6.622 Power Electronics *Prof. David Perreault*

Lecture 5 — Intro to DC/DC

1 First Averaged Circuit Rules

KCL

$$\sum_j i_j = 0$$

$$\frac{1}{T}\int_T \sum_j i_j \, dt$$

$$\sum_j \frac{1}{T}\int_T i_j \, dt$$

$$\sum_j < i_j >= 0$$

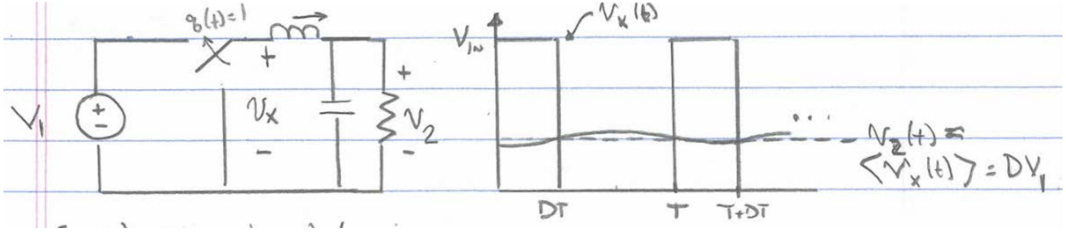
KCL applies to time averaged currents (constant charge).
The same is true for KVL ($\sum_k < V_k >= 0$).

So for a power converter in periodic steady state:

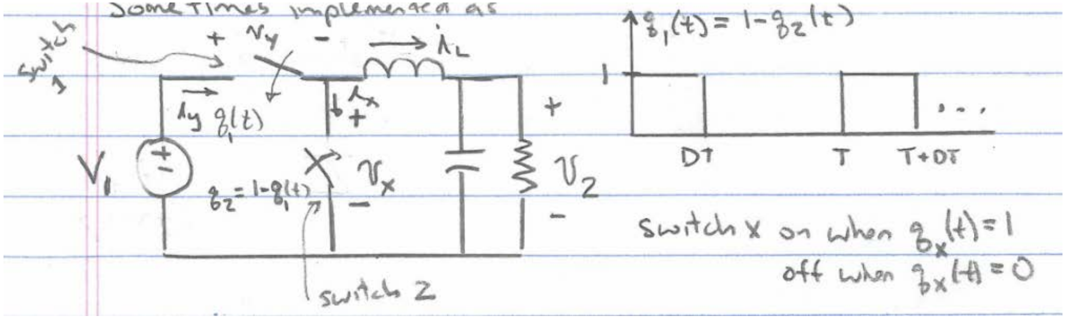
1. Averaged KCL $\sum_j < i_j >= 0$
2. Averaged KVL $\sum_k < V_k >= 0$
3. Capacitor in P.S.S. $< \lambda_c >= 0$
4. Inductor in P.S.S. $< V_L >= 0$
5. If system lossless (Conservation of energy) $< P_{in} >=< P_{out} >$

2 Review

Switching regulator example "Buck Converter"



Sometimes implemented as:

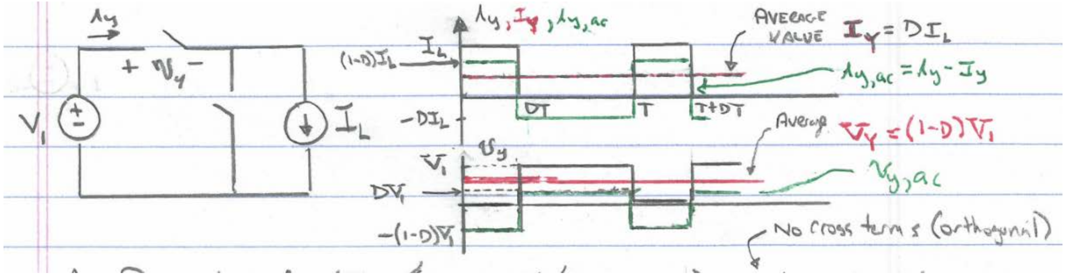


Text on bottom: Switch X on when $q_x(t)=1$, off when $q_x(t)=0$
Assuming Ls and Cs are very big: $v_0(t)=V_0, i_2(t)=I_2$
Using average relation in P.S.S. $<v_L>=<v_x>-<v_2>$

