Date: ____________________

Name: ________________________

ID: ______________________________

LABORATORY EXPERIMENT NO. 5

PHASE ANGLE AND VOLTAGE DROP BETWEEN SENDER AND RECEIVER

OBJECT

1. To regulate the receiver end voltage.
2. To observe the phase angle between the voltages at the sending and the receiving end of the transmission line.
3. To observe the line voltage drop when the sending and receiving end voltages have the same magnitude.

DISCUSSION

In the previous experiment we saw that a resistive or inductive load at the end of a transmission line produces a very large voltage drop, which would be quite intolerable under practical conditions. Motors, relays and electric lights work properly only under stable voltage conditions, close to the potential for which these devices are rated.

We must, therefore, regulate the voltage at the receiver end of the transmission line in some way so as to keep it as constant as possible. One approach which appears promising, is to connect capacitors at the end of the line because, as we saw in Experiment 4, these capacitors produce a very significant voltage rise. This, indeed, is one way by which the receiving end voltage is regulated in some practical instances. Static capacitors are switched in and out during the day, and their value is adjusted to keep the receiver end voltage constant.

For purely inductive loads, the capacitors should deliver reactive power equal to that consumed by the inductive load. This produces a parallel resonance effect in which reactive power required by the inductance is, in effect, supplied by the capacitance and none is furnished by the transmission line.

For resistive loads, the reactive power, which the capacitors must supply to regulate the voltage, is not easy to calculate. In this experiment, we shall determine the reactive power by trial and error, adjusting the capacitors until the receiver end voltage is equal to the sender end voltage.

Finally, for loads which draw both real and reactive power (they are the most common) the capacitors must be tailored to compensate first, for the inductive component of the load and second, for the resistive component.

INSTRUMENTS AND COMPONENTS

Power Supply Module *(0-120/208V 3φ)*	*EMS 8821*
Resistance Module	*EMS 8311*
Three-Phase Transmission Line Module	*EMS 8329*
Capacitance Module	*EMS 8331*
AC Metering Module *(250V/250V/250V)*	*EMS 8426*
Three-Phase Watt-Varmeter (2) *(300W/300var)*	*EMS 8446*
Phase Angle Meter	*EMS 8451*
Connection Leads	*EMS 9128*

EXPERIMENTS

Caution: High voltages are present in this Laboratory Experiment! Do not make any connections with ~~the power on!~~ 180 ohms

☐ **5-1)** Set the impedance of the transmission line to ~~120~~ *ohms* and connect voltmeters and watt-varmeters as shown in *Fig. 5-1*. The load will be modified during the course of the experiment. The circuit should be connected to the three-phase variable voltage supply.

☐ **5-2)** Using the power supply control knob, adjust E_1 to ~~200 volts~~ and keep it constant for the remainder of the experiment. Increase the resistive

100 volts

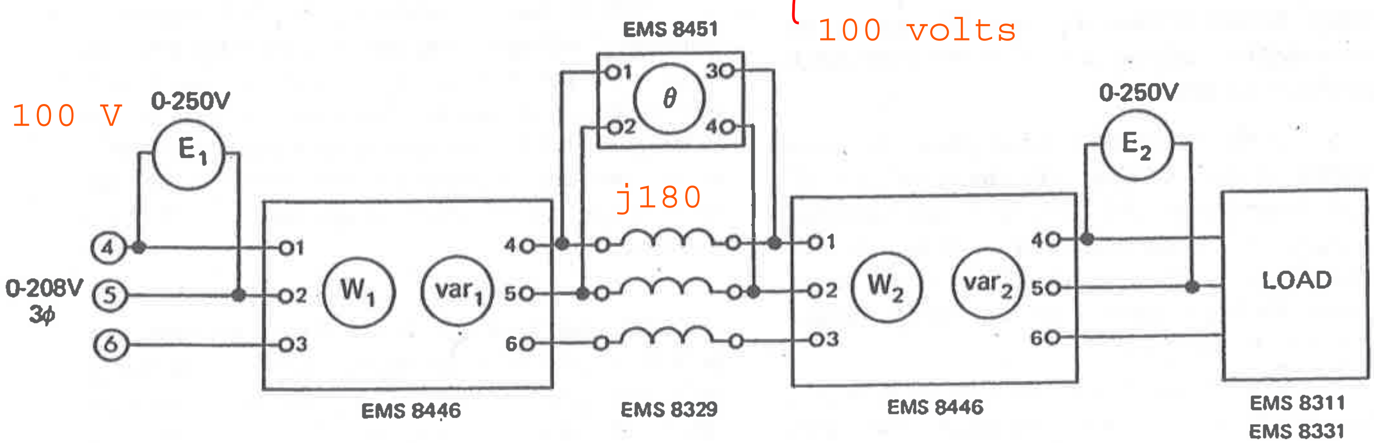

Fig. 5-1

VOLTAGE REGULATION WITH RESISTIVE LOAD								
	R (Ω)	E_1 (V)	W_1 (W)	var_1 (var)	E_2 (V)	W_2 (W)	var_2 (var)	ANGLE (°)
EXPERIMENT 5-2								
	1200							
	600							
	300							

