12a. Power Converter Basics

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Today:
4. Switching Power Converters - Basics

High Level System:

Grid  \rightarrow  AC/DC  \rightarrow  Battery  \rightarrow  Inverter/Motor Drive  \rightarrow  Electric Motor

Review

\[ I \leq I_i \]

\[ V_1 \leq V_0 \quad \text{and} \quad V_2 \leq 0_2 \]

Grid  \rightarrow  EV Charger

Power into the EV Charger, \( P_2 \)

\[ P_2 = \frac{V_1 \cdot V_2}{12} \cdot \sin (\omega - \theta_i) \]

The EV charger regulates voltage and 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)

\[ V_{in} \rightarrow V_0 \]

\[ V_0 \rightarrow V_{out} \]

\[ D = \text{duty cycle} \quad 0 \leq D \leq 1 \]

i.e. \( D = 33\% = \frac{1}{3} \)
\[\langle V_o \rangle = \frac{V_{in} \cdot DT}{T} = \frac{P}{V_{in}} = \langle V_o \rangle\]

We can generate the right average value by switching.

Add a filter (LPF) to extract AC.

All elements of filter (LC) are lossless. High efficiency possible.

\[V_{sw}(\omega) = \frac{Z_C}{Z_L + Z_C} \cdot V_{sw}\]

\[V_o(\omega) = \frac{Z_C(\omega)}{Z_L(\omega) + Z_C(\omega)} \cdot V_{sw}(\omega)\]

\[\omega \to 0 \quad Z_L(\omega) \to 0, \quad Z_C \to \infty\]

\[V_o(\omega) = V_{sw}(\omega) \quad \text{inductor is short at DC}\]

\[\omega \to \infty \quad Z_C \to 0, \quad Z_L \to 0\]

\[\frac{V_o}{V_{sw}} \to 0\]

Low pass filter.

\[u_c = \frac{1}{2\pi fC}\]

\[V_{sw} \quad \text{...}^\uparrow\]
\[ f_{sw} = \frac{1}{T} \]

Low frequency DC component passes through
⇒ High frequency switching are filtered out

**Buck converter**

\[ \langle V_{sw} \rangle = D \cdot V_{in} \]
\[ V_0 = \langle V_{sw} \rangle = D \cdot V_{in} \]

**Observation:** \( \langle V_L \rangle ? \)

\[ \langle V_{sw} \rangle = \langle V_L \rangle + \langle V_0 \rangle \]
\[ \Rightarrow \langle V_L \rangle = 0 \]

This makes sense from an energy perspective

by for an ideal power converter in steady state, \( \langle P_{in} \rangle = \langle P_{out} \rangle \)

\( \langle \text{energy} \rangle \) in \( L, C \) should be constant

\[ \langle E, L \rangle = \frac{1}{2} L \langle i_L^2 \rangle \]
\[ \langle E, C \rangle = \langle \frac{1}{2} C V_c^2 \rangle \]
\( \langle E_L \rangle = \frac{1}{2} L i_c^2 \)  
\( \langle E_c \rangle = \frac{1}{2} c V_o^2 \)

\( \langle \frac{dE_L}{dt} \rangle = 0 \)  
\( \langle \frac{dE_c}{dt} \rangle = 0 \)

\( \langle V_L \rangle = \langle \frac{d}{dt} i_c \rangle = 0 \)  
\( \langle i_c \rangle = \langle c \frac{dV_o}{dt} \rangle = 0 \)

In periodic steady state:
\[ \langle V_L \rangle = 0, \quad \langle i_c \rangle = 0 \]
\[ \langle P_{in} \rangle = \langle P_{out} \rangle \]

Example: Boost Converter

Example Circuit Diagram

\[ \langle V_{sw} \rangle = 0 \cdot V_o = V_{in} \]

\[ \frac{V_o}{V_{in}} = \frac{1}{D} \quad \text{Reverse of Buck} \]

\[ V_{out} = \frac{1}{D} \cdot V_{in} \]

Note: Common convention in Boost is that the low side switch is active.

\[ \frac{V_o}{V_{in}} = \frac{1}{1-D} \]

By we can abstract this
AC/DC + DC/AC Conversion

Recall Buck LC Filter

\[ V_{in} \]

\[ V_{sw} \]

\[ V_{out} = \frac{1}{2\pi f L C} U \]

\[ f = 60 \text{ Hz} \quad \omega_0 = 2\pi f = 377 \text{ rad/s} \]

Instead of \( D \), we have \( D(t) \)

\[ D(t) = M \cdot \sin(\omega_0 t) \]

\[ V_{in} \]
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**

- Grid Voltage
- Rectified Voltage
- $V_{sw}$

**EV charger controls $V_{sw}$**

To control power flow into/out of EV (Battery).
By control Power flow in/out of EV (Battery)
By also controls current phase = \( \Phi \)
By also control \( P + Q \)