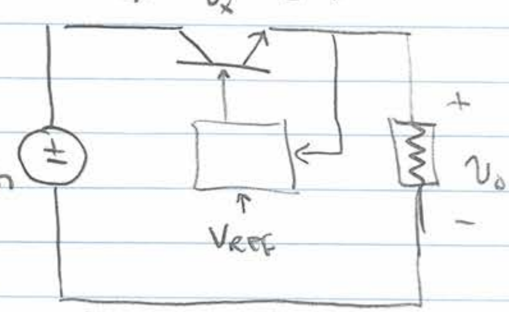
6.334 Lecture Notes — Analysis Meth + Rectifiers

☆ From Last lecture: Linear vs. switching

(Short summary to make point)

LINEAR REGULATOR

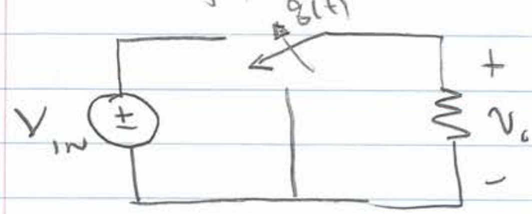


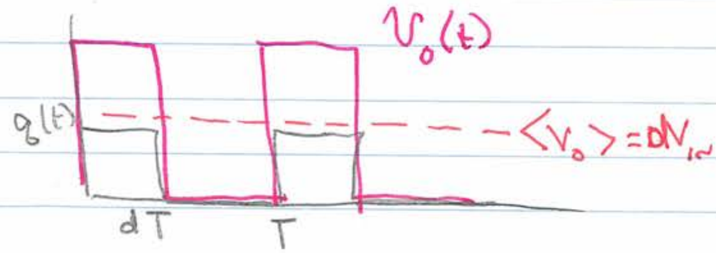
V_x controlled so $V_o = V_{REF}$

$\eta = \frac{V_o}{V_{IN}}$ ∴ $V_{IN} = 15$ $V_o = 5V \rightarrow 33\%$
$V_{IN} = 15$ $V_o = 1.5V \rightarrow 10\%$

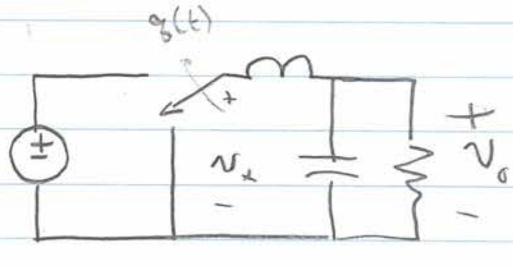
$\langle P_{diss} \rangle = \langle v_x i_o \rangle = V_x I_o \neq 0$

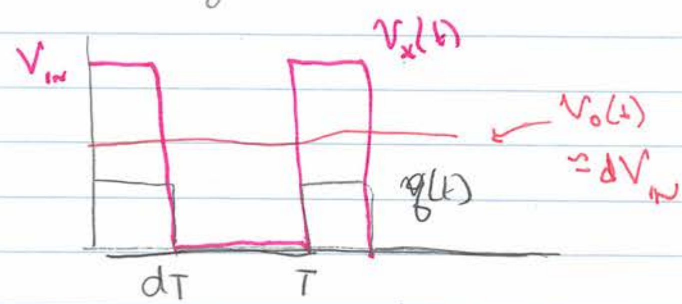
switching regulator.





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.

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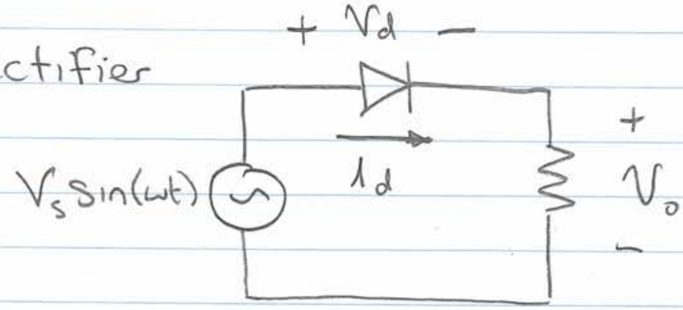
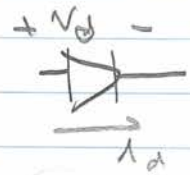
★ Method of Assumed States

