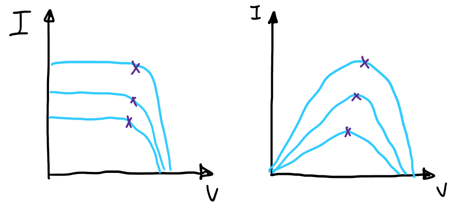
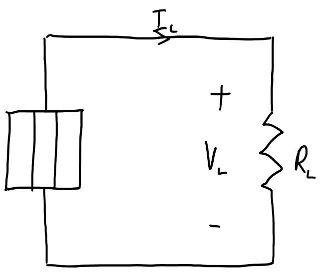
MPPT: DC-DC

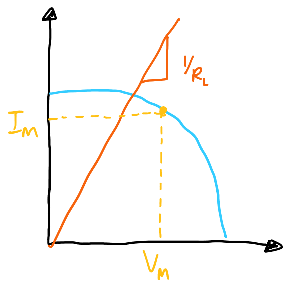
Tuesday, March 5, 2024 4:00 PM

Maximum Power Point Tracking



As ambient conditions change, the optimal operating point (V, I) moves around

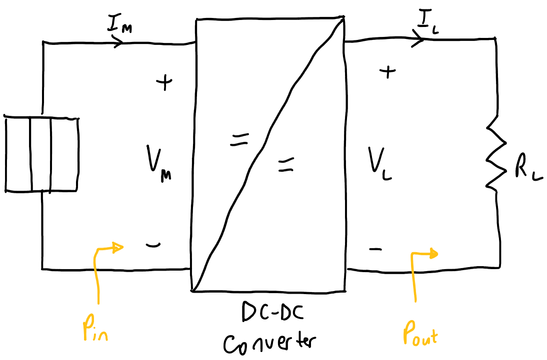




In general,

$$(V_L, I_L) \neq (V_{MPP}, I_{MPP})$$

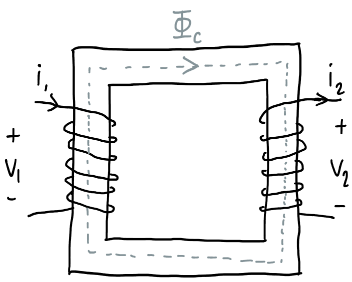
- **GOAL** Design a circuit to track the MPP



Desired characteristics:

1) $\eta = 100\%$ or $V_m I_m = V_L I_L$
2) Control capability as MPP changes, want to fix operation at MPP

- **QUESTION** How to construct DC-DC converter?
  - Seek inspiration from AC domain $\longrightarrow$ transformers



Faraday's Law:

$$\frac{V_1}{V_2} = \frac{n_1}{n_2}, \quad n_1 i_1 = n_2 i_2$$

Ideal transformer: $V_1 i_1 = V_2 i_2$

$\rightarrow$ transformer saturates at DC

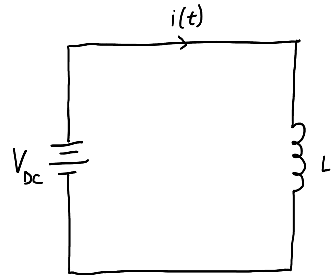
→ turns ratio is fixed, but we want increased flexibility/control

- DC-DC converters
  - buck converter
  - boost converter
  - buck-boost converter
  - flyback, Cuk, etc. ...

- Composed of energy storage (C,L), switches (FETs, diodes), control (digital, analog)

- Some fundamentals

1)



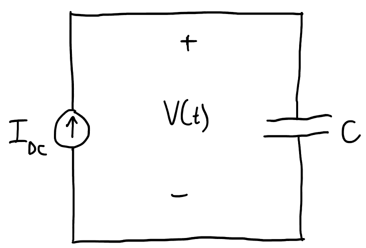
$V_{DC} = L \frac{di}{dt}$

$\frac{di}{dt} = \frac{V_{DC}}{L}$

→ $i(t) \uparrow$

BAD IDEA

2)



$I_{DC} = C \frac{dv}{dt}$

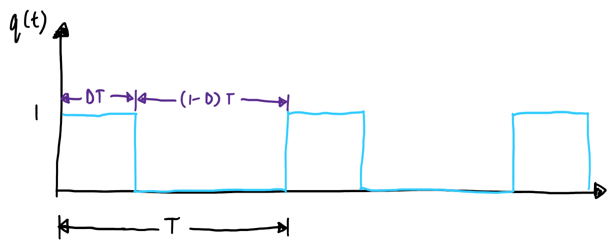
→ $V(t) \uparrow$ by similar logic from 1

BAD IDEA

- Relevant because DC-DC converters are composed of L and C.