Table 5-1

load in steps, keeping all three phases balanced. Take readings of E_1, W_1, var_1, E_2, W_2, var_2 and the phase angle between E_1 and E_2.

Note: E_1 is chosen as the reference voltage for the phase-angle meter.

Record your results in *Table 5-1*, and draw in *Fig. 5-2* a graph of E_2 as a function of the load power W_2, in watts.

On this curve, spot the phase-angle corresponding to the various real power loads W_2.

Caution: Always remove the capacitive load prior to removing the resistive load. A severe overload is otherwise to be expected.

☐ 5-3) Now, connect a three-phase balanced capacitive load in parallel with the resistive load. Repeat Experiment 5-2 but for each resistive load adjust the capacitive load so that the load voltage E_2 is as close as possible to ~~200~~ *volts*. (E_1 must be kept constant at ~~200~~ *volts*). Record your results in *Table 5-2*. 100 volts

Draw a graph of E_2 as a function of W_2, and superpose it on the previous graph which you drew in Experiment 5-2. Note that the addition of static capacitors has yielded a much more constant voltage, and furthermore, the power W_2 which can be delivered has increased.

On this curve, spot the phase angle between E_2 and E_1 as well as the reactive power var_2 which was used for the individual resistive load settings.

☐ 5-4) In this experiment, we shall observe a significant voltage drop along a transmission line even when the voltages E_1 and E_2 at the sender and receiver ends are equal in magnitude. How is it possible to have a voltage drop when the voltages at the two ends are equal? The answer is that the drop is due to the *phase angle* between the two voltages.

Using the circuit shown in *Fig. 5-3*, set the load resistance per phase at ~~171.4~~ *ohms*, and with E_1 = *200 volts*, adjust the capacitive reactance until the load voltage is as close as possible to ~~200~~V. Measure E_1, W_1, var_1, E_2, W_2, var_2, E_3 and the phase angle. Record your results in Table 5-3. 300 ohms

