2015

Electrical Machines Laboratory ENEE3101

Electrical Engineering Department

Birzeit University

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Experiment 1
Introduction to Electrical Machines
(ON F.B.)

Objective:

To study some basic information about ac and dc machine such as B.H. curve of magnetic circuit stator and armature winding generating a rotating field , the effect of interpoles (commutating poles) on the direction of main field poles.

Theory:

- The flux density in any part of magnetic circuit is related to excitation by the equation: $F = (B/\mu).L$

Where: F = excitation, ampere turns = $N.I = HL$

B = flux density Teslas (webers/M^2) = Φ/A

L = length of flux path, m

μ = absolute permeability

In ferromagnetic material μ is not constant, it is greatest at low flux densities, from previous equation we can show that there is a relation between H and B, $(B = \mu H)$

This relation is called B.H. curve and $B = f(e)$ and $H = f(i)$,so BH curve is a VI curve which is called saturation curve.

- For ac machine some of different form of stator winding arrangement which can be made up from the EMT-180 - 12 slot stator.

We can arrange the winding to obtain , 2 pole , 4 pole single phase or two phase as shown in the experiment.

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- In single phase machine two phase stator winding will produce a rotating field with the currents in the two winding displaced by approximately 90°. The phase shift due a capacitor connected in series with one winding (the start winding) can be calculated from measurements of voltage appearing across each element.

The rotating field produced by a wound stator can be demonstrated by magnetic compass placed in the bore . The needle can be made to rotate in synchronism with the speed of rotating field given by the equation

$$n = (120*f)/p$$

where   n = synchronous speed in revolution/ minute (rpm)

         f = supply frequency in HZ

         p = number of poles per phase

- In dc machine a distortion of the main field by armature reaction may be counteracted by an interpole field acting at right angle to it.

  Brush-shifting may be used to improve commutation as an alternative or in *addition to interpoles*. For improvement of commutation in DC motors, brushes are to be shifted opposite to the direction of armature rotation.

Components Required:

a) 2-L4 coils, 2-L5 coils, 2-L1 coils , 2-L2 coils , 2-L8 coils, 2-L9 coils.

b) 1-12 slots stator, 1-squirrel-cage rotor.

c) 1-resistor/capacitor board, variable AC/DC supply, AVO meters.

Experimental Procedure:

Note: Ask your lab supervisor before switching on any power supply

1 . Saturation:

1. Make the connections as shown in Figure 1

2. **Ask your lab supervisor before switching on** the ac supply. Raise the current applied to the L5 coils in step of 0.2A up to 2A, measuring excitation current and output voltage at each step.

3. Plot the results to give a graph of excitation current and output voltage.

Q#1: At what excitation current does your graph begin to depart from straight line?
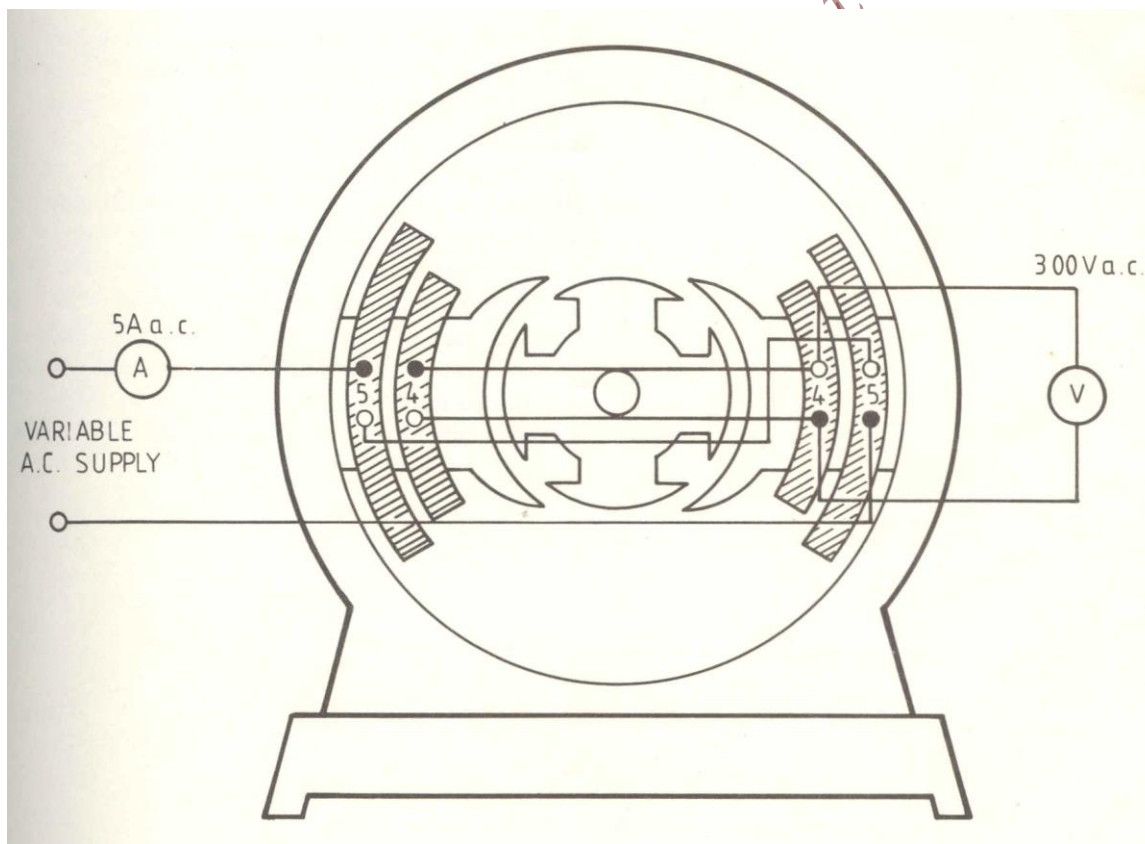
Figure 1

2. Interpoles Flux:

1. Make the connections as shown in Figure 2

2. Switch on the dc supply and adjust to 0.5 amp with the switch shorting out the interpole coils and note the direction of compass needle which will be in direction of field

3. Open the switch across the interpole coils and readjust the supply current to 0.5A, and note the deflection of the compass needle due to interaction of the main and interpole field.
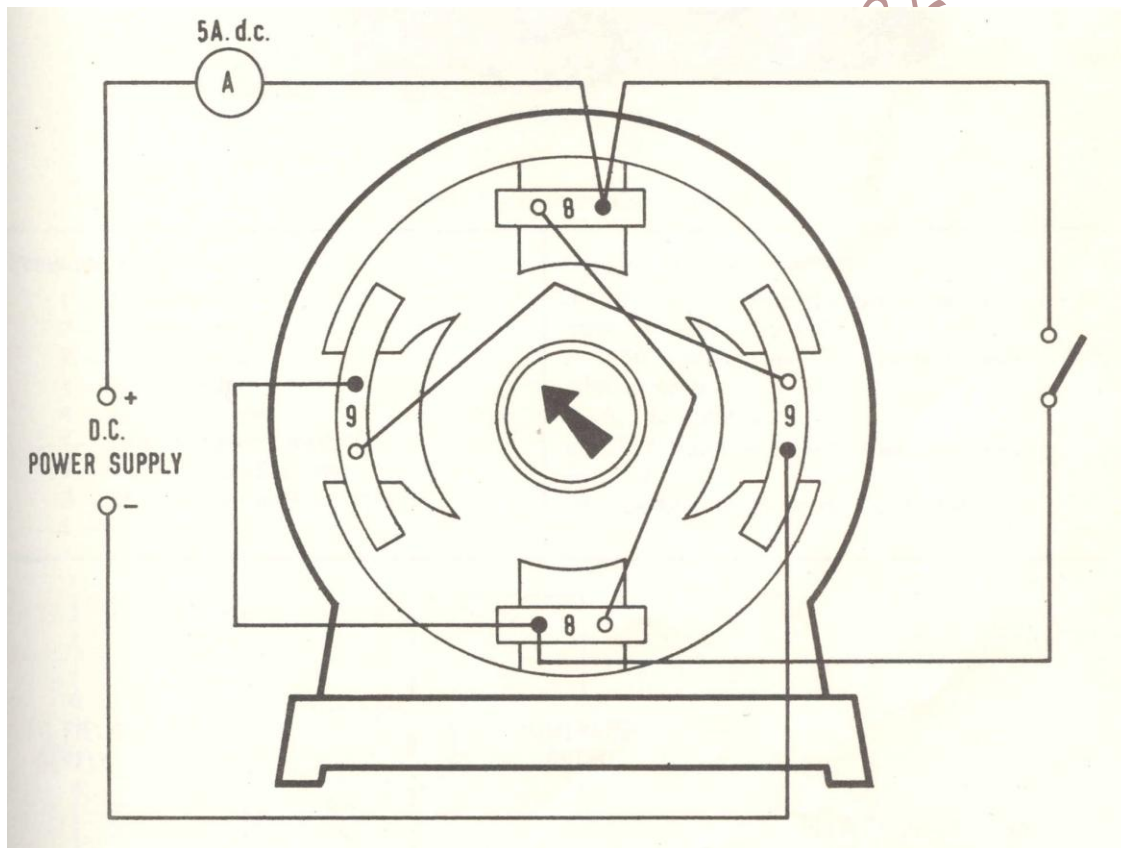
Figure 2

3. Stator Windings:

1. Make the first connections in Figure 3

2. Switch on the dc supply and move the compass in the vicinity of the teeth to identify the poles and trace the flux paths between poles.

3. Repeat the previous procedure for the other connections in Figure 3
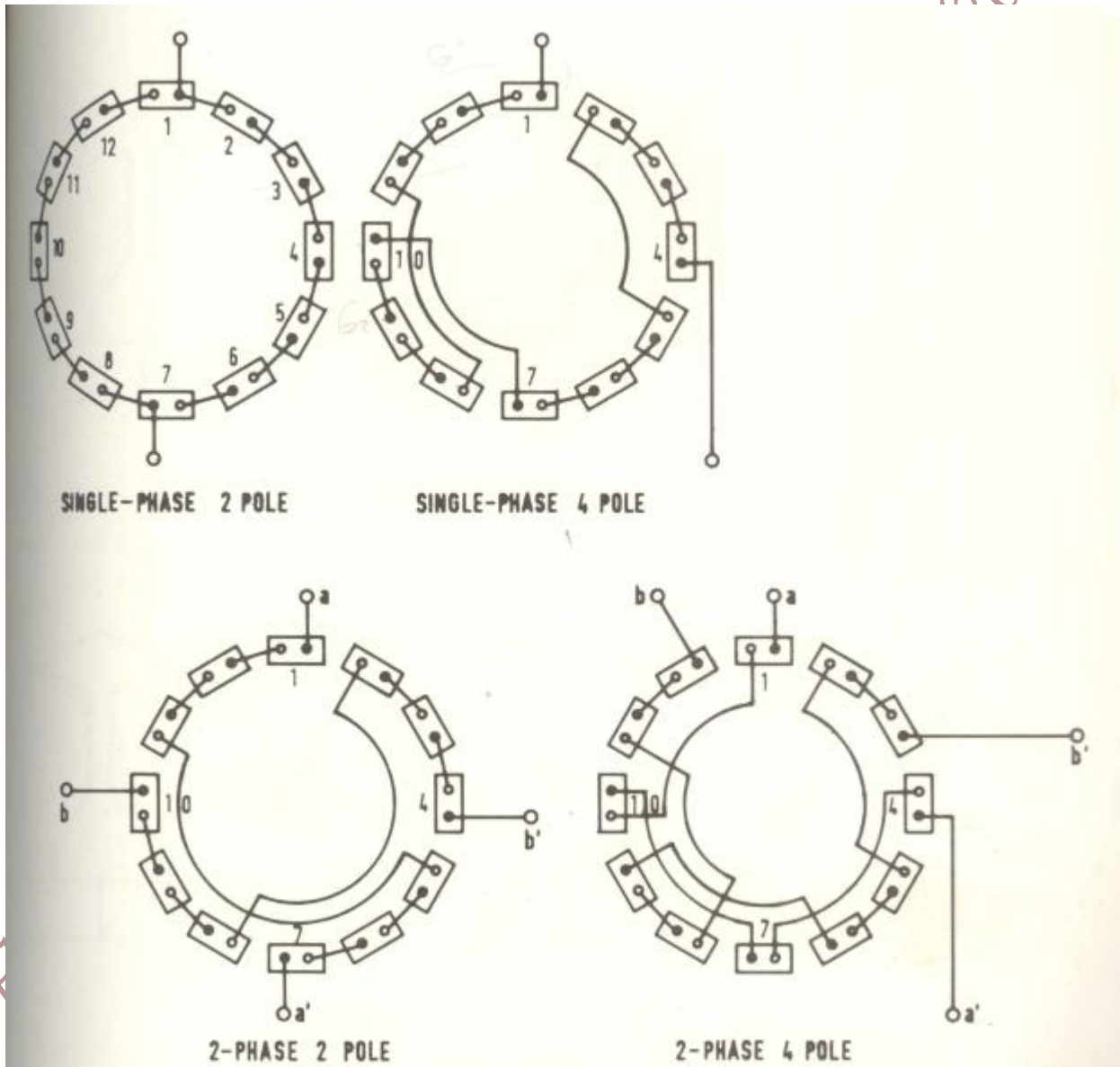
Figure 3

4. Rotating Field:

1. Make the connections as shown in Figure 4

2. **Ask your lab supervisor before switching on** the 125 ac supply, then measure the voltages

$$Vs \; \text{--} \; \text{across the supply} = 125$$

$$Vc \; \text{--} \; \text{across the capacitor}$$

$$Vl \; \text{--} \; \text{across the stator winding}$$

3. From these results construct the phasor diagram and obtain the phase shift due the capacitor.

Q#2: Calculate the synchronous speed of this motor.
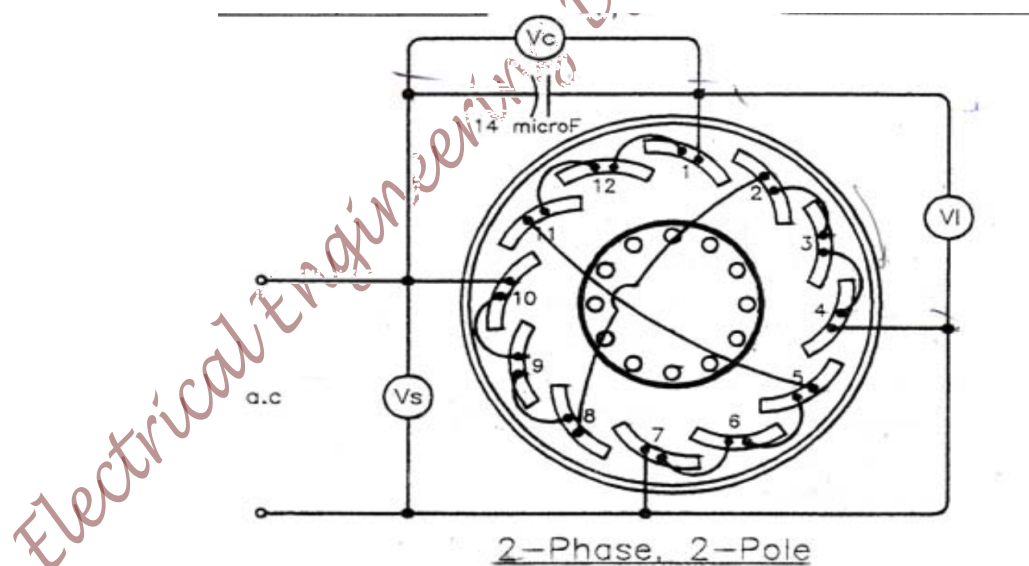
Figure 4

Experiment 2
Single-Phase Transformers

Objectives

1. Connecting various transformers and then demonstrating the significance of the terms "voltage transformation", "current transformation" and "no-load current" with appropriate experimental circuits.

2. Setting up a measurement circuit for determining short-circuit voltage and sustained short circuit current and then be able to measure these values.

3. Conducting open circuit test on transformer.

4. Deriving the equivalent circuit parameter of transformer.

5. Investigating a transformer's voltage behavior when it is connected to a resistive load and determining its efficiency as a function of the load.

6. Investigating and interpreting a transformer's voltage behavior when it is connected to an inductive or capacitive load.

Equipments Required

Single-phase transformer	733 97
Single-phase toroidal core transformer	733 98
Single-phase autotransformer	733 99
Variable Transformer 0 ... 260 V / 4 A	726 85
Resistive load	73240
Inductive load	732 42
Capacitive load	732 41
2 AC Power Meter (GW Instek)	GPM 8212

Theory

The law of induction is fundamental to the way that a transformer works. This law states that a voltage will be induced in a coil that is exposed to a periodically changing magnetic field. Since a transformer is generally employed to connect two differing voltage levels, it is necessary to have both sides uniquely designated with indices. Typically the side intended as the input is designated the primary side and labeled with the index 1. The side of the transformer to which the load is connected is designated the secondary side and labeled with the index 2.

According to the law of induction, if the number of turns in the windings are represented by N_1 and N_2 then the relationship between respective voltages for an ideal transformer will be:

$$V_1/V_2 = N_1/N_2 \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots 2.1$$

The voltage conversion ratio is the most important rating for a transformer. If one disregards transformer losses, then the apparent power must be the same on both sides. This can be used to derive a ratio for the currents as follows:

$$I_1/I_2 = N_2/N_1 \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots 2.2$$

The higher transmission voltage is made, the smaller the current will be for the same amount of transmitted power. This allows high-voltage lines to be utilized that have a smaller conductor cross section which, in turn, is more economical.

In addition to a transformer's transformation ratio there are other factors which also determine the operational behavior of a transformer. These are nominal apparent power, no-load current, short circuit voltage, and efficiency.

The experiments, to be performed here, will use one transformer with a laminated core and another transformer which has a toroidal core, each of these will have two secondary windings. The operational behavior for both types will be similar; differences arise only in their short-circuit voltages and no-load current.

Furthermore, a distinction must be made between the physical structure differences for "isolating transformers" and "autotransformers". An isolating transformer has absolutely no galvanic coupling between its windings, whereas the autotransformer is formed by two, series-connected, parts of a single winding. One portion of the winding, referred to as the common winding, is common to both sides. The other portion of the winding, referred to as the auxiliary winding or series winding, together with the common winding forms the high voltage side.

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Voltages can be transformed up or down with an autotransformer. Its overall potential power output is referred to as its throughput rating. Its transfer from input to output winding is in part galvanic and part inductive. The greater the galvanic portion contributes to the amount of power transferred, the smaller the inductive portion will be. It is this inductive portion, also referred to as "nominal power" that determines the physical size of the transformer. This means that the savings of copper and iron, in comparison to a transformer with separate windings, becomes larger as the difference between input and output voltages becomes smaller. The experiments to be performed here will use an autotransformer that has multiple taps.

Autotransformer is special form of transformer having one winding, a portion of which is common to both the primary and the secondary circuits. The current in the high-voltage circuit flows through the series and common windings as shown in the following Figure 2.1
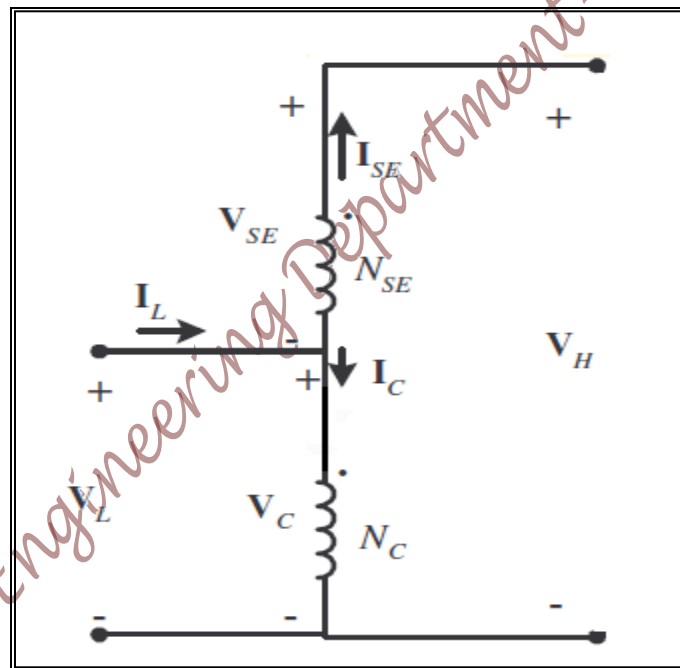
Figure 2.1 A step up autotransformer

The current in the low-voltage circuit flows through the common winding and adds vectorially to the current in the high-voltage circuit to give the input winding current. Thus, an electrical connection exists between high-voltage and low-voltage windings. Because of this sharing of parts of the winding, an autotransformer having the same kilovolt-ampere (kVA) output rating is generally smaller in weight and dimensions than a two-winding transformer. One possible

disadvantage of auto-transformers is that the windings are not insulated from each other and that the autotransformer provides no isolation of the primary and secondary circuits.

Autotransformers of large sizes are used for interconnecting high-voltage power systems. They are used in small sizes for intermittent-duty starting of motors. For this use the motor is connected for a short time to the common winding voltage, and then connected to the full line voltage. Small, variable-ratio autotransformers are used in testing and as components of other apparatus.

From figure the voltages and currents in the coils are related by the equations

$V_L = V_C$……………………………………………………………………………..2.3

$V_H = V_C + V_{SE}$…………………………………………………………….........2.4

$I_L = I_C + I_{SE}$…………………………………………………………………..2.5

$I_H = I_{SE}$…………………………………………………………………………2.6

The voltage current relationship between the two sides can be found by the following equation

$V_L / V_H = N_C / (N_{SE} + N_C)$………………………….. …………..……………………………2.8

The current relationship between the two sides can be found by the following equation

$I_L / I_H = (N_{SE} + N_C) / N_C$………………………………………………………..2.9

Experimental Procedure

<u>Note:</u>

Do not turn on any equipment without prior notice from lab supervisor.

PART A: Single-phase Transformer

- **Voltage and Current Transformation & Open Circuit Test**

1. Set up the circuit as shown in Figure 2.2
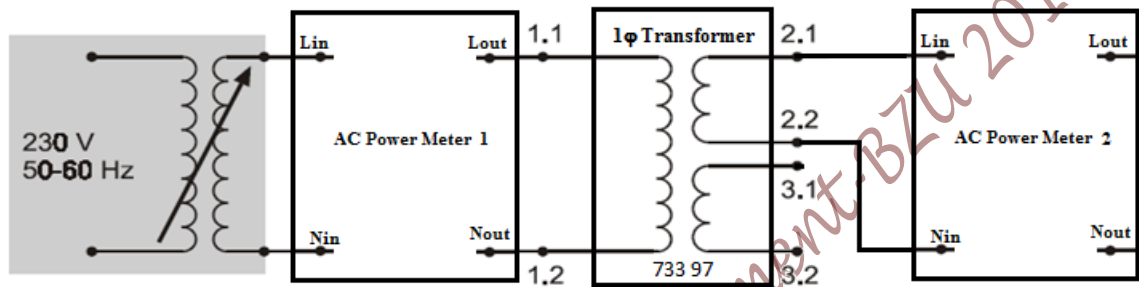
Figure 2.2 Circuit for Measuring Voltage Transformation in a Single-phase Transformer

2. Using the data printed on the transformer, fill in Table 2.1.

Table 2.1: Nominal Data for the single phase Transformer Under Test

Nominal voltage (Primary) V_1:	
Nominal voltage (Secondary) V_2:	
Nominal voltage (Secondary) V_3:	
Nominal current (Secondary) I_2:	
Nominal current (Secondary) I_3:	
Number of Turns N_1:	
Number of Turns N_2:	
Number of Turns N_3:	

3. The transformer to be investigated is to be operated at no-load.

4. Turn on the circuit and select the voltage V_1 = 230 V on the Variable Transformer (72685) that powers the circuit.

5. Measure the no load primary current I_0 of the transformer and the voltage across each of the secondaries V_2 and V_3 (between terminals 2.1 & 2.2, and 3.1 & 3.2, respectively).

6. Also, measure voltage V_{23} (between terminals 2.1 and 3.2) when the two secondary windings connected in series (by connecting terminal 2.2 with terminal 3.1).

7. Measure the wattmeter reading for the primary side (P_{oc1}), V_{oc1} & I_{oc1} when terminal 2.2 & 3.1 are connected.

8. Reduce the input voltage to zero then Turn it off (Variable Transformer).

   Q1: Calculate the voltages V_1, V_2 and V_3 to the turn counts N_1, N_2 and N_3 of their respective windings.

   Q2: From P_{oc}, V_{oc} & I_{oc} calculate the excitation branch parameter X_m & R_c.

9. Change the circuit to match Figure 2.3 in order to determine the current transformation ratio.

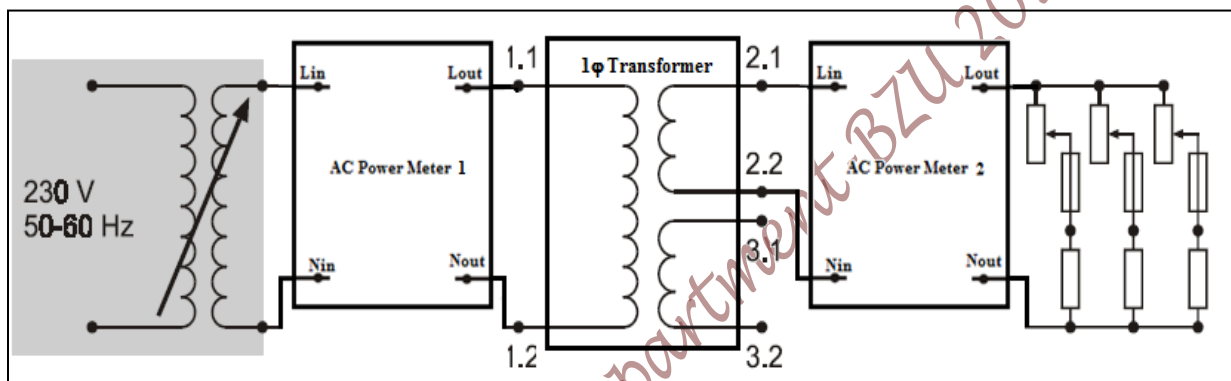**Figure 2.3 Circuit for Measuring Current Transformation in a Single-phase Transformer**

10. Set the resistive load to a value of 90% and turn on the circuit. Turn on the circuit, again select the voltage 230 V on the Variable Transformer that powers the circuit.

11. Reduce the load's resistance (**never allow it to be below its 10% value!**) value until rated current flows in the secondary side of the Transformer. Measure the corresponding current on the primary side.

12. Turn off power supply (Variable Transformer), and set it output to zero V.

   Q3: Reference the currents I_1 and I_2 to the number of turns N_2 and N_1 of their respective windings.

- **Short-Circuit Test and Sustained Short-circuit Current:**
  This part is intended to investigate the transformer's behavior when the secondary winding is shorted. Short-circuit voltage and sustained short-circuit current are also determined. A transformer exhibits different values for short-circuit voltage depending upon whether one or both of the secondary windings are loaded. The higher of these values results when both

windings are shorted. The rated current for the primary side is required for this measurement. This was established during the previous part.

1. Set up the circuit as shown in Figure 2.4
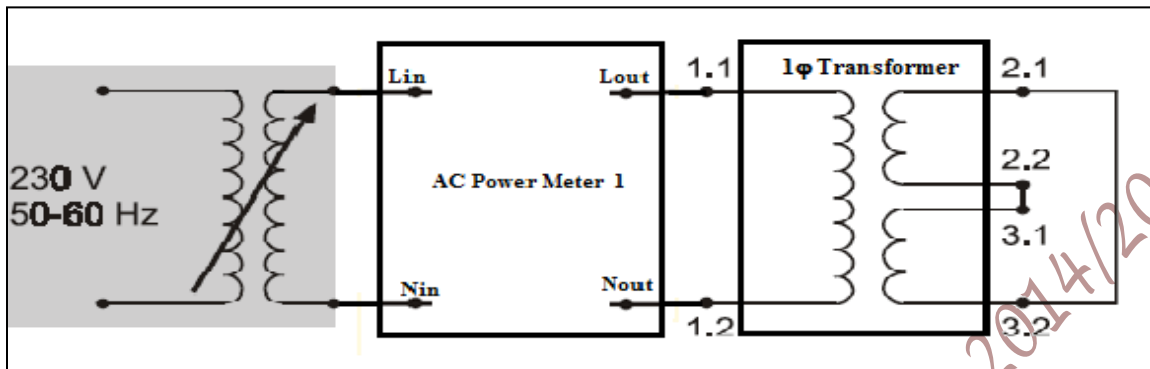
Figure 2.4: Circuit for Measuring Short-circuit Voltage

2. **Be sure that power supply set to zero before turning it on.**

3. Turn on power supply (Variable Transformer), beginning from zero, slowly increase the voltage of the Variable Transformer until the current flowing in the primary side reaches its rated value (I_{SC}); then read the corresponding voltage at primary side at primary side (Vsc), the short circuit power $P_{sc.}$

4. Reduce the input voltage to zero then Turn it off (Variable Transformer).

   Q4: Determine the relative short-circuit voltage (Vsc)pu of the single-phase transformer under test; (Vsc)pu = (Vsc) /Vrated

   Q5: Form the readings of short circuit test (Isc, Vsc & Psc), calculate the transformer equivalent series impedance (Req1& Xeq1).

   Q6: From your result in **Q2** and **Q5** draw the transformer equivalent circuit.

   Q7: Sustained short-circuit current is that current which flows after transient reaction has died out when nominal voltage is applied to the primary side. Since this has a very high value it cannot be measured directly. Therefore, calculate its value from the secondary side's rated current and the relative short-circuit voltage with the help of the equation.

   $I_{ss}=I_{2N}$ /(V_{SC})pu……………………………………………………………….2.10

   Q8: Determine the transformer sustained short-circuit current?

   Q9: Explain the equation in part (8).

- **Voltage Behavior with Resistive Load, Evaluating Efficiency:**

1. Change the circuit to match Figure 2.5.

2. Three separate resistors are to be connected in parallel to increase current handling capability.
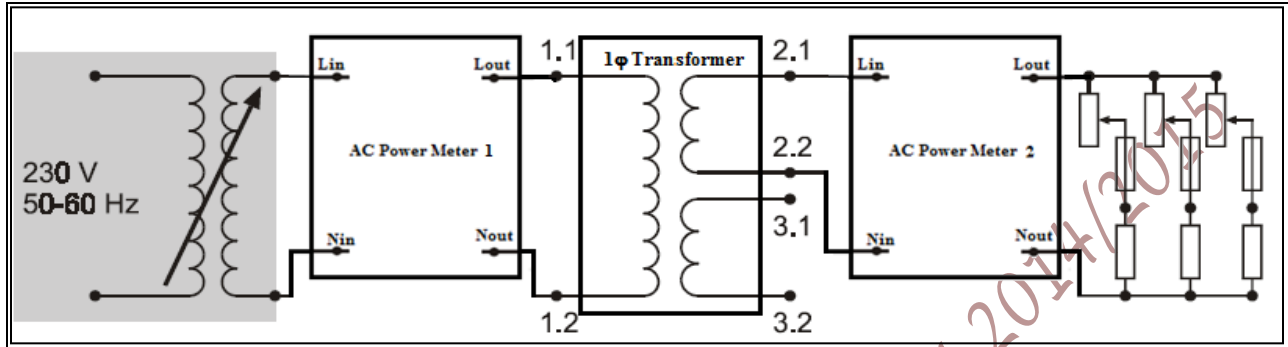
Figure 2.5: Circuit for Investigating Voltage Behavior with Resistive Load and for evaluating Efficiency

3. First set the resistive load to a value of 90% and turn the circuit on.

4. Turn on power supply (Variable Transformer).

5. Set the Variable Transformer to maintain a voltage of 230 V.

6. Change the load according to the settings prescribed by Table 2.2. For each setting, measure the corresponding values of current I_1, cos ϕ, voltage V_2, current I_2, input power (P1)and output power(P2).

NOTE:

When load currents I_2 are over 1.4 A, these measurements should be made expeditiously in order to avoid overloading the transformer!

Table 2.2: Voltage Behavior and Efficiency for a Resistively Loaded Single-phase Transformer

Setting	R/ [%]	90	80	70	60	50	40	30	20
Measure	I_1 [A]								
	cos ϕ								
	V_2 [V]								
	I_2 [A]								
	P_1 [W]								
	P_2 [W]								
Calculated	P_1 [W]								
	P_2 [W]								
	η [%]								

7. Reduce the input voltage to zero then Turn it off (Variable Transformer).

   Q10: Measure P_1, P_2, and efficiency.

   Q11: Calculate voltage regulation VR.

   Q12: How large is the power factor when the transformer is loaded to its rated current value?

   Q13: Draw a single graph that contains the measured values for voltage V_2 and efficiency η as a function of load current I_2.

   Q14: Where does the efficiency reach its maximum?

- **Voltage Behavior With Inductive or Capacitive Load:**

  Both secondary windings are to be connected in series in order to transfer more power. This permits load-current-invoked changes to secondary voltage to become more distinct.

1. Replace the resistive load with an inductive load and change the circuit to match Figure 2.6. Here too, the inductive load elements are to be connected in parallel to increase current handling capability.
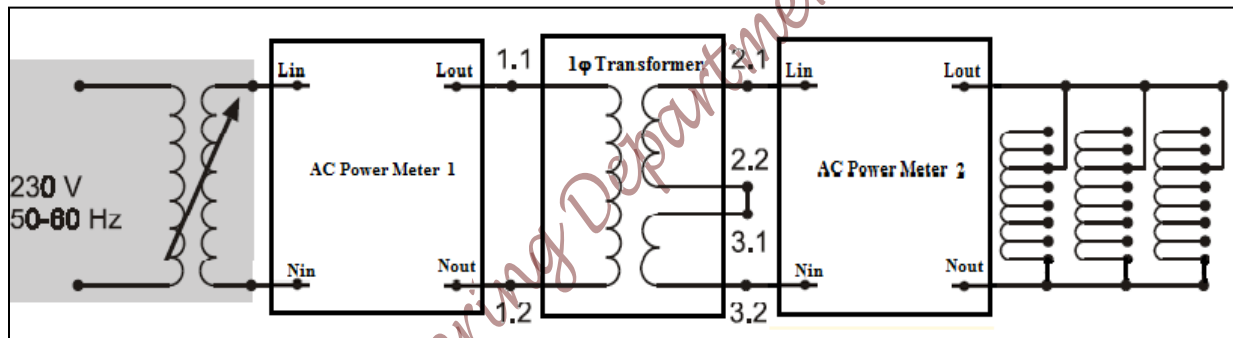
Figure 2.6: Circuit for Investigating Voltage Behavior with Inductive Load

2. Turn on power supply (Variable Transformer).

3. Set the Variable transformer powering the circuit to 230 V and maintain this value during the measurement. First measure the no-load voltage in the secondary side.

   NOTE:

   Perform the measurements quickly, 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 spikes when the secondary circuit is opened.

4. Take measurements for secondary current and secondary voltage with inductive loads set to the values prescribed by Table 2.3, also calculate the voltage regulation for each step.

Table 2.3: Voltage Behavior for an Inductively Loaded Single-phase Transformer

L$_{indiv.}$ [H]	Open (from pervious part)	6.0	4.8	2.4	1.2
L$_{total}$ [H]	open	2.0	1.6	0.8	0.4
I$_2$ [A]					
V$_2$ [V]					
P$_1$ [W]					
P$_2$ [W]					
η[%]					
VR					

5. Turn off power supply (Variable Transformer).

6. Replace the inductive load with a capacitive load and then repeat the above measurement series appropriately for values of capacitive load as specified in Table 2.4. These values of capacitance are to be created by connecting appropriate capacitors together in parallel.

7. Turn on power supply (Variable Transformer).

8. Begin the measurements with no-load on the secondary side and maintain a supply voltage of 230 V.

Table 2.4: Voltage Behavior for a Capacitively Loaded Single-phase Transformer

C[μF]	open	4	8	12	16	20
I$_2$[A]						
V$_2$[V]						
P$_1$[w]						
P$_2$[w]						
VR						
η[%]						

9. Reduce the input voltage to zero then Turn it off (Variable Transformer).

Q15: Calculate the voltage regulation for each step of measurement and Tabulate in Table 2.4

Q16: Draw a single graph containing the measured voltage values for both measurement series. Represent these values as a function of the load current.

Q17: Draw η

Q18: What characteristic differences does a transformer exhibit as load current is increased when it is connected to a resistive, inductive, or capacitive load?

➢ PART B: Single-phase Autotransformer:

• Voltage and Current Transformation:

1. Set up the circuit as shown in Figure 2.7

2. Using the data printed on transformer plate, fill in Table 2.5.

3. The transformer to be investigated is to be operated at no-load for this time.

4. Turn on the circuit and select the voltage $V_1 = 230$ V on the Variable Transformer that powers the circuit.

5. Measure the no load primary current I_0 of the autotransformer and the voltage across each of the secondary windings $V_{2.1}$ and $V_{2.2}$ with respect to the reference point (2)

6. Measure the AC power meter reading P_{oc}, V_{oc} & I_{oc} for the primary side
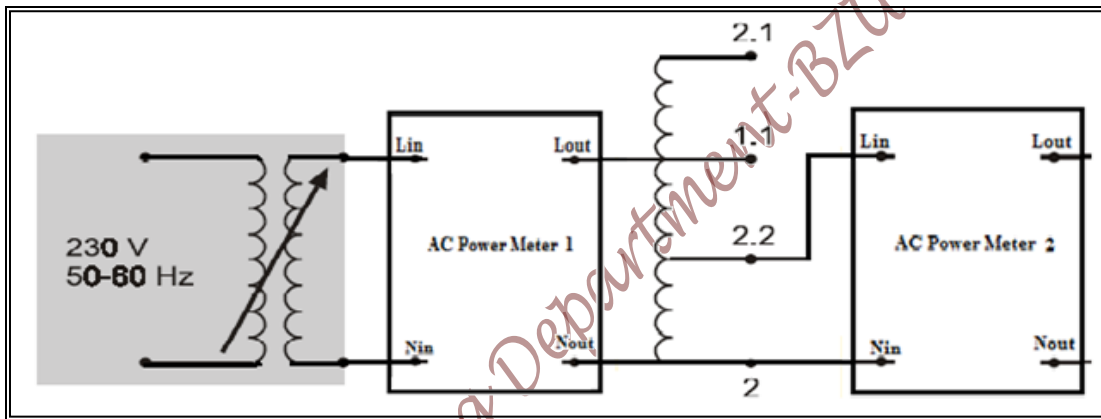
Figure 2.7: Circuit for Measuring Voltage Transformation in a Single-phase Autotransformer

Table 2.5: Nominal Data for the Autotansformer Under Test

Nominal voltage $V_{1.1}$:	
Nominal voltage $V_{2.1}$:	
Nominal voltage $V_{2.2}$:	
Nominal current $I_{1.1}$:	
Nominal current $I_{2.1}$:	
Nominal current $I_{2.2}$:	
Number of Turns N_1:	
Number of Turns N_2:	
Number of Turns N_3:	

7. Reduce the input voltage to zero and turn it off (Variable Transformer).

Q19: Calculate voltage $V_{1.1}$ to number of turns $N_1 + N_2$, the voltage $V_{2.2}$ to turn count N_1 and the voltage $V_{2.1}$ to turn count $N_1 + N_2 + N_3$ of respective windings.

Q20: From P_{oc}, V_{oc} & I_{oc} calculate the excitation branch parameter X_m & R_c.

