NEUB CSE 121 Lecture 1: Introduction to Electrical Engineering

What is engineering?

Engineering can be simply described as the purposeful use of science.
Oxford dictionary defines engineering as
The branch of science and technology concerned with the design, building, and use of engines, machines, and structures.
Wikipedia defines engineering as
Engineering is the application of mathematics, science, economics, empirical evidence, and social and practical knowledge to invent, innovate, design, build, maintain, research, and improve structures, machines, tools, systems, components, materials, processes, solutions, and organizations.
No matter how we describe engineering it is clear engineering the application of science in such a matter, which helps human to lead life easily. Engineering can be also considered as simplification of scientific knowledge for use in everyday life.

What is Electrical Engineering?

Electrical engineering is the is the branch of engineering concerned with systems that produce, transmit, and measure electric signals. Electrical engineering combines the physicist's models of natural phenomena with the mathematician's tools for manipulating those models to produce systems that meet practical needs. Electrical systems pervade our lives; they are found in homes, schools, workplaces, and transportation vehicles everywhere. We begin by presenting a few examples from each of the five major classifications of electrical systems:

- communication systems
- computer systems
- control systems
- power systems
- signal-processing systems

The international system of units

Before diving into details of engineering, we have to recall about the units necessary for representing any measurements.

Base units:

All units in science are derived from seven base units:

Table 1 Seven base units in SI

Quantity	Basic Unit	Symbol
Mass	kilogram	kg
Distance	metre	m
Time	second	s
Current	ampere	A
Amount	mole	mol
Temperature	Kelvin	K
Light Intensity	candela	cd

PREPARED BY
SHAHADAT HUSSAIN PARVEZ

Derived units

There are many other units that we use, but all of these are derived by multiplication or division of some combinations of the base units. You can think of it like letters and words. We have 26 letters in the alphabet but we have thousands of words in our language. **Here are some of the derived units**:

Table 2 Some of derived units

Quantity	Unit	Symbol	Formula
Velocity	metre per second	ms^{-1}	ms^{-1}
Acceleration	metre per second squared	ms^{-2}	ms^{-2}
Force	Newton	N	$kg\ ms^{-2}$
Work or Energy	joule	J	$kg\ m^2s^{-2}$
Pressure	Pascal	Pa	$kg\ m^{-1}s^{-2}$
Frequency	hertz	Hz	s^{-1}
Charge	coulomb	C	A s
Power	Watt	W	J/s
Electric Potential	Volt	V	J/C
Electric Resistance	Ohm	Ω	V/A
Electric Conductance	Siemens	S	A/V
Electric Capacitance	Farad	F	C/V
Magnetic Flux	Webber	Wb	V.S
Inductance	Henry	H	Wb/A

Prefixes

Now you have units, you often need to group these into larger or smaller numbers to make them more manageable. For example, you don't say that you are going to see someone who lives 100,000 m away from you, you say they live 100 km away from you. **Here a quick list of the common quantities used:**

Table 3 Standardized prefixes to signify power of 10

Name	Symbol	Scaling factor	Common example
Peta	P	10^{15}	Data center storages are measured in petabytes
Tera	T	10^{12}1,000,000,000,000	Large computer hard drives can be terabytes in size.
Giga	G	10^{9} 1,000,000,000	Computer memories are measured in gigabytes.
mega	M	10^{6} 1,000,000	A power station may have an output of 600 MW (megawatts).
Kilo	k	10^{3} 1,000	Mass is often measured in kilogrammes (i.e. 1000 grammes).
Deci	d	10^{-1} 0.1	Fluids are sometimes measured in decilitres (i.e. 0.1 litre).
centi	c	10^{-2} 0.01	Distances are measured in centimetres (i.e. 100th of a metre).
Milli	m	10^{-3} 0.001	Time is sometimes measured in milliseconds.
Micro	µ	10^{-6} 1,000,000th	micrometres are often used to measure wavelengths of electromagnetic waves.
Nano	n	10^{-9}	nanometres are used to measure atomic spacing.
Pico	p	10^{-12}	picometres used to measure atomic radii.
femto	f	10^{-15}	
atto	a	10^{-18}	

Other system of units

Although now a days all scientific measurements are measured in SI units, before standardization was common, there were many different system of units used in the past. The usage varied from regions to regions. Even to this day, there are examples of widespread usage of other systems of units. Here are some of the common systems of units.

