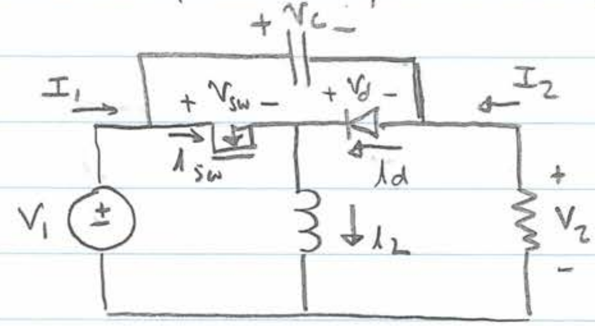
6.334 Lecture — DC/DC Lecture #3

Consider Device and passive component ratings of converters:

Indirect



for now, assume L, C big
$i_L \approx I_L$, $v_c \approx V_c$

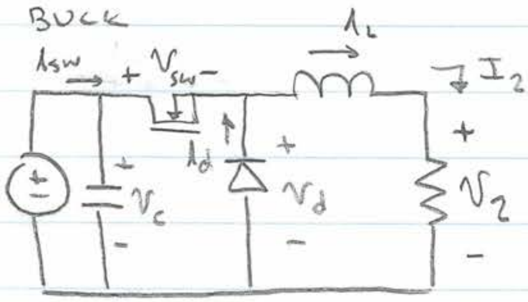
FROM LAST TIME
$$I_L = |I_1| + |I_2|$$
$$V_c = |V_1| + |V_2|$$

So we have

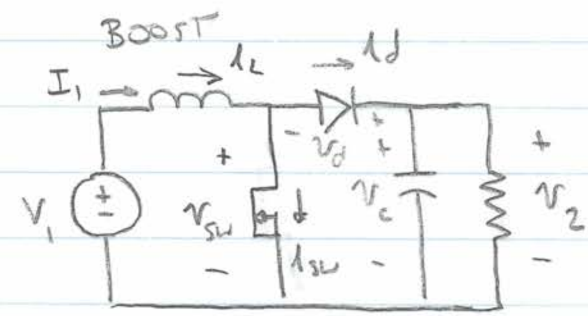
$$v_{sw,max} = v_{d,max} = V_c = |V_1| + |V_2|$$
$$i_{sw,max} = i_{d,max} = I_L = |I_1| + |I_2|$$

Lets look at direct converters (L, C big: $i_L \approx I_L$, $v_c \approx V_c$)

BUCK



BOOST



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

FOR THE DIRECT CONVERTER TYPES (L, C Big)

$$v_{sw,max} = v_{d,max} = V_c = \max(|V_1|, |V_2|)$$
$$i_{sw,max} = i_{d,max} = I_L = \max(|I_1|, |I_2|)$$

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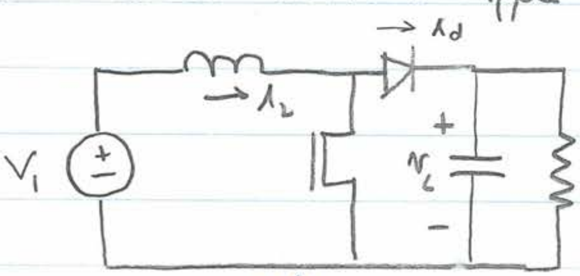
So, based on device and passive component stresses, we would choose a direct converter over an indirect converter whenever possible!

In practice, component selection does depend on ripple in many cases. Let's see how to <u>approximately</u> calculate ripple effects.

