Announcements

• HW #1 due Friday (8/28)
Part I: Converters in Equilibrium

2. Principles of steady state converter analysis
3. Steady-state equivalent circuit modeling, losses, and efficiency
4. Switch realization
5. The discontinuous conduction mode
6. Converter circuits

Inductor waveforms

Averaged equivalent circuit

Discontinuous conduction mode
Transformer isolation

Predicted efficiency
Switch Realization: Semiconductor Devices

The IGBT

Switching loss

Part II: Converter Dynamics and Control

7. Ac modeling
8. Converter transfer functions
9. Controller design
10. Input filter design
11. Ac and dc equivalent circuit modeling of the discontinuous conduction mode
12. Current-programmed control
Part II: Converter Dynamics and Control

Closed-loop converter system

Averaging the waveforms

Small-signal averaged equivalent circuit

Part III: Magnetics

13. Basic magnetics theory
14. Inductor design
15. Transformer design
Part III: Magnetics

Chapter 2: Converters in Equilibrium
Buck Converter Review

- $T_s$: Switching Period
- $f_s = \frac{1}{T_s}$: Switching Frequency
- $D$: Duty Cycle
  - $0 \leq D \leq 1$
  - $D' = 1 - D$

Conversion Ratio:
- $M = \frac{V_o}{V_i}$
- $M(D) = D'$ for the Buck Converter

Average of $v_s(t)$:
- $V_s = \langle v_s(t) \rangle = \frac{1}{T_s} \int v_s(t) dt$

- $V_s = \frac{1}{T_s} \left( DT_s V_i + (1 - DT_s) V_o \right)$
- $V_o = DV_i$

Ideal Conditions:
- $V = V_s = D' V_i$
- $0 \leq V \leq V_o$

Three Basic DC-DC PWM Converters

- Buck Converter: Step-down, $V \geq V_o$
- Boost Converter: Step-up, $V \leq V_i$
- Buck-Boost Converter: Step-up or Step-down, Inverting, $1/V \geq V_o$, $V \leq 0$
Chapter 2: Goals

- Develop techniques for easily determining output voltage of an arbitrary converter circuit
- Derive the principles of inductor volt-second balance and capacitor charge (amp-second) balance
- Introduce the key small ripple approximation
- Develop simple methods for selecting filter element values
- Illustrate via examples

Buck Output Voltage Ripple

Actual output voltage waveform, buck converter

\[ v(t) = V + v_{ripple}(t) \]

Assume we’ve designed such that ripple(\(t\)) is negligible

\[ v(t) = V + v_{ripple}(t) \]
The Small Ripple Approximation

In a well-designed converter, the output voltage ripple is small. Hence, the waveforms can be easily determined by ignoring the ripple:

\[ |v_{\text{ripple}}| \ll V \]

\[ v(t) = V \]

Buck Switching Intervals: Inductor Current

Fundamentals of Power Electronics Chapter 2: Principles of steady-state converter analysis
**Subinterval 1**

\[ v_2(t) = L \frac{di_2(t)}{dt} = V_0 - V(t) \]

- Apply Small Ripple Approx
- \( L \frac{di_2(t)}{dt} = V_0 - V \)
- Solve for \( \frac{di_2(t)}{dt} \)
- \( \frac{di_2(t)}{dt} = \frac{V_0 - V}{L} \)

**Subinterval 2**

\[ v_2(t) = L \frac{di_2(t)}{dt} = 0 - V(t) \]

- Apply S.R.A.
- \( L \frac{di_2(t)}{dt} = -V \)
- \( \frac{di_2(t)}{dt} = \frac{-V}{L} \)
Current Waveform

Transient vs. Steady-State Operation
Volt-Second Balance

If in steady-state:
\[ i_l(t) = i_l(t_4) = i_l(t_3) \]

Amount I go up in 1 same as amount down in 2

In 1:
\[ 2\Delta i = \frac{V}{L} DT_4 \]

In 2:
\[ -2\Delta i = \frac{V}{L} DT_3 \]

If in steady state:
\[ \frac{V}{L} DT_4 = \frac{V}{L} DT_3 \Rightarrow \frac{V_D}{L} = \frac{V}{L} DT_4 \]

\[ VT = +V_D + V_D' = V(D + D') \]

\[ V_D = V \rightarrow M(D) \approx \frac{V_D}{D} = D \]