Electrical, Controls, Instrumentation

Ricky Nguyen's knowledge bank

EC&I Knowledge Encyclopedia

Changed by:	Date	Comment
Ricky N.	16/07/2022	

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Contents

List of Figures

List of Tables

1 UQ Subjects

This chapter goes through the UQ courses that was undertaken from 2016 to 2019. The format will be as follows, for each section, where possible:

1. Lecture notes (Use "LEC##: TITLE HERE" for each heading)
2. Tutorial questions (Use "TUT##: TITLE HERE" for each heading)
3. Summary of all equations used (Use "EQU##: TITLE HERE" for each heading)
4. References & other helping material (Use "REF##: TITLE HERE" for each heading)
5. Australian Standards (Use "STD##: TITLE HERE" for each heading)

In terms of text colour and highlights, the format will be as follows where possible:

1. Black = normal text
2. Red = Important
3. Blue = References
4. Green = Key Takeaways

1.1 CSSE2002 - Java Language

1.2 CSSE2010 - Embedded Programming

1.3 CSSE2310 - C Language

1.4 CSSE3010 - Advanced Embedded

1.5 MATH1051 - Linear Calculus

1.6 MATH2001 - Advanced Calculus

1.7 MATH2010 - Partial Differential Equations

1.8 STAT2202 - Advanced Statistics

1.9 ELEC2003 - Electronics & Circuits Pt.1

1.10 ELEC2004 - Electronics & Circuits Pt.2

1.10.1 LEC01: Capacitors and Inductors, RL and RC Circuits

Capacitors

Capacitors and inductors are linear circuit elements that can store electrical energy. The ideal capacitor stores energy in the form of **charge**.

$$C = \frac{\epsilon A}{d} \tag{1}$$

Where:

- C = capacitance in Farads (F)
- A = conductor plates area (both top and bottom) (mm^2)
- ϵ = dielectric of permitivity (constant)
- d = plate separation distance (m)

$$Q = CV \tag{2}$$

Where:

- Q = stored charge
- C = capacitance (F)
- V = applied voltage (V)

In DC, a capacitor is effectively an open circuit; when a steady voltage is applied. When the voltage changes, the stored charge changes also as per equation (2) by taking the derivative. Thus,

$$i(t) = \frac{dq(t)}{dt} = C\frac{dv(t)}{dt} \tag{3}$$

KEY TAKEAWAY: Change in voltage induces a current because there are charges moving. This electrical energy is stored in "capacitance" in the form of an electric field.

Energy storage in capacitors is calculated by integrating the instantaneous power $P(t)$. Thus,

$$P(t) = v(t)i(t) = Cv(t)\frac{dv(t)}{dt} \tag{4}$$

Integrating the instanteous power:

$$W(t) = \frac{1}{2}Cv^2(t) \tag{5}$$

Capacitors can be combined in series and in parallel to yield a single equivalent capacitance. Note: the behaviour of equivalent capacitance is the opposite of resistors. Series:

$$C_{EQ} = \frac{1}{\frac{1}{C_1} + \frac{1}{C_2} + \frac{1}{C_3} ...} \tag{6}$$

Parallel:

$$C_{EQ} = C_1 + C_2 + C_3 ... \tag{7}$$

Inductors

The ideal inductor stores energy in an **induced magnetic field**.

$$\phi = LI \tag{8}$$

Where:

- ϕ = induced magnetic flux
- L = inductance in Henrys (H)
- I = applied current (A)

In DC, an inductor is effectively a short circuit (i.e. a wire with no resistance). When the current changes, the induced field also changes. Thus,

$$v(t) = \frac{d\phi(t)}{dt} = L\frac{di(t)}{dt} \tag{9}$$

KEY TAKEAWAY: The rate of change in magnetic flux induces a voltage. Thus, alternating current (AC) induces a change in magnetic field and thus produces a voltage. Inductance is the tendency of an electrical conductor to oppose a change in the electric current flowing through it.