8. Change the circuit to match Figure 2.8 in order to determine the current transformation ratio. **Note** that the output is taking from point 2.2 (observe the circle)
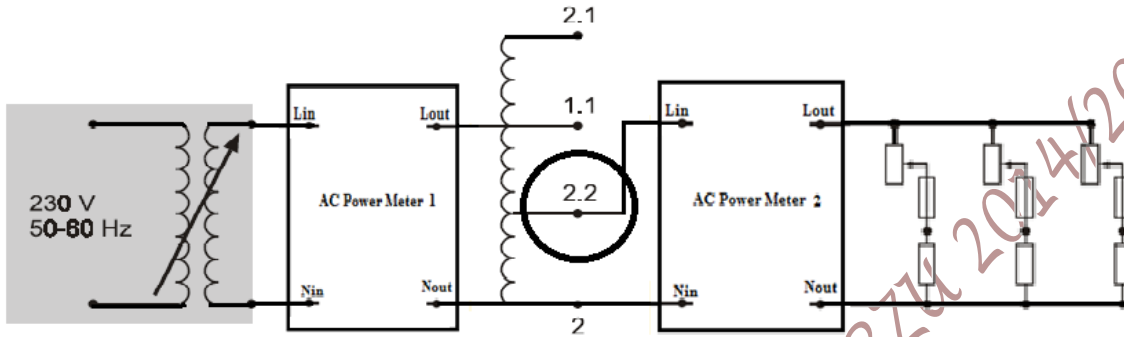
Figure 2.8: Circuit for Measuring Current Transformation in a Single-phase Autotransformer

8. Set the resistive load to a value of 90% and turn on the circuit. Turn on power supply (Variable Transformer). Again select the voltage 230 V on the Variable Transformer that powers the circuit.

9. Reduce the load's resistance (**never allow it to be below its 5% value!**) value until rated current flows in the secondary side of the auto transformer. Measure the corresponding current on the primary side.

10. **Reduce the input voltage to zero** and then turn it off (Variable Transformer)

Q21: Reference the currents I_1 and I_2 to the number of turns N_2 and N_1 of their respective windings.

- **Short-Circuit Test and Sustained Short-circuit Current:**

This experiment is intended to investigate single-phase autotransformer behavior when the secondary winding is shorted (jumper terminals 2.2-2 together). Short-circuit voltage and sustained short-circuit current are also to be determined. The rated current for the primary side is required for this measurement. This was established during the previous experiment.

1. Set up the circuit as shown in Figure 2.9

2. **Be sure that the power supply is set to zero before turning on**

3. Turn on power supply (Variable Transformer)

4. 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 at primary side at primary side (V_{sc}), the short circuit power (P_{sc}).

5. Turn off power supply (Variable Transformer).
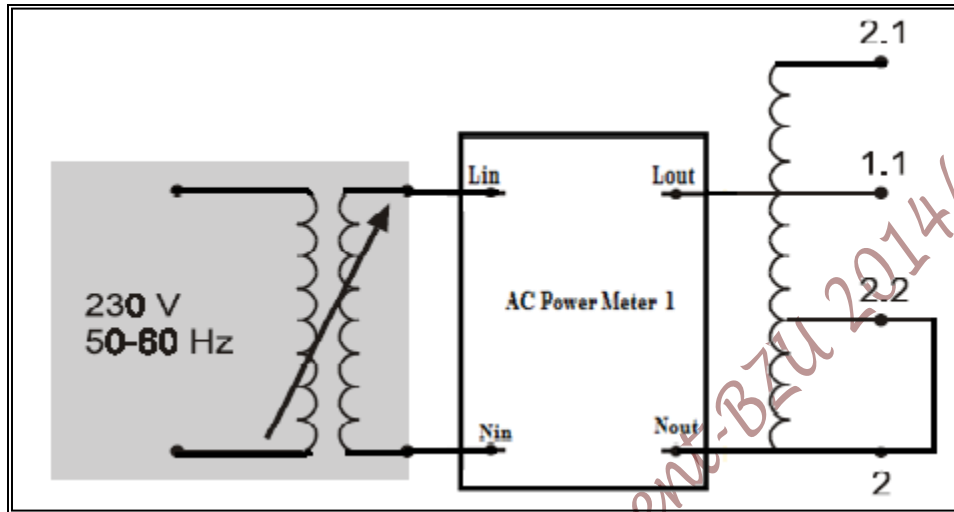
Figure 2.9: Circuit for Measuring Short-circuit Voltage

Q22: Determine the relative short-circuit voltage ($V_{sc})_{pu}$ of the autotransformer.

$$(V_{sc})_{pu} = V_{sc}/V_{rated}$$

Q23: Form the readings at short circuit test (I_{sc}, V_{sc} & P_{sc}), calculate the transformer equivalent series impedance (Req1,Xeq1).

Q24: From your results of **Q20** and **Q23** in this section draw the transformer equivalent circuit.

Q25: Sustained short-circuit current is that current which flows after transient reaction has died out when nominal voltage is applied to the primary side. Since this has a very high value it cannot be measured directly. Therefore, calculate its value from the secondary side's rated current and the relative short-circuit voltage with the help of the equation:

$$I_{ss}=I_{2N} /(V_{sc})_{pu} .$$

Q26: Determine the transformer sustained short-circuit current.

- **Voltage Behavior with Resistive Load, Evaluating Efficiency:**

1. Change the circuit to match Figure 2.10
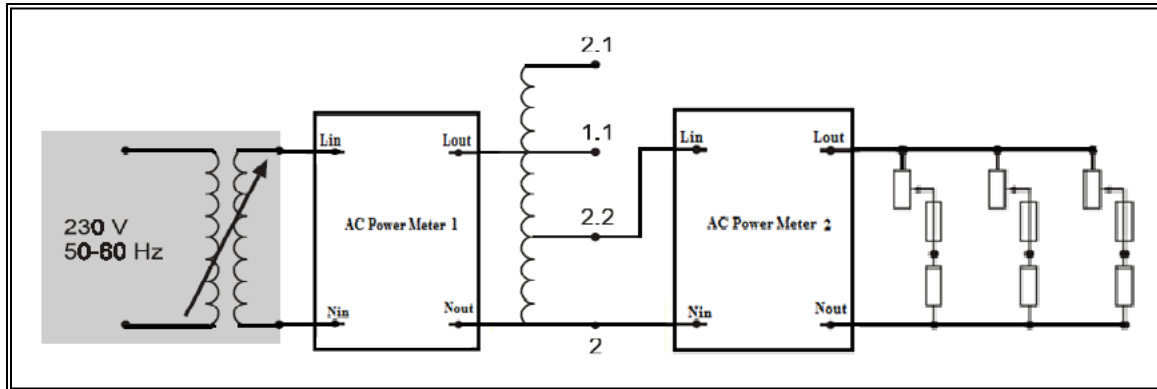
Figure 2.10: Circuit for Investigating Voltage Behavior with Resistive Load and for evaluating Efficiency

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

3. First set the resistive load to a value of 90% and turn the circuit on.

4. Turn on power supply (Variable Transformer).

5. Set the variable transformer to maintain a voltage of 230 V

6. Change the load according to the settings prescribed by Table 2.6. For each setting, measure the corresponding values for current I_1, cos ϕ , voltage $V_{2.2}$, current $I_{2.2}$, input power P_1 and output power $P_{2.2}$.

Table 2.6: Voltage Behavior and Efficiency for a Resistively Loaded Single-phase Autotransformer

Setting	R[%]	90	80	70	60	50	40	30	20
Measure	I[A]								
	cos ϕ								
	$V_{2.2}$ [V]								
	$I_{2.2}$ [A]								
	P_1 [W]								
	$P_{2.2}$ [W]								
Calculated	P_1 [W]								
	$P_{2.2}$ [W]								
	η[%]								

7. Turn on the power supply (Variable Transformer).

8. After the measurements have been taken, calculate P_1, P2.2, and efficiency.

Q27: How large is the power factor when the transformer is loaded to its rated current value?

Q28: Draw a single graph that contains the measured values for voltage V_2 and efficiency η as a function of load current I_2.

Q29: Where does the efficiency reach its maximum?

Q30: Compare measured and calculated transformer powers.

Q31: What is the voltage regulation VR?

- **Voltage Behavior With Inductive or Capacitive Load:**

1. Replace the resistive load with an inductive load and change the circuit to match Figure 2.11. Here too, the inductive load elements are to be connected in parallel to increase current handling capability.
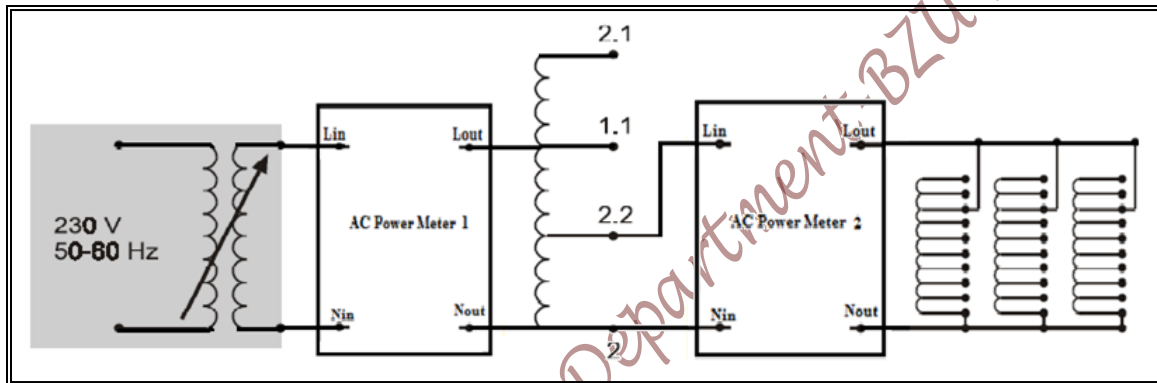
Figure 2.11: Circuit for Investigating Voltage Behavior with Inductive Load

2. Turn on power supply (Variable Transformer).

3. Set the Variable Transformer powering the circuit to 230 V and maintain this value during the measurement. First measure the no-load voltage in the secondary side.

NOTE:

Perform the measurements quickly, 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.

10. Take measurements for secondary current and secondary voltage with inductive loads set to the values prescribed by Table 2.11, also calculate the voltage regulation for each step.

Table 2.11: Voltage Behavior for an Inductively Loaded Single-phase Autotransformer

$L_{indiv.}$ [H]	open	6.0	4.8	2.4	1.2	1	0.8
L_{total} [H]	open	2.0	1.6	0.8	0.4	0.33	0.27
$I_{2.2}$ [A]							
$V_{2.2}$ [V]							
P_1[W]							
$P_{2.2}$[W]							
η[%]							
VR							

4. Turn off power supply (Variable Transformer).

5. Replace the inductive load with a capacitive load and then repeat the above measurement series appropriately for values of capacitive load as specified in Table 2.12. These values of capacitance are to be created by connecting appropriate capacitors together in parallel.

6. Turn on power supply (Variable Transformer).

7. Begin the measurements with no-load on the secondary side and maintain a supply voltage of 230 V.

Table 2.12: Voltage Behavior for a Capacitively Loaded Single-phase Autotransformer

C [µF]	0	2	4	8	12	16
$I_{2.2}$ [A]						
$V_{2.2}$ [V]						
P_1[w]						
$P_{2.2}$[w]						
VR						
η[%]						

8. Turn off power supply (variable transformer).

Q32: Calculate the voltage regulation for each step of measurement and Tabulate in Table 2.12

Q33: Draw a single graph containing the measured voltage values for both measurement series. Represent these values as a function of the load current.

Q34: Draw η for each case.

Q35: What characteristic differences does a transformer exhibit as the load current is increased when it is connected to a resistive, inductive, or capacitive load?

➢ PART C: Single-phase Toroidal Core Transformer:

• Voltage and Current Transformation:

1. Set up the circuit as shown in Figure 2.12
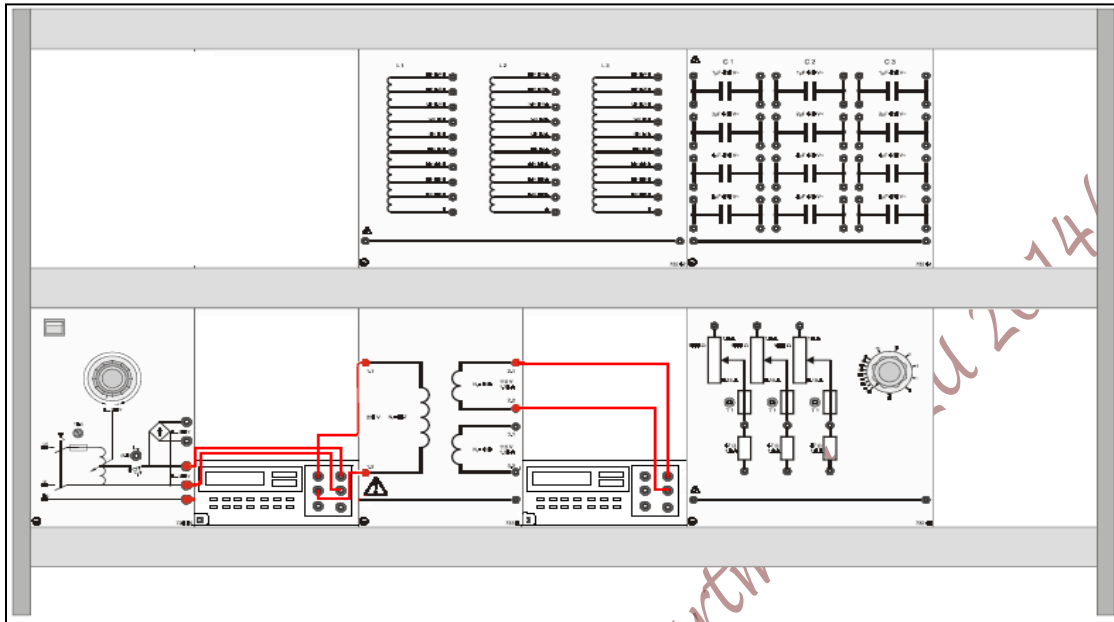
Figure 2.12: Arrangement of Units for Single-phase Toroidal Core Transformer Experiments
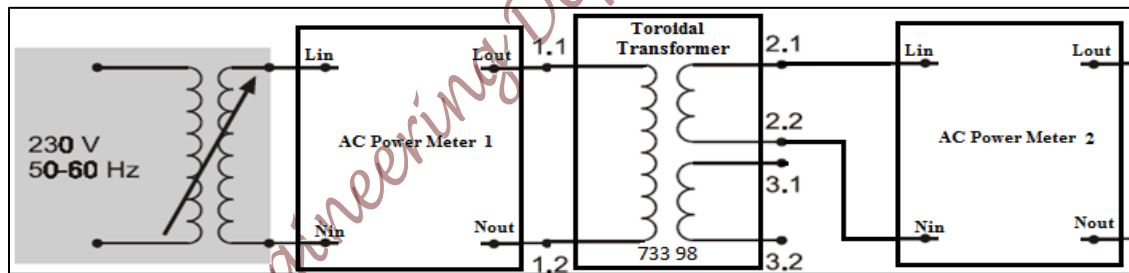
Figure 2.13 Circuit for Measuring Voltage Transformation in a Single-phase Toroidal Core Transformer

2. Using the data printed on the transformer, fill in Table 2.13.

Table 2.13: Nominal Data for the Toroidal Transformer under Test

Nominal voltage (Primary) V_1:	
Nominal voltage (Secondary) V_2:	
Nominal voltage (Secondary) V_3:	
Nominal current (Secondary) I_2:	
Nominal current (Secondary) I_3:	
Number of Turns N_1:	

Number of Turns N_2:	
Number of Turns N_3:	

3. The transformer to be investigated is to be operated with no-load for this time.

4. Turn on the circuit and select the voltage $V_1 = 230$ V on the Variable Transformer that powers the circuit.

5. Measure the no load primary current I_0 of the Toroidal Transformer and the voltage across each of the secondary windings V_2 and V_3 (between terminals 2.1 - 2.2 and 3.1 - 3.2, respectively).

6. Also measure voltage V_{23} (between terminals 2.1 - 3.2), with the two secondary windings connected in series (by connecting terminal 2.2 with terminal 3.1).

7. Measure the AC power meter1 reading P_{OC}, V_{OC}, & I_{OC} for the primary side

8. Reduce the input voltage to zero then Turn it off (Variable Transformer).

   Q36: Calculate the voltages V_1, V_2 and V_3 to the number of turns N_1, N_2 and N_3 of their respective windings.

   Q37: From P_{oc}, V_{oc} & I_{oc} calculate the excitation branch parameter X_m & R_c.

9. Change the circuit to match Figure 2.14 to determine the current transformation ratio.
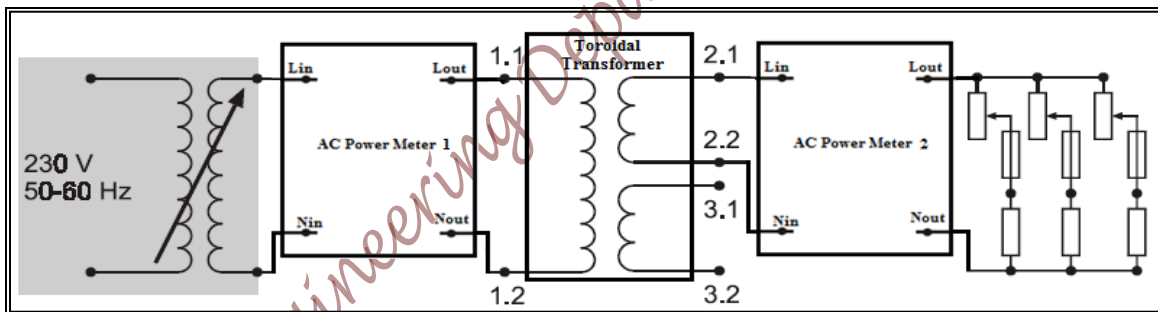
Figure 2.14: Circuit for Measuring Current Transformation in a Single-phase Toroidal Core Transformer

9. Set the resistive load to a value of 90% and turn on the circuit. Turn on power supply (Variable Transformer). Again select the voltage 230 V on the Variable Transformer that powers the circuit.

10. Reduce the load's resistance (**never allow it to be below its 10% value!**) value until rated current flows in the secondary side of Toriodal Transformer. Measure the corresponding current on the primary side.

11. **Reduce the input voltage to zero** then Turn it off (Variable Transformer)

   Q38: Reference the currents I_1 and I_2 to the turn counts N_2 and N_1 of their respective windings.

* **Short-Circuit Test and Sustained Short-circuit Current:**

This part is intended to investigate the toroidal core transformer's behavior when the secondary winding is shorted. Short-circuit voltage and sustained short-circuit current are also determined. Toroidal core transformer exhibits different values for short-circuit voltage depending upon whether one or both of the secondary windings are loaded. The higher of these values results when both windings are loaded. The rated current for the primary side is required for this measurement. This was established during the previous part.

1. Set up the circuit as shown in Figure 2.15
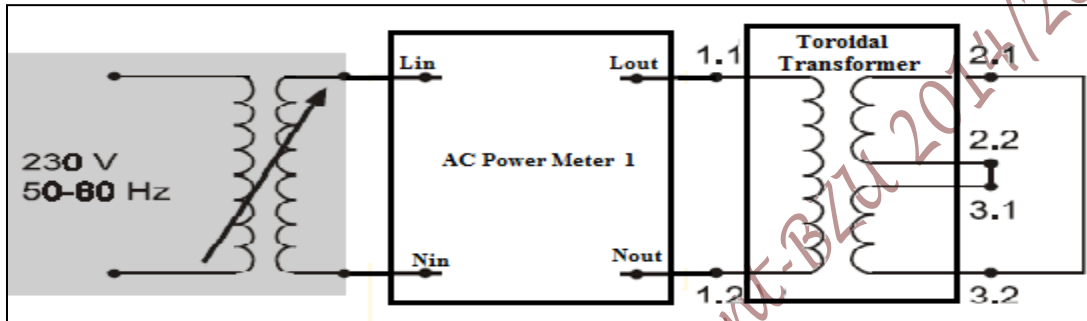
Figure 2.15 : Circuit for Measuring Short-circuit Voltage

2. **Be sure that the power supply is set to zero before turning on.**

3. Turn on power supply (Variable Transformer).

4. 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 at primary side (V_{sc}), and the short circuit power P_{sc}.

   Q39: Determine the relative short-circuit voltage $(V_{sc})_{pu}$ of the Toroidal transformer.

   $(V_{sc})_{pu} = V_{sc}/V_{rated}$………………………………………………………………………….2.11

   Q40: Form the readings at short circuit test (I_{sc}, V_{sc} & P_{sc}), calculate the transformer equivalent series impedance (Req1 & Xeq1).

   Q41: From your result of **Q37** and **Q40** draw the transformer equivalent circuit.

   Q42: Sustained short-circuit current is that current which flows after transient reaction has died out when nominal voltage is applied to the primary side. Since this has a very high value it cannot be measured directly. Therefore calculate its value from the secondary side's rated current and the relative short-circuit voltage with the help of the equation.

   $I_{ss}=I_{2N} /(V_{sc})_{pu}$……………………………………………………………….………………….2.12

   Q43: Turn off power supply (variable transformer).

   Q44: Determine the transformer sustained short-circuit current?

- **Voltage Behavior with Resistive Load, Evaluating Efficiency:**

1. Change the circuit to match Figure 2.16.

2. Three separate resistors are to be connected in parallel to increase current handling capability.
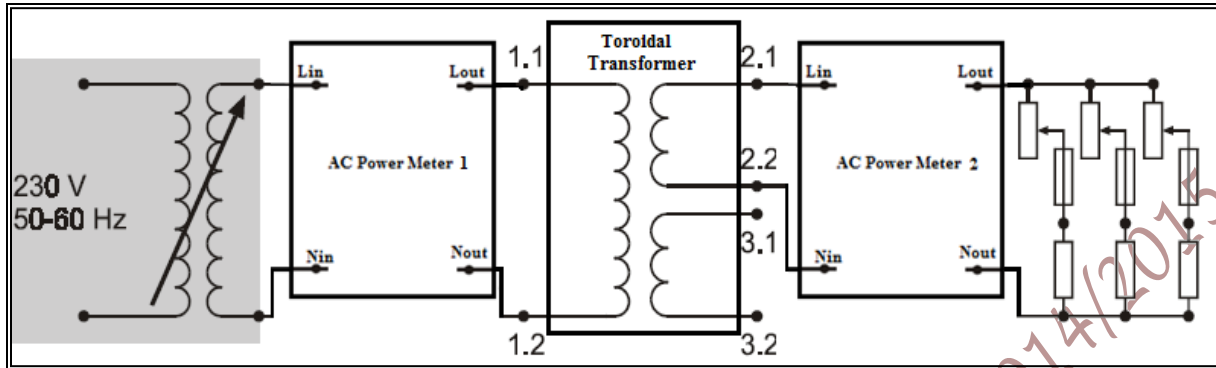
Figure 2.16: Circuit for Investigating Voltage Behavior with Resistive Load and for evaluating Efficiency

3. First set the resistive load to a value of 90% and turn the circuit on.

4. Turn on power supply (Variable Transformer).

5. Set the Variable Transformer to maintain a voltage of 230 V.

6. Change the load according to the settings prescribed by Table 2.14. For each setting, measure the corresponding values for current I_1, $\cos\phi$, voltage V_2 , current I_2, input power (P_1)and output power(P_2).

NOTE:

When load currents I_2 are over 1.4 A, these measurements should be made expeditiously in order to avoid overloading the transformer!

Table 2.14: Voltage Behavior and Efficiency for a Resistively Loaded Single-phase Transformer

Setting	R / %	90	80	70	60	50	40	30	20
Measure	I_1 [A]								
	$\cos\phi$								
	V_2 [V]								
	I_2 [A]								
	P_1 [W]								
	P_2 [W]								
Calculated	P_1[W]								
	P_2 [W]								
	η [%]								

7. Turn off the power supply (Variable Transformer).

8. Calculate the P_1, P_2, and efficiency.

9. Calculate voltage regulation VR.

Q45: How large is the power factor when the transformer is loaded to its rated current value?

Q46: Draw a single graph that contains the measured values for voltage V_2 and efficiency η as a function of load current I_2.

Q47: Where does the efficiency reach its maximum?

Q48: Compare measured and calculated powers.

- **Voltage Behavior With Inductive or Capacitive Load:**

Both secondary windings are to be connected in series in order to transfer more power. This permits load-current-invoked changes to secondary voltage to become more distinct.

Replace the resistive load with an inductive load and change the circuit to match Figure 2.17. Here too, the inductive load elements are to be connected in parallel to increase current handling capability.
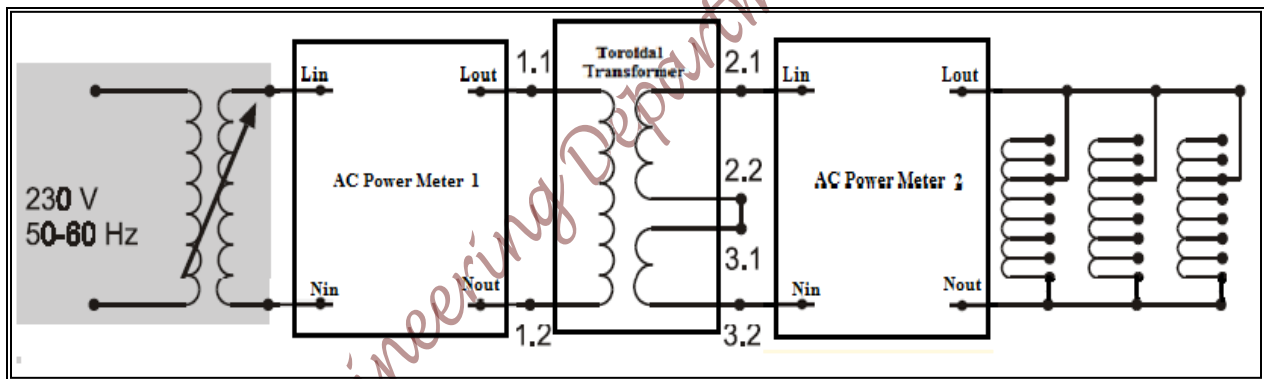
Figure 2.17: Circuit for Investigating Voltage Behavior with Inductive Load

1. Turn on power supply (Variable Transformer).

2. Set the Variable Transformer powering the circuit to 230 V and maintain this value during the measurement. First measure the no-load voltage of the secondary side.

NOTE:

Perform the measurements 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 spikes when the secondary circuit is opened.

3. Take measurements for secondary current and secondary voltage with inductive loads set to the values prescribed by Table 2.15, also calculate the voltage regulation for each step.

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Table 215: Voltage Behavior for an Inductively Loaded Single-phase Transformer

L indiv. [H]	open	6.0	4.8	2.4	1.2	1	0.8	0.6
L total [H]	open	2.0	1.6	0.8	0.4	0.33	0.27	0.2
I_2 [A]								
V_2 [V]								
P_1 [W]								
P_2 [W]								
η [%]								
VR								

4. Turn off power supply (Variable Transformer).

5. Replace the inductive load with a capacitive load and then repeat the above measurement series appropriately for values of capacitive load as specified in Table 2.16. These values of capacitance are to be created by connecting appropriate capacitors together in parallel.

6. Turn on power supply (Variable Transformer).

7. Begin the measurements with no-load on the secondary side and maintain a supply voltage of 230 V.

Table 2.16: Voltage Behavior for a Capacitively Loaded Single-phase Transformer

C [μF]	open	2	6	10	14	16
I_2 [A]						
V_2 [V]						
P_1 [W]						
P_2 [W]						
η [%]						
VR						

8. Turn off power supply (Variable Transformer).

9. Calculate the voltage regulation for each step of measurement and Tabulate in Table 2.8

   Q49: Draw a single graph containing the measured voltage values for both measurement series. Represent these values as a function of the load current.

   Q50: Draw η for each case.

   Q51: What characteristic differences does a transformer exhibit as load current is increased when it is connected to a resistive, inductive, or capacitive load?

➤ **Discussion:**

D1. Why do both voltages of a single-phase transformer behave proportionally to their respective turn counts while their current values are inversely proportional?

D2. How is short-circuit voltage defined for a transformer?

D3. What are the pros and cons of a large value for short-circuit voltage?

D4. Why is short-circuit voltage typically expressed as a relative value (based on nominal voltage)?

D5. What does the term "sustained short-circuit current" mean?

D6. What are the essential differences between transformers with a conventional core and those with a toroidal core?

D7. What determines the efficiency of a transformer?

D8. What limits the amount of power that can be transferred over a transformer?

D9. What are the essential differences between autotransformers and transformers with separate windings?

Experiment 3
Three Phase Transformers

Objectives:

To be familiarized with the relationships between voltage and current in a three-phase transformer connected in:

   A. Delta-to-Delta configuration.
   B. Star-to-Delta configuration.
   C. Star-to-Star configuration.

Equipments Required

   ❖ 3-TRL
   ❖ A3 Ammeter
   ❖ V3 250V ranges
   ❖ R3L
   ❖ 3 phase variable ac supply.

Experimental Procedure:

PART I

A. Delta-to-Delta configuration

Note 1: Connect the individual coils to get the desired number of turns for the primary and secondary as shown in Figure 3-1.
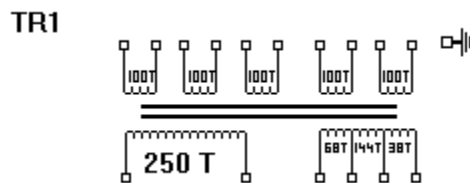
Figure 3-1

1. Set every phase of the AC source to have 120 V, then connect the source as star

2. Make sure that you have 208 V between any two phases

3. Turn off the 3 phase supplies

4. Set each transformer's primary and secondary to have 500 turns each.

5. Set up the equipment as shown in Figure 3-2 "Delta-to-Delta".

6. Set the load resistance to maximum ratios

7. Turn on the three phase sources
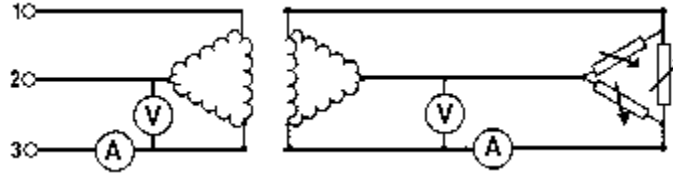
Figure 3-2

Note 2: The three phase sources are connected in Y connection, with a fixed $V_\varphi=120$ for the rest of the experiment.

8. Gradually decrease the load by varying the R3L resistance, make sure that the resistances are varied in steps from ∞ to $1k\Omega$. At each stage take the readings of the input and the output voltages and currents. Draw a table of results as shown in Table 3-1 showing the relationships between the voltages and currents on both sides of the transformer system.

Table 3-1

Resistance Value	Primary Delta Connected		Secondary Delta Connected	
	Ip	Vp	Is	Vs

9. Turn off the three phase sources.

Question 1: For a balanced non-inductive load, draw a phasor diagram for the Δ-Δ transformer connection for the following two cases:

    a. For the system when it is referred to the primary side.

    b. For the system when it is referred to the secondary side.

B. Star-to-Delta configuration.

Note 3: Leave all the secondary connections unchanged.

1. Set up the equipment as shown in Figure 3-3 "Star-to-Delta" connection.
2. Repeat steps 6 to 9 from part A, tabulate your results in Table 3-2.
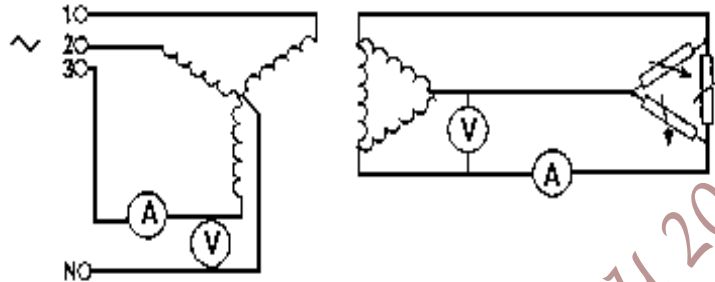
Figure 3-3

Resistance Value	Primary Star Connected		Secondary Delta Connected	
	Ip	Vp	Is	Vs

Table 3-2

Question 2: For a balanced non-inductive load, draw a phasor diagram for the Y-Δ transformer connection for the following two cases:

a. For the system when it is referred to the primary side

b. For the system when it is referred to the secondary side

C. Star-to-Star configuration.

Note 4: Leave all the primary connections unchanged.

1. Set up the equipment as shown in Figure 3-4 "Star-to-Star" connection.

2. Repeat steps 6 to 9 from part A, tabulate your results in Table 3-3
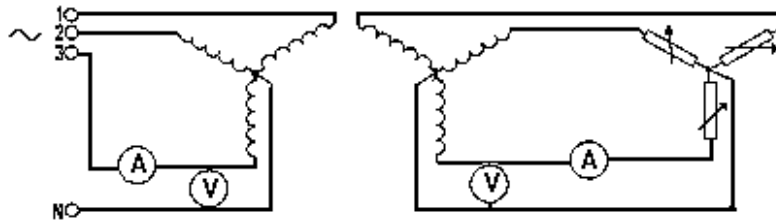
Figure 3-4

Resistance Value	Primary Star Connected		Secondary Star Connected	
	Ip	Vp	Is	Vs

Table 3-3

Question 3: For a balanced non-inductive load, draw a phasor diagram for the Y-Y transformer connection for the following two cases:

    a. For the system when it is referred to the primary side

    b. For the system when it is referred to the secondary side

PART II

➤ PART A: Delta-Delta, 0° Phase Shift:

1. Connect the circuit below.
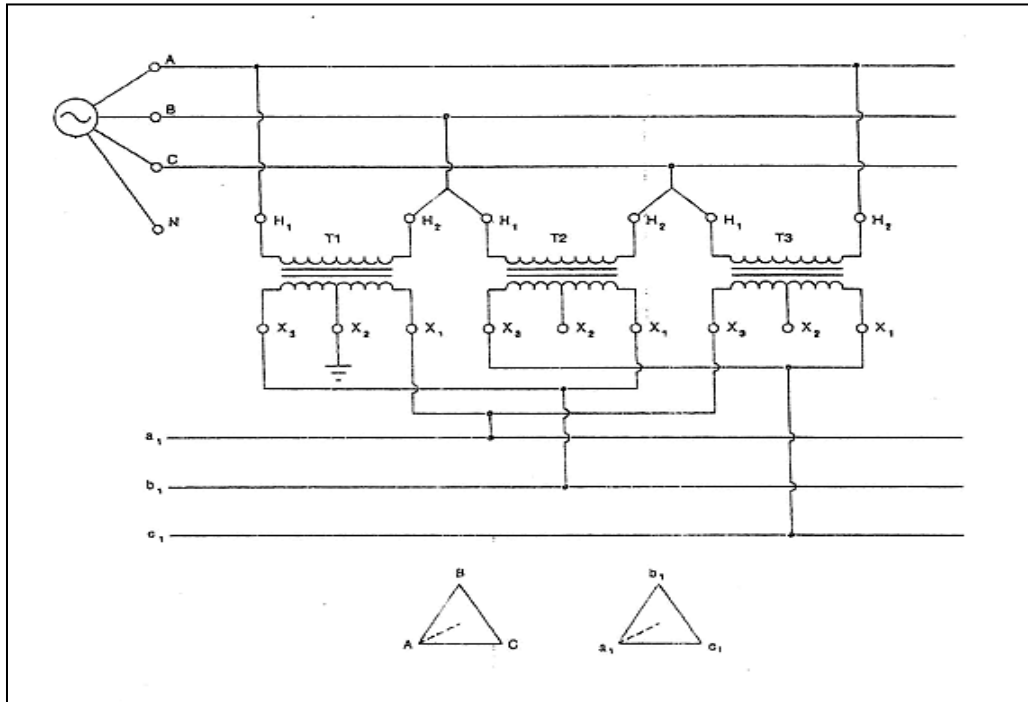
Figure 5.2

2. Turn on the Distribution Transformer Trainer and determine the voltage between lines

- a_1 and b_1 ------------

- b_1 and c_1 ------------

- c_1 and a_1 ------------

3. Turn off the Distribution Transformer Trainer. Leave this configuration connected so as to compare it with the next configuration.

➢ PART B : Delta-Delta, 0° Phase Shift vs Delta-Delta, 0° Phase Shift:

1. Repeat the circuit shown in the previous part, use transformers T4, T5, and T6 and lines a_2, b_2, and c_2. Connect bushing X_2 of transformer T4 to the ground terminal.

2. Turn on the Distribution Transformer Trainer and determine the voltage between lines

- a_1 and a_2 ------------
- b_1 and b_2 ------------
- c_1 and c_2 ---------

3. Turn off the Distribution Transformer Trainer. Leave the configuration connected To T1, T2 and T3 so as to compare it with the next configuration, and disconnect the delta-delta configuration, 0° phase shift on T4, T5 and T6.

➢ PART C : Delta-Delta, 0° Phase Shift vs Delta-Delta, 180° Phase Shift:

1. Connect the circuit shown in the figure below.

Figure 5.3

2. Turn on the Distribution Transformer Trainer and determine the voltage between lines

-   a_2 and b_2 -------------

-   b_2 and c_2 -------------

-   c_2 and a_2 ---------

3. Determine the voltage between lines

-   a_1 and a_2 -------------

-   b_1 and b_2 -------------

-   c_1 and c_2 ---------

    What can you conclude about the phase shift between lines a_1 and a_2 ?

4. Turn off the Distribution Transformer Trainer.

➢ PART D :Open-Delta, 0° Phase Shift:

1. Connect the circuit below.

Figure 5.4

2. Turn on the Distribution Transformer Trainer and determine the voltage between lines

  - a_1 and b_1 -------------
  - b_1 and c_1 -------------
  - c_1 and a_1 ---------

3. Turn off the Distribution Transformer Trainer.

Do your results demonstrate that it is possible to supply a three-phase load with only two transformers?

> ## **PART E :Open-Delta, 0° Phase Shift vs Open-Delta, 0° Phase Shift:**

1. Repeat the circuit shown in the previous part, use transformers T4 and T5 and lines a_2, b_2, and c_2. Connect bushing X_2 of transformer T4 to the ground terminal.

2. Turn on the Distribution Transformer Trainer and determine the voltage between lines

- a_1 and a_2 ------------

- b_1 and b_2 ------------

- c_1 and c_2 ---------

 What can you conclude about the phase shift between lines a_1 and a_2 ?

3. Turn off the Distribution Transformer Trainer. Leave the open-delta configuration connected to T1 and T2 so as to compare it with the next configuration. Disconnect the open-delta configuration. 0° phase shift on T4 and T5.

➢ PART F : Open-Delta, 0° Phase Shift vs Open-Delta, 180° Phase Shift:

1. Connect the circuit shown in the figure below.
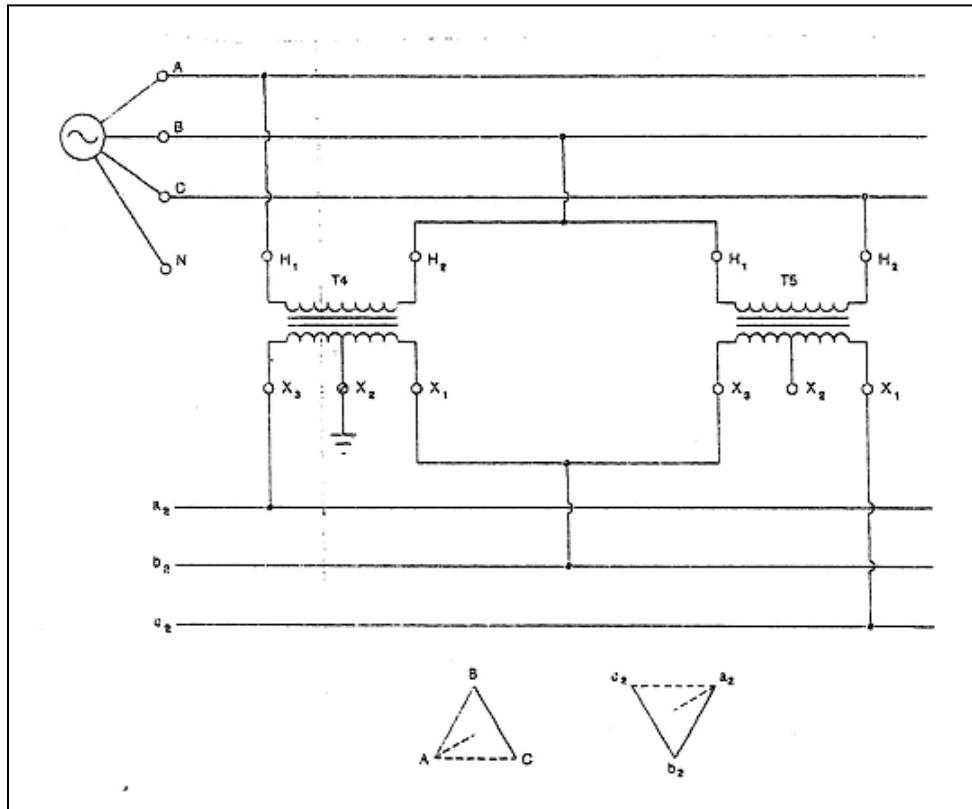
Figure 5.5

2. Turn on the Distribution Transformer Trainer and determine the voltage between lines

   - a_2 and b_2 ------------
   - b_2 and c_2 ------------
   - c_2 and a_2 ------------

3. Determine the voltage between lines

   - a_1 and a_2 ------------
   - b_1 and b_2 ------------
   - c_1 and c_2 ---------

   What can you conclude about the phase shift between lines a_1 and a_2 ?

