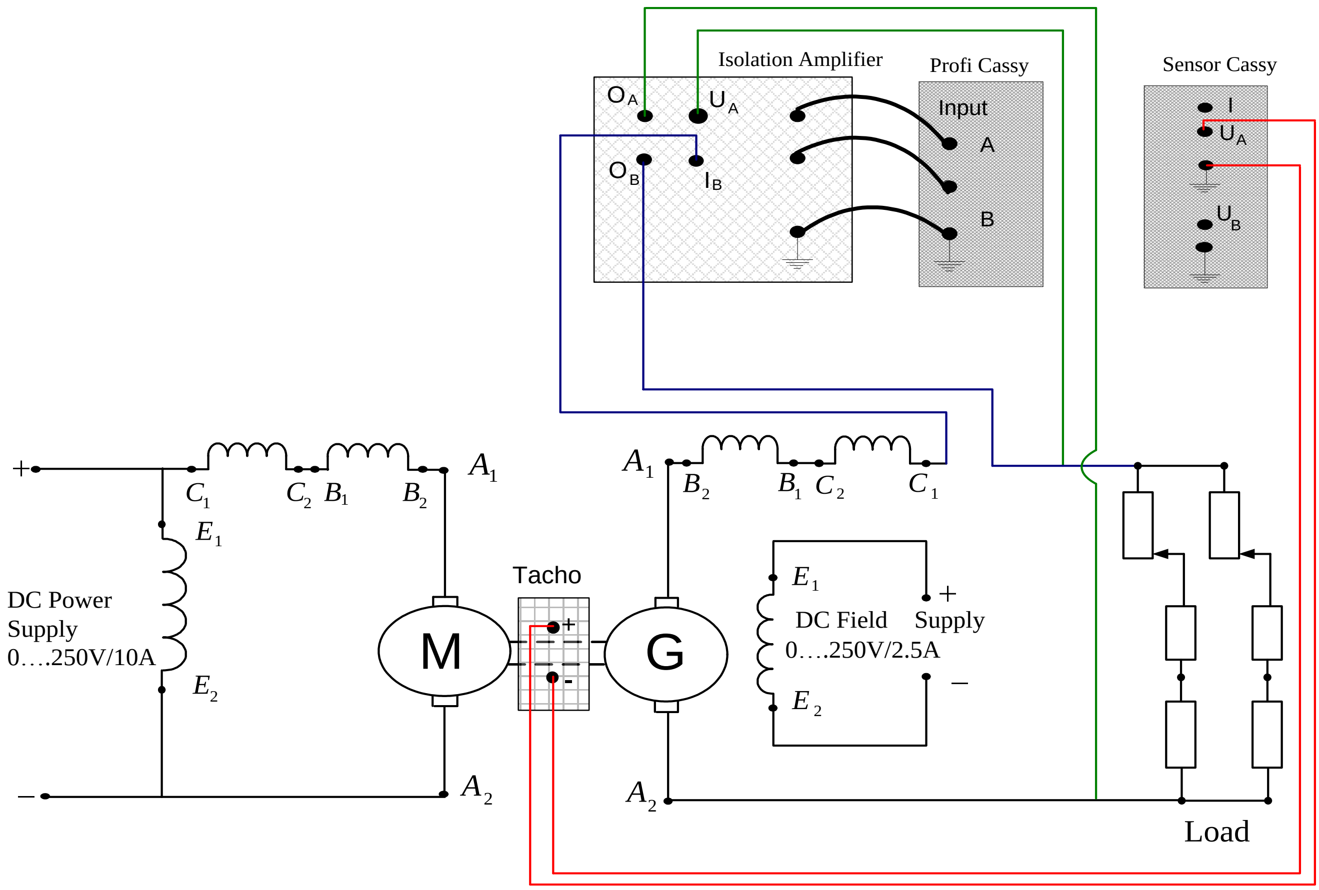


Figure 2: Set Up Load Characteristic for Separately Excited DC Generator

28. Make sure that the current control knob of the DC Motor power supply is set at maximum position (10 A) then gradually apply the DC motor power supply voltage to start the motor till reaching the rated speed of the generator (1700 rpm) and take the measurements for **no load voltage first**.
29. Carry on the measurement and data recording by varying the resistive load from **100% to 10%** in steps as follows 100%, 90%, 80%, 70%, 60%, 50%, 40%, 30%, 25 %, 20%, 15%, 10%.At every step the rotor speed has to be fixed at the rated generator speed of 1700 rpm by slightly adjusting the DC motor power supply voltage before taking the measurement.
30. **Reduce** the **DC motor** supply voltage **to zero**.
31. Switch all power supplies **OFF** and Bring the resistance rotating control back to 100%, save Cassy Lab file but do not close it.

D: Shunt DC Generator Load Characteristic

32. Connect the circuit as shown in Figure 3 using Cassy measurement Connection for load voltage, for load current, and for rotor speed. Note that at this stage the load resistance value has to be at 100%.

33. The same file of step 31 is still open, go to Cassy lab Measurement parameters settings; choose both the **Manual Recording** and **Append new Measurement Series** options.

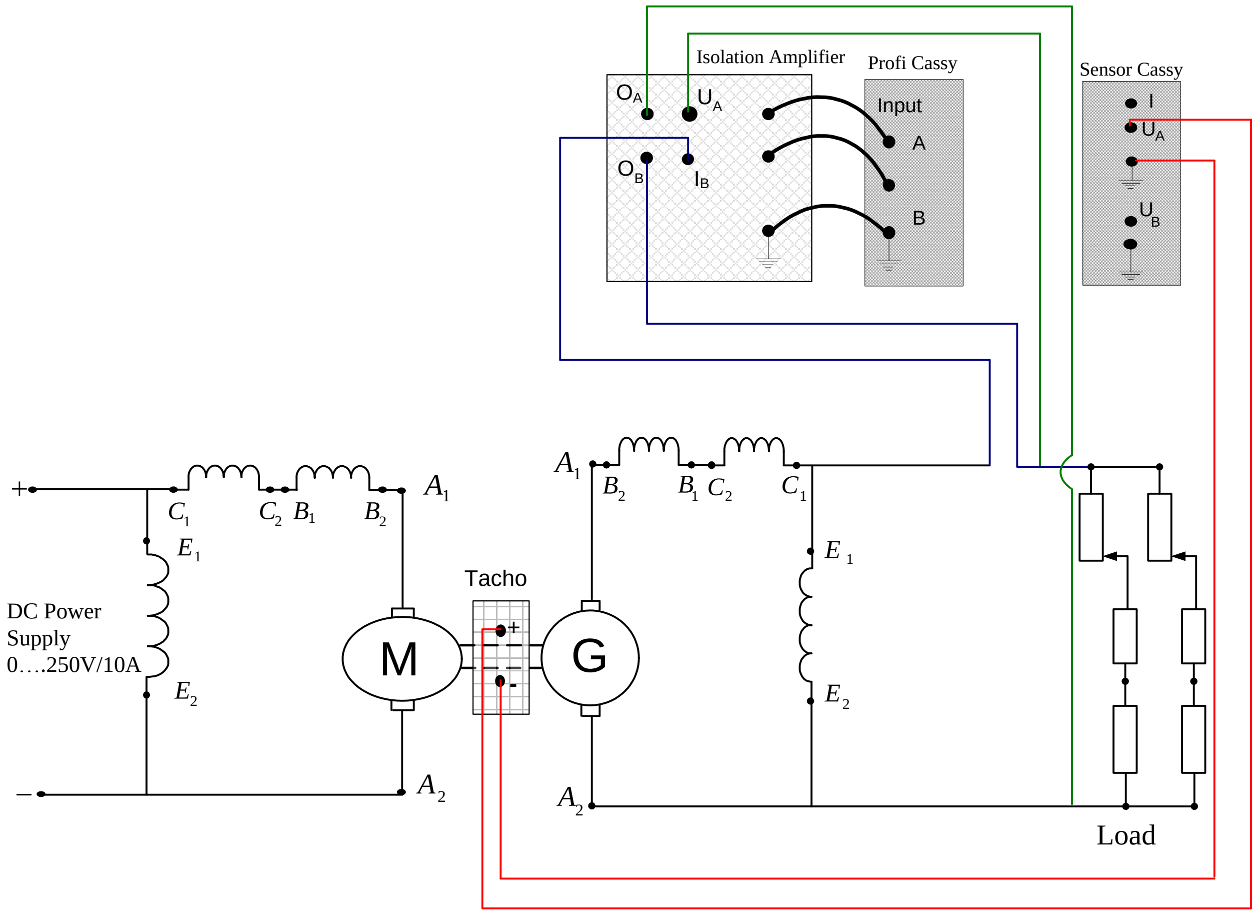


Figure 3: Load Characteristic Set Up for Shunt DC Generator

34. **Ask your instructor to check your connections and CASSY Lab settings. Do not proceed to the next stage unless your connections and settings are completely examined by the instructor.**

35. Repeat 28,29,30 and 31

E: Cumulative Compound DC Generator Load Characteristic

36. Connect the circuit as shown in Figure 4 using Cassy measurement Connection for load voltage, for load current, and for rotor speed. Note that at this stage the load resistance value has to be at 100%.

37. The same file of step 35 is still open, go to Cassy lab Measurement parameters settings; choose both the **Manual Recording** and **Append new Measurement Series** options.

