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**CONCORDIA UNIVERSITY**

**Department of Electrical and Computer Engineering**



**ELEC 331 / 334**

**FUNDAMENTALS OF ELECTRICAL POWER ENGINEERING**

Laboratory Manual

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 **September - 2010**

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Introduction

SAFETY

Engineers are often required to use hand and power tools in constructing prototypes or in setting up experiments. Specifically, electrical engineers use test instruments to measure the electrical characteristics of components, devices, and electronics systems.

These tasks are interesting and challenging, but they may also involve certain hazards if one is careless in his/her work habits. It is therefore essential that students learn the principles of safety at the very beginning of their career and that they practice these principles.

Safe work requires a careful and deliberate approach to each task. Before undertaking an experiment, students must understand what to do and how to do it. They must plan everything, setting out tools, equipment, and instruments on the workbench in a neat and orderly fashion, . Extraneous items should be removed, and all cables should be securely fastened.

**GENERAL SAFETY RULES**

The first rule of personal safety is always:

*Think First!*

This rule applies to all industrial workers as well as to those working with electricity. Develop good habits of workmanship. Learn to use tools correctly and safely. Always study the job at hand and think through your procedures, your methods, and the applications of tools, instruments, and machines before searching. Never permit yourself to be distracted from your work, and never distract another worker engaged in hazardous work. **Don't be a clown!** Jokes are fun and so is "horsing around", but not near moving machinery or electricity. There are generally three kinds of accidents which may occur to electrical students and technicians- electric shock, burns, and equipment-related injuries. Your knowing and studying about them, and observing simple rules will make you a safe person to work with. You could personally be saved from painful and expensive experiences.

**Electric shocks**

What about electric shocks? Are they fatal? The physiological effects of electric currents can generally be predicted with the chart shown in Fig. 1:



**Fig. 1** Physiological effects of electrical currents.

Notice that it is the current that does the damage. Currents above 100 mA, or only one tenth of an ampere, are fatal. A workman who has contacted currents greater than 200 mA may live to see another day if given rapid treatment. Currents less than 100 mA can be serious and painful. A safe rule: **Do not place yourself in a position to get any kind of shock.**

**Nine rules for safe practice and avoiding electric shocks:**

1. **Work with one hand behind you or in your pocket.** A current between two hands crosses your heart and can be more lethal than a current form hand to foot. A wise technician always works with one hand. Watch your TV serviceman.

2. Be sure of the condition of the equipment and the dangers it can present **before** working on it. Many sportsmen are killed by supposedly unloaded guns; many technicians are killed by supposedly "dead" circuits.

3. **Never** rely on safety devices such as fuses, relays, and interlock systems to protect you. They may not be working and may fail to protect you when most needed.

4. **Never** remove the grounding prong of a three-wire plug. This eliminates the grounding feature of the equipment making it a potential shock hazard.

5. **Do not work on a cluttered bench.** A disorganized mess of connecting leads, components and tools only leads to careless thinking, short circuits, shocks, and accidents. Develop systematized and organized work habits.

6. **Do not work on wet floors.** Your contact resistance to ground is greatly reduced on a wet floor. Work on a rubber mat or an insulated floor.

7. **Do not work alone.** It is just good sense to have someone around to shut off the power, to give artificial respiration, or to call a doctor.

8. **Never talk to anyone while working.** Do not let yourself be distracted. Also, don't talk to someone who is working on dangerous equipment. Do not be the cause of an accident.

9. **Always move slowly** working around electrical circuits. Violent and rapid movements lead to accidental short circuits and shocks.

**Burns**

Accidents caused by burns, although usually not fatal, can be painfully serious. The dissipation of electrical energy produces heat.

Four rules for safe practice and avoiding burns:

1. **Resistors get very hot**, especially those that carry high currents such as the ones in this lab. Watch those five- and ten-watt resistors. They will burn the skin of your fingers. Stay away from them until they cool down.

2. Be on guard for all **capacitors which may still retain charges**. Not only can you get a dangerous and sometimes fatal shock, you may also get a burn from an electrical discharge. If the rated voltage of electrolytic capacitors is exceeded or their polarities reversed they may get very hot and may actually burst.

**LABORATORY RULES**

Considering the number of students attending the labs and in order for the lab to operate properly, the students are asked to abide by the following rules:

1. No smoking, eating, or drinking is permitted in the laboratory.

2. Overcoats, lose clothes (i.e. ties) and briefcases are not permitted in the laboratory, however, a table will allocated for those students that must bring these items.

3. All damaged or missing equipment and cables must be reported immediately to the demonstrator. Failure to do so will result in students being charged for damages and losses or extra lab work can be assigned.

4. Writing on work benches will result in ejection from the laboratory.

5. Student are required to have their preliminary calculation completed before being admitted to the corresponding lab session (preparation and participation evaluation).

6. All data must be recorded on the laboratory sheets in ink and must be signed by the demonstrator before students leave.

7. No more than three students are allowed to occupy one laboratory workbench

8. Any student who is more than 30 minutes late will not be permitted into the laboratory room. Furthermore, repeated tardiness will not be tolerated.

9. Do not connect or use any alligator clip leads on equipment binding posts. These posts are meant to be used with banana plugs or straight wires only.

10. Demonstrators must verify all setups before any power switches are switched on.

11. Any changes even minor ones to the setup must be done when the power is off.

12. Any unusual equipment and machine operating conditions such smoke, sparking, loud noise, or burning smell must be immediately reported to the lab demonstrator and all power supplies should be switched off.

13. Always try to maintain low stress conditions during power up and power down. For example, start the variac at zero during a power-up or reduce the armature voltage to zero before power-down. Not only will this increase the life span of expensive equipment in this laboratory but usually fault conditions can be found before harm or serious damage is incurred.

14. Student's complains concerning lab demonstrators should be presented to the full time lab instructor.

**SCOPE OF THE ELECTROMECHANICS LABORATORY**

The main objectives of laboratory work are as follows:

- To provide practical experience in electromechanical devices.

- To provide experience in electrical measurements.

- To provide experience in report-writing.

All three aspects are very important since an engineer spends most of his/her career designing, measuring, and testing his/her designs and reporting on his/her results.

**ORGANIZATION OF THIS MANUAL**

This manual is divided into 5 sections, each section describing one experiment. Each section is broken down into parts as follows:

1. Objectives
2. Introduction
3. Calculations
4. Experimental procedure
5. Questions

The first part gives the objectives of the experiment. The second part provides a brief introduction to the experiment. Relevant theory is often included in this part for the convenience of the student. The third part describes the experimental procedure to be adopted and is itself broken down into subsections. Some of these subsections indicate to the student how to connect and test a particular circuit. Other subsections require the student to carry out a number of preliminary calculations. The fourth part gives a list of questions which should be answered by the student when the experiment has been completed and be included in the lab report.

**EXPERIMENTS**

Each experiment must be studied in advance and required preliminary calculations completed. If the theory is understood, the student knows exactly what to expect in an experiment and accurate measurements can be obtained very quickly.

The procedure section may often dictate that graphs be plotted. It is a very good engineering practice to plot such graphs as the readings are taken. In this way discrepancies can be immediately detected and checked. Often sketches of various waveforms are required. These should be drawn clearly and relevant quantities, such as peak values, should be given.

Devices are invariably characterized with maximum voltage, current, and power ratings. These should never be exceeded. Otherwise, the properties of a device may be impaired, or it may be damaged (motor, transformer)

If in doubt about the use of a particular instrument, the operating instructions provided by the manufacturer should be read. Defective equipment must be reported immediately to the demonstrator or technical support. This is justified also by the fact that some equipment may be used in more than one experiment and knowing the exact characteristics of this equipment may be important.