4. Turn off the Distribution Transformer Trainer.

➢ PART G :Wye-Delta Connection:

1. Connect the circuit below.
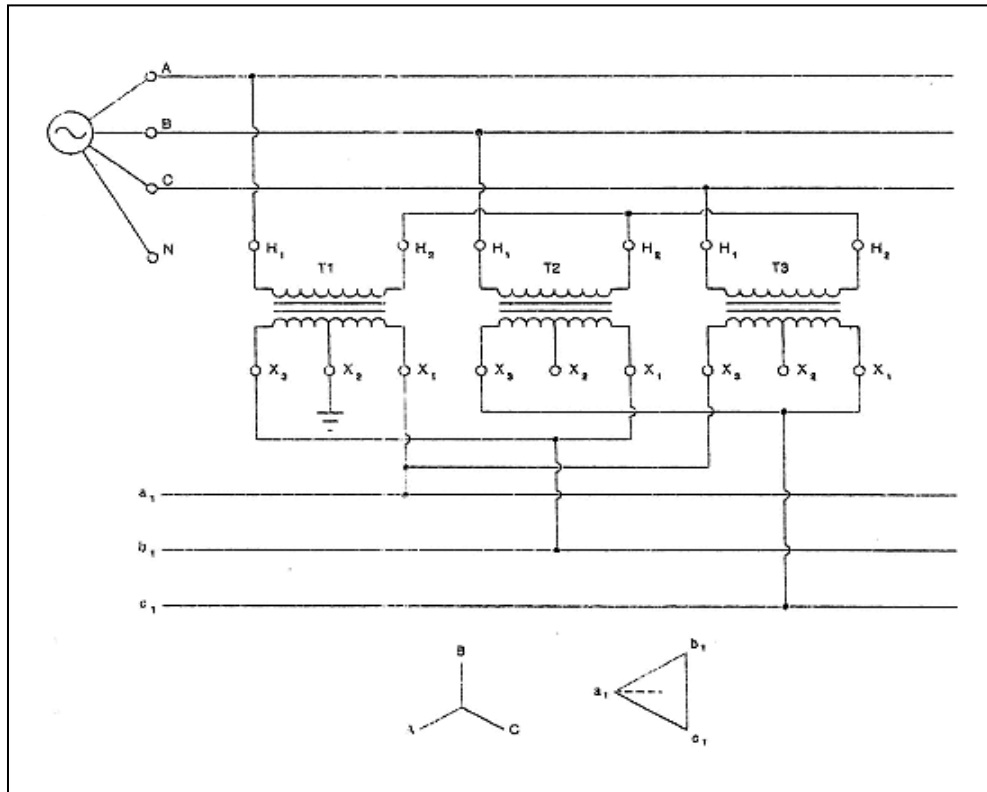
Figure 5.6

1. Turn on the Distribution Transformer Trainer and determine the voltage between Terminals H_1 and H_2 of Transformer

    - T1 -------------
    - T2 -------------
    - T3 ----------

2. Determine the voltage between lines

    - a_1 and b_1 -------------
    - b_1 and c_1 -------------
    - c_1 and a_1 ----------

    What is the phase shift between the primary and secondary voltage?

3. Turn off the Distribution Transformer Trainer. Leave this configuration connected so as to compare it with the next configuration.

➢ PART H : Wye-Delta vs Wye-Delta:

1. Connect the circuit shown in the figure below.
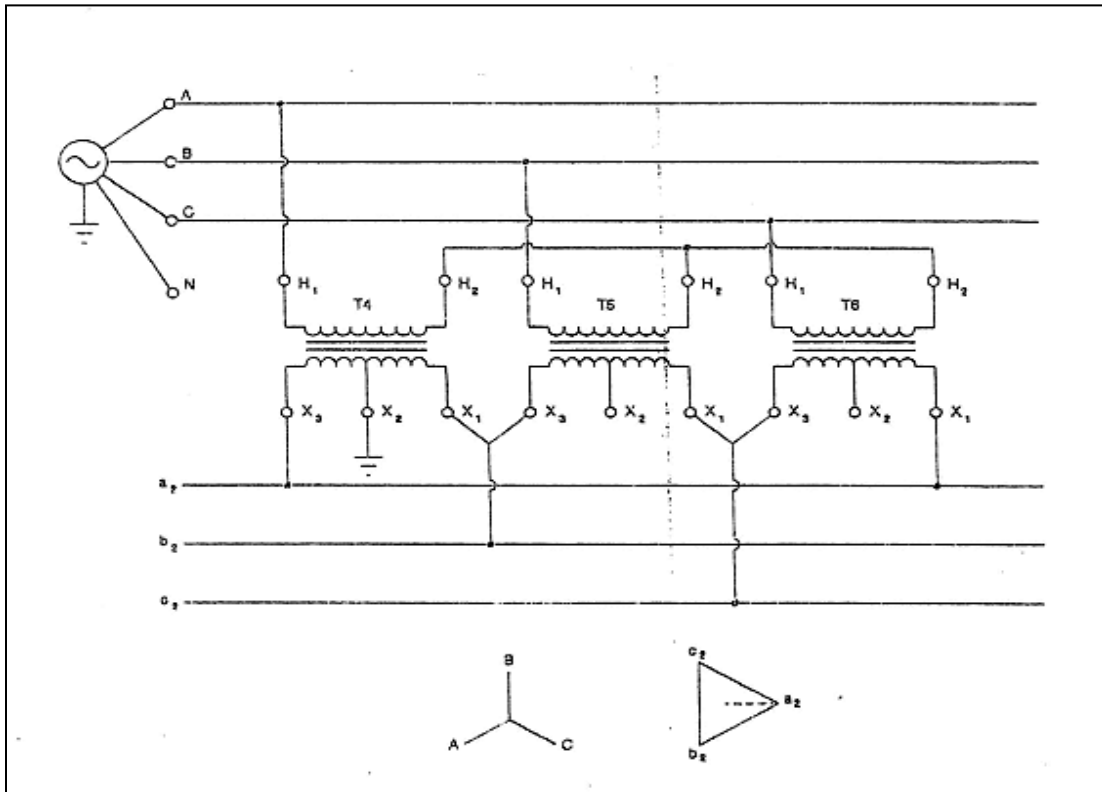
Figure 5.7

2. Turn on the Distribution Transformer Trainer and determine the voltage between lines

- a_1 and a_2 -------------

- b_1 and b_2 -------------

- c_1 and c_2 -----------

What can you conclude about the phase shift between lines a_1 and a_2 ?

3. Turn off the Distribution Transformer Trainer.

➢ PART I :Wye-Delta with Neutral:

1. Connect the circuit shown in the figure below.
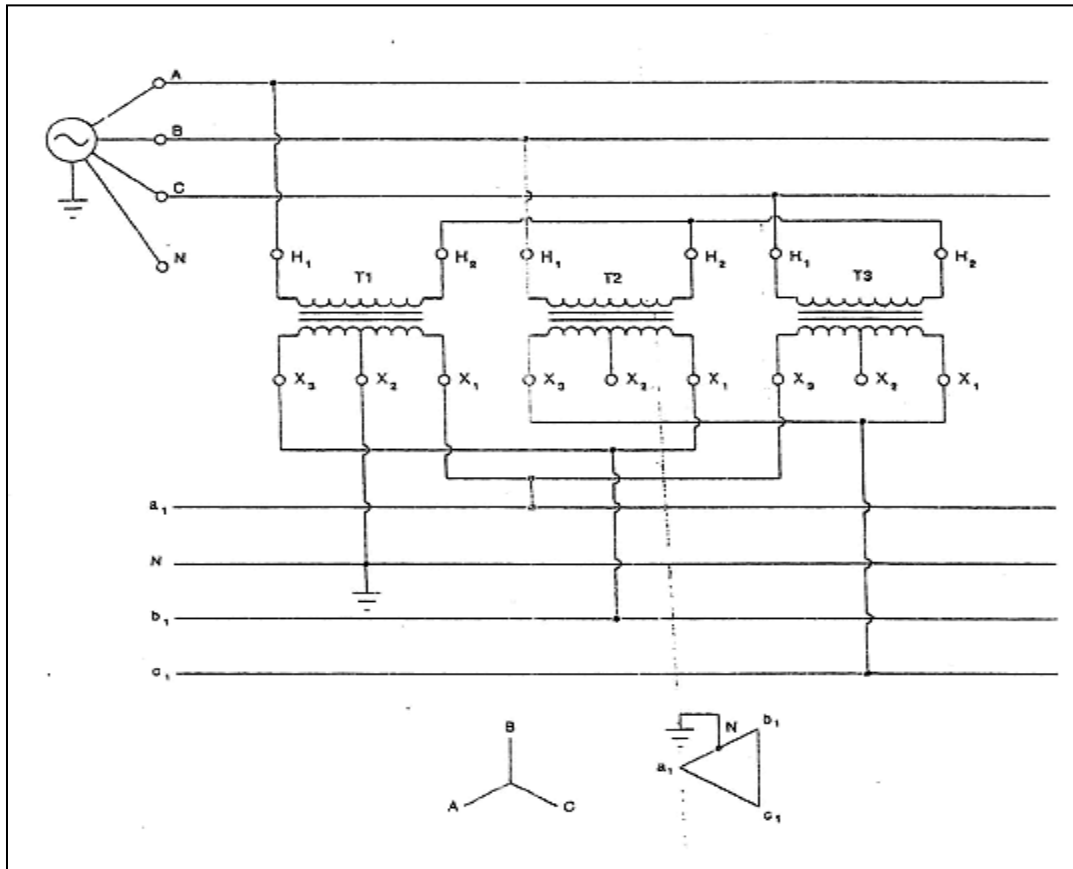
Figure 5.8

2. Turn on the Distribution Transformer Trainer and determine the voltage between lines

- a_1 and b_1 ------------
- b_1 and c_1 ------------
- c_1 and a_1 ------------
- a_1 and N ------------
- b_1 and N ------------
- c_1 and N ------------

3. Turn off the Distribution Transformer Trainer.
4. Leave the configuration connected so as to compare it with the next configuration.

➢ PART J :Wye-Delta with Neutral vs Wye-Delta with Neutral:

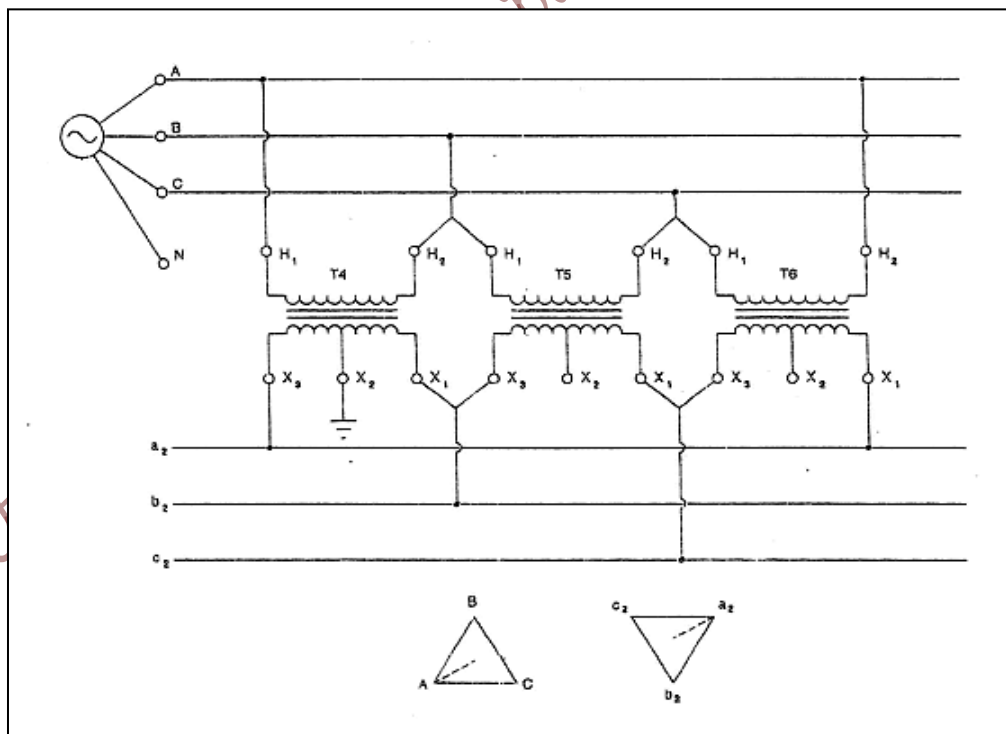1.Connect the circuit shown in the figure below.
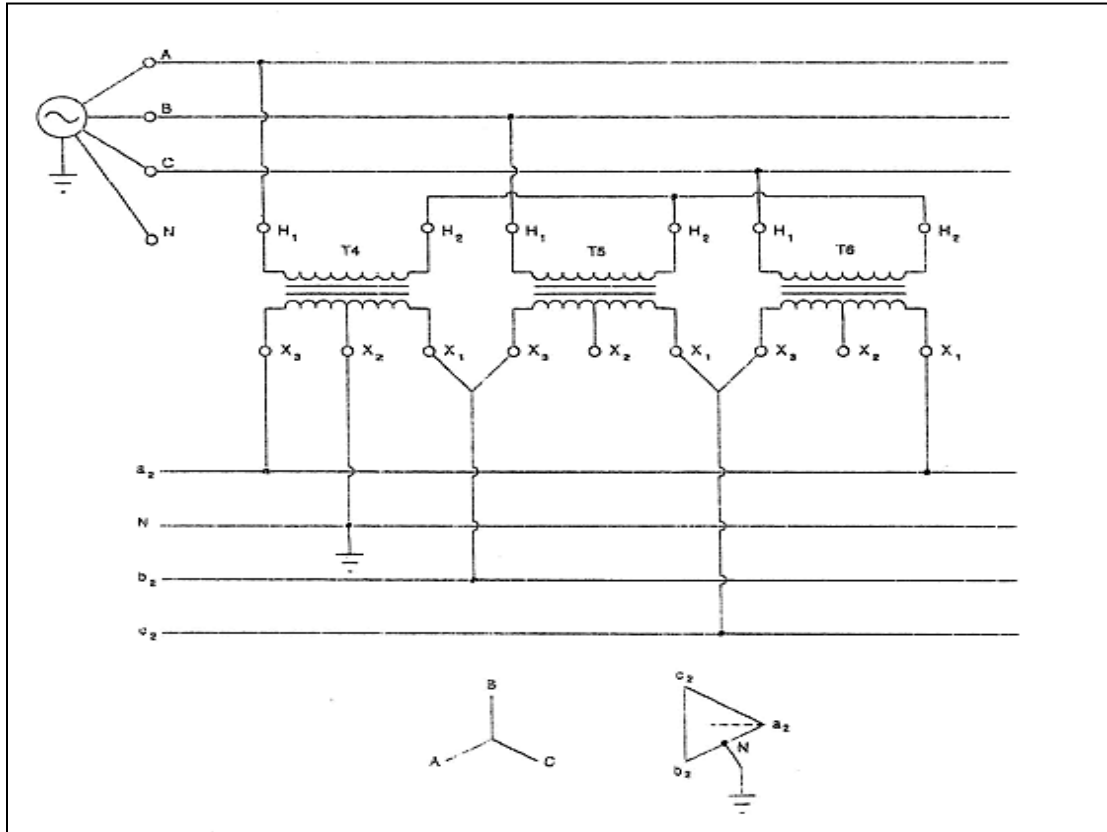
Figure 5.9

2. Turn on the Distribution Transformer Trainer and determine the voltage between lines

- a_2 and b_2 ....
- b_2 and c_2 ....
- c_2 and a_2 ---------
- a_2 and N   -----------
- b_2 and N   -----------
- c_2 and N   -----------

3. Determine the voltage between lines

- a$_1$ and a$_2$ -------------

- b$_1$ and b$_2$ -------------

- c$_1$ and c$_2$ ---------

What can you conclude about the phase shift between lines a$_1$ and a$_2$?

4. Turn off the Distribution Transformer Trainer.

➢ PART H :Delta-Wye connection:

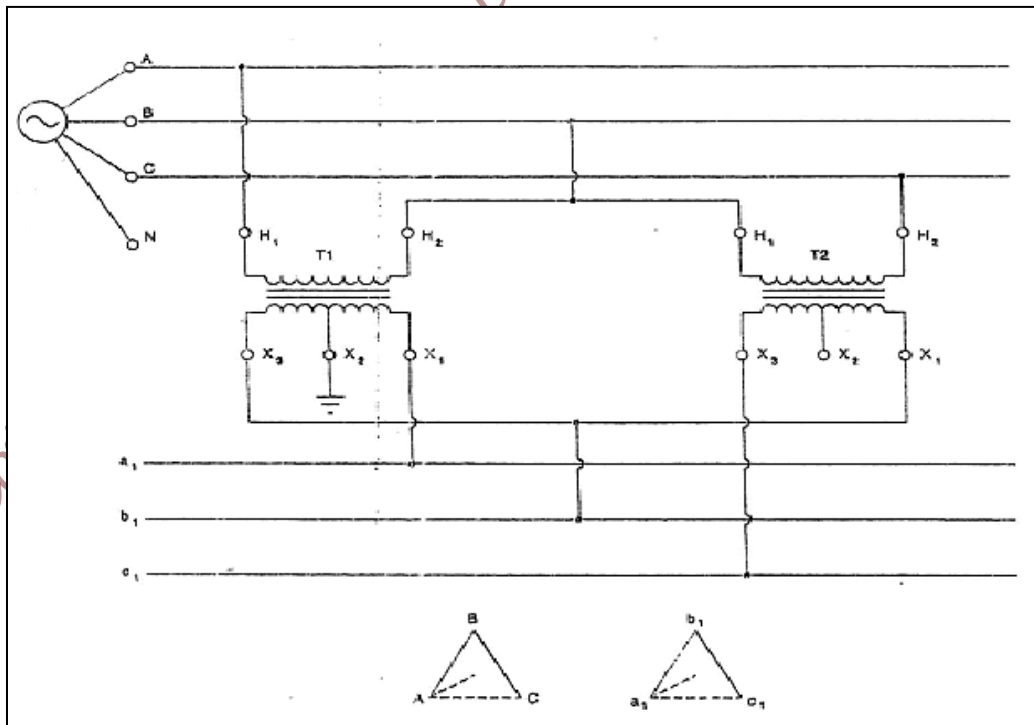Connect the circuit below.
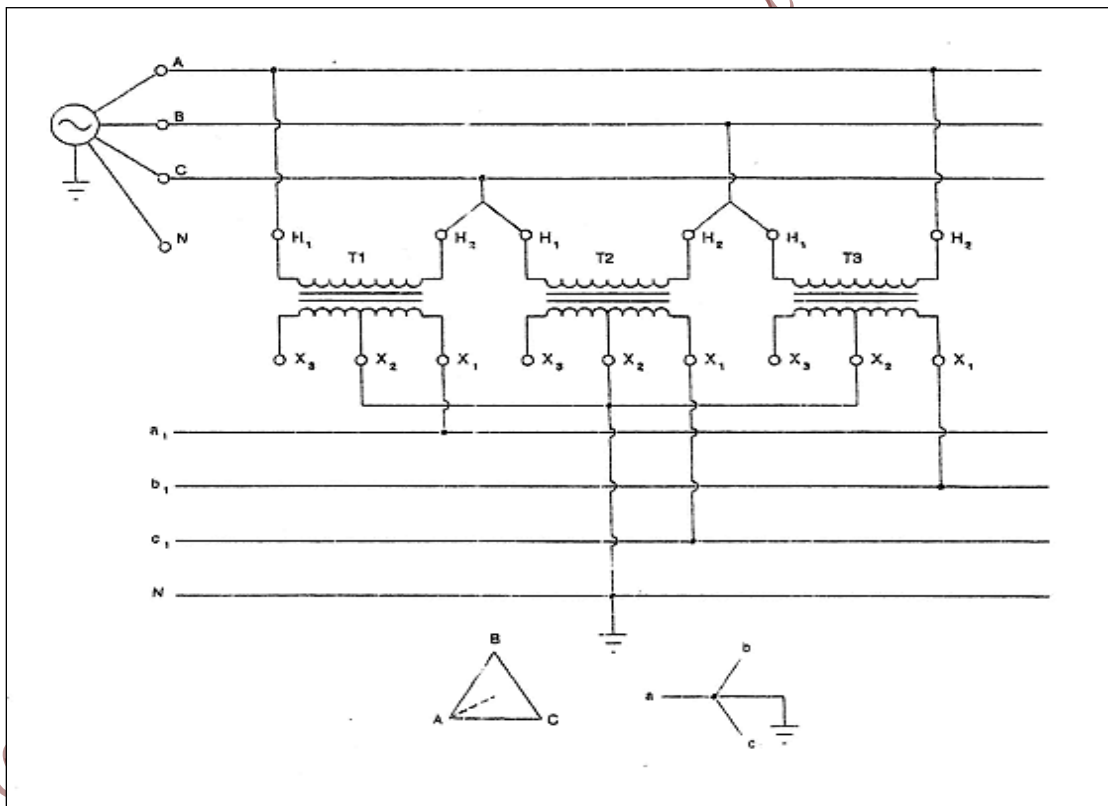
Figure 5.11

Turn on the Distribution Transformer Trainer and determine the voltage between lines

- a_1 and b_1 -------------
- b_1 and c_1 -------------
- c_1 and a_1 ----------
- a_1 and N -------------
- b_1 and N -------------
- c_1 and N -------------
- A and B -------------
- B and C -------------
- C and A -------------

Turn off the Distribution Transformer Trainer.

➢ PART :Wye-Wye Connection:

Connect the circuit below.
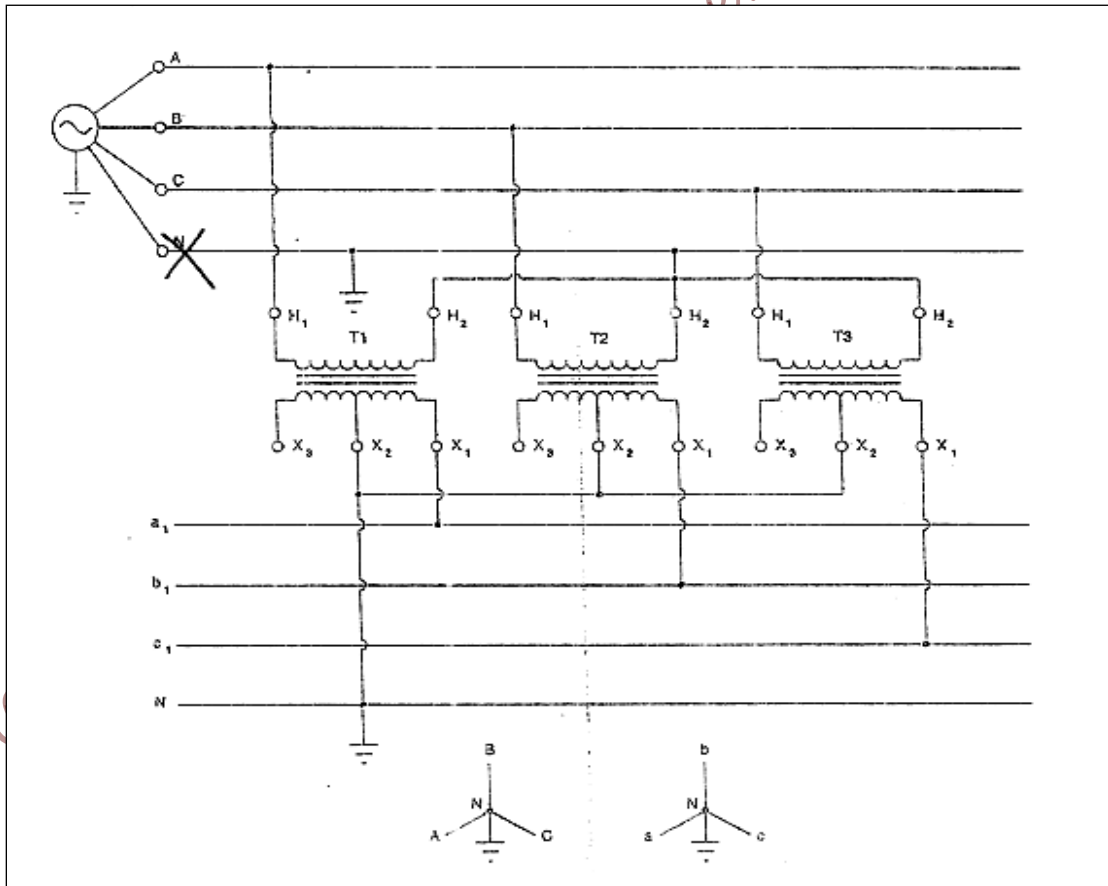
Figure 5.12

Turn on the Distribution Transformer Trainer and determine the voltage between lines

- a_1 and b_1 ------------
- b_1 and c_1 ------------
- c_1 and a_1 ---------
- A and B ------------
- B and C ------------
- C and A ------------
- Turn off the Distribution Transformer Trainer.

Experiment 4
Three Phase Synchronous Generator

Objectives

- Measuring and interpreting no-load voltage, short circuit voltage and load characteristics in generator operation without connection to power lines (isolated)
- Setting up various synchronizing circuits and understanding their manner of operation
- Investigating synchronous machines in four-quadrant operation when connected to power lines and determining efficiency in generator operation

Equipments List:

1 multi-function machine 0.3	732 28
1 machine test system	731 989
1 Extremely low DC power supply	725 352 D
1 External DC power supply	725 852 D
1 resistive load	732 40
1 capacitive load	732 41
1 inductive load	732 42
2 RMS meters	727 10
1 multifunction meter	727230
1 power factor meter	727 12

Theory

Synchronous machines can be equally well used as motors or as generators. They operate at a constant speed that corresponds to the speed of the stator's rotating field, which is referred to as synchronous speed n_s.

$$n_s = \frac{120 f_e}{P} \dots \dots \dots \dots \dots \dots \dots \dots \dots \dots \dots \dots \dots \dots \dots \dots \dots \dots \dots \dots \dots \dots \dots \dots 4.1$$

Where P is the number of poles and f_e is the electrical frequency

The rotor's excitation winding is fed by a direct current via slip rings such that it forms north and south poles. In contrast to asynchronous machines, synchronous machines can produce both active power as well as reactive power when operated as a generator. This means that in so-called "isolated operation" it can be used to supply energy without requiring any additional components, like capacitors. Once a synchronous machine is connected in parallel with a power

grid, active power and reactive power can be adjusted freely and independent of each other; so-called "four-quadrant operation" is possible.

Notations

P_1	Input Power
P_2	Output Power
T_N	Nominal torque
ŋ	Efficiency
I	Line Current
V	Line-Line Voltage
n	Mechanical speed

Experimental Procedure

A. Behavior as a Generator in isolated Operation

1. Using the data printed on the name plate of the machine, fill Table 4.1

Table 4. 1 Nominal data for machine under test

Nominal Voltage V_N when connected in star:	
Nominal Voltage V_N when connected in delta:	
Nominal Current I_N when connected in star:	
Nominal Current I_N when connected in delta:	
Nominal Power Factor, $\cos(\theta_N)$:	
Nominal Power P_N :	
Nominal excitation voltage V_{EN}:	
Nominal excitation current I_{EN}:	
Nominal speed n_N:	

2. Connect the circuit as shown in Figure 4.1.

Note: Do not turn on any part of the equipments without prior notice from the supervisor

3. To study the no load characteristic of the Generator, leave the generator terminals unconnected to any external load(open circuit), connect a voltmeter between any two terminal lines as shown in Figure 4.1

4. Power on the machine test system while pressing on the "Only Motor Operation Button" to allow the machine to work as a generator " the only motor operation led will turn off
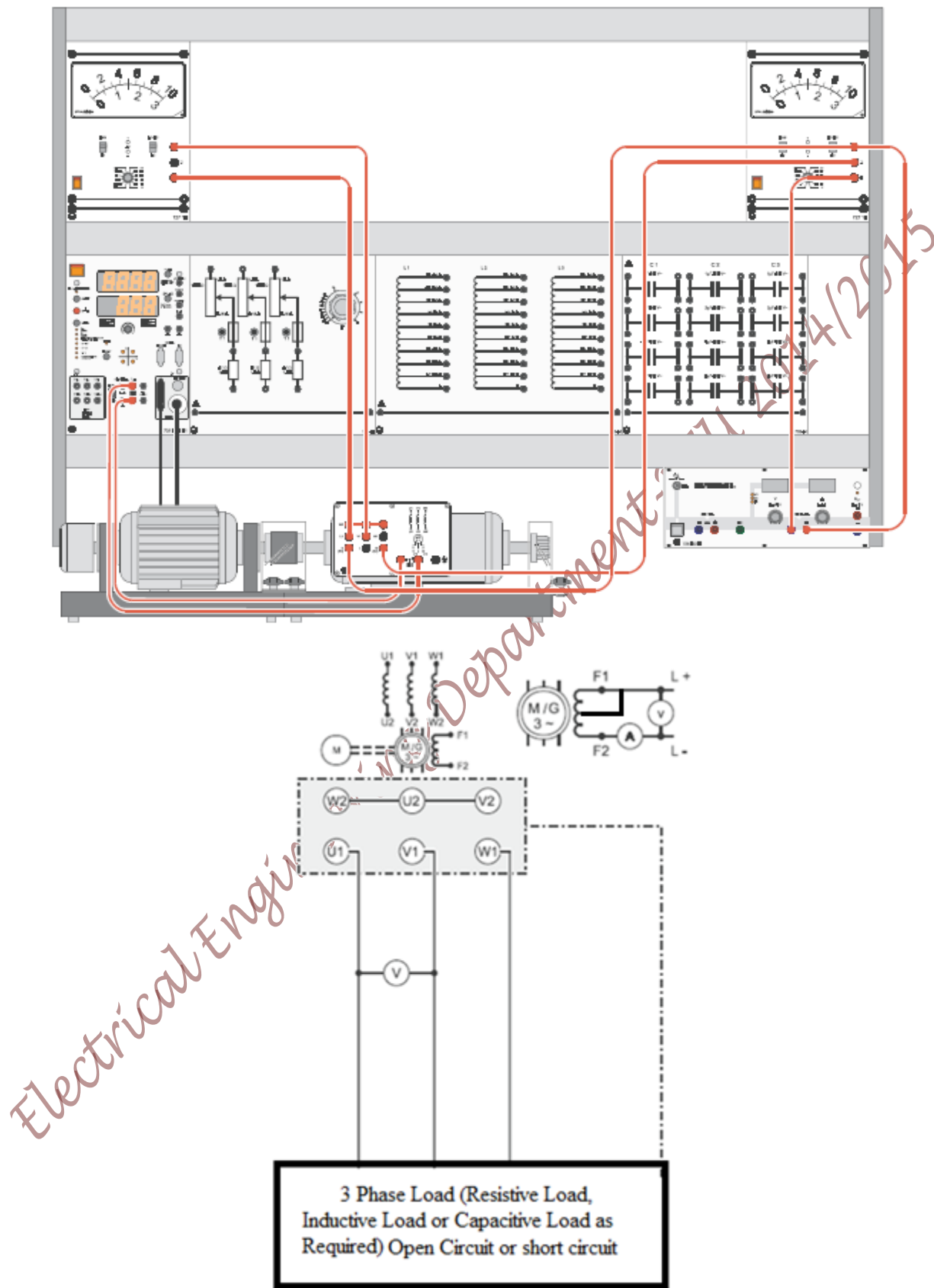
Figure 4. 1 Circuit for studying synchronous Generator

4.1 Generator NO-LOAD Characteristics

a) Press on the RED button on the machine test system to turn on the machine test system, when it becomes on and with the operational mode "Load Characteristics"(first mode) is selected, drive the Generator with a constant speed of 1500 rpm

b) Using the Nominal values of the excitation current and output voltage obtained in Table 4.1, calculate I_E values for the given I_E/I_{EN} values in Table 4.2, then, turn on the external DC power supply to excite the generator with the required I_E, for each I_E values, measure the voltage V_0 (the line to line open circuit voltage) and fill in Table 4.2 note that you may need to use both DC power supplies to get the required value of I_E

c) Turn off the DC power supply, Turn off the machine test system by pressing the RED button

d)

Table 4. 2 Recording of the No-Load Generator characteristics

I_E/I_{EN}	0.0	0.1	0.2	0.3	0.4	0.5	0.6	0.7	0.8	0.9	1.0	1.1	1.2
I_E/[A]	$0.0XI_{EN}$												
V_0/[V]													
V_0/V_N													

4.2 Generator Short Circuit Characteristic

a) Drive the Generator with a speed of 1500 as you did for the previous recording (**refer to step 4 and to step 4.1a**)

b) Change the connection of the circuit to study the short circuit characteristic of the generator, connect the rms meter as an Ammeter in series with one of the Generator Terminals to measure the current in one phase, then short circuit all the terminal of the generator

c) Repeat step **4.1b**, but this time, fill in Table 4.3 Record I_{SC} instead of V_0

Table 4. 3 Recording the Generator Short Circuit Characteristics

I_E/I_{EN}	0.0	0.1	0.2	0.3	0.4	0.5	0.6	0.7	0.8	0.9	1.0	1.1	1.2
I_E/[A]													
I_{SC}/[A]													
I_{SC}/I_N													

Q1: Explain the process of calculating the synchronous reactance X_s, and then calculate its value using the data obtained in Table 4.2 and Table 4.3 at each value of I_E/I_{EN}, fill the results in Table 4.4.

Table 4. 4 Recording the Synchronous Reactance for different values of excitation current

I_E/I_{EN}	0.0	0.1	0.2	0.3	0.4	0.5	0.6	0.7	0.8	0.9	1.0	1.1	1.2
X_s													

Q2: Plot on the same graph 3 plots using a different Y axis for each plot, plots are V_0, I_{SC} and X_S on the Y axis, all versus I_E on the X axis

4.3 Generator Resistive Load Characteristics

a) Change the circuit connection to study the behavior of the Generator for different resistive load values as shown in Figure 4.2, make sure that the load is connected in Y configuration.
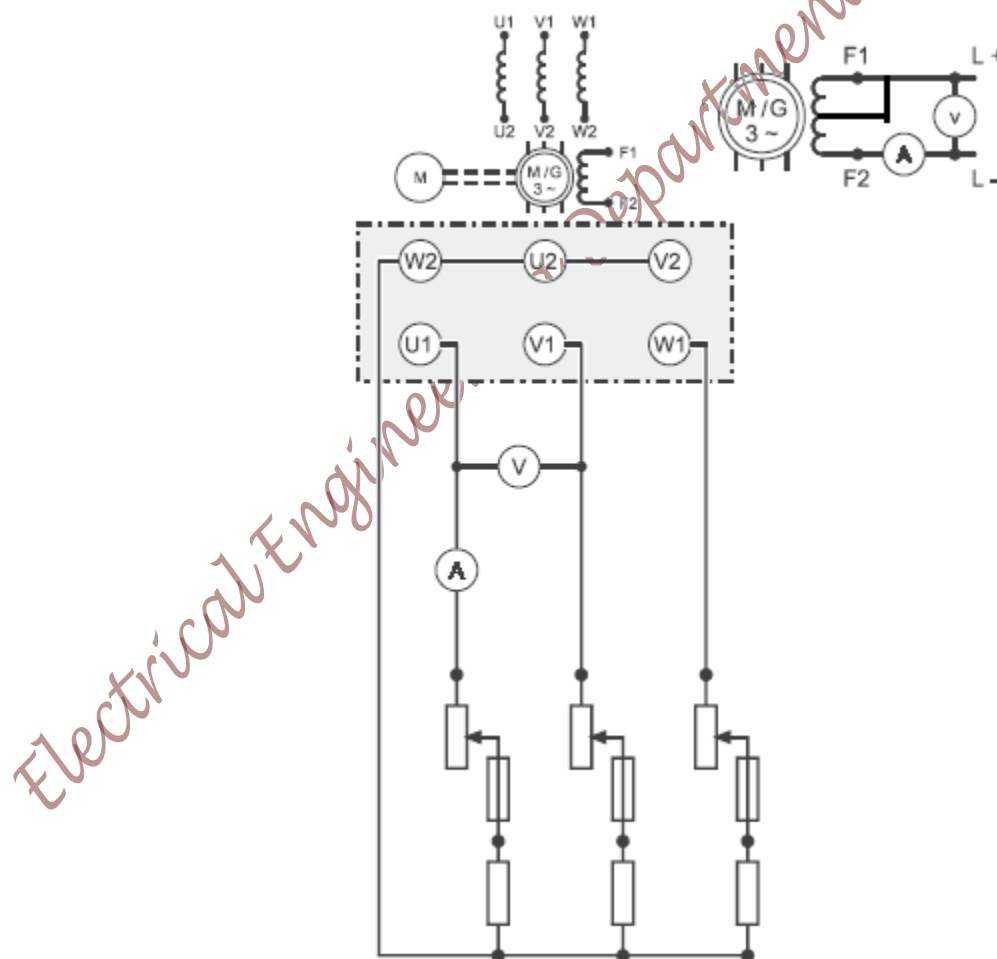
Figure 4. 2 Circuit to study the behavior of the Generator for Resistive Load

b) Set the Resistive Load to 100% of its value, Turn on the machine test system by pressing the RED button, make sure the LED indicating "Only Motor Operation" is off, drive the Generator with constant speed of 1500 rpm, and excite the Generator from the external DC power supply with the Nominal Current obtained in Table 4.1

c) For each percentage value of the Resistive Load in Table 4.5 record the load current (I) in one phase, the line to line output voltage

d) Turn off the DC power supply then turn off the machine test system by pressing on the RED button on the machine test system

Table 4. 5 Generator Resistive Load Characteristic Recording

R%	100	90	80	70	60	50	40	30	20
I/[A]									
V_{L-L}/[V]									
I/I_N									
V_{L-L}/V_N									

4.4 Generator inductive Load Characteristics

a) Connect the circuit of Figure 4.2 but now for the inductive load connected as Y

b) Repeat the above measurement procedure but now for the inductive load values shown in Table 4.6, note that you have to turn off the system each time you need to change the value of the inductive load by setting the excitation current to zero and then pressing the RED button of the machine test system, also note that you have to take the measurements quickly for low values of the inductive load!

Table 4. 6 Generator inductive Load Characteristic Recording

L/[H]	6.0	4.8	2.4	1.2	1.0	0.8	0.6	0.4	0.2
I/[A]									
V_{L-L}/[V]									
I/I_N									
V_{L-L}/V_N									

4.5 Generator Capacitive Load Characteristics

a) Repeat all steps in **4.4** but this time for the Capacitive Load connected in Y, only use the Capacitive Load values specified in Table 4.7 (1 µF and 2 µF), note that you have to de-energize the machine every time you change the load value, also note that you have to take readings quickly!

