Synopsis

The aim of the experiment is to demonstrate the difference between single-phase and three-phase supply systems. It will be shown that among others, three-phase transmission systems have an advantage of increased efficiency and therefore reduced costs over single-phase transmission systems.
Measurements taken will be confirmed by theoretical calculations.

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Introduction

Objective

- To measure the parameters of a set of 3 phase voltages
- To investigate the current and power distributions when supplying balanced and unbalanced 3 phase loads
- To compare the efficiencies of single and three phase transmission systems

Background

Three phase circuits are employed in power systems and rotating machines mainly for economical reasons. Three phase circuits are essentially three single-phase circuits interconnected in order to reduce the total cross sectional area of the conductors required to transmit the power.

Experimental Procedure

3-Phase system representation

The system was constructed as fig.1 below.

The Lico box is used to enable current and power in each phase to be measured without having to break and remake the circuit for each phase.
A current transformer is used to step the current down by a ratio of 10:1.

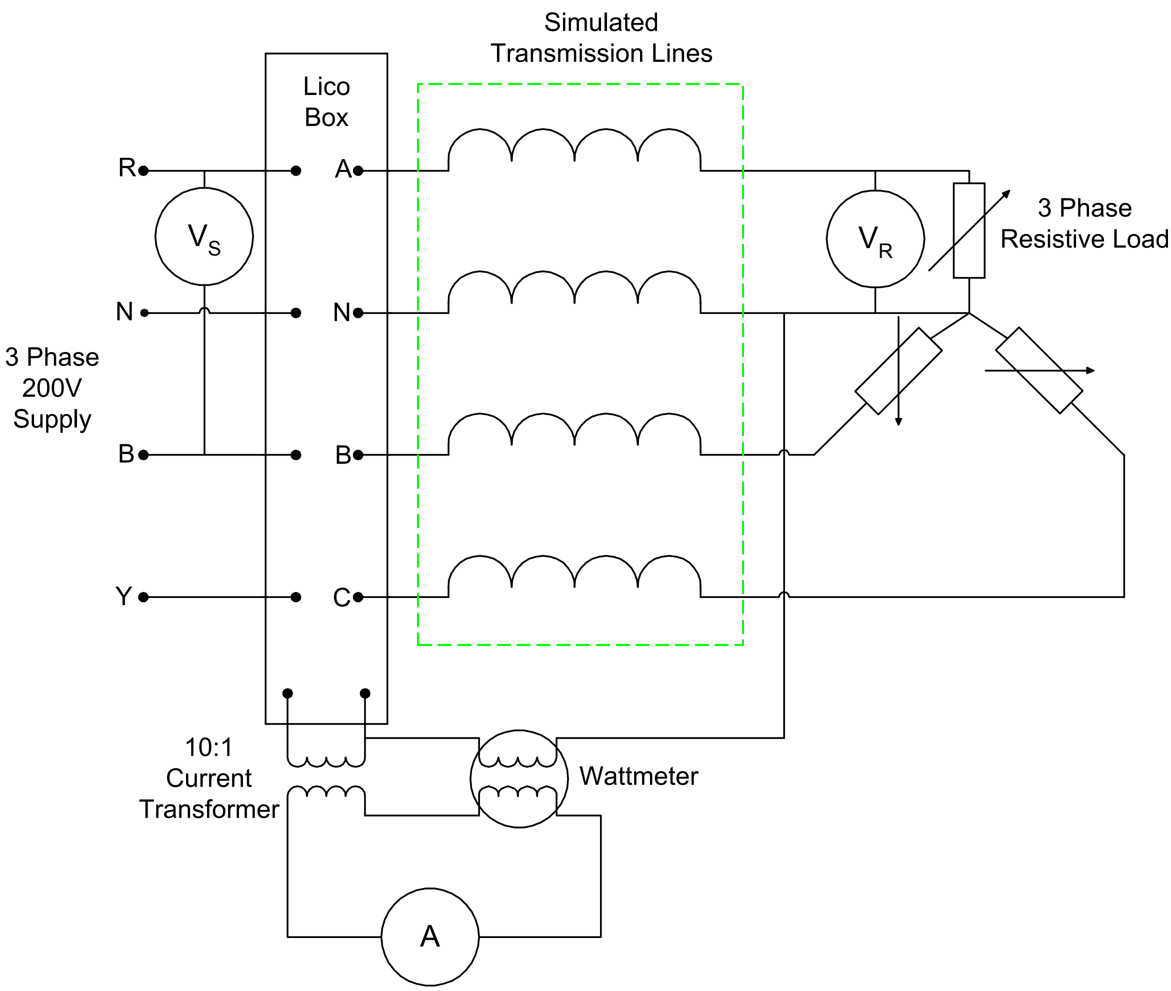

Fig.1 Circuit diagram of representation of three-phase transmission system

Experimental Procedure (Cont.)

Single-Phase system representation

The system was modified as fig.2 below.