Most power converters use semiconductor switches. Some switches are not fully controlled. Lets consider this case

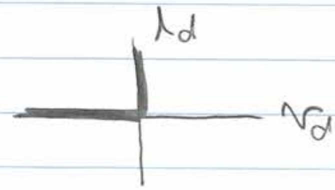
Simple rectifier





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. We use:

The method of assumed states

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

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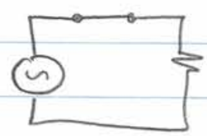
Note: check current if assumed on + Voltage if assumed off

Work through simple rectifier example:

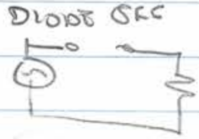
If $V_s \sin(\omega t) > 0$ & we assume diode off : $V_d > 0$
∴ diode must be on!

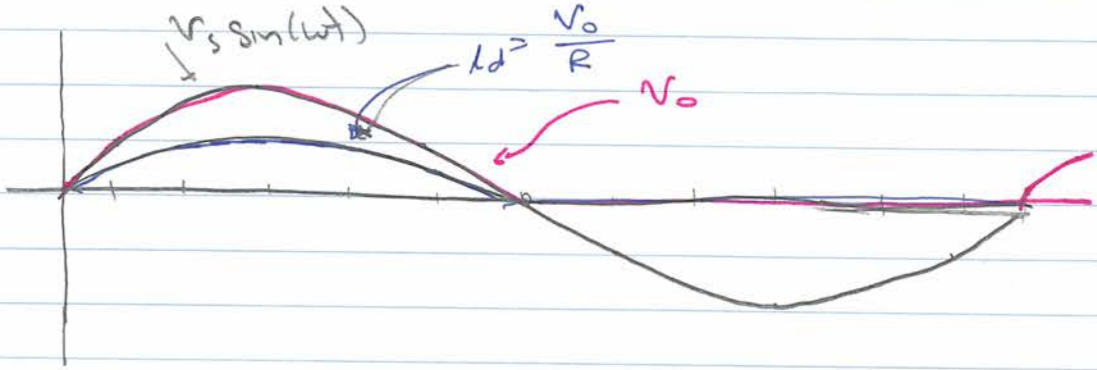
If $V_s \sin(\omega t) < 0$ & we assume diode on : $I_d < 0$
∴ diode must be off!

DIODE ON



DIODE OFF





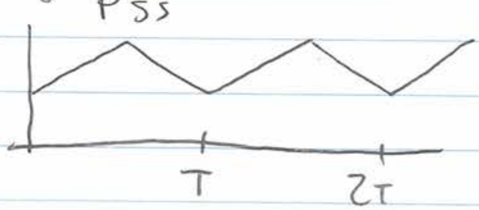
- Simple example, but useful for much more complicated systems
- many switched-system simulators work this way (piecewise linear)

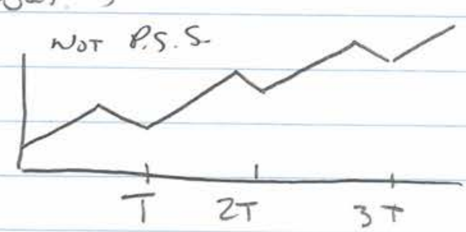
- Note: We identify <u>turn on</u> point by looking at voltage
  <u>turn off</u> point by looking at current

☆ Periodic Steady State

Power converters operate cyclicly. <u>In periodic Steady State</u> (P.S.S.), the system repeats the same behavior in each switching cycle. (look @ state variables!)