Table 4. 7 Generator Capacitive Load Characteristic Recording

C/[µF]	1	2
I/[A]		
V_{L-L}/[V]		
I/I_N		
V_{L-L}/V_N		

Q3: Plot on the same graph (V_{L-L}/V_N) on the Y axis versus (I/I_N) on the X axis for the three different load cases (Resistive Load, Inductive Load and Capacitive Load)

B. Synchronizing Circuits

In this part, we are going to connect the generator in parallel with the main power lines

1. Get familiar with the Manual Synchronizing Unit by studying Figure 4.3

Manual Synchronization Unit

① Line mains input L1, L2, L3 and N
② Generator mains input L'1, L'2, L'3
③ Synchronization lamps
④ Synchronization switch (0 = OFF, 1 = ON)
⑤ Unit's main switch
⑥ Mains voltage and frequency display (U_1 and f_1)
⑦ Generator's voltage and frequency display (U_2 and f_2)
⑧ Zero-Volt indicator ΔU
⑨ Synchronoscope
⑩ Indicators for the directions of the rotating fields
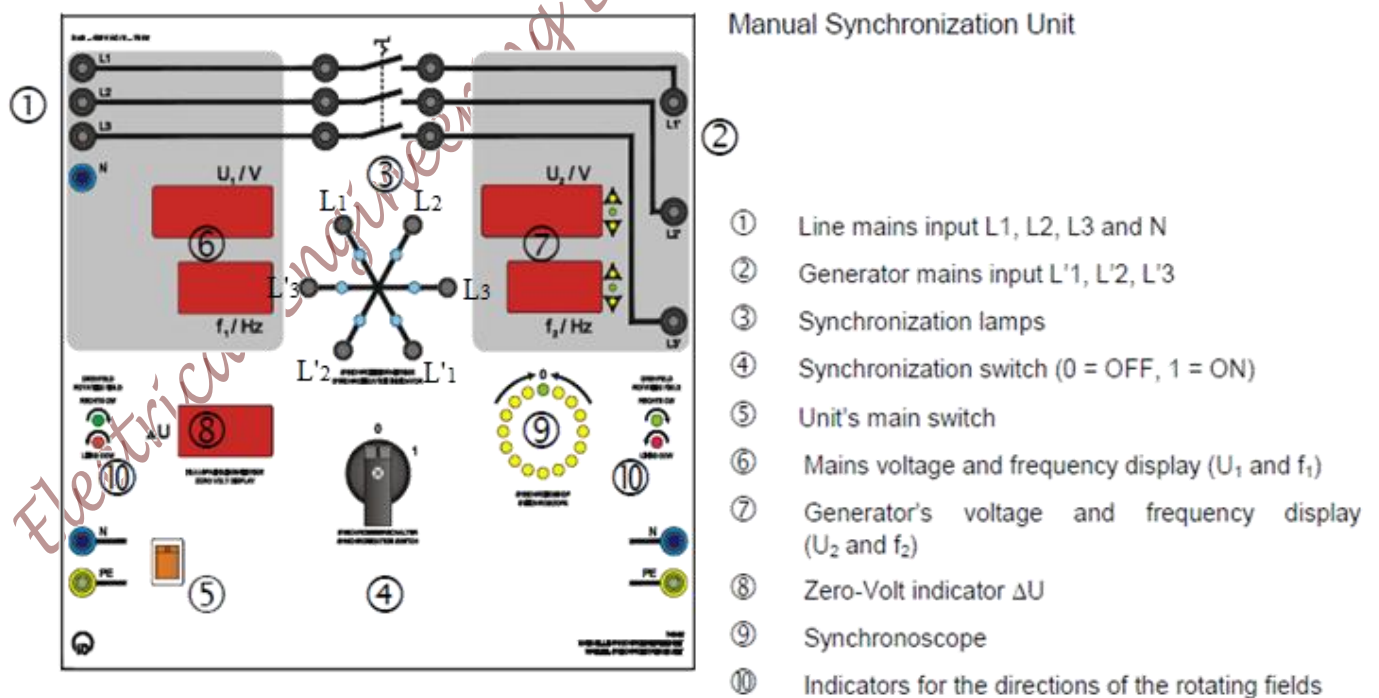
Figure 4.3 Manual Synchronizing Unit

2. Make sure that the Synchronization switch is at the 0 (off) position

3. Connect the three phase power supply to the Line Mains input L_1, L_2, L_3 and N, make sure that the 3 phase power supply is **<u>still OFF</u>**

4. Connect the oncoming generator terminals (through the machine test system unit to measure the output parameters of the generator) to the Generator mains input L'_1,L'_2 and L'_3, drive the generator by the machine test system to a speed of 1507 rpm so that the oncoming generator frequency is slightly higher than the main frequency, then excite the machine with the nominal excitation current found in Table 4.1 using the external power supply

5. Turn on the 3 phase power supply

6. Watch the indicators for the directions of the rotating fields (number 10 on the synchronizing unit), if they indicate the same direction of rotation on both sides, then the oncoming generator has the same phase sequence as the 3 phase power supply, otherwise (if the led in one side is RED and on the other side is Green) turn off the main 3 phase power supply, swap to phases, then turn the 3 phase power supply on, now, the phase sequence on both side should be the same

7. Make sure that you have the same phase sequence on both side, and that the RMS line voltage is the same on both sides, also make sure that the oncoming generator has slightly higher frequency(~50.1Hz) than the main supply

8. Wait and watch the synchroscope indicator, when it reaches the 12 O'clock the synchronization lamps should all be off (no light), at this point you can switch the synchronization switch to the ON state (position 1). Now, directly change the mode of operation of the machine test system from the **Load Characteristics** mode to the **Torque Regulation** Mode so that we can control the output power fed to the grid from our generator

9. Calculate the nominal torque **(T_N)** of the machine under test (AC multifunction machine 732 28) using the nominal values obtained in Table 4.1, for the torque normalized values given in Table 4.8, calculate the actual torque values using the following equation

$$Actual\ Torque\ Value = Normalized\ torque\ value X Nominal\ torque\ value$$

10. Change the torque values in steps as shown in Table 4.8, at each torque value, take readings (using the CBM 10 software) of the generator input power, the generator output power, the output current of the generator and the output power factor of the generator

Table 4.8: studying the behavior of the generator when connected in parallel with the main power grid

T/T$_N$	0.0	0.1	0.2	0.3	0.4	0.5	0.6	0.7	0.8
T$_{act}$									
V									
I									
Cos(ɵ)									
P$_{in}$									
P$_{out}$									

11. To isolate the generator from the grid, Press on the RED button of the machine test system, not that the machine is no longer in generation mode and it is operated as synchronous motor (it is taking electrical power from the grid), turn the main 3 phase power supply off and turn the synchronization switch of the synchronizing unit to the 0 (off) position, now you have isolated the machine from the main 3 phase power supply

Q4: Comment of the measurement obtained in Table 4.8, explain the coarse the values took when increasing the input torque

Experiment 5
Synchronous Motors (SM) and Slip Ring Motors

Objectives

After carrying out the experiments, the student will be capable of:

- Connecting a salient-pole synchronous motor and a slip ring induction motor in a star circuit, starting the motor with line power, and reversing its rotational direction.

- Recording and interpreting various synchronous machine load characteristics in motor operation and determining its efficiency.

- Operating the synchronous motor as a phase shifter and recording its V curve characteristics.

- Putting a three-phase slip-ring induction motor into operation with a starter resistor

- Modifying the torque-speed characteristics with the help of various values startup resistor

- Connecting a three-phase slip ring induction motor as a rotary transformer and investigating its mode of operation

- Recording the machine Run-up characteristics using computer based approach for slip ring motor

Equipment List

1 multi-function machine 0.3	732 28
1 machine test system	731 989
1 CBM 10 computer-based analysis of electrical machines, V.5	728 421
1 three-phase supply unit with FCCB	726 75
1 three pole on/off switch	731 42
1 motor protection switch, 1 ... 1.6 A	732 14
1 Extremely low DC voltage power supply	725 352 D
1 DC voltage power supply	725 852 D
1 power factor meter	727 12
2 RMS meters	727 10
1 Rotor starter resistor	732 29

Notation

P_1	Input Power
P_2	Output Power
T_N	Nominal torque
ŋ	Efficiency
n	Mechanical speed

Theory

Synchronous machines can be equally well used as motors or as generators. They operate at a constant speed that corresponds to the speed of the stator's rotating field, which is referred to as synchronous speed n_s. The rotor's excitation winding is fed by a direct current via slip rings such that it forms north and south poles.

When operating as a motor, the stator's rotary field causes the rotor to move; when operating as a generator just the opposite is true, the rotor being driven inside the stator causes a rotary field to be produced. The rotor continues to lag behind the rotary field by a load angle δ when the motor is loaded. If the load torque exceeds a certain value (the so-called "breakdown torque") then the motor will drop out of step and remain at a standstill; "slipping poles phenomena occurs" Synchronous motors are usually designed such that their breakdown torque is twice as high as their nominal torque. Synchronous motors react less sensitivity to voltage dips than do asynchronous motors. The Output torque changes linearly with stator voltage.

An asynchronous motor's starting current is independent of the load. Starting current will be several times over nominal current if no countermeasures are implemented. However, starting current can be influenced by the amplitude of voltage applied to the stator, by resistors in series, or by a startup transformer. The most frequently used technique is the star-delta switchover. The "stator resistance starting circuit" employs a series resistor in only one of the three phases to reduce starting current. If the machine has a slip ring rotor, then additional resistors can be connected into the rotor circuit to reduce starting current during the startup process. At the same time, this can be used to influence the course of torque and speed characteristics. Related experiments will be performed with a slip ring rotor motor as well as with a multi-function machine.

Experimental Procedure

Note1: <u>Do not turn on any part of the equipments without prior notice from the supervisor</u>

Note2: The machine 732 28 should only be connected in star configuration

Synchronous Motor

A. Basic Circuit

1. Set up the equipment as shown in Figure 5.1

2. Power on all the modules
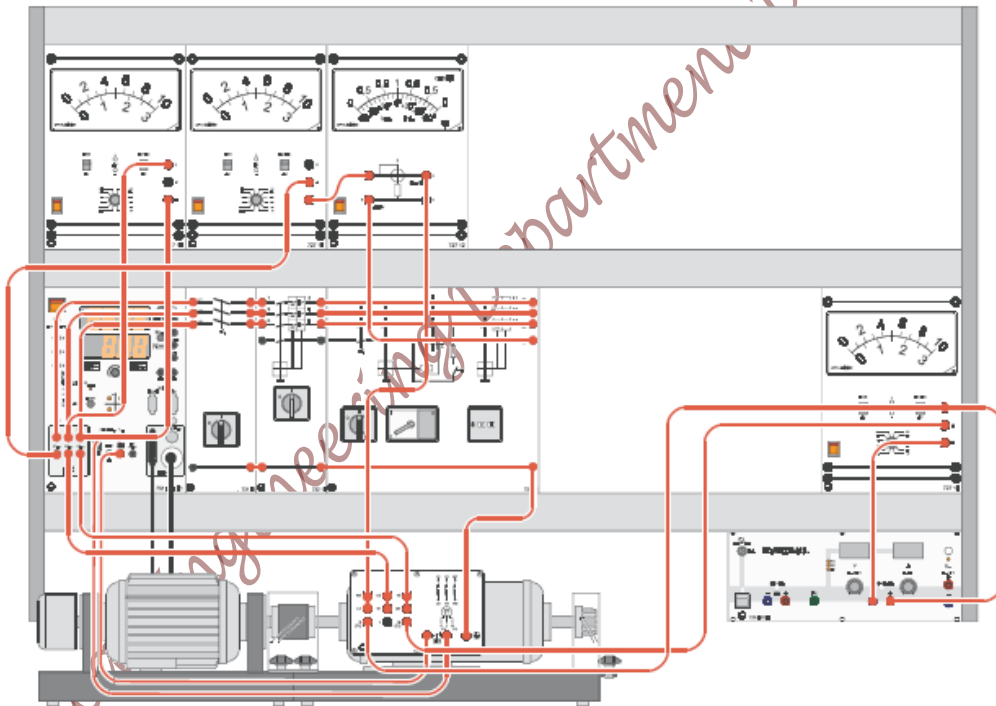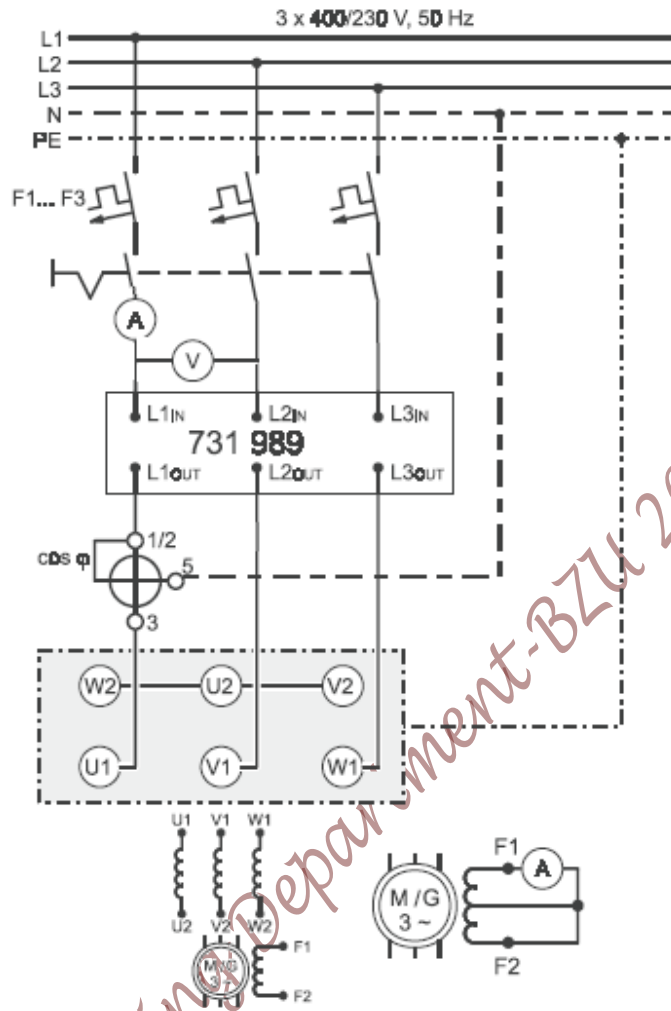
Figure 5. 1 Circuit for studying the behavior of a synchronous Motor

3. Press the ON button of the power circuit breaker module and directly measure the startup current induced in the Rotor winding

4. Measure the steady state current that is induced in the exciter winding, the speed and observe the direction of rotation (by looking on the motor shaft from the coupling side from left to right)

5. Press the OFF button of the power circuit breaker module

Q1: Why is the speed somewhat less than synchronous speed?

6. Make the necessary connection adjustments to reverse the direction of rotation

7. Press the ON button of the power circuit breaker module

8. Measure the speed and observe the direction of rotation

9. Press the OFF button of the power circuit breaker module

10. Undo the changes made in step 6 (reversing the direction of rotation)

11. Using the Extremely low DC power supply, make the connection shown in Figure 5.2 then excite the machine with 1A using the DC source

12. Press the ON button of the power circuit breaker module
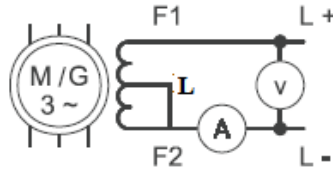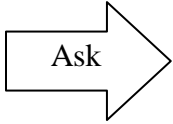
Figure 5. 2 Rotor Connection as required in step 11

13. Measure the speed and observe the direction of rotation

14. Press the OFF button of the power circuit breaker module

Q2: Compare and explain the speed results obtained in **step 13** and in **step 4**

B. Determining Efficiency and Recording Characteristics for SM

a) Efficiency Calculations

1. Using the data printed on the name plate of the machine, fill in Table 5.1

Table 5. 1 Nominal data for the machine under test

Nominal Voltage V_N when connected in star:	
Nominal Voltage V_N when connected in delta:	
Nominal Current I_N when connected in star:	
Nominal Current I_N when connected in delta:	
Nominal Power Factor, $Cos(\theta_N)$:	
Nominal Power P_N:	
Nominal excitation voltage V_{EN}:	
Nominal excitation current I_{EN}:	
Nominal speed n_N:	

2. Using the data obtained in Table 5.1, Calculate the Nominal torque T_N

3. Open the CBM software from Start>>all programs>>CBM10>>MOMO, then go to Measurement>>Settings, set the operational mode to **Torque control** mode

4. Excite the machine with I_{EN} (the nominal excitation current from Table 5.1)

5. Press the ON button of the power circuit breaker module

6. Press the RED button of the machine test system to connect the load torque

7. Set the nominal torque T_N obtained in step 2 as a load for the motor using the machine test system make sure that the output power P_2 matches the nominal power P_N, since the motor

is working at its nominal speed. Slightly adjust the excitation current until the power factor meter reads unity power factor

8. Measure the line-to-line Voltage V_{L-L}, the current in one phase (I), the excitation voltage V_E and the excitation current I_E

9. Press the RED button of the machine test system to disconnect the load torque

10. Press the OFF button of the power circuit breaker module

11. Reduce the output current of the DC power supply to minimum

Q3: Calculate the motor input power, the motor output power from steps 7 and 8

Q4: Calculate the theoretical value of the efficiency η_{eff} based on values obtained from the machine name plate; also calculate the efficiency η_{act} based on the actual measured values, and then compare both values of efficiency

b) Load Characteristics

The relationship between current, power factor and such values with respect to load torque is called Load Characteristics. In this part the machine under test behavior will be studied for different values of load torque. For the following measurements, the normalized value for any reading (I, V, Cos(θ) etc..) can be calculated as:

$$Normalized\ Value = \frac{Actual\ Value}{Nominal\ Value}$$

1. Calculate the T/[Nm] row in Table 5.2

2. Set the extremely low DC voltage power supply to give the nominal excitation current I_{EN}

3. Press the ON button of the power circuit breaker module

4. Press the RED button of the machine test system

5. Make sure you are still in Torque Control Mode, start increasing the torque as shown in Table 5.2, For each value, measure speed (n), phase current (I), and power factor (PF) indicating if it is leading or lagging

6. Press the Red Button on the machine Test System

7. Press the OFF button of the power circuit breaker module

8. Reduce the output current of the extremely low voltage DC power supply to minimum

Ask

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Table 5. 2 Measurement for Load Characteristic Recording with constant excitation current

	T/T$_N$	0.0	0.1	0.2	0.3	0.4	0.5	0.6
	T/[Nm]	T$_N$X0.0						
Measure	n/[rpm]							
	I/[A]							
	Cos (θ)							
	Lag/lead							
calculate	n/n$_N$							
	I/I$_N$							
	P$_1$/[W]							
	P$_1$/P$_N$							
	P$_2$/[W]							
	P$_2$/P$_N$							
	η							
	T/T$_N$	0.7	0.8	0.9	1.0	1.1	1.2	1.3
	T/[Nm]							
Measure	n/[rpm]							
	I/[A]							
	Cos (θ)							
	Lag/lead							
calculate	n/n$_s$							
	I/I$_N$							
	P$_1$/[W]							
	P$_1$/P$_N$							
	P$_2$/[W]							
	P$_2$/P$_N$							
	η							

Q5: Plot on the same graph the normalized values (n/n$_N$, I/I$_N$, P$_1$/P$_N$, P$_2$/P$_N$ and Cos (θ)) on the Y axis versus normalized Load Torque (T/T$_N$) on the X axis, explain the behavior of the motor based on your plots?

C. V Curves and Phase-shift Operation

In this part, we are about to Record the so called V-Curves, V-Curves are representation for the behavior of stator current with the different values of excitation current at constant load torque

1. Using the nominal value of the excitation current obtained earlier, calculate the first row of Table 5.3, these are the excitation current values that you will change while recording

2. For values of excitation current less that the nominal value, use the extremely low DC power supply –the smaller module- which provide low DC current, for higher values of the excitation current, use the DC power supply-the larger module- fill the unshaded values in all the table first using the extremely low DC power supply 725 **3**52 D, then use the DC voltage power supply 725 **8**52 D to fill the shaded part of all the table for higher values of excitation current

3. Record the value of excitation current when the power factor goes from lagging to leading noting the reading on the power factor meter

4. Set the excitation current to its nominal value found earlier, make sure that the machine test system at the Torque Control mode of operation

Ask ⟩ 5. Press the ON button of the power circuit breaker module
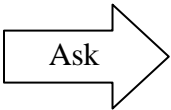
Note 1 for the values of excitation current that are larger than the nominal value (1.5 1.4 1.3 1.2 and 1.1), you have to take reading <u>as fast as possible</u>

Note 2 When reaching low excitation current values<u>; be ready to press the RED button on the machine test system</u> whenever the machine loses synchronism

6. Press the RED button of the machine test system

7. apply a zero torque, start changing the excitation current as required in Table 5.3 and record the stator current

Table 5. 3 Measurement for Recording V Curves at $T/T_N=0$

I_E/I_{EN}	1.1	1.0	0.9	0.8	0.7	0.6
I_E/[A]						
I/[A]						
I/I_N						
I_E/I_{EN}	0.5	0.4	0.3	0.2	0.1	0
I_E/[A]						
I/[A]						
I/I_N						

8. Repeat steps 7 for (T/T$_N$ 0.25, 0.5, 0.75 and 1) this time fill in Tables 5.4, 5.5,5.6 and 5.7 respectively. Make sure that you take the readings that are above the nominal excitation current value quickly. And for low excitation current values, <u>make sure that you press the RED button on the machine test system whenever the machine loses synchronism</u>

Table 5. 4 Measurement for Recording V Curves at T/T$_N$=0.25

I$_E$/I$_{EN}$	1.1	1.0	0.9	0.8	0.7	0.6
I$_E$/[A]						
I/[A]						
I/I$_N$						
I$_E$/I$_{EN}$	0.5	0.4	0.3	0.2	0.1	0
I$_E$/[A]						
I/[A]						
I/I$_N$						

Table 5. 5 Measurement for Recording V Curves at T/T$_N$=0.50

I$_E$/I$_{EN}$	1.1	1.0	0.9	0.8	0.7	0.6
I$_E$/[A]						
I/[A]						
I/I$_N$						
I$_E$/I$_{EN}$	0.5	0.4				
I$_E$/[A]						
I/[A]						
I/I$_N$						

Table 5. 6 Measurement for Recording V Curves at T/T$_N$=0.75

I$_E$/I$_{EN}$	1.1	1.0	0.9	0.8	0.7	0.6
I$_E$/[A]						
I/[A]						
I/I$_N$						

Table 5. 7 Measurement for Recording V Curves at T/T$_N$=1

I$_E$/I$_{EN}$	1.1	1.0	0.9	0.8	0.7
I$_E$/[A]					
I/[A]					
I/I$_N$					

9. Press the RED button of the machine test system to isolate the load torque
10. Press the OFF button of the power circuit breaker module

11. Plot on the same graph the normalized stator current (**I/I$_N$**) on the Y axis versus the normalized excitation current values (**I$_E$/I$_{EN}$**) on the X axis for the previous five Tables

Q7: Explain the resulting curves in step 11. Does the behavior accommodate with the expected theoretical behavior?

Q8: In the previous tables, you have witnessed severe vibration for the motor at low excitation current. Explain this phenomenon?

Slip Ring Motor

Transformer Operation

1. Keep the previous connection, only change the rotor connection as shown in   Figure 5.3
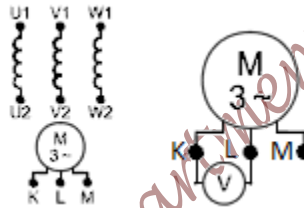
Figure 5.3 Rotor connection for the slip ring motor as a transformer

Ask

2. Press the ON button of the power circuit breaker module

3. Record the reading of the voltmeter of Figure 5.3 on the rotor

4. Press the OFF button of the power circuit breaker switch

Q9: Explain the voltmeter reading obtained in step 3

5. Change the Rotor connection and connect the rotor startup resistor 732 29 as shown in Figure 5.4
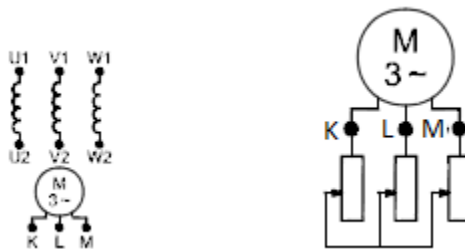
Figure 5.4 Rotor connection for the slip ring motor with the slip ring resistor connected

Ask →
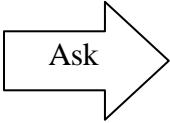
6. Set the rotor start up resistor to position 6
7. Press the ON button of the power circuit breaker module
8. Press the RED button of the machine test system
9. Set the load torque to be 1Nm (you should be at the torque control mode)
10. Record the speed of the motor when the rotor start up resistor is at position 6, continue for various values of rotor resistor as shown in Table 5.8

Table 5.8 speed for a constant load at various values of starter resistor (position 6: 0 resistance, position 1: highest resistance

Position	6	5	4	3	2	1
n/[rpm]						

11. Press the RED button of the machine test system
12. Press the ON button of the power circuit breaker module

Computer based Recording of Run-up Characteristics

In this part, we shall use the computer to plot curves that represent the behavior of the slip ring motor for different values of starter resistor

1. Open the CBM 10 software by going to Start>>All Program>>CBM10>>MOMO.exe (click on MOMO) the software will open up
2. Choose the machine under test type by going to Machine Type in the toolbar click on slip ring motor
3. Display only Torque Y axis by clicking on all other values of I, P_1, P_2 etc... in the left hand column of the program
4. Change the axis settings from Presentations>>Axis scaling, first check all the nominal value boxes, fill in the Nominal Values fields the ones that you have obtained for the machine in this experiment, modify the values of the Y axis for the parameters according to Table 5.9

Table 5.9 Y axis limits for the stated parameter for plotting

Parameter	From	To
n	0	1.2
torque	0	2.5

5. Go to Measurements>>Settings, in the popup window, set the operational mode to **Load Characteristics,** set the start up speed to **1500 rpm**, set the stop speed to **50 rpm**, then press ok

6. Set the starter resistor to position 6 (initial position)

7. Press the ON button of the 745 561 module to power on the motor

8. On the CBM 10 software press on the Green button on the left hand column (this is the synchronization button that will synchronize the machine test system with the motor), wait for synchronization, make sure you choose the Automated Mode recording, then start the plotting by pressing on the RUN button on the software (the blue arrow in the up left corner)

9. When the plotting is over, press on the RED button on the software to isolate the machine test system from the motor

10. Set the starter resistor to position 5

11. Repeat steps 8 and 9 for startup resistor on position 5

12. Repeat steps 8 and 9, but this time for startup resistor positions (4, 3, 2 and 1)

13. Press on the OFF button of the power circuit breaker module

14. If you have a camera, you can take a picture for the plots so that you use them in your reports, otherwise ask your instructor for the curves (**DO NOT** insert your flash disk into the computer!)

Q10: Comment on the plots you obtained?

Q11: Which rotor resistor position yields the maximum startup torque?

Ask

Experiment 6
Three Phase Squirrel Cage Induction Motor

Objectives:

After carrying out the experiments, the student will be capable of:

- Connecting a three-phase squirrel cage motor in a star and a delta circuit and reversing its rotational direction
- Start the three-phase squirrel cage motor with the help of a star-delta starter
- Measuring and interpreting stator current during start-up and after reaching full speed in a star circuit and a delta circuit as well as when configured in a stator-resistance starting circuit
- Determining the efficiency of a squirrel cage induction motor with measuring instruments and comparing it to the value calculated from the data on the rating plate
- Recording and interpreting various squirrel cage motor characteristics as a function of load torque or speed

Equipment List:

1 squirrel cage motor, 400 / 690 V	732 11
1 machine test system	731989
1 CBM 10 computer-based analysis of electrical machines, V.5	728421
1 three-phase supply unit with FCCB	726 75
1 motor protection switch, 1 ... 1.6 A	732 14
2 RMS meters	727 10
1 power factor meter	727 12
1star-delta starter	731 50
1star-delta switch	731 48
1 power circuit breaker module	745 561
1 motor protection switch 1 ... 1.6 A	732 14
1 resistive load	732 40

Notations

P_1	Input Power
P_2	Output Power
T_N	Nominal torque
ŋ	Efficiency
I	Line Current
V	Line-Line Voltage
n	Mechanical speed

Theory

The asynchronous (induction) motor represents the most important, yet simple, special case in the area of polyphase machines. Because of its high operational safety and low cost, it is preferred for a broad power range of unregulated drive mechanisms. Various asynchronous motors types arise from the design of the rotor, implemented either as a squirrel cage rotor or as a slip ring rotor.

The stator's rotary field is produced by the three outer conductors of a 3-phase system to which it is connected. The magnetic field rotates at synchronous speed n_s

$$n_s = \frac{120 f_e}{P} \dots \dots \dots \dots \dots \dots \dots \dots \dots \dots \dots \dots \dots \dots \dots \dots \dots \dots \dots \dots 6.1$$

Where P is the number of poles and f_e is the electrical frequency

However, the rotor rotates at a speed less than the synchronous speed, the mechanical speed (n) which is given by:

$$n = (1 - s)n_s \dots \dots \dots \dots \dots \dots \dots \dots \dots \dots \dots \dots \dots \dots \dots \dots \dots \dots \dots \dots \dots 6.2$$

Where s is called the slip and is given by:

$$s = \frac{n_s - n}{n_s} \dots \dots \dots \dots \dots \dots \dots \dots \dots \dots \dots \dots \dots \dots \dots \dots \dots \dots \dots \dots \dots . 6.3$$

A change in the direction of rotation can be easily accomplished by swapping stator connections for two of its input power phases. The mechanical output power of any electrical machine is given by equation 6.4, this equation is used to calculate the nominal torque (T_N) if the machine is operating at its nominal speed and nominal power

$$p_N = \omega_N \times t_N \dots \dots \dots \dots \dots \dots \dots \dots \dots \dots \dots \dots \dots \dots \dots \dots \dots \dots \dots \dots \dots . 6.4$$

Experimental Procedure:

Note: Do not turn on any part of the equipments without prior notice from the supervisor

Note**:** in all the figures in this experiments, the $F_1...F_3$ symbol is the motor protection switch 732 14 connected in series with the power circuit breaker module 745 561

A. Basic Circuit

1. Set up the equipment as shown in Figure 6.1
2. Turn on all the modules

ASK → 3. PressON button of the power circuit breaker module to provide the machine with power
4. measure the current in one phase, the line to line voltage, the phase voltage the speed and its direction
5. Press the OFF button of the power circuit breaker module to turn off the machine

Q1: How do you reverse the direction of rotation?

6. Make the necessary connection adjustments to reverse the direction of rotation
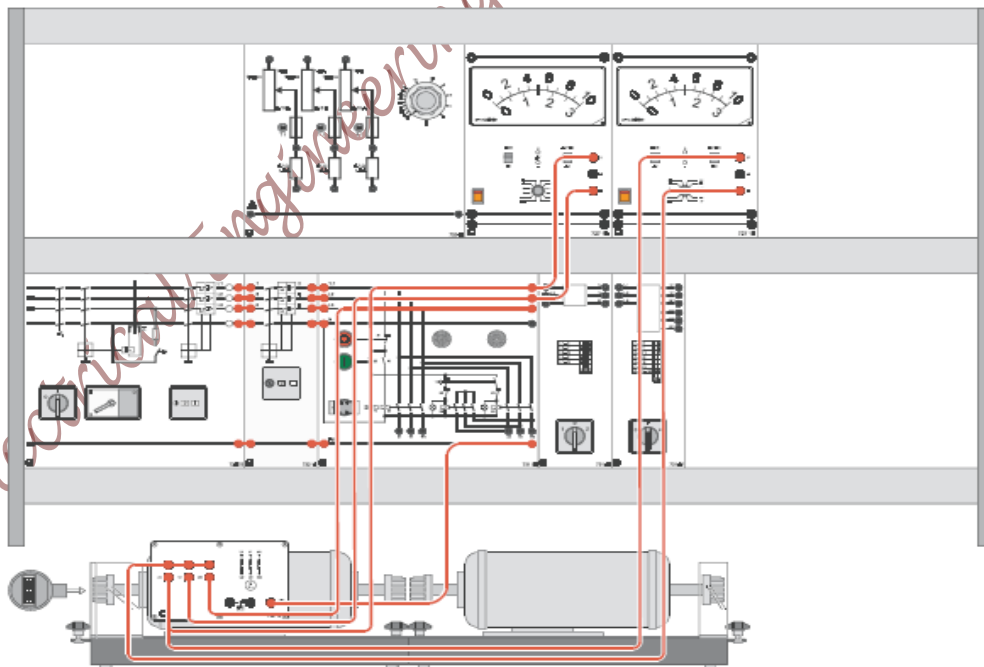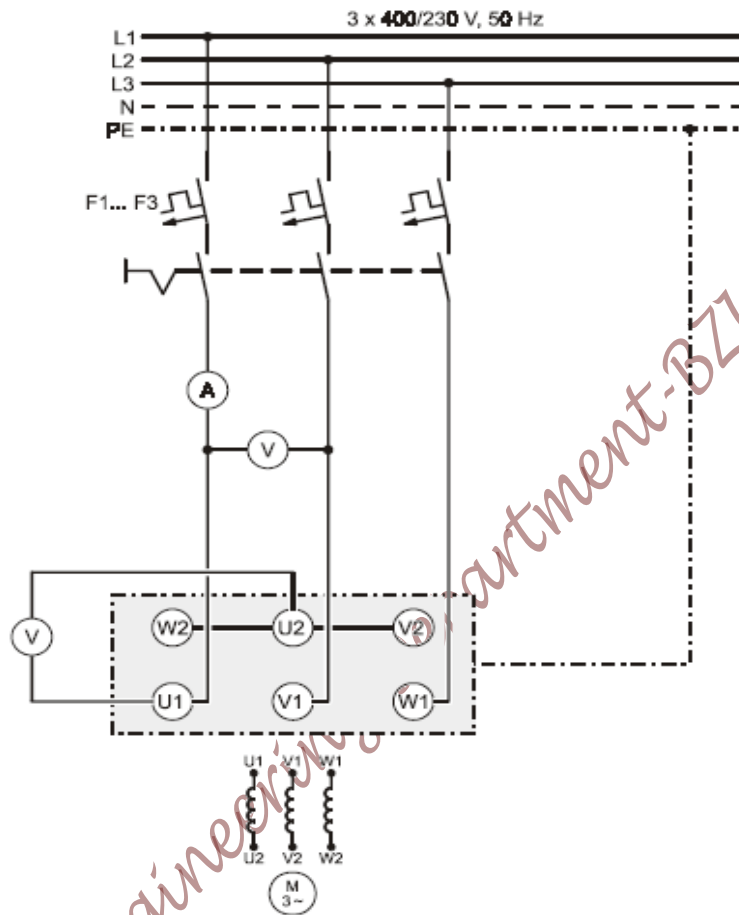
Figure 6.1 Circuit for studying the behavior of squirrel cage induction motor in Y connection

ASK

7. Repeat steps 3, 4 and 5, record your measurements

8. Change the connection to reverse the direction of rotation (changes made in step6)

9. Change the circuit connection to match Figure 6.2

Figure 6. 2 Circuit for studying the behavior of squirrel cage induction motor in delta connection

10. Repeat steps, 3,4 and 5 but now for the circuit connected in delta

11. To study the effect of startup resistor, connect the circuit shown in Figure 6.3 use the resistive load 732 40,note that you have to connect the machine test system 731 989 in order to measure the speed

12. Set both used RMS meters to read current with scale 1A

13. Set R% resistor indicator or the resistive load 732 40 to zero, press the ON button on the Power Circuit Breaker Module 745 561, directly measure the startup current (I_1) in the lead that is connected in series with the Resistor, and measure the startup current (I_2) in any lead that is not connected to the Resistor, fill your results in Table 6.1 and Table 6.2, make your measurement quickly, when you are done, press the OFF button on the Power Circuit Breaker Module 745 561, wait for the machine to stop

14. Repeat step 11 for different values of R% as required in Table 6.1 and Table 6.2(note: dot not wait until the motor reaches full speed)
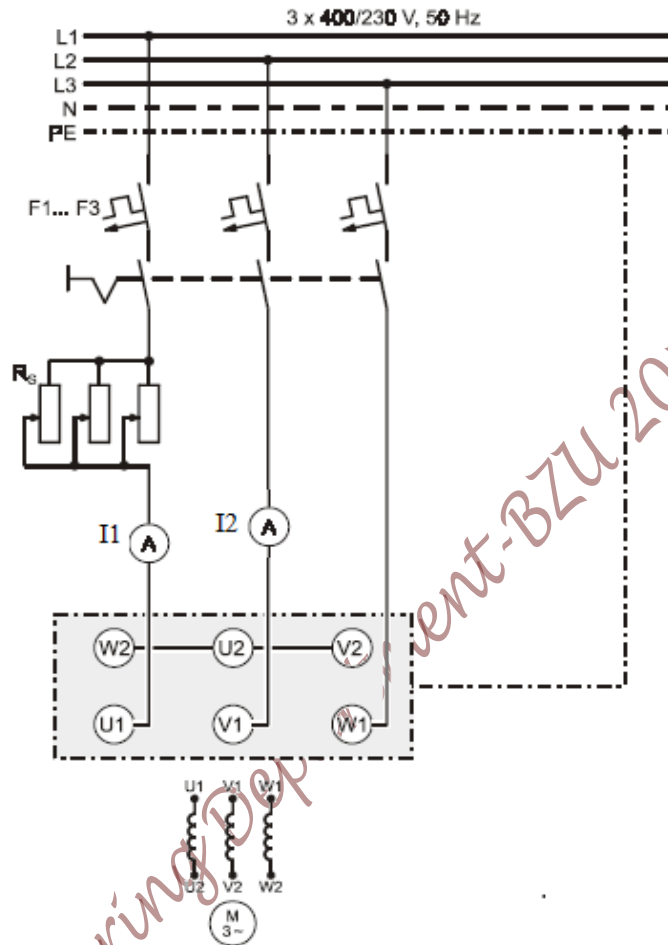
Figure 6. 3 studying the effect of startup resistor

Table 6.1 The effect of a startup resistor on the startup current

R$_s$/%	0	10	20	40	60	80	100
I$_1$/[A]							

Table 6.2 current recording in one of the leads that is not connected to the startup resistor

R$_s$/%	0	10	20	30	60	80	100
I$_2$/[A]							

Q2: Comment on the reading of the current values in Table 6.1 and in Table 6.2, compare them to each other?

B. Using a Star-Delta starter to change from Star to Delta connection

1. Connect the circuit as shown in Figure 6.4, make sure to setup the 731 48 switch module to Star initially
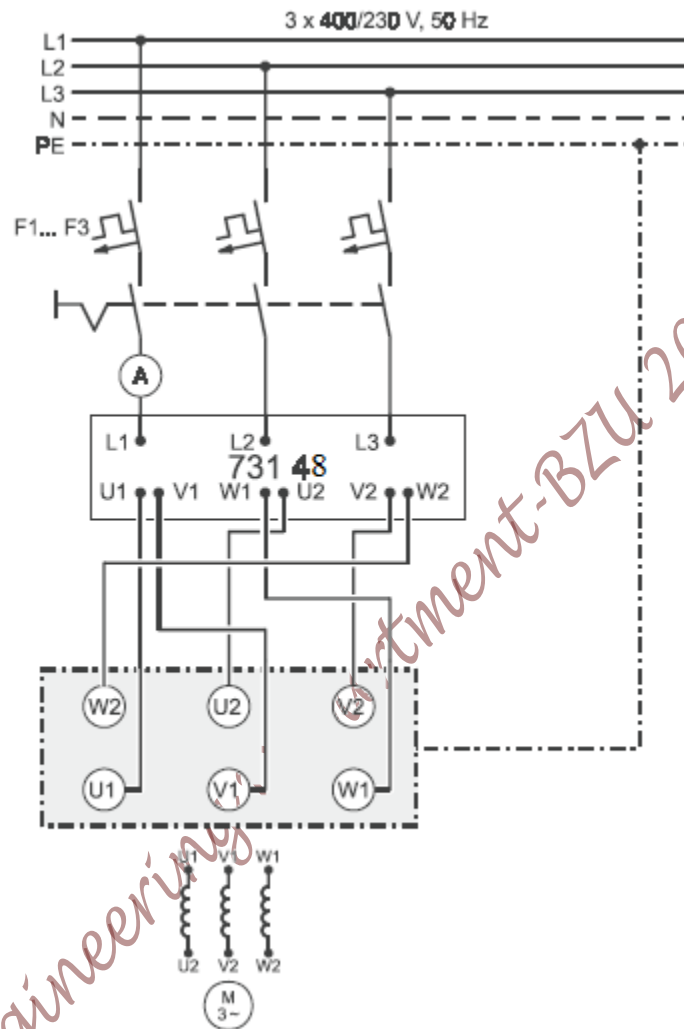
Figure 6.4 The circuit with a startup switch connected

ASK

2. Press the ON button of the 745 561 module to turn the motor on, measure the startup current (I_1) immediately after the motor is on, then measure the current (I_2) when the machine is at steady state, switch the 731 48 switch to change the connection to Delta and measure the current(I_3) immediately after switching the 731 47 switch, finally, measure the current (I_4) when the machine is at steady state for the Delta connection

3. While the machine is running, and the 731 48 switch is on the Delta position, change the switch position from Delta to Star and immediately measure the current(I_5) after the switch over

4. Press on the OFF button of the 745 561 module

Q3: How does the motor behave when it is switched over?

