Lecture 7

Power Converter Losses
& Component Selection

Objectives:

- Compute the device power losses to estimate converter efficiency.
- Examine other types of system losses (motor & capacitor loss).
- Discuss motor parameter extraction methods.
- Introduction to component selection for Inverter design.

Keywords:

Switching loss
Turn-ON / Turn-OFF times
Conduction loss
On-State Resistance ($R_{DS,ON}$)
Reverse recovery loss
Reverse recovery charge / time
Equivalent Series Resistance (ESR)

Conduction Power Losses

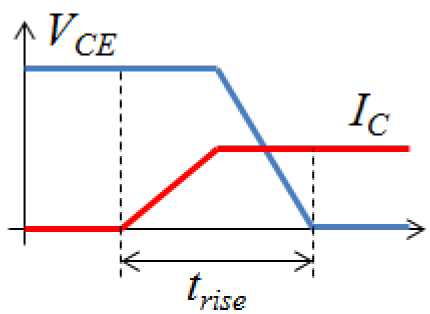
When analyzing the efficiency of a power electronics circuit (or when selecting components), there are three main loss terms we should consider. The first is the conduction loss while the device is ON. If using MOSFETs, we can model the device as simply a resistance from drain-to-source, commonly labeled as $R_{DS,on}$.

$$P_{con,FET} = I_{D,rms}{}^{2} R_{DS,on}$$

Note: the RMS value of a square wave is: $I_{rms} = I_{pk}\sqrt{D}$

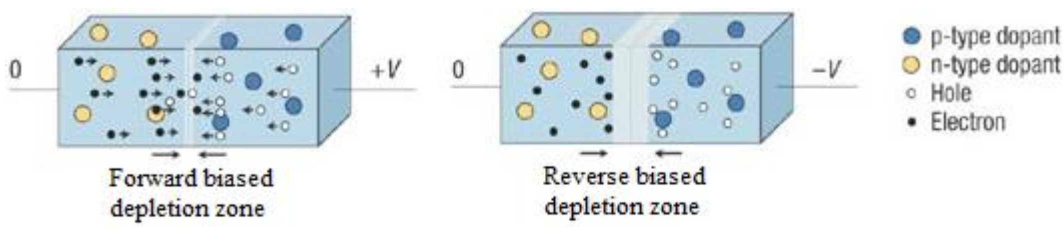
Switching Power Losses

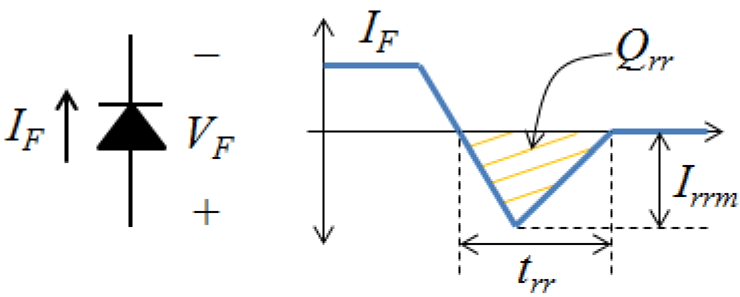
The second power loss comes from the switching process of the transistor. The voltage and current cannot change instantaneously – there exists a short time when a voltage and current appear at the device during turn-ON and turn-OFF.



$$P_{sw} = \frac{1}{2} V_{DC} I_D \left(\frac{t_{on} + t_{off}}{0.8} \right) f_s$$

Reverse Recovery Loss





$$P_{rr} = V_{DC} Q_{rr} f_s$$

Other Electrical Losses

$$P_{con,Dio} = V_F I_{F,avg}$$

$$P_{cap} = I_{C,rms}{}^2 ESR_C$$

Losses in the Machine Losses

$$P_{Cu} = {I_{AC,rms}}^2 R_s$$

$$P_{Fe} = \eta V \ f \ B_{\max}^k + \frac{V\left(d \ \pi \ f \ \hat{B}_m\right)^2}{6\rho}$$

$$P_{Fric} = B_m {\omega_m}^2$$

Rule of Thumb for Inverter / Motor Design

$$P_{con} \approx P_{sw}$$

$$P_{Cu} \approx P_{Fe}$$

Motor Parameter Extraction

- Spinning motor at a known speed and measuring the Back-EMF, we can compute the flux linkage constant by integrating the waveform.

- Applying a constant current without allowing the shaft to spin (locking the rotor) and measuring the voltage, we can compute the phase resistance.

- Energizing the machine with a sinusoidal voltage while locking the rotor, the inductive voltage will dominate. We can find the leakage inductance.

Device & Power Ratings

- From motor power and voltage ratings, determine the current rating.

$$V_{\phi,pk} = \frac{V_{DC}}{\sqrt{3}}, \quad V_{LL,pk} = V_{DC}, \quad V_{\phi,rms} = \frac{V_{DC}}{\sqrt{2}\sqrt{3}}$$

$$P_{AC} = 3V_{\phi,rms} I_{\phi,rms}, \quad \text{thus:} \quad I_{\phi,rms} = \frac{P_{AC}}{3V_{\phi,rms}} = \frac{\sqrt{6}P_{AC}}{3V_{DC}}$$

- From voltage and current ratings, find semiconductor devices to allow for 50% tolerance on voltage and current.

- Determine a reasonable efficiency value for power electronics – estimate the range of switch resistances and switching losses.

$$\eta_{inv} = \frac{P_{AC}}{P_{DC}} = \frac{P_{AC}}{P_{AC} + P_{con} + P_{sw} + P_{rr} + P_{cap}} \qquad \eta_{inv} \approx 90\% \sim 98\%$$

$$\eta_{mot} = \frac{P_{mech}}{P_{AC}} = \frac{P_{mech}}{P_{mech} + P_{Cu} + P_{Fe} + P_{fric}} \qquad \eta_{mot} \approx 80\% \sim 90\%$$

Searching for Components

- Search for MOSFETs
    - Sort by voltage rating and current rating
    - Sort by package and remove tape & reel entries

- Search for battery packs and compute the total energy

$$E_{batt} = nV_{nom}Q_{batt} = (12)(3.7\text{V})(16\text{Ah}) = 710\text{Wh}$$

- From total energy and assumed top speed, we can estimate range.

$v_{\max} = 40\text{mph}$ at $P_{mech} = 2\text{kW}$ output, thus $P_{DC} = \dfrac{2\text{kW}}{\eta_{inv}\eta_{mot}} \approx 2.3\text{kW}$

$$t_{run} = \frac{E_{batt}}{P_{DC}} = \frac{710\text{Wh}}{2300\text{W}} = 0.31\text{h}$$

$$d_{run} = v_{\max}t_{run} = (40\text{mph})(0.31\text{h}) \approx 12.3\text{mi}$$