Boost Converter

3-2-1 Circuit diagram and key waveforms

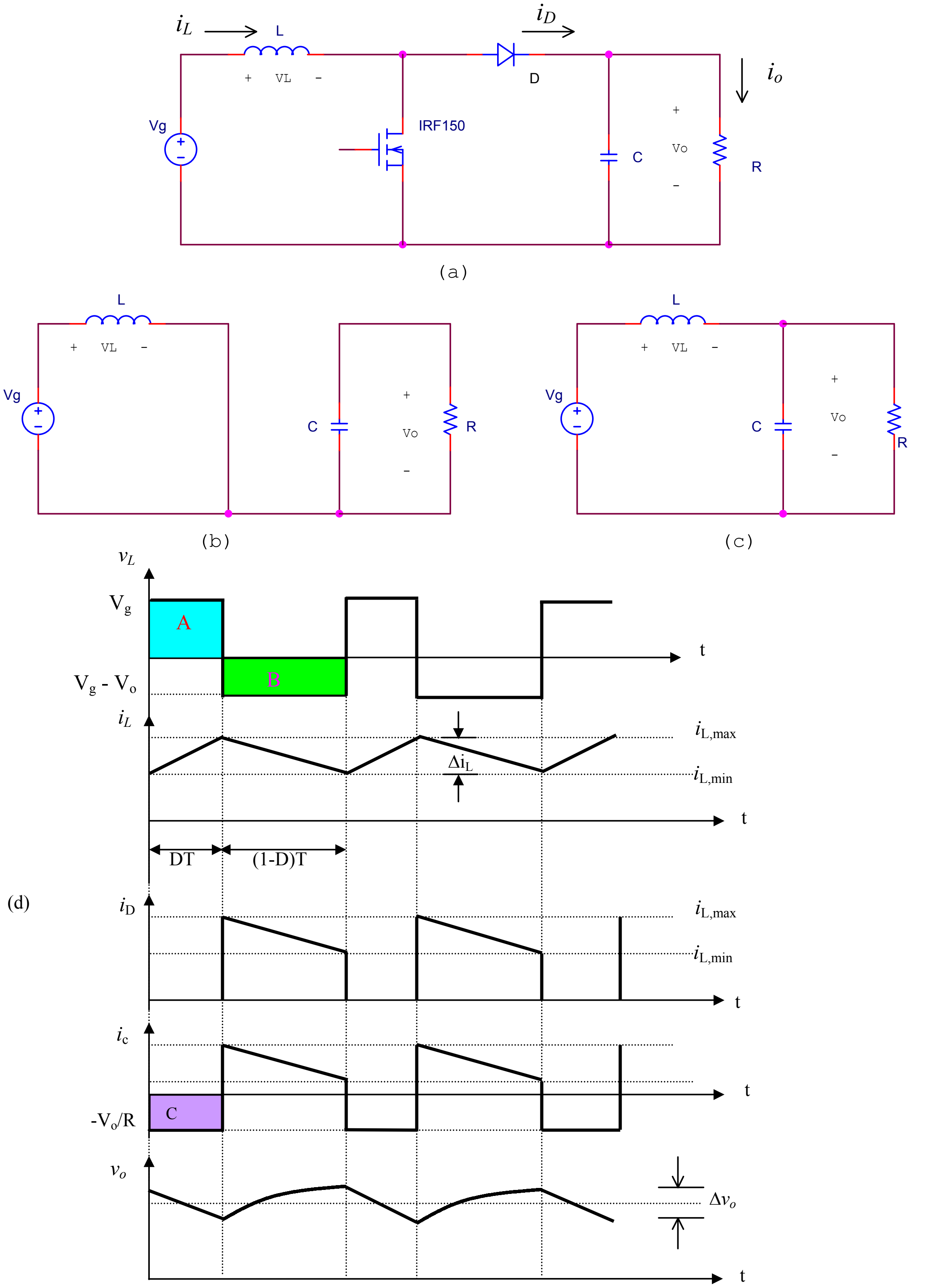


Figure 3-2 (a) Boost converter (b) switch on for a time duration *DT* (c) switch off for a time duration *(1-D)T* (d) key waveforms.

3-2-2 Circuit description and operation

Circuit description. The three basic dc-dc converters use a pair of switches, usually one controlled (eg. MOSFET) and one uncontrolled (ie. diode), to achieve unidirectional power flow from input to output. The converters also use one capacitor and one inductor to store and transfer energy from input to output. They also filter or smooth voltage and current.

The dc-dc coverters can have two distinct modes of operation: Continuous conduction mode (CCM) and discontinuous conduction mode (DCM). In practice, a converter may operate in both modes, which have significantly different characteristics. Therefore, a converter and its control should be designed based on both modes of operation. However, for this course we only consider the dc-dc converters operated in CCM.

