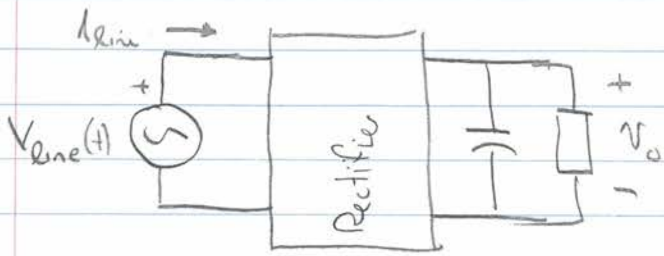
6.334 Lecture — Switched-Mode Rectifiers

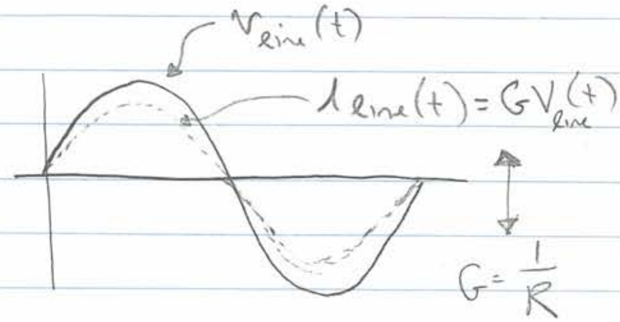
- Phase-controlled rectifiers allow control of output voltage or current but the power factor becomes poor very quickly $\left\{ \text{e.g. } V_o = V_{d0}\cos(\alpha),\ k_p = \frac{4}{\pi\sqrt{2}}\cos(\alpha) \right\}$

- power quality issues and regulations are requiring rectifier 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 p.f. to stay within breaker/fuse/thermal limits of source (e.g. ~1.7 kW from 110 V / 15 A)

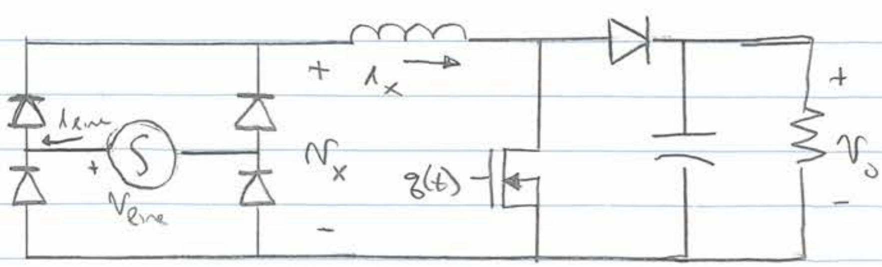
→ We need to draw close to sinusoidal current in phase w/ the line voltage ⇒ We want to look like a resistor to the utility!



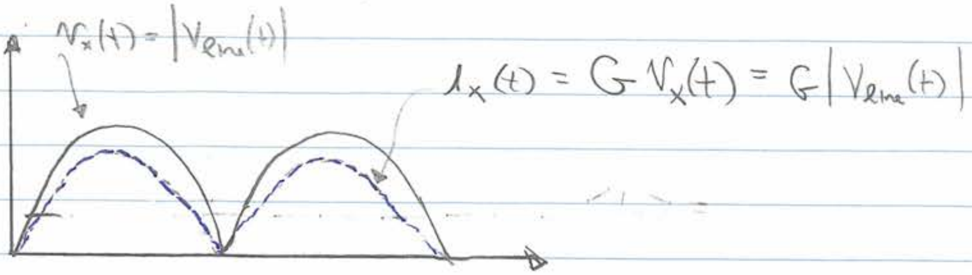


To do this, use a Switched-Mode Rectifier (SMR)

e.g., UPF Boost Rectifier (simulation in sinerect.sch)