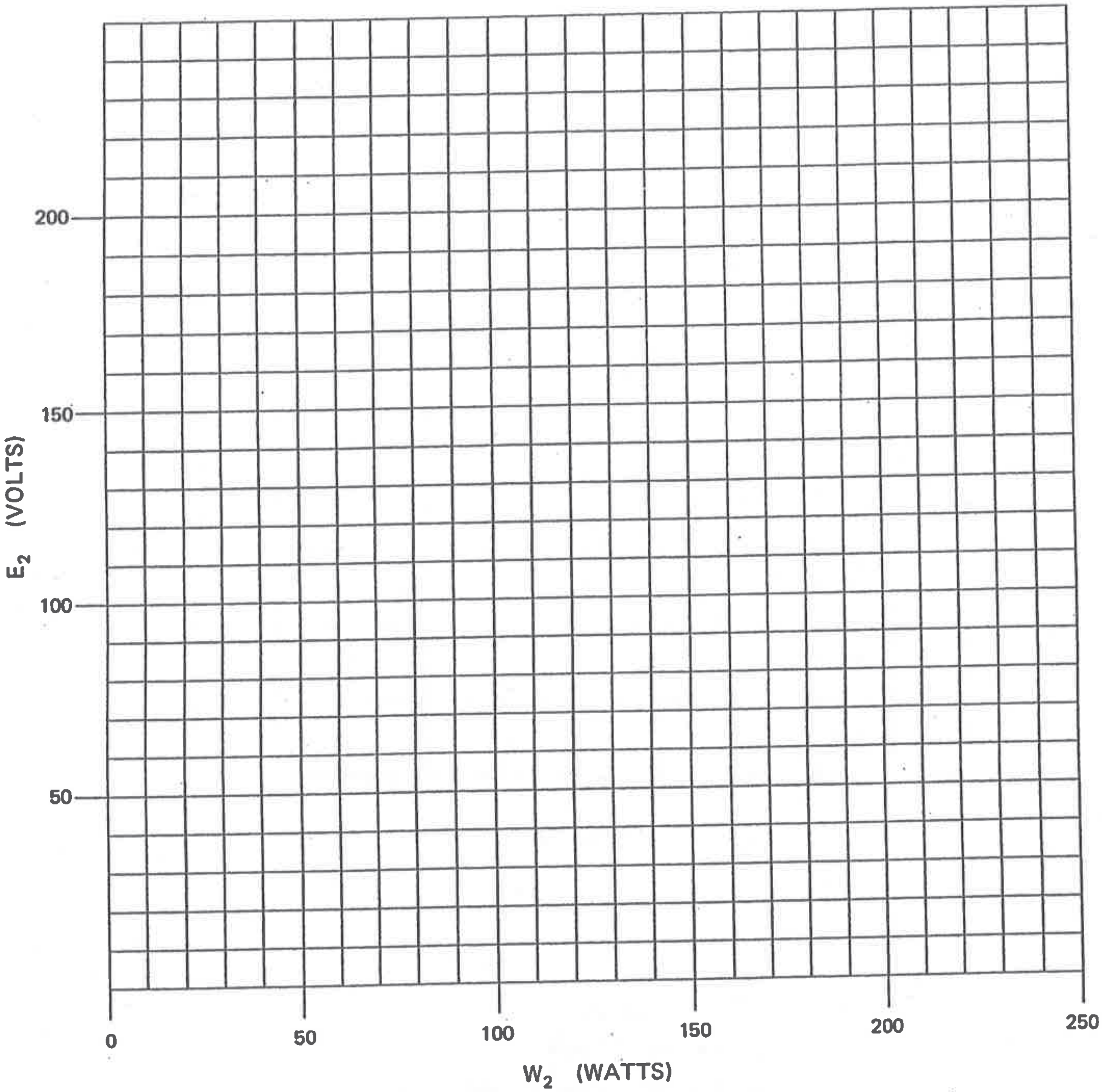

Fig. 5-2

E_1 = ... E_2 = ...

E_3 = ...

W_1 = ... W_2 = ...

var_1 = ... var_2 = ...

phase angle = ...

☐ 5-5) Using the results of Experiment 5-4, calculate the voltage, current, real power and reactive power per phase. Draw a phasor diagram of the sender and receiver-end voltages, and verify the voltage drop against the measured value. (See sample calculation on Page 5-6).

VOLTAGE REGULATION WITH RESISTIVE LOAD AND STATIC CAPACITORS									
	R (Ω)	X_C (Ω)	E_1 (V)	W_1 (W)	var_1 (var)	E_2 (V)	W_2 (W)	var_2 (var)	ANGLE (°)
EXPERIMENT 5-3									
	1200								
	600								
	300								

