Circuit Analysis with Devices: Theory and Practice

Chapter 14

Inductive Transients

Robbins and Miller

Circuit Analysis with Devices: Theory and Practice

Transients

- Voltages and currents during a transitional interval
  - Referred to as transient behavior of the circuit
- Capacitive circuit
  - Voltages and currents undergo transitional phase
  - Capacitor charges and discharges

Robbins and Miller

Transients

- Inductive circuit
  - Transitional phase occurs as the magnetic field builds and collapses

Circuit Analysis with Devices: Theory and Practice
THOMSON DELMAR LEARNING

Voltage Across an Inductor

- Induced voltage across an inductor is proportional to rate of change of current

$$v_L = L\frac{\Delta i}{\Delta t}$$

Voltage Across an Inductor

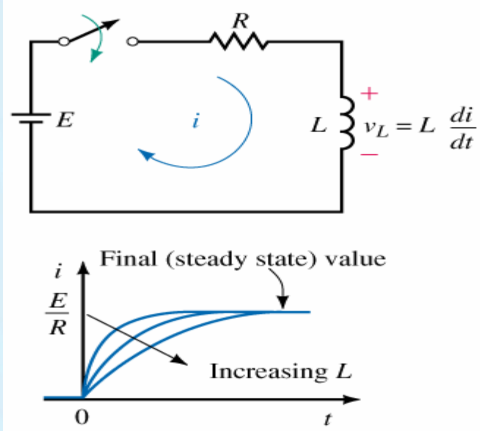
- If inductor current could change instantaneously
  - Its rate of change would be infinite
  - Would cause infinite voltage

Circuit Analysis with Devices:
Theory and Practice
THOMSON
DELMAR LEARNING

Continuity of Current

- Infinite voltage is not possible
  - Inductor current cannot change instantaneously
  - It cannot jump from one value to another, but must be continuous at all times
- Use observation when analyzing circuits

Circuit and Waveforms for Current Build-up



(b) Adding inductance causes a transient to appear. *R* is held constant here

Inductor Voltage

- Immediately after closing the switch on an *RL* circuit
  - Current is zero
  - Voltage across the resistor is zero

Circuit Analysis with Devices: Theory and Practice

THOMSON DELMAR LEARNING

Inductor Voltage

- Voltage across resistor is zero
  - Voltage across inductor is source voltage
- Inductor voltage will then exponentially decay to zero

9

Robbins and Miller

Circuit Analysis with Devices: Theory and Practice

THOMSON DELMAR LEARNING

Open-Circuit Equivalent

- After switch is closed
  - Inductor has voltage across it and no current through it
- Inductor with zero initial current looks like an open circuit at instant of switching

10

Robbins and Miller

Circuit Analysis with Devices: Theory and Practice

THOMSON DELMAR LEARNING

Open-Circuit Equivalent

- This statement will later be applied to include inductors with nonzero initial currents

Circuit Analysis with Devices: Theory and Practice

THOMSON DELMAR LEARNING

Initial Condition Circuits

- Voltages and currents in circuits immediately after switching
  - Determined from the open-circuit equivalent

Robbins and Miller

Copyright © 2007 Thomson Delmar Learning

Initial Condition Circuits

- By replacing inductors with opens
  - We get initial condition circuit
- Initial condition networks
  - Yield voltages and currents only at switching

Circuit Analysis with Devices:
Theory and Practice
THOMSON DELMAR LEARNING

Circuit Current

- Current in an *RL* circuit is an exponentially increasing function of time
- Current begins at zero and rises to a maximum value

$$i(t) = \frac{E}{R}\left(1 - e^{-Rt/L}\right)$$

Copyright © 2007 Thomson Delmar Learning

Circuit Voltages

- Voltage across resistor is given by *i•R*
- Voltage across resistor is an increasing function as well (because the inductor current is passing through it)

$$v_R = E\left(1 - e^{-\frac{Rt}{L}}\right)$$

15

Circuit Analysis with Devices:
Theory and Practice
THOMSON DELMAR LEARNING

Circuit Voltages

- By KVL,voltage across inductor is

$$E - v_R$$

- Voltage across inductor is an exponentially decreasing function of time

$$v_L = E \bullet e^{-Rt/L}$$

16

Robbins and Miller
Copyright © 2007 Thomson Delmar Learning

Time Constant

- $\tau = L/R$
- Units are seconds
- Equations may now be written as

$$i = \frac{E}{R}\left(1 - e^{-t/\tau}\right)$$
$$v_L = E \cdot e^{-t/\tau}$$
$$v_R = E\left(1 - e^{-t/\tau}\right)$$