38. **Ask your instructor to check your connections and CASSY Lab settings. Do not proceed to the next stage unless your connections and settings are completely examined by the instructor.**

39. Repeat the four steps of step 35.

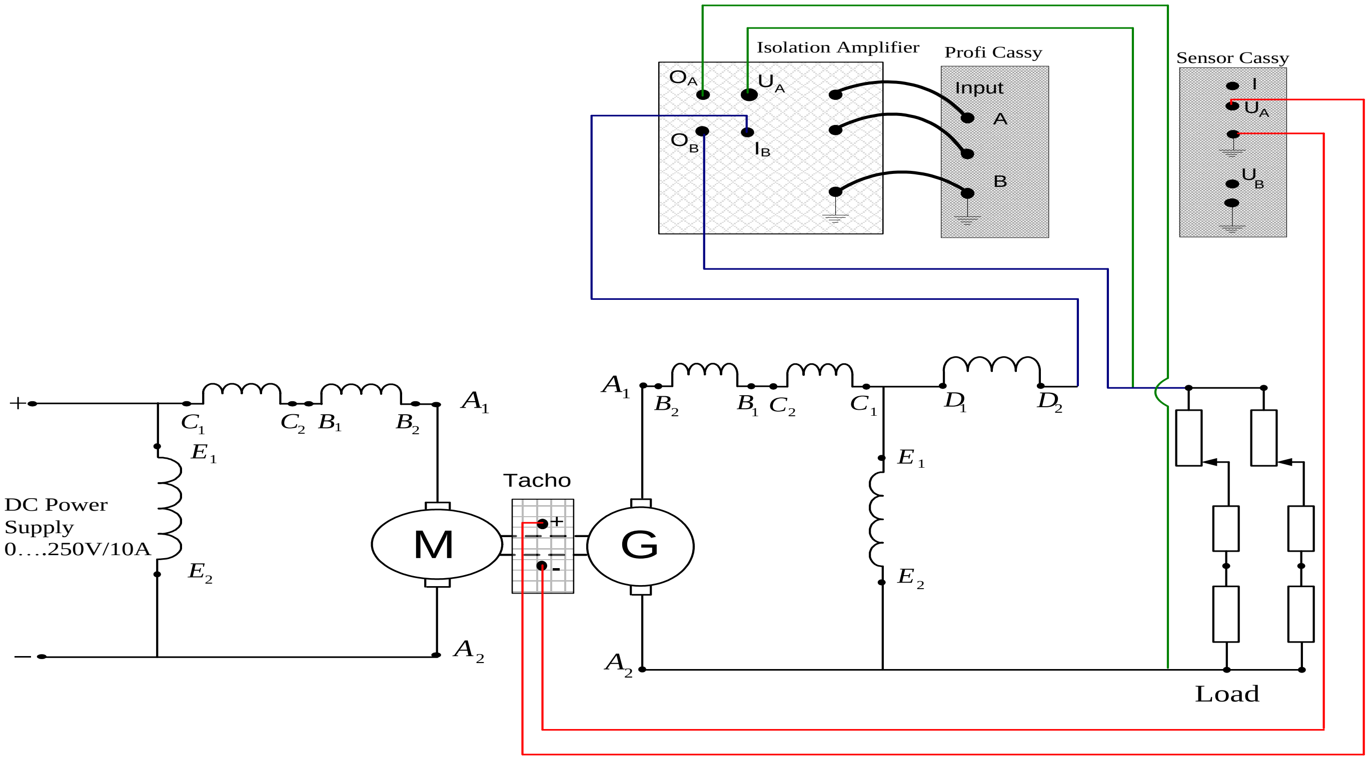


Figure 4: Cumulative Compound DC Generator Set Up

<u>F: Differential Compound DC Generator Load Characteristic</u>

40. Connect the circuit as shown in Figure 5 using Cassy measurement Connection for load voltage, for load current, and for rotor speed. Note that at this stage the load resistance value has to be at 100%.

41. The same file of step 35 is still open, go to Cassy lab Measurement parameters settings; choose both the **Manual Recording** and **Append new Measurement Series** options.

42. **Ask your instructor to check your connections and CASSY Lab settings. Do not proceed to the next stage unless your connections and settings are completely examined by the instructor.**

43. Repeat 39 but the resistance variation should stop at 30 %

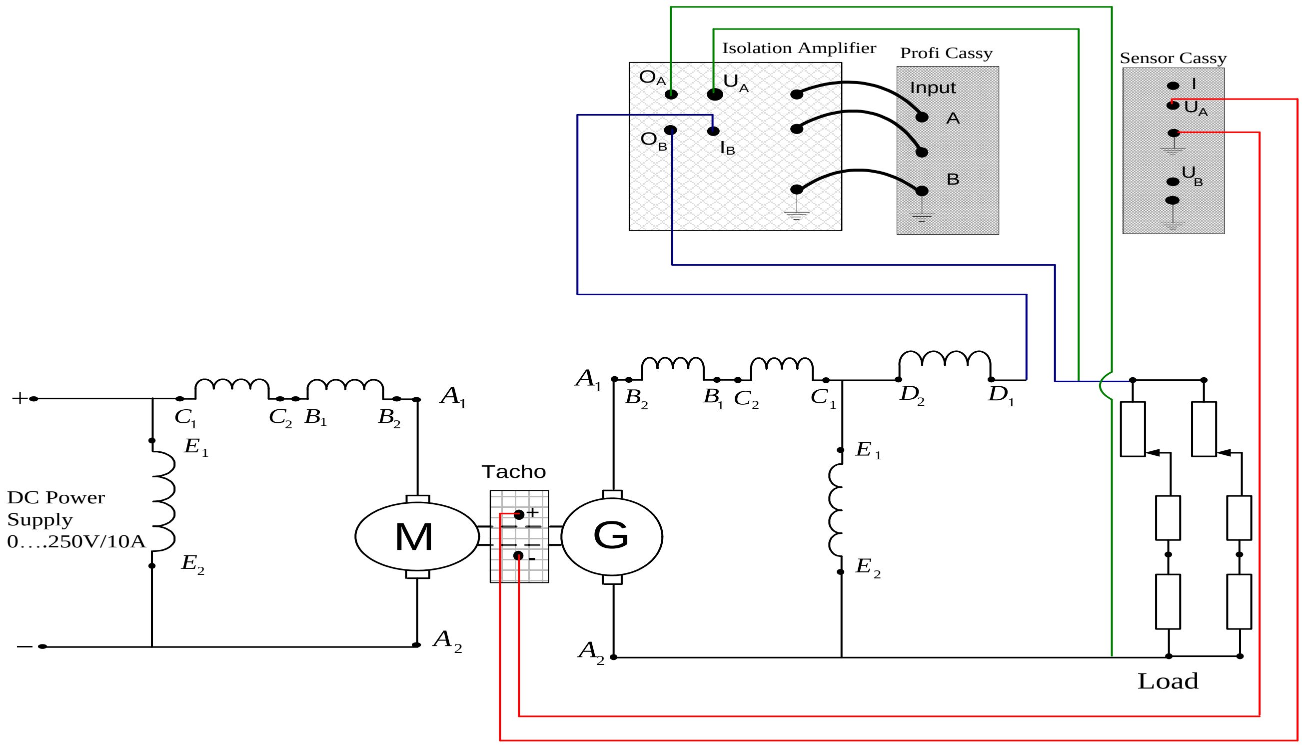


Figure 5: Differential Compound DC Generator Set Up

Report:

1. Display the recorded data of table 1, table 2, table 3, and table 4.
2. Display the appended plot of the Generator Open Circuit Characteristics; indicate the speed on each curve.
3. Use a copy of the file of step 2 Cassy file then use the available curves to deduce the OCC plot for the speed of 2040 rpm.
4. Use the Cassy lab **Fit Function** feature to find the slope of tangent to the OCC at rated speed. What information you can get out of the slope?
5. Repeat step 4 for the OCC of 1400 rpm.
6. Display the appended plot of the Generator load characteristics.
7. Use the recorded data to find the voltage regulation at rated load or close to it for the separately excited and for the compound generators.
8. Give your explanation of the sharp decline behavior of shunt load characteristics.

EXPERIMENT # 7: DC MOTORS CHARACTERISTICS

Objectives:

- To experiment the variation of speed of separately excited DC motor with the torque variation.
- To study speed versus load torque characteristics of a DC Shunt motor.
- To observe and try the behavior the DC Compound motor under loading conditions.
- To run the DC series motor case under torque variations.
- To conduct a comparative study for load characteristics of all tested motor versions evaluate the performance of the machine.

Apparatus:

- DC Motor.
- Magnetic Powder Break
- Control unit
- Variable DC Power Supply 40….250V/10A.
- Variable DC Field Supply 0….250V/2.5A.
- Tachogenerator.
- 1 Profi-Cassy.
- 1 Sensor-Cassy.
- 1 Isolation Amplifier, Four Channel.
- 1 Control Unit.
- 1 AC Adapter.
- 2 Professional Digital Multimeter.
- 1 Cassy Computer Data Acquisition and processing Interface package.

- 1 set of 32 safety connectors, black/blue/yellow.

Theory :

For DC shunt and long shunt compound motors, current and flux are related by:

$V_t = E_a + I_a R_a$ (1)

$E_a = K_a \, \omega_m \Phi$ (2)

Which gives

$$\omega_m = \frac{V_t - I_a R_a}{K_a \Phi} \quad (3)$$

Using the equation

$I_a = T_{dev} / (K_a \Phi)$ (4)

We can write

$$\omega_m = \frac{1}{K_a \Phi} V_t - \frac{R_a}{(K_a \Phi)^2} T_{dev} \quad (5)$$

Equation (5) shows the relation between torque, speed, terminal voltage and flux of the motor.

Procedure:

A: Preliminary Measurements

1. First read and enter the rating plate data of the DC Generator in Table 1.

Table 1: Motor Plate Data

Nominal Voltage (V)	
Nominal Current (Armature and Series Winding) (A)	
Nominal Armature Current (Shunt Winding) (A)	
Nominal Speed (RPM)	

Nominal Power (W)	

2. Then use the Professional Digital Multimeter to measure the machine resistances and enter it in Table 2.

Table 2: Motor Winding Resistances

$R_{A1,A2}(\Omega)$	$R_{B1,B2}(\Omega)$	$R_{C1,C2}(\Omega)$	$R_{D1,D2}(\Omega)$	$R_{D1,D3}(\Omega)$	$R_{D2,D3}(\Omega)$	$R_{E1,E2}(\Omega)$	$R_{E1,E3}(\Omega)$	$R_{E2,E3}(\Omega)$

B: Separately excited DC Motor

3. Connect the circuit as shown in Figure 1 using Cassy measurement Connection for the indicated armature current, applied voltage, rotor speed and applied torque. For the Control Unit setting, do the following:
   i. Set the torque scale to 10 which gives maximum torque of 10 N.m.
   ii. Select the manual control mode of the load, i.e., set the load to "MAN/EXT" mode at position 1.
   iii. Set n_{min}% to 20. This will prevent the motor speed to drop below 20% of the rpm of the speed scale.
   iv. Set M_{max} % to 60. This will limit the maximum torque to 60% of 10 Nm, i.e., 6 N.m.
   v. Connect the motor thermal protection to the "TEMP. ALARM" in Control Unit.