Table 5-2

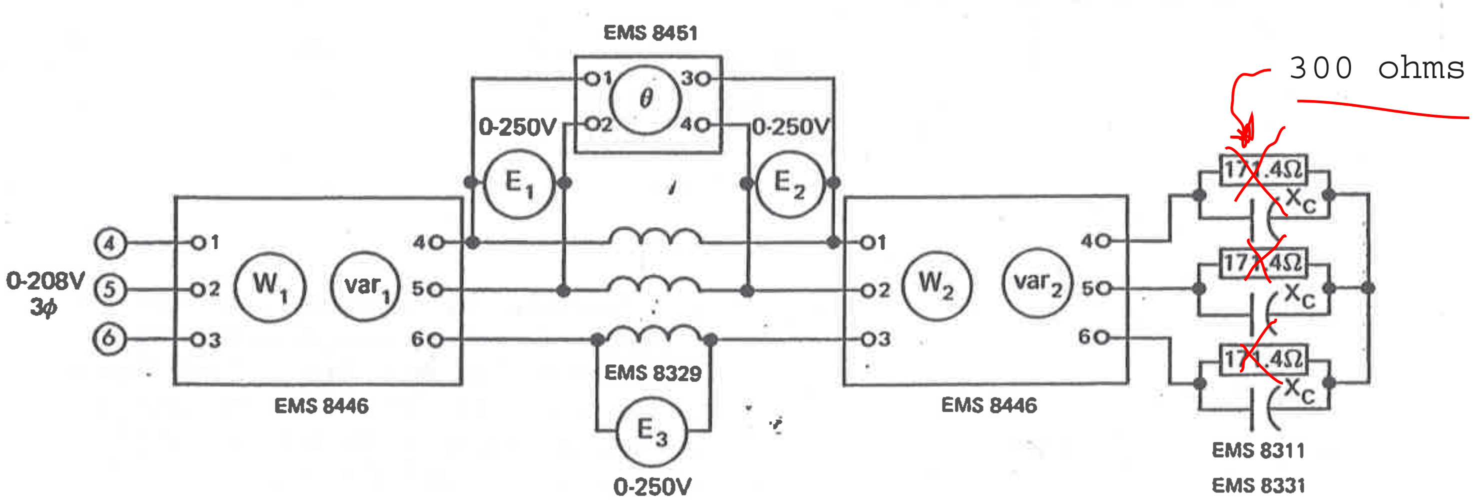

Fig. 5-3

SAMPLE CALCULATION

To understand the results of Experiment 5-4, we shall make a brief analysis assuming the following readings.

$E_1 = 300V$ $\quad E_2 = 300V$

$E_3 = 140V$

$W_1 = +600W$ $\quad W_2 = +510W$

$var_1 = +170var$ $\quad var_2 = -280var$

phase angle $= 48°$ *lag*

We shall first reduce all voltages and powers to a per-phase basis, assuming a wye connection. Since E_1 and E_2 are the line-to-line voltages, the corresponding line to neutral voltages are $\sqrt{3}$ times smaller.

Real power W_2 is smaller than W_1 because of the I^2R loss in the transmission line.

Furthermore, the source is delivering *170 var* to the right, while the load (owing to the negative sign) is delivering *280 var* to the left. As a result, the transmission line is absorbing *(170 + 280) = 450 var.*

The real and reactive powers per phase are 1/3 of the values indicated above; the per-phase values are therefore as follows:

$$E_1/\sqrt{3} = 300/\sqrt{3} = 173V$$

$$E_2/\sqrt{3} = 300/\sqrt{3} = 173V$$

$$E_3 = 140V$$

$$W_1/3 = +200W$$

$$W_2/3 = +170W$$

$$var_1/3 = +57var$$

$$var_2/3 = -93var$$

phase-angle $= 48°$ *lag*

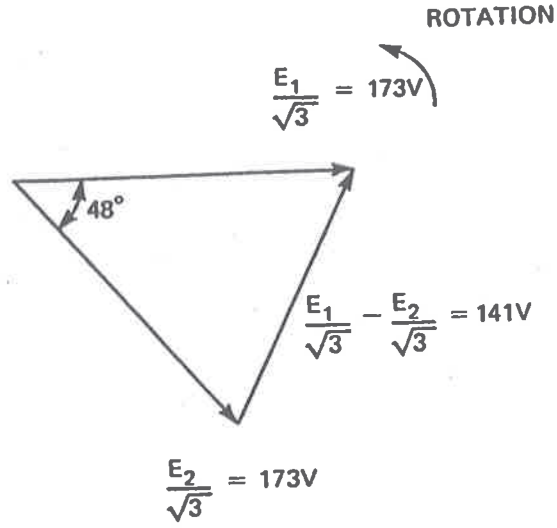

Fig. 5-4

If we draw phasor $E_2/\sqrt{3}$ 48 degrees behind phasor $E_1/\sqrt{3}$, we can scale off the length of the vector $(E_1/\sqrt{3})-(E_2/\sqrt{3})$. It is found to be *141 volts,* which is very close to the measured voltage drop E_3 in the line.

The reactive power received by the line (per-phase) is *(93 + 57) = 150 var.*

The real power consumed by the line due to its resistance is *(200 — 170) = 30 Watts.*

The apparent power absorbed by the line is $\sqrt{150^2 + 30^2} = 153$ *volt-amperes.*

Since the voltage across one line is *141 volts,* the current in the line must be

$$I = \frac{VA}{E_3} = \frac{153}{141} = 1.08A$$

We could, of course, have measured this current directly, but a measurement of the real and reactive power and a knowledge of the voltages is sufficient to enable us to calculate everything about the line.

CALCULATIONS OF EXPERIMENT 5-5

QUESTIONS AND PROBLEMS

1. A three-phase transmission line has a reactance of *100 ohms* per phase. The sender voltage is *100kV* and the receiver voltage is also regulated to be *100kV* by placing a bank of static capacitors in parallel with the receiver load of *50MW.*

Calculate:

a) The reactive power furnished by the capacitor bank.

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b) The reactive power supplied by the sender.

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c) The voltage drop in the line per phase.

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d) The phase angle between the sender and receiver voltages.

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e) The apparent power supplied by the sender.
