Chapter 2: Goals

- Develop techniques for easily determining output voltage of an arbitrary converter circuit
- Derive the principles of *inductor volt-second balance* and *capacitor charge (amp-second) balance*
- Introduce the key *small ripple approximation*
- Develop simple methods for selecting filter element values
- Illustrate via examples

Buck Converter Review

Pulse-Width Modulation (PWM)

$T_s \rightarrow$ switching period

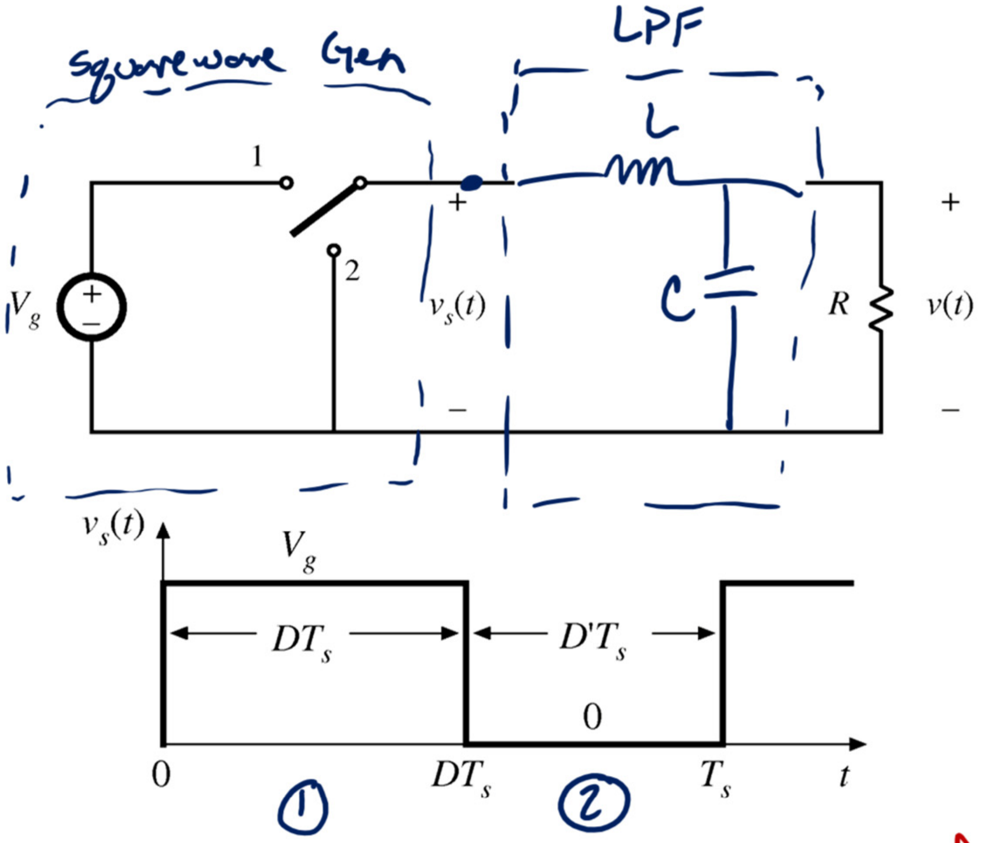
$f_s = \frac{1}{T_s} \rightarrow$ switching frequency