Each group is required to work at the same bench location each week. Equipment and components must be returned to their places. The benches must be left clear at the end of the experiment.

Since the laboratory represents a significant portion of the student's practical training, it is imperative that the students perform all the experiments. If a student has missed an experiment due to circumstances entirely beyond his/her control, that student will have the opportunity to perform it at the end of the term. However, it is most unlikely that arrangements can be made for any individual to perform more than one experiment at this time. Any student who misses more than one experiment will not be eligible for any form of passing grade. That is, should a student miss more than one experiment, the student will earn the grade "R" (REPEAT)! Information concerning these arrangements will be provide by the full time lab instructor.

**LAB REPORTS**

For each experiment, a lab report must be written which can be regarded as a record of all activities, observations, and discussions pertaining to the experiment. Lab reports should above all be legible and should contain as much relevant information as possible. A lab report should consist of papers stapled together with a title page identifying the course, lab section, experiment, date, student's name, student's ID number, and demonstrator's name. Any reports without a proper title page will be rejected.

Each lab report should be divided into five parts as follows:

|  |  |
| --- | --- |
| **Objectives:** | they have to be stated clearly and can be copied from the lab manual. |
| **Preliminary Calculations:** | results and a summary of computations should be given. |
| **Experimental procedure and results:** | should be broken down into items 1, 2, 3, etc., as in the lab manual. Each item should briefly contain the conditions of the experiment and the results. |
| **Questions and discussions:** | answer all the questions (if any) posed in the lab manual or by the lab demonstrator. Discuss any problems encountered during the experiment and any important observations made during the report write-up. |
| **Conclusions:** | should be brief |

**GRADING SCHEME**

Each lab report will be marked out of seven. Late lab reports will be marked out of three and no lab will be accepted after the last day of classes. There will be a final lab test based on experiments performed during the term. The grading scheme is as follows:

A. Lab reports:

1. Objectives and preliminary calculations 15%
2. Experimental results 25%
3. Questions, discussion and conclusions 25%
4. Preparation 15%

B. Experimental setup and participation 20%

It is important that the student prepares for each experiment by reading the instructions before the student goes to the laboratory. Therefore, both the preparation and the participation will be evaluated during the laboratory.

Experiment 1

**Power Measurement In Three-Phase Circuits**

**I. Objectives**

There are three objectives to this experiment:

- To study the relationship between voltages and currents in three-phase circuits with delta and wye connections;

- To measure power in three-phase circuits using the two-wattmeter method;

- To become familiar with the principle of power factor correction.

**Ii. Introduction**

A three-phase circuit is usually connected in either delta or wye configuration. Power in a three-phase circuit is usually measured using two wattmeters. At power factors less than 0.5, one of the instruments has a negative reading. When a reading is negative, it is necessary to reverse the voltage or current connection in order to obtain an upscale deflection (with the Lab-Volt dual three-phase wattmeter, the reversal is done with a toggle switch). Remember that all voltage and current quantities are line-to-line and line quantities unless otherwise specified. Note that in Fig. 1-1 the voltage and current isolators E1 and I1 are combined to form a single wattmeter in a two wattmeter system. Similarly, E2 and I2 form the second wattmeter

When the source and load are both balanced, expressions for the wattmeter readings are:





where is the load angle.

When the power factor is less than unity, a current that is greater than the minimum is required to transmit a given active power, resulting higher transmission losses and loading of transformers. There are techniques that minimize these losses. For inductive loads, for example, the most common solution is to install capacitor banks in parallel with the loads.

Three-phase ac circuits, transformers, ac machines and their per-phase equivalent circuits can be described by phasor diagrams. Figure 1-1 shows a wye-connected 3-phase source that is connected to a wye-connected load. In this case, the voltage sources and the load elements are assumed to be equal, hence the system is said to be balanced. The phase load-angle, , is the same for each load.

Figure 1-1

Figure 1-2 shows the phasor diagram that corresponds to the 3-phase system given in Fig. 1-1. The per-phase equivalent circuit is also shown as they would appear on an oscilloscope display. Note that the voltage Van is taken as the reference for the single-phase equivalent circuit.



Figure 1-2

Refer to: 1) Chapman, Stephen J., Electric Machinery Fundamentals, New York, McGraw Hill, Appendix A. Examples A-1 and A-2, pgs. 695 – 698. 2) Dr. Lopes webpage: [www.ece.concordia.ca](http://www.ece.concordia.ca) – Faculty and Staff – Faculty – Lopes, Luiz A. C., Personal Webpage, Coursework, ELEC 331, - Additional Material - 2 Wattmeter Method. The URL is:

http://users.encs.concordia.ca/~lalopes/Courses/ELEC331-F07/2-Wattmeters%20method.pdf

1. **Pre-Lab Calculations**
2. Calculate the power factor (cos), load angle (), wattmeter readings *P*1 and *P*2, total power from *P*1 and *P*2 readings (*P*1+*P*2) and total power using the direct method (Pphase = 1.73 VI cos**) for the followings loads and operating conditions, with loads wye-connected to a 208 V, three-phase line-to-line power supply. Sketch a 3-phase phasor diagram showing the current phasors for parts a,b and c. Indicate whether the the currents are leading or lagging. Sketch the 3-phase phasor diagram indicating the angles between Vab and Ia, Vcb and Ic forpart d.

(a) Each resistive load element rated at 120 V, 0.4A;

(b) Each capacitor load element rated at 120 V, 0.4A;

1. Each inductor load element rated at 120 V, 0.4A;
2. Each load element rated at 120 V, 0.4 A with 0.5 power factor lagging.
3. For the resistive load, compute the value of the resistance required in a delta connection, for the same power dissipation. Sketch the per-phase (single phase) phasor diagram?
4. For the 0.5 power factor load defined in 1(d), compute the values of R and L assuming R and L are in series. Sketch the per-phase (single phase) phasor diagram?
5. Add a capacitor in parallel to the R-L load in 3. Compute the value of the capacitor required to bring the power factor to unity. If a 4.4 μF capacitor is used, what is the power factor? What is the per-phase (single phase) phasor diagram?

**Iv. Procedure**

|  |
| --- |
| **Warning:****High voltages are present in this experiment!** **Do not make any connection while the power is on.** |

1. Connect the circuit as shown in Fig. 1-3 with the resistive load unit in a wye configuration. Have your instructor check the circuit. The numbers 4,5,6 in Fig 1-3 correspond to the Lab-Volt voltage source connections. Refer to the appendices for instructions on how to set up the oscilloscope, PC and data acquisition software. If necessary, use E1 and E2 to verify the phase rotation of the voltage source. (The polarity of E2 must be the reverse of connection shown in Fig. 1-3).

 

 Fig. 1-3

1. Set the resistance of each section to 300 Ω. Turn on the power supply and observe the ammeter to make sure there is no short circuit. Slowly adjust the line voltage to 208 Vac as indicated by the voltmeter.
2. Measure and record the measurements shown in Fig. 1-3. (The line voltages and currents, the phase-voltages and currents, the wattmeter readings and the powers, P, S and Q indicated on the PC (LVDAM).
3. Measure and record the phase angle between the phase voltage (V), and the phase current (I), using the oscilloscope (model Fluke; refer to Appendix for setting the Oscilloscope. Note that the phase angle can also be seen using the LVDAM phasor-analyzer on the PC. Printing these diagrams is optional for parts 3, 6 and 7.
4. Return the voltage to zero and turn off the power supply.
5. Replace the resistive load of Fig. 1-3 with the capacitor load. Set capacitance of each section to 4.4 μF and repeat Step 3 and 4.
6. Replace the resistive load of Fig. 1-3 with the inductor load. Set inductance of each section to 0.46 H (3.2 H || 1.6 H || 0.8 H) and repeat Step 3 and 4.
7. Replace the resistive load of Fig. 1-3 with the resistive-inductive load composed of R = 300 Ω and L = 0.46 H (3.2 H || 1.6 H || 0.8 H) connected in series, and repeat Step 3 and 4. Print the waveforms that are observed on the oscilloscope. All the phase angles can also be seen using the LVDAM phasor-analyzer on the PC. Print these diagrams in phase related groups (E1 and I1, E2 and I2, E3 and I3).
8. Connect a capacitor of 4.4 μF in parallel across each phase of the RL series-load as shown in Fig. 1-4, and repeat Step 3 and 4. Print the waveforms that are observed on the oscilloscope. All the phase angles can also be seen using the LVDAM phasor-analyzer on the PC. Print these diagrams in phase related groups (E1 and I1, E2 and I2, E3 and I3).



