

Lecture 2: Volt-Second and Capacitor Charge Balance

ECE 481: Power Electronics

Prof. Daniel Costinett

Department of Electrical Engineering and Computer Science

University of Tennessee Knoxville

Fall 2015



THE UNIVERSITY OF
TENNESSEE
KNOXVILLE

Announcements

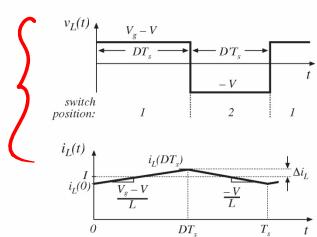
- HW #1 due Friday (8/28)

Part I: Converters in Equilibrium

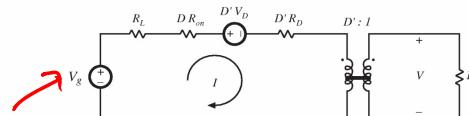
- 2. Principles of steady state converter analysis
- 3. Steady-state equivalent circuit modeling, losses, and efficiency
- 4. Switch realization
- 5. The discontinuous conduction mode
- 6. Converter circuits

Part I: Converters in Equilibrium

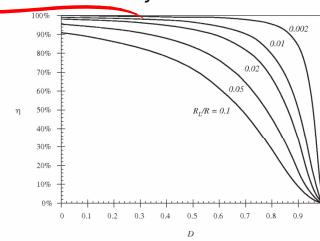
Inductor waveforms



Averaged equivalent circuit



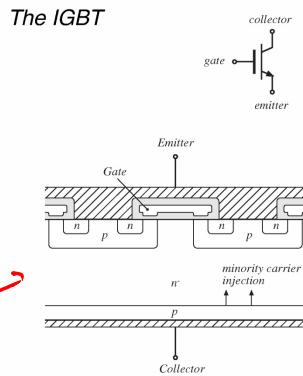
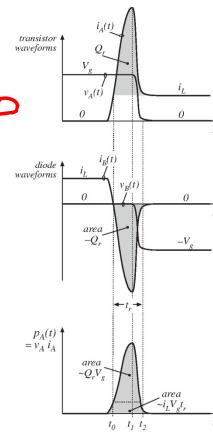
Predicted efficiency



Discontinuous conduction mode

Transformer isolation

Switch Realization: Semiconductor Devices

The IGBT*Switching loss**Fundamentals of Power Electronics*

26

Chapter 1: Introduction

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

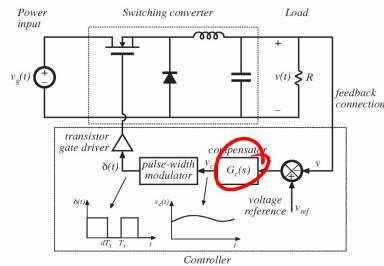
Fundamentals of Power Electronics

29

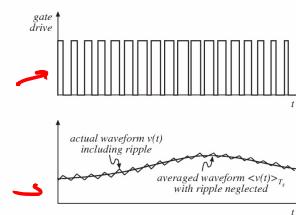
Chapter 1: Introduction

Part II: Converter Dynamics and Control

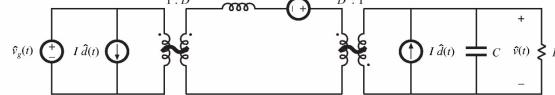
Closed-loop converter system



Averaging the waveforms



Small-signal averaged equivalent circuit



Fundamentals of Power Electronics

7

28

Chapter 1: Introduction

THE UNIVERSITY OF
TENNESSEE
KNOXVILLE

Part III: Magnetics

- 13. Basic magnetics theory
- { 14. Inductor design
- 15. Transformer design

Fundamentals of Power Electronics

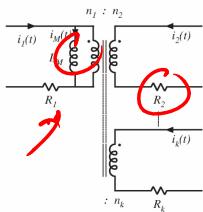
31

Chapter 1: Introduction

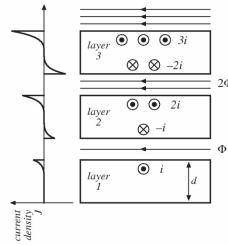
THE UNIVERSITY OF
TENNESSEE
KNOXVILLE

Part III: Magnetics

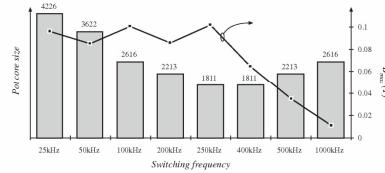
transformer design



the proximity effect



transformer size vs. switching frequency



Fundamentals of Power Electronics

30

Chapter 1: Introduction

THE UNIVERSITY OF
TENNESSEE 
KNOXVILLE

Chapter 2: Converters in Equilibrium



THE UNIVERSITY OF
TENNESSEE
KNOXVILLE

Buck Converter Review

T_s = switching Period
 $f_s = \frac{1}{T_s}$ = switching frequency

D = Duty Cycle
 $0 \leq D \leq 1$
 $D' = 1 - D$

Average of $v_s(t)$
 $v_s = \langle v_s(t) \rangle_{T_s} = \frac{1}{T_s} \int_0^{T_s} v_s(t) dt$

