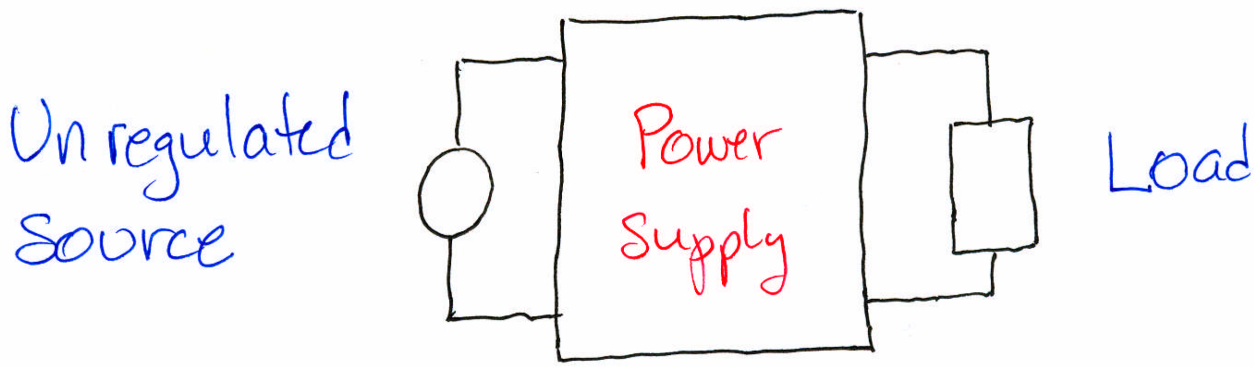
6.002 - Lecture 26

Power Electronics

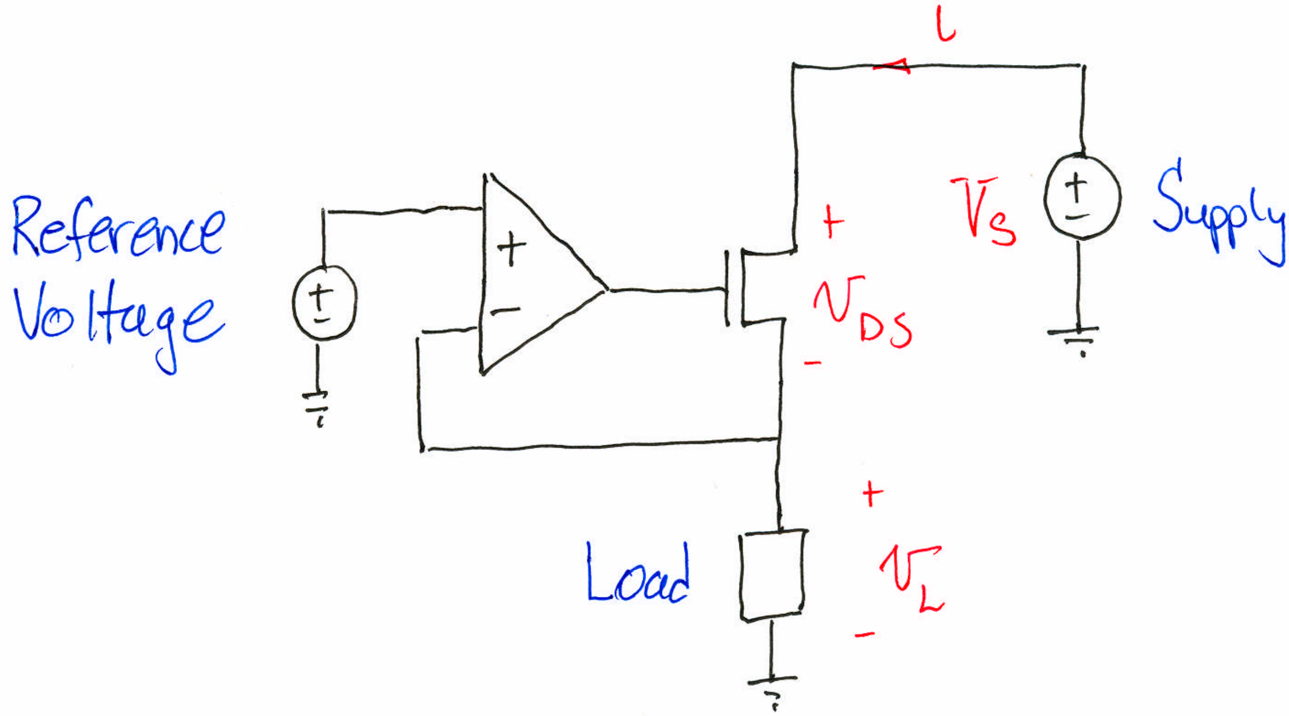
- Introduction To Power Electronics
- Power Supplies
- Example: Solar-Powered Motor Drive