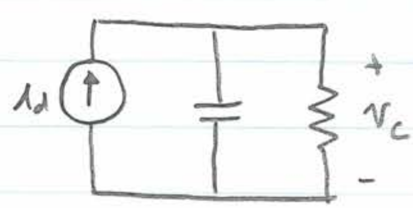
To calculate <u>capacitor voltage ripple</u> we

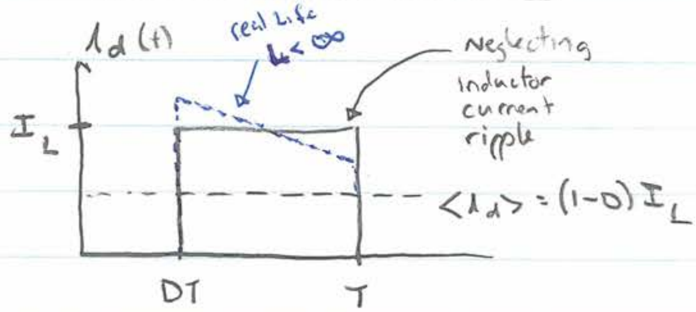
1. Neglect ripple in inductor (assume $L \approx \infty$ so $\Delta i_{L,pp} \approx 0$)
2. assume <u>all</u> current ripple goes into capacitor
3. Calculate voltage ripple
4. verify assumption afterwards

Ex: Boost converter ripple



model as





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

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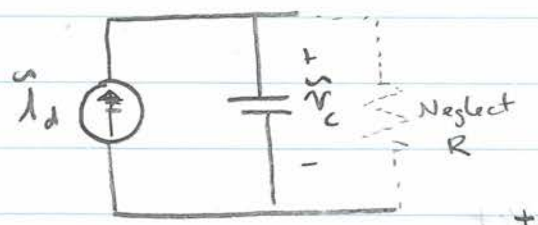
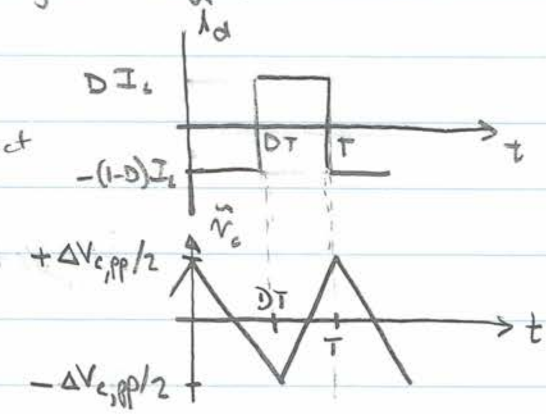
Under this assumption, a "ripple only" model is:





- ripple in V_c is triangular
- The average value of a Δ wave is half-way between its peaks, so we get ripple between $\pm \Delta V_{c,pp}/2$

$i = C \frac{\Delta V_c}{\Delta t}$

$$i = C\frac{dV_c}{dt} \Rightarrow \Delta V_c = \frac{1}{C}\int i_c \, dt$$

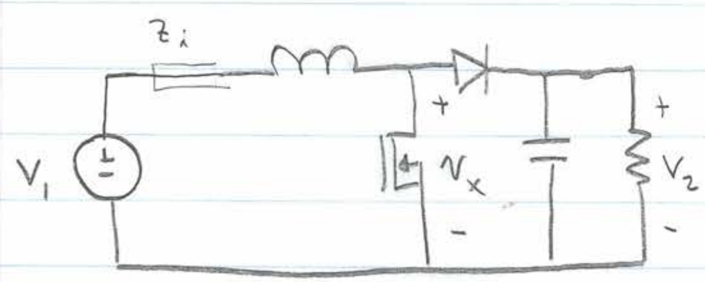
$$\therefore \quad \boxed{\Delta V_{c,pp} = \frac{D(1-D)I_L T}{C}}$$