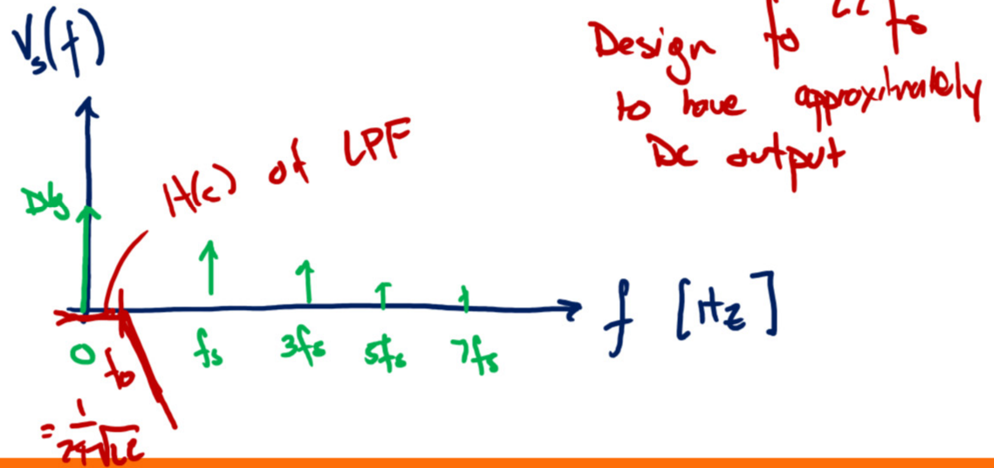
$0 \le D \le 1 \rightarrow$ Duty Cycle

$D' = 1-D$

$M = \frac{V}{V_g}$ = "Conversion Ratio"

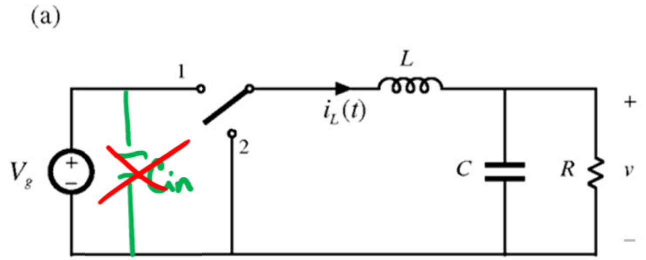
$$\langle v_s \rangle \Big|_{T_s} = \frac{1}{T_s}\int_0^{T_s} v_s(t)\,dt = \frac{1}{T_s} D V_g T_s = DV_g$$