Power Supply Objectives



- Regulated load voltage or current despite an unregulated source.
- High efficiency.
- AC / DC source and AC/DC load.

Linear Power Supply Example

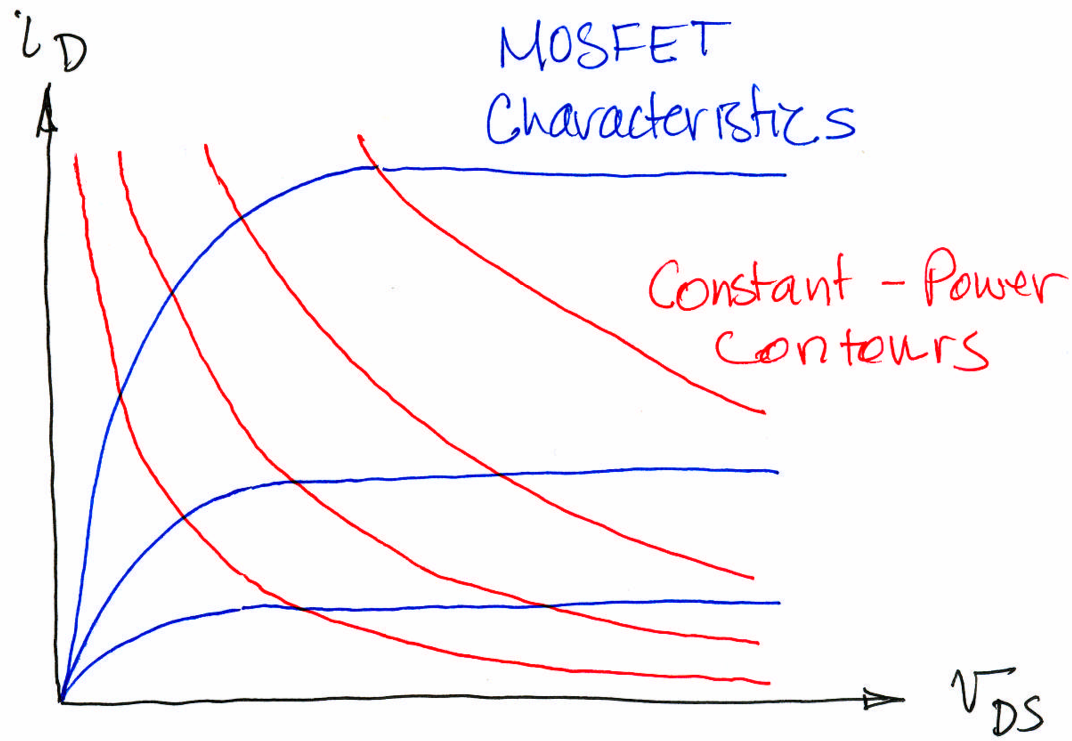


$$\underbrace{V_S\, i}_{\text{Power From Supply}} = \underbrace{v_{DS}\, i}_{\text{Power Lost In MOSFET}} + \underbrace{v_L\, i}_{\text{Power Into Load}}$$

Suppose: $V_S = 12 \ldots 6$ Volts, $v_L = 5\,V$ and $i = 1\,A$.

