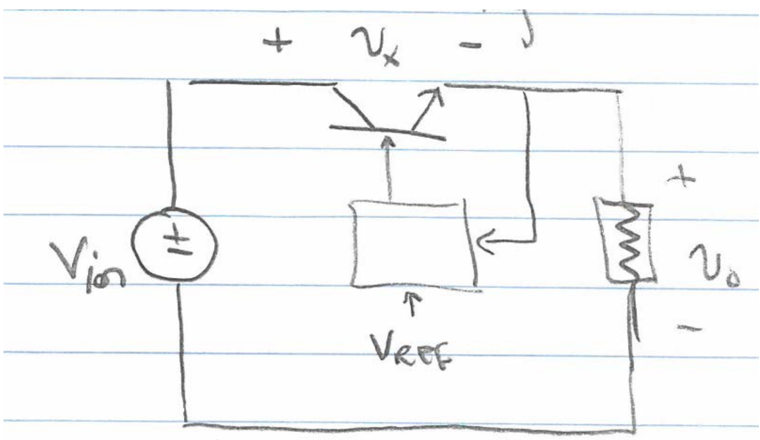
6.622 Power Electronics *Prof. David Perreault*

Lecture 2 — I Analysis Methods and Rectifiers

1 Last Lecture: Linear vs. Switching Regulators

1.1 Linear Regulator



V_x controlled so...

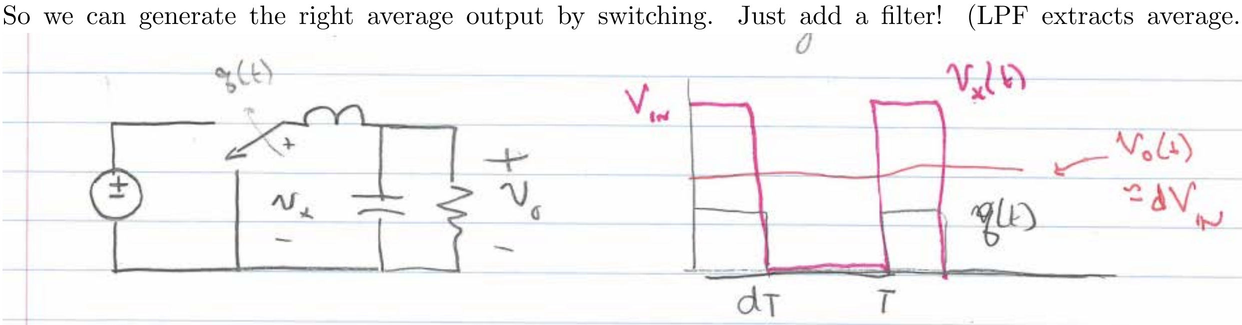
$$V_o = V_{ref}$$

$$\eta = \frac{V_o}{V_{in}}$$

$$< P_{diss} >=< V_x i_o >= V_x I_o \neq 0$$

1.2 Switching Regulator

So we can generate the right average output by switching. Just add a filter! (LPF extracts average.)