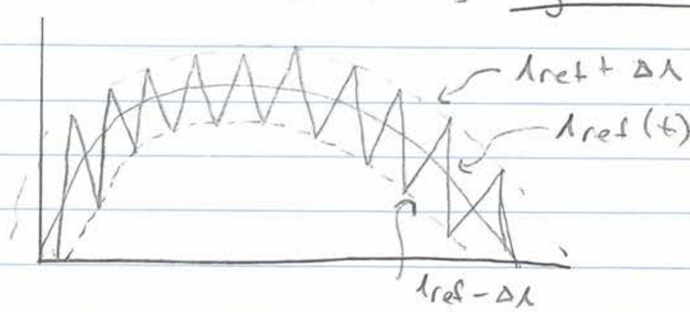
6.334 Lecture — Switched-Mode Rectifiers



For ideal devices $\overline{P_{IN}} = \overline{P_{OUT}} = \langle v_x i_x \rangle$
$$= \langle G\, v_x v_x \rangle = \tfrac{1}{2} G\,|V_{line}|^2$$

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

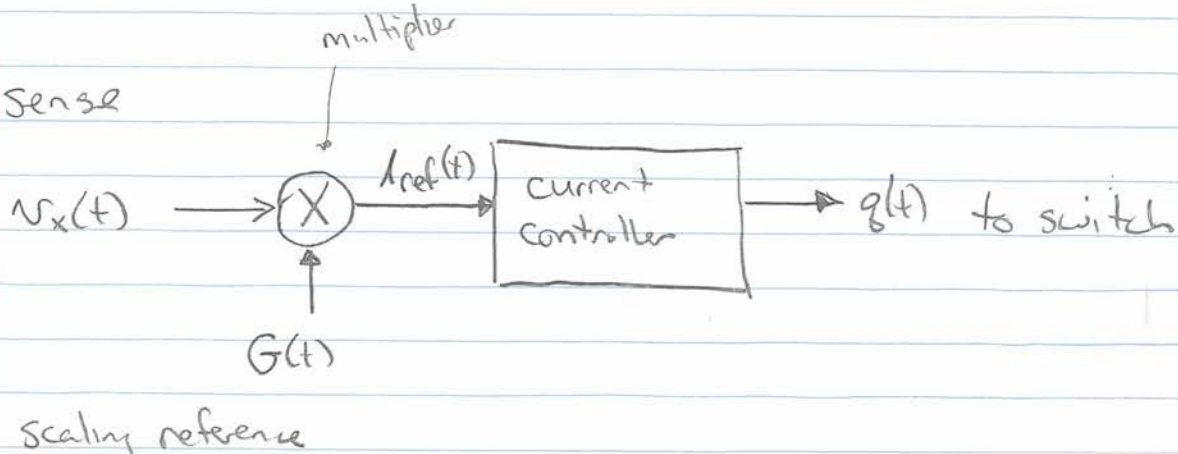
→ current control could be done by hysteresis control (from before



control $q(t)$ to make i_x track reference w/in bounds.

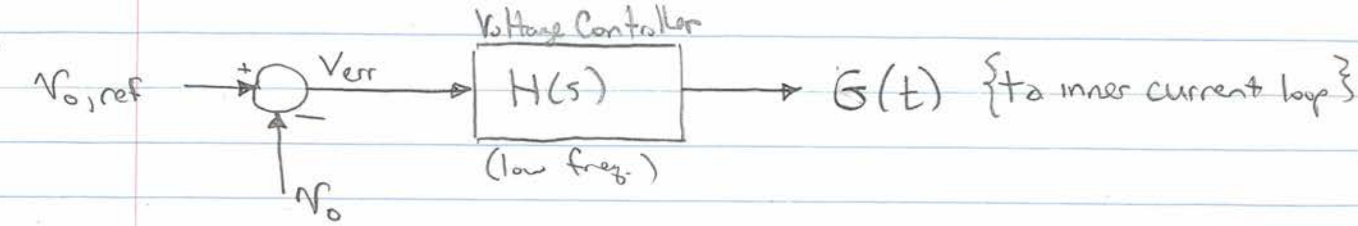
→ could use peak current control (as we discussed in Control lectures, or average current control or many similar versions.