4. Activate Cassy lab for applied voltage as UA_1, armature current as UB_1, rotor speed as UA_2, and the load torque as UB2.

5. Select the **Averaged Values** and the **Zero point left** options for the sensor input setting for the four parameters.

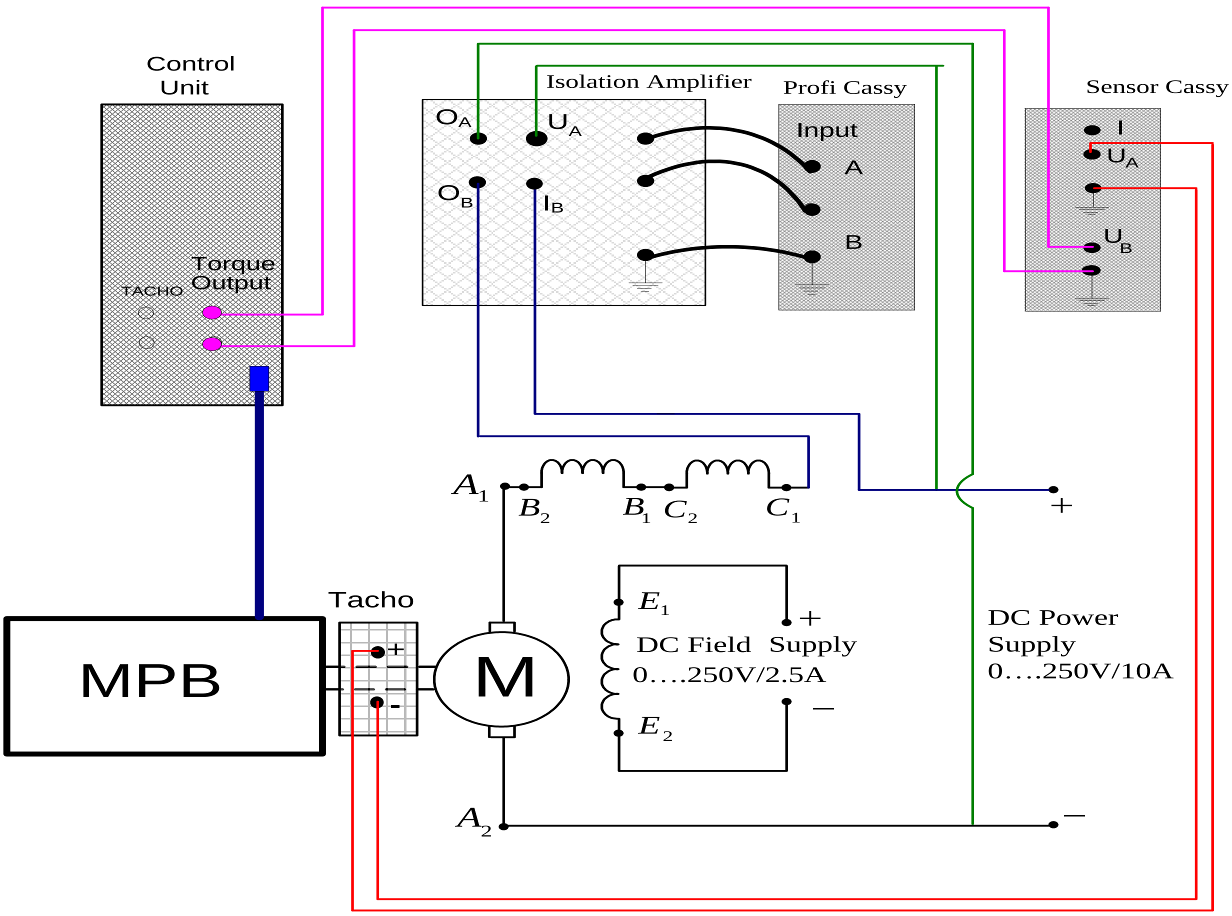


Figure 1: Separately Excited Motor Sep Up

6. Select the **New Quantity** feature to define the applied Voltage, as (UA_1*100 V), to define the armature current as (UB_1 A) and to define rotor speed as (UA_2*1000 rpm) then to define the applied torque as (UB_2 N.m).
7. Fix the **Manual Recording option** in Cassy lab Measurement parameters settings.
8. Go to Cassy lab **display** option and adjust it to conduct the online plotting for Motor speed versus applied torque.

9. **Ask your instructor to check your connections and CASSY Lab settings. Do not proceed to the next stage unless your connections and settings are completely examined by the instructor.**

10. Make sure that the both DC supplies are OFF and their voltage control knobs are at zero position.
11. Gradually apply the DC field supply voltage till reaching the rated field current (0.24 A).

12. Gradually apply the DC Motor power supply voltage to start the motor till reaching a speed of 2100 rpm. The student is now ready for online data recording and plotting.

13. Vary the applied torque using the manual option of the control block from 0 N.m by a step of 0.25 N.m till reaching the torque that cause the rated armature current of 4.8 A.

14. Record and Conduct an online plotting of the motor speed versus the applied torque excitation step (12 to 15 points).

15. Bring the applied torque, the DC field voltage and the motor DC power supply back to zero and save Cassy lab file. Keep the same file ON

C: Shunt DC Motor

16. Connect the circuit as shown in Figure 2 using Cassy measurement Connection for the indicated source current, applied voltage, rotor speed and applied torque

17. Go to Cassy lab Measurement parameters settings; choose both the **Manual Recording** and **Append new Measurement Series** options.
18. **Ask your instructor to check your connections and CASSY Lab settings. Do not proceed to the next stage unless your connections and settings are completely examined by the instructor.**
19. Repeat 10, 12, 13, and 14.

20. Bring the applied torque, the motor DC power supply back to zero and save Cassy lab file. Keep the same file ON.

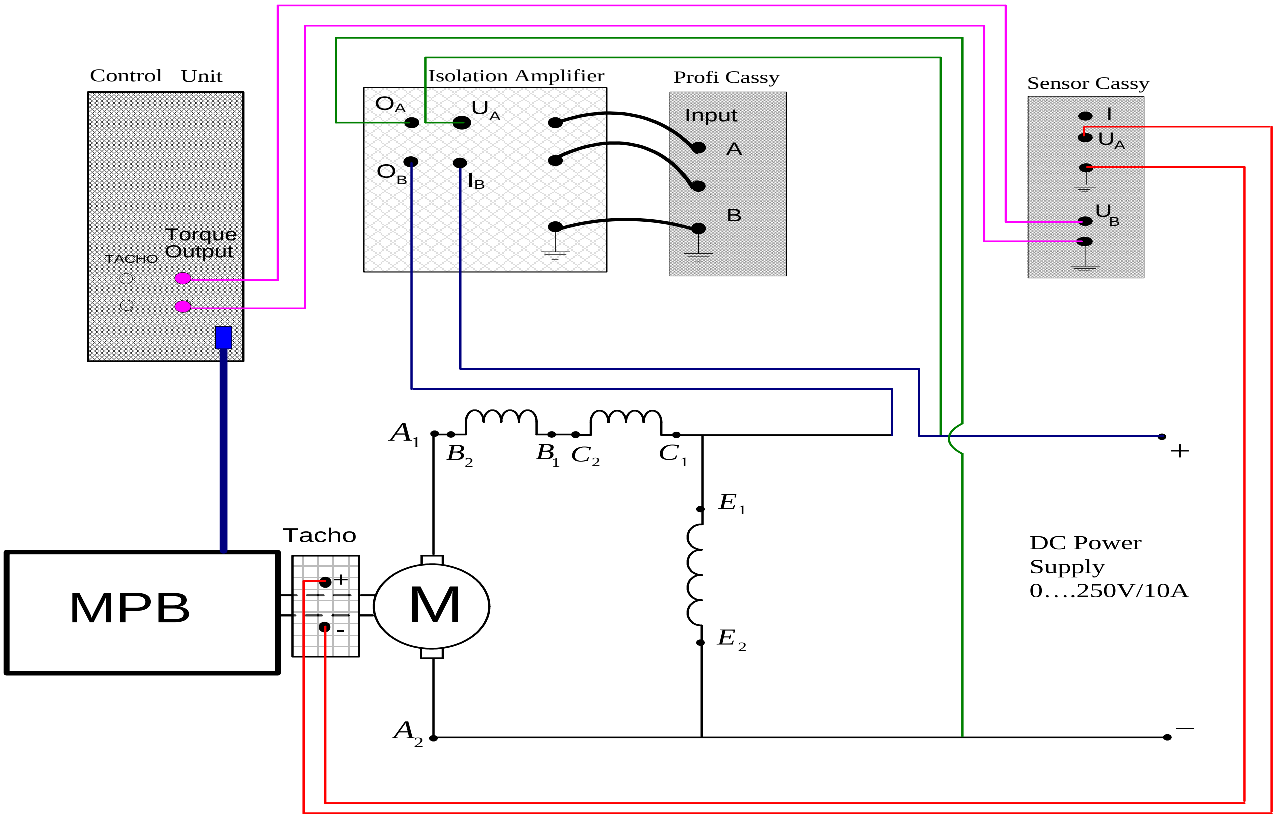


Figure 2: Shunt DC Motor Sep Up

D: Cumulative Compound DC Motor

21. Connect the circuit as shown in Figure 3 using Cassy measurement Connection for the indicated source current, applied voltage, rotor speed and applied torque

