ECE 398GG – ELECTRICAL VEHICLES

12a. Power Converter Basics

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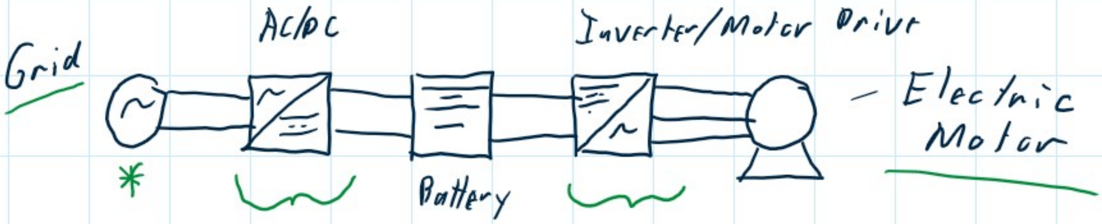
Power Electronics

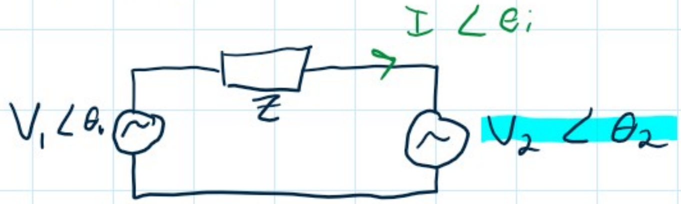
Tuesday, March 29, 2022 9:15 AM

Today:
↳ Switching Power Converters - Basics

High Level System:



Review



Grid EV Charger

Power into the EV Charger, P_2

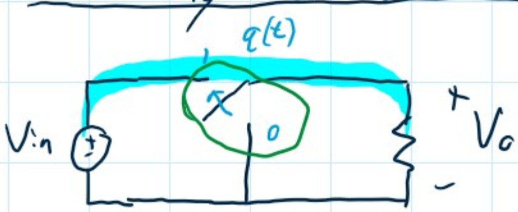
$$P_2 = \frac{V_1 \cdot V_2}{|Z|} \cdot \sin(\theta_2 - \theta_i)$$

↳ EV charger regulates Voltage + Phase the grid "sees" to control power flow

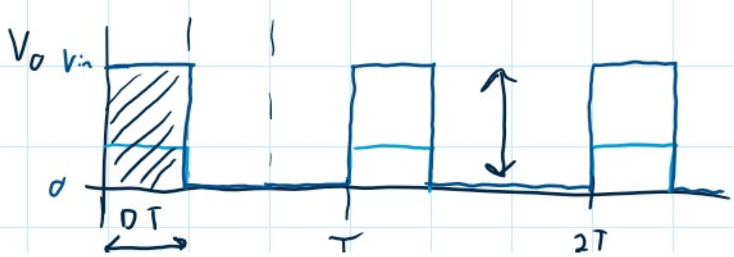
How? Power Electronics [ECE 464/469]

Goal: want to regulate V_{out}, from V_{in}

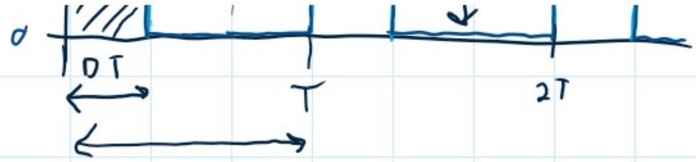
Switching Converter (DC-DC)



