


KLM Technology Group Practical Engineering Guidelines for Processing Plant Solutions	 Engineering Solutions www.klmtechgroup.com	Page : 1 of 70
		Rev: 01 Rev 01 May 2015
KLM Technology Group #03-12 Block Aronia, Jalan Sri Perkasa 2 Taman Tampoi Utama 81200 Johor Bahru Malaysia	Kolmetz Handbook Of Process Equipment Design ELECTRICAL CIRCUITS AND APPLICATIONS (ENGINEERING FUNDAMENTALS)	Editor / Author Karl Kolmetz

KLM Technology Group has developed; 1) Process Engineering Equipment Design Guidelines, 2) Equipment Design Software, 3) Project Engineering Standards and Specifications, and 4) Unit Operations Manuals. Each has many hours of engineering development.

KLM is providing the introduction to this guideline for free on the internet. Please go to our website to order the complete document.

www.klmtechgroup.com

KLM Technology Group with their key partners specialize in;

- 1) Process Engineering Equipment Design Guidelines**
- 2) Training for Refining, Chemicals, Ethylene and Equipment Design**
- 3) Process Engineering Consulting Studies**
- 3) Distillation Equipment Supply (Random and Structured Packing, Trays)**
- 4) Commissioning Assistance**

KLM Technology Group Practical Engineering Guidelines for Processing Plant Solutions	Kolmetz Handbook Of Process Equipment Design	Page 2 of 70
	ELECTRICAL CIRCUITS AND APPLICATIONS	Rev: 01
	(ENGINEERING FUNDAMENTALS)	May 2015

TABLE OF CONTENT

INTRODUCTION

Scope	10
General Consideration	11
A. Circuit Element	11
1. Passive Element	11
2. Active Element	12
B. Circuit Diagram	12

DEFINITION	16
------------	----

NOMENCLEATURE	18
---------------	----

Greek Letters	19
---------------	----

THEORY

A. CIRCUIT LAWS	20
1) Ohm's Law	20
2) Kirchhoff's Laws	20
3) Thevenin's Theorem	22
4) Norton's Theorem	25
5) Thevenin and Norton Equivalence	26
6) Superposition Theorem	27
7) Millman's Theorem	29

KLM Technology Group Practical Engineering Guidelines for Processing Plant Solutions	Kolmetz Handbook Of Process Equipment Design	Page 3 of 70
	ELECTRICAL CIRCUITS AND APPLICATIONS	Rev: 01
	(ENGINEERING FUNDAMENTALS)	May 2015

8) Reciprocity Theorem	30
B. ELECTRIC CIRCUIT ANALYSIS	
1) Linear Circuit Analysis	30
a. Time Domain Analysis	31
b. The Branch Current Method	34
c. The Mesh Current Method	35
d. The Node Voltage Method	36
e. Input and Output Resistance	37
f. Transfer Resistance	38
g. Network Reduction	39
2) Nonlinear Circuit Analysis	40
a. Graphical	40
b. Sinusoidal Analysis	41
c. Phasor Analysis	45
d. Frequency Response (Laplace) Analysis	47
C. CIRCUIT MODELING TECHNIQUES	53
1) Source Transformations	53
2) Thevenin and Equivalent Circuit	54
3) Maximum Power Transfer	55
D. SAFE CIRCUIT DESIGN	55
E. THREE PHASE CIRCUIT DESIGN	61
1) Three Phase Circuit Overview	61

KLM Technology Group Practical Engineering Guidelines for Processing Plant Solutions	Kolmetz Handbook Of Process Equipment Design ELECTRICAL CIRCUITS AND APPLICATIONS (ENGINEERING FUNDAMENTALS)	Page 4 of 70
		Rev: 01
		May 2015

2) Wye Connection 64

3) Delta Connection 65

F. CIRCUIT BREAKERS 66

REFERENCES

KLM Technology Group Practical Engineering Guidelines for Processing Plant Solutions	Kolmetz Handbook Of Process Equipment Design	Page 5 of 70
	ELECTRICAL CIRCUITS AND APPLICATIONS	Rev: 01
	(ENGINEERING FUNDAMENTALS)	May 2015

LIST OF TABLE

Table 1. Representation of Phasor Voltages and Current	46
Table 2. Element Voltage – Current Relationships	46
Table 3. Impedances and Admittances of Circuit Elements	47
Table 4. Impedance Relationship for Laplace Analysis	49
Table 5. Laplace Transforms of common functions	50