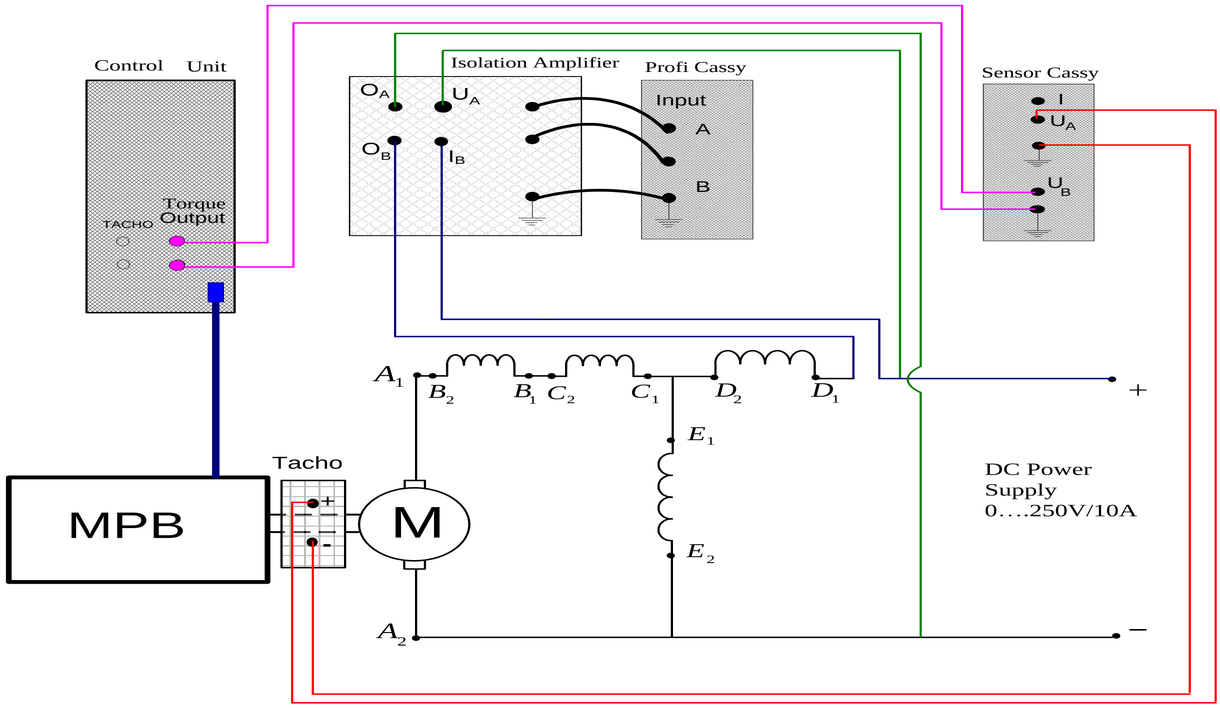


Figure 3: Cumulative Compound Motor Sep Up (D_1-D_2)

22. Repeat 17, 18, 19 and 20.
23. Replace D_1-D_2 connection of figure 3 by D_3-D_2 as shown in Figure 4.

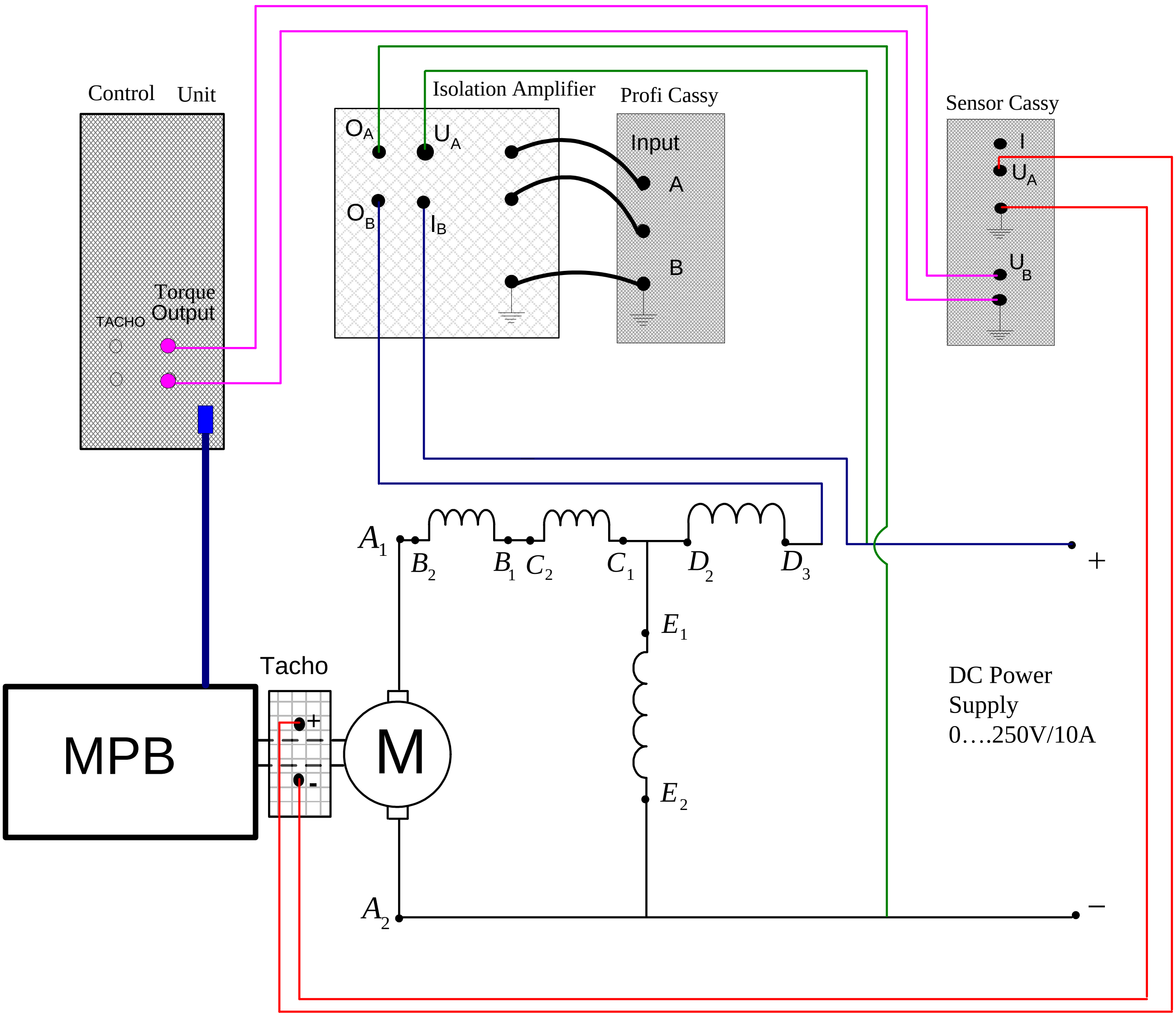


Figure 4: Cumulative Compound Motor Sep Up (D_3-D_2)

24. Repeat 22.

<u>E: Series DC Motor</u>

25. Connect the circuit as shown in Figure 5 using Cassy measurement Connection for the indicated armature current, applied voltage, rotor speed and applied torque.

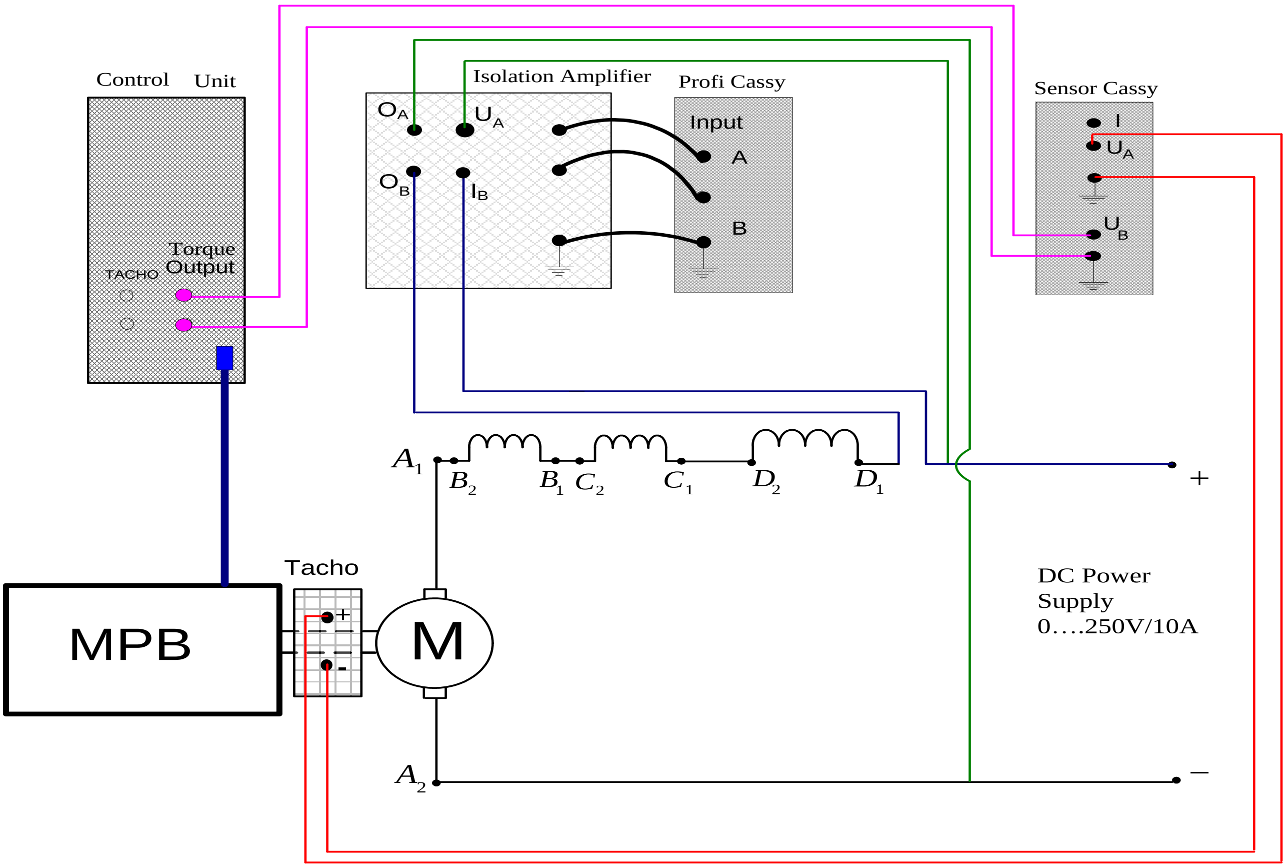


Figure 5: Series DC Motor Sep Up (D_1-D_2).

