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EE1101: Circuits and Network Analysis

Lecture 19: KVL and Inductance

September 12, 2025
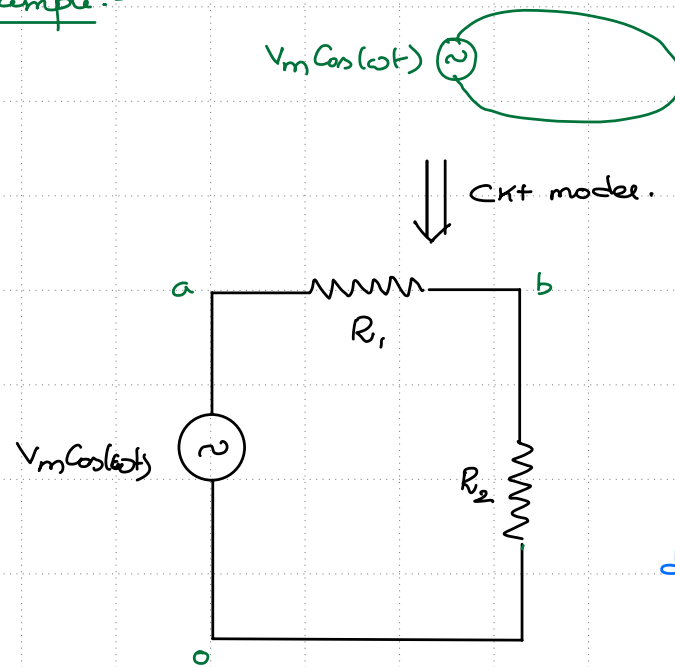
Topics :

1. Kirchhoff's Voltage Law (KVL) for AC Circuits

2. Inductance

KVL for AC Circuits (Not a Practical Scenario; but Chosen to demonstrate the validity of KVL)

Example:-

$V_m \cos(\omega t)$ ⟹ Wire can be modelled as a Resistance.

$$\Downarrow$$

Resistance

$$\Downarrow$$

Ckt model.

⟹ def the magnitude of current is the wire.

a R_1 b

$V_m \cos(\omega t)$ R_2

o

Assume that mag of current is not very large (x) ⟸ def the magnitude of current is the wire.
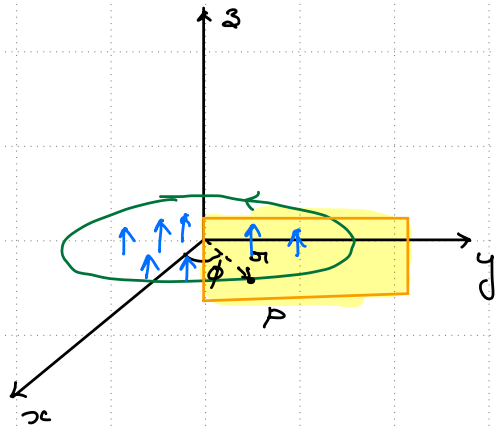
def: $V_{ab} = -\int_{b}^{a} \vec{E} \cdot \vec{d\ell}$ ($\because$ path independence of potential is not established, def potential where <mark>path is along the ckt elem</mark>)

Apply Maxwell's 2nd Eqn!

Lenz's Law.

$$\oint \vec{E} \cdot \vec{d\ell} = -\frac{d\lambda}{dt}$$

$$\int_{o}^{a} \vec{E} \cdot \vec{d\ell} + \int_{a}^{b} \vec{E} \cdot \vec{d\ell} + \int_{b}^{o} \vec{E} \cdot \vec{d\ell} = -\frac{d\lambda}{dt}$$

$$-V_{ao} - V_{ba} - V_{ob} = -\frac{d\lambda}{dt} \Rightarrow \boxed{V_{ao} + V_{ba} + V_{ob} = \frac{d\lambda}{dt}}$$

KVL for AC Circuits

Current $\longrightarrow \hat{\phi}$

mag. field intensity $\vec{H}$ = along $\hat{3}$

magnetic field: $\oint \vec{H} \cdot \vec{dl} = I_{enc}$

$$\oint H_3 \, d3 = I_{enc} = N i \quad \leftarrow \text{no. of turns}$$

$$|H| \propto N i$$

$i = I \cos \omega t \implies (H \propto N I \cos \omega t$

$\vec{B}$ (mag flux density): $\vec{B} = \mu \vec{H} \implies (|\vec{B}| \propto \mu_0 \mu_r N I \cos \omega t$

flux $\phi = \int \vec{B} \cdot \vec{ds} \propto \mu_r N I \cos \omega t \, (\pi r^2)$

flux linkage $\lambda = N \phi \propto \mu_r (N^2) I \cos \omega t \, (r^2)$

$$\frac{d\lambda}{dt} \propto \mu_r N^2 I (r^2) \omega$$

dominant / while building inductor

Circuit domain (in simple terms)

$\mu_r N^2 I (r^2) \omega$ is not

significant $\implies \frac{d\lambda}{dt} \approx 0$

$\Downarrow$

KVL $\implies \oint \vec{E} \cdot \vec{dl} = 0 \implies \sum V = 0.$

KVL for Circuit domain = $\sum_{i \in loop} V_i = 0$

(both for DC & AC)

on the other hand, for long transmission lines, (r) is significant even though freq is low.
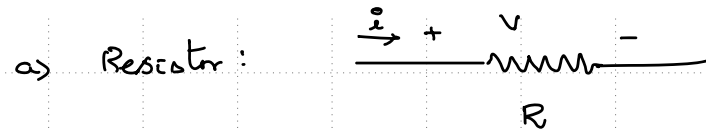
effective radius is very small for circuits

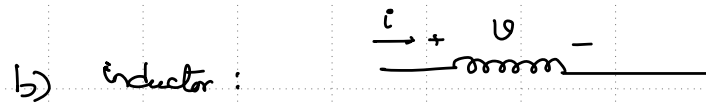on the other hand, for antennas & waveguides, freq of operation is high so $\frac{d\lambda}{dt}$ is significant

freq of operation $\left(\frac{d\lambda}{dt} \text{ at low freq} \right.$ is not significant $\left. \right)$

Inductance   Ckt elem:

a) Resistor: $\xrightarrow{i}$ +   v   −   R $v = iR$

b) Inductor: $\xrightarrow{i}$ +   v   −

$$v = \frac{d\lambda}{dt} = L\frac{di}{dt} \quad (\lambda = Li)$$

↓   mag core   where $\mu_r \gg 1$
&
No. of turns are relatively high

↓ dep on geometry &
Prop of magnetic core.