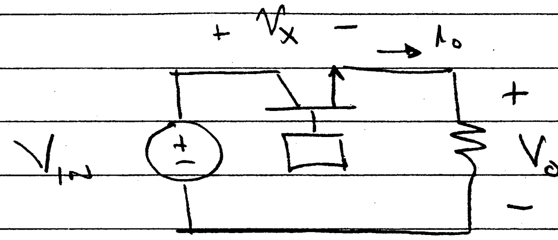
Power Electronics Notes - D. Perreault

★★ **Introduction: switching power electronics**

Read KSV Ch 1

Linear regulator



control V_x such that $V_o = V_{o,REF}$

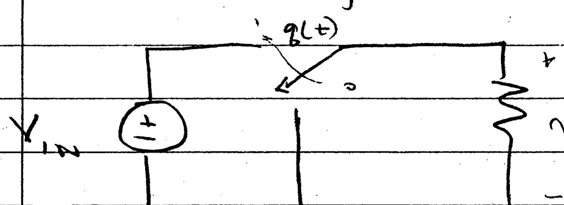
→ simple, accurate, high-bandwidth

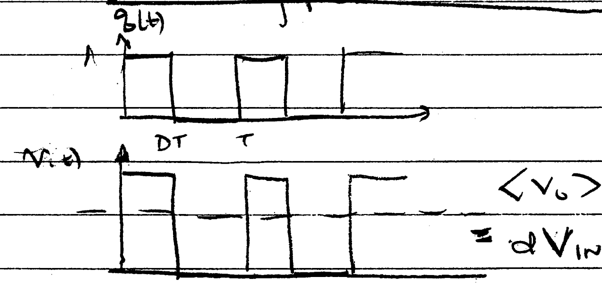
but $P_{diss} = \langle V_x i_o \rangle > 0$

$$\eta = \frac{P_{OUT}}{P_{IN}} = \frac{V_o i_o}{V_{IN} i_o} = \frac{V_o}{V_{IN}}$$

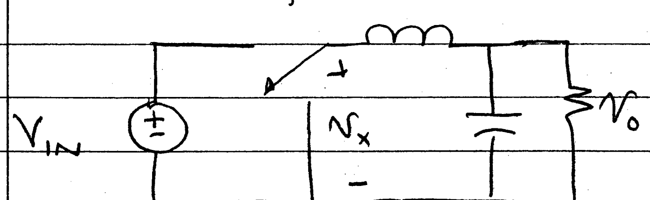
$(@ V_{IN} = 15V, V_o = 5V \rightarrow \eta = 33\%)$

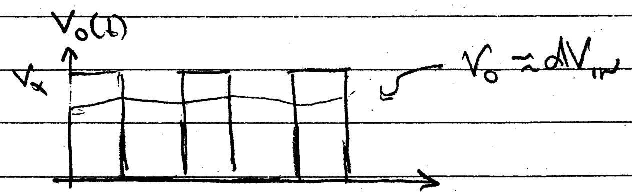
For Efficiency we will consider switching power converters

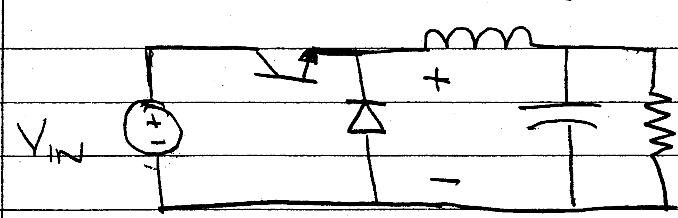




Add filtering







NOTE: ONLY LOSSLESS ELEMENTS

L, C energy storage

Switches { block V, carry I } NOT at same time!!

★ Use semiconductors as switches

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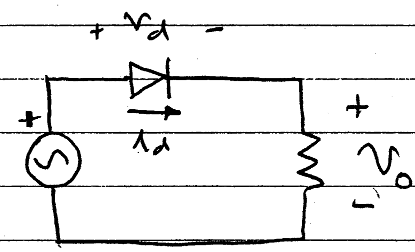
★★ Introduction to analysis techniques

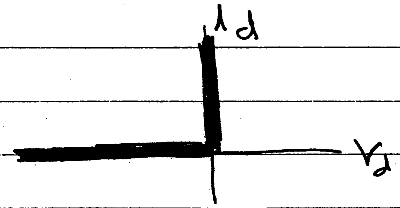
★ Method of assumed states

Semiconductor switches are typically not fully controllable. Lets consider how to analyze a switching circuit in time domain:

Simple Rectifier



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



The method of assumed states allows us to figure out which un/semi-controlled switches are on as a function of time.