$$<v_L>=\frac{1}{T}[DT(v_1-v_2)+(1-D)T(-v_2)]=0 \Rightarrow V_2=Dv_1$$

2.1 Aside

What do switch 1 and switch 2 do? Let's ignore inductor ripple.



Average power into switch 1:

$$<P_1>=<(V_Y+v_{Y,AC})(I_Y+i_{Y,AC})>=<V_YI_Y>+<v_{Y,AC}i_{Y,AC}>$$

Where the right side has no cross terms (orthogonal)

$$<P_1>=D(1-D)I_LV_1+\{D[-(1-D)^2I_LV_1]+(1-D)[-D^2I_LV_1]\}$$

$$=D(1-D)I_LV_1-D(1-D)I_LV_1=0$$

Where the first term is average power into switch due to i_Lv and the second term is average power into switch due to $i_{ac,l},v$ (Could not exactly read this part from original notes)

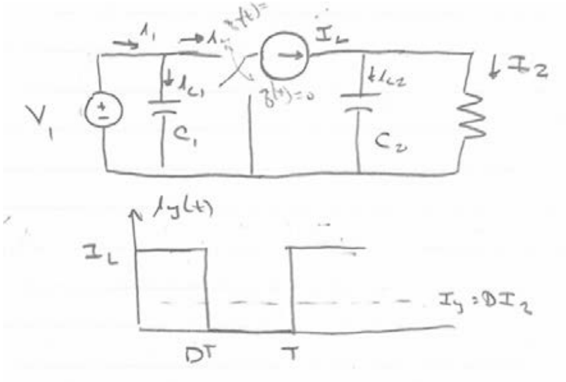
Switch S_1 takes average power in from the current, voltage and puts equal power out at ac current, voltage. Converts power (efficiently) from dc to ac waveforms! ("inverting" "switch") S_2 does the opposite (converts power from ac waveforms to dc waveforms!) (rectifying switch)

3 Review

Consider input current:
L's, C's big, $i_l(t) \approx I_L$
P.S.S. $< i_{c2} >= 0 \therefore I_2 = I_L$
P.S.S.

$$< I_{c1} >= 0 \therefore I_1 =< i_1 >=< i_y >= DI_2$$

$$\therefore I_1 = DI_2$$

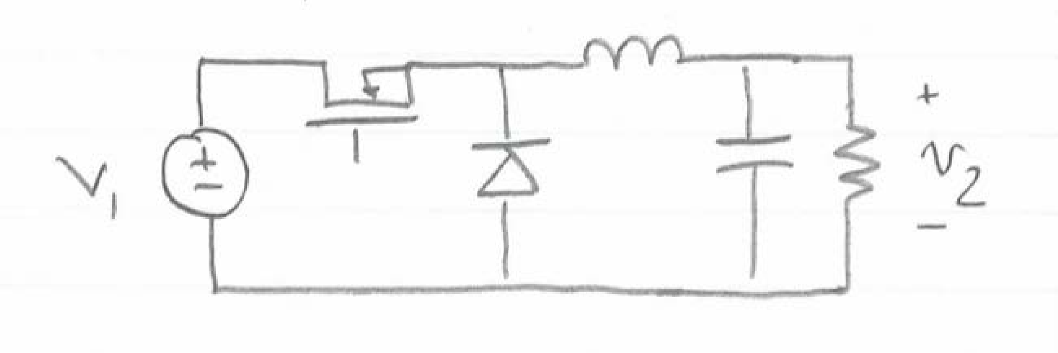


Combining with previous result that $DV_1 = V_2$: $I_1V_1 = I_2V_2 \leftarrow$ Lossless system!