#  Fig. 1-4

1. Connect the circuit as shown in Fig. 1-5 with the resistive load unit connected in delta, and have your instructor check the circuit. Be sure to note the high and low sides of the load elements and the meters. Depending on the orientations of the components, there is one correct set of results that is relatively easy to explain. There are several other data sets that do not correspond to the normal conventions of describing 3-phase power circuits. These variations will have to be explained in your report.
2. Set the resistance of each section to 300 Ω. Turn on the power supply and adjust the line voltage to obtain **the same phase current as the phase (line) current in Step 3** where the load is connected in wye. Record the value of source voltage.

 

 **Fig. 1-5**

1. Measure and record the values as before.
2. Return the voltage to zero and turn off the power supply.

**V. Questions**

1. Derive the transformation from a wye to delta connection for an equivalent power rating, assuming a three-phase balanced load. From this transformation, calculate the equivalent delta (or wye) connected R, C, L, and RL (R||L) load-components for each of the measurements taken in Steps 8, 9 and 11. Make sure all units (Ohms, Farads, and Henries) are clearly indicated.
2. Calculate and tabulate the theoretical and experimental power factors for different loads (Steps 8 and 9). How well (%) do the experimental readings from the dual-wattmeters, the 2-wattmeters readings (LabVolt DAQ), the single-phase readings (LabVolt DAQ) and the phasor analyzer (LabVolt DAQ), compare with a theoretical calculation of power and power factor based on the 2-wattmeter method? Sketch the 3-phase phasor diagram that corresponds to the circuit of Step 9. If necessary, include a sample calculation to explain each table entry.
3. Tabulate and compare the theoretical value of the load current phase-angle of the single-phase equivalent circuit with the value observed on the oscilloscope for Steps 4, 6 and 7. Include a sample calculation for entry.
4. Compare the power factor variation in Steps 8 and 9 and comment on the results. What would be the required capacitor value for unity power factor? Why is unity power factor desirable?
5. Calculate the theoretical voltage across each load element value for Step 11. Sketch the phasor diagram of the 3-phase delta connected system. Show Vline, Iline, Vphase, Iphase and the associated angles and magnitudes. Sketch the phasors used in the 2-wattmeter method. Could the same phasors be used when applying the 2-wattmeter method to describe the wye-connected system?

ELEC 331, Data Tables for Experiment 1

Table Data for Wye Connected Load (\* print-out of graphical display is recommended)

|  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
| R() | XL() | XC() | W1 (W)  | W2 (W) | Vph (V)  | Iph (A) | P3,Q3,S3 (W, Var, VA) | phLab-VoltPhasor(deg or rad) | phOscillo-scope(deg or rad) | Vab (V) | Ia (A) | **∠** Vab, IarefVab | Vcb(V) | c(A) | **∠**Vcb, Ic refVab | P1, S1(W, VA) | P2, S2(W, VA) |
| 300 | 0 | 0 |  |  |   |  |  |  | \* |  |  | \* |  |  | \* |  |  |
| 0 | 0 | 600 |  |  |  |  |  |  | \* |  |  |  |  |  |  |  |  |
| 0 | 300||600||1200 | 0 |  |  |  |  |  |  | \* |  |  |  |  |  |  |  |  |
| 300 | 300||600||1200 | 0 |  |  |  |  |  | \* | \* |  |  | \* |  |  | \* |  |  |
| 300 | 300||600||1200 | 600 |  |  |  |  |  | \* | \* |  |  |  |  |  |  |  |  |

Table 2 Data for Delta Connected Load (\* print-out of graphical display is recommended) I ph is same as 300  load above

|  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
| R() | XL() | XC() | W1(W) | W2(W) | Vph(V)  | Iph(A)N.BSee Iph above | P3, Q3,S3 (W, Var, VA) | phLab-VoltPhasor(deg or rad) | e**-Vab**,i-IaOscillo-scope(deg or rad) | Vab(V) | Ia(A) | **∠**Vab, IarefVab | Vcb(V) | c(A) | **∠**Vcb, IcrefVab | P1, S1(W, VA) | P2, S2(W, VA) |
| 300 | 0 | 0 |  |  |  |  |  | \* | \* |  |  | \* |  |  | \* |  |  |

E3, I3 are phase parameters. E1, I1, E2, I2 are the line (line-to-line) parameters: Vab, Ia, Vcb and Ic. E2 is oriented to support the 2-Wattmeter method. All numerical data can be recorded in a LabVolt data table, copied to Notepad and printed.

**Experiment 2**

**Single-Phase Transformers**

**I. Objectives**

**There are two objectives to this experiment:**

- To obtain the equivalent circuit model parameters of a single-phase transformer using standard tests;

- To study the voltage regulation of the transformer with varying resistive, inductive and capacitive loads.

**Ii. Introduction**

The approximate circuit model of a transformer is usually determined with the open circuit test performed at the rated voltage, and the short circuit test performed at the rated current. Fig. 2-1 shows the approximate circuit model of a transformer.



**Fig. 2-1** The approximate circuit model of a transformer

The open circuit admittance of this circuit is:



and the short circuit equivalent impedance (leads 3 and 4 are shorted and the effects of *Rm* and *Xm* are neglected) is:



Once the model is determined, it can be used to predict the voltage regulation for different load conditions. The predicted results from the model can be verified using the experimental results in this lab.

**Iii. Calculations**

For a 120/208 V, 60 VA single-phase transformer, the approximate equivalent circuit parameters, seen from the low voltage side, are given as:

*Req* = 0.06 *pu*, *Xeq* =0.04 *pu*, *Rm* = 20.45 *pu*, *Xm = 35.5 pu*

1. Draw the approximate equivalent circuit and show all model components.
2. Using the base values of *VB* = 120 V and *SB* = 60 VA, compute:

(a) Base current and impedance;

(b) Real values of the equivalent circuit parameters;

(c) Per-unit and the real values of the magnetizing current.

1. Compute the voltage regulation and efficiency for the following loads, considering the rated transformer power on the high voltage side:

(a) resistive load;

(b) inductor load;

(c) capacitor load;

(d) an inductor in series with a resistor giving rated load power (60 VA) at a power factor of 0.5;

(e) a capacitor in parallel with a resistor giving rated load power (60 VA) at a load angle of 20 degrees.

**Iv. Procedure**

|  |
| --- |
| **Warning:****High voltages are present in this experiment!** **Do not make any connection while the power is on.** |

**1. Open Circuit Test**

1. Connect the transformer as shown in the Fig. 2-2. Leave the secondary winding open.



**Fig. 2-2**

2. Connect the output of the isolators to the oscilloscope (Fluke model, Refer to the Appendix for setting the oscilloscope).

3. After the circuit is checked by your demonstrator, turn on the power supply and adjust to 120 Vac as indicated by the voltmeter across the power supply terminals 4 and N.

