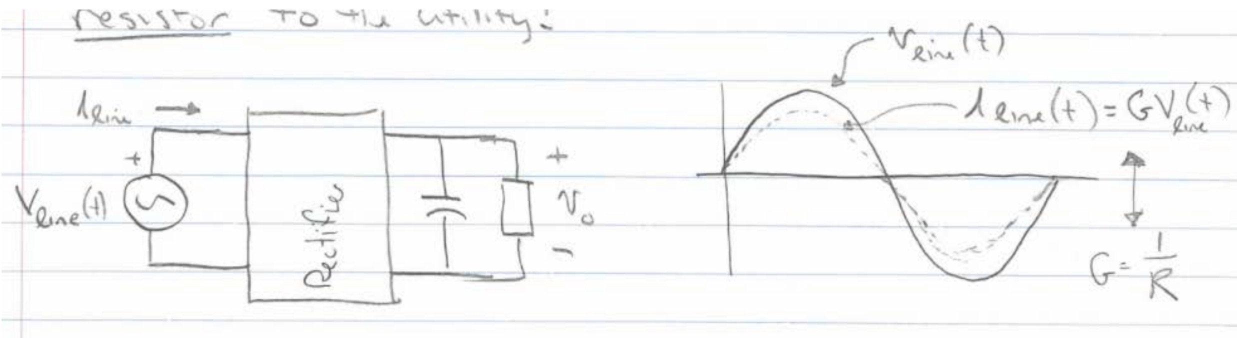
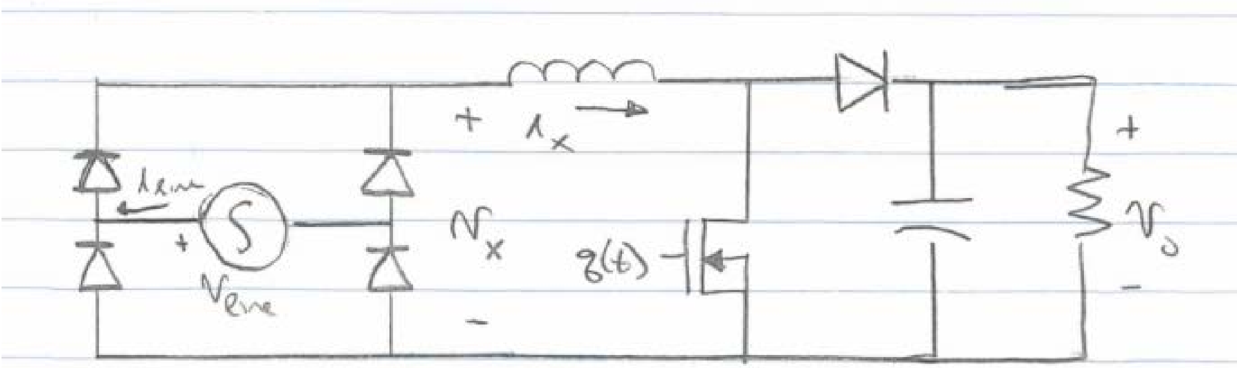
6.622 Power Electronics *Prof. David Perreault*

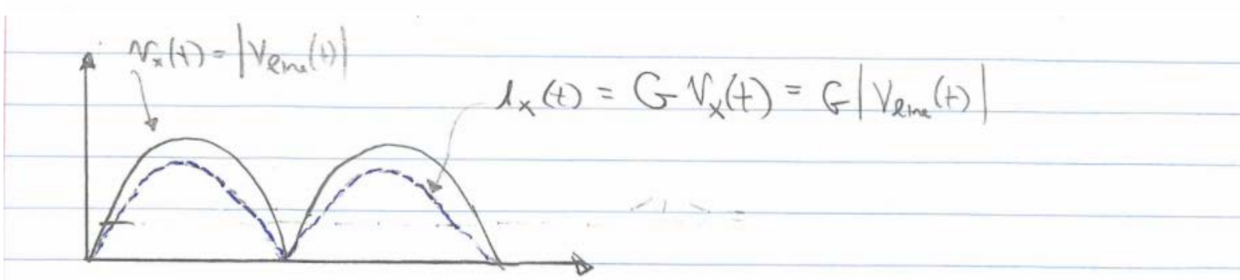
Lecture 20 - Switched-Mode Rectifiers

- Phase controlled rectifiers allow control of output voltage or current but the power factor becomes poor very quickly $\{(e.g., V_o = V_{do}\cos(\alpha))\ k_p = \frac{4}{\pi\sqrt{2}}\cos(\alpha)\}$
- Power quality issues and regulations are requiring rectifiers loads on the utility to achieve high power factor (e.g., IEC 1000 -¿ fixed limits on harmonic content of current)
- When lots of power is needed, we must draw it at high pf. to stay within breaker/fuse thermal limits of source (e.g., 1.7 kW from $110V/15A$)
- We need to draw close to sinusoidal current in phase w/ the voltage =¿ We want to look like a resistor to the utility!