> Note: The trick is to be careful about when one is dealing with <u>instantaneous</u> variables and when one is dealing with <u>average</u> variables!

e.g. at a given instant, $i_y(t) \neq < i_y(t) >$

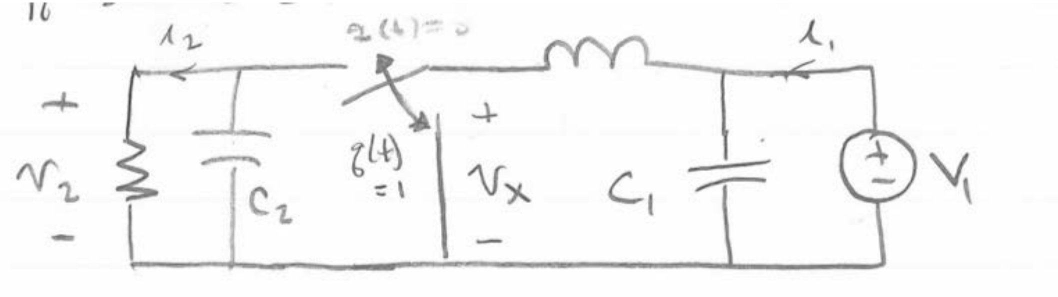
Switch implementation for this case, $v_1, v_2 > 0$



Power flows form 1 to 2.

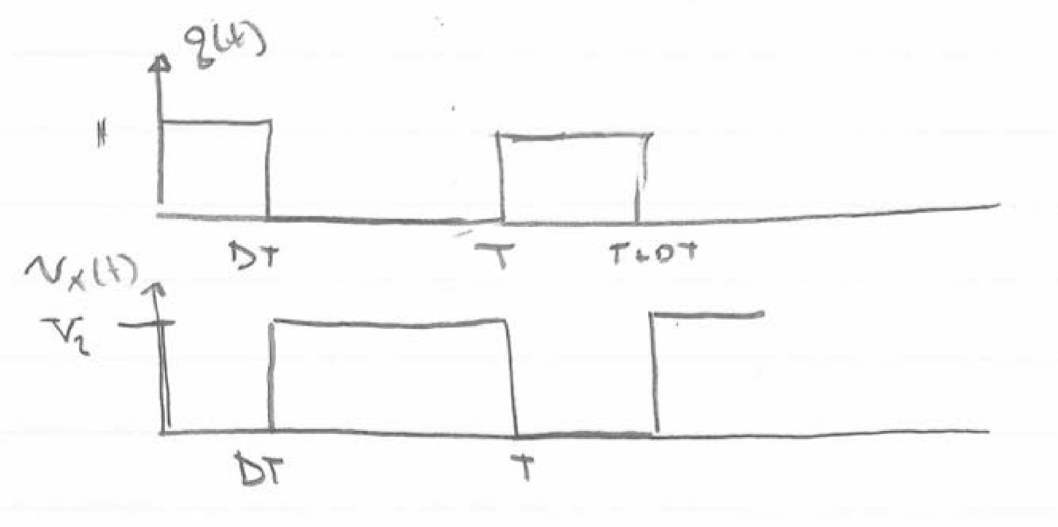
"Down" or "buck" converter. A type of "direct" converter because in one switch state, power flows directly from input to output.

Suppose we switch source and resistor.



*note: redefine q(t) = 1 as switch "down" position.