→ these techniques start with a current reference we desire to track; To do this:



6.334 Lecture — Switched-Mode Rectifiers

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



[SHOW SIMULATION!] simrect.sch

- we get Unity Power Factor (input current will be ∝ to voltage)

But: (1) The outer loop (∴ control bandwidth) must be much slower than $2\omega_{line}$ so G(t) does not change much within a line cycle.

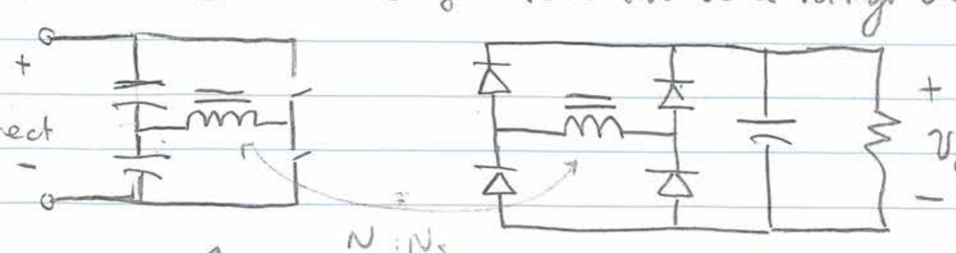
(2) To compute the current ref, we need a multiplier (which can be costly) → some techniques get around this (e.g., edge of dcm mode)

(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 60 Hz Xformer at input (big + heavy) or provide an isolation stage

NOTE: AN ISOLATION STAGE ALSO PROVIDES TRANSFORMATION TO A FINAL OUTPUT VOLTAGE

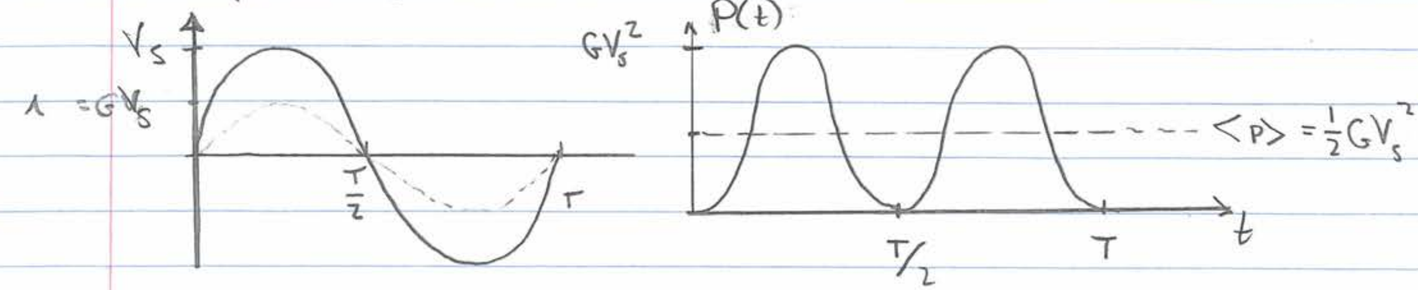
Follow-on Isolation Stage (can also scale voltage down w/ $N_S : N_P$)



run @ 50% duty ratio

BUT ADDITIONAL ISOLATION STAGE ADDS COMPLEXITY + LOSSES (efficiency impact)

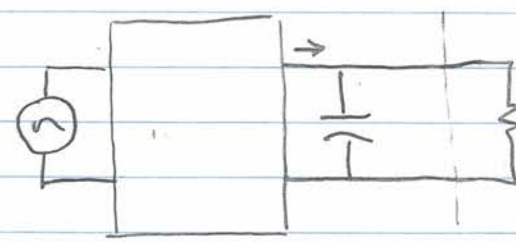
(4) Single-Phase UPF (or PFC) power supplies require Large capacitors to buffer the power pulsations from the line:



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

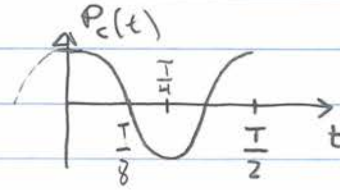
$$\boxed{\langle P \rangle = \frac{1}{2} G V_s^2}$$

$$= P_{OUT}$$



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

$$P_C = \frac{1}{2} G V_s^2 \cos(2\omega t) = P_{OUT} \cos(2\omega t)$$



Peak-to-Peak energy swing:

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

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

★ Required buffer capacitance ∝ to Power!