LIST OF FIGURE

Figure 1. Electrical circuit diagram	13
Figure 2. Single device electrical circuit	13
Figure 3. Example of Circuit Branches	14
Figure 4. Example of Nodes in Practical Circuit	14
Figure 5. Definition of a Loop	15
Figure 6. Definition of a Mesh	15
Figure 7. Closed Loop	21
Figure 8. Kirchhoff Current Law	22
Figure 9. R_{TH} as the input resistance at the terminals	23

KLM Technology Group Practical Engineering Guidelines for Processing Plant Solutions	Kolmetz Handbook Of Process Equipment Design ELECTRICAL CIRCUITS AND APPLICATIONS (ENGINEERING FUNDAMENTALS)	Page 6 of 70
		Rev: 01
		May 2015

Figure 10. Linear Circuit with a variable load	24
Figure 11. Linear Circuit	24
Figure 12. R_{TH} and P_{max} graph	25
Figure 13. Complete Circuit	26
Figure 14. The Principle of Superposition	28
Figure 15. Zeroing voltage and current source	29
Figure 16. Circuit with a Single Energy – Storing Element	31
Figure 17. Response of the Circuit in Figure (A)	32
Figure 18. Response of the Circuit Shown in Figure (B)	33
Figure 19. Circuit with two Energy – Storing Elements	34
Figure 20. Electrical Circuit	36
Figure 21. Passive Network	38
Figure 22. Load line	40
Figure 23. Graphical solution equation	41
Figure 24. Transformation of nonlinear circuit of Thevenin	41
Figure 25. A sketch of $V_m \sin \omega t$: (a) as a fuction of ωt (b) as a function of t	43
Figure 26. Phasor Diagram	46

KLM Technology Group Practical Engineering Guidelines for Processing Plant Solutions	Kolmetz Handbook Of Process Equipment Design	Page 7 of 70
	ELECTRICAL CIRCUITS AND APPLICATIONS	Rev: 01
	(ENGINEERING FUNDAMENTALS)	May 2015

Figure 27. Transfer Function and representation of a system	50
Figure 28. Poles on the s-plane stability	51
Figure 29. Source Transformation relationship.	
(a) Series Circuit (b) Parallel Circuit	54
Figure 30. A simple two – wire electrical power system	55
Figure 31. A toaster electrical circuit with a conductive metal case	56
Figure 32. Accident touching the wire bare	57
Figure 33. No danger of shock touching the case of wire	57
Figure 34. Accidental contact with conductive case	58
Figure 35. Grounded Case	59
Figure 36. Ground Fault Detection	60
Figure 37. Contac accident with metal case	60
Figure 38. Ground Fault Interrupter system	61
Figure 39. (a) Single-phase power falls to zero three times each cycle,	
(b) Three-phase power never falls to zero.	62
Figure 40. Producing a single – phase voltage	63
Figure 41. The voltages of a three-phase system are 120° out of phase	

KLM Technology Group Practical Engineering Guidelines for Processing Plant Solutions	Kolmetz Handbook Of Process Equipment Design ELECTRICAL CIRCUITS AND APPLICATIONS (ENGINEERING FUNDAMENTALS)	Page 8 of 70
		Rev: 01
		May 2015

with each other

63

Figure 42. A wye connection is formed by joining one end of each

of the windings together

64

Figure 43. Line and phase voltages are different in a wye connection

64

Figure 44. Three-phase delta connection

65

Figure 45. Molded Case Circuit Breaker

66

Figure 46. Cutaway View of Molded Case Circuit Breaker

67

Figure 47. Simple Circuit Breaker Control Circuit – Breaker Open

69

KLM Technology Group Practical Engineering Guidelines for Processing Plant Solutions	Kolmetz Handbook Of Process Equipment Design ELECTRICAL CIRCUITS AND APPLICATIONS (ENGINEERING FUNDAMENTALS)	Page 9 of 70
		Rev: 01
		May 2015

INTRODUCTION

Scope

An electrical circuit or electrical network is an array of interconnected elements wired so as to be capable of conducting current. Each electrical circuit has at least four basic parts, there are a source of electromotive force, conductors, load or loads, and some means of control. The fundamental two-terminal elements of an electrical electrical circuit are the resistor, the capacitor, the inductor, the voltage source and the current source.