Energy storage in inductors is calculated by integrating the instantaneous power $P(t)$. Thus,

$$P(t) = v(t)i(t) = Li(t)\frac{di(t)}{dt} \tag{10}$$

Integrating the instanteous power:

$$W(t) = \frac{1}{2}Li^2(t) \tag{11}$$

Inductors can be combined in series and in parallel to yield a single equivalent inductance. Note: the behaviour of equivalent inductance is the same as resistors. Series:

$$L_{EQ} = L_1 + L_2 + L_3 ... \tag{12}$$

Parallel:

$$L_{EQ} = \frac{1}{\frac{1}{L_1} + \frac{1}{L_2} + \frac{1}{L_3} ...} \tag{13}$$

Other topics found:

- Solving RC Circuits & Forced responses & Transient analysis
- Approaches to solve circuits
- Class exercises

1.10.2 LEC02: Nodal & Mesh Analysis and Network Theorems

The Basics

These are the fundamental electrical basics:

- $V = IR$ (Ohm's Law)
- $P = VI = \frac{V^2}{R} = I^2R$
- Kirchhoff's current law (KCL): Sum of currents into a node = 0
- Kirchhoff's voltage law (KVL): Sum of voltages around a loop = 0
- Series and parallel circuits (voltage and current dividers)
- $R_{series} = R_1 + R_2 + R_3$; $R_{parallel} = \frac{1}{\frac{1}{R_1}+\frac{1}{R_2}+\frac{1}{R_3}}$
- Voltage Divider: $V_{out} = V_{in}\frac{R_x}{R_{total}}$ where V_{out} is the voltage you want; V_{in} is the source voltage; R_x is the resistor you will find V_{out}; and R_{total} is the total resistance
- Current Divider: $I_n = I_{in}\frac{R_{eq}}{R_n}$ where I_n is the current you want; I_{in} is the source current; R_n is the resistor in which the desired current flows through I_n; and R_{eq} is the equivalent resistance of the resistors

Node and Mesh Analysis

Note: For a network with n nodes, both methods will result in n independent equations, with n unknown variables.

- Nodal analysis: Set voltages at each node as the unknown variables, apply KCL. Note: Currents going into the node are positive, and currents going out of the node are negative. Use KCL when the source is a current source; typically.
- Mesh analysis: set the current through each branch as the unknown variables, apply KVL; Note: choose a direction for a loop and stick to that direction for all loops. Voltages going from negative to positive (e.g. Voltage Sources) are positive and voltages going from positive to negative (e.g. resistors) are impedances. Use KVL when the source is a voltage source; typically.

Procedure: Nodal (KCL)

The below steps for the method to use Nodal Analysis:

1. Label all circuit parameters - identify the unknown parameters (voltages and currents).
2. Identify all essential nodes.
3. Select a node as the reference node (ground node). Assign it a potential of 0 volts. All other voltages are measured with respect to the reference node.
4. Label the voltages at all other nodes.
5. Apply KCL at each node and express currents in terms of node voltages.
6. Solve the resulting equations for node voltages.
7. WHAT HAPPENS IF THERE ARE V AND I SOURCES? We may need to define a 'super-node' (this is where a voltage source connects two nodes; thus, like a node, Current in = Current out) See Figure 1

Procedure: Mesh (KVL)

The below steps for the method to use Mesh Analysis:

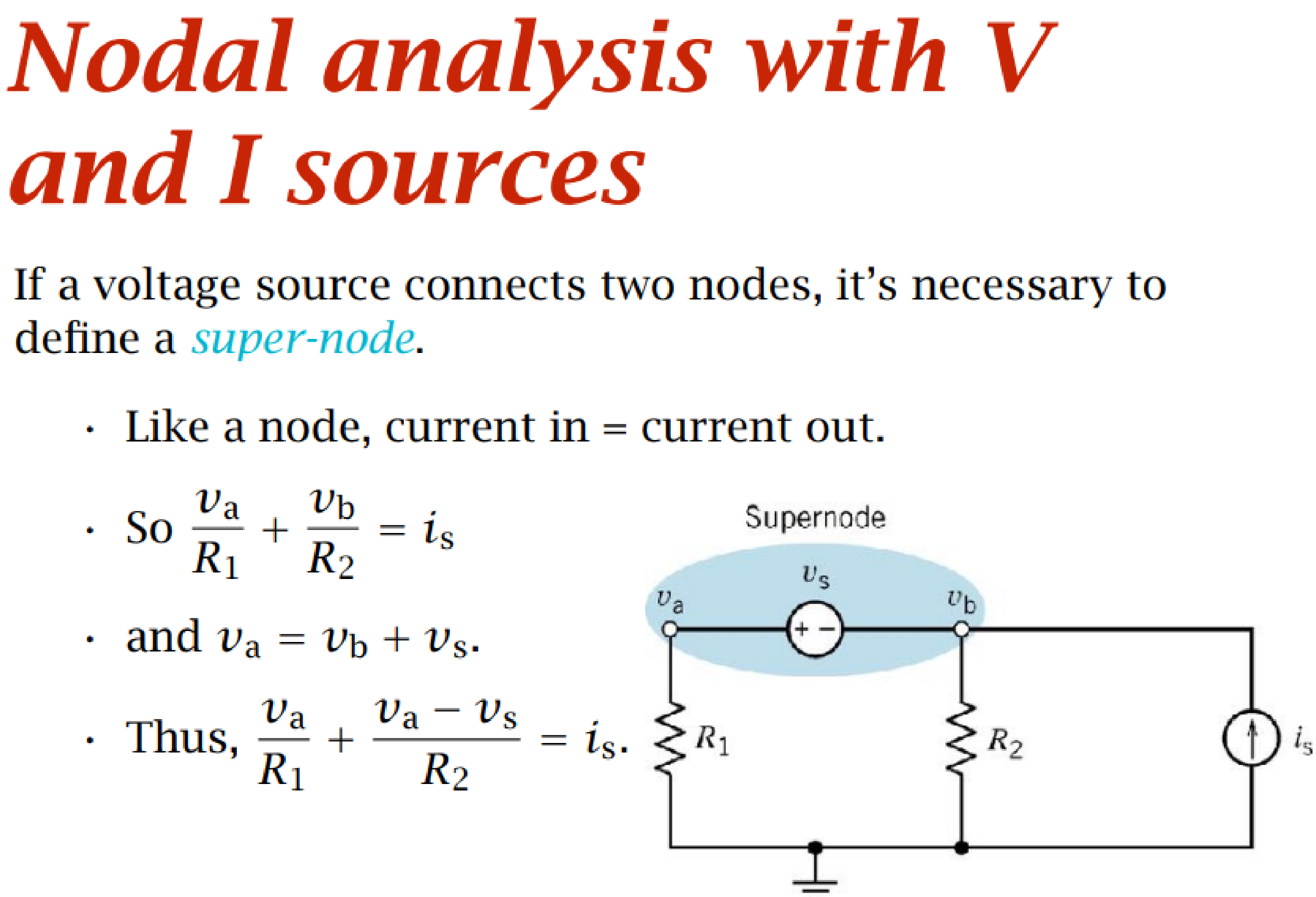


Figure 1: Snapshot - Super-Nodes in Circuit Analysis (Nodal)