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

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

$$\therefore \boxed{C \geq \frac{2 P_{OUT}}{\omega V_{max}^2 (1 - K^2)}}$$

@ $P_{OUT} = 1\,kW$, $V_{max} = 200\,V$, $K = 0.95$, $\omega = 377 \frac{rad}{sec}$ $\Rightarrow C \geq 1.4\,mF$

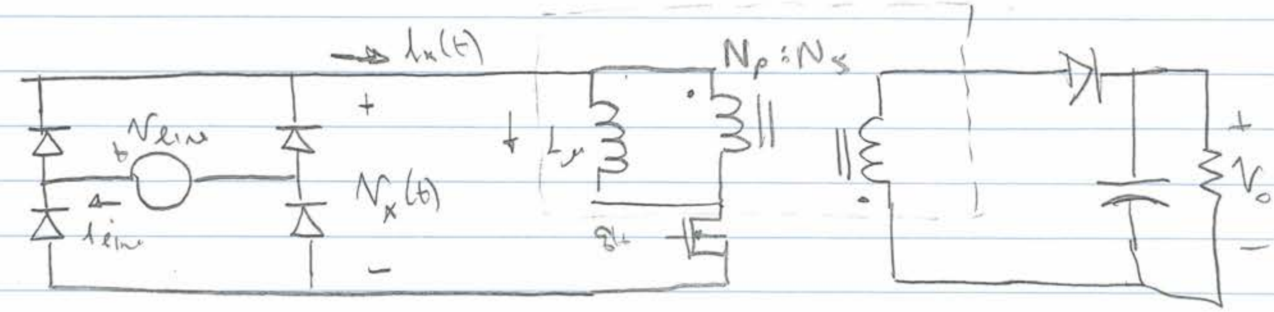
6.334 Lecture — Switched-Mode Rectifiers

much ongoing research on SINGLE-STAGE UPF Converters

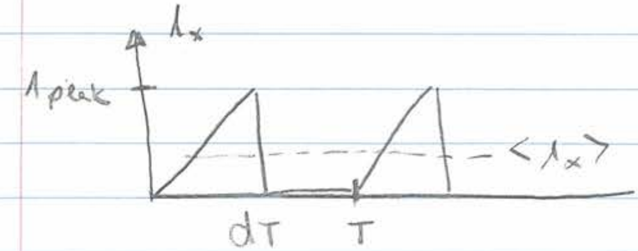
→ do 1. UNITY POWER FACTOR
2. OUTPUT VOLTAGE CONTROL
3. ISOLATION

All with a single conversion step.

One example: DCM Flyback converter



suppose we operate under duty-ratio control in DCM



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

$$\therefore \quad \bar{i}_x(t) = \frac{1}{T}\left[\frac{\bar{v}_x(t)}{2L_\mu}(dT)^2\right] = d^2 \frac{T}{2L_\mu} \bar{v}_x(t)$$

- so for a given duty ratio (const over ½ line cycle) we get a current $i_x(t)$ that tracks $v_x(t)$, and unfolded $i_{line}(t)$ follows $v_{line}(t)$ (no multipliers needed!) → UPF operation
- we get isolation without an extra stage
- we can control output power, output voltage simply by controlling duty ratio

BUT: High device, magnetics stresses, need much input filtering (high ripple)

⇒ IF Time, cover 3Φ SMR systems (Note: ~10 min exist to do so.)

MIT OpenCourseWare
https://ocw.mit.edu

6.622 Power Electronics
Spring 2023

For information about citing these materials or our Terms of Use, visit: https://ocw.mit.edu/terms