Electrical circuit is an important and perhaps the oldest branch of electrical engineering. A circuit is an interconnection of electrical elements. There are two aspects to circuit theory, analysis and design. Circuit analysis involves in different elements of the circuit, given the values of the sources or excitation. On the other branch, circuit design focuses on the design of circuit that exhibit a certain pre-specified voltage or current characteristic at one or more.

This Engineering Fundamental provides an overview one of the electrical circuit with the basic laws of electrical circuit analysis, the basic circuit element and the application. This module will help develop the basic of generation, transmission and distribution of electricity.

KLM Technology Group Practical Engineering Guidelines for Processing Plant Solutions	Kolmetz Handbook Of Process Equipment Design ELECTRICAL CIRCUITS AND APPLICATIONS (ENGINEERING FUNDAMENTALS)	Page 10 of 70
		Rev: 01
		May 2015

General Considerations

A. Circuit Elements

An electric circuit is simply an interconnection of 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. Our aim in this section is to gain familiarity with some important passive and active elements.

1) Passive element

In the linear and nonlinear circuit, there are three passive circuit elements are resistors or resistance (R), inductors or inductance (L), and capacitors or capacitance (C). A passive circuit element is incapable of delivering power to a circuit. However, inductors store energy in the form of current and capacitors store energy in the form of voltage so they can release energy previously stored back to the circuit.

a) Resistance

All electrical devices that consume energy must have a resistor (also called a resistance) in their circuit model. Inductors and capacitors may store energy but over time return that energy to the source or to another circuit element. Resistance is a measure of how hard it is for charges to move in the system.

b) Inductance

The circuit element that stores energy in a magnetic field is an inductor (also called Inductance). With time-variable current, the energy is generally stored during some parts of the cycle and then returned to the source during others. When the inductance is removed from the source, the magnetic field will collapse, in order the words, no energy is stored without a connected source.

c) Capacitance

The circuit element that stores energy in an electric field is a capacitor (also called capacitance). When the voltage is variable over a cycle, energy will be stored during one part of the cycle and returned in the next. While an inductance cannot retain energy after removal of the source because the magnetic field collapses, the capacitor retains the charge and the electric field can remain after the source is removed.

KLM Technology Group Practical Engineering Guidelines for Processing Plant Solutions	Kolmetz Handbook Of Process Equipment Design ELECTRICAL CIRCUITS AND APPLICATIONS (ENGINEERING FUNDAMENTALS)	Page 11 of 70
		Rev: 01
		May 2015

2) Active element

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. An ideal dependent (or controlled) source is an active element in which the source quantity is controlled by another voltage or current. It should be noted that an ideal voltage source (dependent or independent) will produce any current required to ensure that the terminal voltage is as stated; whereas an ideal current source will produce the necessary voltage to ensure the stated current flow.

a) Voltage

Voltage is the force created by the separation of charges. Kind of like when two opposite poles of a magnet are put close together, but are separated by a short distance. A force tries to pull them together, but are separated by a short distance. A force tries to pull them together. When there are more negative charges on the inside of the membrane of a cell, there is a force driving positive charges inward to neutralize them. The unit of voltage is the volt and it is represented by the symbol V. voltage is also called “potential” or “potential difference”.

b) Current

Current is defined as the time rate of change of charge passing through a predetermined area. The symbol for current is (I). The basic measurement for current is the ampere (A). The name of the unit is a tribute to the French scientist Andre Marie Ampere. To produce current, the electrons must be moved by a potential difference. There are two type of Electric current, direct current (DC) and alternating current (AC). DC is a current that remains constant with time. AC is a current that varies sinusoidally with time.

B. Circuit Diagram

Every circuit diagram can be constructed in a variety of ways may look different but are in fact identical. The diagram presented in a problem may not suggest the best of several methods of solution. Consequently, a diagram should be examined before a solution is started and redrawn if necessary to show clearly how the elements are interconnected.