Circuit Analysis with Devices: Theory and Practice
THOMSON DELMAR LEARNING

Time Constant

- The larger the inductance
  - The longer the transient
- The larger the resistance
  - The shorter the transient

Circuit Analysis with Devices: Theory and Practice

THOMSON DELMAR LEARNING

Time Constant

- As *R* increases
  - Circuit looks more and more resistive
  - If *R* is much greater than *L*
  - Circuit looks purely resistive

19

Robbins and Miller

Circuit Analysis with Devices: Theory and Practice

THOMSON DELMAR LEARNING

Interrupting Current in an Inductive Circuit

- When switch opens in an *RL* circuit
  - Energy is released in a short time
  - This may create a large voltage
  - Induced voltage is called an inductive kick
- Opening of inductive circuit may cause voltage spikes of thousands of volts

20

Robbins and Miller

Interrupting a Circuit

- Switch flashovers are generally undesirable
  - They can be controlled with proper engineering design
- These large voltages can be useful
  - Such as in automotive ignition systems

Circuit Analysis with Devices: Theory and Practice
THOMSON DELMAR LEARNING

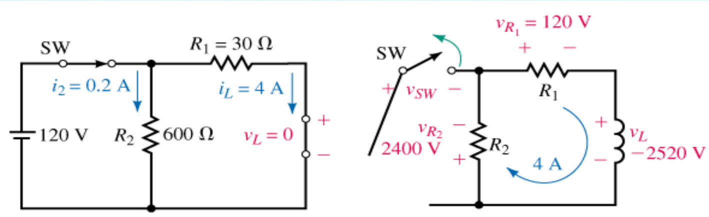
Interrupting a Circuit

- It is not possible to completely analyze such a circuit
  - Resistance across the arc changes as the switch opens

Robbins and Miller
Copyright © 2007 Thomson Delmar Learning

Interrupting a Circuit

- In circuit shown, we see changes after switch opens:



(a) Circuit just before the switch is opened

(b) Circuit just after SW is opened. Since coil voltage polarity is opposite to that shown, v_L is negative

23

Circuit Analysis with Devices:
Theory and Practice

THOMSON
DELMAR LEARNING

Inductor Equivalent at Switching

- Current through an inductor
  - Same after switching as before switching
- An inductance with an initial current
  - Looks like a current source at instant of switching
- Its value is value of current at switching

24

Robbins and Miller
Copyright © 2007 Thomson Delmar Learning

De-energizing Transients

- If an inductor has an initial current I_0, equation for current becomes

$$i = I_0 e^{-t/\tau'}$$

- $\tau' = L/R$. R equals total resistance in discharge path

Circuit Analysis with Devices: Theory and Practice
THOMSON DELMAR LEARNING

De-energizing Transients

- Voltage across inductor goes to zero as circuit de-energizes

$$v_L = V_0 e^{-t/\tau'}$$

where

$$V_0 = -I_0 R_T$$

De-energizing Circuits

- Voltage across any resistor is product of current and that resistor

$$v_R = R \bullet I_0 e^{-t/\tau'}$$

- Voltage across each of resistors goes to zero

Circuit Analysis with Devices: Theory and Practice
THOMSON DELMAR LEARNING

More Complex Circuits

- For complex circuits
  - Like capacitive circuits
    - Necessary to determine Thévenin equivalent circuit using inductor as the load

Robbins and Miller
Copyright © 2007 Thomson Delmar Learning

More Complex Circuits

- R_{Th} is used to determine time constant
- $\tau = L/R_{Th}$
- E_{Th} is used as source voltage