Chapter 2: Converters in Equilibrium

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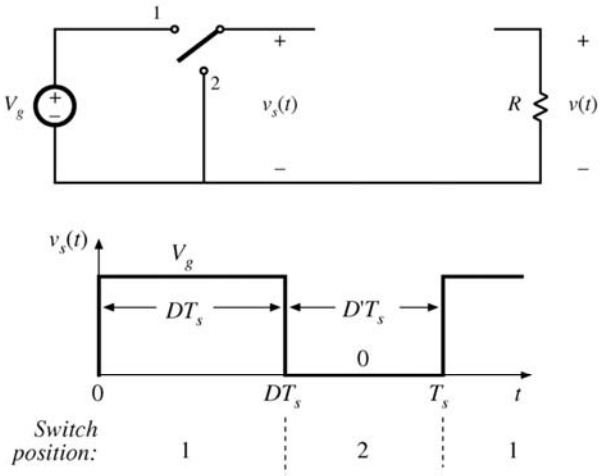
Buck Converter Review



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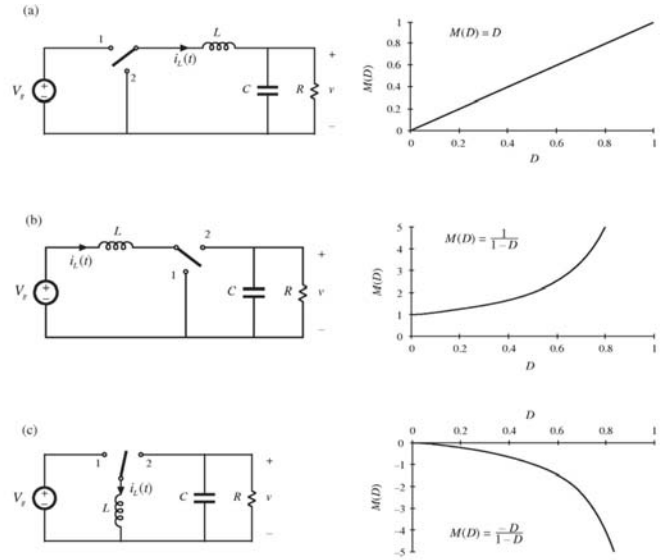
Three Basic DC-DC PWM Converters

Buck

Boost

Buck-boost



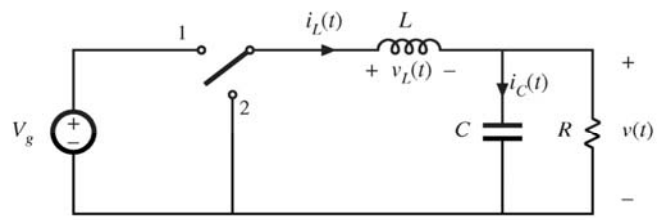
Chapter 2: Goals

- 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

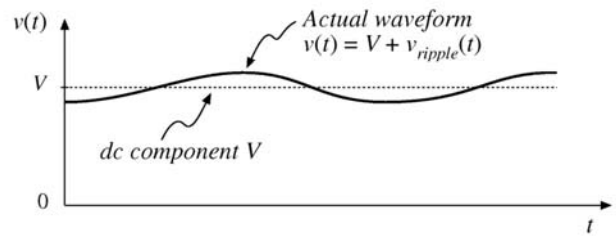
Actual output voltage waveform, buck converter