KLM Technology Group Practical Engineering Guidelines for Processing Plant Solutions	Kolmetz Handbook Of Process Equipment Design	Page 12 of 70
	ELECTRICAL CIRCUITS AND APPLICATIONS	Rev: 01
	(ENGINEERING FUNDAMENTALS)	May 2015

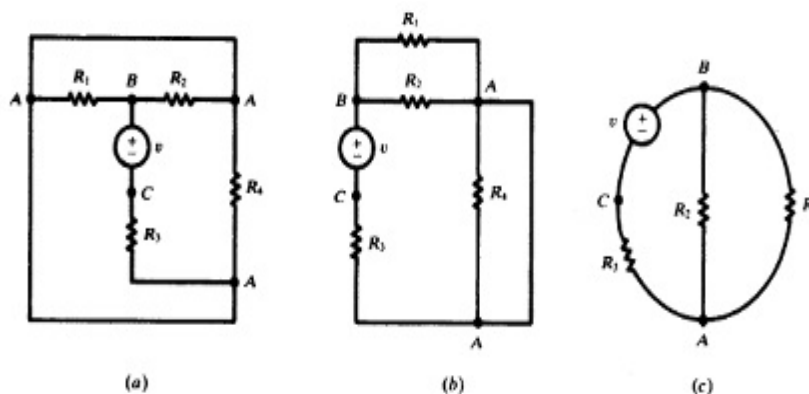


Figure 1. Electrical circuit diagram

An electrical device is represented by a circuit diagram or network constructed from series and parallel arrangement of two-terminal elements. The analysis of the circuit diagram predicts the performance of the actual device. A two terminal element in general form is shown in Figure 2, with a single device represented by the rectangular symbol and two perfectly conducting leads ending at connecting points A and B.



Figure 2. Single device electrical circuit

a) Branch

A branch is any portion of circuit with two terminals connected to it. A branch may consist of one or more circuit elements (Figure 3). In practice, any circuit element with two terminals connected to it is a branch.

KLM Technology Group Practical Engineering Guidelines for Processing Plant Solutions	Kolmetz Handbook Of Process Equipment Design	Page 13 of 70
	ELECTRICAL CIRCUITS AND APPLICATIONS	Rev: 01
	(ENGINEERING FUNDAMENTALS)	May 2015

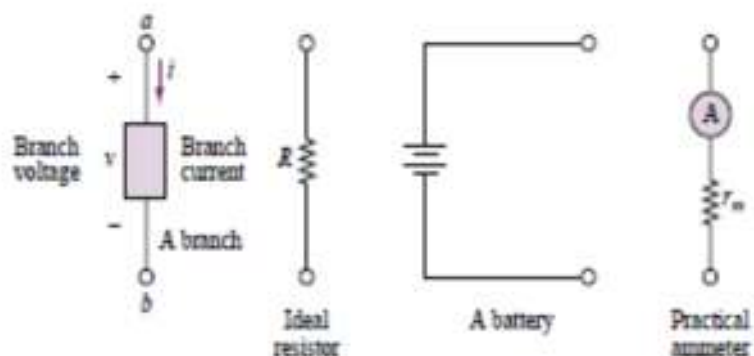


Figure 3. Example of Circuit Branches

b) Node

A node is the junction of two or more branches (one often refers to the junction of only two branches as a *trivial node*). Figure 4 illustrates the concept. In effect, any connection that can be accomplished by soldering various terminals together is a node. It is very important to identify nodes properly in the analysis of electrical networks.

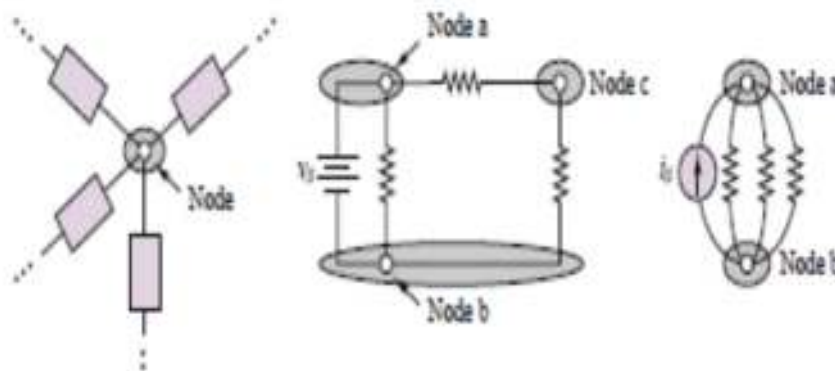


Figure 4. Example of Nodes in Practical Circuit

KLM Technology Group Practical Engineering Guidelines for Processing Plant Solutions	Kolmetz Handbook Of Process Equipment Design	Page 14 of 70
	ELECTRICAL CIRCUITS AND APPLICATIONS	Rev: 01
	(ENGINEERING FUNDAMENTALS)	May 2015

c) Loop

A loop is any closed connection of branches. Various loop configurations are illustrated in Figure 5.