Table 4 Comparison of the English and metric systems of units.

English	Metric		
	MKS	CGS	SI
Length: Yard (yd) (0.914 m)	Meter (m) (39.37 in.) (100 cm)	Centimeter (cm) (2.54 cm = 1 in.)	**Meter (m)**
Mass: **Slug** (14.6 kg)	Kilogram (kg) (1000 g)	Gram (g)	**Kilogram (kg)**
Force: **Pound** (lb) (4.45 N)	Newton (N) (100,000 dynes)	Dyne	**Newton (N)**
Temperature: Fahrenheit (°F) $\left(=\frac{9}{5}°C + 32\right)$	Celsius or Centigrade (°C) $\left(=\frac{5}{9}(°F - 32)\right)$	Centigrade (°C)	**Kelvin (K)** K = 273.15 + °C
Energy: Foot-pound (ft-lb) (1.356 joules)	Newton-meter (N•m) or joule (J) (0.7376 ft-lb)	Dyne-centimeter or erg (1 joule = 10^7 ergs)	**Joule (J)**
Time: Second (s)	Second (s)	Second (s)	**Second (s)**

If you have any problem with some mathematical operations used during the course (Conversion between levels of power of tens, conversion between system of measurements and/or using calculators for scientific calculations etc), you can refer to chapter 1 of 'Introductory circuit analysis' by Boylestad (10th edition)

Circuit Theory

An ***electric circuit*** can be simply defined as interconnection of electrical elements. For and circuit to allow current to flow there must have a closed path.

Charge is an electrical property of the atomic particles of which matter consists, measured in coulombs (C).

Here are some of the points that should be noted about charge

1. The coulomb is a large unit for charges. In1Cof charge, there are $1/(1.602 \times 10^{-19}) = 6.24 \times 10^{18}$ electrons. Thus realistic or laboratory values of charges are on the order of pC, nC, or µC.
2. According to experimental observations, the only charges that occur in nature are integral multiples of the electronic chargee $=- 1.602 \times 10^{-19}$ C.
3. The law of conservation of charge states that charge can neither be created nor destroyed only transferred. Thus the algebraic sum of the electric charges in a system does not change.

The rate of flow of charge is known as the ***electric current***.

$$i = \frac{dq}{dt} \qquad (1.1)$$

Here
i = The current in amperes
q = The charge in coulomb
t = The time in seconds

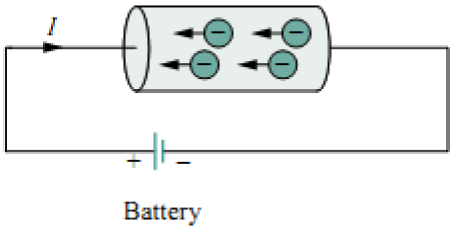

Figure 1 Electric current due to flow of electronic charge in a conductor.

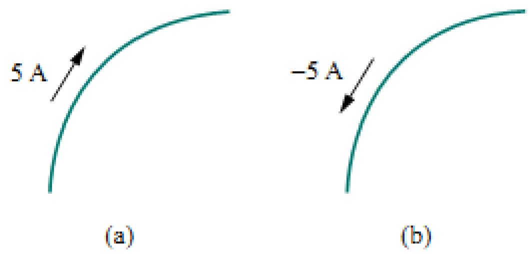

Figure 2 Conventional current flow: (a) positive current flow, (b) negative current flow.

The charge transferred between time t0 and t is obtained by integrating both sides of Eq. (1.1). We obtain

$$q = \int_{t_0}^{t} i\,dt \qquad (1.2)$$

A ***direct current*** (dc) is a current that remains constant with time. E.g. Batteries, solar cell, etc
An ***alternating current*** (ac) is a current that varies sinusoidally with time. E.g. mains supply, generator etc.