D = duty cycle
$0 \leq D \leq 1$



i.e. $D = 33\% = 1/3$



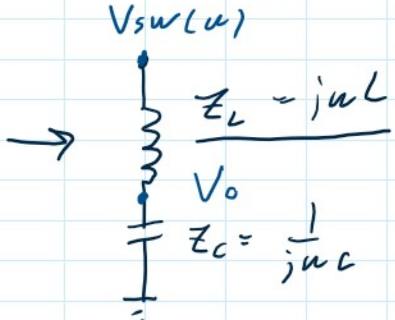
i.e. $D = 33\% = 1/3$

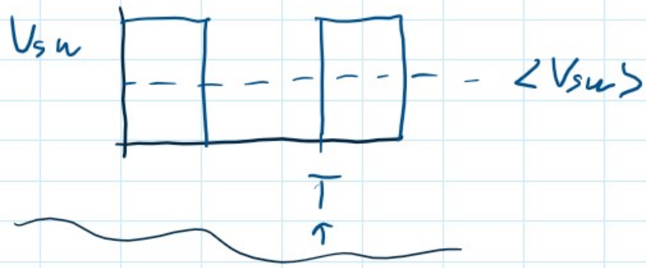
$$\langle V_o \rangle = \frac{V_{in} \cdot DT}{T} = D V_{in} = \langle V_o \rangle$$

↳ we can generate the right <u>average</u> value by switching

↳ add a filter (LPF) to extract Avg

↳ all elements of filter (LC) are lossless
↳ high efficiency possible





$$V_o = \frac{Z_C}{Z_L + Z_C} \cdot V_{sw}$$

$$V_o(\omega_k) = \frac{Z_C(\omega_k)}{Z_L(\omega_k) + Z_C(\omega_k)} \cdot V_{sw}(\omega_k)$$

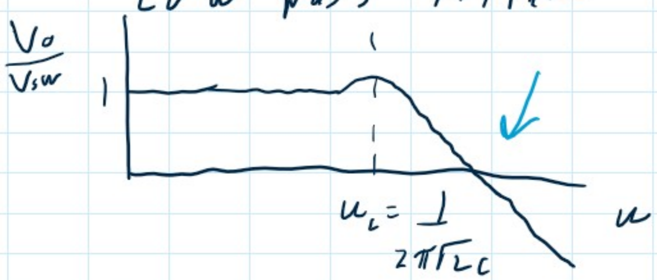
$\omega \Rightarrow 0$ $\quad Z_L(\omega) \Rightarrow 0$, $Z_C \Rightarrow \infty$

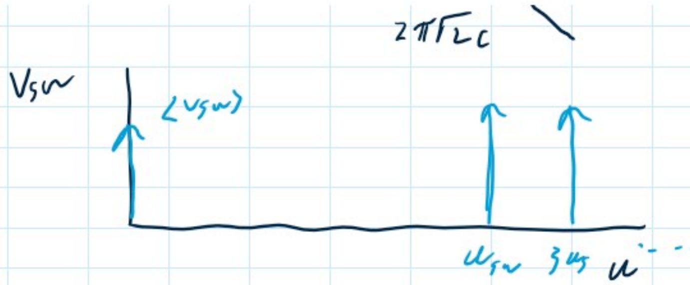
$V_o(\omega_0) = V_{sw}(\omega_0)$ [inductor is short at DC]

$\omega \Rightarrow \infty$ $\quad Z_L \Rightarrow \infty$, $Z_C \Rightarrow 0$

$V_o(\omega_\infty) \Rightarrow 0$

Low pass filter



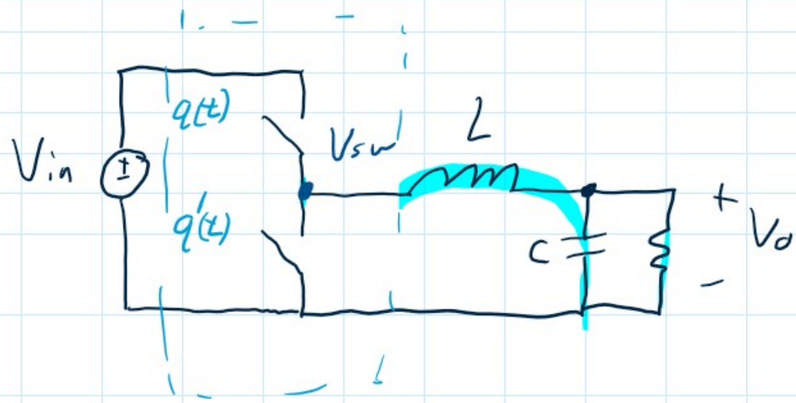


$f_{sw} = \frac{1}{T}$

Low frequency DC component passes through

↳ High frequency switching are filtered out

Buck converter



$\langle V_{sw} \rangle = D \cdot V_{in}$ $\quad V_o = \langle V_{sw} \rangle = D V_{in}$

observation: $\langle V_L \rangle$?