Buck converter containing practical low-pass filter



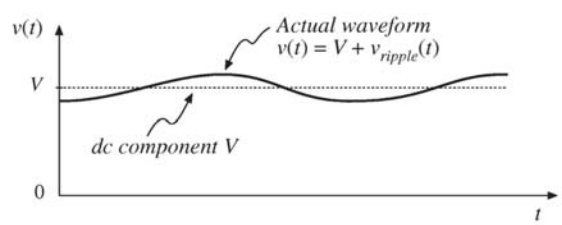
Actual output voltage waveform

$v(t) = V + v_{ripple}(t)$



The Small Ripple Approximation

$v(t) = V + v_{ripple}(t)$

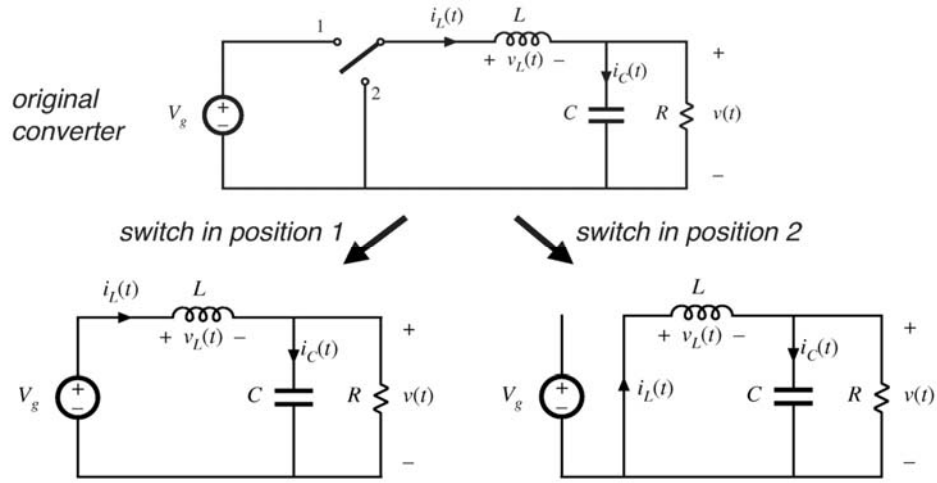


In a well-designed converter, the output voltage ripple is small. Hence, the waveforms can be easily determined by ignoring the ripple:

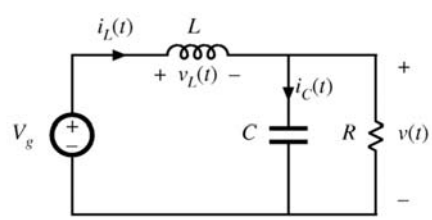
$$\left\| v_{ripple} \right\| \ll V$$

$$v(t) \approx V$$

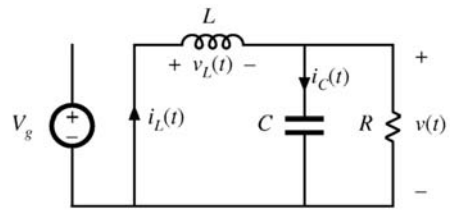
Buck Switching Intervals: Inductor Current