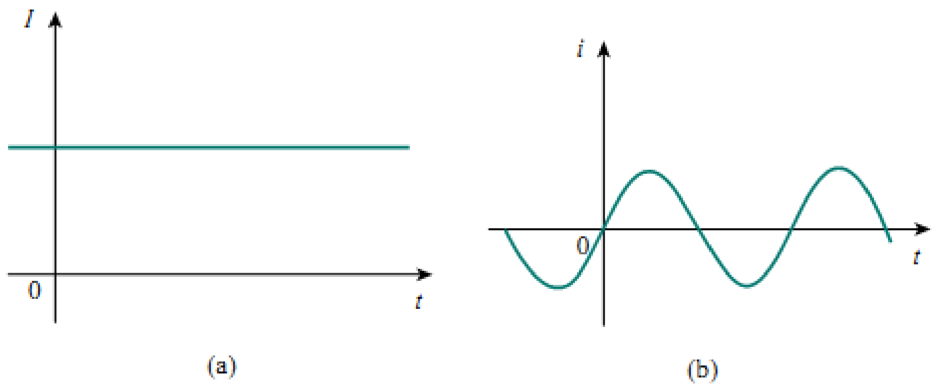

Figure 3 Two common types of current: (a) direct current (dc), (b) alternating current (ac).

Whenever positive and negative charges are separated, energy is expended. ***EMF (Voltage)*** is the energy per unit charge created by the separation. We express this ratio in differential form as

$$V = \frac{dw}{dq} \qquad (1.3)$$

Here
V = The voltage in volts
q = The charge in coulomb
w = The energy in joules

Potential Difference (also called voltage) is the energy required to move a unit charge through an element, measured in volts (V).
Notation plays a very important role in the analysis of electrical and electronic systems. To distinguish between sources of voltage (batteries and the like) and losses in potential across dissipative elements, the following notation will be used:

- E for voltage sources (volts)
- V for voltage drops (volts)

V for voltage drops (volts)
An occasional source of confusion is the terminology applied to this subject matter. Terms commonly encountered *include potential, potential difference, voltage, voltage difference (drop or rise), and electromotive force*. As noted in the description above, some are used interchangeably. The following dentitions are provided as an aid in understanding the meaning of each term:

Potential: *The voltage at a point with respect to another point in the electrical system. Typically the reference point is ground, which is at zero potential.*
Potential difference*: The algebraic difference in potential (or voltage) between two points of a network.*
Voltage*: When isolated, like potential, the voltage at a point with respect to some reference such as ground (0 V).*
Voltage difference*: The algebraic difference in voltage (or potential) between two points of the system. A voltage drop or rise is as the terminology would suggest.*
Electromotive force (emf)*: The force that establishes the flow of charge (or current) in a system due to the application of a difference in potential. This term is not applied that often in today's literature but is associated primarily with sources of energy.*

The ideal Basic circuit Element

An ideal basic circuit element has three attributes: (1) it has only two terminals, which are points of connection to other circuit components; (2) it is described mathematically in terms of current and/or voltage; and (3) it cannot be subdivided into other elements. We use the word ideal to imply that a basic circuit element does not exist as a realizable physical component.

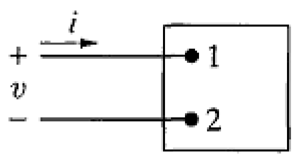

Figure 4 An ideal basic circuit element

Passive sign convention

The passive sign convention uses a positive sign in the expression that relates the voltage and current at the terminals of an element when the reference direction for the current through the element is in the direction of the reference voltage drop across the element.

Table 5 Interpretation of Reference Directions in figure 4

	Positive Value	Negative Value
v	voltage drop from terminal 1 to terminal 2 *or* voltage rise from terminal 2 to terminal 1	voltage rise from terminal 1 to terminal 2 *or* voltage drop from terminal 2 to terminal 1
i	positive charge flowing from terminal 1 to terminal 2 *or* negative charge flowing from terminal 2 to terminal 1	positive charge flowing from terminal 2 to terminal 1 *or* negative charge flowing from terminal 1 to terminal 2

Power is the time rate of expending or absorbing energy, measured in watts (W). Mathematically it can be written as

$$p = \frac{dw}{dt} \qquad (1.4)$$

Here
p = The Power in watts
t = The Time in seconds
w = The energy in joules

So 1 watt is equal to 1 J/S
The power associated with the flow of charge follows directly from the definition of voltage and current

$$p = \frac{dw}{dt} = \frac{dw}{dq} \times \frac{dq}{dt}$$
$$p = vi \qquad (1.5)$$

Here
p = The Power in watts
v = The Voltage in volts
i = The current in amperes

The equation 1.5 is known as the power equation.
Some of the other equations for finding the power are as follows

$$p = \frac{v^2}{R} \qquad (1.6)$$

$$p = i^2 R \qquad (1.7)$$

Here
p = The Power in watts
v = The Voltage in volts
i = The current in amperes
R = The Resistance in ohm

If the power is positive (that is, if p > 0), power is being delivered to the circuit inside the box. If the power is negative (that is, if p < 0), power is being extracted from the circuit inside the box.
Passive sign convention is satisfied when the current enters through the positive terminal of an element and p =+ vi. If the current enters through the negative terminal, p =– vi.