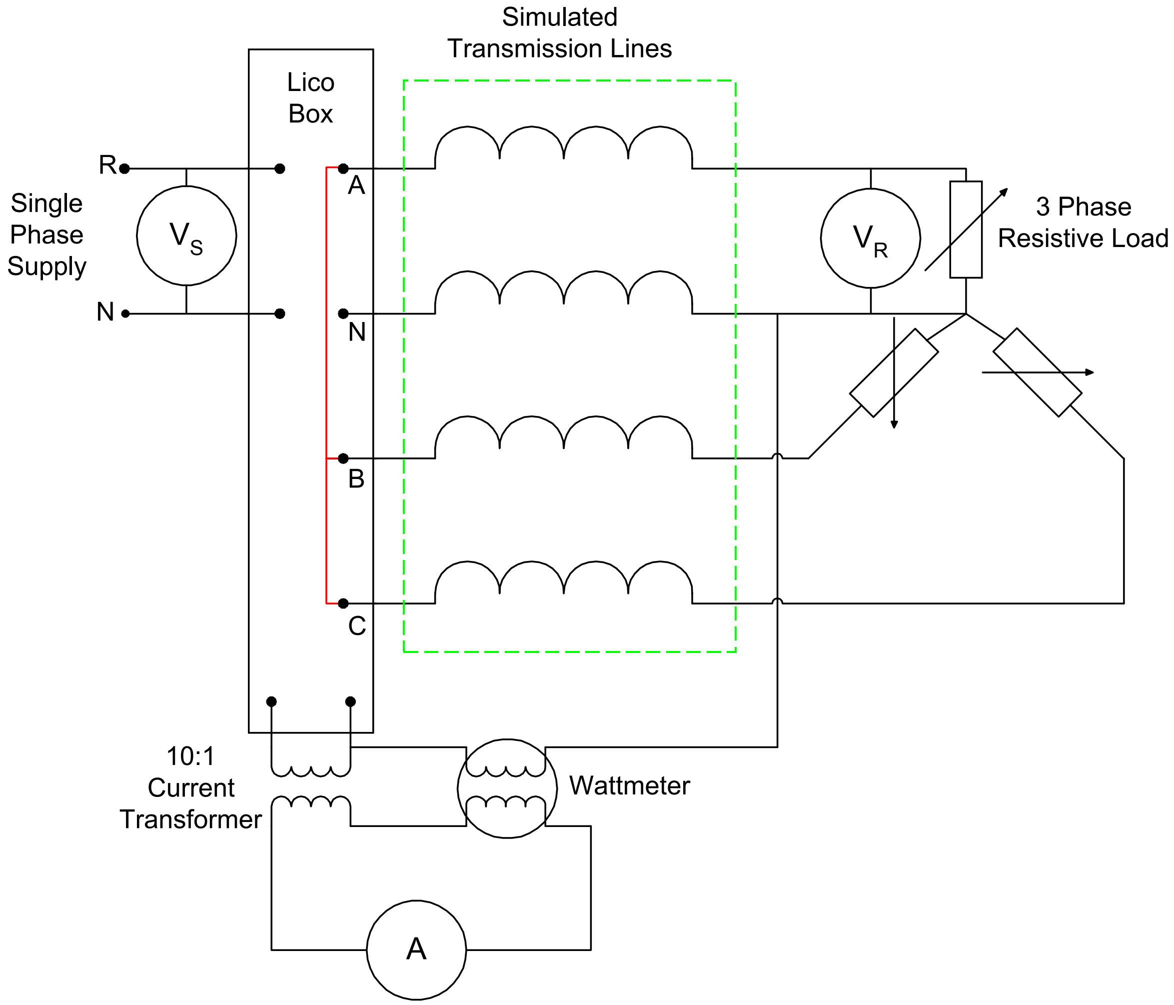

Fig.2 Circuit diagram of representation of single-phase transmission system

Equipment Used

Equipment	Serial Number
Lico Phase Selection Switch Box	5B6
Inductor (Neutral)	S1/5566
Inductor (Blue Phase)	S1/5564
Inductor (Yellow Phase)	S1/5563
Inductor (Red Phase)	S1/5562
3 Phase Loading Resistor	51-5536
Voltmeter (V_{supply})	EE51-6366
Voltmeter (V_R)	EE51-6108
Wattmeter	EE51-6184
Ammeter	EE51-6349
10:1 Current Transformer	469488

Fig.3 Table of equipment used and serial numbers

Experimental Procedure (cont.)