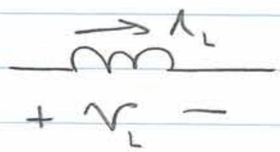
e.g.,





(often, we can look at the states at the <u>end</u> 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:



$$v_L = L \frac{d\lambda_L}{dt}$$

take average over time $\quad \langle v_L \rangle = \langle L \frac{d\lambda_L}{dt} \rangle = L \langle \frac{d\lambda_L}{dt} \rangle$

In periodic steady state $\quad \langle \frac{d\lambda}{dt} \rangle = 0$! no change over time

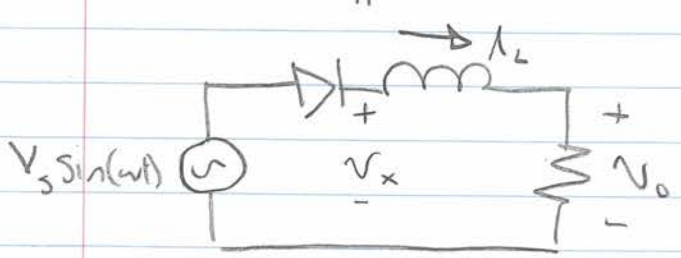
So:

Inductor in P.S.S.	$\langle V_L \rangle = 0$
Capacitor in P.S.S.	$\langle \lambda_C \rangle = 0$

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:

Example: Suppose we add an inductor to our simple rectifier for smoothing



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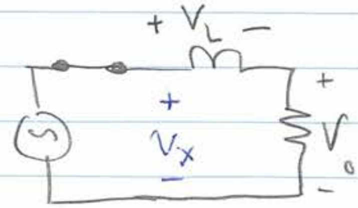
Suppose we assume the diode is always on:



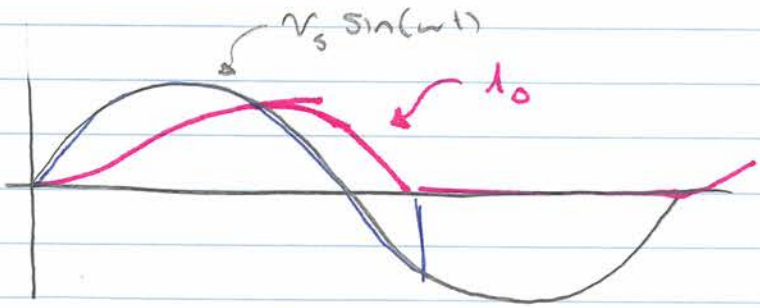
KVL: $V_s \sin(\omega t) - V_L - V_o = 0$

TAKE AVERAGE

$\langle V_s \sin(\omega t) \rangle - \langle V_L \rangle - \langle V_o \rangle = 0$

($\langle V_s \sin(\omega t)\rangle \to 0$; $\langle V_L \rangle \to 0$ in P.S.S.)

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



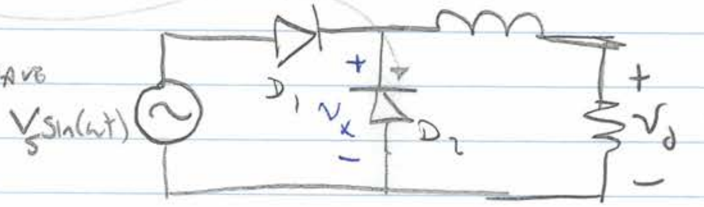
SHOW SIMULATION

In P.S.S. $\langle V_L \rangle = 0 \therefore \langle V_o \rangle = \langle V_x \rangle$. 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

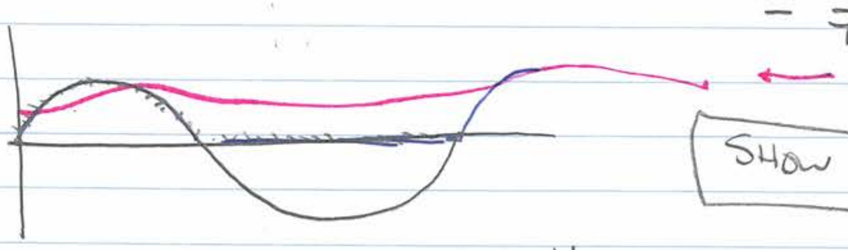
FREE-WHEELING DIODE

HALF-WAVE RECT



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 w/ source replacement + Fourier series.