To do this, use a switch-mode rectifier (SMR)
UPF boost rectifier (simulation in sinerct.seh)



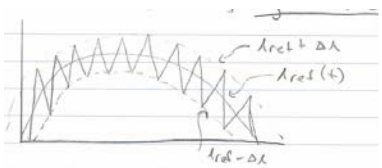


For ideal devices

$$\overline{P_{in}} = \overline{P_{out}} =< V_x l_x >$$
$$=< GV_xV_x >= \frac{1}{2}G|V_{line}|^2$$

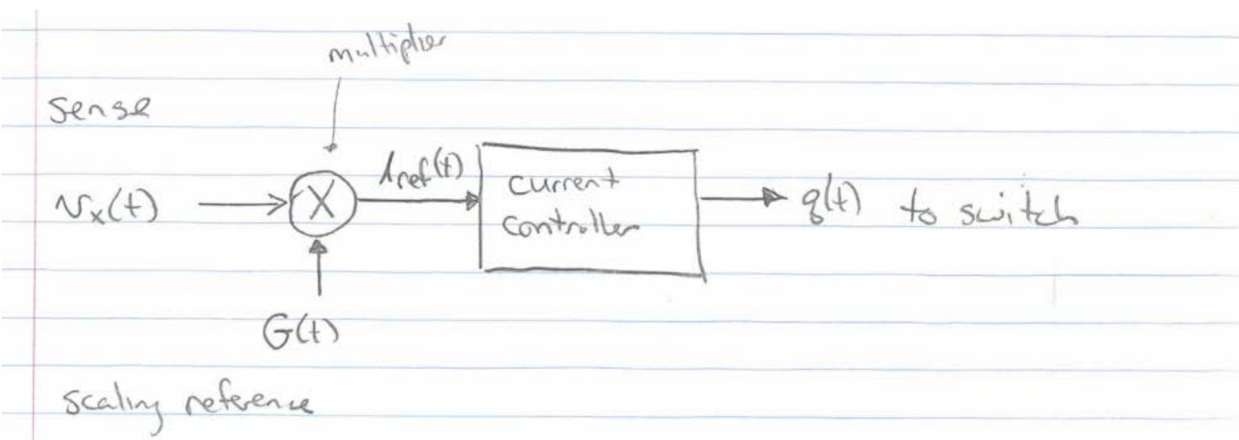
So we can control output power to be desired value by making rectifier input current $\propto$ to input voltage with a controlled proportionality constant

- Current control could be done by hysteresis control (from before)

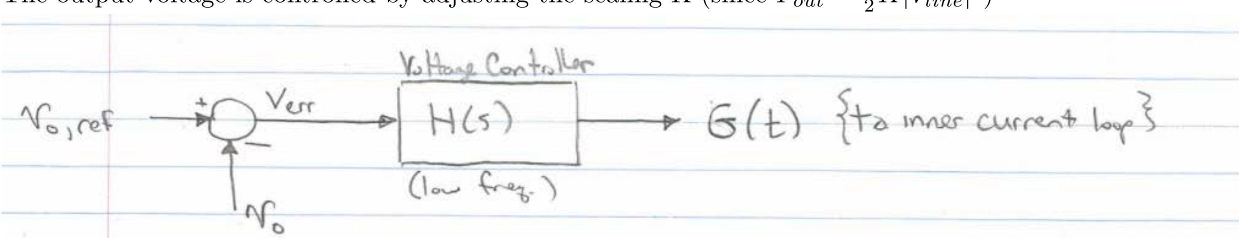


Control q(t) to make i_x track reference within bounds.

