Ohm's Law and Its Application in Electrical Circuits

Introduction

Ohm's Law is one of the fundamental principles in electrical circuit theory. It describes the relationship between voltage, current, and resistance in an electrical circuit and is essential for designing and analyzing both simple and complex electrical systems. Ohm’s Law applies to both full circuits and individual components within a circuit.

Ohm's Law: The Fundamental Equation

Ohm's Law states that the voltage (VV) across a resistor is directly proportional to the current (II) flowing through it and the resistance (RR) of the resistor. Mathematically, it is expressed as:

V=IRV = IR

where:

- VV = Voltage (in volts, V)
- II = Current (in amperes, A)
- RR = Resistance (in ohms, Ω)

This equation provides a simple yet powerful way to analyze and design electrical circuits by determining one of the three variables if the other two are known.

Applications of Ohm's Law

Ohm’s Law is widely used in electrical engineering and physics for:

- Calculating the required resistance in a circuit to achieve a specific current or voltage.
- Designing electrical networks and circuit components.
- Analyzing electrical faults and determining the behavior of electrical loads.
- Understanding power dissipation in electrical components.

Ohm's Law in a Full Circuit

In a complete electrical circuit containing a voltage source (such as a battery) and one or more resistors, Ohm’s Law helps determine the current flowing through the circuit. The total resistance in a simple series circuit is given by:

Rtotal=R1+R2+...+RnR_{total} = R_1 + R_2 + ... + R_n

The total current in the circuit can then be determined using:

I=VRtotalI = \frac{V}{R_{total}}

where VV is the total voltage supplied by the power source.

Example:

Consider a circuit with a 12V battery connected to a 4Ω resistor and an 8Ω resistor in series. The total resistance is:

Rtotal=4Ω+8Ω=12ΩR_{total} = 4Ω + 8Ω = 12Ω

Using Ohm’s Law, the current in the circuit is:

I=12V12Ω=1AI = \frac{12V}{12Ω} = 1A

The voltage drops across each resistor can be calculated using Ohm's Law:

V1=IR1=(1A)×(4Ω)=4VV_1 = I R_1 = (1A) \times (4Ω) = 4V

V2=IR2=(1A)×(8Ω)=8VV_2 = I R_2 = (1A) \times (8Ω) = 8V

These voltage drops sum to the total supplied voltage:

V1+V2=4V+8V=12VV_1 + V_2 = 4V + 8V = 12V

which confirms Kirchhoff’s Voltage Law.

Ohm’s Law in Circuit Components

Ohm’s Law applies to each component within a circuit, whether they are in series or parallel.

1. Series Circuits

- The same current flows through all resistors in a series circuit.
- The total resistance is the sum of individual resistances:
  Rtotal=R1+R2+...+RnR_{total} = R_1 + R_2 + ... + R_n
- The voltage drop across each resistor follows Ohm's Law.

2. Parallel Circuits

- The voltage across each parallel resistor is the same.
- The total current is the sum of the currents through each branch:
  Itotal=I1+I2+...+In$I_{total} = I_1 + I_2 + ... + I_n$
- The equivalent resistance is given by:

1Rtotal=1R1+1R2+...+1Rn$\frac{1}{R_{total}} = \frac{1}{R_1} + \frac{1}{R_2} + ... + \frac{1}{R_n}$

Example:

Consider a circuit where a 10V battery is connected to two resistors, 5Ω and 10Ω, in parallel. The total resistance is calculated as:

1Rtotal=15Ω+110Ω=210+110=310$\frac{1}{R_{total}} = \frac{1}{5Ω} + \frac{1}{10Ω} = \frac{2}{10} + \frac{1}{10} = \frac{3}{10}$

Rtotal=103Ω≈3.33Ω$R_{total} = \frac{10}{3}Ω \approx 3.33Ω$

Using Ohm’s Law, the total current is:

Itotal=10V3.33Ω≈3A$I_{total} = \frac{10V}{3.33Ω} \approx 3A$

The individual currents through each resistor are:

I1=10V5Ω=2A$I_1 = \frac{10V}{5Ω} = 2A$

I2=10V10Ω=1A$I_2 = \frac{10V}{10Ω} = 1A$

which add up to the total current:

Itotal=I1+I2=2A+1A=3A$I_{total} = I_1 + I_2 = 2A + 1A = 3A$

This confirms Kirchhoff’s Current Law.

Power Dissipation in Circuits

Power dissipation in a resistor follows the formula:

P=VI$P = VI$

Using Ohm’s Law, this can also be expressed as:

P=I2R$P = I^2 R$

or

$$P = \frac{V^2}{R}$$

where:

- P = Power (in watts, W)
- V = Voltage (in volts, V)
- I = Current (in amperes, A)
- R = Resistance (in ohms, Ω)

Example:

For a 5Ω resistor with a 2A current flowing through it, the power dissipated is:

$$P = (2A)^2 \times 5Ω = 4A^2 \times 5Ω = 20W$$