1. Assume a state (on/off) for all semi/un controlled switches
2. Calculate voltages + currents in the system (Linear circuit theory)
3. See if any switch conditions are violated
   e.g. "on" diode has negative current
   "off" diode has positive voltages
4. If no violations → done
   If violation assume a new set of states

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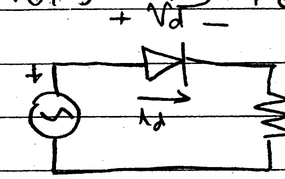
Simple Rectifier

Example: $V_s \sin(\omega t)$

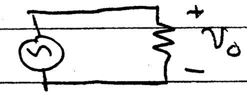
(Trivial but fundamental)



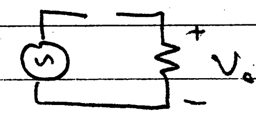
- If $V_s \sin(\omega t) > 0$ and we assume diode off: $V_d > 0$
  since this is not possible diode must be on during this condit.

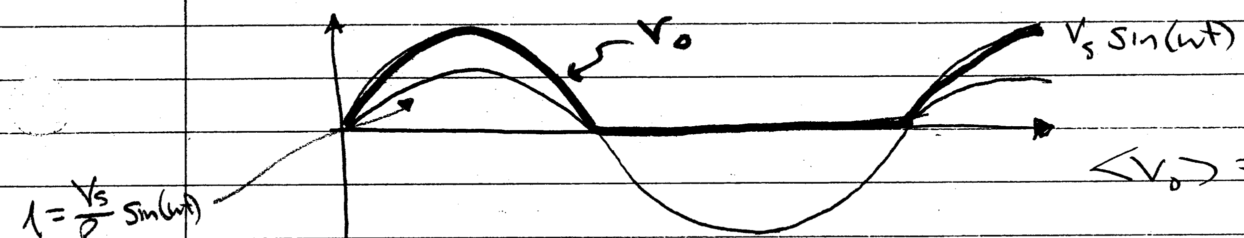
- If $V_s \sin(\omega t) < 0$ and we assume diode on: $i_d < 0$
  since this is not possible diode must be off during this condit.

$V_s \sin(\omega t) > 0 \rightarrow$ diode on



$V_s \sin(\omega t) < 0 \rightarrow$ diode off





$\langle V_o \rangle = \frac{V_s}{\pi}$

Very simple example but principle works in general

In power electronics we are often interested in the <u>periodic steady state.</u>

In <u>Periodic Steady state</u> the system returns to the same point at the end of every cycle (beginning matches end) so things are operating cyclicly.

IN P.S.S. inductor $\langle V_L \rangle = 0 \rightarrow$ average $\frac{di_L}{dt} = 0$

capacitor $\langle i_C \rangle = 0 \rightarrow$ average $\frac{dV_C}{dt} = 0$

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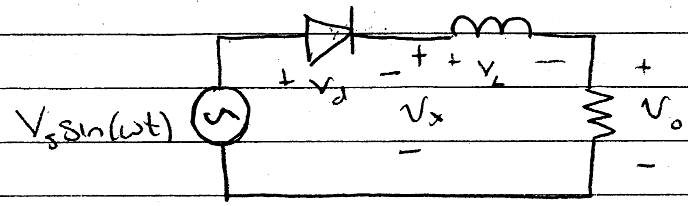
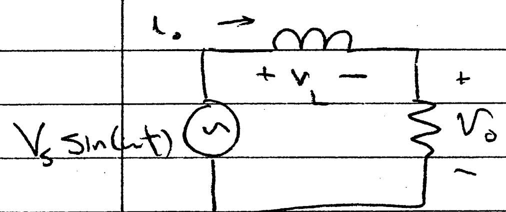
The P.S.S. conditions are useful for analysis. Consider adding a filter to smooth the ripple current in our simple rectifier