Wattmeter connections

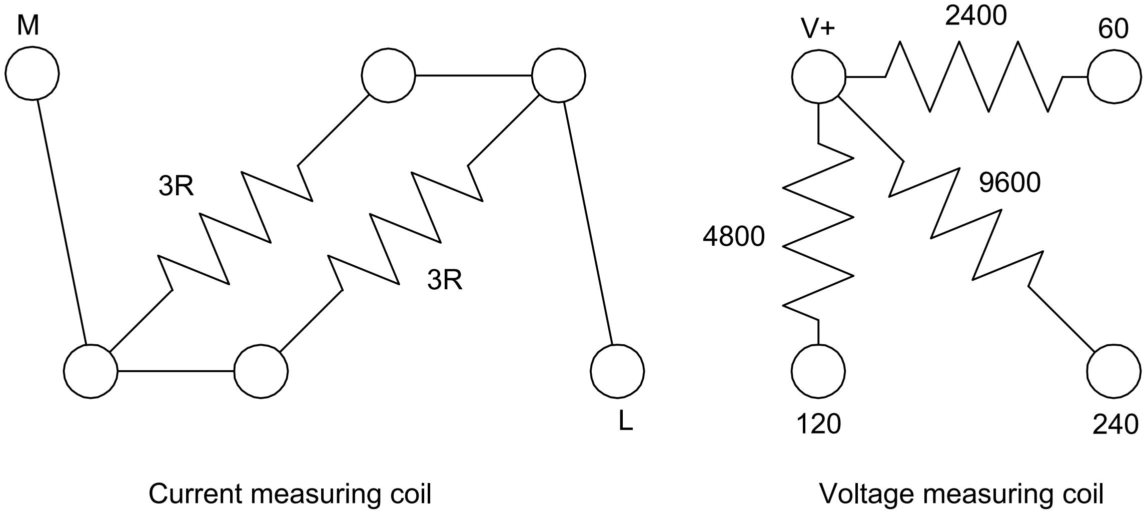

Fig.4 Wattmeter connections

3-Phase load resistor connections / settings

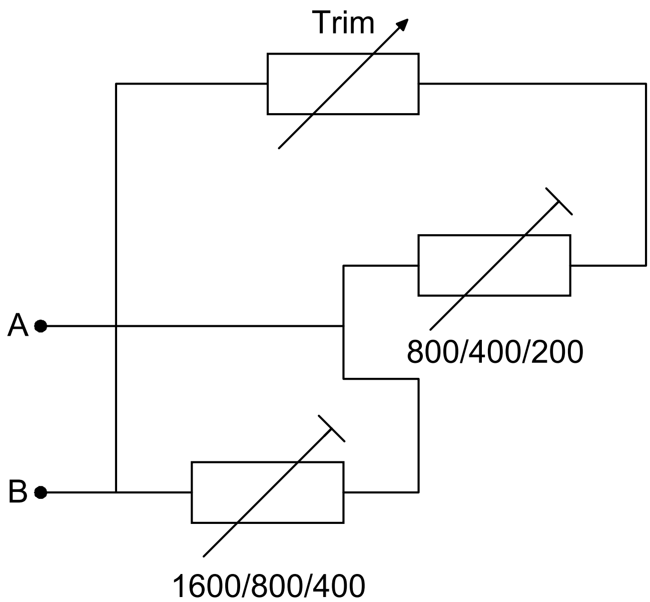

Fig.5 Load resistor connections and settings

Results

Tabulated results

Load Setting=800/1600		
V_S=206V		
V_R=99V		
Phase	Current (A)	Power (W)
Red	5.7	660
Yellow	5.7	660
Blue	5.7	660
Neutral	0	0

Fig.6 Current and power readings for load setting of 800/1600 (Balanced load)

Load Setting=400/800		
V_S=207V		
V_R=110V		
Phase	Current (A)	Power (W)
Red	2.9	406
Yellow	2.9	406
Blue	2.9	406
Neutral	0	0

Fig.7 Current and power readings for load setting of 400/800 (Balanced load)

V_S=207V		
V_R=125V		
Phase	Current (A)	Power (W)
Red	2.6	280
Yellow	3.1	460
Blue	4.6	460
Neutral	1.5	0

Fig.8 Current and power readings for unbalanced load

V_S=129V	
V_R=48V	
Current (A)	Power (W)
8.4	510

Fig.9 Current and power readings for single phase mode – load unchanged from above

Results (cont.)

Phasor Diagram for unbalanced load.