If C's, L's big, same analysis:

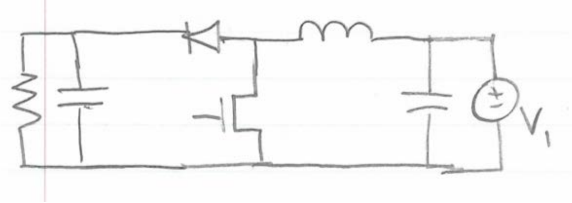


$$< v_L >= 0 \therefore < v_x >= (1-D)V_2 = V_1$$

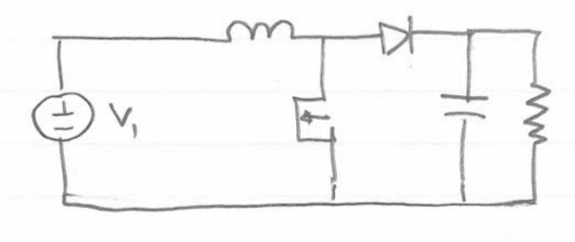
$$\therefore V_2 = \frac{V_1}{1-D} \text{ and } \frac{I_2}{1-D} = I_1$$

If $v_1, v_2 > 0$, then power flows from $2 \leftarrow 1$ and $v_2 > v_1$

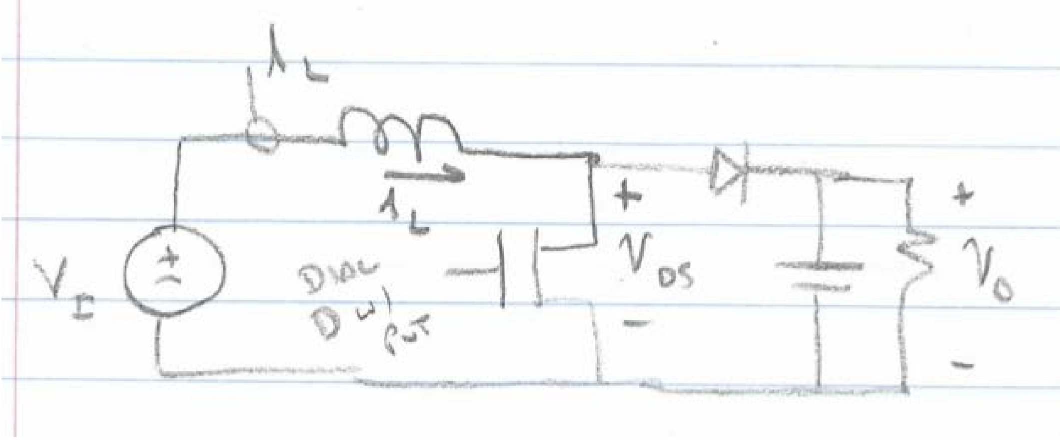
Boost converter (or "up" converter):



Sometimes drawn $L \rightarrow R$ power flow (But nothing fundamental about it).



* Show boost converter demo circuit built by Katie R. and Sauparna Das



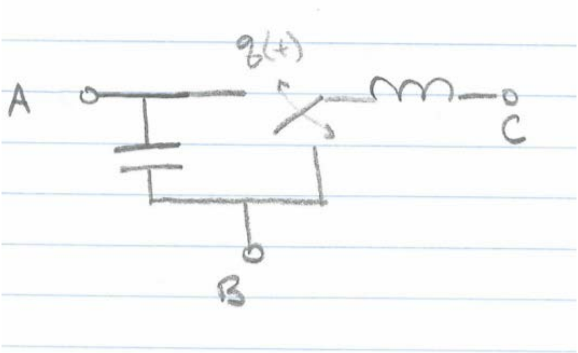
Show:

1. v_{DS}
2. i_L
3. v_0 on scope

Explain boost operation:

- Switch turns on, i_L rises and incrementally stores energy in L from V_I
- Switch turns off and this energy plus additional energy from V_I is transformed to output
- Steady state voltages are determined by $V_2 = \frac{V_1}{1-D}$

Either back or boost can be viewed as a connection of a ”canonical cell”



- Direct connection has B common
- one <u>cannot</u> tell power flow direction without knowing
  1. external networks
  2. switch implementation
  3. control

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