$$v_s = \frac{1}{T_s} (D T_s V_g)$$

If LPF is ideal

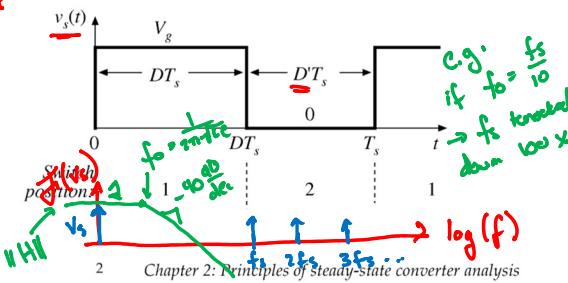
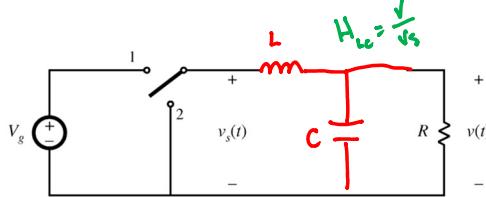
$$V = V_s = D V_g$$

$$0 \leq V \leq V_g$$

Fundamentals of Power Electronics

$$M = \text{conversion ratio} = \frac{V}{V_g}$$

$$M(D) = D, \text{ for the Buck}$$

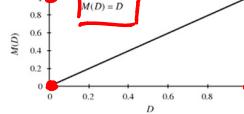
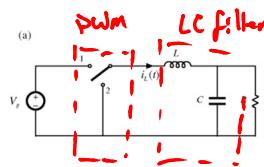


Chapter 2: Principles of steady-state converter analysis

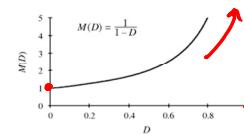
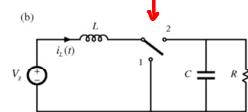
THE UNIVERSITY OF TENNESSEE KNOXVILLE

Three Basic DC-DC PWM Converters

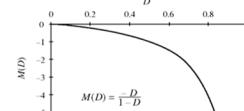
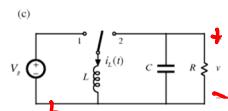
Buck
step-down
 $V \leq V_g$



Boost
step-up
 $V \geq V_g$



Buck-boost
step-up or
step-down
inverting
 $|V| \leq V_g, V \leq 0$



Fundamentals of Power Electronics

Chapter 2: Principles of steady-state converter analysis

THE UNIVERSITY OF TENNESSEE KNOXVILLE

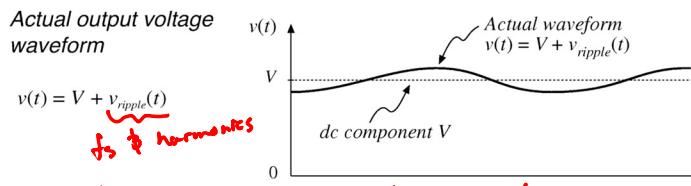
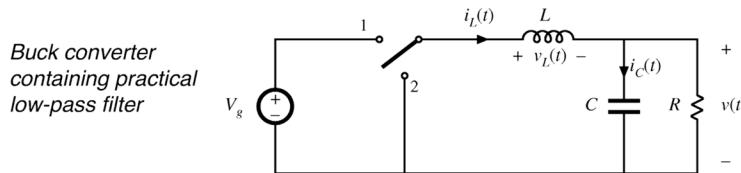
Chapter 2: Goals