- Guiding principle
  - $\langle V_L \rangle = 0$
  - $\langle i_c \rangle = 0$

3) Switching Waveform



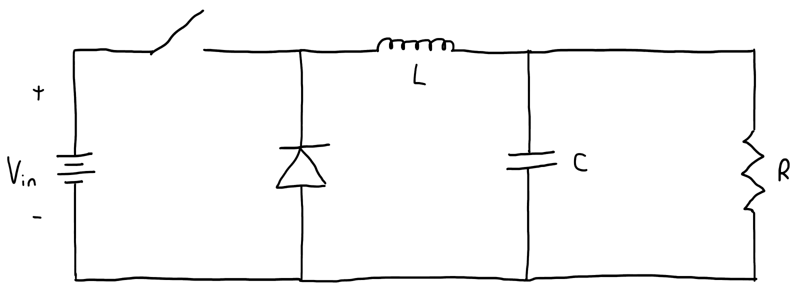
$$\langle q(t) \rangle = \frac{1 \times DT + 0 \times (1-D)T}{T}$$

$$= D \qquad 0 \leq D \leq 1$$

duty cycle

- DC-DC converters have switches that are controlled by "switching signals"
- Average behaviour is important in DC-DC converters

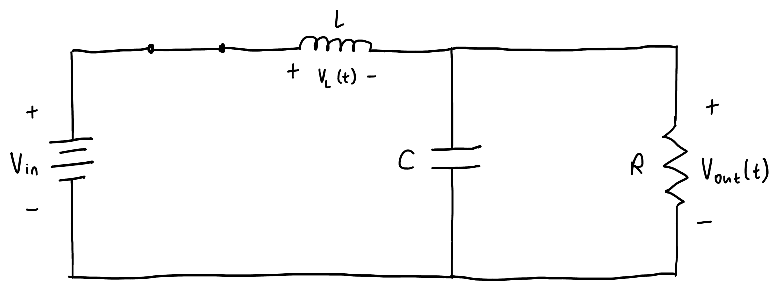
- DC-DC Buck Converter



- Ideal switch controlled by q(t)
- Ideal diode
- Energy Storage L, C

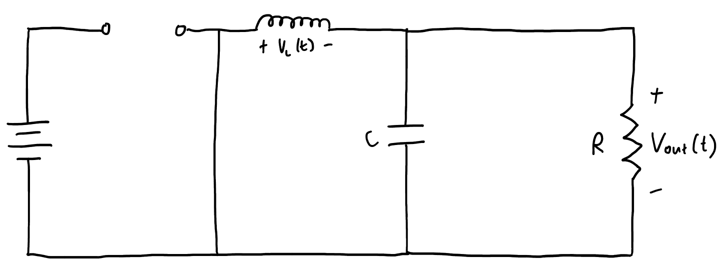
- Operating Principle

1) When switch is closed, diode is in reverse bias



$$V_L(t) = V_{in} - V_{out}(t)$$

2) When switch is open.



$V_L(t) = -V_{out}(t)$

- If capacitor is large, $V_{out} \approx$ constant $= V_{out}$

on average

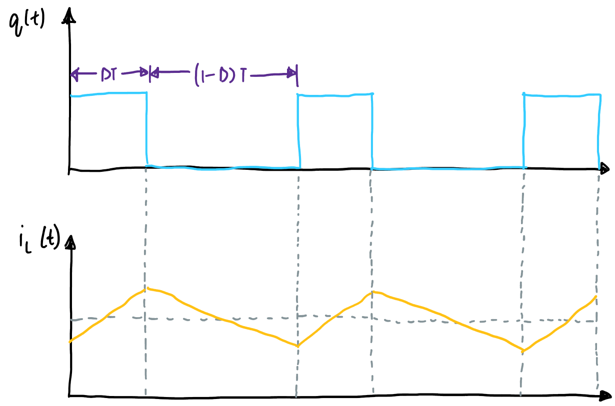
$$\langle V_L(t) \rangle = 0 = \frac{1}{T}\left(DT\left(V_{in} - V_{out}\right) + (1-D)T(-V_{out})\right)$$

$$0 = D V_{in} - D V_{out} - V_{out} + D V_{out}$$

$$\boxed{V_{out} = D V_{in}} \qquad 0 \leq D \leq 1$$

- Since D is tunable, we have built a controllable DC-DC converter that can deliver output voltage < input voltage