- Could use peak current control (as we discussed in control lectures), or average current control or many similar versions
- These techniques start wtih a current reference we desire to track. to do this:



The output voltage is controlled by adjusting the scaling K (since $P_{out} = \frac{1}{2}K|V_{line}|^2$)



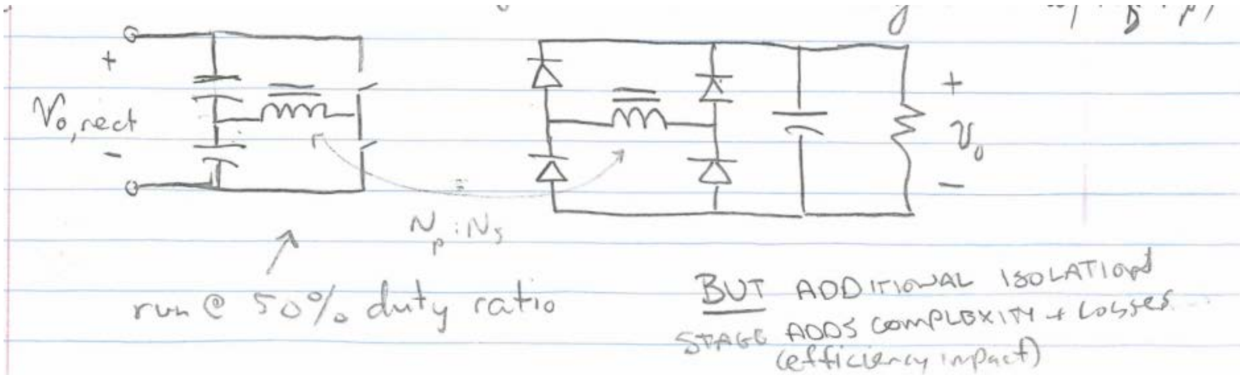
We get unity power factor (input current will be $\propto$ to voltage)

But:

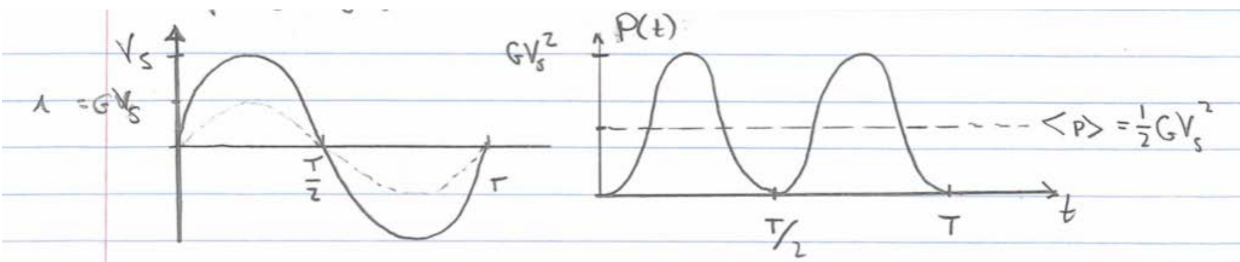
1. The outer loop (* control bandwidth) must be much slower than $Z\omega_{line}$ so $G(t)$ does not change much within a line cycle.
2. To compute the current ref we need a multiplier (which can be costly) $\rightarrow$ some techniques get around this (e.g., edge of dcm mode)
3. Isolation is needed for most off-line applications

This topology does not provide isolation, output must float wrt ground unless we either use a 60Hz xformer at input (big, heavy) or provide an isolation stage. (Note: an isolation stage also provides transformation to a final output voltage)

Follow-on isolation stage (can also scale voltage down w/ $N_s : N_p$)

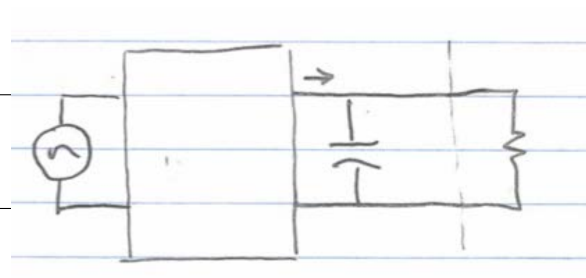


4. Single-phase UPF (or PFC) power supplies require large capacitors to buffer the power pulsations from the line:

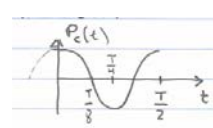


$$P(t) = GV_s^2 sin^2(\omega t) = \frac{1}{2}GV_s^2 - \frac{1}{2}GV_s^2 cos(2\omega t)$$

$$< P >= \frac{1}{2}GV_c^2$$
$$= P_{out}$$



If power to the load is contant, the capacitor must source



$$P_c = \frac{1}{2}GV_s^2 fos(2\omega t) = P_{out}cos(2\omega t)$$

Peak-to-peak energy swing:

$$\Delta E_{c,pp} = \int_{\frac{T}{8}}^{\frac{T}{8}} P_{out}cos(2\omega t)dt = \frac{P_{out}}{2\omega}[sin(2\frac{\omega T}{8}) - sin(-2\frac{\omega T}{8})]$$

$$\Delta E_{c,pp} = \frac{P_{out}}{\omega}$$

$$\Delta E_{c,pp} = \frac{1}{2}CV_{max}^2 - \frac{1}{2}CV_{min}^2 = \frac{1}{2}C(V_{max}^2 - V_{min}^2)$$

If $V_{min} = KV_{max}, \Delta E_{c,pp} = \frac{1}{2}CV_{max}^2(1 - K^2) = \frac{P_{out}}{\omega}$

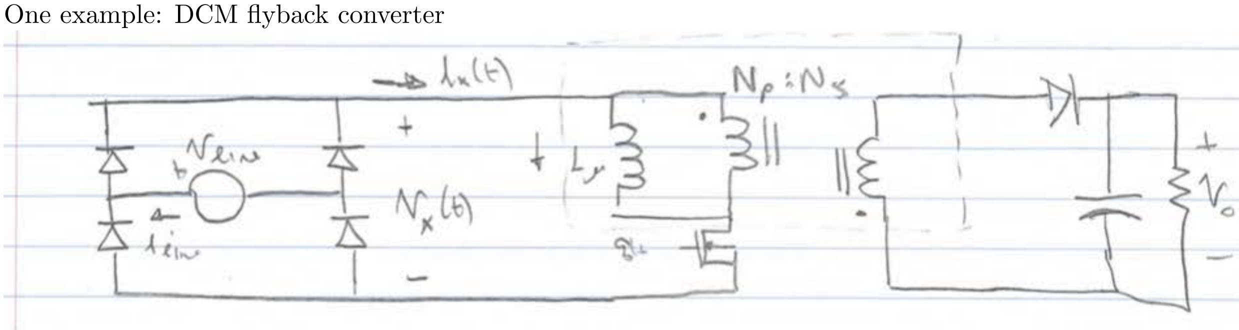
$\therefore$ $\boxed{\Delta E_{c,pp} = \frac{P_{out}}{\omega}}$ $@P_{out} = 1KW, V_{max} = 200V, K = 0.95, \omega = 377\frac{rad}{sec}$ $\Rightarrow C \geq 1.4mF$

Much ongoing research on <u>single-stage UPF converters</u>

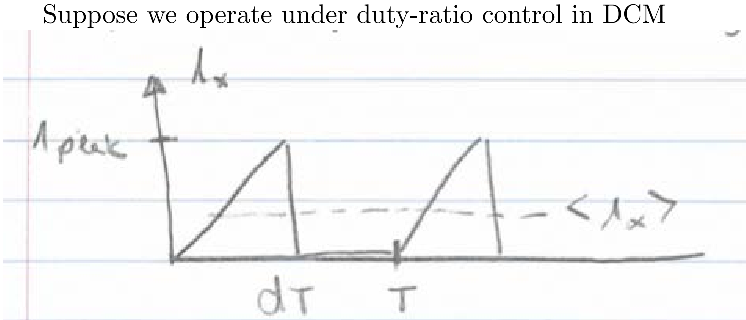
1. Unity double factor
2. Output voltage control
3. Isolation

All with a single converter step

One example: DCM flyback converter



Suppose we operate under duty-ratio control in DCM



$$i_{peak} = \frac{v_x(t)}{L_\mu}dT$$

$$\therefore \overline{i_x(t)} = \frac{1}{T}[\frac{\overline{V_x(t)}}{2L_\mu}(dT)^2] = d^2\frac{T}{2L_\mu}\overline{V_x(t)}$$

- So for a given duty ratio (constant over $\frac{1}{2}$ line cycle), we get a current $i_x(t)$ that tracks $V_x(t)$ and unfolded $i_{line}(t)$ follows $V_{line}(t)$ (no multiplier needed!) $\Rightarrow$ UPF operation
- We get isolation without an extra stage
- We can control output power, output voltage simply by controlling duty ratio
- <u>BUT</u>: High device magnetics stresses / need much input filtering (high ripple)

$\Rightarrow$ If time, cover 3Φ SMR systems