$$\underline{\langle V_{sw} \rangle} = \langle V_L \rangle + \underline{\langle V_o \rangle}$$

$$\Rightarrow \underline{\langle V_L \rangle = 0}$$

This makes sense from an energy perspective

↳ for an ideal power converter in steady state, $\langle P_{out} \rangle = \langle P_{in} \rangle$

$\langle energy \rangle$ in L, C should be constant

$\langle E_L \rangle = \langle \frac{1}{2} L i_L^2 \rangle \quad \langle E_C \rangle = \langle \frac{1}{2} C V_c^2 \rangle$

⟨energy⟩ in L, C must be constant

$$\langle E, L \rangle = \langle \tfrac{1}{2} L i_L^2 \rangle \qquad \langle E, C \rangle = \langle \tfrac{1}{2} C V_C^2 \rangle$$

$$\left\langle \frac{dE_L}{dt} \right\rangle = 0 \qquad \left\langle \frac{dE_C}{dt} \right\rangle = 0$$

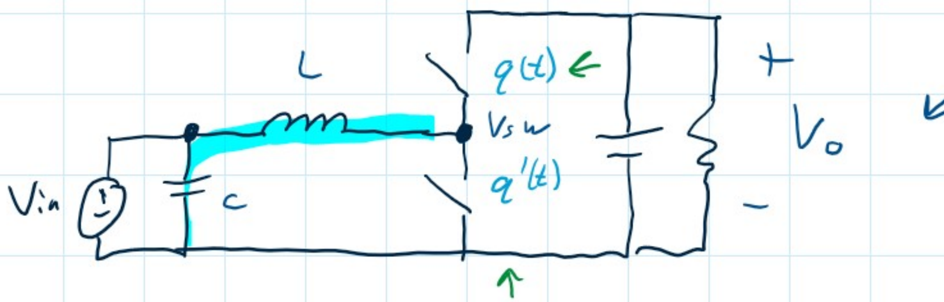
$$\langle V_L \rangle = \left\langle L \frac{di_L}{dt} \right\rangle = 0 \qquad \langle i_C \rangle = \left\langle C \frac{dV_C}{dt} \right\rangle = 0$$

In Periodic Steady state

$$\boxed{\langle V_L \rangle = 0, \quad \langle i_C \rangle = 0}$$

$$\langle P_{in} \rangle = \langle P_{out} \rangle$$

Example: Boost Converter



$$\langle V_{sw} \rangle = D \cdot V_o = V_{in}$$

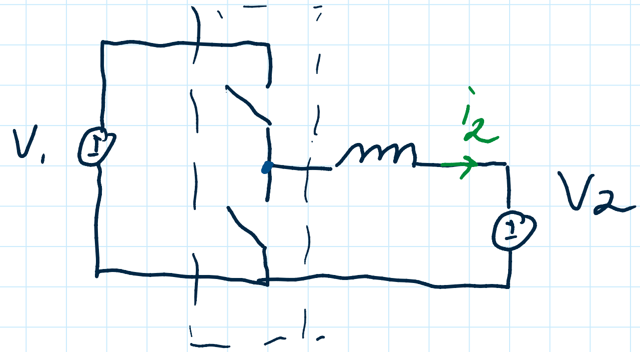
$$\frac{V_o}{V_{in}} = \frac{1}{D} \quad \text{- reverse of Buck}$$