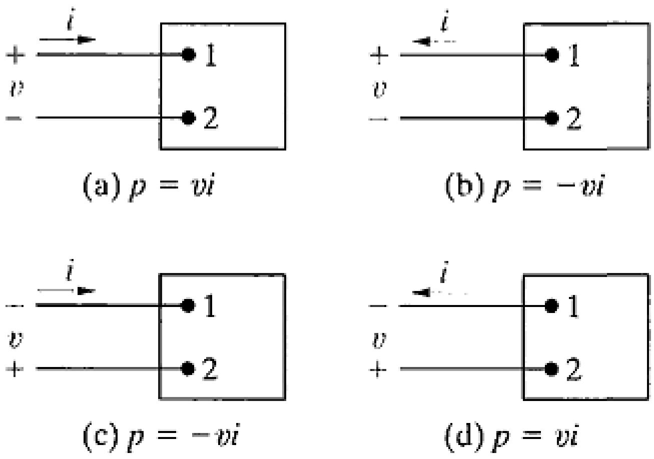

Figure 5 Polarity reference and the expression of power

The law of conservation of energy must be obeyed in any electric circuit. For this reason, the algebraic sum of power in a circuit, at any instant of time, must be zero:

$$\sum p = 0 \qquad (1.8)$$

This confirms the fact that the total power supplied to the circuit must balance the total power absorbed.
From Eq. (1.5), the energy absorbed or supplied by an element from time t_0 to time t is

$$w = \int_{t_0}^{t} p\,dt = \int_{t_0}^{t} vi\,dt \qquad (1.9)$$

Energy is the capacity to do work, measured in joules (J).
Some of the other equations for finding the energy are as follows

$$w = \frac{v^2}{R} t \qquad (1.10)$$

$$w = i^2 R\, t \qquad (1.11)$$

Here
w = The Energy in joules
v = The Voltage in volts
i = The current in amperes
R = The Resistance in ohm
t = The Time in seconds

The electric power utility companies measure energy in watt-hours (Wh),where

$$1Wh = 3{,}600\,J$$

Sometimes bills can be measured in Kilo Watt-hour (KWh), where

$$1KWh = 3{,}600{,}000\,J$$

Circuit Elements

There are two types of elements found in electric circuits: passive elements and active elements. An active element is capable of generating energy while a passive element is not. Examples of passive elements are resistors, capacitors, and inductors. Typical active elements include generators, batteries, and operational amplifiers.

The most important active elements are voltage or current sources that generally deliver power to the circuit connected to them. There are two kinds of sources: independent and dependent sources.

An ***ideal independent source*** is an active element that provides a specified voltage or current that is completely independent of other circuit variables.

In other words, an ***ideal independent voltage*** source delivers to the circuit whatever current is necessary to maintain its terminal voltage. Physical sources such as batteries and generators may be regarded as approximations to ideal voltage sources.

Similarly, an ***ideal independent current source*** is an active element that provides a specified current completely independent of the voltage across the source. That is, the current source delivers to the circuit whatever voltage is necessary to maintain the designated current.

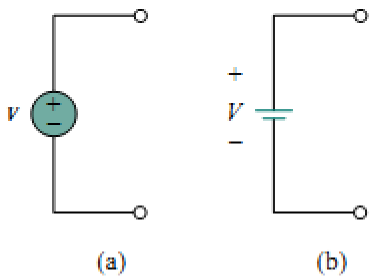

Figure 6 Symbols for independent voltage sources: (a) used for constant or time-varying voltage, (b) used for constant voltage (dc).

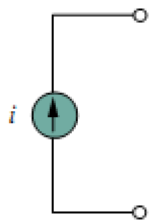

Figure 7 Symbol for independent current source.