4. Measure and record input and output voltages, input current, phase angle (degrees) of primary side, and print the input voltage and input current waveforms. Use the harmonic analyzer on the PC (LVDAM) to observe the harmonic content of the first 10 harmonics of the current waveform.

5. Repeat Parts (1) (2) and (4) using the transformer high voltage side (208 V side) as the primary (change the input voltage terminals from ‘4’ and ‘N’ to ‘4’ and ‘6’, adjust the input voltage to 208 V for this Step).

**2. Short Circuit Test**

1. Connect the circuit as shown in Fig. 2-3.(Note: remember to return the input voltage terminals to ‘4’ and ‘N’).



**Fig. 2-3**

2. Make sure that the power is turned off until the circuit is checked by your instructor. After the circuit connections have been verified, turn on the power supply. **With the variac initially at Zero**, increase the voltage **very slowly** until the rated input current (0.5 A on DMM) is reached. This normally occurs when the input voltage is between 5% to 10% of the rated voltage, or 10 V.

3. Measure and record the input voltage, input and output currents, phase angle (degrees) of the primary side and print the input voltage and input current waveforms.

4. Repeat Parts (2) and (3) with the low-voltage side (120 V) shorted (0.3 A rated current) and power supplied to the 208 V side.

**3. Resistive Load Test**

1. Connect the circuit of Fig. 2-4 with a variable resistive load and have your instructor check the circuit. Connect the three sets-of-three parallel resistances in series as the variable load.



**Fig. 2-4**

2. Put the switches of all the individual load resistances in the down (open) position. This represents an open circuit or an infinitely large load. Turn on the power supply and adjust the Variac until the input voltage is 120 V. Measure all the parameters indicated in Fig. 2-4 (Vin, Iin, Pin, phase-angle, Vout, Iout, Pout).

3. Next put the switches of the three 1200 Ohm resistances in the up (closed) position (3600 Ohms). Pay attention to the input current (DMM). It should not exceed the value of 0.6 A (slightly above the rated value of 0.5 A). If the current reaches 0.6 A, adjust the load to decrease it below 0.5 A, and have the lab instructor check your circuit. Measure the parameters indicated in Fig. 2-4. Note the input voltage and current waveforms observed on the oscilloscope. Make sure that the phase angle (degrees) is measured accurately. Next, disconnect the 1200 Ohm resistors and connect the three 600 Ohm resistors in series. Take the measurements as before. Repeat for the three 300 Ohm resistors in series and finally for the three 200 Ohm resistances in series (300 Ohms paralleled with 600 Ohms). When you are finished, reduce the input voltage to zero and turn off the power supply. Remove the load from the transformer. Do not remove the voltmeter E2 or the ammeter I2.

**4. Inductive Load Test**

1. Disconnect the variable resistive load and connect the variable inductive load in the same manner as above in Section 3-1. Repeat the measurements for five loads: the open circuit (all switches down), 3600 Ohms, 1800 Ohms, 900 Ohms, and 600 Ohms.

2. Measure the input and output currents, voltages, and powers as indicated in Fig. 2-4. Print the input voltage and current waveforms. Make sure that the phase angle (degrees) is measured accurately. Measure the input and output currents, voltages, and powers. When you are finished, reduce the input voltage to zero and turn off the power supply. Remove the load from the transformer. Do not remove the voltmeter E2 or the ammeter I2.

**5. Capacitive Load Test**

1. Disconnect the variable inductive load and connect the variable capacitive load in the same manner as above in Section 3-1. Repeat the measurements for five loads: the open circuit (all switches down), 3600 Ohms, 1800 Ohms, 900 Ohms, and 600 Ohms.

2. Measure the input and output currents, voltages, and powers as indicated in Fig. 2-4. Print the input voltage and current waveforms. Make sure that the phase angle (in degrees) is measured accurately. Use the harmonic analyzer on the PC (LVDAM) to observe the harmonic content of the first 10 harmonics of the current waveform. When you are finished, reduce the input voltage to zero and turn off the power supply.

**V. Questions**

1. Explain why the current waveform in Part 1(4) is distorted.
2. Calculate the *pu* values of *Rm*, *Xm*, *Req*, *Xeq* as "seen" from the primary winding for the approximate equivalent circuit.
3. Calculate the same parameter’s *pu* values referred to the secondary winding.
4. Refer the values obtained in Question 2 to the secondary and show that these values and the values obtained in Question 3 are the same (within experimental error).
5. Using an appropriate circuit model from the parameters determined above, calculate the voltage regulations for the currents and power factors of Parts 3, 4 and 5. Compare with the measured values. Show all the calculations used to justify your choice of a circuit model.
6. From the circuit model, calculate the efficiency for the three load tests (Parts 3, 4 and 5) and compare with measured values obtained from either wattmeter readings or the real power derived from the scope measurements. First, plot the curves of the efficiency versus the load current for the different kinds of loads using the observed experimental values (voltage, current, power, and power factor). Then use the derived circuit model to recalculate the same values and draw a second set of curves in the same figure. Indicate theoretical and experimental points.
7. Repeat the previous question, showing now how the voltage regulation varies with the load current for different types of loads (theoretical and measured).
8. Calculate the load impedance (magnitude and phase) from the secondary current, voltage, and power measurements of Part 4 and refer these values to the primary using the approximate equivalent circuit model. Compare this impedance value with the input impedance measured by the primary current, voltage, and power measurements. Comment on the accuracy of the transformer model based on the results obtained. For the case of the capacitive load with the maximum current, indicate what harmonic components are present and what frequencies they represent. Draw the phasor diagram of the transformer under full-load conditions for each load type, resistive, inductive and capacitive.

**Experiment 3**

**DC MACHINES**

1. **Objectives**

There are two objectives to this experiment:

- To study the structure of a DC machine;

- To examine the torque operation and speed characteristics of a shunt motor.

**Ii. Introduction**

DC machines have been used extensively for many years in variable speed drive applications, such as in automobiles, trains, aircraft, air conditioners, heaters and defrosters, etc;

The main advantage of the DC machine is its simplicity in speed control. Speed control can be achieved by means of:

(a) Armature voltage control;

(b) Field control;



**Fig. 3-1** The circuit model of a DC motor

Basic DC motor equations, for steady-state conditions, are



The induced voltage *Ea* is equal to

 or , for an unsaturated machine;

Since < 0.1 *Vt* , at the rated conditions, 



**Iii. Calculations**

Consider a 1/4 hp, 120 V, 1800 rpm shunt dc machine with a typical efficiency of 75%. Losses for rated operation are as follows: 10% in the armature circuit resistance, 5% in field excitation, and 10% in mechanical loss. Compute the following:

(a) input power and rated armature current;

(b) armature resistance, in Ω;

(c) no-load speed, assuming no armature reaction, for a 120 V armature voltage;

(d) speed-torque curve, for a 120 V armature voltage, up to rated torque (approximately);

(e) no-load and full-load speeds for a 60 V armature voltage with rated field current, and the speed regulation curve;

(f) speed-torque curve for a field weakening of 70% rated field and at the rated armature voltage, compute the rated torque; explain why it decreases in the field weakening region;

**Iv. Procedure**

|  |
| --- |
| **Warning:****High voltages are present in this experiment!** **Do not make any connection while the power is on.** |

**1. Structure of the DC Machine**

Unlock the DC motor/generator Module, and place it on the working bench.