$$V_{out} = \frac{1}{D} \cdot V_{in}$$

Note: common convention in Boost is the low side switch is active switch

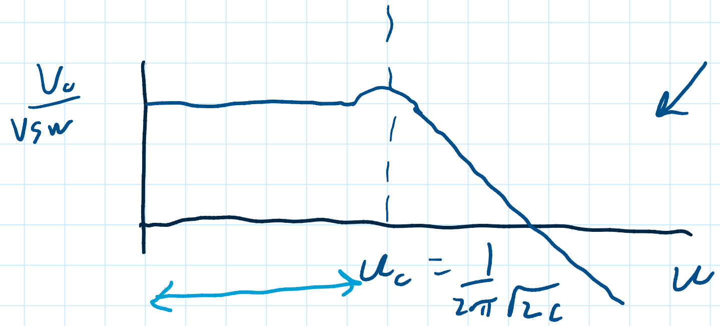
$$\frac{V_o}{V_{in}} = \frac{1}{1-D}$$

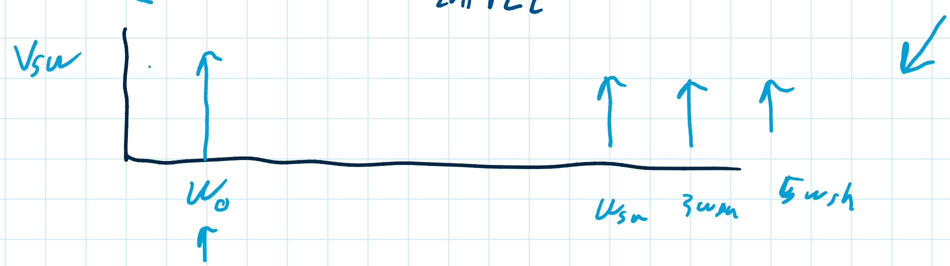
↳ we can abstract this



AC / DC + DC / AC conversion

recall Buck LC Filter

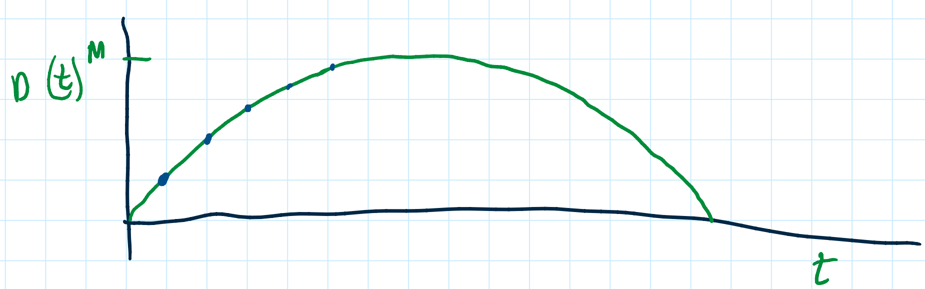


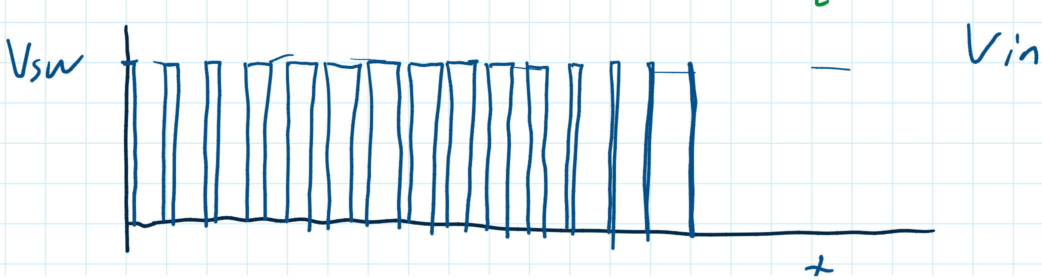


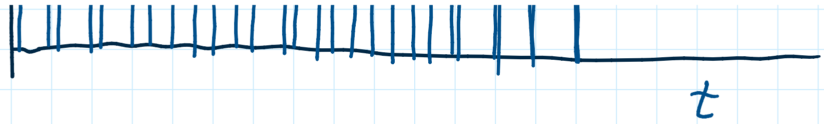
$f = 60\,Hz \qquad \omega_0 = 2\pi f = 377\ rad/s$