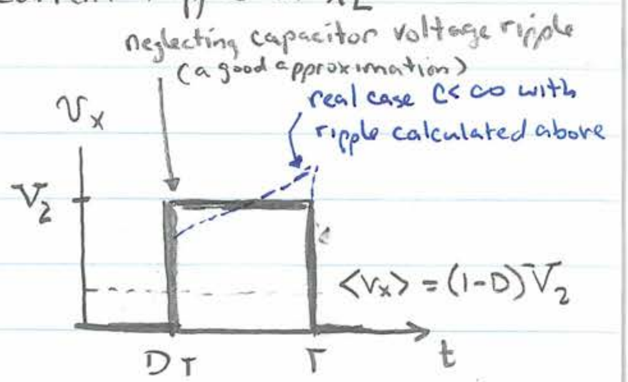
where $I_L = I_1$

So to limit ripple below 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





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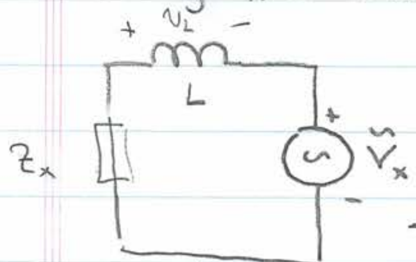
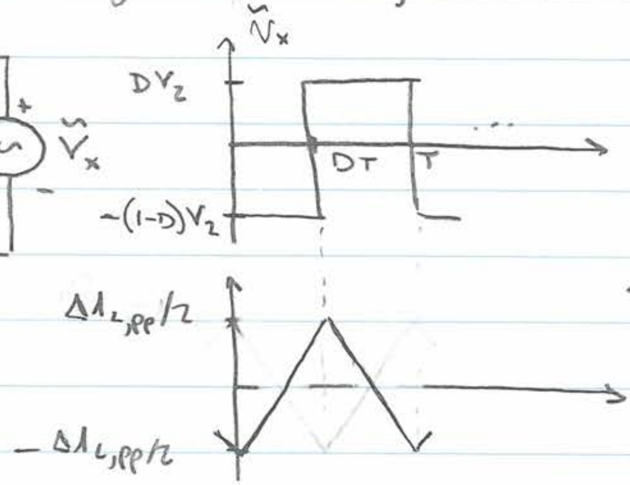
modeling v_x with equivalent source, throw out dc components:





neglecting any drop on Z_x

Neglecting Z_x, $v_L = -\tilde{v}_x$

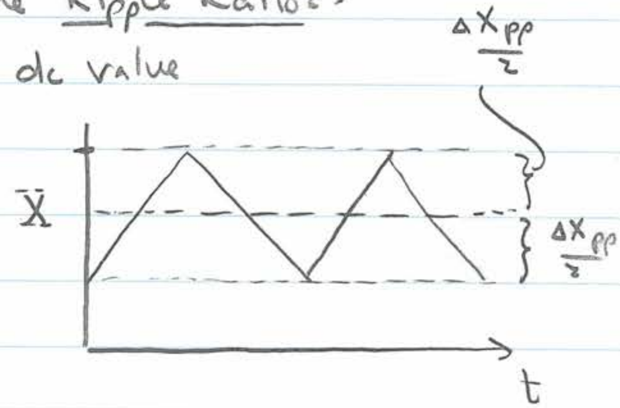
$V = L\frac{\Delta i}{\Delta t}$ $\therefore$ $$\Delta i_{L,pp} = \frac{D(1-D)V_2 T}{L}$$

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

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

$$R_C \triangleq \frac{\Delta V_{C,pp}/2}{V_C}$$

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



$\therefore$ $v_{C,pk} = V_C(1+R_C)$ $\quad i_{L,pk} = I_L(1+R_L)$

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

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

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

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

So energy storage increases with

1. switching period
2. output power
3. conversion ratio
4. smaller ripple spec.

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

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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:
$$V_{c,pk} = V_{sw,pk} = V_{d,pk} = \max(|V_1|,|V_2|)(1+R_c)$$
$$I_{L,pk} = I_{sw,pk} = I_{d,pk} = \max(|I_1|,|I_2|)(1+R_L)$$

Indirect:
$$V_{c,pk} = V_{sw,pk} = V_{d,pk} = (|V_1|+|V_2|)(1+R_c)$$
$$I_{L,pk} = I_{sw,pk} = I_{d,pk} = (|I_1|+|I_2|)(1+R_L)$$

If time, define metric for switch size: switch stress parameter

$$S.S.P. \triangleq V_{sw,pk} \cdot I_{sw,pk}$$