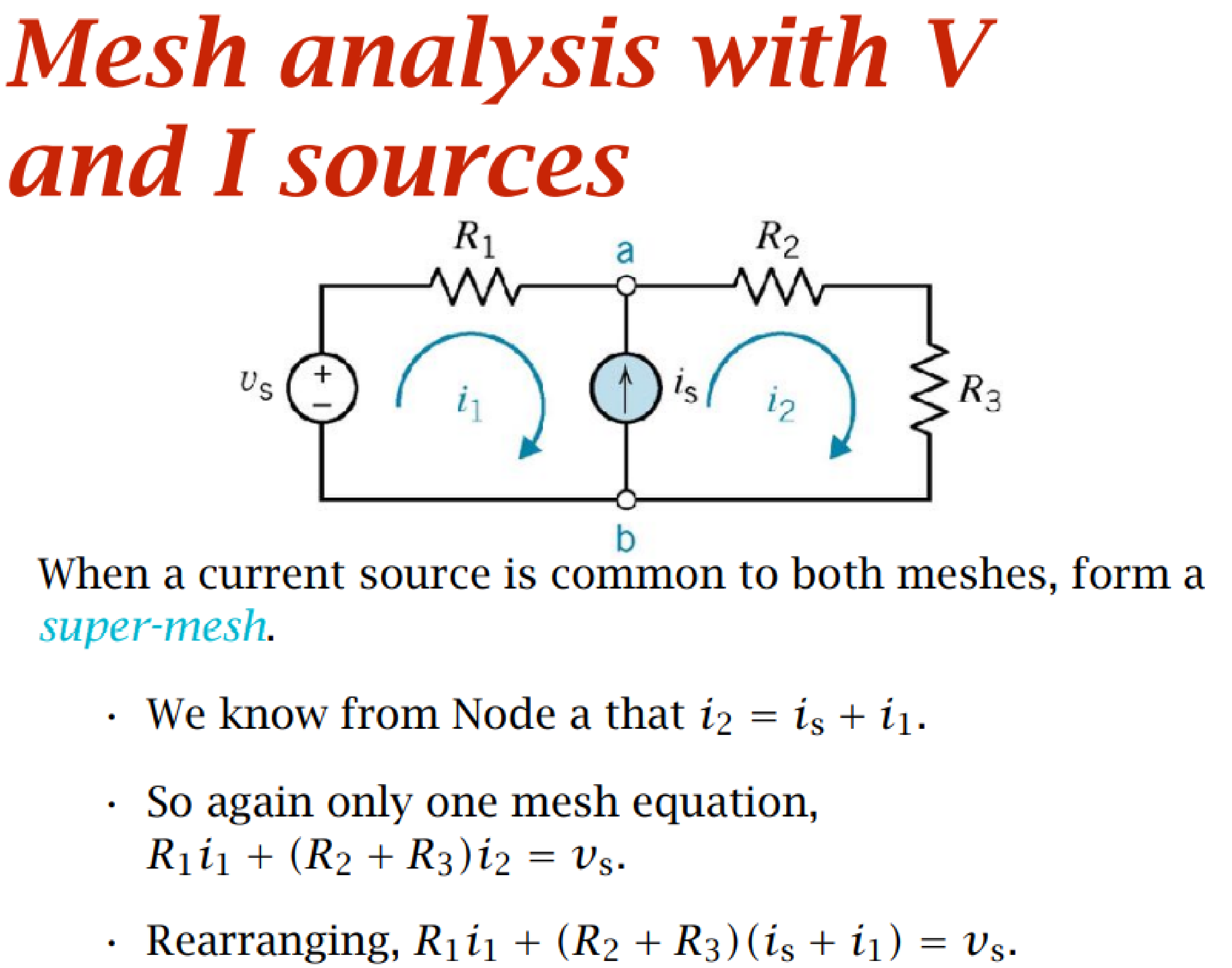
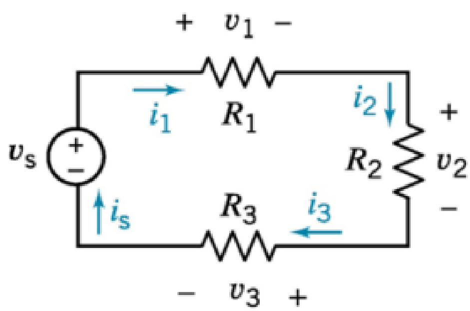


Figure 2: Snapshot - Super-Mesh in Circuit Analysis (Mesh)

1. Label all circuit parameters and identify unknown parameters (voltages and currents).
2. Identify all meshes of the circuit.
3. Assign mesh currents and label polarities.
4. Apply KVL at each mesh and express voltages in terms of the mesh currents.
5. Solve the resulting simultaneous equations for the mesh currents.
6. Now that the mesh currents are known, the voltages may be obtained from Ohm's law.
7. WHAT HAPPENS IF THERE ARE V AND I SOURCES? We may need to define a 'super-mesh' (this is where the current is found common to both meshes) See Figure 2

Kirchhoff-based solution strategy

How to obtain a solvable case with KCL and KVL?