- 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

some of the basic converters

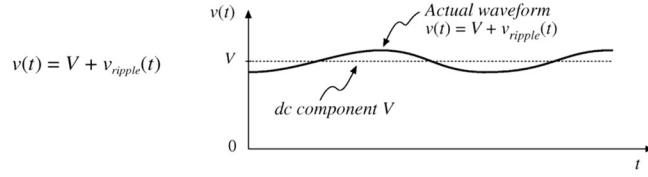
Buck Output Voltage Ripple

Actual output voltage waveform, buck converter



Assume we've designed such that $v_{\text{ripple}}(t)$ is negligible

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:

$$\|v_{\text{ripple}}\| \ll V$$

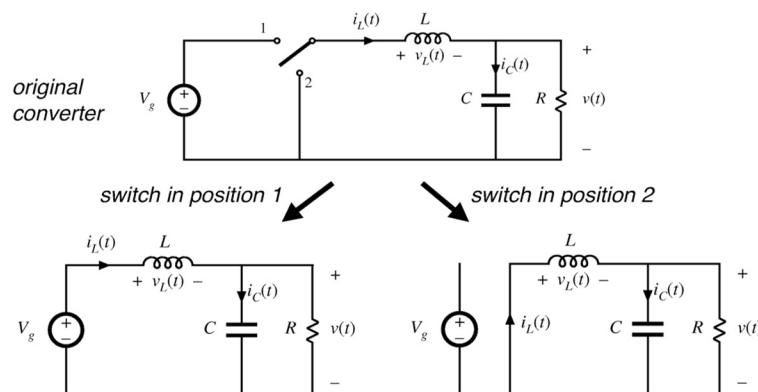
$$v(t) \approx V$$

Fundamentals of Power Electronics

Chapter 2: Principles of steady-state converter analysis



Buck Switching Intervals: Inductor Current



Fundamentals of Power Electronics

Chapter 2: Principles of steady-state converter analysis



Subinterval 1

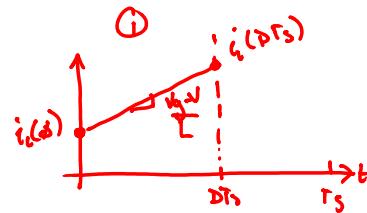
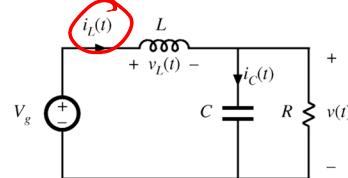
$$v_L(t) = L \frac{di_L(t)}{dt} = \sqrt{g} - v(t)$$

↓
Apply Small Ripple Approx

$$L \frac{di_L(t)}{dt} = \sqrt{g} - v$$

↓
solve for $\frac{di_L}{dt}$

$$\frac{di_L(t)}{dt} = \frac{\sqrt{g} - v}{L}$$



THE UNIVERSITY OF
TENNESSEE 
KNOXVILLE

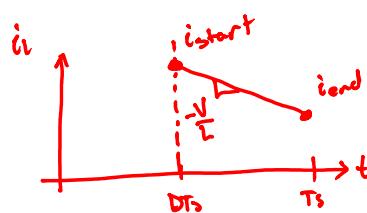
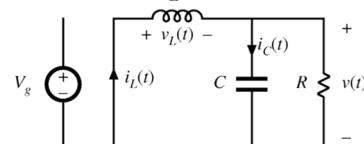
Subinterval 2