5. The switch from Star to Delta can be accomplished automatically, connect the circuit as shown in Figure 6.5
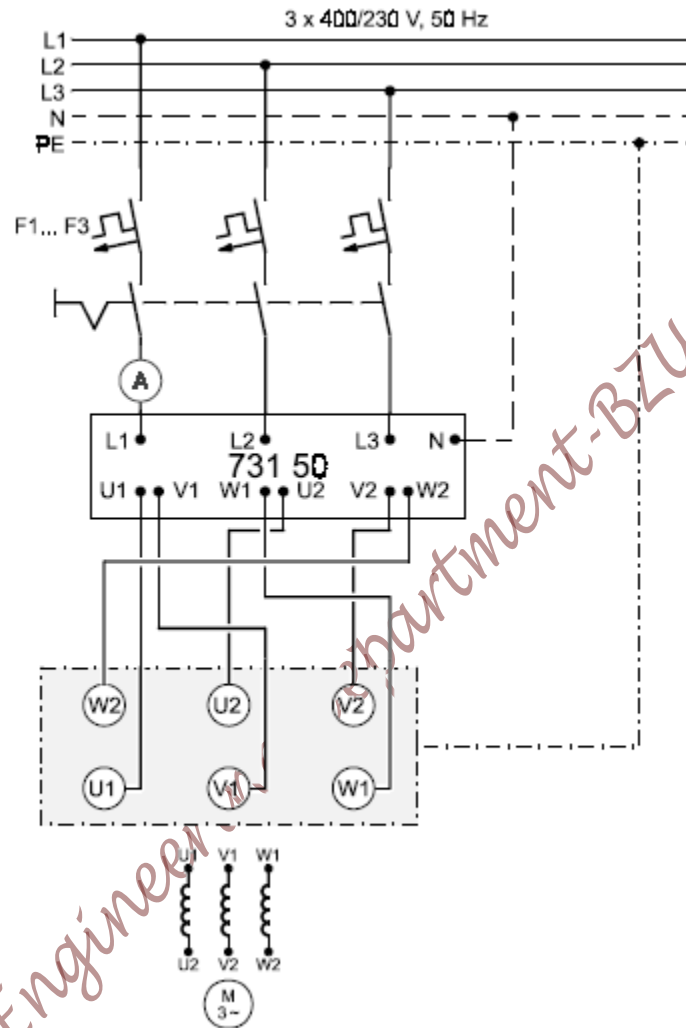
Figure 6.5 Circuit for studying the automated switch over from star to delta connection

6. The switching time of the 731 50 switch can be set by the timer on it, however, the switching time was chosen to be 30 second to show you the best results possible

7. Using the CBM 10 computer software, go to Measurement>>setting>>choose under the operation mode the "flywheel mode" then press OK, this mode simulate a heavy load

8. Synchronize the machine test system by pressing on the RED button

ASK ⟩ 9. Turn the motor on by pressing the ON button of the 745 561 module

10. Initially, the motor is connected in Star configuration via the 731 50, now switch the LOGIC 1 button of the switch to start the motor, after 30s the 731 50 switch will change the connection to Delta, observe the ammeter reading throughout the whole process,

11. Press the OFF button of the 745 561 module to turn the motor off

Q:4 Why do we need a Star-Delta starter switch? What advantages/disadvantages the Star connection has over the Delta connection? Explain your answer using the observation from the previous results of the 731 50 switch?

C. Determining Efficiency and Recording Characteristics in Motor Operation

c) Efficiency Calculations

1. Using the data printed on the name plate of the machine, fill Table 6.3
2. Connect the circuit as shown in Figure 6.6

Table 6. 3 Nominal data for the machine under test

Nominal Voltage V_N when connected in star:	
Nominal Voltage V_N when connected in delta:	
Nominal Current I_N when connected in star:	
Nominal Current I_N when connected in delta:	
Nominal Power Factor, $\text{Cos}(\theta_N)$:	
Output Nominal Power P_{2N} :	
Nominal speed n_N:	
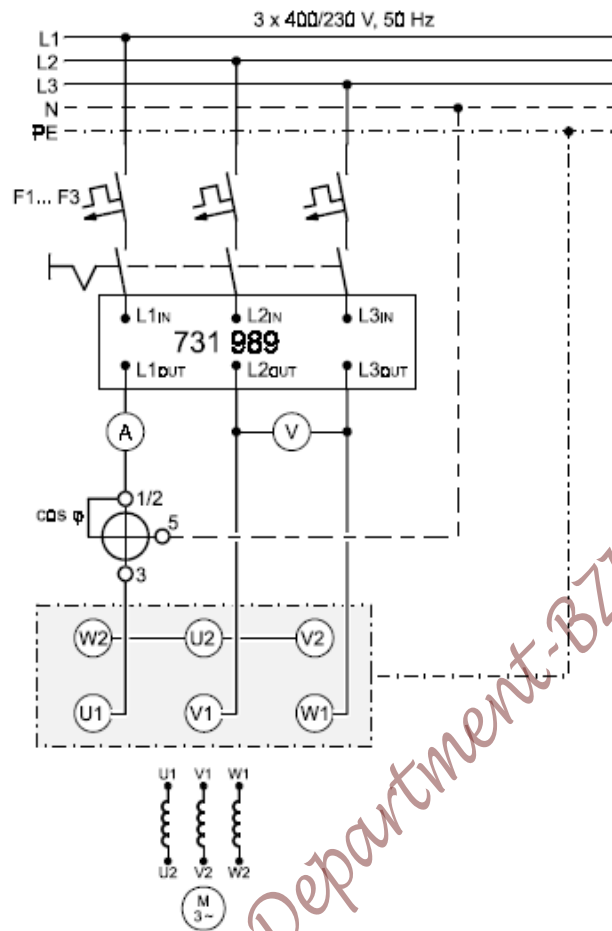
Figure 6. 6 Circuit for studying the squirrel cage induction motor when connected in star configuration

3. Using the data obtained in Table 6.3, Calculate the Nominal torque ($T_{N\Delta}$) if the machine is connected in delta configuration, and the Nominal torque (T_{NY}) if the machine is connected in Y configuration

ASK

4. Press the ON button of the 745 561 module

5. Using the CBM 10 computer software, go to Measurement>>setting>>choose under the operation mode the "torque control mode" then press OK, this mode allows you to control the load torque on the machine

6. Press the RED button of the machine test system then set the calculated nominal torque value as a load for the machine, modify the load torque slightly until the output power of the machine comes near the recorded nominal value, at this condition, the machine is working on its nominal point

7. Measure the line-to-line Voltage (V_{L-L}), the current in one phase, the power factor Cos(θ), the speed of rotation and the load torque

8. Unload the motor by pressing the RED button on the machine test system, make sure it displays "off"

9. Press the OFF button of the power circuit breaker module

Q5: Calculate the machine's active power using the data obtained in steps 6 & 7

Q6: Calculate the theoretical value of the efficiency (η_{eff}) based on values obtained from the machine rating; also calculate the actual efficiency (η_{act}) based on the actual measured values

d) Load Characteristics

The relationship between current, power factor and such values with respect to load torque is called Load Characteristics, in this part, we will study the machine under test behavior for different values of load torque. For the following measurements, the normalized value for any reading (I, V, Cos(θ) etc..) can be calculated as:

$$Normalized\ Value = \frac{Actual\ Value}{Nominal\ Value} \dots \dots \dots \dots \dots \dots \dots \dots \dots \dots \dots \dots \dots \dots \dots \dots 6.5$$

1. Use the nominal values obtained in step 3 and step 7 from the previous part to calculate the normalized values required in Table 6.4

ASK ▷ 2. Press the ON button of the power circuit breaker module

3. Press the RED button of the machine test system to synchronize it with the motor

4. Start increasing the torque in steps as shown in Table 6.4 (first, you have to calculate the actual torque for the given normalized torque values using equation 6.5), for each torque value, measure mechanical speed (n), phase current (I), and power factor (PF)

5. Press the RED Button on the machine Test System

6. Press the OFF button of the power circuit breaker module
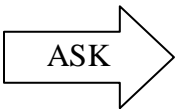
Q7: Plot on the <u>same window</u> the normalized values (n/n_r, I/I_N, P_1/P_N, P_2/P_N andCos (θ)) and **ŋ** on the Y axis versus normalized Load Torque (T/T_N) on the X axis and comment on your plots

Table 6.4 Measurement for Load Characteristic recording for the squirrel cage motor when connected in star

	T/T$_{N,act}$	0.0	0.1	0.2	0.3	0.4	0.5	0.6	0.7
	T/[Nm]	0.0XT$_N$							
Measure	n/[rpm]								
	I/[A]								
	Cos (θ)								
calculate	n/n$_N$								
	I/I$_{N,act}$								
	P$_1$/[W]								
	P$_1$/P$_{1N}$								
	P$_2$/[W]								
	P$_2$/P$_{2N}$								
	ꞃ								
	T/T$_{N,act}$	0.8	0.9	1.0	1.1	1.2	1.3	1.4	1.5
	T/[Nm]								
Measure	n/[rpm]								
	I/[A]								
	Cos (θ)								
calculate	n/n$_N$								
	I/I$_{N,act}$								
	P$_1$/[W]								
	P$_1$/P$_{1N}$								
	P$_2$/[W]								
	P$_2$/P$_{2N}$								
	ꞃ								

Q8: Explain the behavior of the machine by studying the obtained plots in step 4?

7. Change the circuit connection to connect the motor in **Delta configuration**
8. Repeat steps 1, 2, 3, 4 ,5 and 6 (the procedure required to fill Table 6.4), but this time for Delta connection, fill in Table 6.5

Table 6.5 Measurement for Load Characteristic recording for the squirrel cage motor when connected in Delta

	$T/T_{N,act}$	0.0	0.1	0.2	0.3	0.4	0.5	0.6	0.7
	$T/[Nm]$	$0.0XT_N$							
Measure	$n/[rpm]$								
	$I/[A]$								
	$Cos(\theta)$								
calculate	n/n_N								
	$I/I_{N,act}$								
	$P_1/[W]$								
	P_1/P_{1N}								
	$P_2/[W]$								
	P_2/P_{2N}								
	η								
	$T/T_{N,act}$	0.8	0.9	1.0	1.1	1.2	1.3	1.4	1.5
	$T/[Nm]$								
Measure	$n/[rpm]$								
	$I/[A]$								
	$Cos(\theta)$								
calculate	n/n_N								
	$I/I_{N,act}$								
	$P_1/[W]$								
	P_1/P_{1N}								
	$P_2/[W]$								
	P_2/P_{2N}								
	η								

Q9: Compare your plots for step 5 for both cased (when the system is connected in Star and when the system is connected in Delta

D. Computer based Recording of Run-up Characteristics

In this part, we shall use the computer to plot curves that represent the behavior of the motor once when connected in Star and another when connected in Delta

1. Open the CBM 10 software by going to Start>>All Program>>CBM10>>MOMO.exe (click on MOMO) the software will open up

2. Choose the machine under test type by going to Machine Type in the toolbar click on Squirrel Cage Induction Motor 400/690V

3. Click on T, I, P_1, P2 , efficiency and Cos(ϴ) from the left side column so that only the Torque Y axis is displayed

4. Change the axis setting from Presentations>>Axis scaling, first check all the nominal value boxes, fill in the Nominal Values fields the ones that you have obtained for the machine in this experiment, modify the values of the Y axis for the parameters according to Table 6.6

Table 6.6 Y axis limits for the stated parameter for plotting

Parameter	From	To
n	0	1.2
torque	0	2.5

ASK

5. Press the ON button of the 745 561 module to power on the motor

6. On the CBM 10 software press on the Green button on the left hand column (this is the synchronization button that will synchronize the machine test system with the motor), wait for synchronization, make sure you choose the Automated Mode recording,

7. Go to Measurements>>Settings, in the popup window, uncheck the only motor operation box, set the operational mode to **Load Characteristics,** set the start up speed to 1700rpm, set the stop speed to -600 rpm, then press ok

8. start the plotting by pressing on the RUN button on the software (the blue arrow to the upper left corner)

9. When the plotting is over, press on the RED button on the software to isolate the machine test system form the motor

10. Press on the OFF button of the power circuit breaker module

11. Change the motor connection to Star connection, and repeat steps from 5 to 10

12. Save your plot by copying it to clip board by the copy to clip board function on the software, copy it to a document file

Q10: Determine the behavior of the machine throughout the entire plotting process, and explain the modes of operation?

Eexperiment 7
Separate Winding "SW" Squirrel Cage Motor

Objectives:

After carrying out the experiments, the student will be capable of:

- Operating a changeable-pole, three phase, induction motor having two separate windings at low and high speeds
- Connecting and operating a changeable-pole, three-phase, induction motor having two separate windings with the aid of a pole-changer
- Record and interpreting various characteristics at low and high speeds

Equipment List:

1 "SW" squirrel cage motor	732 26
1 machine test system	731989
1 CBM 10 computer-based analysis of electrical machines, V.5	728421
1 three-phase supply unit with FCCB	726 75
1 motor protection switch, 1 ... 1.6 A	732 14
2 RMS meters	727 10
1 power factor meter	727 12
1 power circuit breaker module	745 561
1 motor protection switch 1 ... 1.6 A	732 14
1 pole-changer, separate windings	731 57

Notations

P_1	Input Power
P_2	Output Power
T_N	Nominal torque
ŋ	Efficiency
I	Line Current
V	Line-Line Voltage
n	Mechanical speed

Theory

The asynchronous (induction) motor represents the most important, yet simple, special case in the area of polyphase machines. Because of its high operational safety and low cost, it is preferred for a broad power range of unregulated drive mechanisms. Various asynchronous motors types arise from the design of the rotor, implemented either as a squirrel cage rotor or as a slip ring rotor.

The stator's rotary field is produced by the three outer conductors of a 3-phase system to which it is connected. The magnetic field rotates at synchronous speed n_s

$$n_s = \frac{120 f_e}{P} \dots \dots \dots \dots \dots \dots \dots \dots \dots \dots \dots \dots \dots \dots \dots \dots \dots \dots \dots \dots \dots \dots \dots 7.1$$

Where P is the number of poles and f_e is the electrical frequency

Not that we can control the motor speed by changing the number of poles in the motor, however, this require a set of separate windings on the motor which will eventually increase the motor cost

However, the rotor rotates at a speed less than the synchronous speed, the mechanical speed (n) which is given by:

$$n = (1 - s)n_s \dots \dots \dots \dots \dots \dots \dots \dots \dots \dots \dots \dots \dots \dots \dots \dots \dots \dots \dots \dots \dots \dots \dots 7.2$$

Where s is called the slip and is given by:

$$s = \frac{n_s - n}{n_s} \dots \dots \dots \dots \dots \dots \dots \dots \dots \dots \dots \dots \dots \dots \dots \dots \dots \dots \dots \dots \dots \dots \dots 7.3$$

A change in the direction of rotation can be easily accomplished by swapping stator connections for two of its input power phases. The mechanical output power of any electrical machine is given by equation 7.4, this equation is used to calculate the nominal torque (T_N) if the machine is operating at its nominal speed and nominal power

$$p_N = \omega_N \times t_N \dots \dots \dots \dots \dots \dots \dots \dots \dots \dots \dots \dots \dots \dots \dots \dots \dots \dots \dots \dots \dots \dots 7.4$$

Experimental Procedure:

Note: <u>Do not turn on any part of the equipments without prior notice from the supervisor</u>

Note**:**in all the figures in this experiments, the $F_1…F_3$ symbol is the motor protection switch 732

14 connected in series with the power circuit breaker module 745 561

A. Basic Circuit

1. Set up the equipment as shown in Figure 7.1
2. Turn on all the modules

ASK

3. Press the ON button of the power circuit breaker module to supply the machine with

   power

4. Measure the current in one phase, the line to line voltage, the speed and its direction

5. Press the OFF button of the machine test system to isolate the power from the machine

6. Change the connection to match Figure 7.2
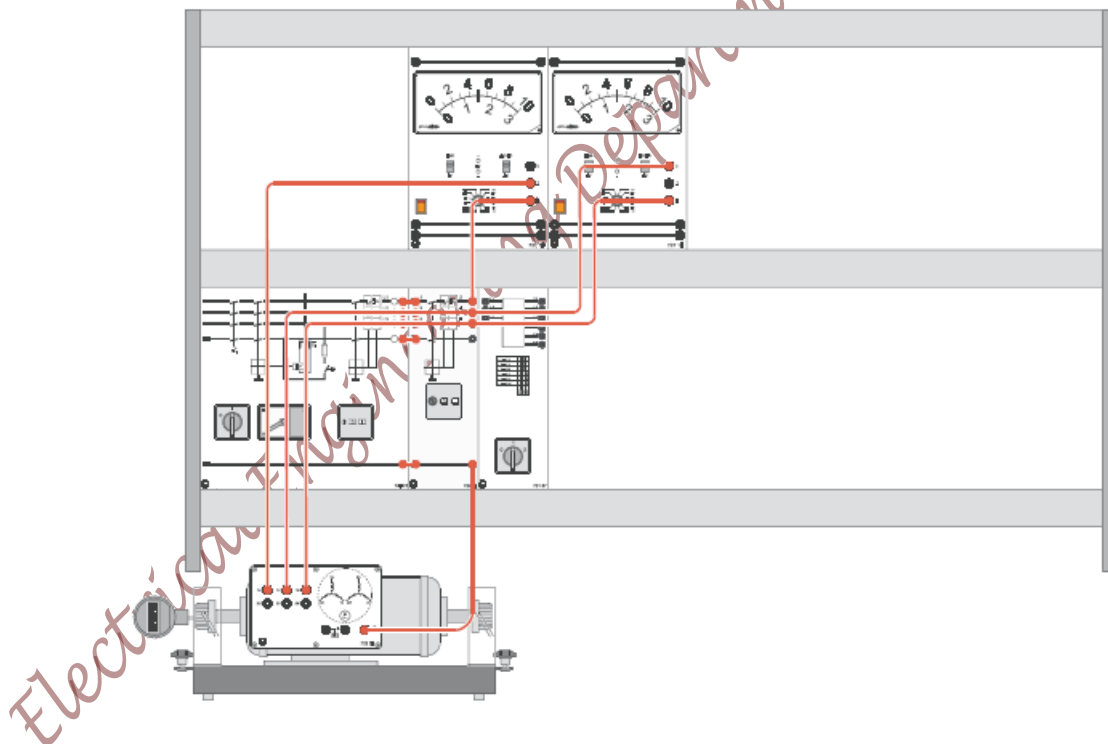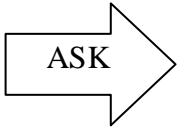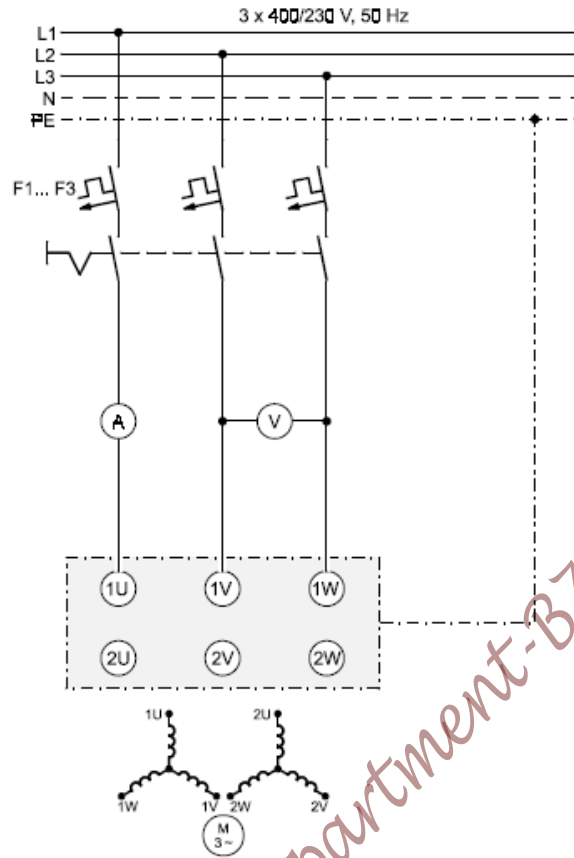
Figure 7.1 Circuit for studying the behavior of SW squirrel cage induction motor

7. Repeat steps 3, 4 and 5, record your measurements

Q1: Compare the speed in both cases, and explain the behavior, what is the number of poles in each case?
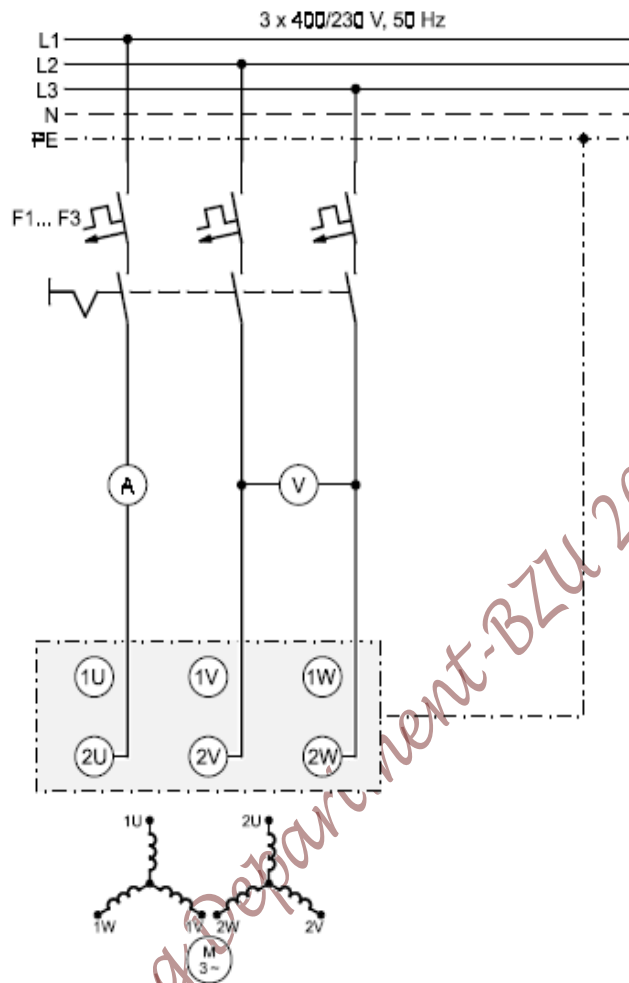
Figure 7. 2 Circuit for studying the behavior of SW squirrel cage induction motor

8. Change the connection to match Figure 7.3
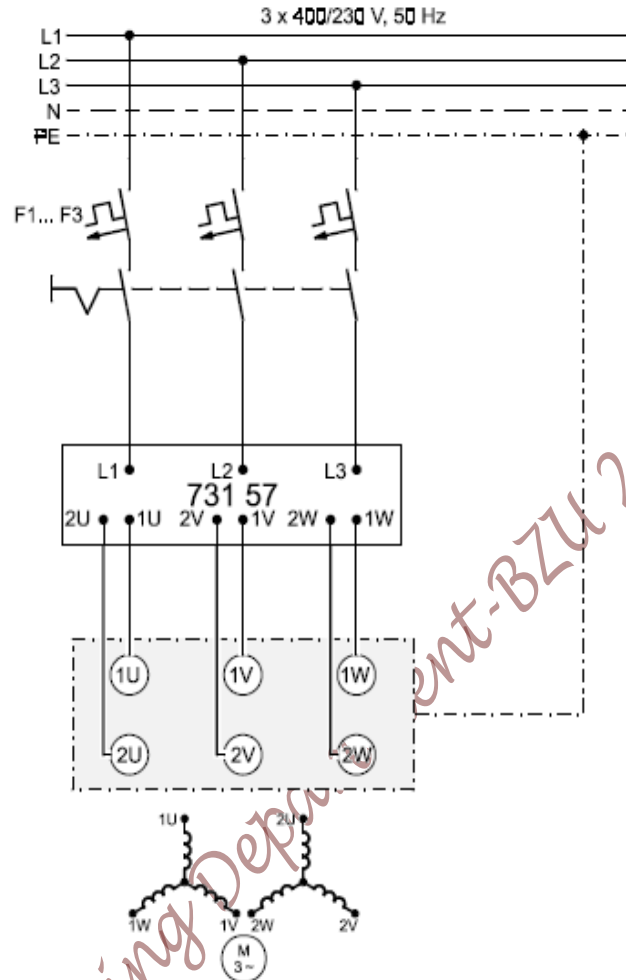
Figure 7.3 The usage of a pole-changer to change the speed of rotation

ASK ⟩ 9. Press the ON button of the power circuit breaker module

10. Test the functionality of the power circuit breaker module by changing its position from 0 to 1 to 2

11. Press the OFF button of the power circuit breaker module

Q2: Explain the functionality of the pole change switch 731 57 used earlier?

B. Determining Efficiency and Recording Characteristics in Motor Operation

a) Efficiency Calculations

1. Using the data printed on the name plate of the machine, fill Table 7.1

2. Connect the circuit as shown in Figure 7.4

Table 7.1 Nominal data for the machine under test

Nominal Voltage V_N	
Nominal current I_N (low speed)	
Nominal Current I_N (high speed)	
Nominal Power Factor, $\cos(\theta_N)$ (low speed)	
Nominal Power Factor, $\cos(\theta_N)$ (high speed)	
Nominal speed n_N (low speed)	
Nominal speed n_N (high speed)	
Nominal Power P_N (low speed)	
Nominal Power P_N (high speed)	
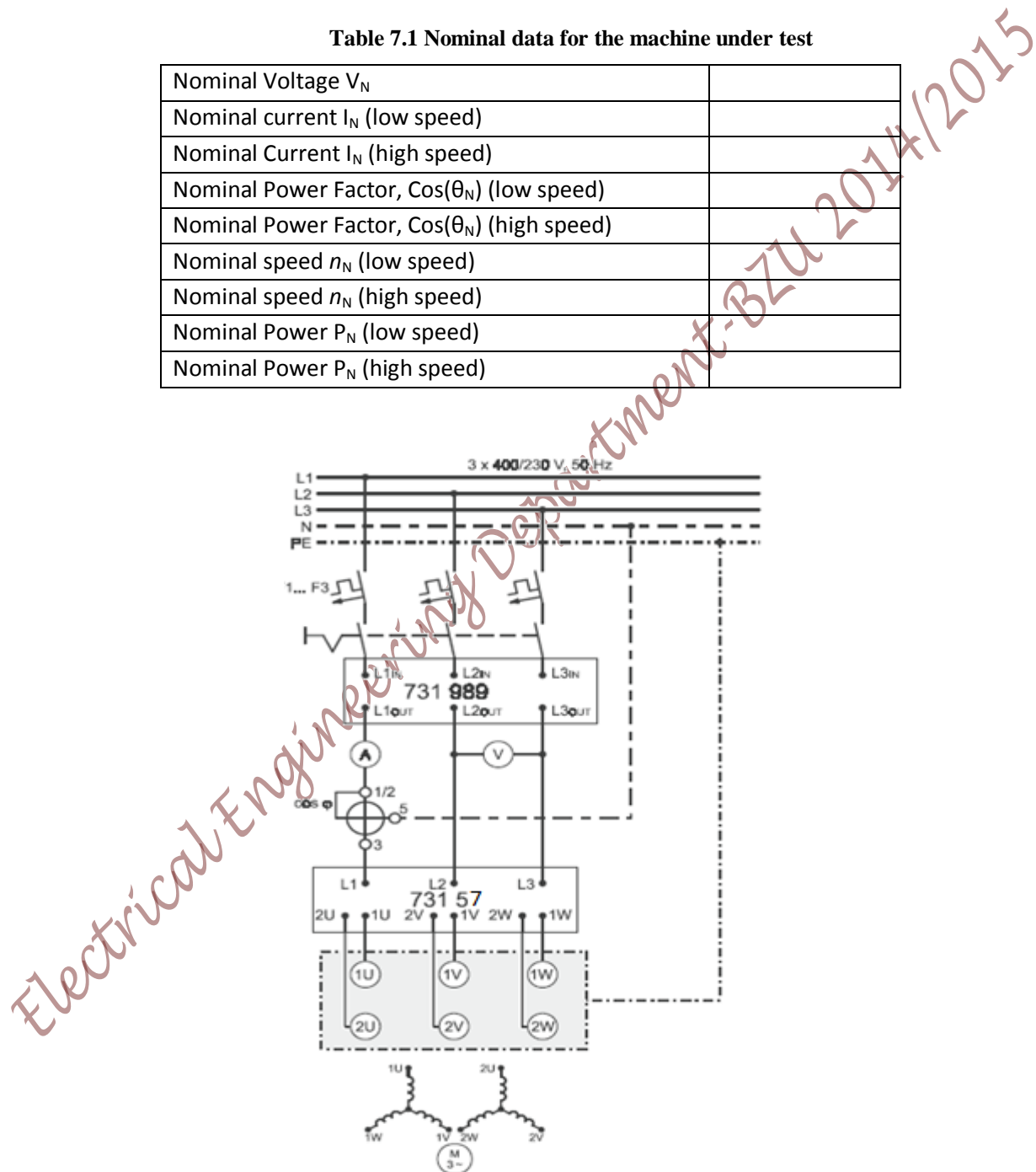
Figure 7. 4 Circuit for studying the SW squirrel cage induction motor
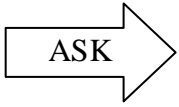
3. Using the data obtained in Table 7.1, Calculate the Nominal torque (T_N)

4. Set the pole-changer switch to the low speed position (position 1)

5. Press the ON button of the power circuit breaker module

6. Using the CBM 10 computer software, go to Measurement>>setting>>choose under the operation mode the "torque control mode" then press OK, this mode allows you to control the load torque on the machine

7. Press the RED button of the machine test system then set the calculated nominal torque value as a load for the machine, modify the load torque slightly until the output power of the machine comes near the recorded nominal value, at this condition, the machine is working on its nominal point

8. Measure the line-to-line Voltage (V_{L-L}), the current in one phase, the power factor $\cos(\theta)$, the speed of rotation and the load torque

9. Unload the motor by pressing the RED button on the machine test system, make sure it displays "off"

10. Now set the pole-changer switch to high speed position and repeat steps 7 to 9

11. Press the OFF button of the power circuit breaker module

Q3: For low speed and high speed, calculate the machine's active power using the data obtained in step 7 and 8

Q4: For both low speed and high speed, calculate the theoretical value of the efficiency (η_{eff}) based on values obtained from the machine rating; also calculate the actual efficiency (η_{act})based on the actual measured values

b) Load Characteristics

The relationship between current, power factor and such values with respect to load torque is called Load Characteristics, in this part; we will study the machine under test behavior for different values of load torque. For the following measurements, the normalized value for any reading (I, V, $\cos(\theta)$ etc..) can be calculated as:

$$Normalized\ Value = \frac{Actual\ Value}{Nominal\ Value} \dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots.\ \dots\dots 7.5$$

1. Use the nominal values obtained in steps 7 and 8 from the previous part to calculate the normalized values required in Table 7.2 and fill **T/[Nm]** rows in the Table

2. Set the pole-changer to the low speed position (position 1)

ASK

3. Press the ON button of the power circuit breaker module
4. Press the RED button of the machine test system to synchronize it with the motor, make sure you still are on the Torque control mode
5. Start increasing the torque in steps as shown in Table 7.2 (for each torque value, measure mechanical speed (n), phase current (I), and power factor (PF)
6. Press the RED Button on the machine Test
7. Press the OFF button of the Power circuit breaker module
8. Plot on the <u>same graph</u> the normalized values (n/n$_r$, I/I$_N$, P$_1$/P$_N$, P$_2$/P$_N$ andCos (θ)) and **ŋ** on the Y axis versus normalized Load Torque (T/T$_N$) on the X axis

Table 7.2 Measurement for Load Characteristic recording for the SW squirrel cage in low speed mode

	$T/T_{N,act}$	0.0	0.1	0.2	0.3	0.4	0.5	0.6	0.7
	T/[Nm]	$0.0XT_N$							
Measure	**n/[rpm]**								
	I/[A]								
	Cos (θ)								
calculate	**n/n$_N$**								
	I/I$_{N,act}$								
	P$_1$/[W]								
	P$_1$/P$_{1N}$								
	P$_2$/[W]								
	P$_2$/P$_{2N}$								
	ŋ								
	$T/T_{N,act}$	0.8	0.9	1.0	1.1	1.2	1.3	1.4	1.5
	T/[Nm]								
Measure	**n/[rpm]**								
	I/[A]								
	Cos (θ)								
	n/n$_N$								

calculate	$I/I_{N,act}$								
	$P_1/[W]$								
	P_1/P_{1N}								
	$P_2/[W]$								
	P_2/P_{2N}								
	η								

Q7: Relate the observations you have obtained fromstep 8 to the theoretical relationships?

9. Repeat steps 3 to 7 (the procedure required to fill Table 7.2), but this time for the high speed, fill your results in Table 7.3

Table 7.3 Measurement for Load Characteristic recording for the SW squirrel cage in high speed mode

	$T/T_{N,act}$	0.0	0.1	0.2	0.3	0.4	0.5	0.6	0.7
	$T/[Nm]$	$0.0XT_N$							
Measure	$n/[rpm]$								
	$I/[A]$								
	$Cos(\theta)$								
calculate	n/n_N								
	$I/I_{N,act}$								
	$P_1/[W]$								
	P_1/P_{1N}								
	$P_2/[W]$								
	P_2/P_{2N}								
	η								
	$T/T_{N,act}$	0.8	0.9	1.0	1.1	1.2	1.3	1.4	1.5
	$T/[Nm]$								
Measure	$n/[rpm]$								
	$I/[A]$								
	$Cos(\theta)$								
calculate	n/n_N								
	$I/I_{N,act}$								
	$P_1/[W]$								
	P_1/P_{1N}								
	$P_2/[W]$								
	P_2/P_{2N}								
	η								

Q8: Compare your plots for step 8 for both cased (when the system is operating on the high speed and when the system is operating on the low speed)

c) Computer based Recording of Run-up Characteristics

In this part, we shall use the computer to plot curves that represent the behavior of the motor once when operating with the high speed another when operating on the low speed

1. Open the CBM 10 software by going to Start>>All Program>>CBM10>>MOMO.exe (click on MOMO) the software will open up
2. Choose the machine under test type by going to Machine Type in the toolbar click on Squirrel Cage Induction Motor 400/690V
3. Click on T, I, P_1, P_2 , efficiency and Cos(ө) from the left side column so that only the Torque Y axis is displayed
4. Change the axis setting from Presentations>>Axis scaling, first check all the nominal value boxes, fill in the Nominal Values fields the ones that you have obtained for the machine in this experiment, modify the values of the Y axis for the parameters according to Table 7.4

Table 7.4 Y axis limits for the stated parameter for plotting

Parameter	From	To
n	0	1.2
torque	0	2.5

5. Set the pole changer to position 2 (the high speed position)
6. Press the ON button of the 745 561 module to power on the motor
7. On the CBM 10 software press on the Green button on the left hand column (this is the synchronization button that will synchronize the machine test system with the motor), wait for synchronization, make sure you choose the Automated Mode recording,
8. Go to Measurements>>Settings, in the popup window, check the only motor operation box, set the operational mode to **Load Characteristics,** set the start up speed to 1490rpm, set the stop speed to 50 rpm, then press ok

ASK

9. start the plotting by pressing on the RUN button on the software (the blue arrow to the upper left corner)

10. When the plotting is over, press on the RED button on the software to isolate the machine test system form the motor

11. Press on the OFF button of the power circuit breaker module

12. Change the pole change to the low speed position (position 1)

13. Repeat steps from 6 to 11

14. Save your plot by copying it to clip board by the copy to clip board function on the software, copy it to a document file

Q9: Determine the behavior of the machine throughout the entire plotting process, and explain the modes of operation?

Experiment 8
Shunt, Separately Excited and Series DC Motors

Objectives

After carrying out the experiment, you will be capable of:

1. Connecting a shunt and series wound motor to a power source with or without an armature series resistance, starting the motor, and reversing its direction of rotation

2. Performing measurements to determine the motor's efficiency and comparing this value to the value derived from rating plate data

3. Recording and interpreting various shunt and series wound motor load characteristics

4. Understanding the influence of armature series resistance and the field shunt resistance

5. Controlling the machine's speed with armature series resistance and with field shunt resistance

6. Measuring and interpreting the motor's load characteristics with computer-based techniques

Equipments required

DC Multifunction Machine	731 86
Machine Test System	731 989
CBM 10 computer-based analysis of electrical machines,V.5.81	728 421
Three pole on/off switch	731 42
DC motor power supply, (40-260)V, 300 W	725 852 D
2 RMS meters	727 10
Resistive load	73240
Field Regulator Generator	731 96
Starter for 300W Series resistor	731 94
Power Circuit Breaker Module (PCBM)	745561

Notations

P_1	Input power
P_2	Output power
T_n	Nominal torque
η	Efficiency
n	Mechanical speed
I_A	Armature current
V_A	Armature voltage
I_E	Excitation current
V_E	Excitation voltage

Theory

Direct current motors utilize the force exerted by a magnetic field on a current-carrying conductor loop to produce rotary motion. A magnetic field is created in the fixed portion of the machine, referred to as the exciting field, whereas the armature winding forms the conductor loop. Rotary motion would normally come to an end no later than when the exciting field and the armature field exhibit the same direction. However, a so-called "commutator" is employed which reverses the polarity of the armature winding at this position such that force continues to be exerted on the armature. If a DC machine is driven mechanically, then it acts as a generator. In this situation, an alternating current is induced into the armature which is subsequently rectified by the commutator. These machines require only very minor changes to their circuitry to affect a change between motor and generator operation.

Up to these days, DC machines still have a solid position in drive technology. In contrast to polyphase machines, they are suitable for rotary speeds well over the 10,000 rpm range. Their performance range extends from under one Watt to over ten Megawatts. In their operational behavior, they differ primarily by the manner in which the exciter winding is interconnected with respect to the armature winding. The armature and exciter windings are arranged in parallel for shunt excitation, whereas current is routed in series through the armature and exciter windings for series excitation. If the exciter winding on a shunt wound machine is fed from a separate voltage source, one refers to this as separately excited DC motor.

If a motor reduces its speed only slightly with increasing amounts of load, this behavior is referred to as "shunt characteristic". Shunt wound motors are well suited as drives for constant speed, for example in tool machines, conveyors or rolling mills.

Speed Control of Series DC Motors

There is only one efficient way to change the speed of a series DC motor; By changing the terminal voltage of the motor. If the terminal voltage is increased, the speed increases for any given torque. The speed of series DC motors can also be controlled by the insertion of a series resistor into the motor circuit

Speed Control of Shunt DC motor

By changing the armature voltage, insertion of a resistor in the armature circuit or by changing the excitation current.