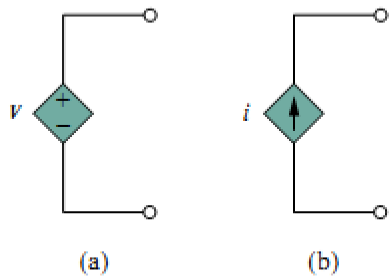

Figure 8 Symbols for: (a) dependent voltage source, (b) dependent current source.

The figures 6 and 7 above shows the symbols for ideal voltage and current sources respectively

An ***ideal dependent (or controlled) source*** is an active element in which the source quantity is controlled by another voltage or current.

Since the control of the dependent source is achieved by a voltage or current of some other element in the circuit, and the source can be voltage or current, it follows that there are four possible types of dependent sources, namely:

1. A voltage-controlled voltage source (VCVS).
2. A current-controlled voltage source (CCVS).
3. A voltage-controlled current source (VCCS).
4. A current-controlled current source (CCCS).

Figure 8 above shows the symbols for ideal dependent sources. Dependent sources are useful in modeling elements such as transistors, operational amplifiers and integrated circuits. An example of a current-controlled voltage source is shown below

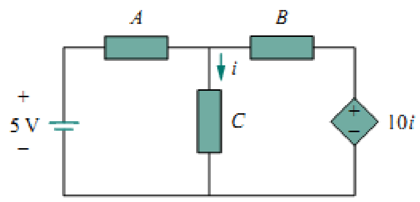

Figure 9 Example of a current controlled voltage source

Resistance

The flow of charge through any material encounters an opposing force similar in many respects to mechanical friction. This opposition, due to the collisions between electrons and between electrons and other atoms in the material, *which converts electrical energy into another form of energy such as heat, is called the* ***resistance*** *of the material*. The unit of measurement of resistance is the ohm, for which the symbol is Ω, the capital Greek letter omega. The circuit symbol for resistance appears in Fig. 10 with the graphic abbreviation for resistance (R).

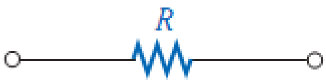

Figure 10 Resistance symbol and notation

The resistance of any material with a uniform cross-sectional area is determined by the following four factors:

1. Material
2. Length
3. Cross-sectional area
4. Temperature

The chosen material, with its unique molecular structure, will react differentially to pressures to establish current through its core. Conductors that permit a generous flow of charge with little external pressure will have low resistance levels, while insulators will have high resistance characteristics.

As one might expect, the longer the path the charge must pass through, the higher the resistance level, whereas the larger the area (and therefore available room), the lower the resistance. Resistance is thus directly proportional to length and inversely proportional to area.

As the temperature of most conductors increases, the increased motion of the particles within the molecular structure makes it increasingly difficult for the "free" carriers to pass through, and the resistance level increases.

For a fixed temperature the relationship between Resistance and other factor can be summarized by the equation below

$$R = \frac{\rho l}{A} \qquad (1.12)$$

Here
$R =$ The Resistance in ohm
$\rho =$ The Resistivity in
$l =$ The Length in meter
$A =$ The Cross sectional area in m^2

Table 6 Resistivity of common materials

Material	Resistivity (Ω·m)	Usage
Silver	1.64×10^{-8}	Conductor
Copper	1.72×10^{-8}	Conductor
Aluminum	2.8×10^{-8}	Conductor
Gold	2.45×10^{-8}	Conductor
Carbon	4×10^{-5}	Semiconductor
Germanium	47×10^{-2}	Semiconductor
Silicon	6.4×10^{2}	Semiconductor
Paper	10^{10}	Insulator
Mica	5×10^{11}	Insulator
Glass	10^{12}	Insulator
Teflon	3×10^{12}	Insulator

Ohm's law states that the voltage v across a resistor is directly proportional to the current i flowing through the resistor.

i.e. $v \propto i$

$$v = iR \qquad (1.13)$$

Here
R = The Resistance in ohm
v = The Voltage in volts
i = The current in amperes

The equation 1.13 is one of the simple representation of ohms law.

The ***resistance R*** of an element denotes its ability to resist the flow of electric current; it is measured in ohms (Ω).

We may deduce the resistance of a material by the formula

$$R = \frac{v}{i} \qquad (1.14)$$

A ***short circuit*** is a circuit element with resistance approaching zero.

An ***open circuit*** is a circuit element with resistance approaching infinity.

