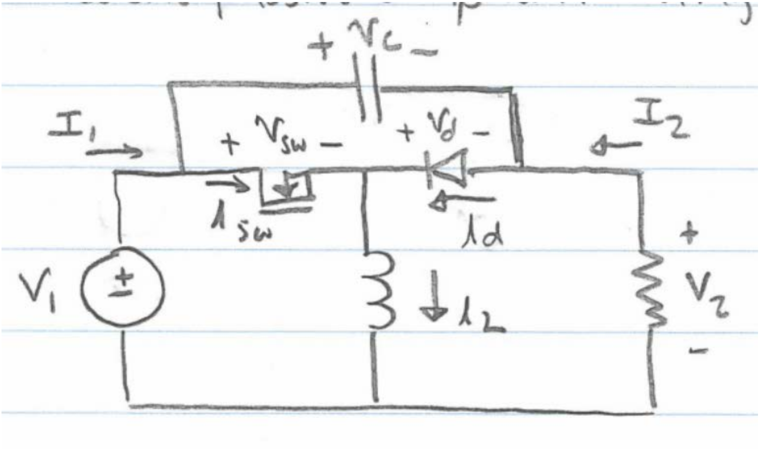
6.622 Power Electronics *Prof. David Perreault*

Lecture 7 — DC/DC Lecture 3

1 Converters

Consider device and passive component ratings of converters:

Indirect:



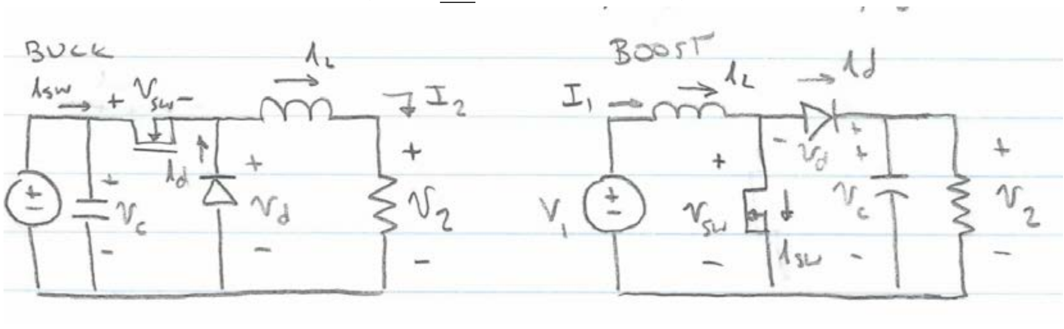
For now, assume L, C <u>big</u>

$i_L \approx I_L, v_c \approx V_c$

$$I_L = |I_1| + |I_2|$$
$$V_c = |V_1| + |V_2|$$

So we have $$\boxed{\begin{aligned} v_{sw,max} = v_{d,max} = v_c = |V_1| + |V_2| \\ i_{sw,max} = i_{d,max} = I_L = |I_1| + |I_2| \end{aligned}}$$

Let's look at direct converters (L, C: <u>big</u>: $i_L \approx I_L, v_c \approx V_c$)



$$v_{sw,max} = v_{d,max} = V_c = V_1 \qquad v_{sw,max} = v_{d,max} = V_c = V_2$$
$$i_{sw,max} = i_{d,max} = i_L = I_2 \qquad i_{sw,max} = i_{d,max} = i_L = I_1$$

For the direct converter types $$\boxed{\begin{aligned} v_{sw,max} = v_{d,max} = v_c = \max|V_1| + |V_2| \\ i_{sw,max} = i_{d,max} = I_L = \max|I_1| + |I_2| \end{aligned}}$$

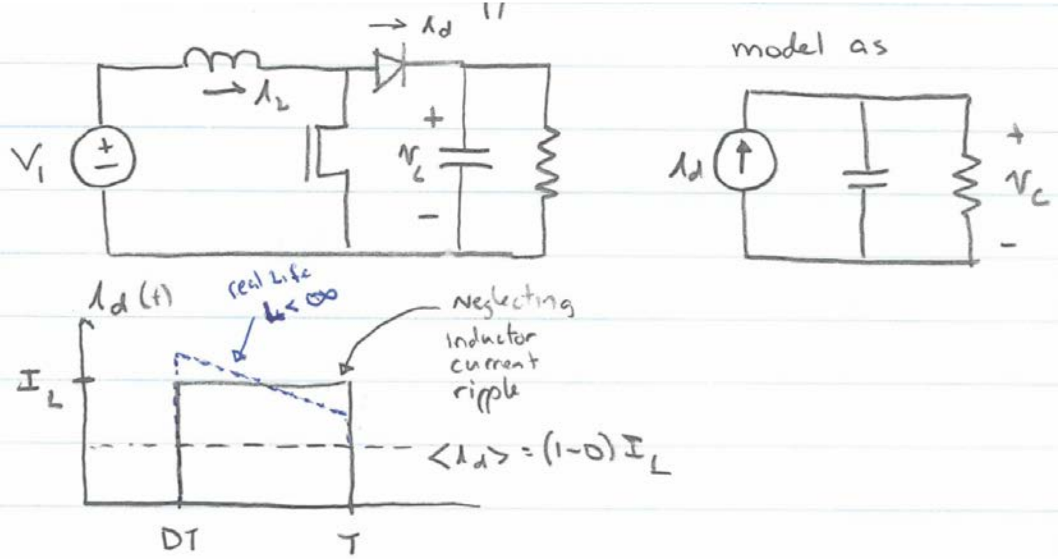
So based on device and passive component stresses, we would choose a direct converter over an indirect converter whenever possible!