Experimental Procedure

Notes:

1. Do not turn on any equipment without prior notice from lab supervisor, note the ask sign reminder ASK and ask your supervisor whenever you there

2. The *F1……F3* symbol is the motor protection switch 732 14 (3 phase circuit breaker)

A. Studying the Shunt DC motor

1. Set up the circuit as shown in Figure 8.1.

2. Turn on the DC motor supply, then set its output to 220V

3. Set the Starter for 300W Series resistor (731 94) to its 0% value

ASK

4. Press the ON button of the Power Circuit Breaker Module (PCBM) 745 561

5. Observe the direction of rotation and measure the speed (by looking at the shaft end of the motor connected to Machine Test System from the coupling side)

6. Press the OFF button of the Power Circuit Breaker Module (PCBM)

ASK

7. Make the necessary connections to change the direction of rotation
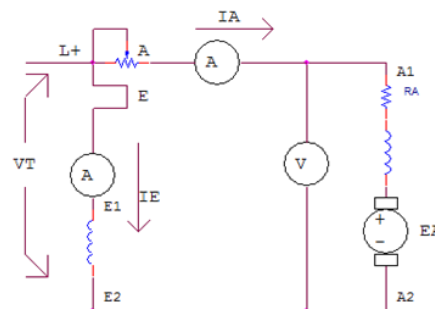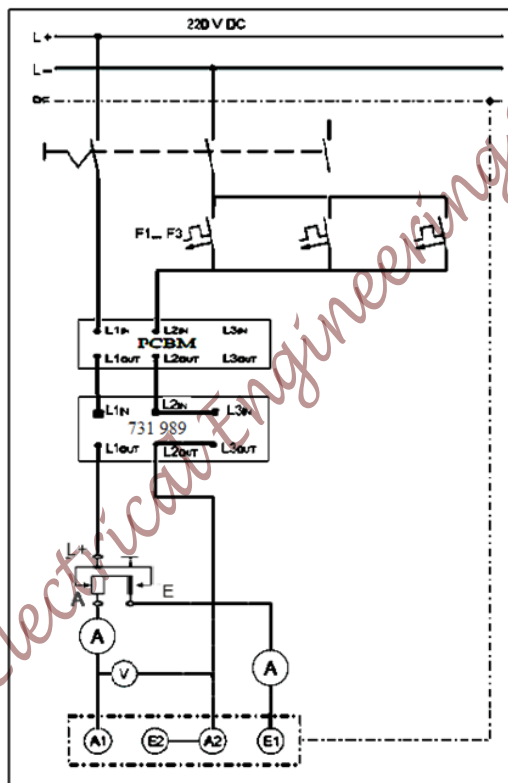
The equivalent circuit of a Shunt DC motor with a series armature resistance, note that we have connected two Ammeters in order to be able to measure the current in the armature winding (IA) and the in exciter/field winding (IE/IF)

Figure 8.1: Connection of the shunt wound DC motor with an equivalent circuit description

8. Repeat steps 3 and 4, record the speed and the direction of rotation

9. Set the Starter for 300W Series resistor (731 94) to its maximum value (100 % position)

10. Undo the connection for reversing the direction of rotation

11. Turn on the DC motor supply, <u>MAKE SURE</u> that you set its value to 155V to protect the motor from a very high current when the starting resistor is set to zero and the motor is loaded

12. Using CBM10 software, go to measurement>>Setting>> set the operating mode to flywheel

13. Press RED button (M!=0) of the Machine Test System (731 989)

14. Press the ON button of the Power Circuit Breaker Module (PCBM)

15. Measure the current I_1 in the armature immediately after turn-on then measure its value I_2 again after the motor has come up to full speed

16. Press the RED button of the Machine Test System (731 989)

17. Press the OFF button of the Power Circuit Breaker Module (PCBM)

18. Set Starter for 300W Series resistor (731 94) to its minimum value (0 position)

19. Repeat steps 12 to15

Q1: Compare the current values for the two starter positions, Comment!

A.1 Effect of changing the armature series resistance on motor operation

1. Using the data printed on the machine name plate, fill in Table 8.1

2. Determine the machine's nominal torque, input power, and efficiency

Table 8.1: Nominal Data for the Machine Under Test

Nominal voltage (armature) V_{AN}	
Nominal current (armature) I_{AN}	
Nominal voltage (excitation) V_{EN}	
Nominal current (excitation) I_{EN}	
Nominal speed n_N	
Nominal power P_N	

3. Turn on the DC motor supply, then set its output to 220V

4. Using the CBM10 software, go to Measurement>>Setting>> choose under the operating mode the **Torque Control Mode** then press OK

5. Press the ON button of the Power Circuit Breaker Module (PCBM)

6. Press the RED button of the Machine Test System

7. Increase the applied torque (near T_N) until reaching the point at which the machine is giving its nominal output power, measure the speed (n), the armature voltage (V_A), the excitation voltage (V_E), the armature current (I_A) and the excitation (field) current (I_E)

8. Set the applied load torque to **zero**

9. Set the Starter for 300W Series resistor (731 94) to its 30% value

10. Calculate the required actual load torque using $T[Nm]=(T/T_N)*T_N$ and fill in Table 8.2, apply the required torque and measure the speed, fill in Table 8.2

11. Set the applied load torque to **zero**

12. Set the armature series resistance to its 60% value

13. Repeat step 10 but this time fill in Table 8.3

14. Repeat steps 11 to 13 but this time for R=90% and fill in Table 8.4

15. Press the RED button of the Machine Test System

16. Press the OFF button of the Power Circuit Breaker Module (PCBM)

Table 8.2: Torque- speed characteristics for the shunt DC motor when the armature resistance=30%

	T/T_N	0	0.3	0.5	0.7	0.9	1.1	
Calculate	T[Nm]							R=30%
Measure	n [rpm]							
Calculate	n/n_N							

Table 8.3: Torque- speed characteristics for the shunt DC motor when the armature resistance=60%

	T/T_N	0	0.3	0.5	0.7	0.9	1.1	
Calculate	T[Nm]							R=60%
Measure	n [rpm]							
Calculate	n/n_N							

Table 8.4: Torque- speed characteristics for the shunt DC motor when the armature resistance=90%

	T/T_N	0	0.3	0.5	0.7	0.9	1.1	
Calculate	T[Nm]							R=90%
Measure	n [rpm]							
Calculate	n/n_N							

Q2: On the same graph, plot the torque speed characteristic using the data obtained in the above Tables, relate the results of the expected theoretical background and explain?

A.2 Efficiency Test and Recording Load Characteristics of Shunt motor

1. Set the Starter for 300W Series resistor (731 94) to its 0% value
2. Press the ON button of the PCBM
3. Press the RED button of the Machine Test System
4. Set the load torque to zero, take reading of the speed (n), the armature current (I_A) and the excitation current (I_E) and fill in Table 8.5, continue for other values of load torque **T**
5. Press the RED bottom (M!=0) of Machine Test System
6. Press the OFF button of the PCBM and turn off the DC motor supply

Q3: Using the data obtained in **step 4**, calculate the actual machine input power P_1, the actual machine output power P_2 and the machine efficiency

Q4: On the same graph, plot as a function of load torque **T** (X axis) the values: speed, armature current, exciter current, input power, output power and efficiency. Discuss those plots using your theoretical knowledge

Table 8.5: Measured values for determining the load characteristic of a shunt motor

	$T/ T_{N,act}$	0	0.2	0.4	0.6	0.8	1	1.1	1.3
	T [Nm]	$0XT_N$	$0.2XT_N$						
Measure	**n [rpm]**								
	I_A **[A]**								
	I_E **[A]**								
Calculate	n / n_N								
	I_A / I_{AN}								
	I_E / I_{EN}								
	$P_1[W]$								
	P_1/ P_{1N}								
	$P_2 [W]$								
	P_2 / P_{2N}								
	$\eta / [\%]$								

A.3 Plotting the torque speed curve of a Shunt motor using CBM10 software

In this part, we shall use the computer to plot curves that represent the behavior of a shunt motor:

1. Open the CBM 10 software by going to Start>>All Program>>CBM10>>MOMO.exe (click on MOMO) the software will open up.
2. Go to "Machine Type" in the toolbar click on **shunt motor**

3. Click on torque (**T**) and line current (**I**) from the left side column to display these values plots versus the speed.

4. Go to Presentations>>Axis Setting, set the speed range, the torque range and the current range as in the following Table

Parameter	From	To
n	1800	2200
torque	0	3
I	0	3

5. Go to Measurements>>Settings, in the popup window set the operational mode to **Load Characteristics**, set the **start up speed** to **2200rpm**, set the **stop speed** to **1800 rpm**, then press ok

6. Turn on the DC motor supply, then set its output to 220V

ASK ⟩ 7. Press the ON button of the Power Circuit Breaker Module

8. On the CBM 10 software press on the Green button on the left hand column (this is the synchronization button that will synchronize the Machine Test System with the motor), wait for synchronization, make sure you choose the Automated Mode recording, then start the plotting by pressing on the RUN button on the software (the blue arrow to the upper left corner)

9. When plotting is over, press on the RED button on the software to isolate the Machine Test System form the motor

10. Press on the OFF button of the Power Circuit Breaker Module (PCBM)

11. Reconnect the circuit as in Figure 8.1 (only add the starter series resistor)

12. Set the starter resistor (731 94) to 30% and repeat steps 7 and 8

13. Repeat step 12 but this time for starter resistor of 60% and 90%

14. To save your plots, you can either take them from your lab Teaching Assistant or if you have a mobile phone camera you can take a picture of the plots

Q5: Comment on the plots you obtained?

A.4 Studying the effect of changing the field resistance on the shunt motor

1. Make the necessary changes so that the connections match Figure 8.2, note that we have inserted the Field Regulator Generator resistor (731 96)

ASK ⟩ 2. Press the ON button of the PCBM

3. Using the CBM10 software, go to Measurement>>Settings then choose under the operating mode the **Torque control** Mode

4. Press the RED button (M!=0) of the Machine Test System

5. Set the load torque to the nominal torque value found in part A.1 step 7

6. Set the Field Regulator Generator Resistor to its 0% position, record the excitation current (I_E) and the speed, fill the results in Table 8.6

7. Continue for other values of the field shunt resistance and fill in Table 8.6

Table 8.6 The effect of changing the field current on the behavior of a Shunt motor

Setting	R / [%]	0	10	20	30	40
Measure	I_E [A]					
	n [rpm]					
Calculated	I_E / I_{EN}					
	n/n_N					
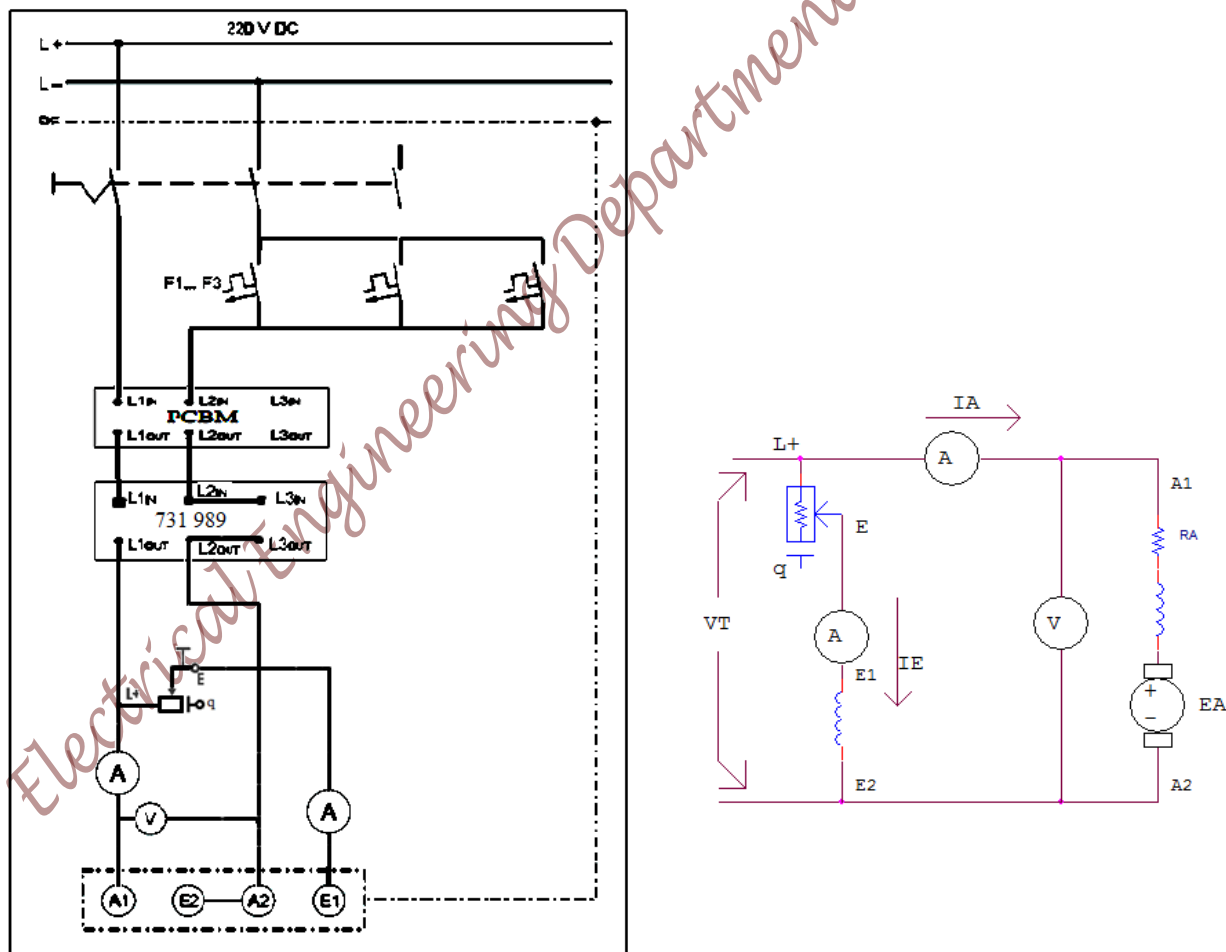
Figure 8.2: Circuit for studying the effect of changing the field current on the Shunt motor behavior

8. Press the RED button of the Machine Test System

9. Press the OFF button of the PCBM

10. Turn off the DC motor supply

Q6: Produce a graph of the relationship between the speed vs the excitation current (I_E)? Discuss your graph using your theoretical background?

B. Separately Excited DC Motor (SE DC Motor)

1. Make the necessary connection changes for the circuit to match Figure 8.3, note that you have to remove the Field Regulator Generator resistor, and to connect the excitation winding to the fixed terminal of the DC power supply, the rest of the connection are the same

Note that the armature voltage is taken from the DC motor supply variable output terminal, and the excitation voltage is now separated from the armature voltage and is taken from the fixed 200 V output terminal from the same DC motor supply
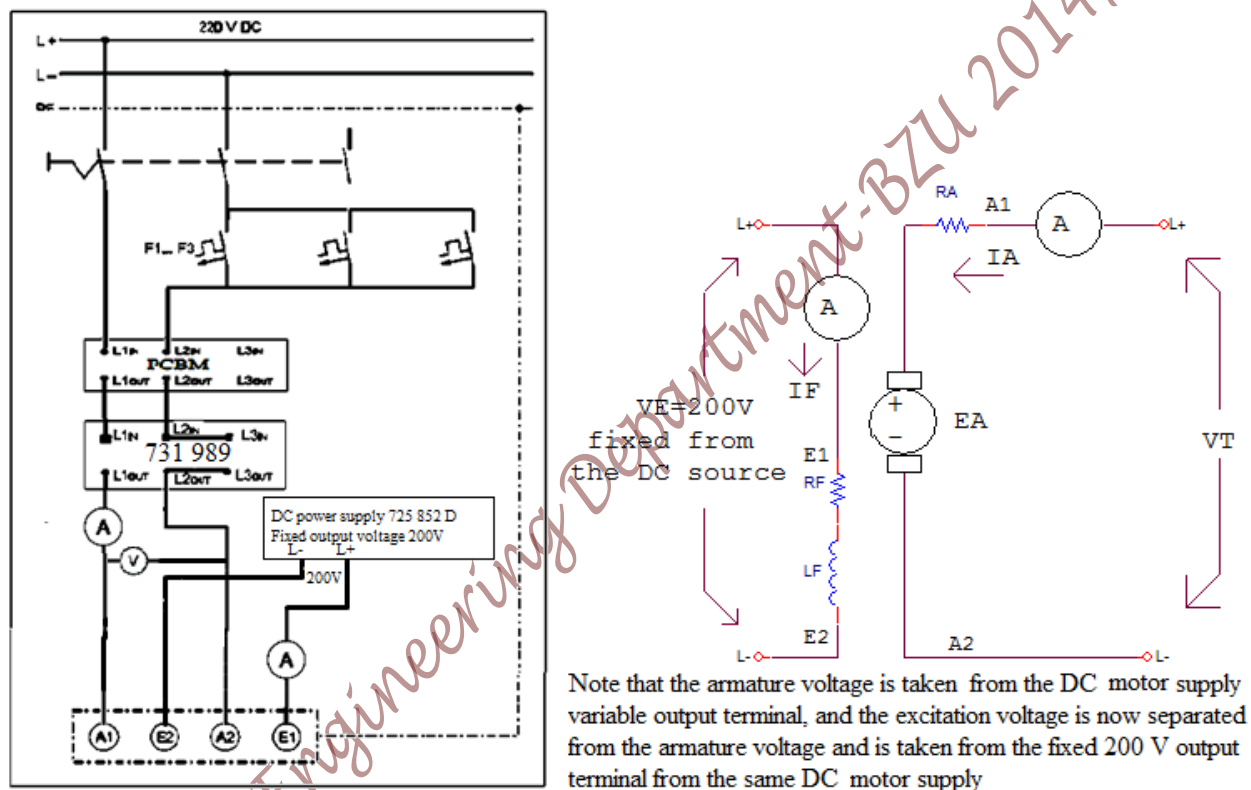
Figure 8.3: Circuit for studying the effect of changing the armature voltage on the SE DC Motor behavior

ASK

2. Turn on the DC motor supply and set its output to 220V (armature voltage)

3. Press the ON button of the PCBM

4. Press the RED button of the Machine Test System, make sure you are still on the torque control operating mode

5. Set the load torque to the machine nominal torque value found earlier (part A.1 step 7)

6. Set the armature voltage value to 220V, measure the speed, fill in Table 8.7 continue for other values of armature voltage

Table 8.7: The effect of changing the armature voltage on the SE DC Motor

V$_A$ [V]	220	198	176	154	132	110	88
n [rpm]							

Q7: Plot a graph of the relationship between the armature voltage (V$_A$) on the Y axis and the speed (n) on the X axis, relate the results with the theoretical background

7. Set the load torque to **zero**

8. Set the armature voltage V$_A$=220 V

9. Increase the load torque as required in Table 8.8 and record the speed

10. Repeat steps 7 to 9 but this time for armature voltage of 200V in Table 8.9, for armature voltage of 150V in Table 8.10 and for armature voltage of 110V in Table 8.10

Table 8.8: Studying the torque speed characteristic of the separately excited motor for V$_A$=220V

	T/T$_N$	0	0.3	0.6	0.9	1	
Calculate	T[Nm]						**V$_A$=220**
Measure	n [rpm]						
Calculate	n/n$_N$						

Table 8.9: Studying the torque speed characteristic of the separately excited motor for V$_A$=200V

	T/T$_N$	0	0.3	0.6	0.9	1	
Calculate	T[Nm]						**V$_A$=200**
Measure	n [rpm]						
Calculate	n/n$_N$						

Table 8.10: Studying the torque speed characteristic of the separately excited motor for V$_A$=150V

	T/T$_N$	0	0.3	0.6	0.9	1	
Calculate	T[Nm]						**V$_A$=150**
Measure	n [rpm]						
Calculate	n/n$_N$						

Table 8.11: Studying the torque speed characteristic of the separately excited motor for V$_A$=110V

	T/T$_N$	0	0.3	0.6	0.9	1	
Calculate	T[Nm]						**V$_A$=110**
Measure	n [rpm]						
Calculate	n/n$_N$						

ASK ▷ **11.** Press the RED button of the Machine Test System

12. Press the OFF button of the PCBM

13. Turn off the DC power supply

Q8: Plot on the same graph the torque speed characteristics using the data obtained in the above tables (V_A=220, V_A=200, V_A=1500 and V_A=110), relate the results with the theoretical background?

B.1 plotting the torque speed characteristic for different armature voltages for a separately excited DC motor using the CBM10 software

1. Go to the CBM10 software, File>>Close Characteristic set, then choose all the plots listed under the "Curve(s):" window then press on the (>) sign then OK then NO

2. Go to Measurements>>Settings, in the popup window set the operational mode to **Load Characteristics**, set the **start up speed** to **2200rpm**, set the **stop speed** to **1800 rpm**, then press ok

3. Turn on the DC motor supply and set its output to 220 V

ASK ⟩ **4.** Press the ON button of the PCBM

5. From the CBM10 software press on the Green button to synchronize the Machine Test System with the motor, then press on the RUN blue arrow in the upper left corner, wait for the plotting to end

6. From the CBM10 software, press the RED button to isolate the Machine Test System from the motor, then reduce the DC power supply (armature voltage) to 150V, repeat step 5

7. Repeat step 6 but this time for armature voltage=110V

8. Press the OFF button of the PCBM

9. Turn off the DC motor supply

Q9: Comment on the plots you have obtained and discuss them with your theoretical backgrounds?

C. Studying the Series Motor

NOTE: Never unload the series DC motor when it is operating at rated terminal voltage!

1. Make the necessary connection changes for the circuit to match Figure 8.4, note that the fixed DC voltage (200V) connected to the exciter winding (E_1 to E_2) is removed, and the (D_1D_2) winding is used, the rest of the connections are the same

ASK ⟩ **2.** Turn on the DC motor supply and set its output voltage to 45V

3. Press the ON button of the PCBM

4. Measure the speed and notice the direction of rotation by looking at the motor from the coupling side

5. Press the OFF button of the PCBM

6. Make the necessary connection changes for the circuit to match Figure 8.5, note that only the Starter series resistor 731 94 is inserted, the remaining connections are the same.
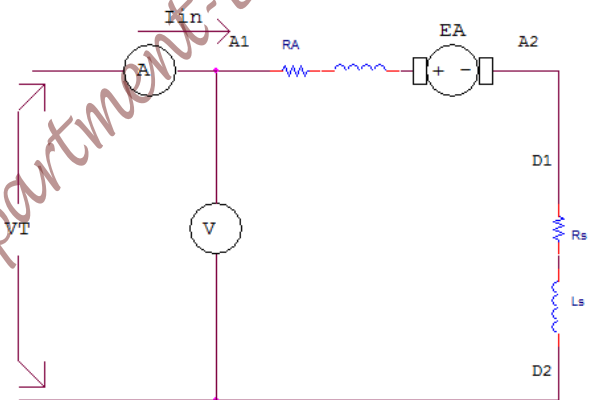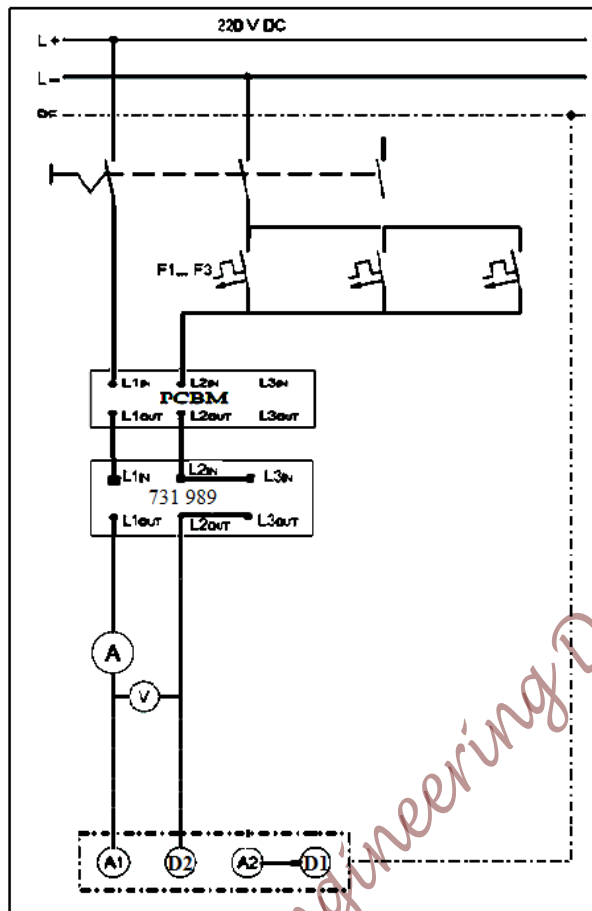
Figure 8.4: Connection of the series wound motor without a starter

7. Set the DC motor supply to give a terminal voltage of 110V

8. Set the Starter Series resistor to its 100% value

9. From the CBM10 software, go to Measurements>>Settings under the operating mode choose **flywheel** mode then press OK

10. Press the RED button of the Machine Test System

11. Press the ON button of the PCBM

12. Measure the starting current ($I_{1,100\%}$) directly after start up and the steady state current ($I_{ss,100\%}$)

13. Press the RED button of the Machine Test System
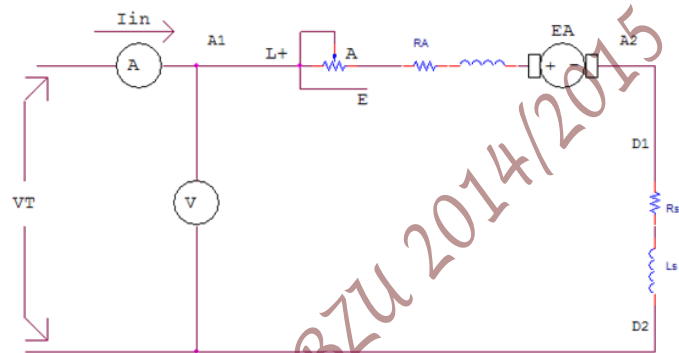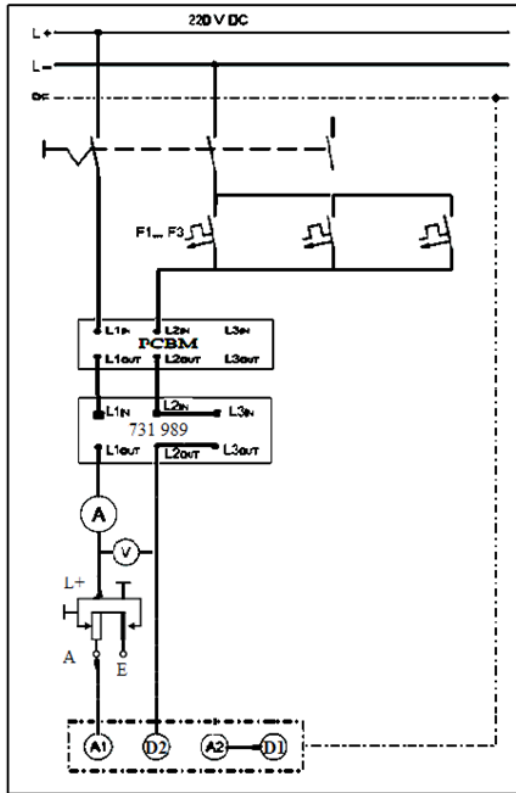
Figure 8.5: Connection of the series wound motor with an armature series resistance inserted

14. Press the RED button of the Machine Test System

15. Press the OFF button of the PCBM

16. Set the armature series resistance to its 0% value

17. Repeat steps 10 to 14, measure the starting current ($I_{1,0\%}$) and the steady state current ($I_{ss,0\%}$)

Q9: Compare the starting currents ($I_{1,100\%}$ and $I_{1,0\%}$) and the steady state currents ($I_{ss,100\%}$ and $I_{ss,0\%}$)

C.1 Efficiency Test and Recording Load Characteristics of a Series motor

1. Reconnect the circuit as in Figure 8.5 (by only removing the Starter Series resistor)

2. Refer to part **A.1 Table 8.1** to determine the machine nominal input voltage (V_{inN}), nominal input current (I_{inN}), nominal speed (n_N) and nominal output power (P_{2N})

3. Calculate the machine's nominal torque (T_N)

4. Set the DC motor supply to 45V

5. From the CBM10 software, go to Measurements>>Settings under the operating mode choose **Torque Control** mode then press OK

6. Press the ON button of the PCBM

7. Press the RED button of the Machine Test System

8. Set the load torque to 0.14 Nm

9. Increase the DC motor supply output to the machine's nominal input voltage (V_{AN})

10. Increase the torque (near T_N) until reaching the point at which the machine is giving its nominal output power

11. Measure the speed (n), the input voltage (V_{in}) and the input current (I_{in})

Q10: Using the data obtained in **step 10**, calculate the actual machine input power $P_{in,act}$, the actual machine output power $P_{out,act}$ and the machine's efficiency

12. Set the load torque to $0.1 * T_N$, measure the speed (n), the input current (I_{in}) and the input voltage (V_{in}), fill your results in Table 8.12, continue for other values of load torque. Make sure that the terminal voltage is maintained at its rated value (220) for the entire Table

ASK

13. Press the ON button of the PCBM

14. Press the RED button of the Machine Test System and turn off the DC motor supply

Table 8.12: Measured values for determining the load characteristic of a series motor

	T/ $T_{N,act}$	0.1	0.3	0.5	0.8	1.0	1.2	1.4
	T [Nm]	$0.1 X T_N$						
Measure	n [rpm]							
	I_{in} [A]							
	V_{in} [V]	220	220	220	220	220	220	220
Calculate	n / n_N							
	I_{in} / I_{inN}							
	P_1[W]							
	P_1 / P_{1N}							
	P_2 [W]							
	P_2 / P_{2N}							
	η / [%]							
	P_2 [W]							
	P_2 / P_{2N}							
	η / [%]							
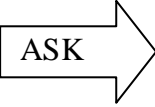
Q11: On the same graph, plot as a function of load torque **T** (X axis) the values: speed, input current, input power, output power and efficiency, discuss those plots using your theoretical knowledge

C.2 Plotting the torque speed characteristic for different armature voltages for a Series DC motor using the CBM10 software

1. Go to the CBM10 software, File>>Close Characteristic set, then choose all the plots listed under the "Curve(s):" window then press on the (>) sign then OK then NO

2. Go to "Machine Type" in the toolbar click on **Series motor**

3. Go to Measurements>>Settings, in the popup window set the operational mode to **Load Characteristics**, set the **start up speed** to **4100 rpm**, set the **stop speed** to **1000 rpm**, then press ok

4. Go to Presentations>>Axis Setting, set the speed range, the torque range and the current range as in the following Table

Parameter	From	To
n	1000	4100
torque	0	3
I	0	3

5. Turn on the DC motor supply and set its output to **zero**

ASK ⟩ 6. Press the ON button of the PCBM

7. Slowly increase the input voltage until the motor is rotating near **4100 rpm,** measure the terminal voltage

8. From the CBM10 software press on the Green button to synchronize the Machine Test System with the motor, then press on the RUN blue arrow in the upper left corner, wait for the plotting to end

9. From the CBM10 software, press the RED button to isolate the Machine Test System from the motor, then reduce the DC motor supply (input voltage) so that the motor is running near **3000 rpm,** measure the terminal voltage

10. Reduce the DC power supply (armature voltage) so that the motor is running near **3000 rpm,** then repeat step 8

11. Press the RED button of the Machine Test System

12. Press the OFF button of the PCBM

13. Comment on the plots you have taken and discuss them with your theoretical backgrounds?

C.3 Speed Control Circuits of Series motor:

1. Make the necessary connection changes so that the circuit matches Figure 8.6, note that we have inserted the Resistive load 731 40 (connected in parallel) in series with the armature terminal A1, also note that we have added a voltmeter to measure the voltage across the armature terminal V_A

2. Set the DC motor supply to 100V

3. Go to Measurements>>Settings, in the popup window set the operational mode to **Torque control mode**

ASK

4. Press the ON button of the PCBM

5. Press the RED button of the Machine Test System

6. Set the load torque to 0.14Nm

7. Increase the DC motor supply to give the nominal input voltage (220V)

8. Increase the load torque to 0.7Nm
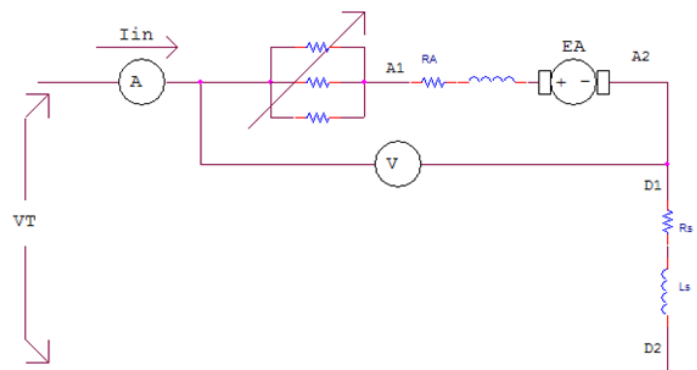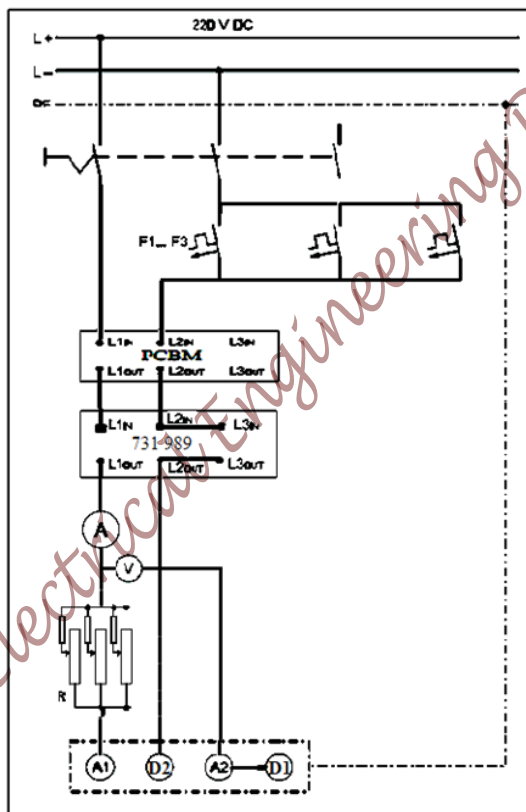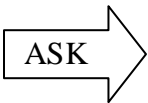
Figure 8.6: Circuit for speed control of a series wound motor by way of armature resistance

9. Change the Resistive load (731 40) according to the Table 8.13 below and measure speed and armature voltage in relationship to resistive load, you have to take readings as fast as possible

Table 8.13 : The effect of changing the armature resistance in a series motor

Setting	R / [%]	0	5	10	15
Measure	V_A [V]				
	n [rpm]				
Calculate	V_A/V_N				
	n/n_N				

Q12: Produce a normalized graph of the relationship between speed and armature voltage, discuss your graphs with your theoretical backgrounds?

1. Press the OFF button of the PCBM

2. Press the RED button of the Machine Test System

3. Change the circuit connection to match Figure 8.7
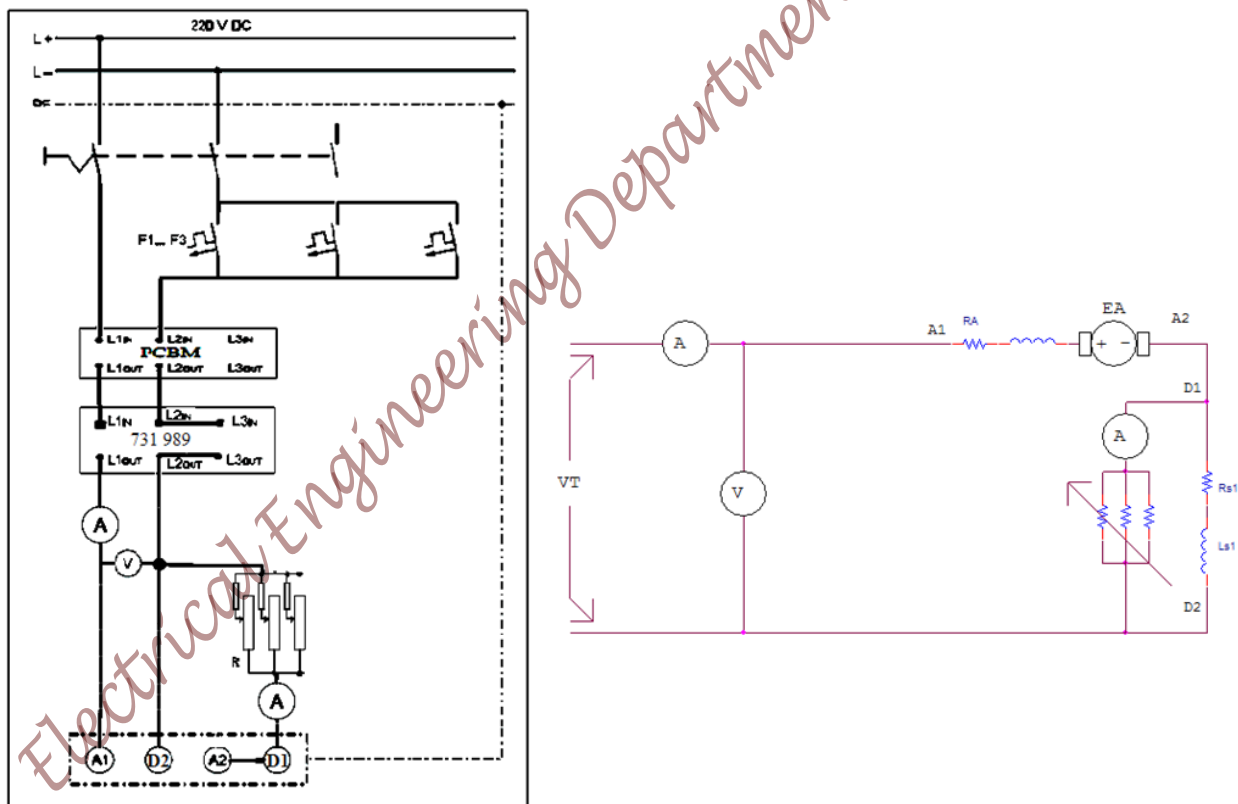
Figure8.7: Circuit for speed control of a series wound motor by way of armature resistance

4. Set the DC power supply to 100V

5. Set the Field Regulator Generator (731 96) resistor to 100%

6. Press the ON button of the PCBM

7. Press the RED button of the Machine Test System

8. Set the load torque to 0.14Nm

9. Increase the DC motor supply to give the nominal input voltage (220V)

Table 8.14 : The effect of changing the shunt resistance on the motor

Setting	R / [%]	100	80	60	40	20	10	5
Measure	I1 [A]							
	n [rpm]							
Calculate	I_1/I_N							
	n/n_N							

10. Increase the load torque to 0.7Nm

11. Measure the current in the field resistor (I_1) and fill in Table 8.14, continue this reading for the other values of the shunt resistor (80,60,40…) as in Table 8.14

12. Reduce the terminal voltage to 100V, then press the RED button of the Machine Test System

13. Press the OFF button of the PCBM

Q13: Produce a normalized graph of the relationship between speed and the current I_1, discuss your plots with your theoretical backgrounds?

Experiment 9
Compounded DC Motor and Universal Motor

Objectives

After carrying out the experiments, you will be capable of:

1. Studying the compounded-wound motor, reverse the direction of rotation

2. Studying the Speed control methods of the compounded DC motor

3. Measuring and interpreting the compounded-wound motor load characteristics

4. Studying a Universal Motor and reversing the direction of rotation

5. Speed control of a Universal Motor and studying its load characteristics

Equipments Required

DC Multifunction Machine	**731 86**
Machine Test System	731 989
CBM 10 computer-based analysis of electrical machines,V.5.81	728 421
2 RMS meters	727 10
Resistive load	73240
Field Regulator Generator	731 96
Universal motor	732 00
Power Circuit Breaker Module (PCBM)	745 561
Motor protection switch, 2.4...4 A	732 84
Isolating variable transformer 0 ...260 V	726 85
Power factor meter	727 12
Starter for 300W Series resistor	731 94
DC Motor Supply, 300 W, 0-260 V	725 852 D

Notations

P_1, P_2	Input power, Output power
T_n	Nominal torque
H	Efficiency
N	Mechanical speed
V, I	Voltage, Current

Theory

Compounded DC motor is a motor with both a shunt and a series field. Compounded motors can be connected in two ways, cumulatively or differentially. Compounding is the expression used for the technique of employing a series winding in combination with a shunt winding to attain stronger or weaker fields. Cumulatively compounded motor results when a stronger field is being produced while a differentially compounded motor results when a weaker field is being produced, however, differentially compounded motor is unstable and is not appropriate for any application

The techniques available for the control of speed in a Cumulatively Compounded DC motor are the same as those available for a shunt motor: by changing field resistance (R_F), armature voltage (V_A) and armature resistance (R_A).

Common uses of the compounded motor include elevators, air compressors, conveyors, presses and shears. Compounded motors can be operated as shunt motors by disconnecting the series field.

The universal motor can be operated with either DC or AC power. It exhibits a series characteristic, whereby – with increasing load torque – its speed does drop somewhat more when operating on AC power than it does when operating on DC power.