26. Go to Cassy lab Measurement parameters settings; choose both the **Manual Recording** and **Append new Measurement Series** options.

27. **Ask your instructor to check your connections and CASSY Lab settings. Do not proceed to the next stage unless your connections and settings are completely examined by the instructor.**

28. Gradually Apply **50 V** to start the motor and increase the applied torque gradually to reduce the speed below 2000 rpm.

29. Gradually increase the applied voltage from 50 to 225 V by a step of 25 V with a **simultaneous increase of the Apply torque to keep the speed below or equal to 2000 rpm**. **The applied torque should not exceed 5 N.m.** The student is now ready to take the online measurement.

30. Start the reduction of the applied torque from the value of 5 N.m by a step of 0.3 N.m till the speed reaches **3500 rpm.** Plot the speed versus the applied torque. Watch out, while reducing the toque at every step, the increases rapidly.
31. Bring the motor DC power supply back to zero, the applied torque back to zero and save Cassy lab file. Put all supplies OFF. Save your cassy lab files in your USB removable hard drive.

<u>Report:</u>

1. Display the recorded data of table 1, table 2.
2. Display the appended plot of the recorded of the Generator Open Circuit characteristics.
3. Use the recorded data to find the speed regulation at rated load for separately excited, shunt machine, compound (D_1-D_2), and compound (D_3-D_2).
4. Give your physical explanation in text format to the behavior of compound (D_1-D_2), and compound (D_3-D_2) load characteristics.
5. What is the reason behind the sharp increase of the motor speed when the load decreases?
6. Use the **Parameters/Formula** and **Display** Cassy Lab features to plot the motor **efficiency** in percent versus the applied torque, and then order them. Give your comment on the performance each motor relative the industrial applications.

EXPERIMENT # 8:	**DETERMINATION OF PARAMETERS OF THREE PHASE SYNCHRONOUS GENERATORS**

Objectives:

- To read and understand the ratings present on the name plate of the multifunction DC motor and AC generator.
- To run the multifunction AC machine as synchronous generator.
- To get the open circuit and short circuit characteristics of synchronous generator.
- To determine its synchronous impedance, synchronous reactance and armature resistance.

Apparatus:

- 1 Variable AC power supply 0- 400V / 2.5A.
- 1 AC multifunction machine
- 1 DC multifunction machine
- 1 DC supply, 40-250 / 10 A V
- 1 DC supply , 0-250 V / 2.5 A
- 1 AC Ammeter, 0 – 10 A
- 1 AC Voltmeter, 0 – 400 V
- 1 Tacho generator
- 1 Variable Resistance (Rheostat)
- 2 Couplings with coupling guards
- 3 Shaft end guards
- 1 Control unit
- Isolation Amplifier, CASSY unit, Profi- CASSY unit and PC
- Sufficient quantity of safety cables

Theory:

For a certain excitation, the synchronous impedance per phase of a synchronous machine can be calculated as

$$\mathbf{Z_s = E_a / I_a} \qquad (1)$$

Where

E_a is the open circuit per phase voltage and I_a is the short circuit current.

The synchronous reactance then can be calculated as

$$X_s = \sqrt{Z_s^2 - R_a^2} \qquad (2)$$

Where R_a is considered as 1.5 times the armature DC resistance, $R_{DC,}$ given as

$$R_{DC} = \frac{V_{DC}}{2.I_{DC}} \qquad (3)$$

X_s is the saturated reactance when E_a is taken from the open circuit characteristics and I_a is the corresponding short circuit current for the same excitation current I_f.

For a certain load current I_a, the internal voltage per phase can be written as

$$E_a = V_t + I_a(R_s + j X_s) \qquad (4)$$

Where,

V_t is the terminal voltage per phase. Note, I_a is a complex number

The voltage regulation of the generator at the rated load is given as:

$$VR = \frac{(V_{NL} - V_{FL})}{V_{FL}} \, x \; 100\,\% \qquad (5)$$

Where,

$V_{NL} = E_a$

and $V_{FL} = V_t\,(rated)$

Therefore in order to find the parameters of the synchronous generator, three tests are required to run

1) Open circuit or no load test
2) Short Circuit test
3) DC resistance test

Procedure:

Note the rated values of current, voltage and speed of the synchronous generator as well as the motor that will drive the generator and enter it into the table 1. Please follow the following steps carefully

Table 1: Machine ratings

DC Multifunction Machine		AC Multifunction Machine	
Model No.		Model No.	
Rated Voltage		Rated Voltage	
Rated Current		Rated Current	
Rated Power		Rated Power	
Rated Speed		Rated Speed	
		Power Factor	
		Frequency	

A: Open Circuit Test Connections:

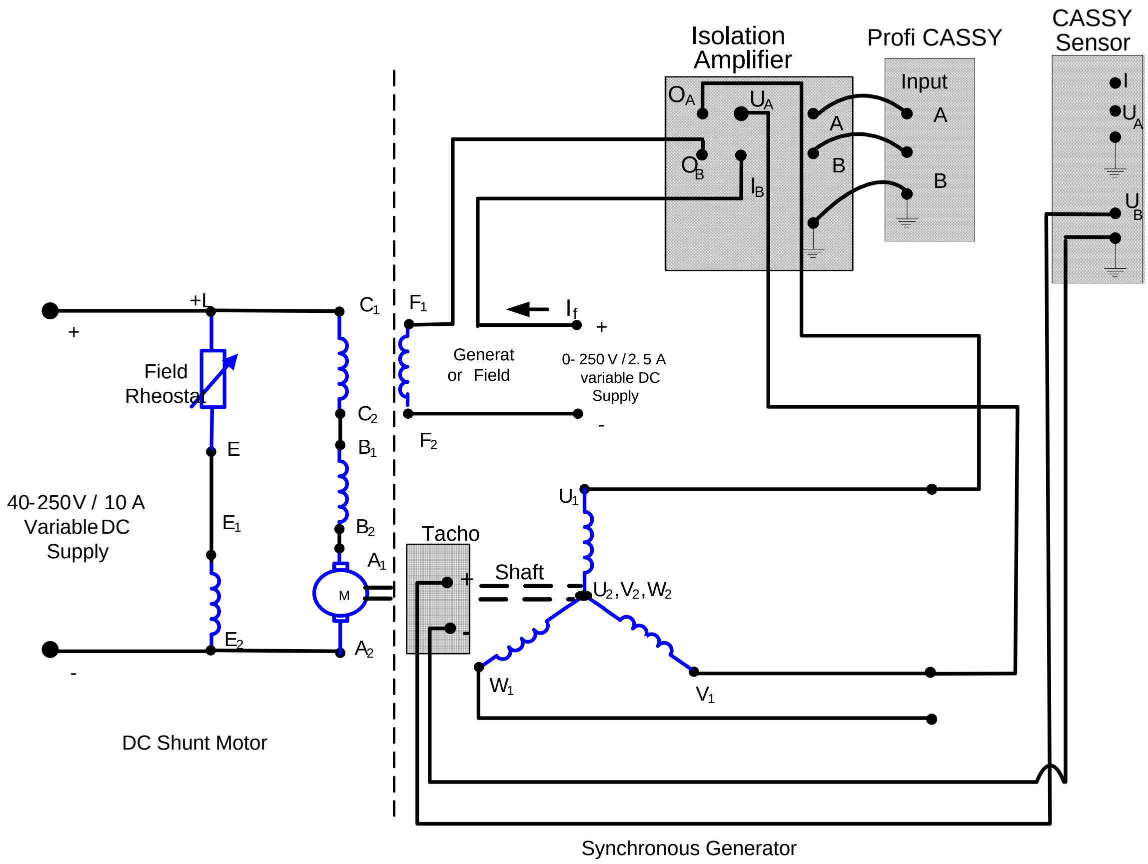


Fig. 1: Connection diagram for the open circuit test of synchronous generator

1. Connect the circuit given in Fig. 1 for running the open circuit test.
2. Connect all the "PE" or ground connections present on the motor, generator and the Tacho generator panels to the "PE "connection of the supply.
3. The CASSY is used to measure the E_a, I_f and speed, N.
4. Switch ON the Isolation Amplifier and Profi-CASSY. Note that the channel A measures the E_a and channel B measures the current I_f.
5. Adjust the scale of the channel A of isolation amplifier at "1/100" and channel B at 1 V/A settings.
6. From the PC, run the CASSY lab Software
7. From the "CASSY", activate channel UA1 and select "RMS" value option.

8. From the "CASSY", activate channel UB1 and UB2 and select "Average" value option for both the channels
9. From "Parameter / Formula / FFT" option, use new quantity to define E_a as UA1* 100 from the formula option. Accordingly adjust the symbol, unit, range etc.
10. Repeat above step to define I_f as UB1 and N as UB2*1000 respectively.
11. From the "Display" option, select I_f as x-axis and E_a as y-axis. Switch off all other signals.
12. Double click on the "setting" icon to select the measuring parameters. Select the " Manual Recording" option
13. **Ask the instructor to check your connections and CASSY lab settings. Do not proceed to next stage unless your connections and settings are completely examined by the instructor.**
14. Make sure that the motor field rheostat is set at minimum position.
15. Turn on the motor variable DC supply and gradually increase and the supply voltage till reaching the motor speed of 1800 rpm which represents the synchronous speed of the generator.
16. As the supply connected to the generator field is OFF, the generator is generating only residual voltage. Press "F9" of the computer to record this value.
17. Turn on the field supply of the generator and carefully increase I_f **very slowly** to reach E_a nearly equal to 50 V. Press "F9" again the record the value.
18. Repeat this process by increasing I_f and recording the corresponding voltage E_a until (E_a = 400 V). Adjust the speed to be kept constant at 1800 rpm at every measurement. Record all values in the computer by clicking "F9" each time. Note that the field voltage should not exceed 8

to 9 Volt and the field current should vary between 0 and 4 A. Return the field power supply to zero.