In practice, component election does depend on ripple in many classes. Let's see how to approximately calculate ripple effects.

To calculate capacitor voltage ripple, we:

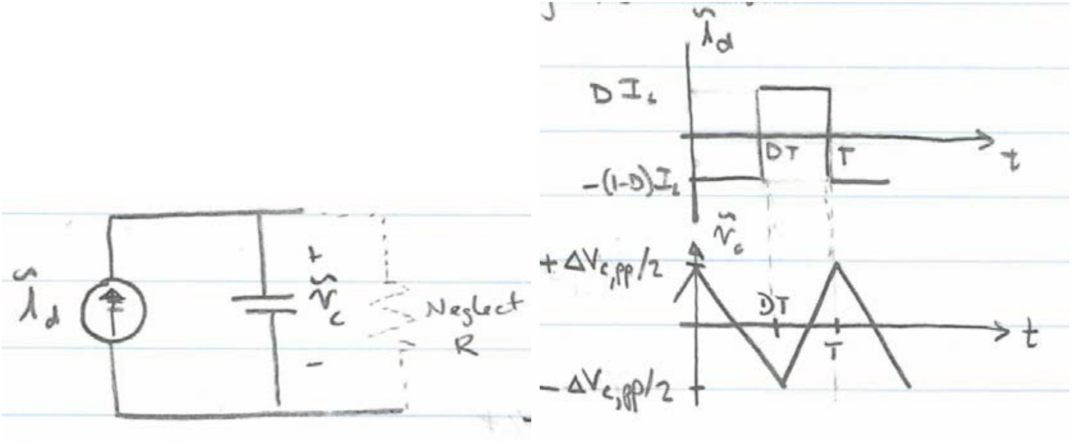
1. Neglect ripple in inductor (assume $L \approx \inf$ so $\Delta i_{2,pp} \approx 0$)
2. assume all current voltage ripple goes into capacitor
3. calculate voltage ripple
4. verify assumption afterward

Ex: Boost converter ripple



So we model the system assuming all ripple current component ($\tilde{i}_d$) goes into the capacitor, and the old dc component $< i_d >$ goes into the resistor. For this to be true, $2\pi f_{sw} >> \frac{1}{RC}$

Under this assumption, a "ripple only" model is:



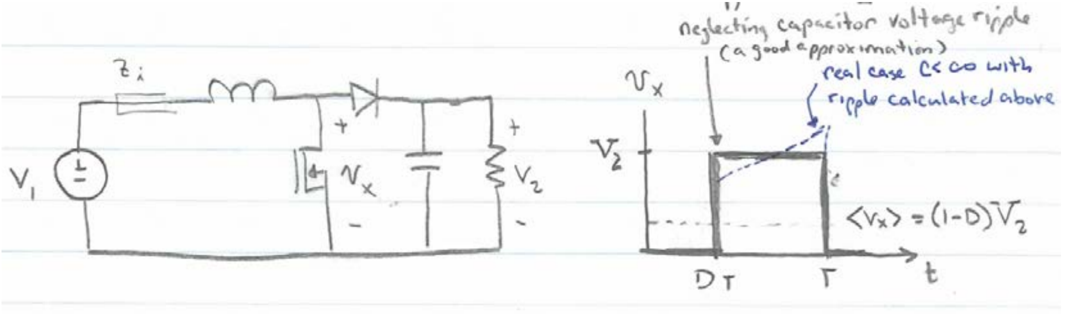
- ripple in v_c is triangular
- the average value of a Δ wave is half-way between its peaks, so we get ripple between $\pm\delta\frac{v_{c,pp}}{2}$