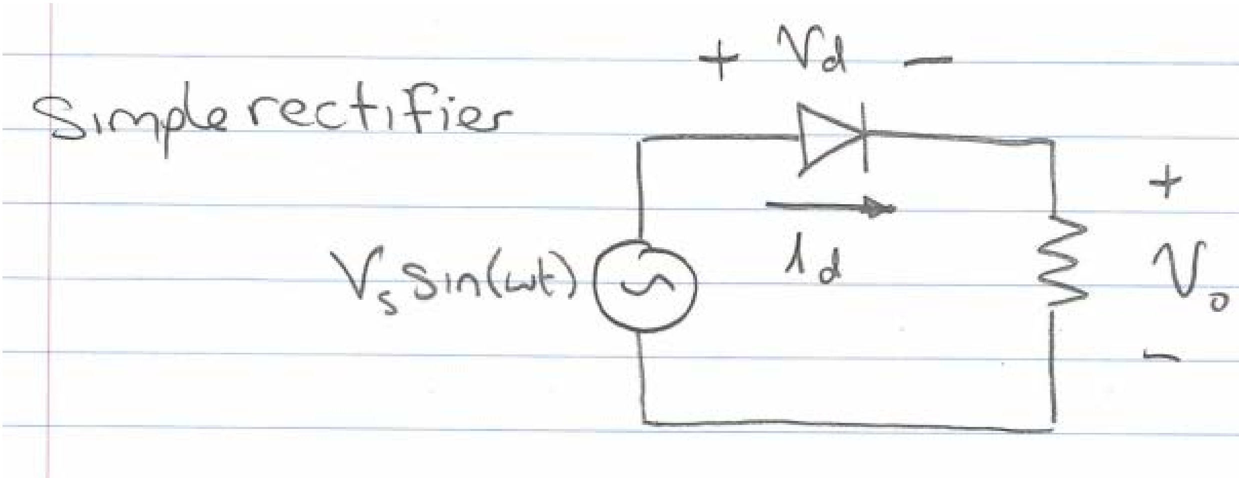


- All elements are lossless (ideally). We can get very high efficiency.
- **Many** design issues to consider.

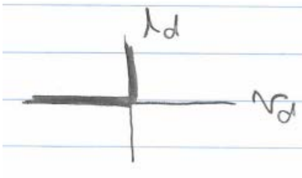
2 Method of Assumed States

Most power converters use semiconductor switches. Some switches are not fully controlled. Let's consider this case.

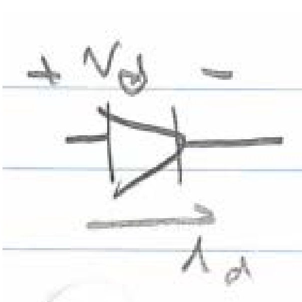
2.1 Simple Rectifier



Diode: An uncontrolled switch



- Cannot sustain positive voltage (will turn on)
- Cannot sustain negative current (will turn off)



In circuits with partly controlled or uncontrolled switches, we need to be able to determine when the switches are on or off. So, we use **the method of assumed states**.

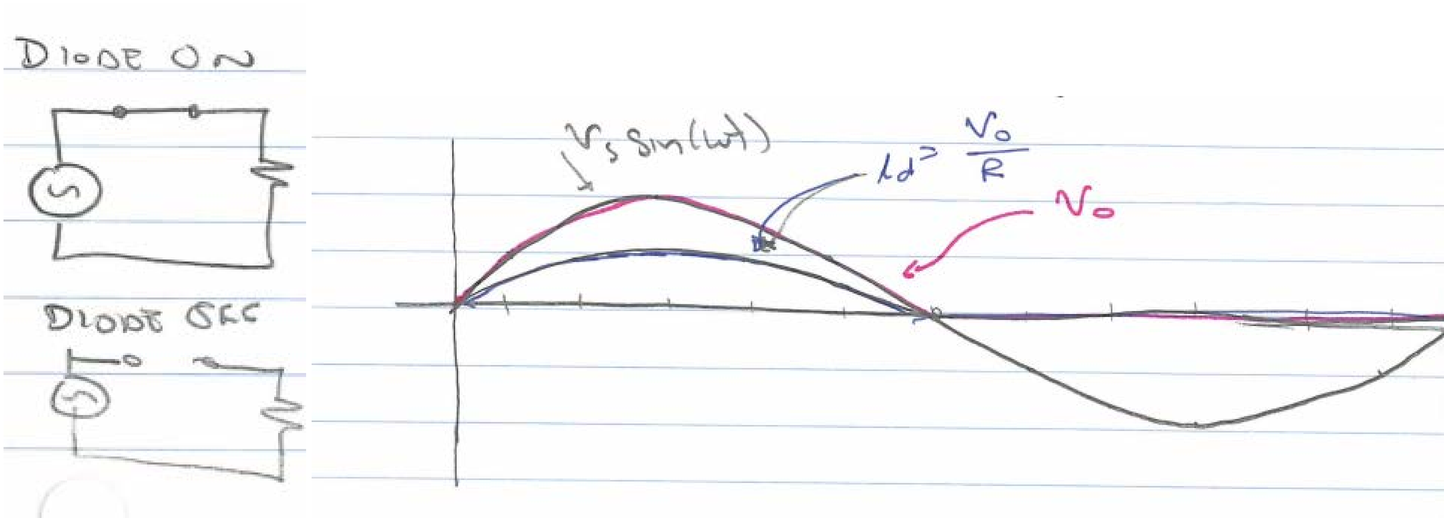
2.2 The Method of Assumed States

1. Assume a state for all switches
2. Calculate voltages and currents in the system
3. See if any switch conditions are violated
4. If not, done. If so, assume a different set of states and try again