Procedure

Notes

3. <u>Do not turn on any equipment without prior notice from lab supervisor</u>

4. The *F1……F3* symbol is the motor protection switch 732 14 (3 phase circuit breaker)

A. Basic Circuits of Compounded Wound motor

1. Set up the circuit as shown in Figure 9.1
2. Turn on the Main switch on the Machine Test System
3. Set the output of the DC motor supply (725 852 D) to 220V

Ask > 4. Press the ON button of the Power Circuit Breaker Module (PCBM)

5. Measure the speed and notice its direction (looking towards the motor from the coupling side)
6. Press the OFF button of the PCBM

Ask > 7. Change the direction of rotation by changing the current flow in the armature

8. Repeat steps 4, 5 and 6

B. Load Characteristics of Compounded Wound motor

1. Enter the rating plate data for the machine to be tested into Table 9.1

2. Determine the machine's nominal torque, input power, and efficiency.

Ask ▷ 3. Press the ON button of the PCBM

Figure 9. 1: Basic circuit for studying the compounded DC motor

4. Using the CBM10 software, go to Measurement>>Setting choose Torque control mode

Table 9.1: Nominal Data for the Machine under Test

Nominal Voltage (armature) V_N:	
Nominal Current (armature and series) I_{AN}:	
Nominal Current (exciter winding) I_{EN}:	
Nominal Speed n_N:	
Nominal Power P_N:	

Ask ▷ 5. Press the RED button of the Machine Test System

6. Set the calculated nominal torque earlier as the motor load

7. Measure the speed, the input voltage, the excitation current (I_E) and the armature current

Q1: Compute the input power, the output power and the efficiency

8. Change the load torque according to Table 9.2, and measure the speed, I_A and I_E

9. Press the RED button of the Machine Test System

10. Press the OFF button of the PCBM

Table 9.2: Measured values for determining the load characteristic of a compounded-wound motor

	$T / T_{N,act}$	0	0.1	0.2	0.3	0.4	0.5	0.6	0.7
	T [Nm]	$0XT_N$	$0.1XT_N$						
Measure	N [rpm]								
	I_A [A]								
	I_E [A]								
Calculate	n / n_N								
	I_A / I_{AN}								
	I_E / I_{EN}								
	P_1 [W]								
	P_1 / P_{1N}								
	P_2 [W]								
	P_2 / P_{2N}								
	η [%]								
	$T / T_{N,act}$	0.8	0.9	1.0	1.1	1.2	1.3		
	T [Nm]								
Measure	N[rpm]								
	I_A [A]								
	I_E [A]								
Calculate	n / n_N								
	I_A / I_{AN}								
	I_E / I_{EN}								
	P_1 [W]								
	P_1 / P_{1N}								
	P_2 [W]								
	P_2 / P_{2N}								
	η [%]								

Q3: Plot on the same graph as a function of load torque (T) the following quantities: speed, current (I_E and I_A), power factor, input power, output power and efficiency. Comment on your plots?

C. Compounded Wound motor with a starting resistor

1. Change the circuit to match Figure 9.2 to investigate the effect of Series Starter Resistor :

2. Set the Starter Series Resistor (731 94) to its maximum value (100 % position).

3. Using the CBM10 software, go to Measurement>>Setting choose **flywheel mode**

Ask → 4. Press the RED button of the Machine Test System
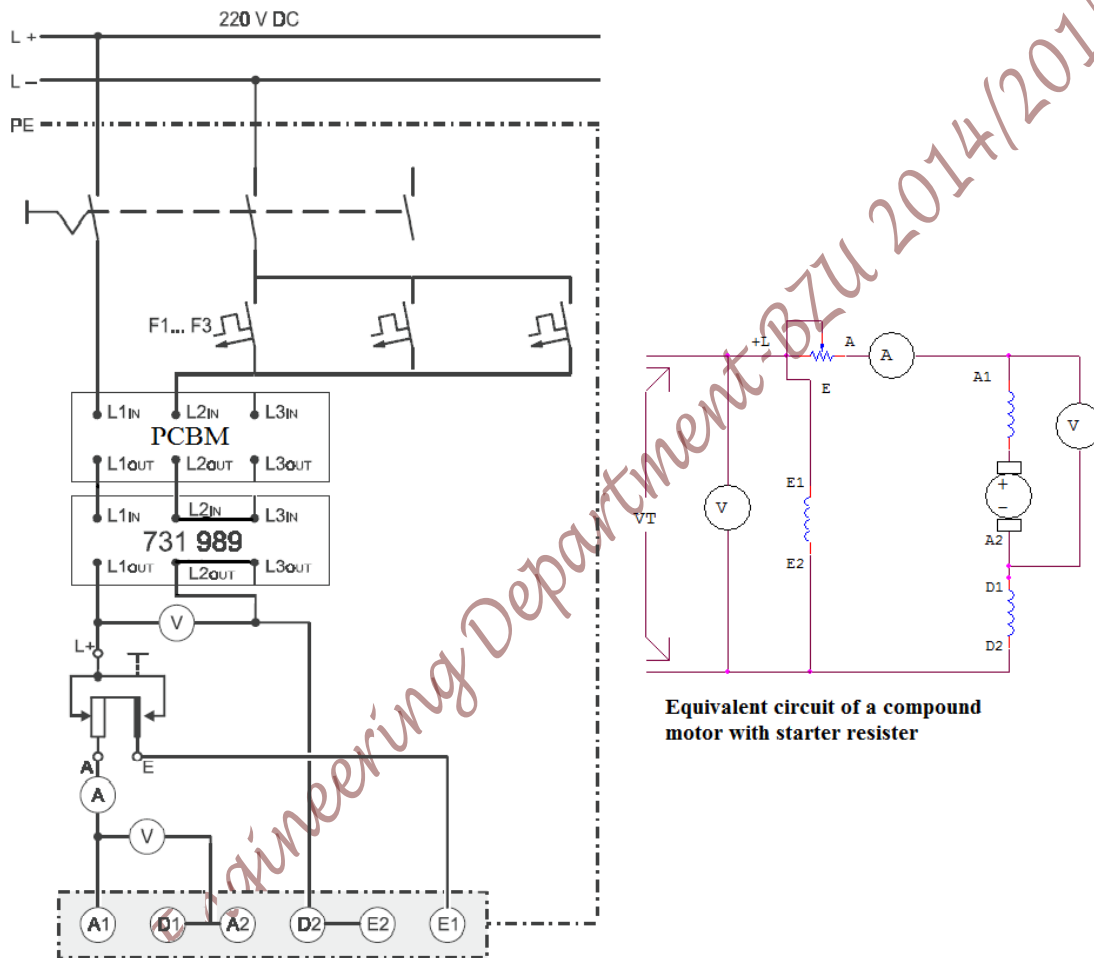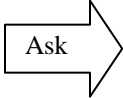
Figure 9.2: Connection of the compounded wound motor with a Starter Series Resistor

5. Press the ON button of the PCBM

6. Measure the startup armature current ($I_{As,100\%}$), then measure the steady state armature current ($I_{Ass,100\%}$)

7. Press the RED button of the Machine Test System

8. Set the Series Starter Resistor (73194) to its minimum value (0 % position)

9. Press the OFF button of the PCBM

10. Repeat steps 4 to 7 but this time Series Starter Resistor at 0% value

Q4: Compare the current values for the two starter positions, explain your readings?

D. Speed Control Circuits of Compounded Wound motor

D1: Armature Control

1. Set the armature series resistance to 0%
2. Press the ON button of the PCBM
3. Using the CBM10 software, go to Measurement>>Setting choose Torque control mode

Ask ⇒

4. Press the RED button of the Machine Test System
5. Set the load to torque to 0.7 Nm
6. Record the armature voltage and fill your results in Table 9.3
7. Continue for other values of the starting resistor and fill in Table 9.3
8. Press the RED button of the Machine Test System
9. Press the OFF button of the PCBM

Table 9.3: The speed/armature-voltage characteristic of a Compounded wound motor

	R [%]	0	5	10	15	20	30	40	50
Measure	V_A [V]								
	N [rpm]								
Calculate	V_A/ V_N								
	n / n_N								

Q5: Produce a normalized graph of the relationship between speed and armature voltage. Comment on your plots with your theoretical background?

D2: Field Resistance Control

1. Change the circuit to Figure 9.3
2. Use the Field Regulator Generator (731 96) and set its value to 0%

Ask ⇒

3. Press the ON button of the PCBM
4. Press the RED button of the Machine Test System
5. Set the load torque to 0.7 Nm

Table 9.4: The speed/exciter-current characteristic of a compounded wound motor

	R [%]	0	10	20	30	40	50	60	70	80	90	100
Measure	n [rpm]											
	I_E [A]											

Calculate	n / n_N									
	I_E / I_{EN}									

6. Measure the speed and the excitation current (I_E), fill your results in Table 9.4
7. Continue for other values of the Field Regulator Generator and fill in Table 9.4
8. Press the RED button of the Machine Test System
9. Press the OFF button of the PCBM

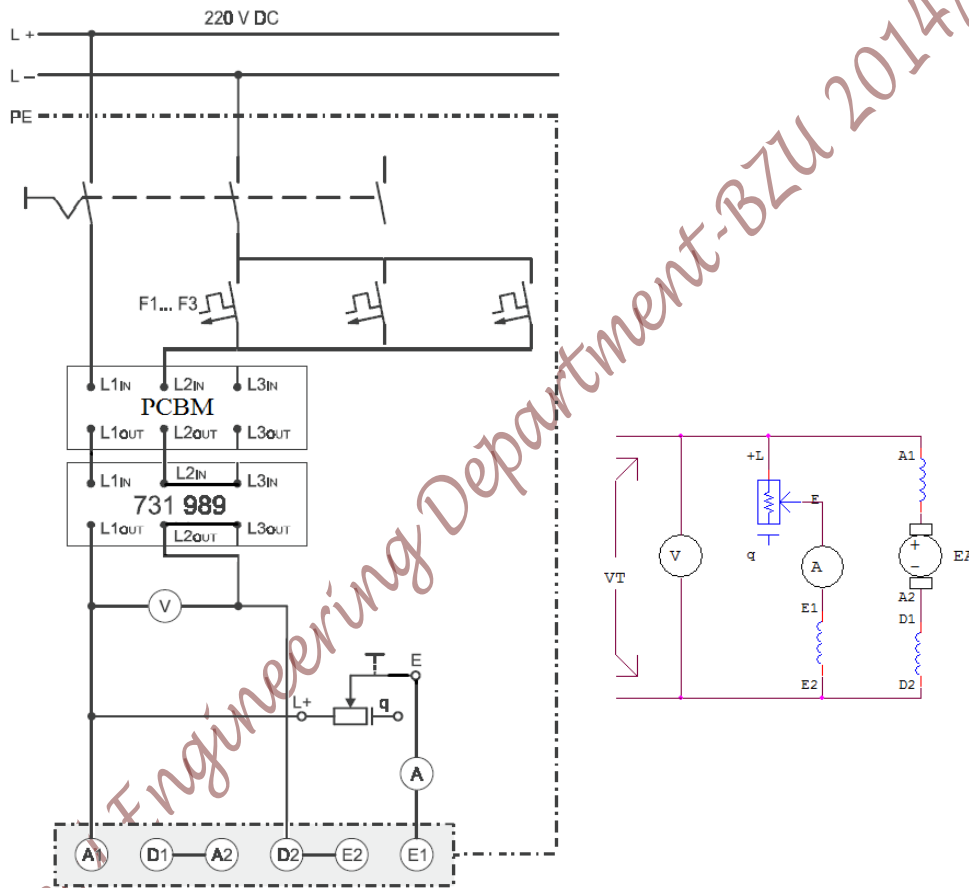**Figure 9.3: Circuit for speed control of a compounded- wound motor via a field regulator**

Q6: Produce a normalized graph of the relationship between speed and exciter current, comment on your figures based on your theoretical background!

Q7: Compare the results of the two speed control techniques studied here based on the measured values obtained, discuss them with your theoretical background!

E. Computer Recording of Load Characteristics of the Compounded Motor

1. Set the Field Regulator Generator to its 0% value

2. Using the CBM10 software, go to Measurement>>Setting choose load characteristic mode, set the start speed to 2250 rpm and the stop speed to 1200 rpm, press OK

3. Go to "Machine Type" in the toolbar click on Compounded motor

4. Click on T, I, P_1, P_2 and efficiency so that only the torque (T) Y axis is displayed

5. Go to Presentation>>axis scaling, set the speed display range from (1200-2250) and the torque display range from (0-3) Nm

6. Press the ON button of the PCBM

7. On the CBM 10 software press on the Green button on the left hand column, make sure you choose the Automated Mode recording, and then start the plotting by pressing on the RUN button on the software (the blue arrow to the upper left corner).

8. When the plot is over, press the RED button of the Machine Test System

9. Set the Field Regulator Generator to its 50% value

10. Repeat steps 7 and 8

11. Press the OFF button of the PCBM

12. Save your plots by copying it to clip board or you can take a photo for the curves

Q8: Explain your plots using your theoretical background?

13. Go to the CBM10 software, File>>Close Characteristic set, then choose all the plots listed under the "Curve(s):" window then press on the (>) sign then OK then NO

14. Change the circuit connection to match Figure 9.2

15. Set the Starter Series Resistor to 0% position

16. Repeat steps 6, 7, 8, 11

17. Set the Starter Series Resistor to 30% position

18. Repeat steps 6, 7, 8, 11

19. Set the DC motor supply output to 110

20. Repeat steps 15, 16, 17 and 18

21. Press the OFF button of the Machine Test System

22. Repeat step 12

F. Basic Circuits of Universal Motor

1. Ask your lab supervisor to install a universal motor (732 00) instead of the Multifunction DC machine

2. Connect the circuit as shown in Figure 9.4, note that you have to use the isolating variable transformer (726 85) as a power supply

Figure 9.4 Circuit for determining the efficiency of a universal motor

3. Switch on the AC input source and set its value to **100V**

4. Press the ON button of the PCBM

5. Measure the speed and notice its direction (looking towards the motor from the coupling side)

6. Press the OFF button of the PCBM

7. Make the necessary connection changes to change the direction of rotation

8. Repeat steps 4 to 6

G. Efficiency Test and Recording Load Characteristics of Universal Motor

1. Undo the connection you made to reverse the direction of rotation (circuit as in Figure 9.4)

2. Using the data printed on machine plate, fill in Table 9.5

Table 9.5: Nominal Data for the Machine under Test (Universal Motor)

Nominal voltage V_N:	
Nominal current I_N:	
Nominal speed n_N:	
Nominal power P_N:	300W[1]
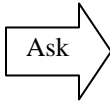
3. Determine the machine's nominal torque, input power, and efficiency

4. Press the ON button of the PCBM

5. Using the CBM10 software, go to Measurement>>Setting choose Torque control mode

6. Press the RED button of the Machine Test System

7. Set the load torque to 0.25Nm, increase the input AC voltage source to the motor's nominal value (230V), then set the load torque so that the machine is producing the nominal output power[1]

8. Measure the speed, the torque, the input current, the input voltage and the power factor

Q9: Determine the machine's effective input power, output power and the actual efficiency

Table 9.6: Measured values for producing universal motor load characteristics

	T/ $T_{N,act}$	0.3	0.4	0.5	0.6	0.7	0.8	0.9	1.0	1.1	1.2	1.3
	T [Nm]											
Measure	N [rpm]											
	I [A]											
	cos φ											
Calculate	n / n_N											
	I / I_N											
	$P_1[W]$											
	P_1/ P_{1N}											
	$P_2 [W]$											
	P_2 / P_{2N}											
	η [%]											

9. Change the load torque to $0.3 \times T_N$, measure the speed, the current and the power factor

10. Fill your results in Table 9.6, continue for other values of the load torque

11. Use the data to find P_1, P_2 and, efficiency for every torque value

12. Set the load torque to 0.25Nm, then set the ac input source to **100V**

13. Press the RED button of the Machine Test System

14. Press the OFF button of the PCBM

---

[1] This value contradicts the 200W shown on the name plate, the name plate is incorrect!

Q10: Produce plots (on the same graph as a function of load torque (T)) the values of speed, current, power factor, input power, output power and efficiency. Discuss your graphs with your theoretical background.

H. Computer-based Recording of Load Characteristics of Universal Motor

1. Open the CBM10 software (MOMO.exe)
2. Using the CBM10 software, go to Measurement>>Setting choose load characteristic mode, set the start speed to 5000 rpm and the stop speed to 2000 rpm, press OK
3. Go to "Machine Type" in the toolbar click on **Universal motor**
4. Click on T, I, P_1, P_2 and efficiency so that only the torque (T) Y axis is displayed
5. Go to Presentation>>axis scaling, set the speed display range from (1800-5000) and the torque display range from (0-0.5) Nm
6. Set the AC input source to **zero voltage**
7. Press the ON button of the PCBM
8. Increase the input ac source until the motor is running near 5000 rpm, measure the input voltage
9. On the CBM 10 software press on the Green button on the left hand column (this is the synchronization button that will synchronize the Machine Test System with the motor), wait for synchronization, make sure you choose the Automated Mode recording, then start the plotting by pressing on the RUN button on the software (the blue arrow to the upper left corner)
10. When the plotting is over, press on the RED button on the software to isolate the Machine Test System form the motor
11. Set the AC voltage source so that the motor is running near 4000 rpm, measure the input voltage
12. Repeat steps 9 and 10
13. Press the OFF button of the PCBM
14. Save your plots by copying them to clip board or by taking a photo

Q12: Explain your plots using your theoretical background!

Discussion

D1 What do the terms "cumulative Compounding" and "differential Compounding" mean?

D2 How does increasing the load affect the speed of a compounded-wound motor?

D3 How should the two exciter windings of a compounded-wound motor be connected?

D4 Describe the universal motor's speed and current relationships to load torque?

D5 What is wrong about operating a universal motor at no-load with nominal voltage?

D6 Name methods for speed control of a universal motor?

Experiment 10
DC Generators

Objectives

- Operating the wound machine as a separately excited generator and as a self-excited generator and changing its direction of rotation

- Recording and interpreting various load characteristics for the wound generator when separately excited and when self-excited

- Operating the compound-wound machine as a generator and changing its direction of rotation

- Recording and interpreting various compound-wound generator characteristics

- Operating the series wound machine as a generator and changing its direction of rotation

- Recording and interpreting various series wound generator characteristics

Equipments Required

DC Multifunction Machine	731 86
Machine Test System	731 989
CBM 10 computer-based analysis of electrical machines, V 5.81	728 421
Three pole on/off switch	731 42
DC motor supply, 40-260 V, 300 W	725 852 D
2 RMS meters	727 10
Resistive load	732 40
Field Regulator Generator	731 96

Notations

P_1	Input power
P_2	Output power
T_n	Nominal torque
η	Efficiency
n	Mechanical speed
I	Current
V	Voltage

Theory

DC generators are dc machines used as generators, there are five major types of dc generators, classified according to the manner in which their field flux is produced:

1) Separately exited generator. In Separately exited generator, the field flux is derived from a separate power source independent of the generator itself.

2) Shunt generator. In Shunt generator, the field flux is derived by connecting the field circuit directly across the terminals of the generator.

3) Series generator. In series generator, the field flux is produced by connecting the field circuit in series with the armature of generator.

4) Cumulatively compounded generator. In Cumulatively compounded generator, both shunt and series are present, and their effects are additive.

5) Differentially compounded generator. In Differentially compounded generator, both a shunt and a series field are present, but their effects are subtractive .

All generators are driven by a source of mechanical power, which is usually called the prime mover of the generator. A prime mover for a dc generator may be a steam turbine, a diesel engine, or even an electric motor. Since the speed of the prime mover of generator affects the output voltage of a generator, and since prime movers can vary widely in their speed characteristics, it is customary to compare the voltage regulation and output characteristics of different generators, assuming constant- speed prime movers.

Procedure

Note: Do not turn on any equipment without prior notice from your lab supervisor

A. Separately excited DC Generator

1. Set up the circuit as shown in Figure 10.2

2. Set the Field Regulator Generator initially to position 0

3. Turn on the Main switch on the Machine Test System

4. Using the CBM10 software, go to Measurements>>Settings uncheck the only motor operation box then press OK

ASK ▷ 5. Press the RED button of the Machine Test System

6. Drive the generator at a speed of 2000 rpm in the clockwise direction (looking towards the generator from the coupling side)

Figure 10.1: Arrangement of units in the experiment for the shunt wound machine

Figure 10 .2: Circuit for the wound machine as a separately excited generator

7. Set the DC motor supply voltage to 205V

8. Press the ON button of the Power Circuit Breaker Module (PCBM)

9. Measure the induced armature voltage and notice its polarity

10. Set the Field Regulator Generator to 100% value, repeat step 9, comment on both readings

11. Press the OFF button of the (PCBM) **then** Set the Field Regulator Generator to its (q) position (this prevent high induction voltage in the exciter when the machine is turned off)

12. Press the RED button of the Machine Test System

13. Set the Field Regulator Generator to its (0) position

ASK ⟹ **14.** Press the RED button of the Machine Test System

15. Drive the generator at a speed of 2000 rpm in the counterclockwise direction (looking towards the generator from the coupling side)

16. Repeat steps 8 to 10

17. Change the Field Regulator Generator to provide the required excitation current given in Table 10.1, then measure the corresponding armature voltage

Table 10.1: No-load characteristic of a separately-excited wound generator at constant speed

	I_E / I_{EN}	0	0.6	0.7	0.8	0.9	1
Calculate	I_E [A]						
Measure	V_o [V]						
Calculate	V_o / V_N						

Q1: Produce a normalized graph of the relationship between these two quantities (V_o vs I_E) then discuss the graph with the theoretical background

18. Set the Field Regulator Generator to give the nominal excitation current (I_E)

19. Change the speed according to Table 10.2 and take readings of the armature voltage (V_o)

Table 10.2: No-load characteristic of a separately-excited shunt wound generator with constant excitation

	n / n_N	0	0.1	0.2	0.3	0.4	0.5	0.6	0.7	0.8	0.9	1
Calculate	n [rpm]											
Measure	V_o [V]											
Calculate	V_o / V_N											

20. Press the OFF button of the PCBM **then** set the Field Regulator Generator to its (q) position

21. Press the RED button of the Machine Test System

Q2: Produce a normalized graph of the relationship between these two quantities (V_o vs n) then discuss the graph with the theoretical background

B. Separately Excited Wound Generator with Resistive Load

1. Change the circuit connections to match Figure 10.3

Figure 10.3: Separately Excited Shunt Wound generator circuit for recording load characteristics

2. Set the load resistance to 100%.

3. Press RED button of the Machine Test System

4. Drive the generator at a speed of 2000 rpm in the clockwise direction (looking towards the generator from the coupling side)
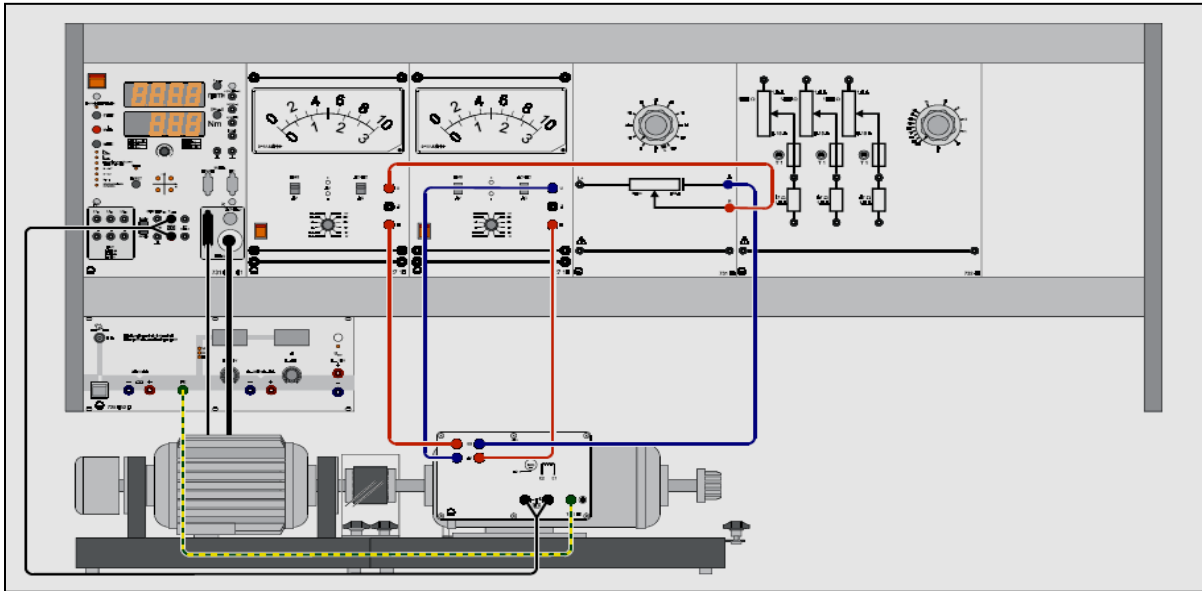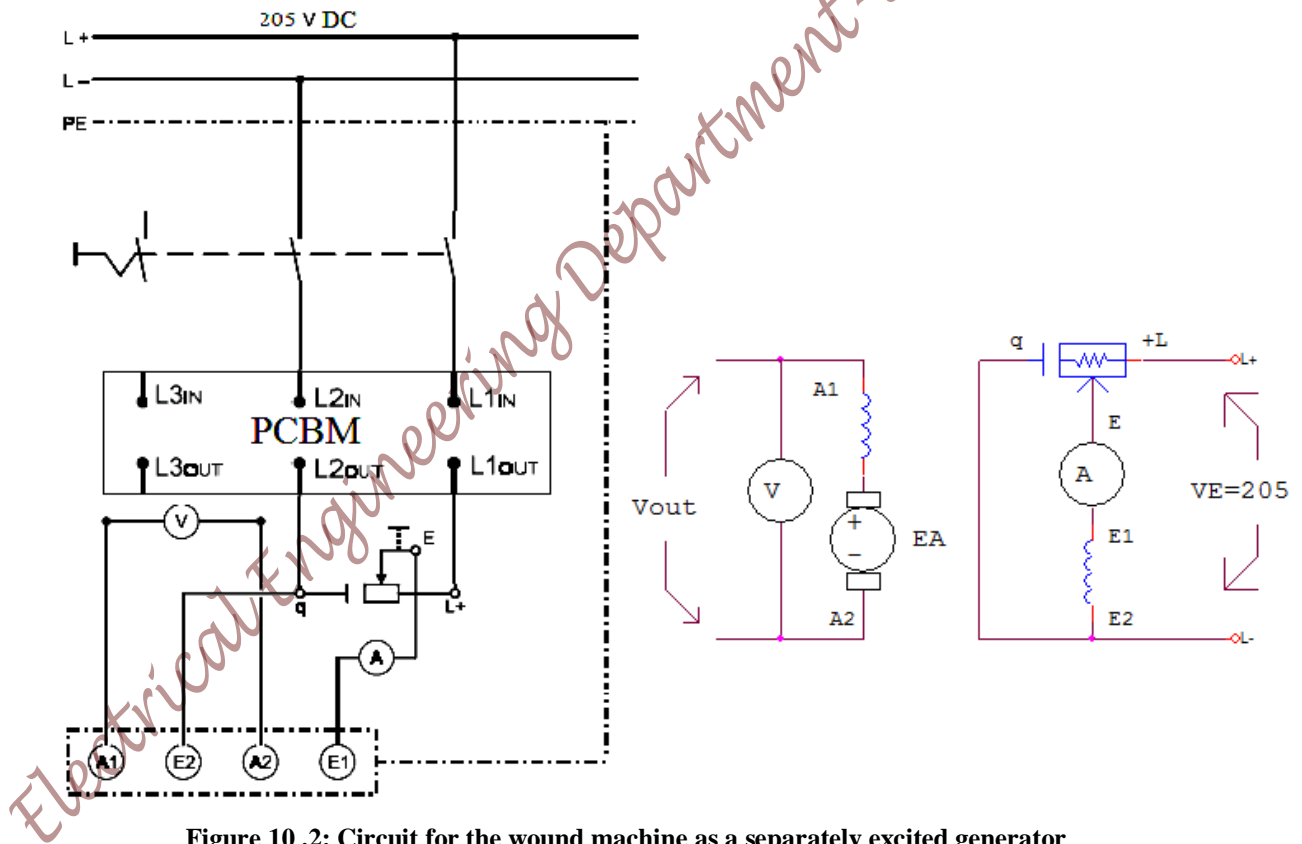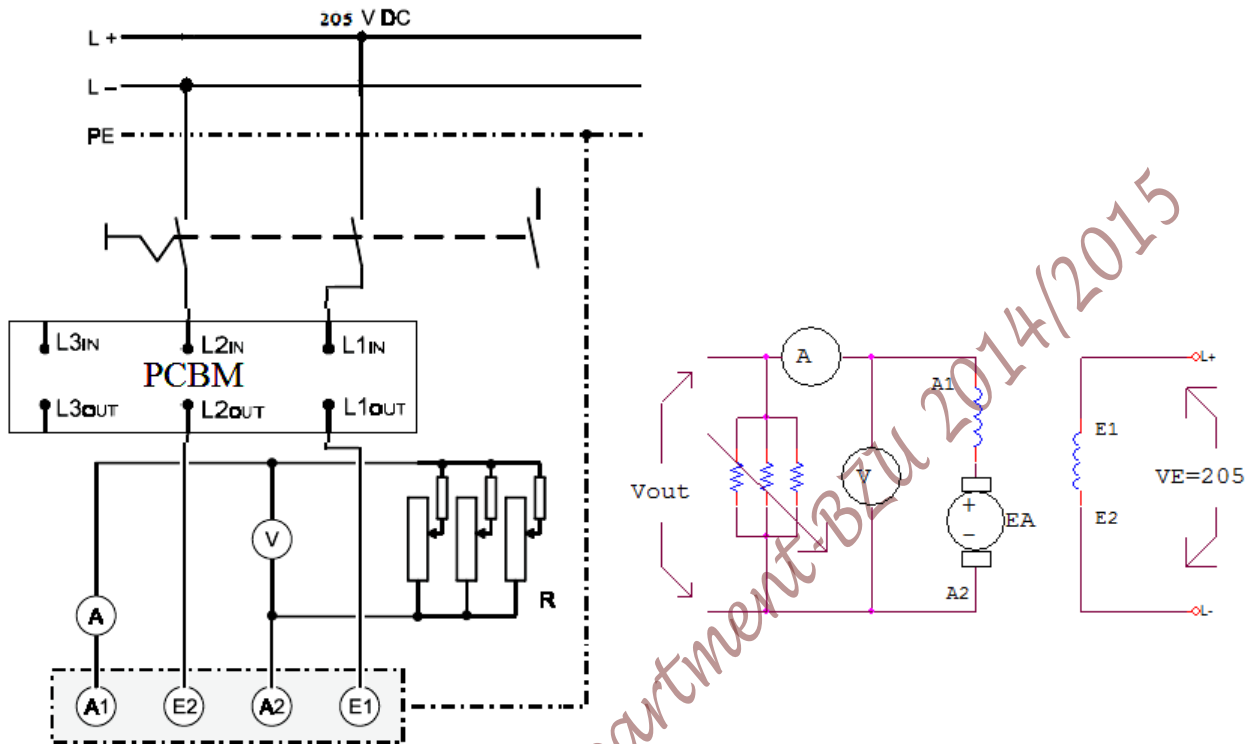
5. Press the ON button of the PCBM

Table 10.3: Measurements for load characteristic of a separately-excited wound generator

|	R[%]	100	90	80	70	60	50	40	30	20	10
Measure	I_A[A]										
	V_A [V]										
Calculate	I_A/I_{AN}										
	V_A/V_{AN}										
	P_2[W]										
	P_2/P_{2N}										

6. Measure the armature current (I_A) and the armature voltage (V_A), fill your results in Table 10.3 and repeat this step for the other values of the Load Resistance

7. Press the OFF button of the PCBM

8. Press the RED button of the Machine Test System

Q3: Represent the measured and calculated values for armature voltage, armature current and output power in a normalized graph as a function of load resistance, comment on the graphs

C. Shunt Wound machine as a self-excited generator

1. Change the circuit to match Figure 10.4, the machine now operates as a shunt generator
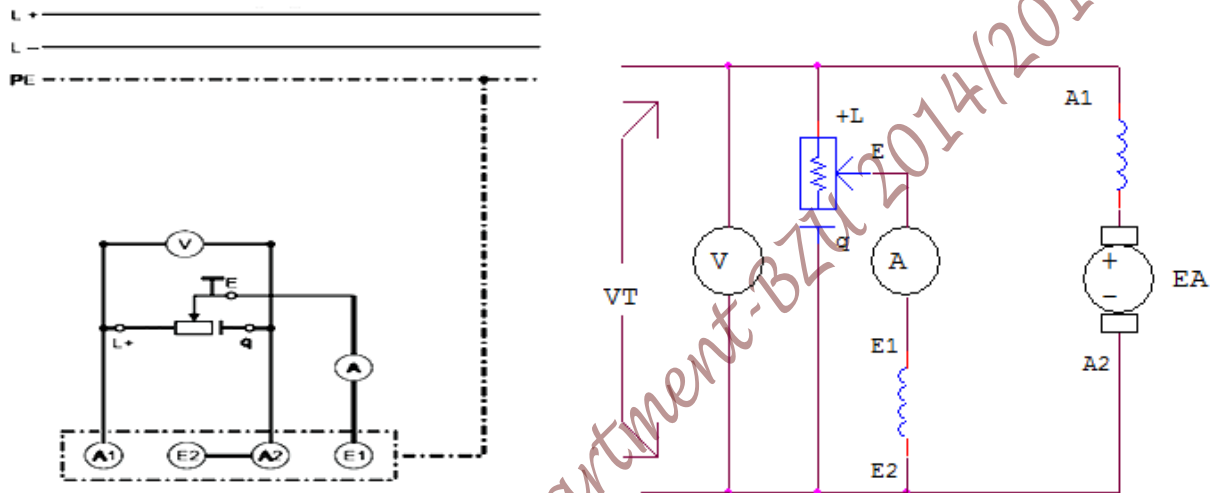
Figure 10.4: Circuit for the shunt wound machine as a self-excited generator

2. Set the Field Regulator Generator initially to position '0'

3. Press the RED button of the Machine Test System

4. Drive the generator at a speed of 2000 rpm in the clockwise direction (looking towards the generator from the coupling side)

5. Set the Field Regulator Generator to a value of 50 %, measure the value and notice the polarity of the produced voltage at the armature's terminals

6. Change the Field Regulator Generator value and observe the voltage produced by the machine

7. Put the Field Regulator Generator into its "q" position while the machine is running and measure the terminal voltage

8. Press the RED button of the Machine Test System

Q4: Explain why the machine produces a voltage even without being excited? Comment on your observations

9. Reverse the polarity of the exciter winding (i.e. connect terminal E1 with A2 and E2 to the Field Regulator Generator's terminal E) Repeat steps (2 to 7) in this part.
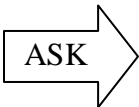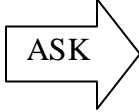
10. Repeat steps 2 to 4

11. Set the Field Regulator Generator to position "q"

12. Press the RED button of the Machine Test System

13. Reconnect the circuit as in Figure 10.4 (undo the connection changes taken in step 9)

ASK

14. Press the RED button of the Machine Test System

15. Drive the generator at a speed of 2000 rpm in the clockwise direction (looking towards the generator from the coupling side)

16. Use the Field Regulator Generator to increase excitation current according to the values in Table 10.4 and measure the corresponding no-load voltage

Table 10.4: No-load characteristic of a self-excited shunt wound generator at constant speed (n=2000 rpm)

	I_E / I_{EN}	0	0.1	0.2	0.3	0.4	0.5	0.6	0.7	0.8	0.9	1
Calculate	I_E [A]											
Measure	V_o [V]											
Calculate	V_o /V_N											

Q5: Produce a normalized graph of the relationship between these two quantities (V_o vs. I_E) then discuss the graph with the theoretical background

17. Set the Field Regulator Generator to its "q" position

18. Press the RED button of the Machine Test System

19. Change the circuit to match Figure 10.5

Table 10.5: Measurements for load characteristic of a self-excited shunt wound generator

	R[%]	100	90	80	70	60	50	40	30	20	10
Measure	I_L[A]										
	V_L [V]										
Calculate	P_2[W]										
	P_2/P_{2N}										

20. Set the Resistive Load to 100%

21. Press the RED button of the Machine Test System

22. Drive the generator at a speed of 2000 rpm in the clockwise direction (looking towards the generator from the coupling side)

23. Measure the load current (I_L) and the load voltage (V_L), record your measurements in Table 10.5, continue for other values of load resistance
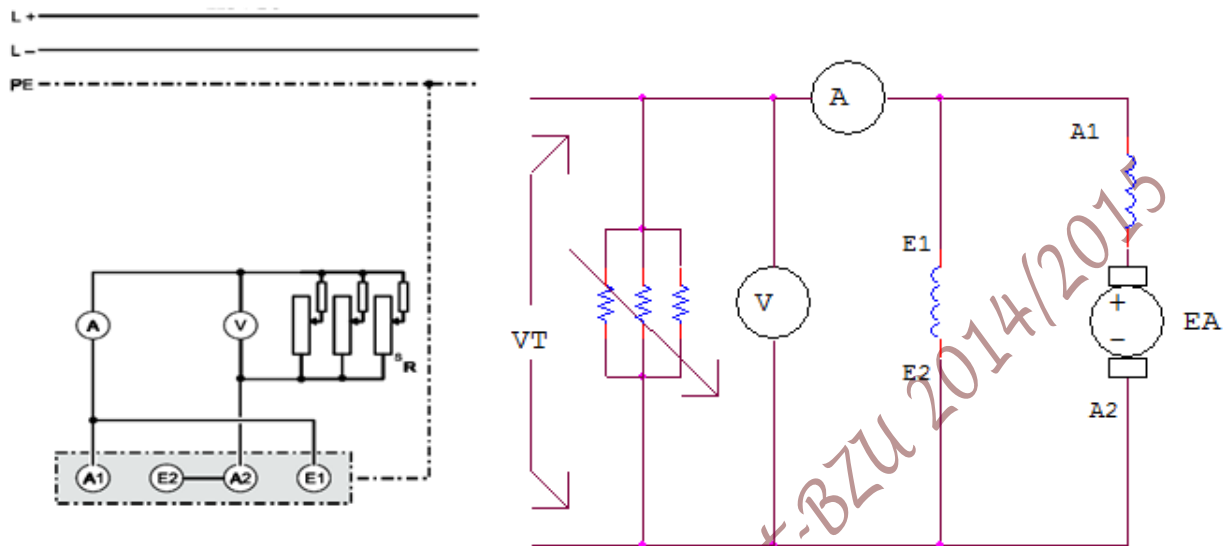

Figure 10.5: Self-Excited Shunt wound generator circuit for recording load characteristics

24. Press the RED button of the Machine Test System

D. Series Wound Machine in Generator Operation

1. Set up the circuit as shown in Figure 10.6

2. Set the resistive load to its 100 % value

3. Press the RED button of the Machine Test System

4. Drive the generator at a speed of 2000 rpm in the clockwise direction (looking towards the generator from the coupling side)

5. Record the terminal voltage and notice its polarity

6. Set the load resistance to 10% and record the terminal voltage and notice its polarity

Q6: Compare both voltage readings (step 5 and 6) and explain the difference in both readings!!