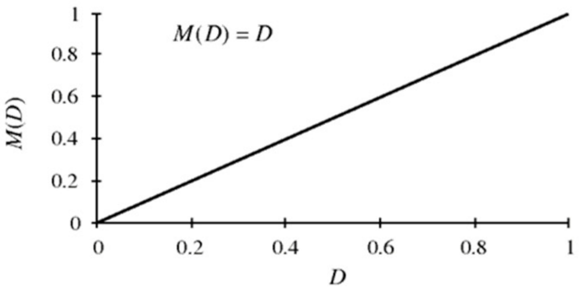




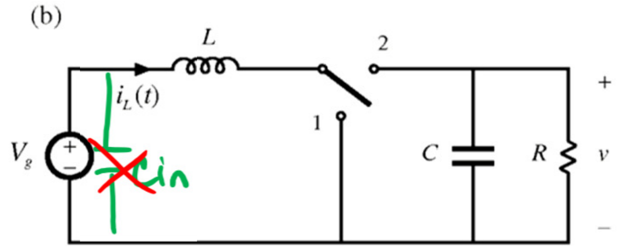
Three Basic DC-DC PWM Converters

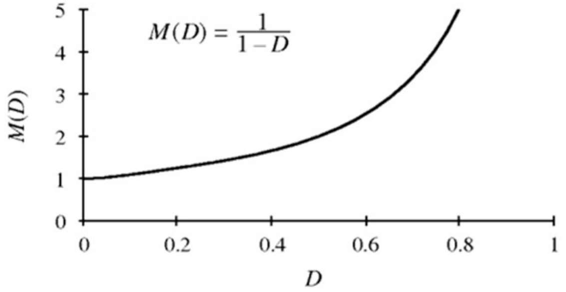
Buck



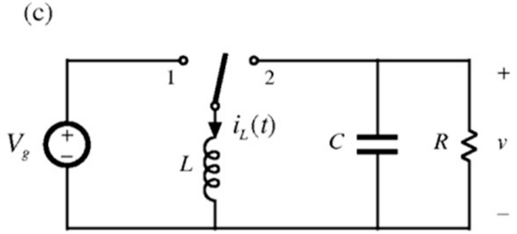


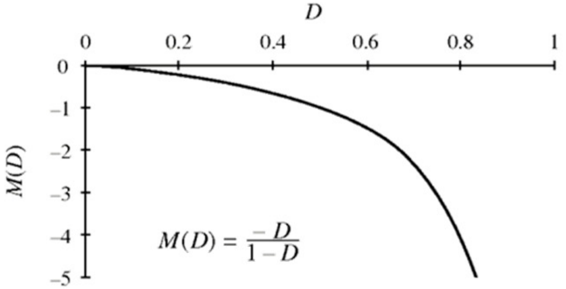
Boost





Buck-boost





Fundamentals of Power Electronics *Chapter 2: Principles of steady-state converter analysis*