A useful quantity in circuit analysis is the reciprocal of resistance R, known as **conductance** and denoted by G:

$$G = \frac{1}{R} = \frac{i}{v} \qquad (1.15)$$

Conductance is the ability of an element to conduct electric current; it is measured in mhos (℧) or Siemens (S).

Equations for power and energy can also be rewritten in terms of conductance

$$p = \frac{i^2}{G} \qquad (1.16)$$

$$p = v^2 G \qquad (1.17)$$

$$w = \frac{i^2}{G} t \qquad (1.18)$$

$$w = v^2 G\, t \qquad (1.19)$$

Here
p = The power in watts
w = The Energy in joules
v = The Voltage in volts
i = The current in amperes
G = The Conductance in Siemens
t = The Time in seconds

TYPES OF RESISTORS

Fixed Resistors

Resistors whose values are fixed are known as fixed resistors. If only resistor is mentioned, fixed resistor is considered by default.

Variable Resistors

Variable resistors, as the name implies, have a terminal resistance that can be varied by turning a dial, knob, screw, or whatever seems appropriate for the application. They can have two or three terminals, but most have three terminals. If the two- or three-terminal device is used as a variable resistor, it is usually referred to as a ***rheostat***. If the three-terminal device is used for controlling potential levels, it is then commonly called a ***potentiometer***. Even though a three-terminal device can be used as a rheostat or potentiometer (depending on how it is connected).

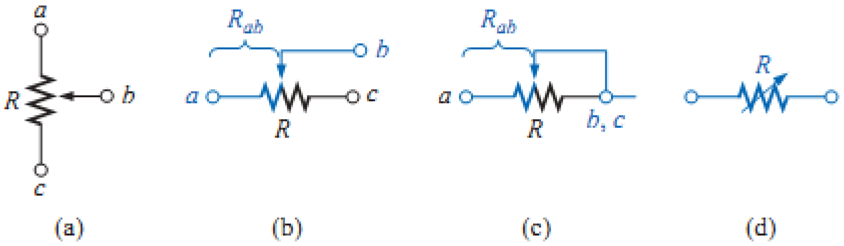

Figure 11 Potentiometer: (a) symbol; (b) and (c) rheostat connections; (d) rheostat symbol.

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NODES, BRANCHES, AND LOOPS

A ***branch*** represents a single element suchas a voltage source or a resistor.
A ***node*** is the point of connection between two or more branches.
A ***loop*** is any closed path in a circuit.

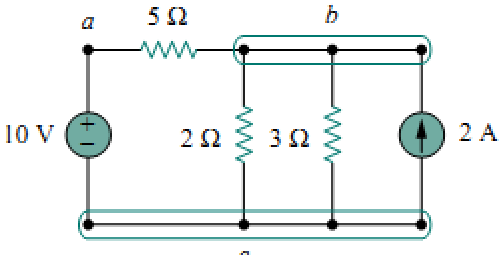

Figure 12 Nodes branches and loops

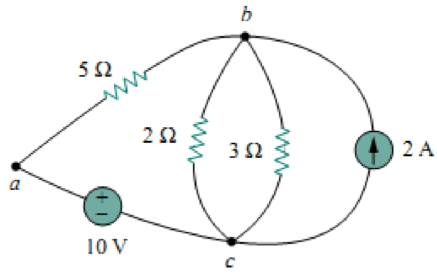

Figure 13 Three noded circuit of figure 12 redrawn

A network with b branches, n nodes, and l independent loops will satisfy the fundamental theorem of network topology:

$$b = l + n - 1 \qquad (1.20)$$

Two or more elements are in ***series*** if they are cascaded or connected sequentially and consequently carry the same current.
Two or more elements are in ***parallel*** if they are connected to the same two nodes and consequently have the same voltage across them.

1. Alexander Example 2.1-2.4
2. Alexander Exercise problems 2.1-2.4 [Based on Ohm's law]
3. Alexander Exercise problems 2.5-2.7 [Based on Nodes, branches and loops]
4. Boylestad Chapter 1-4 examples

Reference books

1. Introductory Circuit analysis by Robert L. Boylestad
2. Fundamentals of Electric circuits by C. K. Alexander and M. N. O. Sadiku

PREPARED BY
SHAHADAT HUSSAIN PARVEZ