A) Identify the followings motor components:

- the armature winding;

- the stator poles;

- the shunt field winding;

- the series field winding;

- the commutator;

- the brushes;

- the neutral position of brushes;

1. Record the number of stator poles, commutator bars, and brushes.
2. Identify the field supply.

**2. Measurement of Winding Resistance**

1. Connect the field circuit as shown in Fig. 3-2.



**Fig. 3-2**

a) Turn on the power supply and slowly increase the dc voltage until the shunt field winding carries the rated current (400 mA).

b) Measure and record the voltage across the shunt field winding.

c) Return the voltage to zero and turn off the power supply.

d) Calculate the resistance and power loss of the shunt field winding.

2. Replace the shunt field winding with the series field winding.

a) Turn on the power supply and slowly increase the dc voltage until the series field winding carries the rated current (3 A). **Warning! This only requires a few volts. Increase the voltage very slowly.**

b) Measure and record the voltage across the series field winding.

c) Return the voltage to zero and turn off the power supply.

d) Calculate the resistance and power losses of the series field winding.

**3. Shunt Motor: No-Load Operation**

Caution: The change of the field current or the load should be made slowly. If the machine accelerates rapidly after the change, switch off the power IMMEDIATELY.

1. Connect the circuit shown in Fig. 3-3, and have your instructor check the circuit.



**Fig. 3-3**

1. Adjust the dial of the field rheostat to the center position. Turn on the power supply, increase the voltage to 120 V and vary the rheostat to obtain rated field current (400 mA). If the direction of the rotation is not clockwise, reduce the voltage to zero, turn off the power supply, and interchange the shunt field connections.
2. Measure and record the motor speed.
3. Slowly adjust the shunt field current to reach the following speeds: n = (1500 rpm) , n = 1600 rpm, n = 1700 rpm, n = 1800 rpm, n = 1900 rpm, n = 2000 rpm. In each step record the field current and armature current.

***Note: Do not change the field adjustment for the rest of the experiment in this part.***

1. Decrease the voltage to 0 V and turn off the power. Disconnect the field current terminals of Fig. 3-3 from variable 0-120 Vdc supply and connect them to fixed 120 Vdc through the Ohmite Rheostat as in Fig. 3-4. Have your instructor check the circuit.
2. Vary the armature voltage from 120 V to 60 V, in 20 V steps, and measure the speed and current.

**4. Separately Excited Motor: Speed-Torque Characteristics**

1. Couple a synchronous generator to the dc motor with a timing belt and connect the synchronous generator as shown in Fig. 3-4. Note that the power generated by the synchronous generator will be dissipated as heat through the resistors connected to its three phase. Thus the complete synchronous generator setup is considered as a **variable** **load to the DC motor**. By varying the resistive load of the synchronous generator, the DC motor load can be varied and the speed-torque characteristics analyzed.
2. Have your instructor check the circuit.



**Fig. 3-4**

1. With the generator switch S OFF (“S position down”) and with the resistive load disconnected, turn on the power supply and increase the voltage to 120 Vdc.
2. Set the shunt field current to the one that gives you a no-load speed of 1800 rpm. Do not change this value.
3. Close the generator switch (“S position up”) and adjust the field current of the synchronous generator to get a phase voltage of 100V at the output of the generator.
4. Apply a load to the DC motor by setting each resistive load to the following values (before changing the load, put the generator switch in ‘down’ position, then change the load and put the switch in ‘up’ position): R = 1200 Ω, 600 Ω, 400 Ω (1200 || 600), and 200 Ω (600 || 300). Measure and record the motor speed, the armature current, and the field current. In each step make sure that the output ac voltage is kept constant by adjusting the field current of the synchronous generator.
5. Without changing the field rheostat, decrease the armature voltage of the DC motor to 100 Vdc, and repeat Step 6.
6. Change the armature voltage to 120 V and set the motor field current to the one that gives you a no-load motor speed of 2000 rpm, and repeat Step 6.

**V. Questions**

1. Would the motor start if only the armature was excited? Justify your answer.

2. Based on the data obtained in no load operation of the shunt motor:

a) Calculate the machine constant Km = K*v* φ for the rated field current.

1. Plot the speed versus the field current for the rated armature voltage.
2. Plot the speed versus the armature voltage for the rated field current.
3. Plot the armature current versus speed for the fixed field current.

3. Which method of the speed control must be used if the speed is to be reduced down to zero? What if the speed is to be controlled above the base speed? Justify your answer.

4. What are the advantages and disadvantages of these two methods?

5. What happens if you disconnect the field current while the motor is running?

6. Separate the losses in the motor for rated operation.

7. Based on the data obtained from the speed-torque characteristics, perform the following two exercises:

(a). Plot the speed versus torque curve for the armature voltage of 120 V and 100 V for the field current that yields 1800 rpm no-load speed on the same graph.

(b). Plot the speed versus torque curve for the two field current adjustments with the armature voltage of 120 V on the same graph.

**Experiment 4**

**Three Phase Induction Machines**

**I. Objectives**

**There are three objectives to this experiment:**

- To study the structure of three phase squirrel cage induction machines;

- To examine the magnetizing current, synchronous speed and slip in a three phase induction motor;

- To study the no-load, blocked-rotor and load characteristics of the induction motor.

**Ii. Introduction**

The circuit model of a three phase induction machine is usually obtained through "no-load" and "blocked-rotor" tests which are equivalent to "open-circuit" and "short-circuit" tests of transformers. In this experiment, the parameters of the equivalent circuit model are measured and results from the circuit model are compared with the experimental results.

**Iii. Calculations**

A three-phase 60 Hz, 1/4 hp, 208 V, 1800 rpm, 4-pole induction machine has a rated current of 1.3 A and the following parameters:



1. Using , and *IB* = 1.3 A as the base values, find the per-unit values of the machine parameters and draw the exact equivalent circuit.
2. From the equivalent circuit, compute the no-load current and power factor for a 208 V/60 Hz operation. Assume the no-load speed is very close to the synchronous speed.
3. From the equivalent circuit and for a blocked rotor, compute the voltage to be applied to obtain the rated current. Compute the corresponding power.
4. For the nominal speed of 1500 rpm with 208 V/60 Hz input voltage, calculate the slip, input current electromagnetic torque, power factor, and efficiency. For the no-load speed of 1795 rpm, repeat the calculations.

***Note: Use the following approximate models for the two test conditions, derived for the IEEE model:***



**Fig. 4-1**

**Iv. Procedure**

|  |
| --- |
| **Warning:****High voltages are present in this experiment!** **Do not make any connection while the power is on.** |

**1. Structure of the Squirrel Cage Induction Machines**

Unlock the squirrel cage induction machine module, and place it on the working bench. Identify the followings:

- the cooling fan;

- end rings of the squirrel cage rotor;

- the spacing of the air gap between rotor and stator.

Is there any electrical connection between the rotor and the stator?

**2. DC Resistance Test**

1. Measure the resistance between each 2 leads (1-2, 2-3, 3-1) using an ohmmeter. Take an average value.

**3. No-Load Test, Synchronous Speed, and Slip**

1. Connect the circuit shown in Fig. 4-2, and have your instructor check the circuit.



**Fig. 4-2**

2. Turn on the power supply. Increase the voltage, from 100 V, measure and record V1, W1, W2, I1, and the speed for each 20 V step, to 200 V, then to 208 V. Compare the power values in the dual watt-meter with ones obtained in the computer.

3. Reverse the motor operation by reversing two stator connections, and repeat Step 2.

**4. Blocked-Rotor Test**

1. with the circuit connected as in Fig. 4-2, Insert the locking pin, and have your instructor check the circuit.
2. Turn on the power supply and slowly increase the voltage to obtain the rated current.

 Measure and record the V1, I1, W1 and W2.

1. **Load Tests**



**Fig. 4-3**

1. Set the dynamometer control knob (‘MANUAL’) at full counterclockwise position for no-load, put the mode switch in the dash box in ‘MAN’ position and the mode switch outside the dash box in ‘DYN’ position.