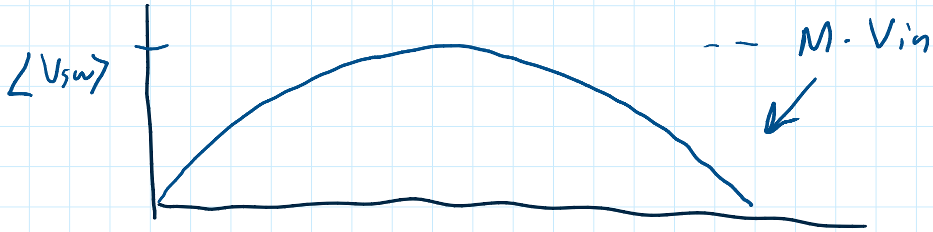
instead of D, we have D(t)

$D(t) = M \cdot \sin(\omega_0 t)$





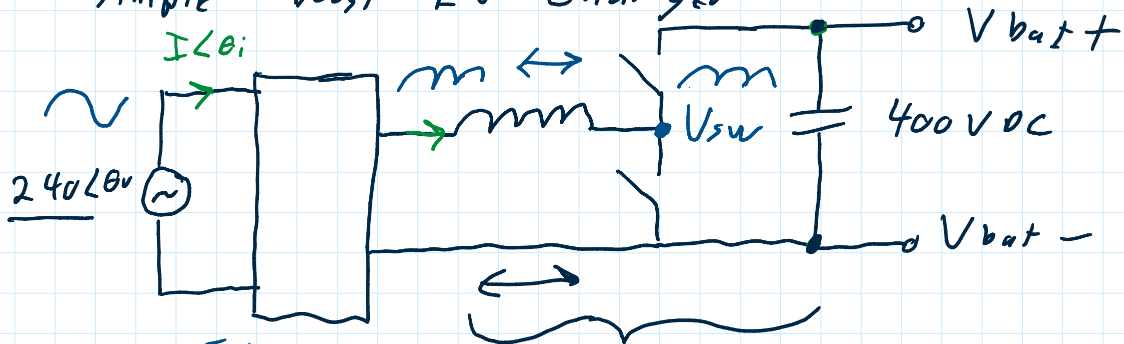


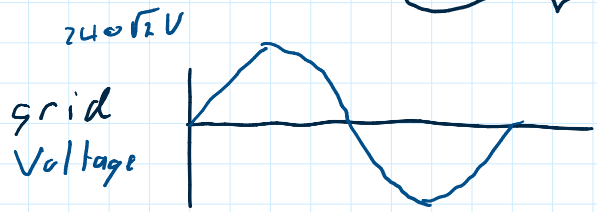


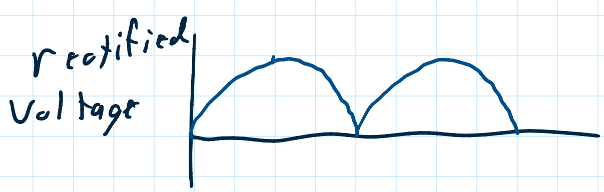
↳ Note: add unfolder, or use bipolar source to get negative half cycle

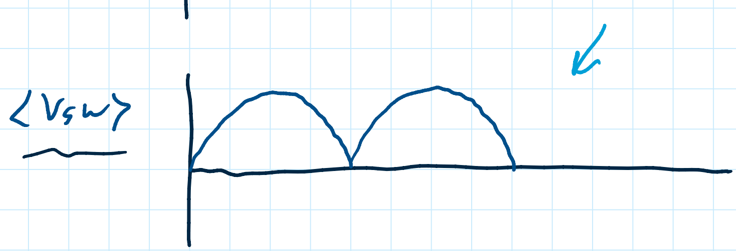
↳ this can be in buck (step down) or Boost operation (step up)

Simple Boost EV charger









EV charger controls <Vsw>

↳ control Power flow into/out of EV (Battery)

↳ control Power flow into/out of EV (Battery)

↳ also controls current phase ⇒ ϕ

↳ also control P + Q