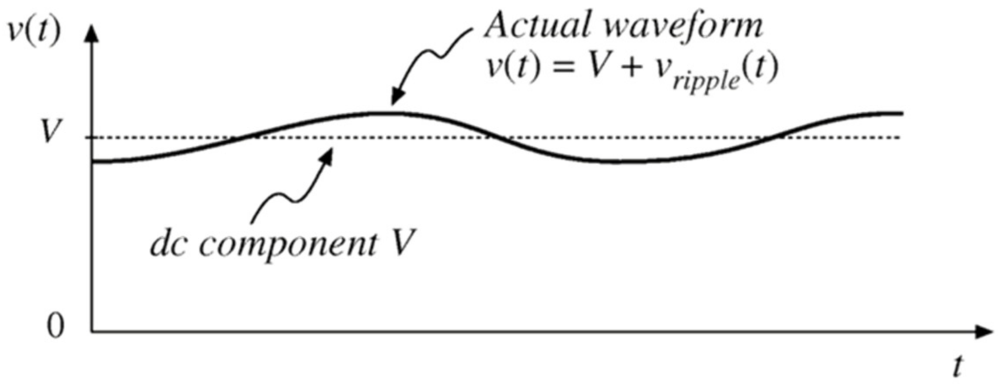
The Small Ripple Approximation

In a well-designed converter

$v_{ripple}(t) \ll V$

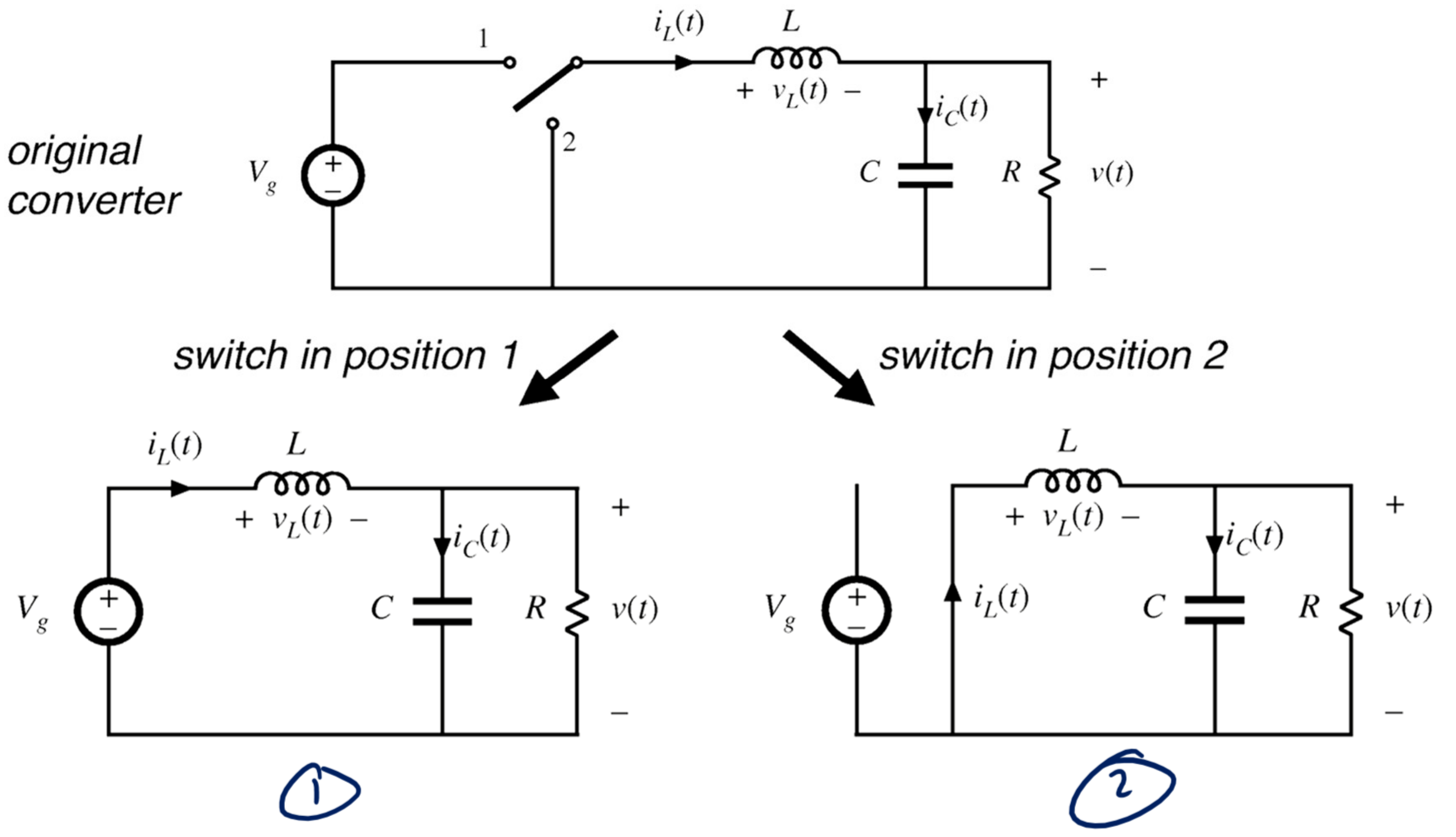
then we can approximate

$v(t) \approx V$



Usually we can apply SRA to most/all L/C elements in PWM converters

Buck Switching Intervals: Inductor Current



Fundamentals of Power Electronics *Chapter 2: Principles of steady-state converter analysis*