2. Turn on the power supply and adjust the line voltage to 208 Vac.

3. Slowly turn the control knob (‘MANUAL’) clockwise to set the torque to the following settings:

1. 0.0, 0.34, 0.68, 1.0, 1.36 N.m..

 Measure and record W1, W2, I1, V1, torque and speed for each setting.

**V. Questions**

1. From the data obtained in no-load test:

a) Calculate the synchronous speed and the number of poles;

b) Calculate the slip just for 100 V and 208 V input voltage;

c) Plot the rotor speed vs. rotor voltage.

2. From the dc resistance test, no-load test and blocked-rotor test, determine the circuit model of the machine. From the model, calculate the current and torque for a slip of 5% and compare with the experimental results.

3. For the rated voltage, calculate the following for no-load conditions with both the model and experimental data:

a) Apparent power;

b) Real power;

c) Reactive power;

d) Power factor.

1. From the load test, draw the torque/speed curve and discuss the results. Calculate the following for the 5 load conditions with experimental data:

a) Apparent power;

b) Real power;

c) Reactive power;

d) Power factor.

1. Explain the different speed control methods and draw the general torque/speed curves for each control. Show all relevant points. Explain the differences, such as efficiency and control complexity, between each speed control scheme. Can speed control be done with voltage control?

**Experiment 5**

**Synchronous Machines**

**I. Objectives**

There are three objectives to this experiment:

- To study the no load saturation curve of the synchronous generator;

- To study the short circuit characteristics of the synchronous generator;

* To study the operation of a synchronous generator connected to the ac supply.

**Ii. Introduction**

To connect a stand-alone synchronous generator to an ac source, the following conditions must be met in order to avoid large transient currents:

1. the same frequency;

2. the same phase sequence;

3. equal voltage amplitude;

4. no phase shift between two voltages.

**Iii. Calculations**

**1. Stand-alone**

A 450 VA, 208 V, 1800 rpm synchronous generator in Y-connected has a 90 synchronous reactance. Neglect all losses.

a) The field voltage is adjusted to give 208 V across the output terminals under no-load conditions. Compute the output voltage and current with different types of loads in Y-connected that are 450 VA under the rated line to line voltage of 208 V: 1. purely resistive load; 2. purely inductive load. Draw the corresponding phasor diagrams.

b) Assuming the magnetic circuit is not saturated, compute the change of excitation current required to maintain 208 V output voltage for the above two types of loads.

**2. Mains Connected**

A 1/4 HP, 208 V, 1800 rpm synchronous machine has a 90 synchronous reactance. Neglect all losses.

1. The machine is connected to a 208 V power system. It is motoring at half rated power and the excitation voltage is adjusted for a unity power factor operation. Compute the armature current *Ia*, internal voltage *EA* and torque angle . Draw the phasor diagram.
2. The excitation voltage is kept constant and the load applied to the motor is reduced to 0. Compute the quantities defined in (a).

c) The excitation voltage is kept constant and the machine operates as a generator and injects half-rated power into AC mains. Compute the quantities defined in (a).

**Iv. Procedure**

|  |
| --- |
| **Warning:****High voltages are present in this experiment!** **Do not make any connection while the power is on.** |

**1. Internal Voltage vs. the Field Current**

Couple the DC motor to the synchronous generator with the timing belt. Adjust the Lab-Volt computer display for ac and dc values. ). **Note that in the Lab-Volt display on the PC (metering screen) the current to the dc machine (I2) and the dc field current of the synchronous generator (I1) must be set to display dc values.**

1. Using the DMM Ohmmeter find the resistance of the stator windings of the synchronous machine (connection points 1 to 4, 2 to 5 and 3 to 6).
2. Connect the circuit shown in Fig. 5-1 (including the large, Ohmite, external rheostat with three terminals), and have your instructor check the circuit.



**Fig. 5-1**

3. Make sure the generator exciter-field rheostat is at full counterclockwise (minimum) position and the switch S is open (down, O).

4. Set the prime mover-dynamometer to the prime mover mode. Set the display switch on the Lab-Volt prime mover to the speed mode (down position).

1. Set the Lab-Volt power supply autotransformer to its full counterclockwise position for zero dc voltage.
2. Set the Ohmite external rheostat dial at its center position.

7. Turn on the power, adjust the autotransformer on the Lab-Volt power supply until the prime mover (permanent magnet dc motor, PMDC) has a speed of 1800 rpm.

***Note: This speed must be kept constant for the entire experiment.***

8. Close the generator field exciter switch, S (up, I). Note that in the Lab-Volt display on the PC (metering screen) the current to the dc machine (I2) and the dc field current of the synchronous generator (I1) must be set to display dc values. All data should be recorded using the Lab-Volt data table function. When the ten readings are taken, a curve can be generated using the Lab-Volt plotting Utility. Plot the open-circuit voltage (y-axis) against the synchronous generator field exciter current (x-axis).

9. Slowly adjust the 200 Ohmite rheostat to obtain a field current (Ifsyn = I1) of 0.01 A dc for the synchronous generator. Take the next readings at 0.02 A dc to 0.08 A dc in steps of 0.02 A dc, then 0.1 A dc and 0.2 A dc to 0.8 A dc in steps of 0.2 A dc. There are 10 measurements. After the dial of the Ohmite rheostat reaches its maximum value (approximately 0.4 A dc), adjust the small 150  generator field exciter rheostat to obtain the required field current (turn clockwise from min. to max.). Measure and record V1, V2, and V3. Record the speed. **Remember to keep the speed constant**. If a measurement is missed, start over. The readings should be taken in one continuous sweep from 0.01 A dc to 0.8 A dc. When the ten sets oRef. Chapman, Electric Machinery Fundamentals, 4th ed, pg. 284 and pg. 292.

1. **To Turn Off The Motor-Generator:** Set the generator field exciter, 150  rheostat at its minimum position - full counter clockwise. Set the Ohmite rheostat to its center position. Open switch S (down, O).
2. Turn autotransformer on the Lab-Volt power supply to the minimum position (counter clockwise). The PMDC motor (prime mover) is now stopped.
3. Turn off the power supply.

**2. Synchronous Machine Short Circuit Current vs. Field Current**

1. Connect the circuit shown in Fig. 5-2 (including the large, Ohmite, external rheostat with three terminals), and have your instructor check the circuit.



**Fig. 5-2**

1. The steps below (3 to 8) are the same as described in steps 3 to 8 in the previous section.
2. Make sure the generator exciter-field rheostat is at full counterclockwise (minimum) position and the switch S is open (down, O).
3. Set the prime mover-dynamometer to the prime mover mode. Set the display switch on the Lab-Volt prime mover to the speed mode (down position).
4. Set the power supply voltage control at its full counterclockwise position for zero dc voltage.

6. Set the Ohmite rheostat dial at its center position.

7. Turn on the power, adjust the autotransformer on the Lab-Volt power supply until the prime mover (permanent magnet dc motor, PMDC) has a speed of 1800 rpm.