$$v_L(t) = L \frac{di_L(t)}{dt} = 0 - v(t)$$

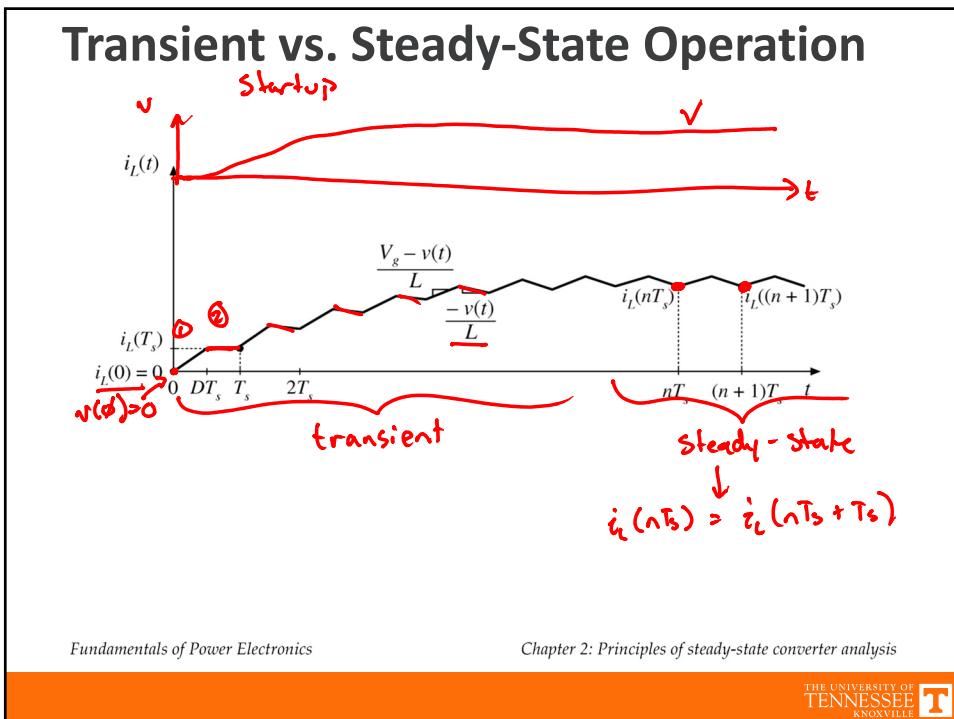
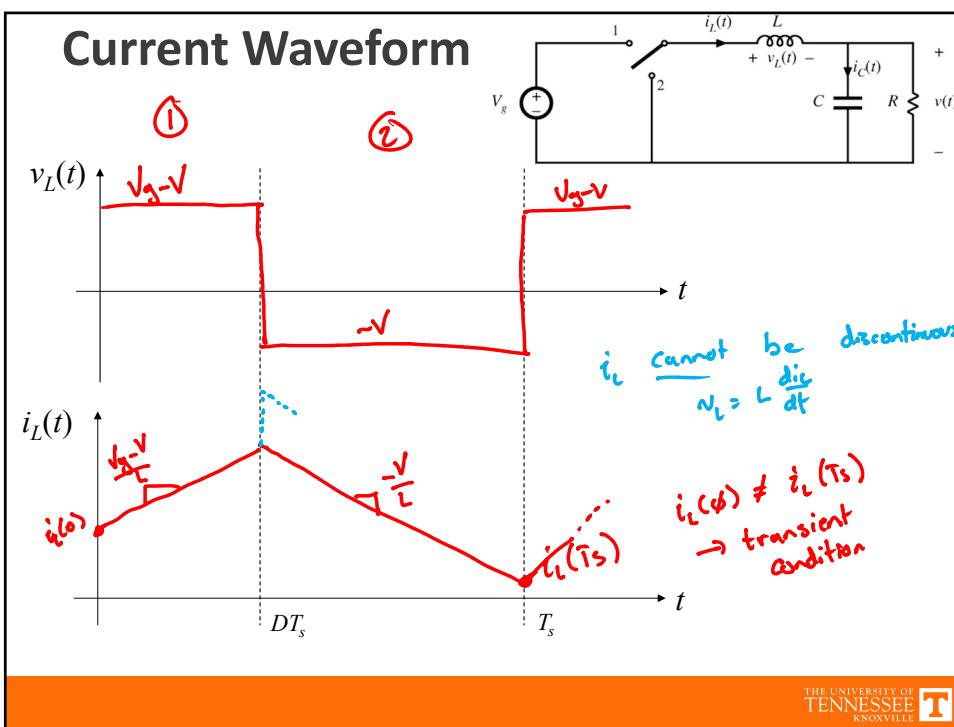
↓
Apply S.R.A.

$$L \frac{di_L(t)}{dt} = -v$$

$$\frac{di_L(t)}{dt} = -\frac{v}{L}$$



THE UNIVERSITY OF
TENNESSEE 
KNOXVILLE



Volt-Second Balance

If in Steady-State
 $i_L(nT_s + T_s) = i_L(nT_s)$

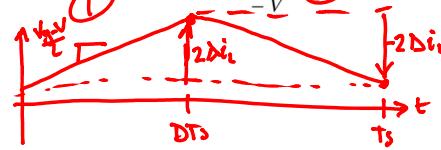
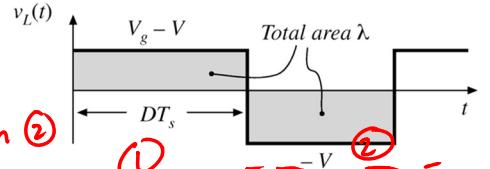
Amount I go up in ①
 same as amount down in ②

In ①:
 $2\Delta i_L = \frac{V_g - V}{L} DT_s$

In ②:
 $-2\Delta i_L = \frac{V}{L} D' T_s$

If in steady state:

$$\frac{V_g - V}{L} DT_s = \frac{V}{L} D' T_s \rightarrow V_g D = +V D' + V D' = V(D + D') \quad \boxed{M(D) > \frac{V}{V_g} = D}$$



Fundamentals of Power Electronics

Chapter 2: Principles of steady-state converter analysis

THE UNIVERSITY OF
TENNESSEE 
KNOXVILLE