Subinterval 1

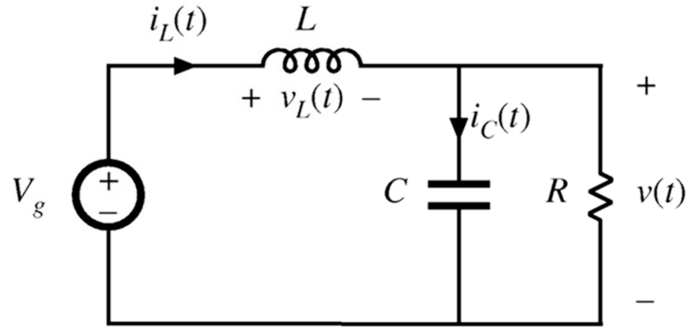
$$v_L(t) = L \frac{di_L}{dt}$$

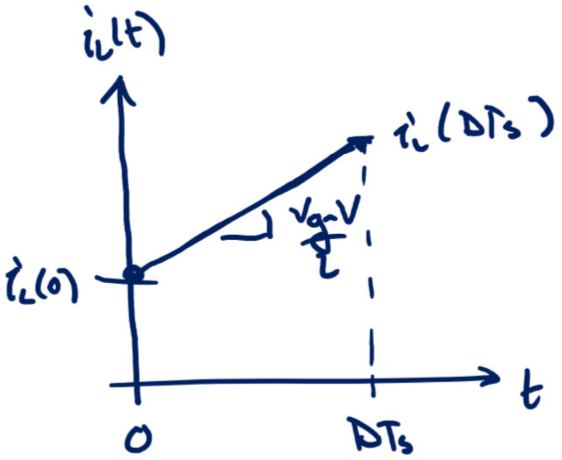
$$V_g - v(t) = L \frac{di_L}{dt}$$

↓ Apply SRA. on $v(t)$

$$V_g - V = L \frac{di_L}{dt}$$

$$\frac{V_g - V}{L} = \frac{di_L}{dt}$$





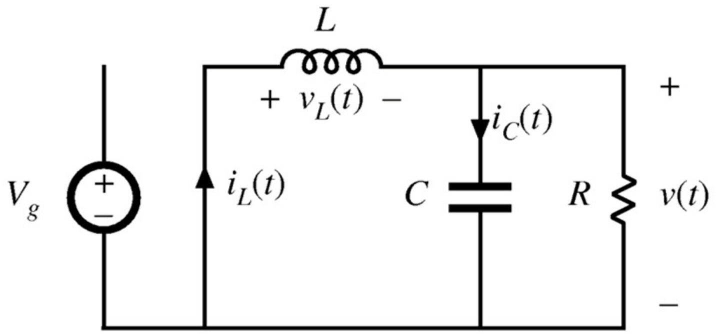
Subinterval 2

$$v_L = L \frac{di_L}{dt}$$

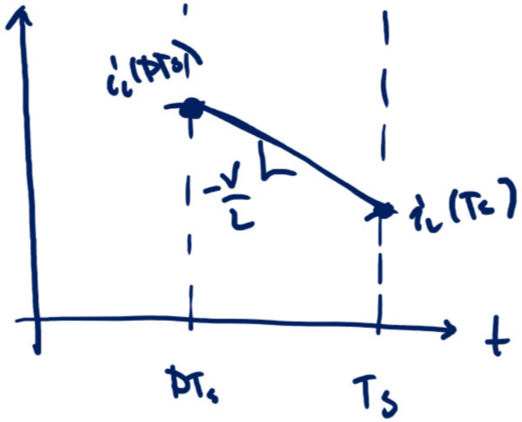
$$\emptyset - v(t) = L \frac{di_L}{dt}$$