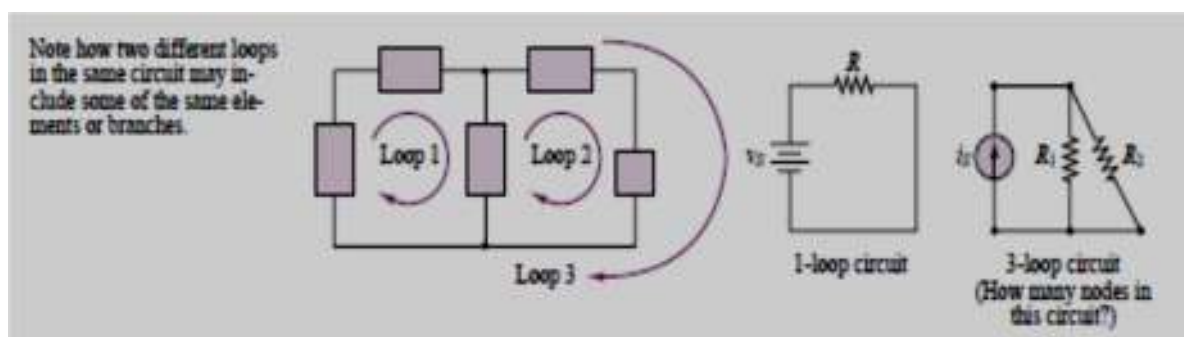


Figure 5. Definition of a Loop

d) Mesh

A mesh is a loop that does not contain other loops. Meshes are an important aid to certain analysis methods. In Figure 6, the circuit with loops 1, 2, and 3 consists of two meshes: loops 1 and 2 are meshes, but loop 3 is not a mesh, because it encircles both loops 1 and 2. The one-loop circuit of Figure 6 is also a one-mesh circuit. Figure 6 illustrates how meshes are simpler to visualize in complex networks than loops are.

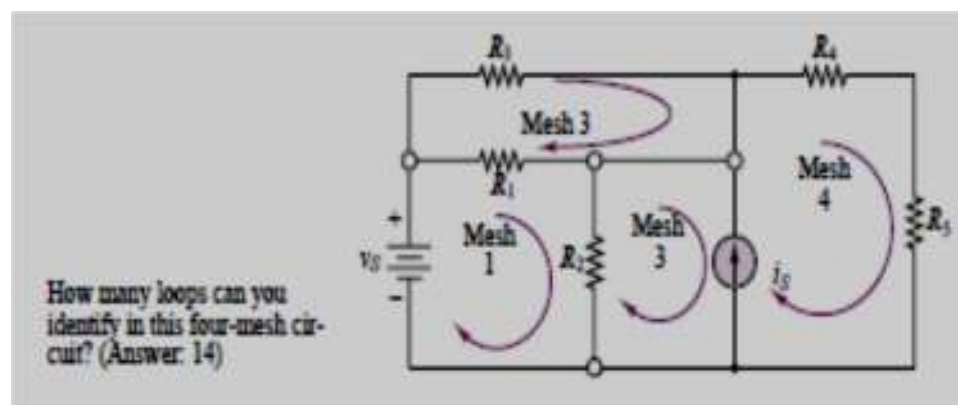


Figure 6. Definition of a Mesh

KLM Technology Group Practical Engineering Guidelines for Processing Plant Solutions	Kolmetz Handbook Of Process Equipment Design ELECTRICAL CIRCUITS AND APPLICATIONS (ENGINEERING FUNDAMENTALS)	Page 15 of 70
		Rev: 01
		May 2015

DEFINITIONS

Active element – A circuit element that generates power

Capacitor – A two-terminal electrical element that satisfies a prescribed algebraic relationship in the charge – voltage ($q - V$) plane.

Controlled source – A current or voltage branch element whose value depends on a branch current or voltage determined elsewhere in the network.

Current – the time rate of change of net charge passing through an arbitrary cross section of an electrical element.

Distributed element – A circuit element whose feature size is comparable to, or significantly larger than, the wavelength of applied energy.

Electrical circuit – An array interconnected elements wired so as to be capable of conducting current.