Then, for $V_S = 12$ Volts, $P_L = 5W$, $P_{MOSFET} = 7\,W$, and efficiency $= 47\%$. Not good!

MOSFET Losses



- Transistors are lossy valves.
- Loss ⇒ lost energy ⇒ lost fuel \$.
  Loss ⇒ heat ⇒ heat management \$.
- Least loss occurs during cutoff ($i_D = 0$) and deep within the triode region ($v_{DS} \simeq 0$).

Power Electronics

- Power electronics are not necessarily "powerful" electronics.

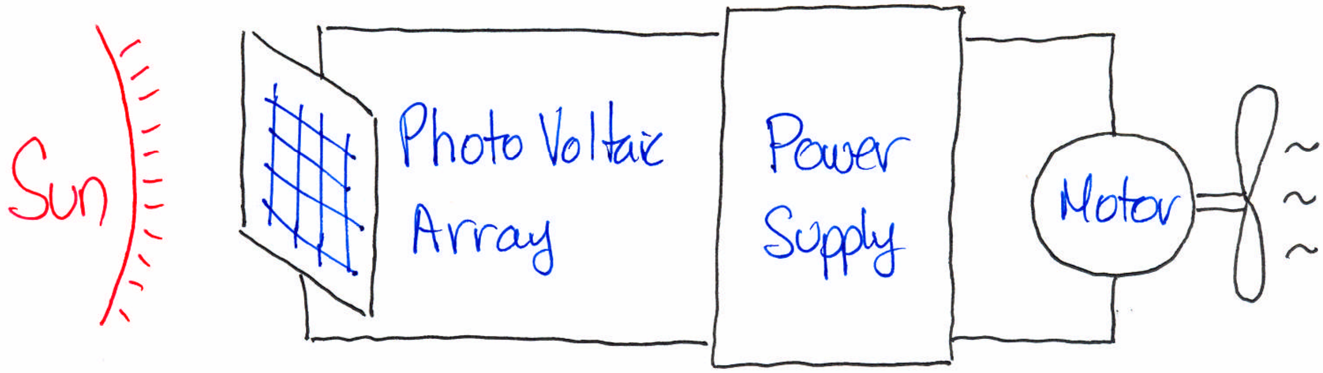
- Power electronics denotes a design paradigm targeting circuits that process energy with very high efficiency.

Transistors/Diodes $\Rightarrow$ Ideal switches: either on or off.

Capacitors/Inductors $\Rightarrow$ Used for energy storage and filtering.

Resistors $\Rightarrow$ No first-order use.