↓ Apply SRA on $v(t)$

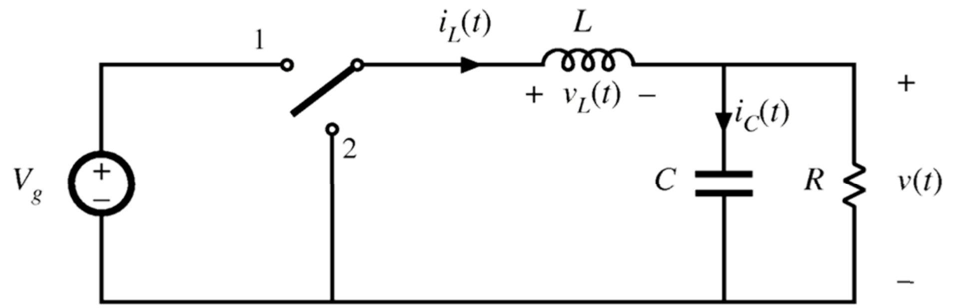
$$0 - V = L \frac{di_L}{dt}$$

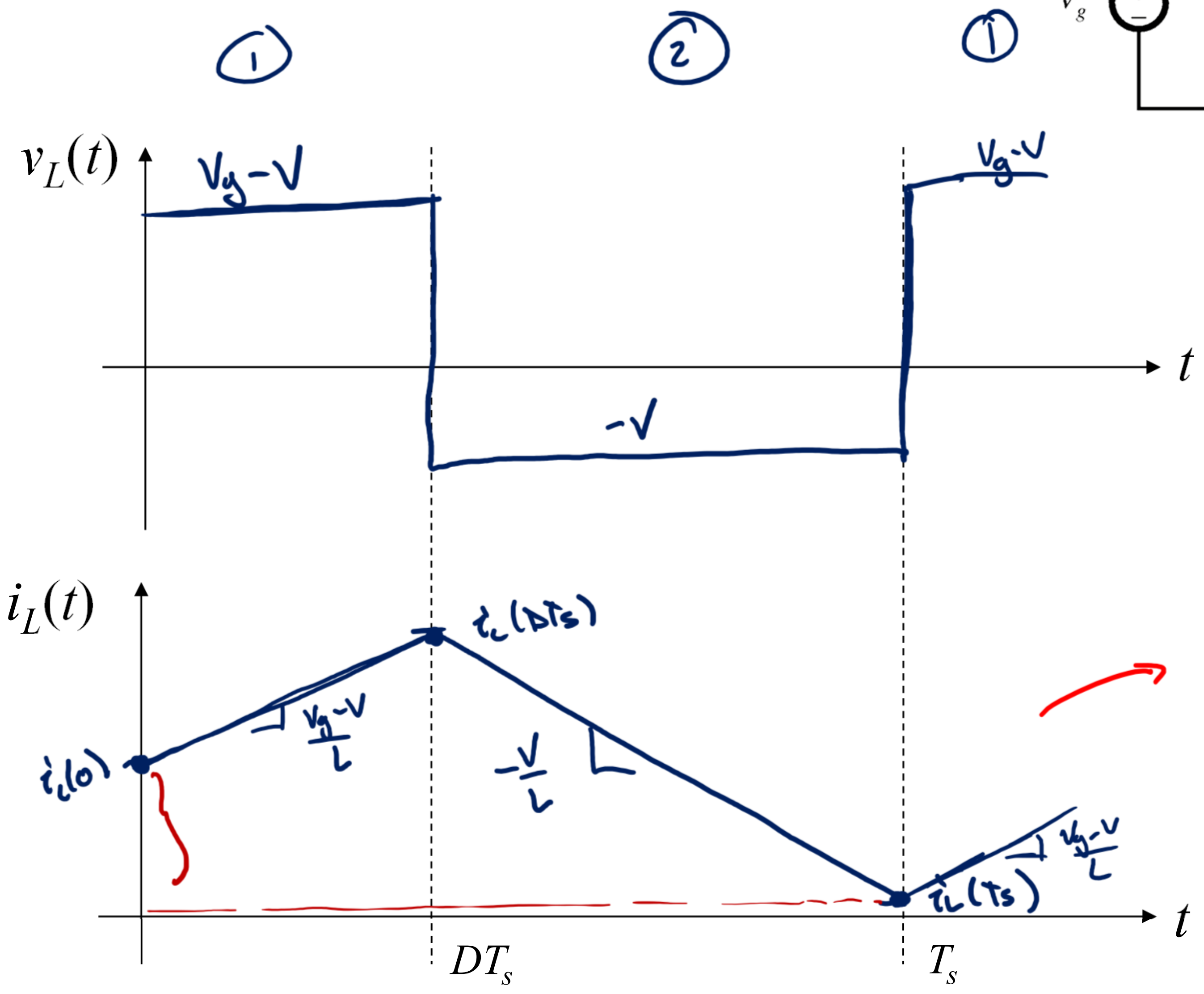


$$\frac{di_L}{dt} = \frac{-V}{L}$$



Current Waveform





Inductor

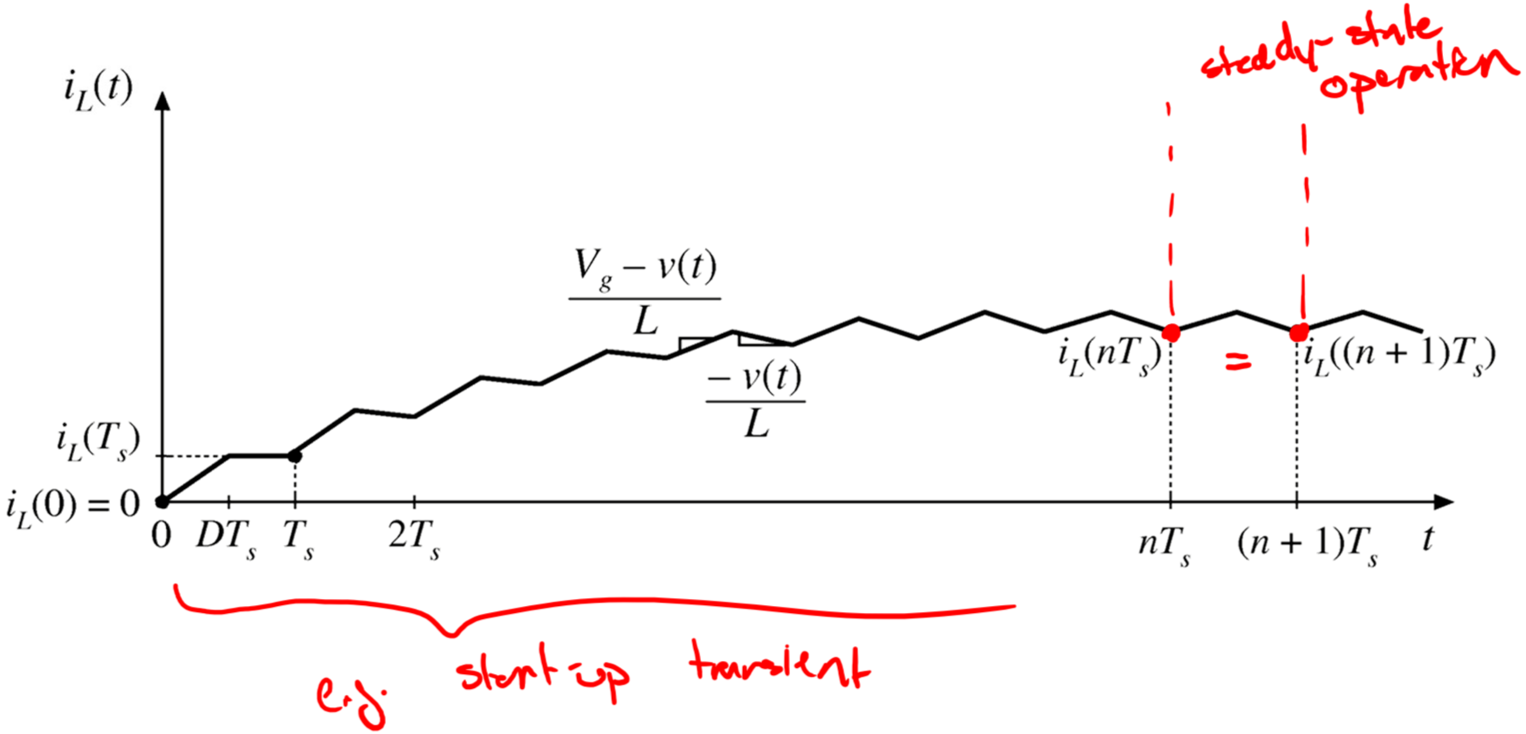
$$v_L = L \frac{di_L}{dt}$$

$i_L(0) \neq i_L(T_s)$

we're in a transient

i.e. not in steady-state

Transient vs. Steady-State Operation



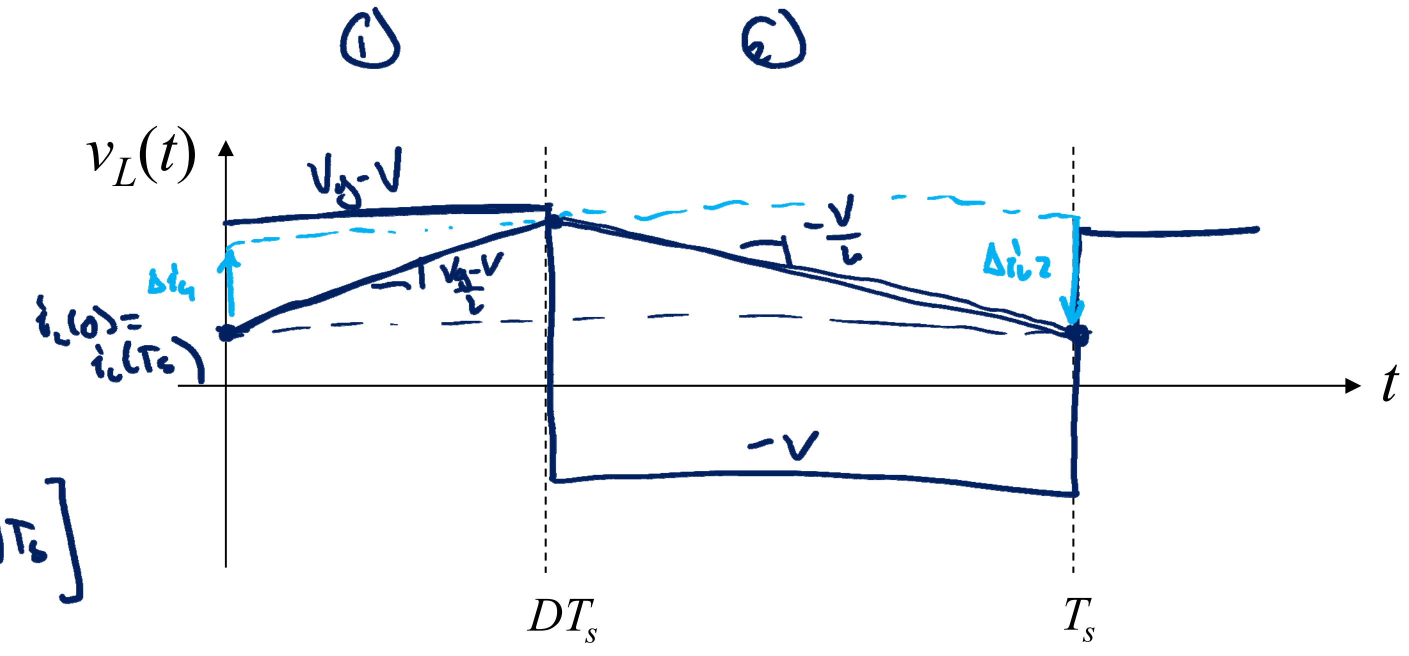