***Note: This speed must be kept constant for the entire experiment.***

1. Close the generator field exciter switch S (up). ). Note that in the Lab-Volt display on the PC (metering screen) the current to the dc machine (I2) and the dc field current of the synchronous generator (I1) must be set to display dc values. All data should be recorded using the Lab-Volt data table function.
2. Slowly adjust the 200 Ohmite rheostat to obtain a field current (Ifsyn = I1) of 0.01 A dc for the synchronous generator. Take the next readings at 0.02 A dc to 0.08 A dc in steps of 0.02 A dc, then 0.1 A dc and 0.2 A dc to 0.8 A dc in steps of 0.2 A dc. There are 10 measurements. After the dial of the Ohmite rheostat reaches its maximum value (approximately 0.4 A dc), adjust the small 150  generator field exciter rheostat to obtain the required dc exciter field current (turn clockwise from min. to max.). At each of the 10 measurements record the generator exciter dc field current, I1, and the ac short-circuit current I3 (IphA, IphB and IphC ) until the maximum generator output short-circuit current of 1 A ac (I3) is reached. The field current, I1, will be about 0.6 Adc. Note that the field current steps are the same as in the previous section. In this section they are being taken against the ac output short-circuit currents. All data should be recorded using the Lab-Volt data table function. When the ten readings are taken, a curve can be generated using the Lab-Volt plotting Utility. Plot the short-circuit current (y-axis) against the synchronous generator field exciter current (x-axis).
3. **To Turn Off The Motor-Generator:** Set the generator field exciter, 150  rheostat at its minimum position - full counter clockwise. Set the Ohmite rheostat to its center position. Open switch S (down, O).
4. Turn autotransformer on the Lab-Volt power supply to the minimum position (counter clockwise). The PMDC motor (prime mover) is now stopped.

12. Turn off the power supply.

**3. Mains Synchronization**

1. Connect the circuit shown in Fig. 5-3 (including the large, Ohmite, external rheostat with three terminals), and have your instructor check the circuit. Make sure that the switch, S, on the 3-lamp synchronization module is in the open position (O).
2. The steps below (3 to 7) are the same as described in steps 3 to 8 in the previous section.
3. Make sure the generator exciter-field rheostat is at full counterclockwise (minimum) position and the switch S is open (down, O).
4. Set the prime mover-dynamometer to the prime mover mode. Set the display switch on the Lab-Volt prime mover to the speed mode (down position)
5. Set the power supply voltage control at its full counterclockwise position for zero dc voltage.
6. Set the Ohmite rheostat dial at its center position.
7. Turn on the power, adjust the autotransformer on the Lab-Volt power supply until the prime mover (permanent magnet dc motor, PMDC) has a speed of 1800 rpm. All data should be recorded using the Lab-Volt data table function.
8. Close the generator field exciter switch S (up). Increase the dc input voltage of the synchronous generator field winding. After the dc input voltage of the synchronous generator field winding reaches its maximum value by adjusting the large Ohmite rheostat, adjust the small 150  generator field rheostat to obtain the dc field current needed to obtain the generator output line voltage El equal to the source line voltage E2 (208V).



**Fig. 5-3**

1. Check if the phase sequence of the two systems is the same. The phase sequence is wrong if the three lights of the synchronization module don’t become bright and dark simultaneously. Turn everything off (the power supply) and interchange any two of the stator leads. (Use the oscilloscope to see the waveforms of E1 and E2).
2. Adjust the motor speed with the DC motor field rheostat until all three lights slowly darken and then slowly brighten. The synchronous generator frequency is very close to that of the ac source. Note the relationship between the brightness of the lamps and the oscilloscope traces E1 (Lab-Volt generator) and E2 (Hydro).
3. Close the synchronizing switch when all three lights are dark.

***Note: When all three lights are completely dark, the generator and the supply voltages are equal and in-phase. When all the lights are fully bright, the generator and the supply voltages are 180 degrees out of phase. The synchronizing switch should not be closed in the latter condition. After the synchronization switch is closed it must be opened before the system can be shut down.***

**4. Mains Connected**

1. Carefully adjust the dc field currents of both the synchronous generator and the dc motor (Ifdc , I2 and Ifsyn, I1) until both wattmeters indicate zero watts. Slowly turn the dial of the Lab-Volt power supply down (counter clockwise) until the DC motor field current (Prime mover, I2) is approximately 0.01 Adc. Measure and record W1, W2, Ifsyn (=I1), Iphase (= I3) and P3. **Record the polarity of W1 and W2 and change the switches when the indicating needles go off-scale.** Using the Lab-Volt phasor analyzer, record the phase angle bet ween E3 and I3 (ref. E3) for all readings. Compare the Lab-Volt oscilloscope with the Lab-Volt phasor analyzer. Use the Lab-Volt data table to collect the results. After the data for this section has recorded, the Lab-Volt plotting utility can be used to verify the results (I2, x-axis and P3, y-axis). Printing the first and last Lab-Volt phasors is optional. Now increase the power supply voltage and take approximately 10 measurements in steps of 0.2 Adc from 0.2 Adc to 1.6 Adc or W1 + W2 = 100W. Measure and record W1, W2, Ifsyn (=I1), Iphase (= I3) and P3 as well as all other circuit meters**. Note that I1 (If synch) and I2 (Prime mover, input field current) are dc values. Set the Lab-Volt metering accordingly**. Set Lab-Volt **PSQ3 to [E3,I3](W)**.

2. Carefully adjust the dc field currents of both the synchronous generator and the dc motor (Ifdc and Ifsyn) until both wattmeters indicate zero watts.

3. Slowly increase only the dc excitation of the generator by turning the 150  rheostat to the maximum position (full clockwise) and the large Ohmite rheostat to its maximum to obtain a current of 0.8 Adc (Ifsyn = I1). Now lower the small exciter rheostat to the minimum position (approximately 0.4 adc, I1). Take a series of measurements by turning the 150  exciter rheostat from the minimum to the maximum position in steps of 0.05 Adc (i.e. 0.4, 0.45, 0.5 Adc…0.8 Adc, 10 measurements). The approximate range will be from 0.4 Adc to 0.8 Adc. **Measure and record W1, W2, Ifsyn (=I1), Iphase (= I3) and Q3 as well as all other ciercuit meters.**  **Record the polarity of W1 and W2 and change the switches when the indicating needles go off-scale.** Note the phase angle between E3 and I3 (ref. E3). Compare the Lab-Volt oscilloscope with the Lab-Volt phasor analyzer. Set Lab-Volt meter **PSQ3 to [E3, I3](Var).** After the data for this section has recorded, the Lab-Volt plotting utility can be used to verify the results (I1, x-axis and Q3 and I3 y-axis). Print the first and last Lab-Volt phasors and oscilloscope traces of the measurement range. **Remember I1 and I2 are dc quantities, I3 and all other parameters are ac quantities.**

4. For best results take all measurements in a continuous sweep.

5. **To Turn Off The Motor-Generator: *Open the switch on the synchronizing module to disconnect the utility, Hydro***. Set the generator field exciter, 150  rheostat at its minimum position - full counter clockwise. Set the Ohmite rheostat to its center position. Open switch S (down, O).

6. Turn autotransformer on the Lab-Volt power supply to the minimum position (counter clockwise). The PMDC motor (prime mover) is now stopped.

1. Turn off the power supply.

Ref. Chapman, Electric Machinery Fundamentals, 4th ed, pg. 355 and pg. 360. Note that the curves found in this experiment are reversed from those in the text since they are generated using a synchronous generator. The curves in the text refer to a synchronous motor where power is absorbed from the utility-bus (Hyd ro) not generated into it.