$$i = c\frac{dv_c}{dt} \rightarrow \Delta v_c = \frac{1}{c}\int i_c dt$$

$$\boxed{\Delta v_{c,pp} = \frac{D(1-D)I_L T}{C}}$$ where $I_L = I_1$

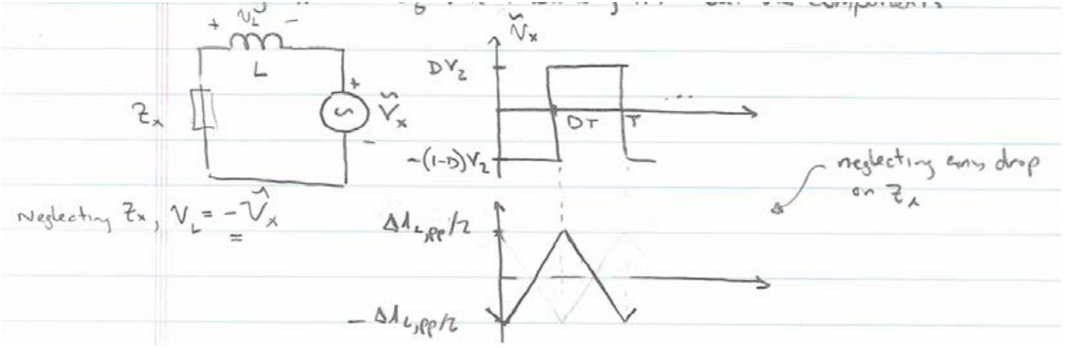
So to limit ripple to be low a specified value $$\boxed{C \geq \frac{D(1-D)I_1 T}{\Delta v_{c,pp}}}$$

Similar calculations can be made for current ripple in i_L.



The flat black line says: neglecting capacitor voltage ripple (a good approximation)
Blue line says: real case (is ∞ with ripple calculated above)

Modeling v_x with equivalent source, throw out dc components:



(Text on left:

neglecting z_x, $v_L = -\hat{v}_x$) (On right arrow: Neglecting any drop on z_i)

$$V = L * \frac{\Delta i}{\Delta t}$$

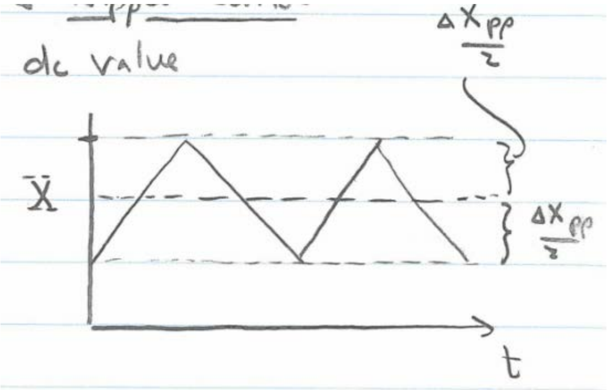
$$\boxed{i_{L,pp} = \frac{D(1-D)V_2 T}{L}}$$

Therefore, $$\boxed{L \geq \frac{D(1-D)V_2 T}{\Delta i_{L,pp}}}$$

From these waveforms we can define Ripple Ratios: ripple magnitude as a fraction of dc value

$$R_c \triangleq \frac{\Delta v_{c,pp/2}}{V_c}$$

$$R_L \triangleq \frac{\Delta i_{L,pp/2}}{I_L}$$



$$\therefore v_{c,pk} = V_c(1 + R_c) \text{ and } i_{2,pk} = I_L(1 + R_L)$$

So from our previous results

$$L \geq \frac{D(1-D)T v_2}{2 I_1 R_L} \qquad C \geq \frac{D(1-D) I_1 T}{2 V_c R_c}$$

Energy storage is one metric for the minimum size of an energy storage component. What is required energy storage?

Capacitor:

$$E_c = \frac{1}{2} C V_{c,pk}^2$$

$$= \frac{1}{2} \frac{D(1-D) I_1 T}{2 V_c R_c} [V_c(1 + R_c)]^2$$

$$\frac{1}{2} \frac{D(I_1 V_1) T}{2} \frac{(1 + R_c)^2}{R_c}$$

$$\boxed{E_c = \frac{D T P_0}{4} \frac{(1 + R_c)^2}{R_c}}$$

So energy storage increases with

1. switching period
2. output power
3. conversion ratio
4. smaller ripple spec (? cannot read space or spec)

Similar arguments for inductor $E_L = \frac{D P_0}{4 f_{sw}} \frac{(1+R_c)^2}{R_c}$

It can be shown that direct converters always require less energy storage (+ hence smaller components) than indirect converters.

We can also factor in ripple on our peak device stresses:
DIRECT:

$$v_{c,pk} = v_{sw,pk} = v_{d,pk} = max(|v_1|, |v_2|)(1 + R_c)$$

$$i_{L,pk} = i_{sw,pk} = i_{d,pk} = max(|I_1|, |I_2|)(1 + R_2)$$

INDIRECT:

$$v_{c,pk} = v_{sw,pk} = v_{d,pk} = (|v_1| + |v_2|)(1 + R_c)$$

$$i_{L,pk} = i_{sw,pk} = i_{d,pk} = (|I_1| + |I_2|)(1 + R_2)$$

If time, define metric for switch size: switch stress parameter
S.S.P. $\triangleq V_{sw,pk} * i_{sw,pk}$

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