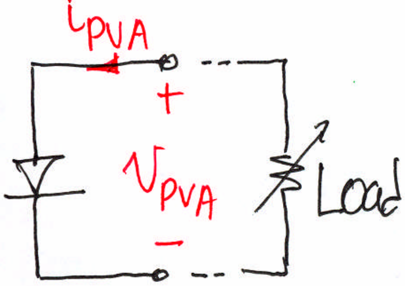
Solar-Powered Motor Drive

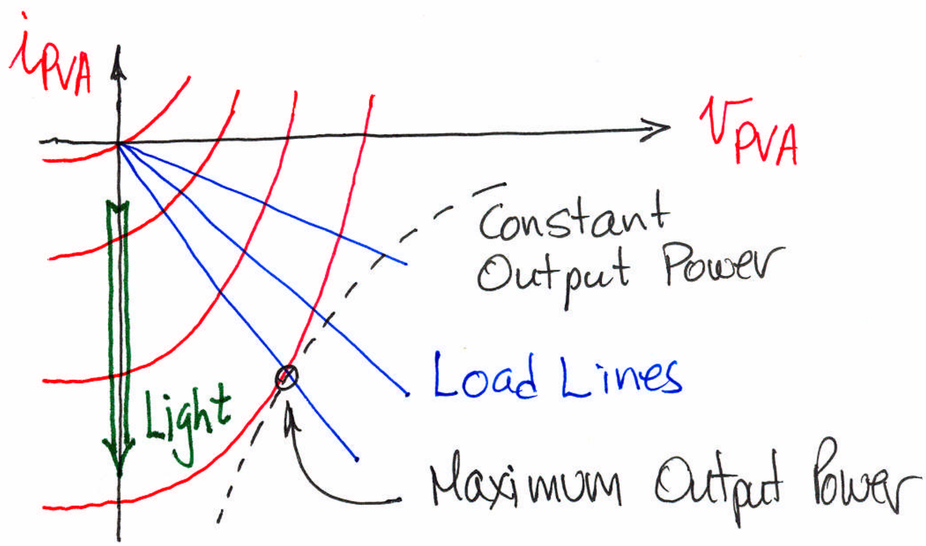


Energy Source	Energy Conversion	Energy Processor	Working Load

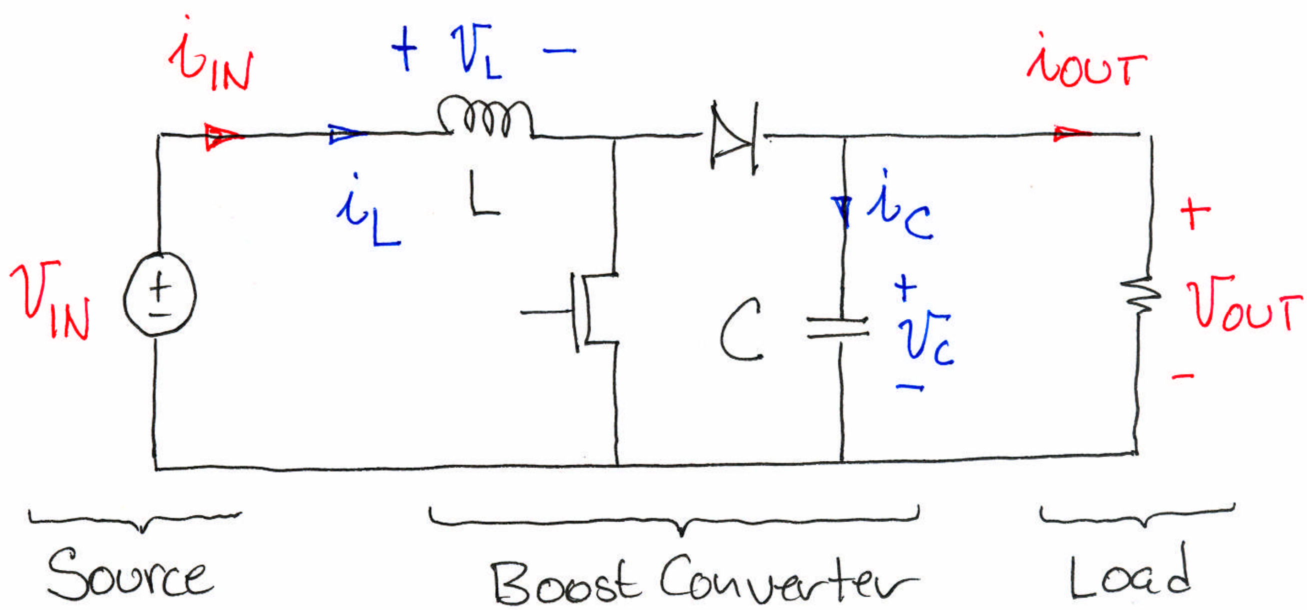
Demo Solar PVA ⇒ 9 V at maximum power } 3:1 Voltage
Demo Motor ⇒ 27 V at the same power } boost desired