**V. Questions**

1. Using data obtained in Part 1 and 2, plot the no-load voltage vs. the synchronous machine dc field current, and short-circuit ac armature current vs. the same dc field current (on the same graph). Compute the synchronous reactance XS at the rated output voltage. From the same graph compute the unsaturated value of XS. What is the value of the armature resistance, RA? Draw the per-phase equivalent circuit of the synchronous generator.
2. Explain why the open-circuit voltage vs. dc field-current curve is not linear.
3. Plot the apparent power and real power against the dc motor field current, I2 (data from Step 4-1). Does the change in dc motor field current mainly affect the real or the reactive power delivered by the synchronous generator? Explain. What parameter is trying to change when the Lab-Volt power supply is varied (I2)? Why doesn’t it actually change? Do the angles of the phase current (I3 vs. E3) support the direction of the power flow?
4. From data obtained in Step 4-3, calculate the apparent and real power delivered by the synchronous generator. Compare the calculated values with the Lab-Volt meters. Use the values of W1 and W2, the phase voltage and current to calculate the phase angle of the phase current at each extreme of the measurement range (first set of values and last set of values). How does this calculated angle compare with the observed values from the Lab-Volt phasor-analyzer and the Lab-Volt oscilloscope? Plot the variation in S (VA) vs. the excitation field current of the synchronous generator. Does the increase in dc field-excitation of the synchronous machine affect mainly the real or the reactive power delivered by the synchronous generator? What parameter is trying to change when the dc exciter voltage is varied (I1)? Why doesn’t it actually change? Do the angles of the phase current (I3 vs. E3) support the change the power factor and the VAr quality? Ref. Ref. Chapman, Electric Machinery Fundamentals, 4th ed, pg. 355 and pg. 360.
5. Are the reactive power values the same in Step 4-1 and 4-3? Explain.
6. Using the data collected in Part 4, Step 1, as well as the values of the per-phase equivalent circuit (XS, RA) and the open-circuit and short-circuit curves, make one sketch of the phasor diagram of the synchronous generator when it is transferring real power to the utility grid. Choose one set of values (when W1 + W2 is approximately 50 Watts for example) as the operating point. Include the phasors for IA, EA, V, jXSIA , and IARA, as well as the current phase angle  and the torque or power angle, . Only one diagram is to be drawn. Ref. Chapman, Electric Machinery Fundamentals, 4th ed, sections 5.5 to 5.8.

**APPENDIX**

**Initial Setup for the Fluke Combiscope Oscilloscope**

**For Laserjet II and III Printers Only**

Choose the following setting on the oscilloscope (Fluke model):

 Turn on the oscilloscope.

 Press AUTOSET to stabilize the display.

 Press UTILITY button. All functions listed below must be checked each time the

 oscilloscope is turned on.

 Press PRINT&PLOT&CLOCK button.

 Press top button. Choose PRINTER.

 Press next button. Turn TRACK knob to choose HP LASERJET II & III.

 Press RS232 button.

 Press BAUD button. Turn TRACK knob to choose 9600.

 Choose 8 BITS.

 Choose 3-WIRE.

 Choose XON-XOFF=ON

 Press RETURN.

 Check information on screen. If correct press RETURN.

 Press yellow ANALOG button to put scope in DIGITAL mode.

 To set the vertical and horizontal modes:

 Use AMPL buttons to set the sensitivity of CH-1,2

 xV/DIV (AC / DC coupled)

 Use TIME/DIV button to set the Time Base:

 xms/DIV

 To get all measurements on the screen, use the followings:

 Press MEASURE button.

 Press CURSORS button.

 Use TRACK knob to choose and adjust your measurements.

 To get a hardcopy, use the followings:

 Press RUN/STOP button to store the figure.

 Press HARDCOPY button to get a hardcopy on the Laserprinter.

The Fluke Combiscope

Connecting to the PC and Printer using the UTILITY button.

 The UTILITY button is used to set the oscilloscope to the parameters necessary to communicate with the software (Combiscope 2.0) installed in the computer (PC). The required https://mail.encs.concordia.ca/horde/imp/message.php?index=9settings are shown in the diagram. Start (1) by pushing the UTILITY button. The UTILIY screen (2) appears. Press the button to the right of the RS232 text. The RS232 menu (3) appears. Use the buttons to the right of the text to set the parameters as shown. The baud rate is set by the Track knob. When all settings are made press the RETURN button. The UTLITY menu will reappear. Press the button (4) to the right of PRINT&PLOT&CLOCK entry. Set the values shown. The HPGL parameter is set by using the track command. Press (5) TEXT OFF to clear the screen.


## Setting the Screen Display Using the MEASURE button.

 The MEASURE button is used to set the screen to display the values being measured at the inputs – channel 1 and channel 2. Start by pressing (1) the MEASURE button. The MEASURE menu (2) will appear on the screen. Press the button to the right of MEAS 1. The MEAS 1 screen (3) will appear. Choose the parameters shown by using the buttons to the right of the set of choices. The mode of the voltage display is set by using the Track knob. The channel is set by using the Delta knob. When the values are correct press RETURN to proceed to the MEAS 2 screen. Turn the MEAS 2 display on using the button to the right. Repeat the steps followed previously for the MEAS 1 setup except the channel is ch2. Press RETURN to recover the MEASURE menu. Press (5) TEXT OFF to clear the screen.


### Setting the Cursors

 The CURSOR button is used to highlight the cursors on the screen in order to make measurements at specific points in the display. Start (1) by pressing the CURSOR button. Use the buttons at the right side of the display (2) to enter the parameters in the CURSORS screen. The READOUT display (3) is used to set the cursors to an initial range of 360o. Toggle the top button to the right of the CRT until **ph** is highlighted. Press TEXT OFF to get a clear view of the waveform. Use the points where the waveform crosses the x-axis (4) to establish the calibration points. Adjust the cursors using the Track control (reference cursor) and the Delta control (differential cursor. When the cursors are in the correct position press TEXT OFF twice to restore the CURSORS READOUT display. Now press the second button to the right of the CRT to set **T=360o**. The top line of text on the CRT will show the correct angle,**ph = 360o**.Press RETURN and TEXT OFF.


### Waveform Measurements with the Combiscope

 The measurement of the voltage and current waveforms and the phase angle between them is fundamental to the study of electrical power engineering. The Combiscope has a variety of measurement modes available through the MEASURE function and the CURSOR controls. In order to set-up the MEASURE and CURSOR displays, go to the sections of this document that refer to these topics. When the control settings are complete, and the wave forms are displayed on the oscilloscope screen, there are several important points to be observed.

The voltage is taken to be the reference phasor. Waveform (A) in (3) corresponds to the phasor (A) in (4). Note that zero degrees is found at the point where the reference waveform (A) crosses the x-axis in (3) and is becoming positive with respect to the y-axis. Waveform (B) in (3) is a lagging current as represented by phasor (B) in (4). The angle  indicates a lagging power factor (PF) or a lagging phase angle.

### Using FLUKEVIEW on the Personal Computer

The Fluke Combiscope communicates with the personal computer (PC) using the FlukeView software. This software will transfer the image on the screen of the Combiscope to the PC. After the image is captured, it can be printed using the print commands on the PC.

Start by turning on the PC and The Combiscope. If the Lab Volt data acquisition software (LVDAM-EMS) is in use **turn off the automatic refresh function**. **The Lab Volt software must be operated in the manual refresh mode**. Use the UTILITY function on t he oscilloscope to set the RS232 and the PRINT&PLOT&CLOCK menus. Refer to the section of this document which explains the settings of the UTILITY control. On the PC use the following sequence of commands.

1) Click the START, PROGRAMS, and FlukeView commands.

2) From the FlukeView menu click the FlukeView Combiscope command

The main FlukeView display will appear with the INSTRUMENT CONNECT dialog box. Set the following parameters on the command panel

1. Com Port = Com 2 on those PCs where Com 1 is used by the mouse
2. Baude Rate = 9600

When the dialog box disappears and the connection is made between the Combiscope and PC an icon will appear in the lower right corner of the main Combiscope screen. The icon appears as a cable without a red x superimposed on it.

The content of the instrument screen (oscilloscope CRT) is transferred by using the commands at the top of the PC main screen. Click the INSTRUMENT command and DISPLAY SCREEN to download the oscilloscope image.

To add text to the waveform on the PC screen, click the OPTIONS command at the top of the main screen on the PC. Click ADD DESCRIPTION to add text at the bottom of the waveform