Volt-Second Balance

In steady-state

$i_L(0) = i_L(T_s) = i_L(kT_s)$

For this to be true:

$\Delta i_{L1} + \Delta i_{L2} = \phi$



$$\frac{V_g - V}{L} DT_s = \Delta i_{L1} = -\Delta i_{L2} = -\left[\frac{-V}{L}(1-D)T_s\right]$$

$$\frac{V_g - V}{L} DT_s - \frac{V}{L}(1-D)T_s = \phi$$

$$(V_g - V)D - V(1-D) = \phi$$

$$V_g(D) - V(D + 1 - D) = \phi$$

$$V_g(D) - V = \phi$$

$$V = DV_g \quad , \quad \frac{V}{V_g} = M = D$$

Derivation of Volt-second Balance

$$\int_0^{T_s} v_L(t)\,dt = \int_0^{T_s} L \frac{di_L}{dt}\,dt$$

$$\frac{1}{L}\int_0^{T_s} v_L(t)\,dt = \int_0^{T_s} \frac{di_L}{dt}\,dt = i_L(T_s) - i_L(0)$$

↳ in steady-state, $= \phi$

$$\frac{L}{T_s}\left(\frac{1}{L}\int_0^{T_s} v_L(t)\,dt\right) = (\phi)\frac{L}{T_s}$$

$$\frac{1}{T_s}\int_0^{T_s} v_L(t)\,dt = \phi \rightarrow \boxed{\langle v_L \rangle\big|_{T_s} = \phi}$$

in steady-state