- Waveforms



Large C → effectively DC voltage source with some small ripple

Large L → effectively DC current source with some small ripple

1) Switch closed: $V_L(t) = V_{in} - V_{out} > 0$

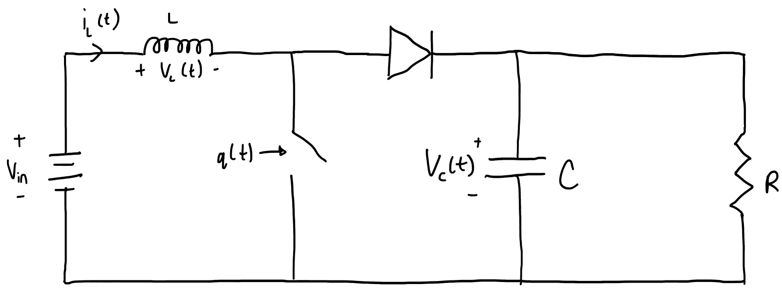
$\frac{di_L}{dt} > 0 \longrightarrow i_L(t) \uparrow$

2) Switch open: $V_L(t) = -V_{out}$

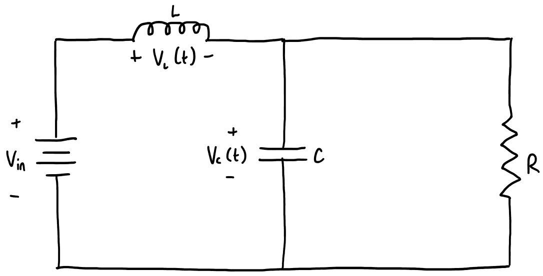
$\frac{di_L}{dt} < 0 \longrightarrow i_L(t) \downarrow$

- What if we want $V_{out} > V_{in}$? ⟶ Boost Converter

- DC-DC Boost Converter

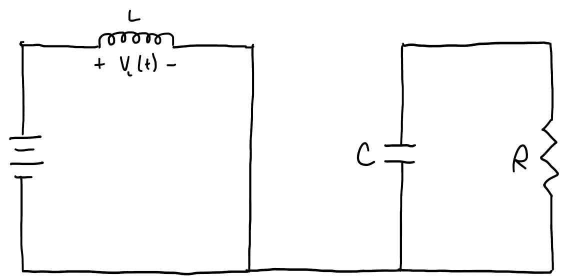


- Switch is open, diode in full bias



$V_L(t) = V_{in} - V_{out}(t)$

- Switch is closed



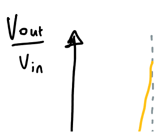
$V_L(t) = V_{in} \rightarrow i_L(t) \uparrow$

$V_L(t) = q(t)\, V_{in} + (1-q(t))(V_{in} - V_{out}(t))$

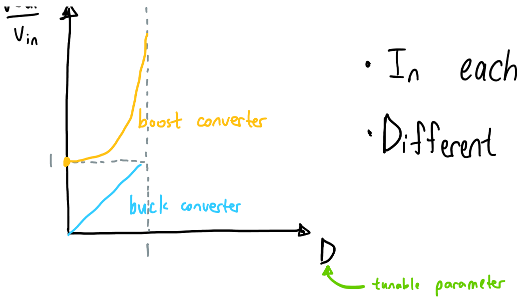
C is large $\rightarrow V_{out}(t) \approx V_{out}$ constant

$$\langle V_L(t) \rangle = 0 = \langle q(t) \rangle V_{in} + \langle 1 - q(t) \rangle (V_{in} - V_{out})$$
$$= DV_{in} + (1-D)(V_{in} - V_{out})$$
$$= DV_{in} + V_{in} - V_{out} - DV_{in} + DV_{out}$$
$$= V_{in} - (1-D)V_{out}$$

$$\boxed{V_{out} = \frac{1}{1-D} V_{in}}$$



- In each topology, we have $V_{out} = f(D)\, V_{in}$



- In each topology, we have $V_{out} = f(D)\,V_{in}$
- Different $f(D)$ can result in $V_{out} \le V_{in}$ (buck), $V_{out} \ge V_{in}$ (boost), or either (buck-boost)