19. Observe the open circuit characteristic of the generator at the end of this part of the experiment.
20. Switch OFF the power supplies to motor and generator file.
21. Save the measurement as CASSY file.

B. Short Circuit Test Connections:

1. Connect the circuit given in Fig. 2 for running the short circuit test. Observe the difference between circuit given in Fig 1 and Fig 2.
2. To run the short circuit test, keep the windings U_1, V_1 and W_1 short. However in order to measure the short circuit current, connects the windings U1 and V1 to the O_C and I_C terminal of the isolation amplifier. Note that channel C now measures current I_a.
3. Adjust the scale of the channel C of isolation amplifier at "1 V/A ".
4. From the "CASSY", activate channel UA2 and select "RMS" value option. From "Parameter / Formula / FFT" option, define new quantity I_a as UA2 from the formula option. Accordingly adjust the symbol, unit, range etc.
5. Double click on the "setting" icon to select the measuring parameters.
6. Select the "Append New Meas. Series" recording option"
7. All other terminals and connections will remain same.
8. Ask the instructor to check your connections and CASSY lab settings. Do not proceed to next stage unless your connections and settings are completely examined by the instructor.

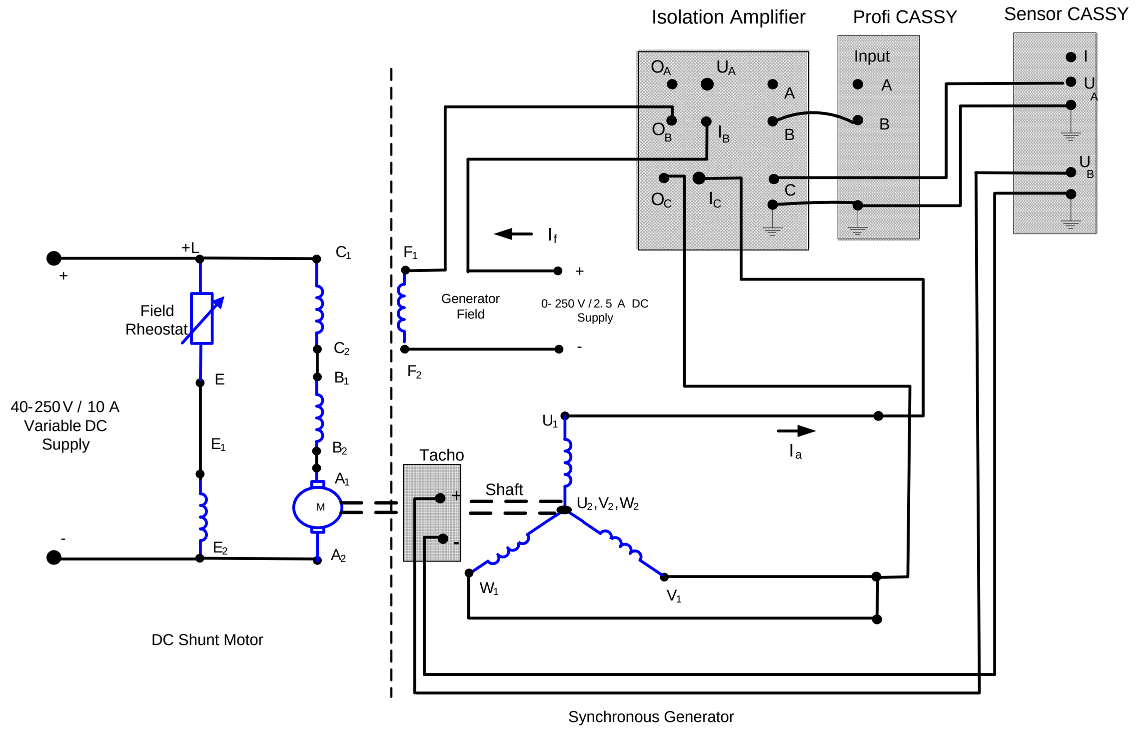


Fig. 2: Connection diagram for the short circuit test of synchronous generator

9. Make sure that all the sources are at OFF and their knobs are at the 0 readings.

10. Turn on the motor variable DC supply and adjust the DC supply and the rheostat until the speed of the motor is adjusted to 1800 RPM.

11. Press "F9" of the computer to record this value. Press "F9" again the record the value

12. Turn on the generator field supply and vary it to get I_a nearly equal to 0.1 A.

13. Repeat this process by changing the I_a in steps of 0.1 A until rated value is reached i.e. 2 A, and record it in the computer by clicking "F9" each time. Adjust the speed to be kept constant at 1800 rpm at every measurement.

14. Observe the short circuit characteristic of the generator at the end of this part of the experiment. Note that both open circuit characteristics (OCC) and short circuit characteristics (SCC) are present on the same graph.

C. DC Resistance Test:

Use Ohmmeter to measure the DC Resistance as shown in Fig. 3.

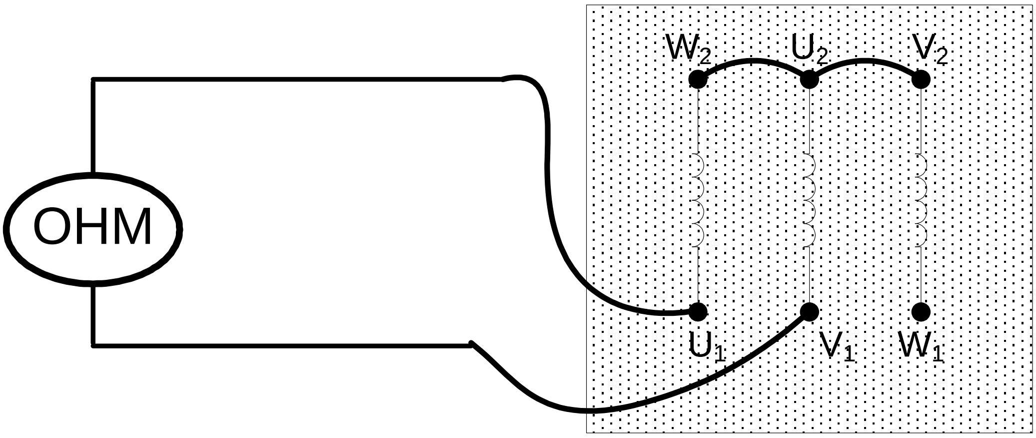


Fig. 3: Wiring diagram under No Load Test

Report:

1. Complete table 1.
2. Get the OCC and SCC characteristics of the synchronous generator and tabulate the corresponding data.
3. Right click mouse at any place on the graph window and select first "Set Marker", and then "Text". Label the two curves by OCC and SCC labels.
4. Right click mouse at any place on the graph window and select first "Set Marker", and then "Vertical Line". Draw two vertical lines, one in the linear region of the characteristics and the other in the saturation region.
5. Note the values of E_a from OCC and I_a from SCC at the intersection point of the vertical lines. Substitute these values in Equation 1 to get the value of synchronous impedance in the two regions.
6. Calculate the synchronous impedance from the values of E_a and I_a found in the linear region of the generator characteristics.
7. Comment on the results obtained in steps 3 – 5.

EXPERIMENT # 9	EQUIVALENT CIRCUIT, PERFORMANCE, AND TORQUE-SPEED CHARACTERISTICS OF 3-Φ INDUCTION MOTORS

Objectives:

- To determine the equivalent circuit parameters of a 3-Φ induction motor.
- To evaluate the performance and the efficiency of the loaded motor.
- To determine the torque-speed characteristics of the motor.

Apparatus:

- 1 kW three-phase squirrel cage induction motor.
- Three-phase variable AC supply 0…400 V / 2.5 A
- Three-phase AC supply.
- Variable DC supply 0…250 V / 2.5 A.
- 2 Professional Digital Multimeters.
- Magnetic brake
- Control unit
- Isolation Amplifier, Profi-CASSY, Sensor-CASSY, and PC
- Tachometer
- Multi Function Meter
- Couplings and coupling guards.

Theory:

Induction motor is an AC machine in which an alternating current is supplied to the stator armature windings directly and to the rotor windings by induction. Because it operates at balanced conditions, only a single phase equivalent

circuit is necessary to analyze the motor performance. Equivalent circuit of the induction motor in which the rotor parameters are referred to the stator side is shown in Fig. 1.

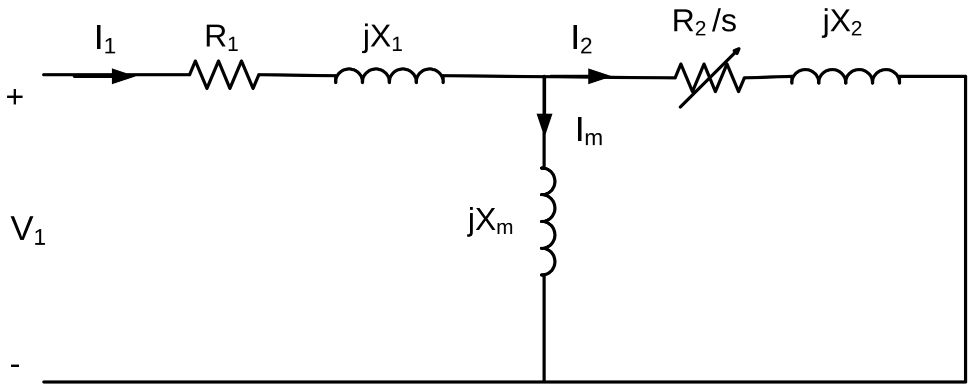


Fig. 1: Induction motor equivalent circuit

In Fig. 1,

V_1 = stator or supply voltage

I_1 = stator current

I_m = magnetizing current

I_2 = rotor current referred to stator

R_1 = stator resistance

X_1 = stator reactance

R_2 = rotor resistance referred to stator

X_2 = rotor reactance referred to stator

X_m = magnetizing reactance

s = slip

The slip of an induction motor is defined as

$$s = \frac{N_s - N_r}{N_s} \tag{1}$$

and,

$$N_s = \frac{120 * f}{p} \tag{2}$$

where

N_s = synchronous speed

N_r = rotor speed

f = supply frequency

p = number of poles

To determine the parameters of the equivalent circuit of the three-phase induction motor, it is subjected to three tests as follows.