PVA

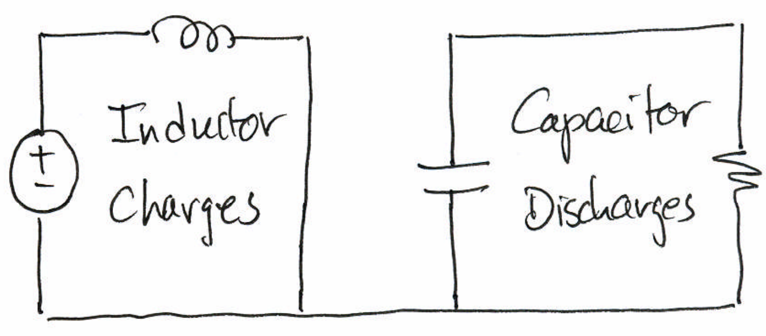




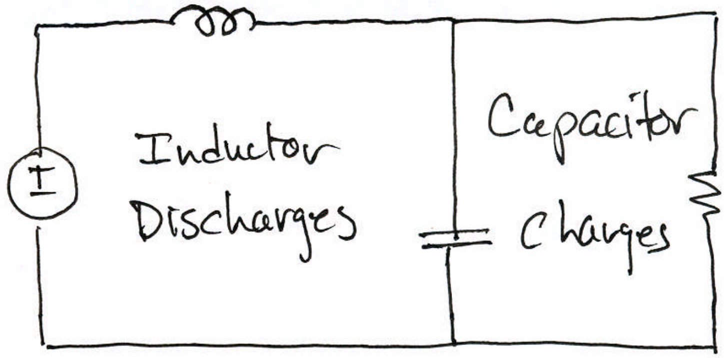
Boost Converter



MOSFET On
Diode Off



MOSFET Off
Diode On

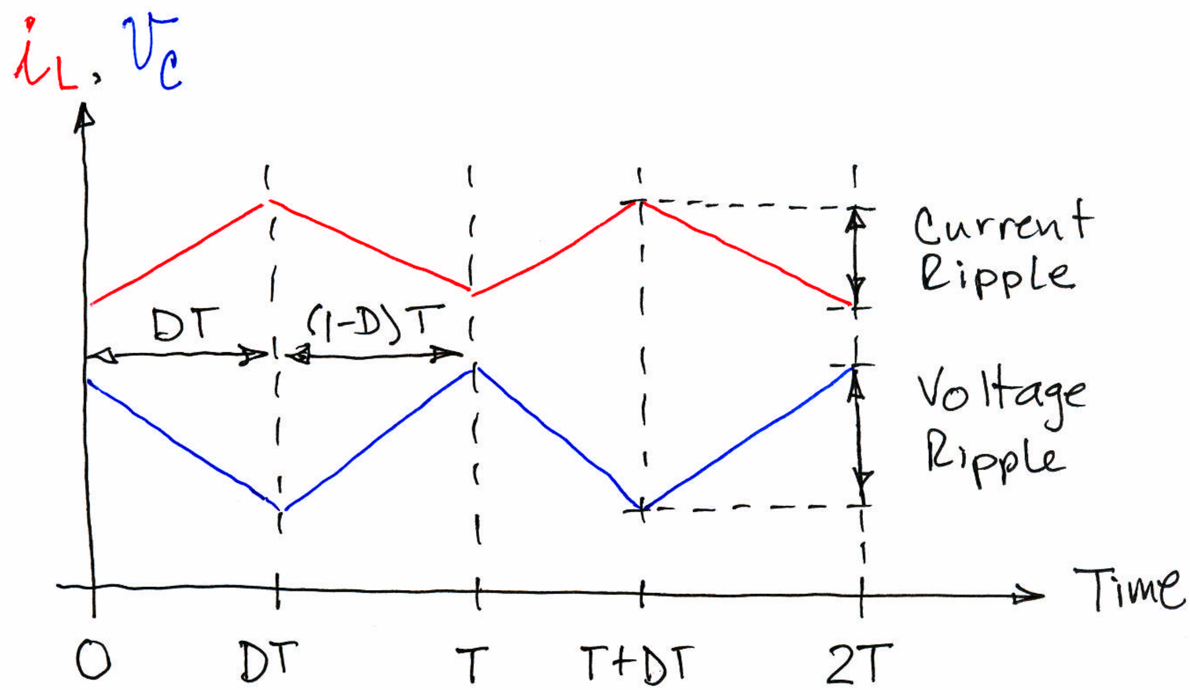


Waveforms I

$D \equiv$ Duty Cycle (MOSFET On)

$T \equiv$ Switching Period

$\frac{1}{T} \equiv$ Switching Frequency (1 kHz ... 100 MHz)



High $1/T$ ⇒ Smaller ripple, smaller L & C, larger switching losses.