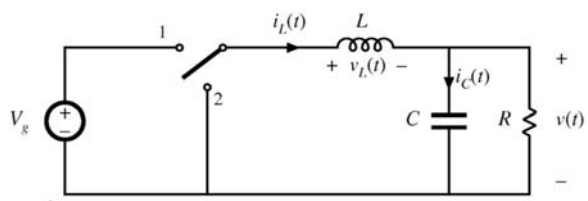
Subinterval 1

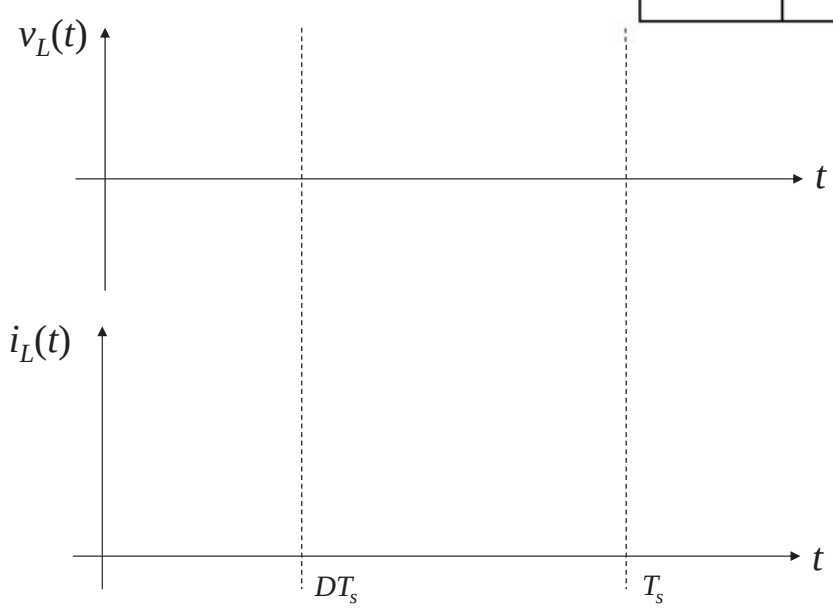


Subinterval 2

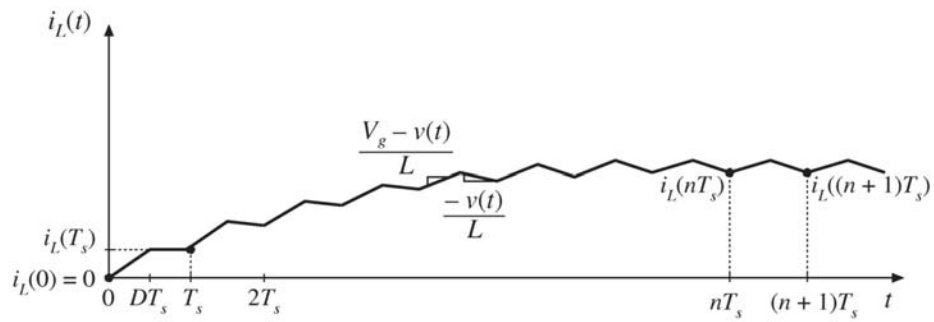


Current Waveform

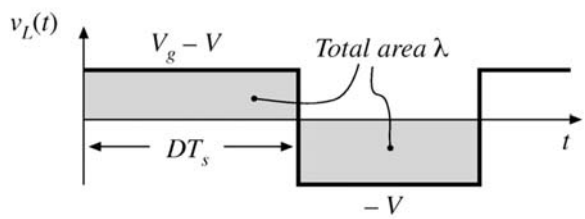




Transient vs. Steady-State Operation



Volt-Second Balance



Derivation of Volt-second Balance

Inductor defining relation:

$$v_L(t) = L\,\frac{di_L(t)}{dt}$$

Integrate over one complete switching period:

$$i_L(T_s) - i_L(0) = \frac{1}{L}\int_0^{T_s} v_L(t)\,dt$$

In periodic steady state, the net change in inductor current is zero:

$$0 = \int_0^{T_s} v_L(t)\,dt$$

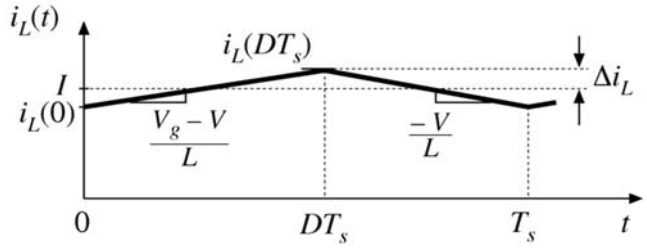
Hence, the total area (or volt-seconds) under the inductor voltage waveform is zero whenever the converter operates in steady state.

An equivalent form:

$$0 = \frac{1}{T_s}\int_0^{T_s} v_L(t)\,dt = \langle v_L \rangle$$

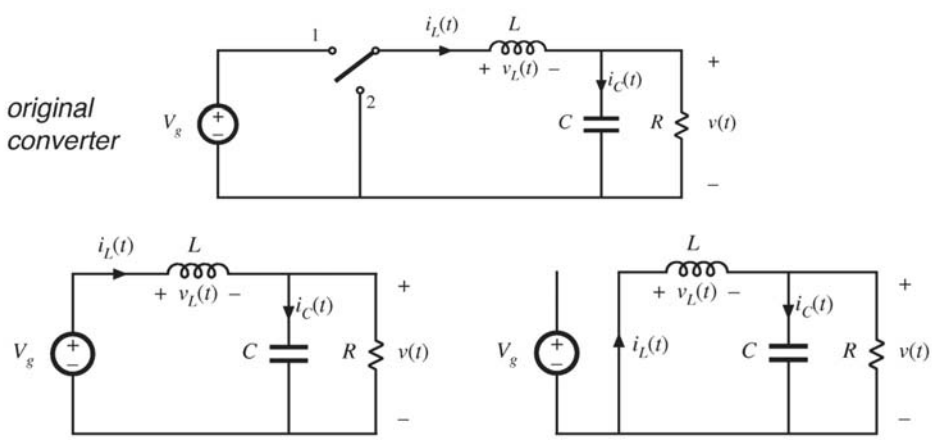
The average inductor voltage is zero in steady state.

Current Ripple Magnitude



$$(\text{change in } i_L) = (\text{slope})(\text{length of subinterval})$$

Capacitor Charge Balance



Derivation of Capacitor Charge Balance

Capacitor defining relation:

$$i_C(t) = C\,\frac{dv_C(t)}{dt}$$

Integrate over one complete switching period:

$$v_C(T_s) - v_C(0) = \frac{1}{C}\int_0^{T_s} i_C(t)\,dt$$

In periodic steady state, the net change in capacitor voltage is zero:

$$0 = \frac{1}{T_s}\int_0^{T_s} i_C(t)\,dt = \langle i_C \rangle$$

Hence, the total area (or charge) under the capacitor current waveform is zero whenever the converter operates in steady state. The average capacitor current is then zero.