DC Test:

In this test, a DC voltage, V_{dc}, is applied to the motor terminals as shown in Fig. 2. The resultant current, I_{dc}, is flowing in the stator. Then the stator resistance per phase can be calculated as

$$R_1 = \frac{V_{dc}}{2I_{dc}} \tag{3}$$

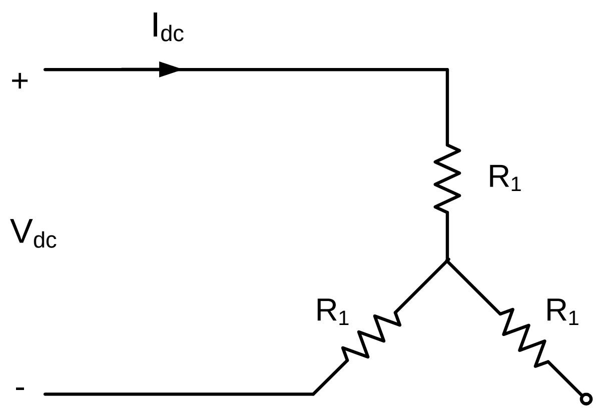


Fig. 2: Equivalent circuit under DC test

No Load Test:

Rated balanced voltage at rated frequency is applied to the stator, and the motor is allowed to run on no-load. When the machine runs on no-load, the slip is close to zero, and the equivalent circuit at the no-load test conditions is given in Fig. 3. Because of the relatively low value of rotor frequency, the rotor core loss

is practically negligible at no-load. Given the measured values of voltage V_{nl}, current I_{nl}, and power P_{nl}, the following expressions can be written.

$$P_{rotational} = P_{nl} - 3I_{nl}^2 R_1 \qquad (4)$$

$$R_{nl} = \frac{P_{nl}}{3 I_{nl}^2} = R_1 + lumped\ losses \qquad (5)$$

$$Z_{nl} = \frac{V_{nl}}{\sqrt{3}\, I_{nl}} = \sqrt{R_{nl}^2 + X_{nl}^2} \qquad (6)$$

$$X_{nl} = \sqrt{Z_{nl}^2 - R_{nl}^2} = X_1 + X_m \qquad (7)$$

$$No\ load\ power\ factor = \cos\varphi_0 = \frac{P_{nl}}{\sqrt{3}\, V_{nl} I_{nl}} \qquad (8)$$

where $P_{rotational}$ is the rotational losses.

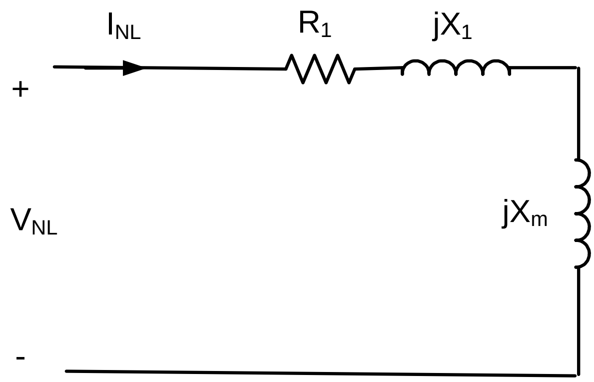


Fig. 3: Equivalent circuit under no load test

Blocked-Rotor Test:

In this test, the rotor of the induction motor is blocked. Therefore, the slip is equal to unity, and a reduced voltage value is applied to the machine stator terminals so that the rated current flows through the stator windings. The shunt branch is neglected since the magnetizing current is small due to small voltage applied. The equivalent circuit corresponding to the blocked rotor test condition

is given in Fig. 4. Given the measured values of voltage V_{bl}, current I_{bl}, and power P_{bl}, the following expressions can be written.

$$R_{bl} = \frac{P_{bl}}{3 I_{bl}^2} = R_1 + R_2 \tag{9}$$

$$Z_{bl} = \frac{V_{bl}}{\sqrt{3}\, I_{bl}} = \sqrt{R_{bl}^2 + X_{bl}^2} \tag{10}$$

$$X_{bl} = \sqrt{Z_{bl}^2 - R_{bl}^2} = X_1 + X_2 \tag{11}$$

The following assumption can be taken.

$$X_1 = X_2 = \frac{1}{2} X_{bl} \tag{12}$$

Finally, the magnetization reactance can be found from Equation (7) as

$$X_m = X_{nl} - X_1 \tag{13}$$

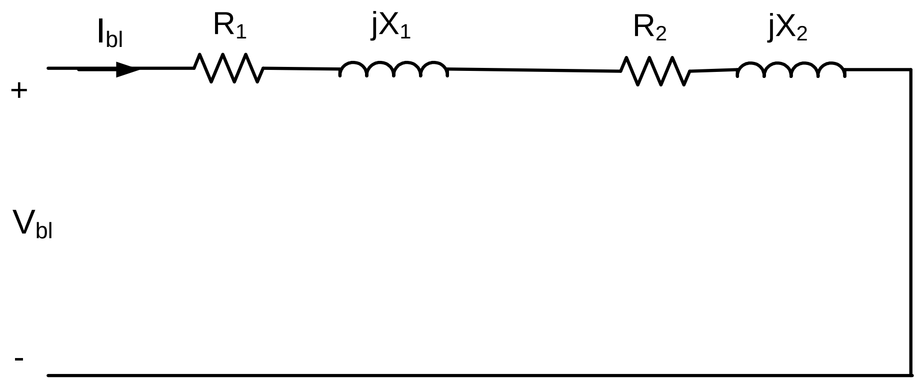


Fig. 4: Equivalent circuit under blocked rotor test

The motor performance can be evaluated by observing the motor efficiency. If the shaft torque is T (Nm) and the rotor speed is N_r (rpm), the output power P_{out} can be calculated as

$$P_{out} = T \times \omega_r \tag{14}$$

Where

$$\omega_r = \frac{2\pi N_r}{60} \cong \frac{N_r}{9.55} \quad (15)$$

Then,

$$P_{out} = \frac{T \times N_r}{9.55} \quad (16)$$

The input power P_{in} can be calculated as

$$P_{in} = 3 \times V_{ph} I_{ph} \cos\phi = \sqrt{3} \times V_L I_L \cos\phi \quad (17)$$

Then, the efficiency of the motor is calculated as

$$\eta = \frac{P_{out}}{P_{in}} \times 100\% \quad (18)$$

<u>Procedure:</u>

Please follow the following steps carefully:

<u>General Inspection</u>

1. Check the nameplate data and enter the rated specifications in Table 1.

Table 1: Nominal data

Nominal voltage when connected Y in V	
Nominal voltage when connected Δ in V	
Nominal current when connected Y in A	
Nominal current when connected Δ in A	
Nominal power factor	
Nominal speed in rpm	
Nominal power in W	

2. Using Equation (16), calculate the nominal torque based on the above data. What is the synchronous speed N_s of this motor? How many poles in the stator windings?

DC Test:

3. Set the Professional multi-meter to measure DC resistance of the stator winding.
4. Connect the circuit as shown in the wiring diagram of Fig. 5 and record the value of one single phase DC resistance
5. Switch OFF the Professional multi-meter

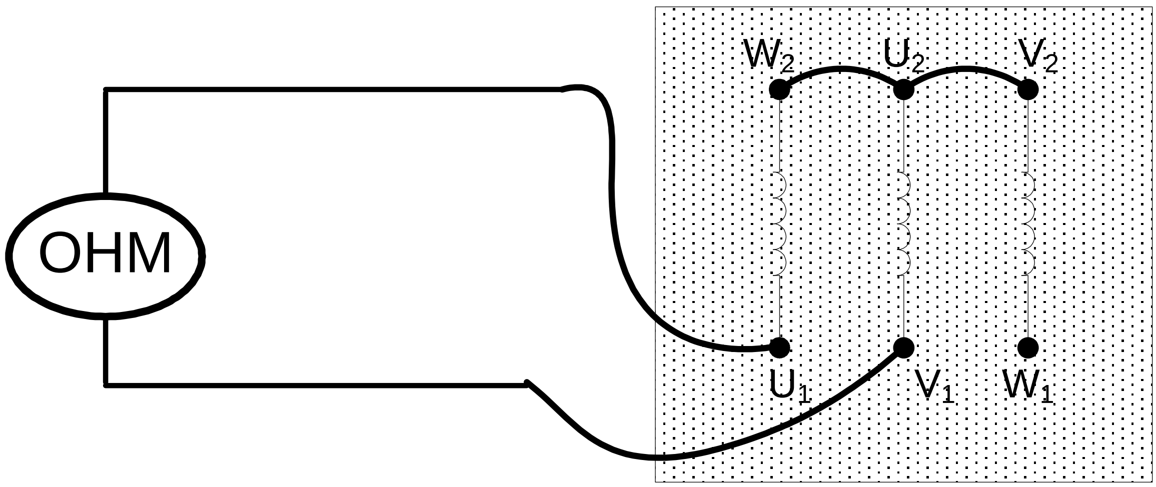


Fig. 5: Wiring diagram under DC Test

No Load Test: ohmmeter

6. Connect the motor thermal protection to the "TEMP. ALARM" in Control Unit.
7. Connect the circuit as shown in the wiring diagram of Fig. 6 to the three-phase variable AC supply 0…400 V.
8. Make sure that tachometer and the brake are disconnected from the motor shaft.