2.3 Example

Here is a simple rectifier example:

$$\begin{cases} \text{If } V_s \sin \omega \cdot t > 0 \text{ and we assume diode off: } V_d > 0 \text{, therefore diode must be on!} \\ \text{If } V_s \sin \omega \cdot t < 0 \text{ and we assume diode off: } V_d < 0 \text{, therefore diode must be off!} \end{cases}$$

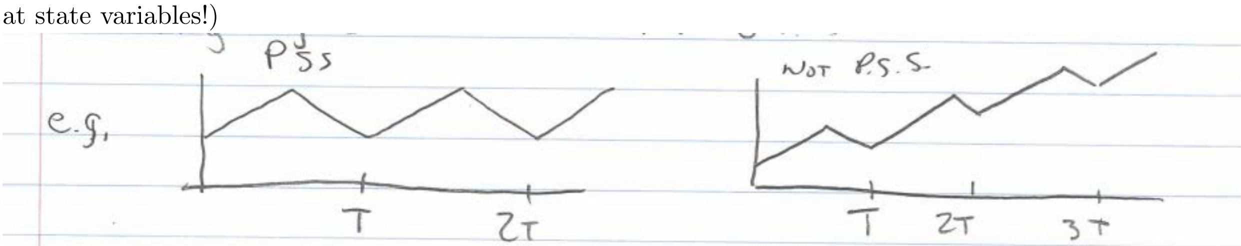


- Check current if assumed on and voltage if assumed off.
- Simple example, but useful for much more complicated systems.
- Many switched system simulators work this way (piecewise linear).

Note: we identify turn on (off) point by looking at voltage (current).

3 Periodic Steady State

Power converters operate cyclicly.
In Periodic Steady State (P.S.S.), the system repeats the same behavior in each switching cycle. (Look at state variables!)



Often, we can look at the state at the end of each cycle to judge.

We are often interested in the periodic steady state condition because that is how the system operates in the absence of disturbance. Also, we can guarantee certain facts which help us analyze the system.

$$< V_L = L\frac{di_L}{dt}$$

Take average over time:

$$< V_L >=< L\frac{di_L}{dt} >= L < \frac{di_L}{dt} >$$

In periodic steady state...

$$< \frac{di_L}{dt} >= 0$$

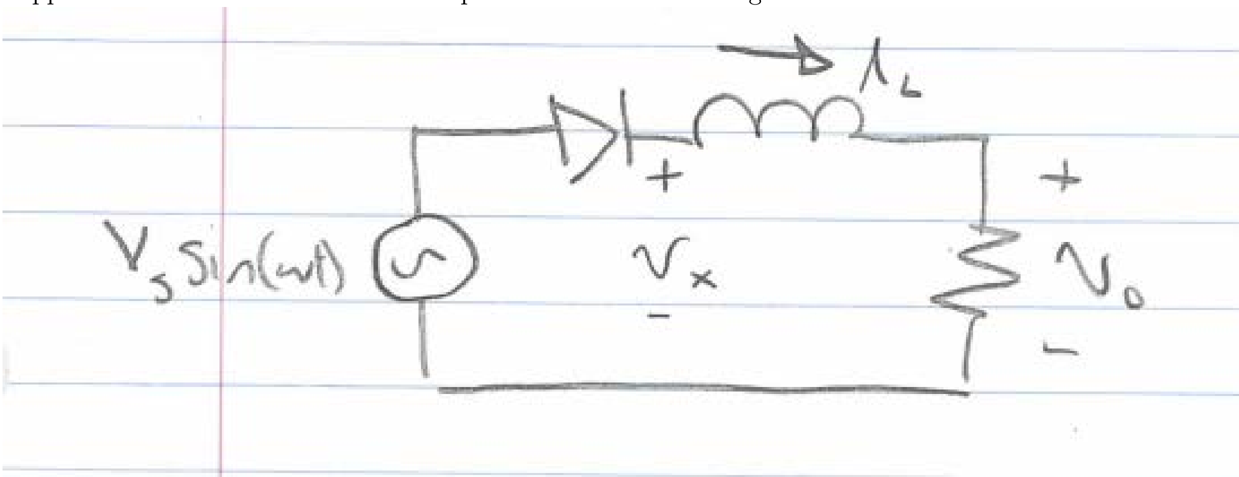
There is no change over time! So . . .