Waveforms II

Ignore ripple and focus on averages.

Cyclic

Inductor: $\int_0^T v_L \, dt = \int_0^T L \frac{di_L}{dt} dt = L\left(i_L(T) - i_L(0)\right) = 0$

$\Rightarrow D v_{IN} + (1-D)(v_{IN} - v_{OUT}) = 0 \Rightarrow v_{OUT} = \frac{v_{IN}}{1-D}$

Cyclic

Capacitor: $\int_0^T i_C \, dt = \int_0^T C \frac{dv_C}{dt} dt = C\left(v_C(T) - v_C(0)\right) = 0$

$\Rightarrow -D i_{OUT} + (1-D)(i_{IN} - i_{OUT}) = 0 \Rightarrow i_{OUT} = (1-D) i_{IN}$

Energy Conservation: $v_{OUT} i_{OUT} = v_{IN} i_{IN}$

In theory, no losses; same behavior as an ideal transformer.

Waveforms III

V_{OUT} Ripple: $\quad i_{OUT} \approx C \dfrac{\Delta V_{OUT}}{DT}$ ... MOSFET On

$$\Delta V_{OUT} \approx \frac{DT\, i_{OUT}}{C}$$

Use small T and large C for small voltage ripple.

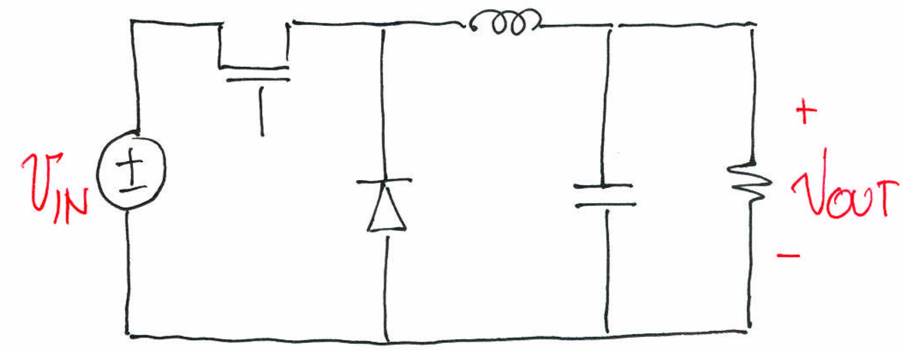
i_{IN} Ripple: $\quad V_{IN} \approx L \dfrac{\Delta i_{IN}}{DT}$ ... MOSFET On

$$\Delta i_{IN} \approx \frac{DT\, V_{IN}}{L}$$

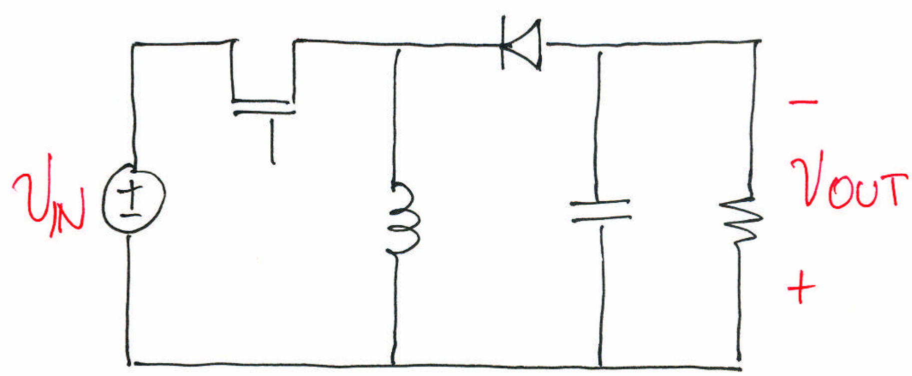
Use small T and Large L for small current ripple.

More Examples

Buck Converter



Buck/Boost Converter



Current Chopper