APPLICATIONS OF RESISTIVE CIRCUITS

CHAPTER - 6
CONTENTS:

- Internal Resistance of Voltage Sources
- Voltage Sources in Series
- Voltage Sources in Parallel
- Voltage Divider Rule
- Current Division Theorem
Internal Resistance of Voltage Sources

- Every source of voltage, whether a generator, battery, or laboratory supply will have some internal resistance.
Internal Resistance of Voltage Sources

- In all the circuit analyses to this point, the ideal voltage source (no internal resistance) was used.
- The ideal voltage source has no internal resistance and an output voltage of $E$ volts with no load or full load.
Internal Resistance of Voltage Sources

In the practical case, where we consider the effects of the internal resistance, the output voltage will be $E$ volts only when no-load ($I_L = 0$) conditions exist.
Internal Resistance of Voltage Sources

By applying Kirchhoff’s voltage law around the indicated loop, we obtain

\[ E - I_L R_{\text{int}} - V_L = 0 \]
\[ E = V_{NL} \]
\[ V_{NL} - I_L R_{\text{int}} - V_L = 0 \]

\[ V_L = V_{NL} - I_L R_{\text{int}} \]

\[ R_{\text{int}} = \frac{V_{NL} - V_L}{I_L} = \frac{V_{NL} - I_L R_L}{I_L} \]

\[ R_{\text{int}} = \frac{V_{NL}}{I_L} - R_L \]

\[ I_L V_L = I_L V_{NL} - I_L^2 R_{\text{int}} \]

- Power to load
- Power output by battery
- Power loss in the form of heat
Example 1. Before a load is applied, the terminal voltage of the power supply is set to 40 V. When a load of 500Ω is attached, the terminal voltage drops to 38.5 V. What is the internal resistance of the source?

Solution: The difference of 40 V − 38.5 V = 1.5 V now appears across the internal resistance of the source. The load current is

\[
38.5 \text{ V} / 0.5 \text{ kΩ} = 77 \text{ mA}
\]

\[
R_{\text{int}} = \frac{V_{NL}}{I_L} - R_L = \frac{40 \text{ V}}{77 \text{ mA}} - 0.5 \text{ kΩ}
\]

\[
= 519.48 \Omega - 500 \Omega = 19.48 \Omega
\]
Example 2. The battery has an internal resistance of $2\Omega$. Find the voltage $V_L$ and the power lost to the internal resistance if the applied load is a $13\Omega$-resistor.

Solution:

$$I_L = \frac{30 \text{ V}}{2 \Omega + 13 \Omega} = \frac{30 \text{ V}}{15 \Omega} = 2 \text{ A}$$

$$V_L = V_{NL} - I_L R_{int} = 30 \text{ V} - (2 \text{ A})(2 \Omega) = 26 \text{ V}$$

$$P_{\text{lost}} = I_L^2 R_{int} = (2 \text{ A})^2(2 \Omega) = (4)(2) = 8 \text{ W}$$
Voltage Sources in Series

The net voltage is determined simply by summing the sources with the same polarity and subtracting the total of the sources with the opposite “pressure.”

\[ E_T = E_2 + E_3 - E_1 = 9\, \text{V} + 3\, \text{V} - 4\, \text{V} = 8\, \text{V} \]
Voltage Sources in Series

Series Aiding

\[ E_1 \]
\[ E_2 \]
\[ E_T = E_1 + E_2 \]

Series Opposing

\[ E_1 \]
\[ E_2 \]
\[ E_T = E_1 - E_2 \]

When the voltages are not equal, the polarity of the resultant voltage is determined by the larger of the two voltages.
VOLTAGE SOURCES IN PARALLEL

Voltage sources of different potentials should never be connected in parallel.

However, when two equal potential sources are connected in parallel, each source will deliver half the required circuit current.
EXAMPLE 3. A 12–V battery and a 6–V battery (each having an internal resistance of 0.05 ) are inadvertently placed in parallel as shown in Figure below. Determine the current through the batteries.

![Diagram of batteries in parallel]

**Solution** From Ohm's law,

\[
I = \frac{E_T}{R_T} = \frac{12 \text{ V} - 6 \text{ V}}{0.05 \Omega + 0.05 \Omega} = 60 \text{ A}
\]

*Tremendous currents will occur within the sources resulting in the possibility of a fire or explosion*
VOLTAGE DIVIDER RULE

The voltage across the resistive elements will be divided as the magnitude of the resistance levels.

\[ R_T = R_1 + R_2 \]
\[ I = \frac{E}{R_T} \]

By Ohm’s Law

\[ V_1 = IR_1 = \left( \frac{E}{R_T} \right)R_1 = \frac{R_1E}{R_T} \]
\[ V_2 = IR_2 = \left( \frac{E}{R_T} \right)R_2 = \frac{R_2E}{R_T} \]

\[ V_x = \frac{R_xE}{R_T} \] (voltage divider rule)
Example 4. Using the voltage divider rule, determine the voltages $V_1$ and $V_3$ for the series circuit of figure below.

Solution:

\[
V_1 = \frac{R_1E}{R_T} = \frac{(2 \, \text{k}\Omega)(45 \, \text{V})}{2 \, \text{k}\Omega + 5 \, \text{k}\Omega + 8 \, \text{k}\Omega} = \frac{(2 \times 10^3 \, \Omega)(45 \, \text{V})}{15 \, \text{k}\Omega} = \frac{90 \, \text{V}}{15} = 6 \, \text{V}
\]

\[
V_3 = \frac{R_3E}{R_T} = \frac{(8 \, \text{k}\Omega)(45 \, \text{V})}{15 \, \text{k}\Omega} = \frac{(8 \times 10^3 \, \Omega)(45 \, \text{V})}{15 \times 10^3 \, \Omega} = \frac{360 \, \text{V}}{15} = 24 \, \text{V}
\]
Current Division Theorem

- Sometimes it is necessary to find the individual branch currents in a parallel circuit when only resistance and total current are known.
- When only two branches are involved, the current in one branch will be some fraction of $I_T$.
- The resistance in each circuit can be used to divide the total current into fractional currents in each branch.
- This process is known as current division.

\[ I_1 = I_T \left( \frac{R_2}{R_1 + R_2} \right) \quad I_2 = I_T \left( \frac{R_1}{R_1 + R_2} \right) \]
Current Division Theorem

\[ I_x = I_T \left( \frac{RT}{R_x} \right) \]

- The ratio of total resistance to individual resistance is the same ratio as individual (branch) current to total current.
- This is known as the current divider formula, and it is a short-cut method for determining branch currents in a parallel circuit when the total current is known.
Example 5.

Three resistors, $R_1 = 510 \, \Omega$, $R_2 = 270 \, \Omega$ and $R_3 = 430 \, \Omega$ are connected in parallel. The total current drawn by the circuit is $300\text{mA}$. What is the current through $R_3$?
Solution

\[ R_T = \frac{1}{\frac{1}{510\Omega} + \frac{1}{270\Omega} + \frac{1}{430\Omega}} \]

\[ R_T = 125.16\Omega \quad \text{Answer} \]

\[ I_3 = I_T \times \left( \frac{R_T}{R_3} \right) = 300\ mA \times \left( \frac{125.16\Omega}{430\Omega} \right) \]

\[ I_3 = 87.32\ mA \quad \text{Answer} \]
Thank You!