Inductor in **P.S.S** $< V_L >= 0$ Capacitor in **P.S.S** $< i_C >= 0$

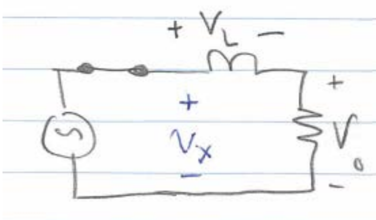
This is similar to the notion that an inductor is a "short" at DC, and a capacitor is an "open" at DC. We can use this in analyzing systems.

3.1 Example

Suppose we add an inductor to our simple rectifier for smoothing.



Suppose we assume the diode is always on.
KVL: $V_S Sin(wt) - V_L\ V_o = 0$

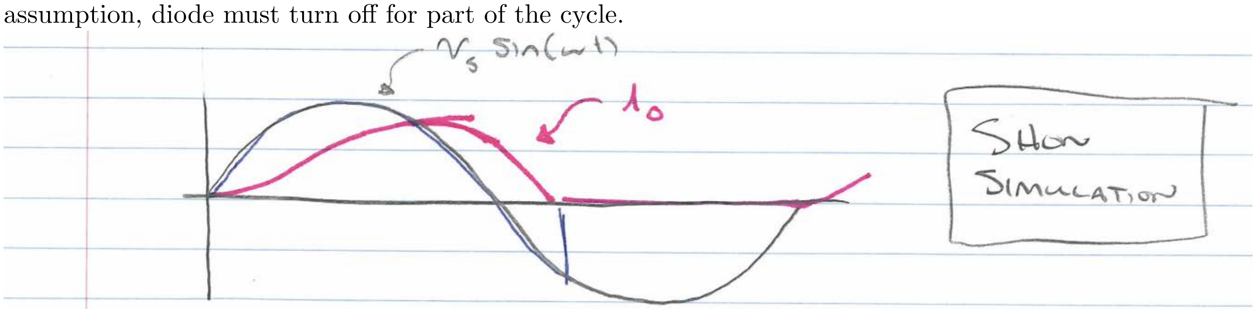


Take average

TAKE AVERAGE

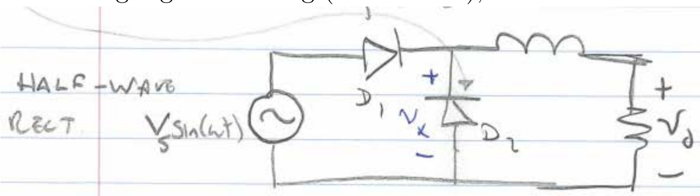
$$\overbrace{\cancel{\langle V_s \sin(\omega t)\rangle}}^{0.} - \overbrace{\cancel{\langle V_L\rangle}}^{0 \text{ in P.S.S.}} - \langle V_o\rangle = 0$$

If diode always on $< V_o >= 0$, so for some part of the time $V_o < 0$ therefore $i_o < 0$. Since this violates our assumption, diode must turn off for part of the cycle.



In P.S.S., $< V_L >= 0$ therefore $< V_o >=< V_x >$. The negative portion of the cycle drives the inductor current to zero!

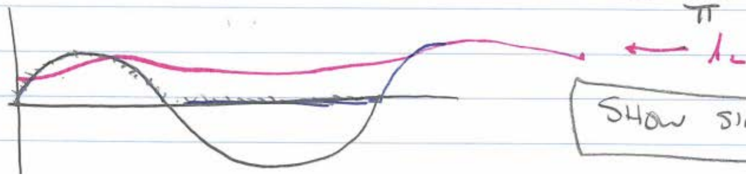
We don't get good filtering (not smooth), but we can fix this with a free-wheeling diode.



In P.S.S. $\langle V_L \rangle = 0$

$$\therefore \langle V_o \rangle = \langle V_x \rangle = \frac{1}{2\pi}\int_0^{\pi} V_s \sin(\varphi)\, d\varphi$$

$$= \frac{V_s}{\pi}$$



SHOW SIMULATION

Note: We could analyze in detail with source replacement + Fourier series.