KCL:

$$i_s - i_1 = 0$$
$$i_1 - i_2 = 0$$
$$i_2 - i_3 = 0$$
$$i_3 - i_s = 0$$

KVL:

$$v_s - v_1 - v_2 - v_3 = 0$$

Branch v-i:

$$v_1 = R_1 i_1$$
$$v_2 = R_2 i_2$$
$$v_3 = R_3 i_3$$

KCL gives

$$i_s = i_1 = i_2 = i_3.$$

Using Ohm's law gives

$$i_s = \frac{v_1}{R_1} = \frac{v_2}{R_2} = \frac{v_3}{R_3}.$$

KVL gives

$$v_1 = v_s - v_2 - v_3$$
$$\Rightarrow i_s = \frac{1}{R_1}(v_s - R_2 i_2 - R_3 i_3)$$
$$\Leftrightarrow i_s = \frac{v_s}{R_1 + R_2 + R_3}$$

Superposition

Applies to all linear systems:

- allows each source in a circuit can be treated independently
- and then, complete response of a circuit is calculated by adding the impact of each independent source.
- One active source. Set all other sources to zero.
- Replace current source with an open circuit (0 amps flowing)
- Replace voltage source with a short circuit (0 volts across source)
- calculate the voltage/current at point of interest
- repeat for each source in the circuits
- add the voltage/current components from each source at the point of interest
- REMEMBER TO CONSISTENTLY FOLLOW THE SIGN CONVENTION!

Linear Circuit Theorems

These below theorems are used in practical network calcalations... i.e in ELEC4300 and ELEC4302 for fault current levels; for the Positive, Negative and Zero Sequence equations.