9. **Ask the instructor to check your connections. Do not proceed to the next stage unless your connections are completely examined by the instructor.**

10. Switch ON the source and increase the voltage slowly until it reaches the rated value (**400 V** L-L). Record V_{nl}, I_{nl} and P_{nl}.

11. Reduce the voltage to 0 V.

12. Switch OFF the source and keep the connections to the supply.

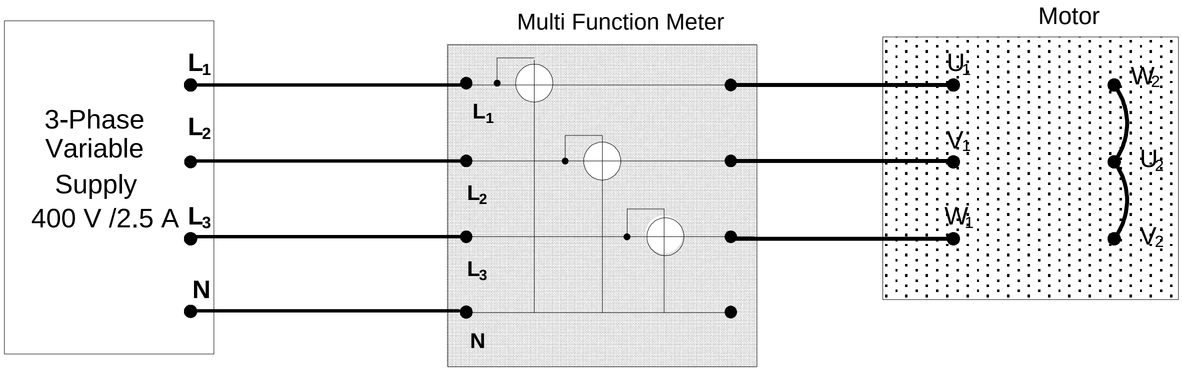


Fig. 6: Wiring diagram under No Load Test

<u>Blocked Rotor Test:</u>

13. Use the same wiring diagram shown in Fig. 6.

14. Block the rotor and prevent it completely from rotation.

15. Make sure that the source voltage at 0 V position.

16. Switch on the source and increase the voltage slowly until the current flowing in the induction motor is the rated value (**2.2 A**). Record V_{bl}, I_{bl} and P_{bl}.

17. Reduce the voltage to 0 V.

18. Switch OFF the source.

Load Test:

19. Attach the tachometer and the magnetic brake to the motor shaft.

20. Connect the circuit as shown in the wiring diagram of Fig. 7. Note that the source used in this test is constant three-phase supply. Make sure that the constant supply is OFF before starting connections.

21. Verify the following channel specifications.

Table 2: Channel specifications

Profi CASSY	channel A	Phase voltage
	channel B	Line current
Sensor CASSY	channel A	Torque
	channel B	Speed

22. In Control Unit, do the following:
    (b) Set the torque scale to 30 which gives maximum torque of 30 Nm.
    (c) Select the manual control mode of the load, i.e., set the load to “MAN/EXT” mode at position 1.
    (d) Set n_{min}% to 20. This will prevent the motor speed to drop below 20% of the synchronous speed.
    (e) Set M_{max}% to 60. This will limit the maximum torque to 60% of 30 Nm, i.e., 18 Nm.

23. In the Isolation amplifier, adjust the scale of channel A as “/100” and the scale of channel B as “1 V/A”.

24. From the PC, run the CASSY Lab software.

25. From the “CASSY” option, activate the channels of Profi CASSY and Sensor CASSY as given in Table 2. Select “RMS Values” option for channels A and B of Profi CASSY (UA1 and UB1). Select “Averaged Values” option for channels A and B of Sensor CASSY (UA2 and UB2).

26. From "Parameter/Formula/FFT" option, use new quantity to define V_{ph} as UA1*100 from the "Formula" option. Accordingly, adjust the symbol, unit, range,…etc.
27. Repeat to define I as UB1, T as UA2*3, and N_r as UB2*1000.
28. From the "Display" option, select T as x-axis and V_{ph}, I, $\cos\phi_1$, and N_r as y-axis. Switch off all other signals.
29. Double click on the "Setting" icon to activate the Measuring Parameters. Select the "Manual Recording" option.
30. **Ask the instructor to check your connections and CASSY Lab settings. Do not proceed to the next stage unless your connections and settings are completely examined by the instructor.**
31. Turn the "Brake" button of the torque from the Control Unit to make it at the lowest left position.
32. Switch ON the source to run the motor. The motor will run at no load condition.
33. Increase the load torque slowly in 10-15 steps till T reaches 8.5 Nm approximately. Record the measurements at each step. Observe T on the computer screen.
34. Reduce the load torque to 0 Nm.
35. Switch OFF the source and save your measurement file.

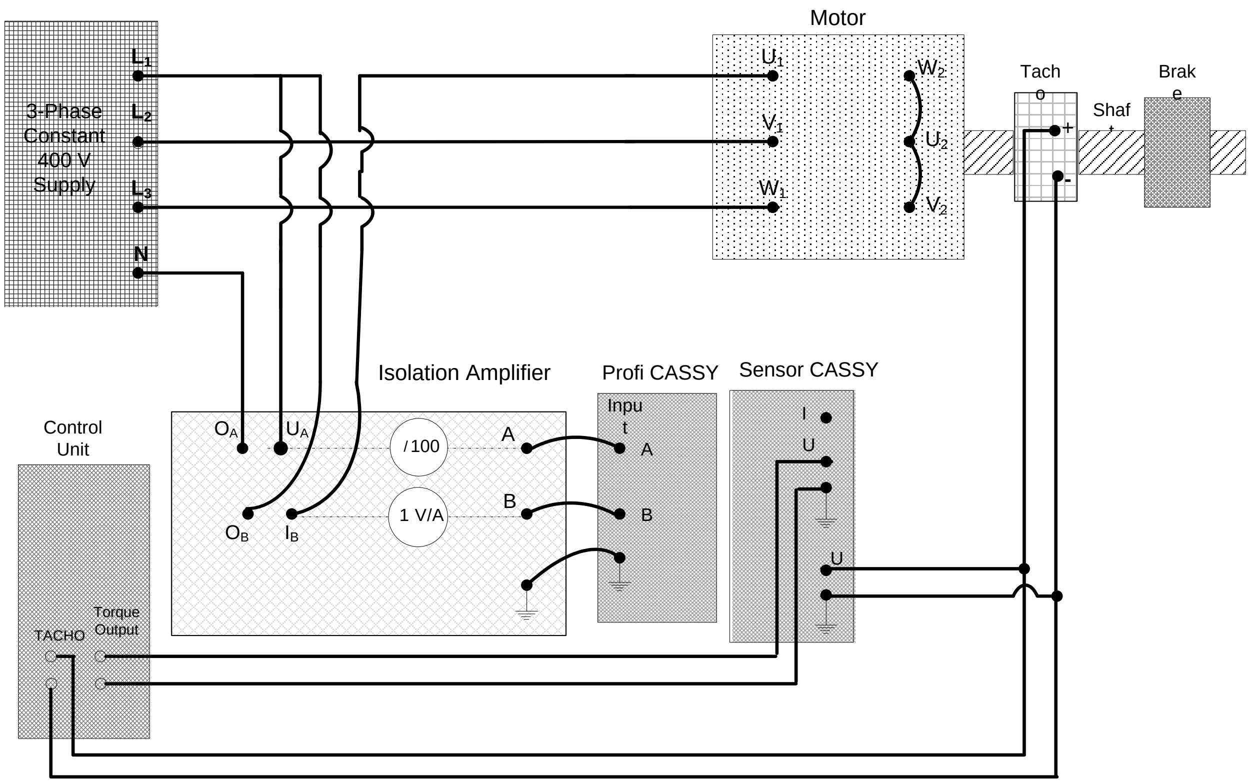


Fig. 7: Wiring diagram under Load Test

Report:

1. Use the recorded nominal ratings of the induction motor to complete Table R1 given below.
2. Record the measurements of equivalent circuit determination tests and complete Table R2.
3. Find the parameters of the equivalent circuit of the three-phase induction motor and the combined rotational losses. Complete Table R3 and attach all calculations in a separate sheet.
4. Based on the recorded measurements, define new quantities of output power P_{out}, input power P_{in}, and efficiency as given in Equations (16), (17), and (18) respectively and complete Table R4.
5. Define the normalized values of V_{ph}, I, T, and N_r as V_n, I_n, T_n, and N_n by dividing each value by the nominal values of these quantities. Define new quantity of normalized efficiency as Eff_n = efficiency/100.

6. Complete Table R5.
7. From the “Display” option, select T_n as X-axis and V_n, I_n, $\cos\phi_1$, N_n, and Eff_n as Y-axis. Switch off all other signals. Adjust the scale of all normalized values properly.
8. Plot V_n, I_n, $\cos\phi_1$, N_n, and Eff_n vs. T_n.

Table R1: Nominal data

Nominal voltage when connected Y in V	
Nominal voltage when connected Δ in V	
Nominal current when connected Y in A	
Nominal current when connected Δ in A	
Nominal power factor	
Nominal speed in rpm	
Nominal output power in W	
Synchronous speed in rpm	
Nominal torque in Nm	
Number of poles	

Table R2: Measurements and calculations of equivalent circuit determination tests

	Voltage (V)	Current (A)	Power in (W)
DC Test			
No Load Test			
Blocked Rotor Test			

Table R3: Calculations of equivalent circuit parameters from tests

R_1	
R_2	
X_1	
X_2	
X_m	

Based on the tests, $P_{rotational}$ = W

Table R4: Measurements and calculations of load test

T	***V***	***I***	**cosϕ_1**	N_r	P_{out}	P_{in}	***Eff***

Table R5: Normalized quantities

T_n	V_n	I_n	**cosϕ_1**	N_n	Eff_n