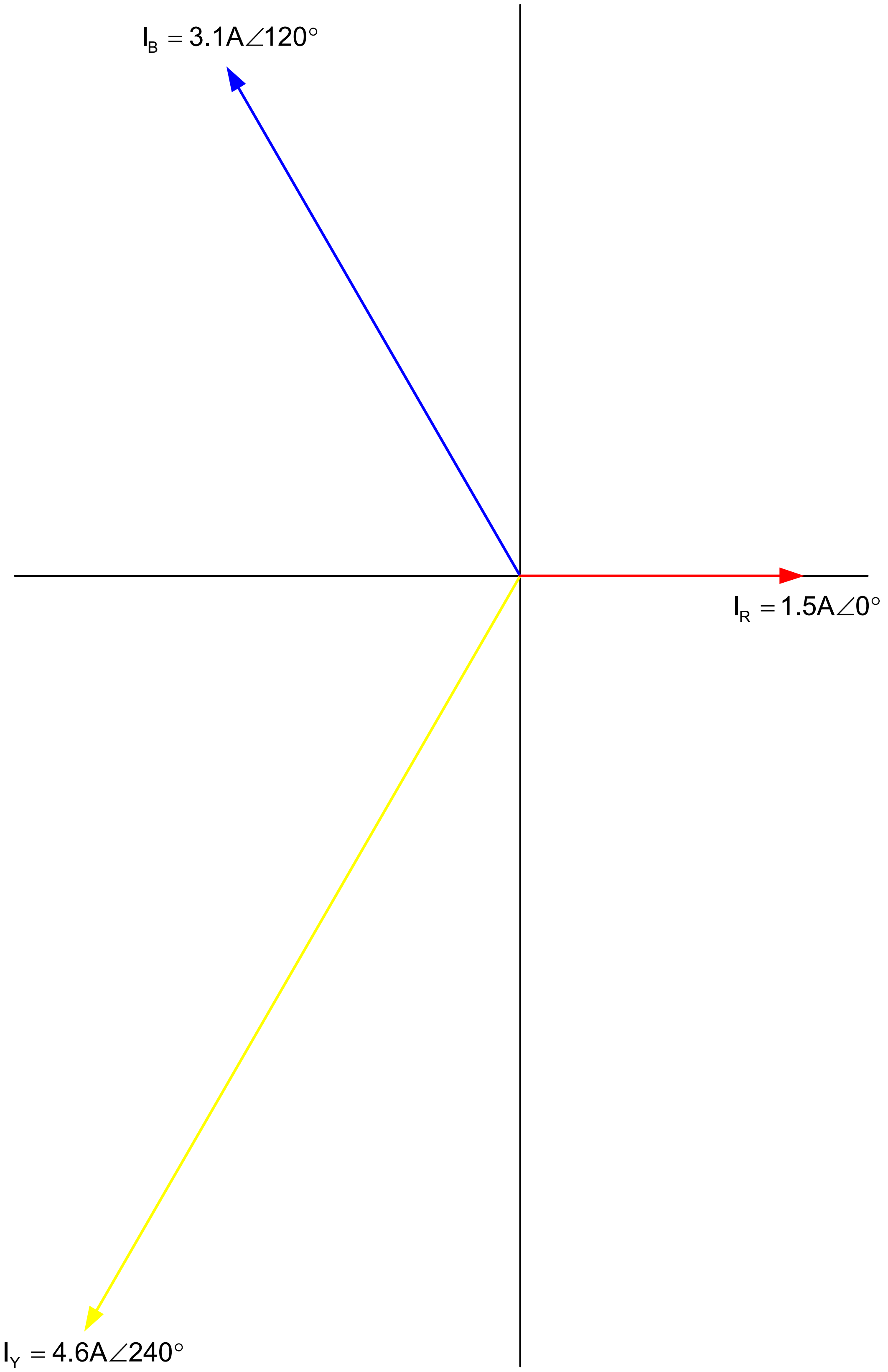

Fig.10 Phasor diagram for 3-phase unbalanced load

Calculations

Balanced Load
(See table fig.6)

$$\text{Total active output power} = \sqrt{3} \cdot V_L \cdot I_L \cdot \cos\Phi$$
$$\therefore \text{Total active output power} = 3 \cdot V_{ph} \cdot I_{ph} \cdot \cos\Phi$$
$$\text{But, } \cos\Phi = 1\text{, for a resistive load}$$
$$\therefore \text{Active power per phase} = V_{ph} \cdot I_{ph}$$
$$\text{Active power per phase} = 99 \times 5.7$$
$$\text{Active power per phase} = 564.3 \text{ W}$$

$$\text{Input power per phase} = 660 \text{ W}$$

$$\therefore \text{Efficiency } \eta = \frac{P_{out}}{P_{in}} = \frac{564.3}{660} = 0.855 \text{ or } 85.5\%$$

Unbalanced load
(See table fig.8)

$$\overline{I_R} + \overline{I_B} + \overline{I_Y} = \overline{I_N} \text{ for a unbalanced load}$$
$$\overline{I_R} = 1.5\text{A}\angle 0^\circ$$
$$\overline{I_B} = 3.1\text{A}\angle 120^\circ$$
$$\overline{I_Y} = 4.6\text{A}\angle 240^\circ$$
$$1.5\angle 0^\circ + 3.1\angle 120^\circ + 4.6\angle 240^\circ = \overline{I_N}$$
$$\therefore \overline{I_N} = 2.685\text{A}\angle -151^\circ \text{ (Calculated)}$$

$$\overline{I_N} = 2.6\text{A (Measured)}$$

$$\therefore \text{Percentage error} = \frac{2.685 - 2.6}{2.685} \times 100\% = 3.166\%$$

Single-phase mode
(See table fig.9)

$$\text{Output power} = V_R \cdot I$$
$$\text{Output power} = 48 \times 8.4$$
$$\text{Output power} = 403.2 \text{ W}$$

$$\text{Input power} = 510 \text{ W}$$

$$\therefore \text{Efficiency } \eta = \frac{P_{out}}{P_{in}} = \frac{403.2}{510} = 0.791 \text{ or } 79.1\%$$

Discussion

With the experiment set as a three phase balanced system, as the results show there was no current flow in the neutral line as would be expected ($\overline{I_R} + \overline{I_B} + \overline{I_Y} = 0$). In this (balanced) case, the neutral line could be disconnected giving us a three-wire star-connected system.