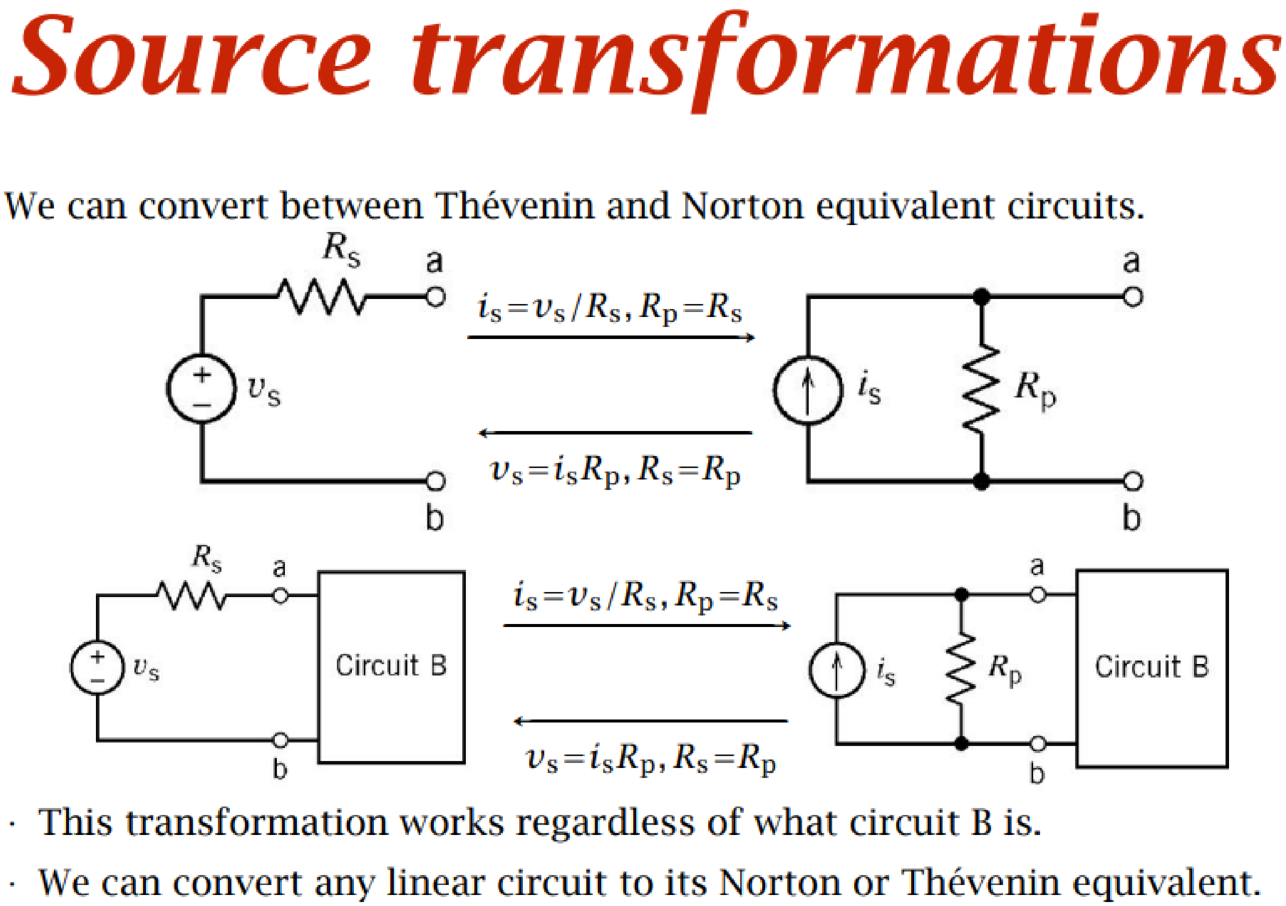


Figure 3: Snapshot - Thevenin and Norton Source Transformation

- **Thevenin's theorem** states that any resistive circuit can be replaced by a voltage source and a series resistance; and can be extended to circuits with L and C. It's characterised by: open-circuit voltage v_{oc}, short-circuit current i_{sc} and series resistance R_t; where $v_{oc} = v_s$ [voltage open circuit is now the thevenin voltage source], $R_t = R_s$ [equivalent resistance is now the thevenin resistance], and $i_{sc}\frac{v_s}{R_s}$ [thevenin current calculated once you have gotten the other two variables].
- **Norton transformation** means that any circuit may be modelled by a current source with a parallel resistance; It's characterised by: short-circuit current i_{sc}, open-circuit voltage v_{oc} and parallel resistance R_p; where $i_{sc} = i_s$ [current short circuit is now the thevenin current source], $v_{oc} = i_s R_p$ [open-circuit voltage voltage is calculated once you have gotten the other two variables].

Thevenin and Norton can be transformed to each other (Figure 3):

Other topics found:

- Definitions: Ideal Sources (Voltage, Current), Independent vs Dependent Sources
- Approaches to solve circuits
- Maximum power transfer
- Class exercises

1.10.3 LEC03: Operational Amplifiers (Op Amps)

Other topics found:

- Solving op amps
- Inverting, summing, non-inverting amplifier
- Voltage follower
- Differential amplifier
- Virtual earth
- Amplifier limitations
- Class exercises
- MUCH MORE!!!

1.10.4 LEC05: Integrators and Differentiators

Other topics found:

- Control systems engineering - Integrators and Differentiators
- etc

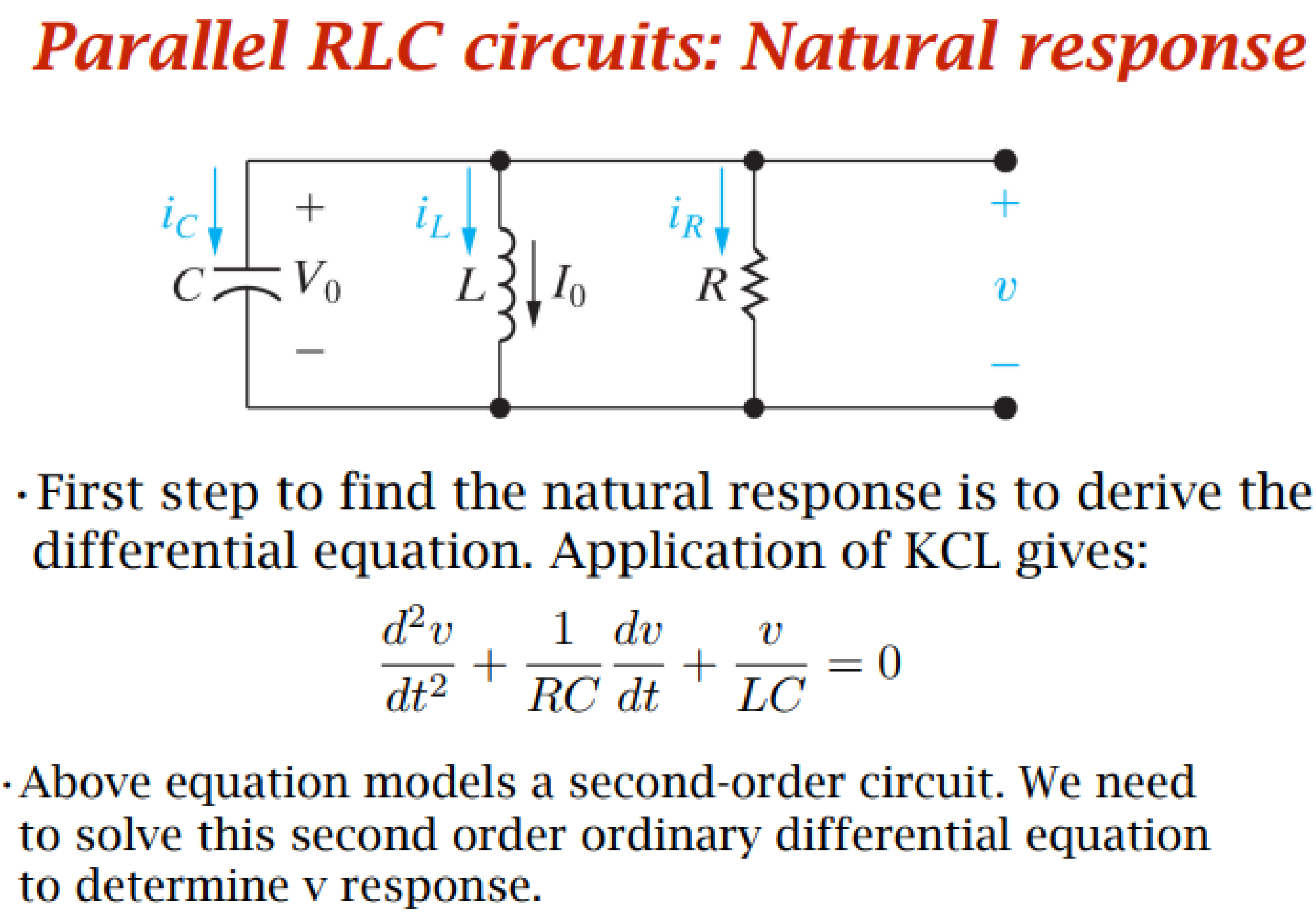


Figure 4: Snapshot - Parallel RLC Circuit

1.10.5 LEC06: RLC Circuits

Parallel RLC

RLCs means that we have to solve second order differential equations (ODEs). See Figure 4

Assume: $v = Ae^{st}$, thus using Laplace transforms to solve the differential equation: $s^2 + \frac{s}{RC} + \frac{1}{LC}$. Solve using the quadratic formula.

Thus, the natural response of parallel RLC:

$$v = A_1 e^{s_1 t} + A_2 e^{s_2 t} \tag{14}$$

$$s_1 = -\frac{1}{2RC} + \sqrt{(\frac{1}{2RC})^2 - \frac{1}{LC}} \tag{15}$$

$$s_2 = -\frac{1}{2RC} - \sqrt{(\frac{1}{2RC})^2 - \frac{1}{LC}} \tag{16}$$

We define damping coefficient and undamped natural frequency as:

$$\alpha = \frac{1}{2RC} \tag{17}$$

$$\omega = \frac{1}{\sqrt{LC}} \tag{18}$$

Determining the damping, we need to find the roots of the characteristic equation:

$$s_1 = -\alpha + \sqrt{\alpha^2 - \omega_0^2} \tag{19}$$

$$s_2 = -\alpha - \sqrt{\alpha^2 - \omega_0^2} \tag{20}$$

Thus, by defining $\zeta = \frac{\alpha}{\omega_0}$ (damping ratio), there are three cases:

1. Overdamped case ($\zeta > 1$): $s_1 > s_2$ are both real.
2. Critically damped case ($\zeta = 1$): $s_1 = s_2 = -\alpha = -\omega_0$.
3. Underdamped case ($\zeta < 1$): s_1 and s_2 are complex.