Inductor – A two-terminal electrical element that satisfies a prescribed algebraic relationship in the flux current ($\phi - I$) plane.

Mesh Analysis – a method that is used to solve planar circuits for the currents (and indirectly the voltages) at any place in the circuit.

Node - is the point of connection between two or more branches.

Loop - is any closed path in a circuit.

Passive element – A circuit element whose feature size is significantly smaller than the wavelength of applied energy.

Power – The time rate of change of energy applied to an electrical element.

Resistor – A two-terminal electrical element that satisfies a prescribed algebraic relationship in the voltage – current ($V - I$) plane.

KLM Technology Group Practical Engineering Guidelines for Processing Plant Solutions	Kolmetz Handbook Of Process Equipment Design ELECTRICAL CIRCUITS AND APPLICATIONS (ENGINEERING FUNDAMENTALS)	Page 16 of 70
		Rev: 01
		May 2015

Voltage – The energy applied to an element per unit of charge transported through the element.

KLM Technology Group Practical Engineering Guidelines for Processing Plant Solutions	Kolmetz Handbook Of Process Equipment Design ELECTRICAL CIRCUITS AND APPLICATIONS (ENGINEERING FUNDAMENTALS)	Page 17 of 70
		Rev: 01
		May 2015

NOMENCLATURE

A	: Area of the cross section, m ²
C	: Capacitance, F
E	: Electric field strength, V/m
f	: Frequency, Hz
I	: Current, Ampere
I _{oc}	: Open circuit current, Ampere
K	: Constant of proportionality, Coulomb ² /Nm ²
L	: Inductance, H
l	: Length, m
M	: Mutual Inductance, H
N	: Total number of nodes
P	: Power rating, W
r	: Distance between two particles, m
R	: Resistance, Ω
R _{TH}	: Thevenin Resistance, Ω
t	: Time, seconds
T	: Period of sinusoid, 1/second
v	: velocity, m/s
V	: Voltage, Volt
V _{oc}	: Open circuit voltage, Volt
Z	: Impedance, Ω

KLM Technology Group Practical Engineering Guidelines for Processing Plant Solutions	Kolmetz Handbook Of Process Equipment Design ELECTRICAL CIRCUITS AND APPLICATIONS (ENGINEERING FUNDAMENTALS)	Page 18 of 70
		Rev: 01
		May 2015

Greek Letters

- ρ : Resistivity of the material, ohm-meters
- θ : Angle
- ϕ : Phase
- \mathcal{L} : Laplace transform

KLM Technology Group Practical Engineering Guidelines for Processing Plant Solutions	Kolmetz Handbook Of Process Equipment Design ELECTRICAL CIRCUITS AND APPLICATIONS (ENGINEERING FUNDAMENTALS)	Page 19 of 70
		Rev: 01
		May 2015

THEORY

A. CIRCUIT LAWS

An electric circuit or network consist of a number of interconnected single circuit elements. The circuit will generally contain at least one voltage or current source. The arrangement of elements results in a new set of constraints between the currents and voltages. These new constraints and their corresponding equations, added to the current-voltage relationships of the individual elements, provide the solution of the network.

1) Ohm's Law

Ohm's law states that the voltage across a resistor is directly proportional to the current I following through the resistor. Mathematical expression for Ohm's Law is follows:

$$V = i \cdot R \quad (1)$$

When an applied voltage E causes a current I to flow through an impedance Z , the value of the impedance Z is equal to the voltage E divided by the current I . Similarly, when a current I passed through an impedance Z , the resulting voltage drop V across the impedance is equal to the current I multiplied by the impedance Z .

2) Kirchhoff's Laws

Through experimentation in 1857 the German physicist Gustav Kirchhoff developed methods to solve complex circuits. Kirchhoff developed two conclusions, known today as Kirchhoff Laws.

There are:

a) Kirchhoff's Voltage Law (KVL)

Kirchhoff's first law is also known as his "voltage law." The voltage law gives the relationship between the "voltage drops" around any closed loop in a circuit, and the voltage sources in that loop. The principle underlying KVL is that no energy is lost or created in an electric circuit terms, the sum of all voltages associated with sources must equal the sum of the load voltages, so that the net voltage around a closed circuit is zero. In equation form:

$$E_{\text{source}} = E_1 + E_2 + E_3 + \dots = I_1R_1 + I_2R_2 + I_3R_3 + \dots \quad (2)$$