For results in table fig.6:
If we calculate V_{Line}, using the formula $V_{Line} = \sqrt{3} \times V_{Phase}$, then:

$$V_{Line} = \sqrt{3} \times V_{Phase}$$
$$V_{Line} = \sqrt{3} \times 99$$
$$V_{Line} = 171.473V$$

Whereas the measured value of V_{Line}, was found to be 206V, giving a percentage error of:

$$\frac{206 - 171.473}{206} \times 100\% = 16.8\%$$

The voltage difference between these two values (206 – 171.473=34.527V) is a voltage drop, as $V_S = V_R + V_{Line}$, due to the inductive reactance of the transmission line.

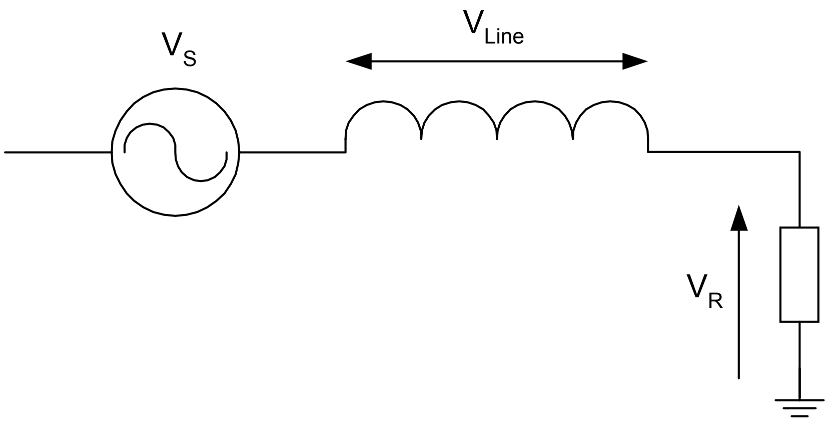

Fig.11 Losses in the transmission line

This voltage drop needs to be kept to a minimum for the supplier, in order to keep the overall system efficiency high and therefore reduce costs.

The advantage of a three-phase distribution system is a higher overall efficiency (85.5% as opposed to 79.1%), this is due to I^2R losses in the neutral return line in single-phase systems.

A balanced three-phase, three-wire circuit having the same voltage between the line wires uses only 75% of the copper required for a single-phase, two-wire circuit. Both circuits will have the same kVA capacity, voltage rating and length of circuit.[1]

[1] DUFF,J & HERMAN,S : "Alternating current fundamentals",(Delmar Publishers),1991; Pg 241.

Discussion (cont.)

Other advantages of three-phase systems are:

- The common ac induction motor is self-starting, and has better efficiency and power factor when used with three-phase systems.
- The ac ripple superimposed on the rectified three-phase output of a dc supply is easier to filter.
- Three-phase motors and generators have a capacity of 150% of that of a similar sized single-phase unit.
- Three-phase power is constant whereas single-phase power is pulsating
- Single-phase loads can be operated on a three-phase system.

Conclusions

From the results, it can be seen that the three-phase transmission system offers increased efficiency and many other benefits over a single-phase system. Additionally, single-phase loads may be operated from a three-phase supply, as a three-phase systems comprises three single-phase circuits combined into one.

Power systems operate with large ratings. The greater the power then, for a given voltage, the greater the current. Eventually the current becomes too large and we have to seek a change of system which can cope. A significant advance can be made using the three-phase system.[2]

[2] MCKENZIE-SMITH,I : “Hughes Electrical Technology”,(Longman),1998; Pg 542.

Reference material

- Lecture notes – A.Faraj
- Alternating Current Fundamentals, 4th Edition, John R.Duff, Stephen L.Herman, Delmar Publishers Inc.
- Electrical and Electronic Principles and Technology, John Bird, Newnes
- Hughes electrical technology, 7th Edition, I McKenzie Smith, Longman
- Direct and Alternating Current Circuits, Bernard Grob, McGraw-Hill

Index of drawings, tables and graphs