If we assume diode is always on in P.S.S. Then

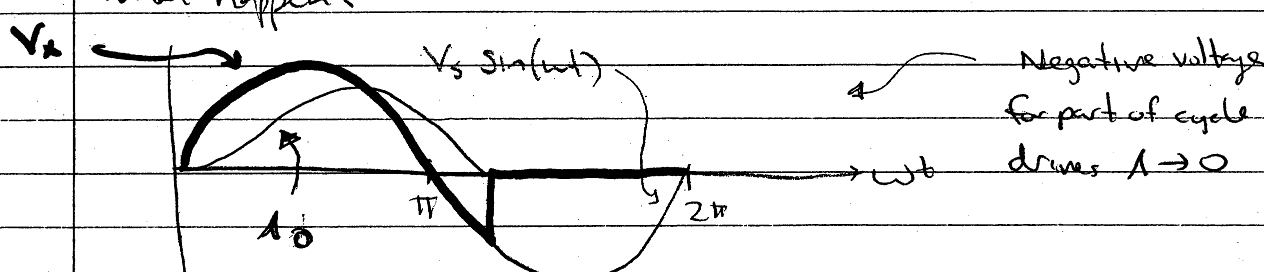


$$V_s \sin(\omega t) - V_L - V_o = 0$$

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

∴ If diode were always on $\langle v_o \rangle = 0$ and i_o must be < 0 part of the time. ∴ we know diode must turn off during part of cycle by Meth. Assumed States

what happens:



Exact analysis in KSV sect 3.2.2. Good for review of time-domain analysis.

main point: Meth. Ass. States + P.S.S. condition are useful tools to determine system analysis

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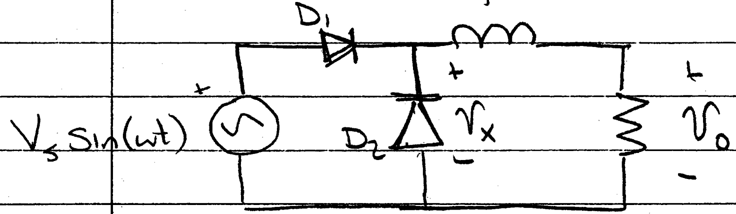
Now, in P.S.S. $\langle V_x \rangle = \langle V_o \rangle$, since $\langle V_L \rangle = 0$

$\langle V_x \rangle$ is pos $\frac{1}{2}$ sin plus some neg $\frac{1}{2}$ sin, so we lose some voltage as compared to a + $\frac{1}{2}$ sin.

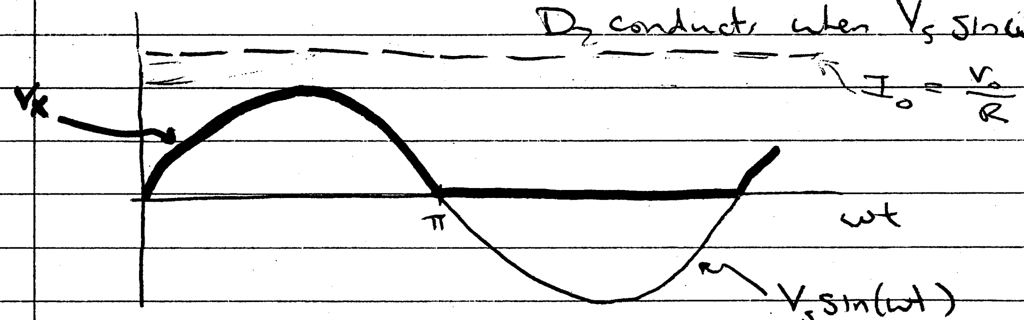
Soln: Freewheeling diode → Half-wave Rectifier



D_2 clamps so that V_x never goes negative. i_o "freewheels"

Use meth. ass. states

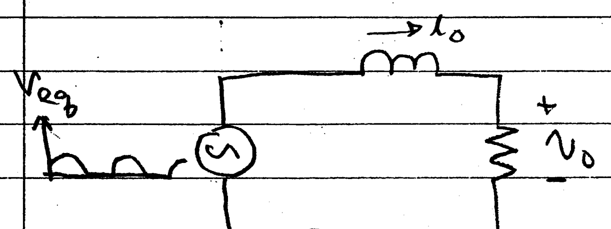
D_1 conducts when $V_s \sin\omega t > 0$
D_2 conducts when $V_s \sin\omega t < 0$



$\langle V_L \rangle = 0$ in p.s.s. $\therefore \langle V_o \rangle = \langle V_x \rangle = \frac{1}{2\pi}\int_0^{\pi} V_s \sin(\varphi)\,d\varphi = \frac{V_s}{\pi}$

Note: This circuit is rarely used today for several reasons, but the analysis technique is the key point. Full-wave rectifier is more common.

★ Note: For analyzing output current, output voltage etc. we can do ~~an~~ <u>equivalent-source replacement</u>



linear circuit with sum of fourier sources.

$$V_{eq} = \sum_{n=0}^{\infty} A_n \cos(n\omega t + \phi_n)$$