7. Press the RED button of the Machine Test System, wait for the speed to reach zero

8. Press the RED button of the Machine Test System

9. Drive the generator at a speed of 2000 rpm in the counterclockwise direction (looking towards the generator from the coupling side)

10. Repeat steps 2, 5 and 6
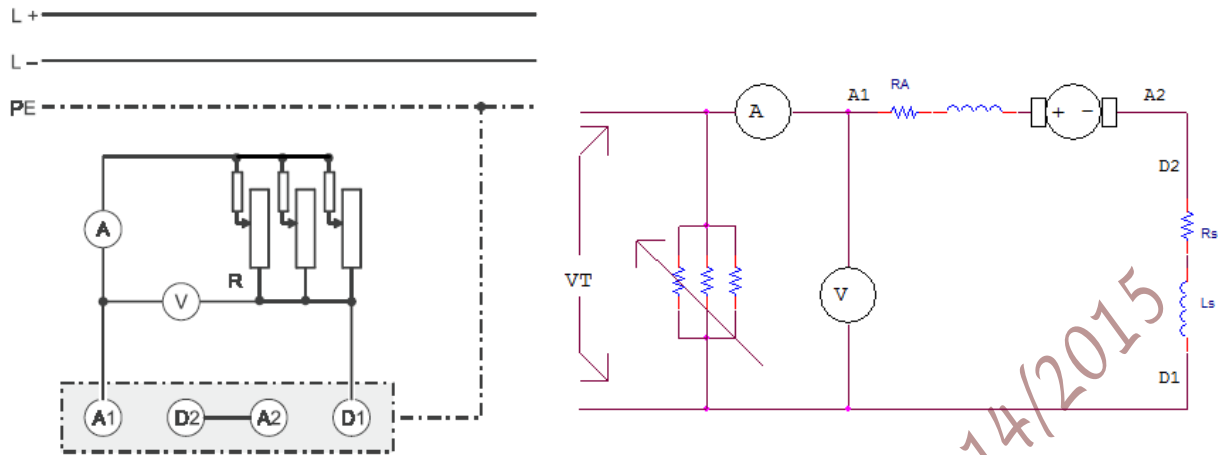
11. Press the RED button of the Machine Test System

Figure 10.6: Circuit for the series wound machine as a generator

12. With the machine at a standstill, change the circuit so that terminals A_2 and D_1 are connected with each other and the load is placed across terminals A_1 and D_2

13. Press the RED button of the Machine Test System

14. Drive the generator at a speed of 2000 rpm in the clockwise direction (looking towards the generator from the coupling side)

15. Repeat steps 2, 5 and 6

16. Press the RED button of the Machine Test System

17. Change the circuit connections to match Figure 10.6

Table 10.6: Series wound generator terminal voltage with respect to speed at constant load (R=70%)

	n / n_N	0.1	0.2	0.3	0.4	0.5	0.6	0.7	0.8	0.9	1
Calculate	n [rpm]										
Measure	V_o [V]										
Calculate	V_o / V_N										

Q7: Produce a normalized graph of the relationship between speed and terminal voltage. Discuss your results based on the theoretical backgrounds

18. Press the RED button of the Machine Test System

19. Drive the generator at a speed of 2000 rpm in the clockwise direction

20. Set the Resistive load to 70%

21. Change the speed according to Table 10.6 and take readings of the terminal voltage

22. Set the load resistance according to Table 10.7, take reading of the load current (I_L) and the load voltage (V_L)

Table 10.7: **Measurements for load characteristic of a series wound generator**

	R[%]	100	90	80	70	60	50	40	30	20	10
measure	I_L [A]										
	V_L [V]										
calculate	P_2[W]										
	P_2/P_{2N}										

23. Press the RED button of the Machine Test System

Q8: Produce a normalized graph of the relationship between voltage, current and output power with respect to load resistance. Discuss your results based on the theoretical backgrounds.

E. Compound-Wound Machine in Generator Operation

1. Set up the circuit as shown in Figure 10.7

2. Set the Field Regulator Generator initially to position 0

3. Press the RED button of the Machine Test System

4. Drive the generator at a speed of 2000 rpm in the clockwise direction

5. Measure the voltage on the machine's terminals along with its polarity

6. Slowly change the Field Regulator Generator value up to 100 % and observe the voltage produced by the machine, then comment on your observation with the result of step 5

7. Set the Field Regulator Generator to its (q) position

8. Press the RED button of the Machine Test System

9. Set the Field Regulator Generator to position 0

ASK

10. Press the RED button of the Machine Test System

11. Drive the generator at a speed of 2000 rpm in the counterclockwise direction (looking towards the generator from the coupling side)
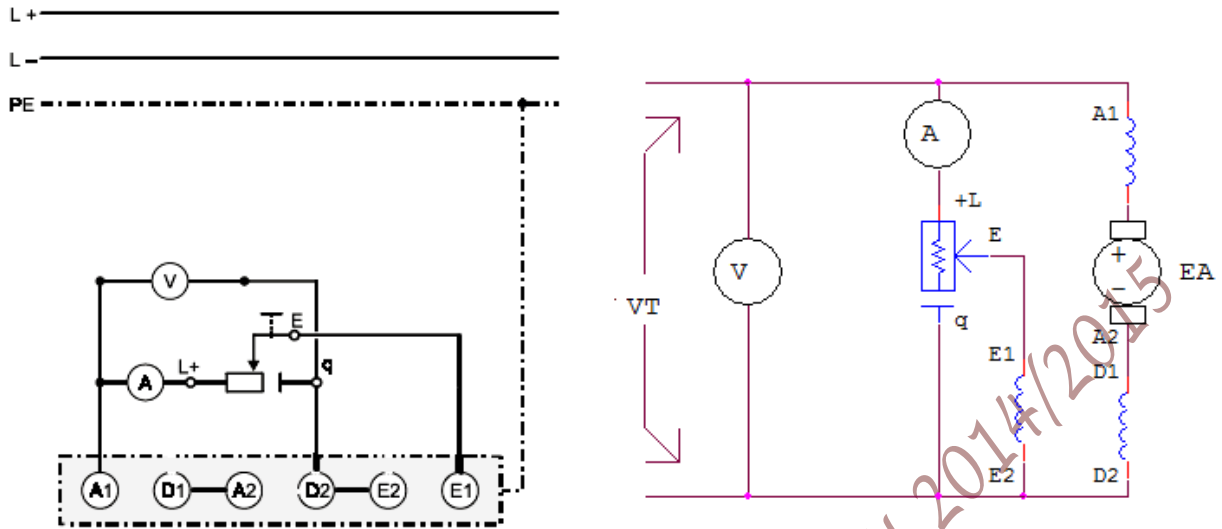
Figure 10.7: Circuit for the compound-wound machine as a generator

12. Measure the voltage on the machine's terminals along with its polarity

13. Set the Field Regulator Generator to position (q)

14. Press the RED button of the Machine Test System

15. Set the Field Regulator Generator to its 0% position

16. Press the RED button of the Machine Test System

17. Change the speed according to Table 10.8, record the terminal voltage in each step

Table 10.8: Compound-wound generator no-load voltage in relationship to speed

	n / n_N	0.1	0.2	0.3	0.4	0.5	0.6	0.7	0.8	0.9	1
Calculate	n [rpm]										
Measure	V_o [V]										
Calculate	V_o /V_N										

18. Set the Field Regulator Generator to its (q) position

19. Press the RED button of the Machine Test System

20. Set the Field Regulator Generator to position 0

Q9: Produce a normalized graph of the relationship between speed and no-load voltage, Discuss your graph with the theoretical background

21. Press the RED button of the Machine Test System, drive the machine with nominal speed (n_N)

22. Change the Field Regulator Generator to its 100% value, measure the current (I_E) and the voltage

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23. Continue for other values of the Field Regulator Generator and fill in Table 10.9

Table 10.9: generator no-load voltage at constant speed in relationship to excitation current

	R[%]	100	90	80	70	60	50	40	30	20	10
Measure	I_E [A]										
	V [V]										
Calculate	I_E/I_{EN}										
	V_A/V_{EN}										

24. Set the Field Regulator Generator to its q position

25. Press the RED button of the Machine Test System

26. Set the Field Regulator Generator to its 0 position

Q10: Produce a normalized graph of the relationship between no-load voltage and excitation current, Discuss your graph with the theoretical background

27. Connect the Resistive load (732 40) connected in parallel to the output of the generator (between terminals E_2 and A_1) refer to Figure 10.7 and set the Resistive load to 100% value, add an ammeter with the Resistive load to measure the load current

ASK

28. Press the RED button of the Machine Test System and drive the generator at nominal speed

29. Measure the load current and the generated voltage, fill in Table 10.10, continue for other values of the Resistive load

Table 10.10: Load characteristics of a compound DC generator

	R[%]	100	90	80	70	60	50	40	30	20	10
Measure	I [A]										
	V [V]										

30. Set the Field Regulator Generator to q%

31. Press the RED button of the Machine Test System

Q11: Plot the load characteristic (V vs R, I vs R and P vs R) of the generator, discuss your results?

Experiment 11
Single Phase IM and Split phase IM

Objectives

After carrying out this experiment, the student will be capable of:

- Connecting a capacitor run motor, a capacitor start motor, a capacitor start and capacitor run motor, a split phase induction motor and reversing the direction of rotation
- Performing measurements to determine the motor's efficiency and making a comparison of this value to the value derived from the rating plate
- Recording and interpreting various load characteristics of the capacitor motor and investigating the influence of its starting capacitor
- Measuring and interpreting the motor's load and run-up characteristics with computer aided techniques
- Recording and interpreting various load characteristics of split phase induction motor

Equipment List

1 capacitor motor F	732 06
1 bifilar-wound motor	732 05
1 machine test system	731989
1 CBM 10 computer-based analysis of electrical machines, V.5.76	728421
1 power circuit breaker module	745 561
2 RMS meters	727 10
1 power factor meter	727 12
1 motor protection switch 1 ... 1.6 A	732 14
1 isolating variable transformer, 0 …260 V	726 85

Notations

P_1	Input Power
P_2	Output Power
T_N	Nominal torque
η	Efficiency
n	Mechanical speed

Theory

Alternating current (a.c.) machines are to be found in numerous fields of applications; above all in household appliances (washing machines, refrigerators, vacuum cleaners) and electric power tools (power drills and wood-working machines).

Single-phase induction motors with squirrel-cage rotors are also in wide-spread use. In addition to its main winding (load winding) this type of motor also has a spatially offset auxiliary winding (starter winding) that develops a phase-shifted current linkage to enable initial start-up. The effect of overlapping alternating fields, produced by the main and auxiliary windings, corresponds to a rotary field. The necessary phase shift for currents in the two windings can be achieved with resistors, inductors or capacitors, whereby resistors or capacitors are generally preferred.

Experimental Procedure

Note: <u>Do not turn on any part of the equipments without prior notice from the supervisor</u>

Note: in all the figures in this experiment, the F_1...F_3 symbols are the motor protection switch 732 14 connected in series with the power circuit breaker module 745 561
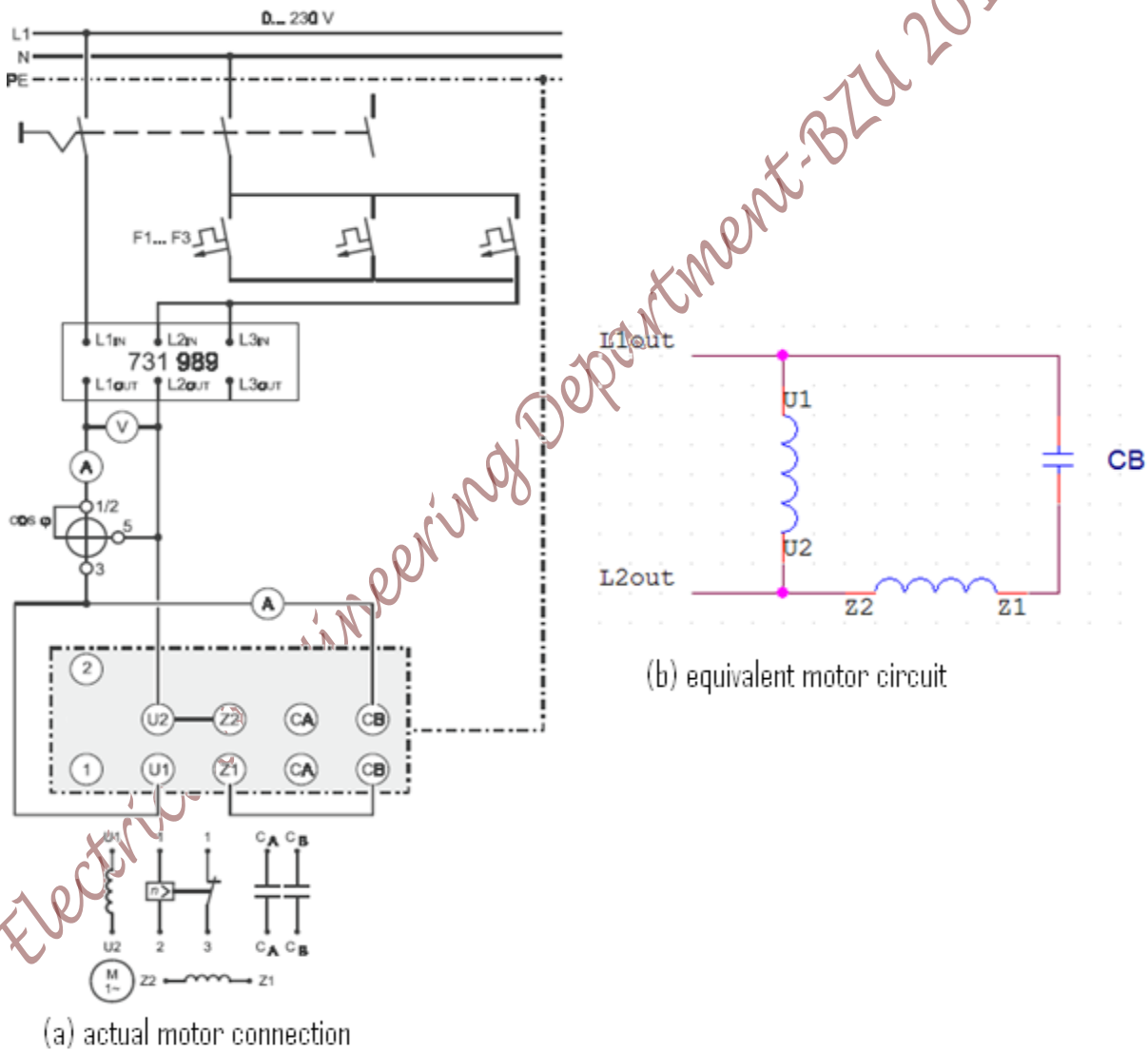
A. Capacitor Run Motor

1. Set up the equipments as shown in Figure 11.1
2. Set the isolating variable transformer 726 85 to give 230 V
3. Turn on all required modules (after the inspection of your lab supervisor)
4. Press the ON button of the power circuit breaker module 745 561 to supply the motor with power
5. Measure the supply voltage, the motor speed and the direction of rotation looking to the motor from left to right
6. Press the OFF button of the power circuit breaker module 745 561

Q1: How do you reverse the direction of rotation?

7. Make the necessary connection adjustments to reverse the direction of rotation
8. Press the ON button of the power circuit breaker module 745 561
9. Measure the supply voltage, the motor speed and the direction of rotation
10. Press the OFF button of the power circuit breaker module 745 561
11. Disconnect the running capacitor and the auxiliary winding

12. Disconnect the DUT enable connection from the Power circuit breaker module and connect its Relay input to its logic zero pin

13. Remove the shaft cover

14. Set the isolating variable transformer 726 85 to give 160 V

15. Press the ON button of the Power circuit breaker module

16. Turn the motor shaft either clockwise or counter clockwise and observe

17. Press the OFF button of the power circuit breaker module

Q2: Why the motor could not start until you provided it with an initial torque? Explain?

Figure 11. 1 Connection for studying the Capacitor RUN motor

A.1 Efficiency Test and Recording Load Characteristics

1. Enter the nominal data for the machine under test in Table 11.1

Table 11.1 Nominal Data for the machine under test

Nominal Voltage V_N	
Nominal Current I_N	
Nominal Power Factor, $Cos(\theta_N)$	
Nominal Power P_N	
Nominal speed n_N	
Starting capacitor C_A	
Running capacitor C_B	

2. Determine the machine nominal torque from the data in Table 11.1

3. Reconnect the running capacitor C_B and the auxiliary winding as shown in Figure 11.1

4. Reconnect the DUT enable of the machine test system with the power circuit breaker

5. Using the CBM 10 software, go to Measurements>>settings, set the operating mode to torque control

6. Press the ON button of the Power Circuit Breaker Module

7. Press the RED button of the machine test system (the motor should be running!)

8. Set the calculated nominal torque found in step 2 as a load for the motor, calculate the output power of the motor ($P_2 = \omega X \tau$), if the value obtained is equal to the nominal Power P_N obtained in Table 11.1, then the motor is operating at its nominal point, otherwise, slightly readjust the load torque until the output power P_2 is almost equal to P_N so that the motor is operating at its nominal point

9. Measure the input voltage, the input current, the current in the auxiliary winding, the power factor, speed and torque

Q3: Using the values obtained in step 8, calculate the actual efficiency?

Q4: Using the data obtained in Table 11.1, calculate the theoretical efficiency? Compare both efficiencies

10. To study the load characteristics of the motor, set the load torque to be ($0.0XT_N$), measure the speed (n), the input current (I), the power factor (PF) and the current in the auxiliary winding (I_C), then fill you results in Table 11.2, continue for other values of load torque

11. Press the RED button of the machine test system to disconnect the load torque

12. Press the OFF button of the power circuit breaker module

13. On the same graph, plot (n/n_N, I/I_N, I_C/I_{CN}, P_1/P_{1N}, P_2/P_{1N} and Ŋ) versus $T/T_{N,act}$

Table 11. 2 Measurement for Load Characteristic recording for the capacitor run motor

	T/T$_{N,act}$	0.0	0.1	0.2	0.3	0.4	0.5	0.6	0.7
	T/[Nm]	0.0XT$_N$							
Measure	n/[rpm]								
	I/[A]								
	Cos (θ)								
	I$_C$/[A]								
calculate	n/n$_N$								
	I/I$_{N,act}$								
	I$_C$/I$_{CN}$								
	P$_1$/[W]								
	P$_1$/P$_{1N}$								
	P$_2$/[W]								
	P$_2$/P$_{2N}$								
	ŋ								
	T/T$_{N,act}$	0.8	0.9	1.0	1.1	1.2	1.3	1.4	1.5
	T/[Nm]								
Measure	n/[rpm]								
	I/[A]								
	Cos (θ)								
	I$_C$/[A]								
calculate	n/n$_N$								
	I/I$_{N,act}$								
	I$_C$/I$_{CN}$								
	P$_1$/[W]								
	P$_1$/P$_{1N}$								
	P$_2$/[W]								
	P$_2$/P$_{2N}$								
	ŋ								

Q5: Compare the motor behavior (from the plots in step 11) with the expected behavior of a capacitor run motor

B. Capacitor Start Motor

1. Connect the circuit as shown in Figure 11.2
2. Set the isolating variable transformer to 30 volts V
3. Press the ON button of the machine test system (after the inspection of your lab supervisor)
4. Slowly increase the input voltage from 30 to 80 V, notice at what speed the centrifugal switch opens (you will hear a tick sound), record the speed at which the switching occurs, then start decreasing the input voltage slightly, until you hear a tick sound again (when the centrifugal switch closes) record the speed
5. Press the OFF button of the power circuit breaker module
6. Set the isolating variable transformer to 230 V
7. Press the ON button of the power circuit breaker module
8. Press the RED button of the machine test system, make sure the selected mode is the torque control mode
9. Repeat step 10, 11, 12 and 13 from part **A.1 efficiency test and recording load characteristics**, but this time fill in Table 11.3, for higher values of torque, the motor may not be able to carry the load, SO be prepared to Press the RED button of the machine test system if the motor is going to stall condition

Q6: Compare the motor behavior (from the plots in step 11) with the expected behavior of a capacitor run motor
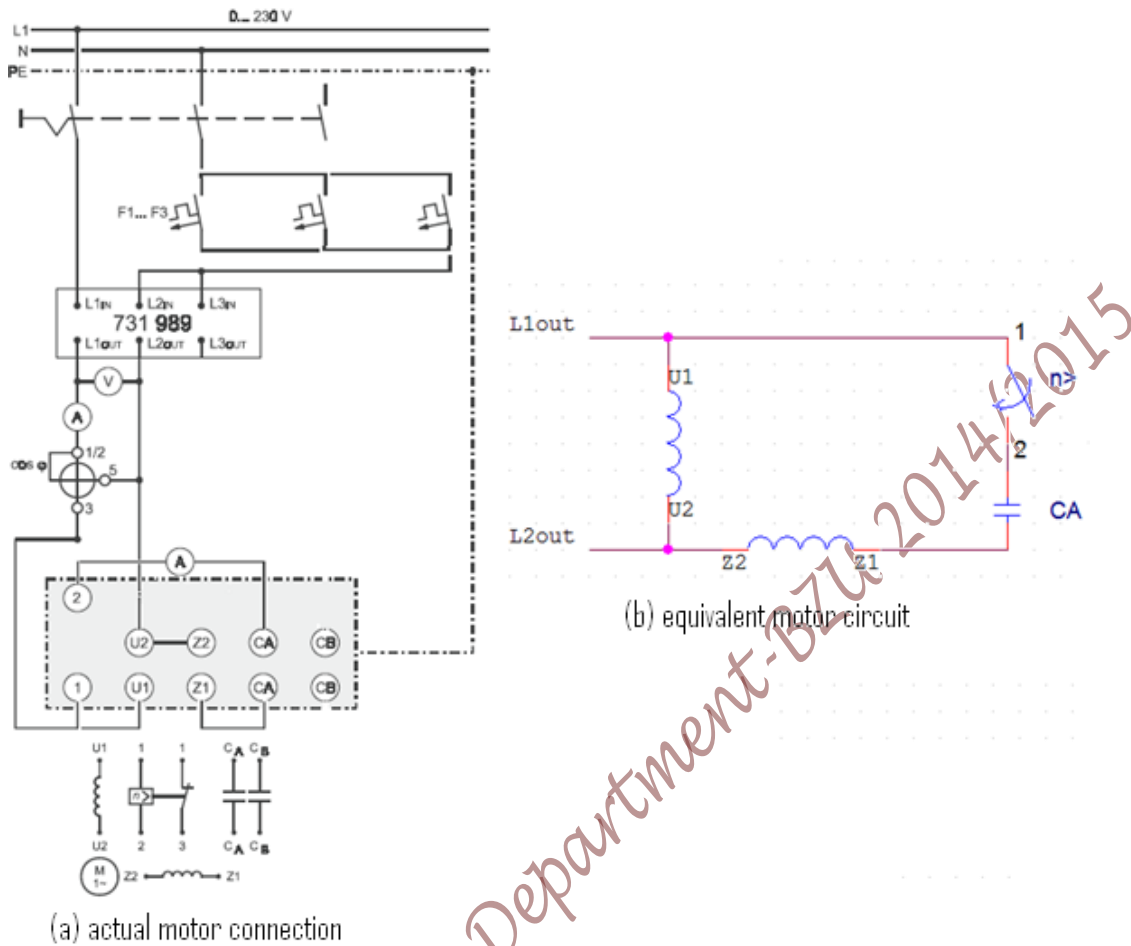
Figure 11. 2 the circuit to study the cpacitor start motor

Table 11.3 Measurement for Load Characteristic recording for the capacitor start motor

	T/T_{N,act}	0.0	0.1	0.2	0.3	0.4	0.5	0.6	0.7
	T/[Nm]	0.0XT_N							
Measure	n/[rpm]								
	I/[A]								
	Cos (θ)								
	I_C/[A]								
calculate	n/n_N								
	I/I_{N,act}								
	I_C/I_{CN}								
	P_1/[W]								
	P_1/P_{1N}								

## C. Computer Based Recording of Run-up Characteristics of Capacitor Motor

In this part, we shall use the computer to plot curves that represent the behavior of the capacitor start motor, capacitor run motor and capacitor start and capacitor run motor

1. Open the CBM 10 software by going to Start>>All Program>>CBM10>>MOMO.exe (click on MOMO) the software will open up
2. Choose the machine under test type by going to Machine Type in the toolbar click on Capacitor Motor F
3. Click on T, I, P_1, P_2 , efficiency and $Cos(\vartheta)$ from the left side column to display these values plots versus the speed
4. Change the axis setting from Presentations>>Axis Setting, first check all the nominal value boxes, fill in the Nominal Values fields the ones that you have obtained for the machine in this experiment, modify the values of the Y axis for the parameters according to Table 7.6

Table 11.3 Y axis limits for the stated parameter for plotting

Parameter	From	To
n	0	1.2
torque	0	2
I	0	2
P_1 and P_2	0	4
$Cos(\vartheta)$ and ŋ	0	1

5. Go to Measurements>>Settings, in the popup window, check the only motor operation box, set the operational mode to **Load Characteristics,** set the start up speed to 1492rpm, set the stop speed to 600 rpm, then press ok
6. Press the ON button of the 745 561 module to power on the motor
7. On the CBM 10 software press on the Green button on the left hand column (this is the synchronization button that will synchronize the machine test system with the motor), wait for synchronization, make sure you choose the Automated Mode recording, then start the plotting by pressing on the RUN button on the software (the blue arrow)
8. When the plotting is over, press on the RED button on the software to isolate the machine test system from the motor
9. Press on the OFF button of the 745 561 module
10. Change the voltage to 125V and repeat steps 6 to 9; comment on the plots
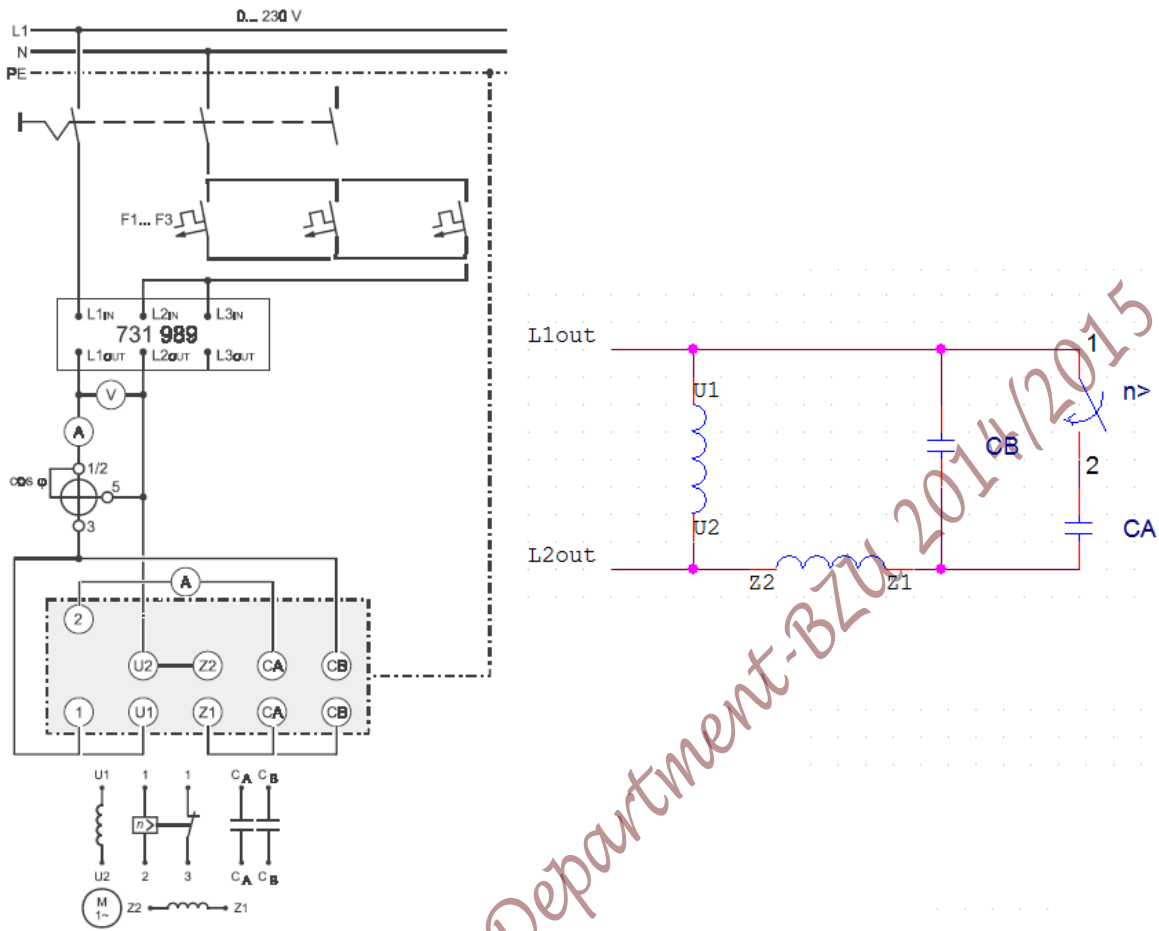
Figure 11. 3 Circuit connection for capacitor start capacitor run motor

11. Change the motor connection to Capacitor Run Motor (as in Figure 11.1), set the voltage back to 230V

12. On the same plots, repeat the plotting procedure for the capacitor run motor (repeat steps step 6, step 7, step 8 and step 9)

13. Change the motor connection to match Figure 11.3 (Capacitor Start and Capacitor Run Motor)

14. Repeat step 12 from this section for the Capacitor Start and Capacitor Run Motor

15. Save your plot by copying it to clip board by the copy to clip board function on the software, copy it to a document file

16. Comment on the plots you have made for the three types of capacitor motor

D. Separate Winding Induction Motor (Bifilar Wound Motor)
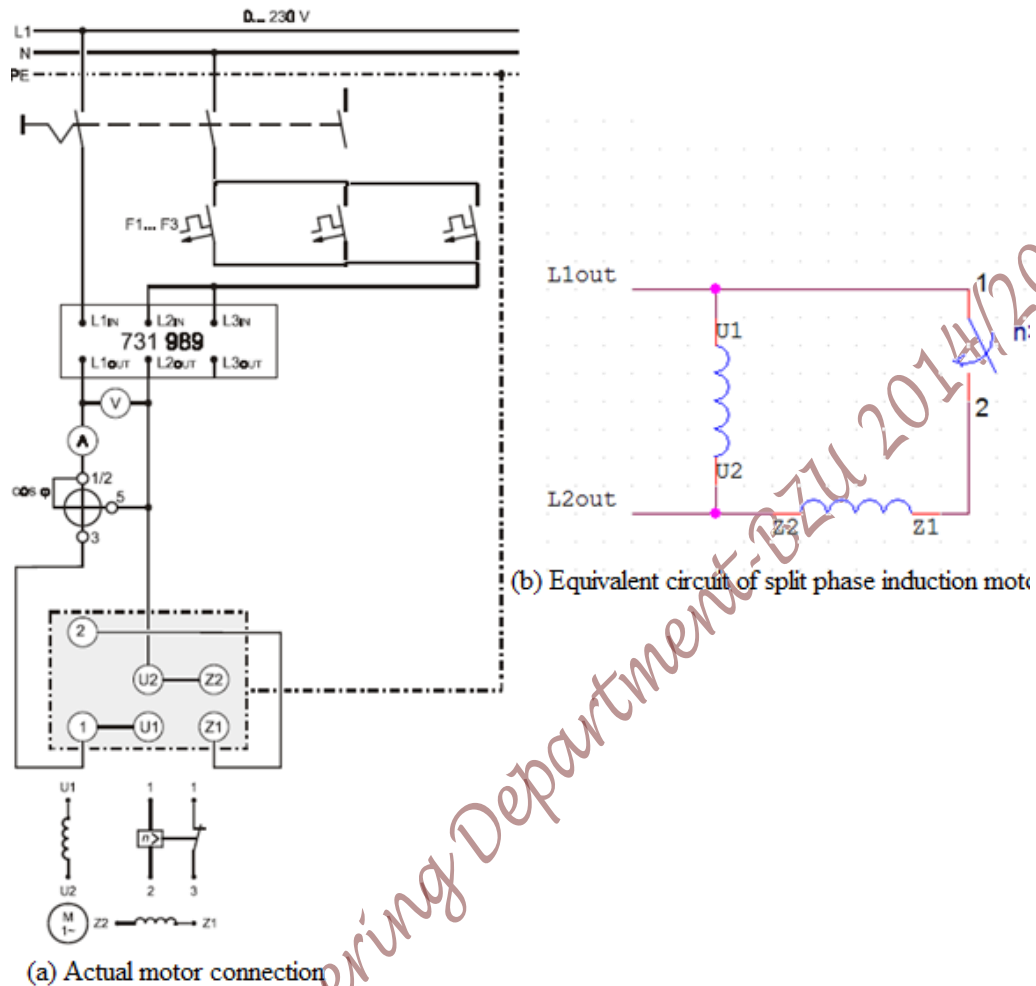
1. Connect the circuit as shown in Figure 11.4

(a) Actual motor connection

(b) Equivalent circuit of split phase induction motor

Figure 11. 4 Circuit for studying separate winding induction motor

2. Enter the nominal data for the machine under test in Table 11.4

Table 11.4 Nominal Data for the machine under test

Nominal Voltage V_N	
Nominal Current I_N	
Nominal Power Factor, $Cos(\theta_N)$	
Nominal Power P_N	
Nominal speed n_N	

3. Based on the data obtained in step 2, calculate the machine's nominal torque

4. Using the CBM 10 software, go to Measurements>>settings, set the operating mode to torque regulation

5. Press the ON button of the power circuit breaker module

6. Press the RED button of the Machine Test System (the motor should be running!)

7. Set the calculated nominal torque found in step 2 as a load for the motor, calculate the output power of the motor ($P_2 = \omega X \tau$), if the value obtained is equal to the nominal Power P_N obtained in Table 11.4, then the motor is operating at its nominal point, otherwise, slightly readjust the load torque until the output power P_2 almost equal to P_N so that the motor is operating at its nominal point

8. Measure the input voltage, the input current, the power factor, speed and torque

Q7: Using the values obtained in step 8 calculate the actual efficiency?

Q8: Using the data obtained in Table 11.4, calculate the theoretical efficiency? Compare both values of efficiencies

9. To study the load characteristics of the motor, set the load torque to be ($0.0XT_N$), measure the speed (n), the input current (I) and the power factor (PF) then fill your results in Table 11.5, continue for other values of load torque

10. Press the RED button of the machine test system

11. Press the OFF button of the power circuit breaker module

12. On the same graph, plot (n/n_N, I/I_N, I_C/I_{CN}, P_1/P_{1N}, P_2/P_{1N} and Ŋ) versus $T/T_{N,act}$

Table 11.5 Measurement for Load Characteristic recording for the split phase Induction motor

	$T/T_{N,act}$	0.0	0.1	0.2	0.3	0.4	0.5	0.6	0.7
	T/[Nm]	$0.0XT_N$							
Measure	n/[rpm]								
	I/[A]								
	Cos (θ)								
calculate	n/n_N								
	$I/I_{N,act}$								
	P_1/[W]								
	P_1/P_{1N}								
	P_2/[W]								
	P_2/P_{2N}								
	Ŋ								
	$T/T_{N,act}$	0.8	0.9	1.0	1.1	1.2	1.3	1.4	
	T/[Nm]								
Measure	n/[rpm]								
	I/[A]								
	Cos (θ)								

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calculate	n/n_N							
	$I/I_{N,act}$							
	P_1/[W]							
	P_1/P_{1N}							
	P_2/[W]							
	P_2/P_{2N}							
	ŋ							

13. In the CBM 10 software, choose the machine type to be Bifilar-Wound Motor

14. Repeat steps (5, 6, 7, 8 and 9 in part **C. Computer Based Recording**…) procedure to study the behavior of the separate winding induction motor

15. Save your plot by copying it to clip board by the copy to clip board function on the software, copy it to a document file

Q9: Comment on the plots explaining the behavior of each motor configuration, advantages and disadvantages

Experiment 12
Introduction to Control Circuits

Objective:

1. To familiarize students with the basic elements of control circuits such as contactors, relays, overloads and timers

2. To install simple control circuits

Theory:

Contactor is a magnetically operated switch. It consists of one set of stationary contacts and one set of movable contacts which are brought together by means of the magnetic force of an electromagnet.

The vast majority of contactors use an electromagnet and contact arrangement that falls into one of two general types, the clapper type and solenoid-type contactor. What is needed electrically to operate the contactor is to provide a voltage of the proper value to the core of the electromagnet. When the voltage is switched on, the previous states of the contacts are changed, the opened contacts become close and the closed contacts become open. Whether the contactor is of the clapper or the solenoid type, the contacts are broken by the pull of gravity or the force of a spring when the electromagnet is de-energized.

Relay is by design an electromechanical amplifier. Automatic control circuits almost contain one or more relays, primarily because relay lends flexibility to the control circuit. When the coil of the relay is energized with 24V and the contacts are controlling a circuit of 380V or more, we are amplifying the voltage through the use of relay. Relay coils require only very low currents in their operating and are used to control circuits of large currents, so they amplify the current. The relay is a single-input device in that it requires only a single voltage or current to activate its coil.

Through the use of multiple outputs, the relay can be a multiple-output device which amplifies the number of operation controlled by the single input. Relay falls into many types according to their use, there are voltage relay, current relay, frequency relay, overload relay, time-delay relay.

Practical:

I) Controlling a three-phase induction motor
A) Study the circuit of Figure 12.1 before connecting it

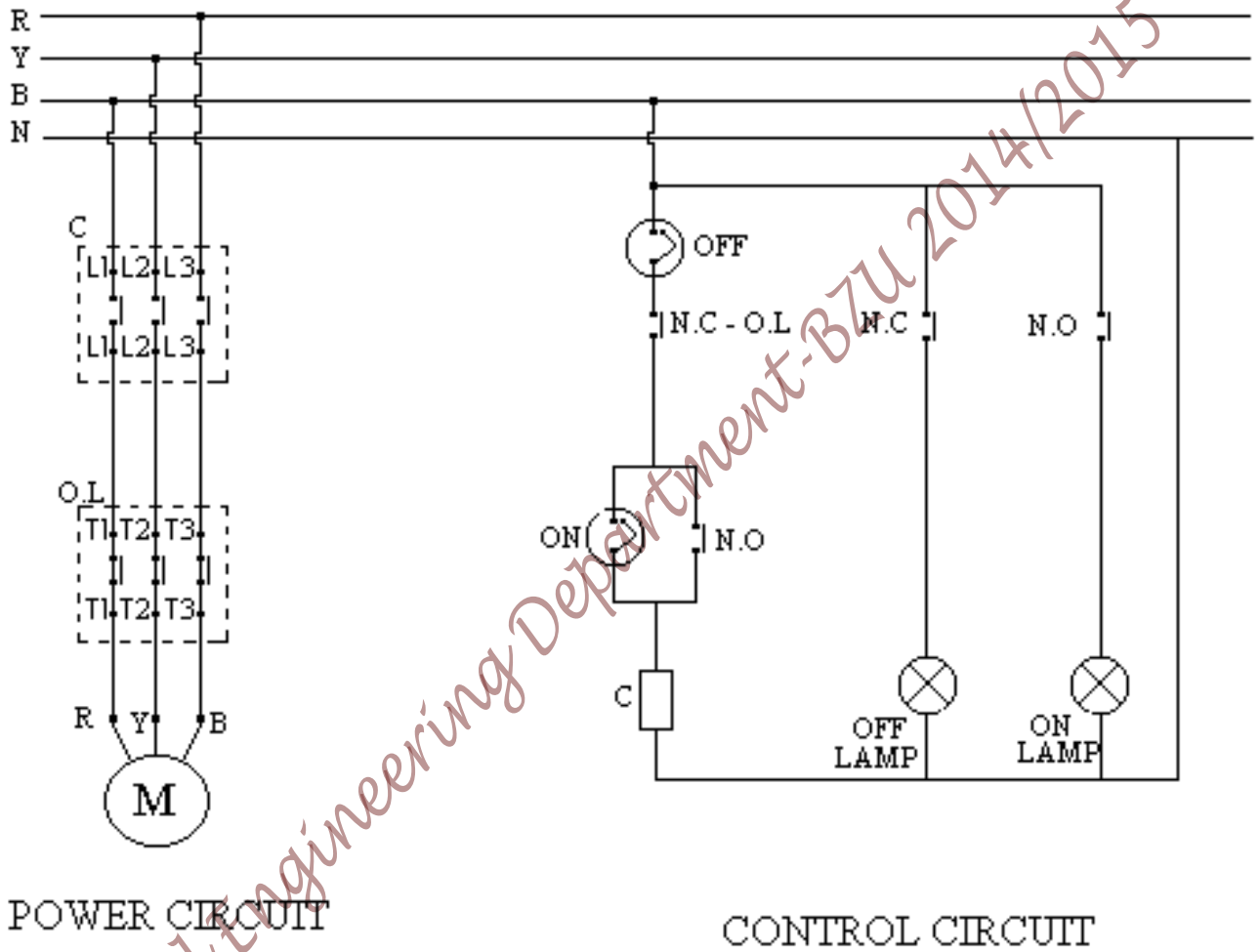B) Connect the circuit of Figure 12.1 and discuss its operation

Figure 12.1: Controlling three-phase induction motor using ON switch, OFF switch, contactor, overload, 2-lamps

II)   Reversing the Direction of Rotation of a Three-Phase Induction Motor

A) Study the circuit of Figure 12.2 before connecting it

B) Connect the circuit of Figure 12.2 and discuss its operation

Figure 12.2: Reversing the direction of rotation of a three-phase induction motor using 2-ON switches, OFF switch, 2-contactors, overload, 3-lamps