Over-damped case $\alpha^2 > \omega_0^2$:

$$v(t) = A_1 e^{s_1 t} + A_2 e^{s_2 t} \tag{21}$$

A_1 and A_2 are determined by solving the following:

$$v(0^+) = A_1 + A_2 \tag{22}$$

$$\frac{dv(0^+)}{dt} = \frac{i_C(0^+)}{C} = s_1 A_1 + s_2 A_2 \tag{23}$$

Critically damped case $\alpha^2 = \omega_0^2$:

$$v(t) = D_1 t e^{-\alpha t} + D_2 t e^{-\alpha t} \tag{24}$$

D_1 and D_2 are determined by solving the following:

$$v(0^+) = D_2 \frac{dv(0^+)}{dt} = \frac{i_C(0^+)}{C} = D_1 - \alpha D_2 \tag{25}$$

Under-damped case $\alpha^2 < \omega_0^2$:

$$v(t) = B_1 e^{-\alpha t} cos(\omega_d t) + B_2 e^{-\alpha t} sin(\omega_d t) \tag{26}$$

where $\omega_d = \sqrt{\omega_0^2 - \alpha^2}$ denotes damped natural frequency. B_1 and B_2 are determined by solving the following:

$$v(0^+) = B_1 \tag{27}$$

$$\frac{dv(0^+)}{dt} = \frac{i_C(0^+)}{C} = -\alpha_1 B_1 + \omega_d B_2 \tag{28}$$

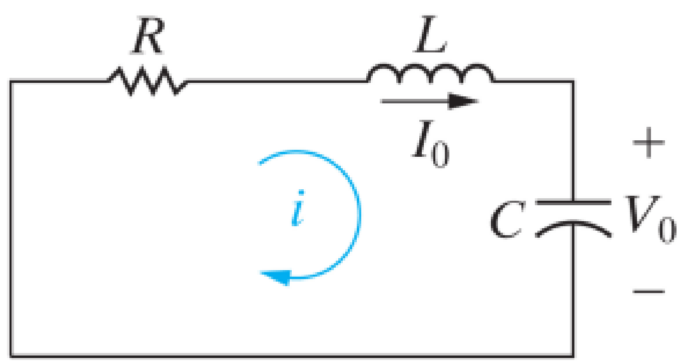
Series RLC

Thus, the resulting characteristic equation is $s^2 + \frac{R}{L}s + \frac{1}{LC} = 0$. The roots are:

$$s_{1,2} = -\frac{R}{2L} \pm \sqrt{(\frac{R}{2L})^2 - \frac{1}{LC}} \tag{29}$$

$$s_{1,2} = -\alpha \pm \sqrt{\alpha^2 - \omega_0^2} \tag{30}$$

Series RLC circuit: Natural response



The following differential equation needs to be solved:

$$\frac{d^2 i}{dt^2} + \frac{R}{L}\frac{di}{dt} + \frac{i}{LC} = 0$$

Figure 5: Snapshot - Series RLC Circuit

We define damping coefficient and undamped natural frequency as (for Series RLC):

$$\alpha = \frac{R}{2L} \tag{31}$$

$$\omega = \frac{1}{\sqrt{LC}} \tag{32}$$

Thus, there are three possible solutions:

1. $i(t) = A_1 e^{s_1 t} + A_2 e^{s_2 t}$ (over damped)
2. $i(t) = B_1 e^{-\alpha t} cos\omega_d t + B_2 e^{-\alpha t} sin\omega_d t$ (under damped)
3. $i(t) = D_1 t e^{-\alpha t} + D_2 t e^{-\alpha t}$ (critically damped)

Other topics found:

- Class exercises

1.10.6 LEC07: Phasor Analysis

PHASORS
Up to phasors

1.11 ELEC3100 - Advanced Electrical Theory

1.12 ELEC3300 - Motors & Electrical Energy

1.13 ELEC3400 - Amplifiers & Electronics

1.14 ELEC4300 - Power System Analysis

1.15 ELEC4302 - Power System Protection

1.16 ELEC4620 - Signal Processing

1.17 ELEC4630 - Image Processing

1.18 ENGG4800 - Project Management

1.19 METR4201 - Control System Analysis