Circuit Operation. When the switch is on for a time duration DT, the switch conducts the inductor current and the diode becomes reverse biased. This results in a positive voltage $v_L = V_g$ across the inductor. This voltage causes a linear increase in the inductor current i_L. When the switch is turned off, because of the inductive energy storage, i_L continues to flow. This current now flows through the diode, and $v_L = V_g - V_o$ for a time duration $(1-D)T$ until the switch is turned on again.

3-2-3 Analytical expressions for $\frac{V_o}{V_g}$, Δi_L, and Δv_o

Assumptions made about the operation of the converter are as follows:

- The circuit is operating in the steady state
- The circuit is operating in the CCM
- The capacitor is large enough to assume a constant output voltage
- The component are ideal.

Equating the integral of the inductor voltage over one time period to zero yields

$$\int_0^T v_L dt = \int_0^{t_{on}} v_L dt + \int_0^{t_{off}} v_L dt = 0$$

$$V_g \times DT + (V_g - V_o) \times (1-D)T = 0$$

$$V_o = \frac{1}{1-D} V_g$$

or

$$\frac{V_o}{V_g} = \frac{1}{1-D}$$

Assuming a lossless circuit, $P_g = P_o$,

Therefore

$$V_g I_g = V_o I_o$$

And

$$\frac{I_o}{I_g} = \frac{V_g}{V_o} = 1 - D$$

For a boost converter, it is obvious that

$$I_g = I_L$$

$$\begin{aligned}\Delta i_L &= \frac{1}{L}\int_0^{DT} v_L dt \\ &= \frac{1}{L}[\text{Shaded area under waveform } v_L \text{ (Area A)}] \\ &= \frac{1}{L}V_g \times DT\end{aligned}$$

From Δi_L we can obtain $i_{L,min}$ and $i_{L,\, max}$

$$i_{L,\min} = I_L - \frac{\Delta i_L}{2}$$
$$i_{L,\max} = I_L + \frac{\Delta i_L}{2}$$

To obtain the average inductor current, we can use the relationship

$$I_D = I_o = (1 - D)I_L$$

Therefore

$$I_L = \frac{I_o}{(1-D)} = \frac{V_o}{(1-D)R}$$

The peak-peak output voltage ripple, Δv_o. From the information of the capacitor current, i_c we can obtain Δv_o.

$$\begin{aligned}\Delta v_o = \Delta v_c &= \frac{1}{C}\int i_c dt \\ &= \frac{1}{L}[\text{Shaded area under waveform } i_c] \\ &= \frac{1}{C} \times \frac{V_o}{R} \times DT\end{aligned}$$

therefore

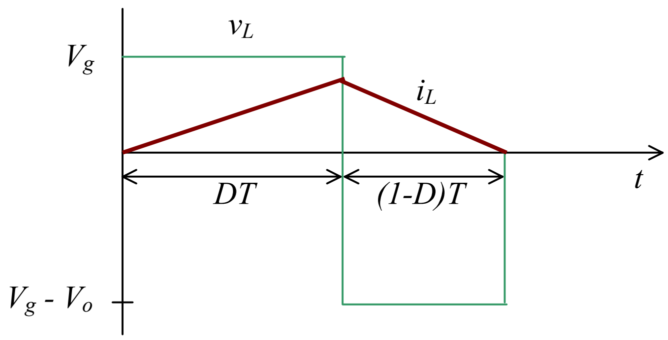
$$\Delta v_o = \frac{1}{C} \times \frac{V_o}{R} \times DT$$

3-2-4 CCM/DCM boundary condition

Being at the boundary between the continuous and the discontinuous mode, by definition, the inductor current i_L goes to zero at the end of the off period. At this boundary, the average inductor current is

$$I_L = \frac{\Delta i_L}{2}$$

the minimum inductor current, $i_{L,\min} = 0$ and the maximum inductor curren $i_{L,\,max} = \Delta i_L$.



We know that for buck converters $I_D = I_o = \frac{V_o}{R}$ and $\Delta i_L = \frac{1}{L} V_g DT = \frac{1}{L}(V_g - V_o)(1-D)T$.

Equation at the CCM/DCM boundary, $I_L = \frac{\Delta i_L}{2}$, can be used to determine the combination of L, f and R that will result in CCM. The minimum load current required for CCM operation is:

$$I_L = \frac{\Delta i_L}{2}$$

$$= \frac{1}{2L} V_g DT$$

but $I_o = (1-D) I_L$

$$\frac{I_o}{1-D} = \frac{\Delta i_L}{2}$$

$$= \frac{1}{2L} V_g DT$$

$$\therefore I_{o,\min} = \frac{1}{2L} V_g D(1-D)T$$

$$= \frac{1}{2L} V_o D(1-D)^2 T$$

If the desired switching frequency f and load resistance R are established, the minimum inductor current required for CCM is:

$$I_L = \frac{\Delta i_L}{2}$$

$$\frac{V_o}{R(1-D)} = \frac{1}{2L} V_g DT = \frac{1}{2L} V_o (1-D) DT$$

$$\therefore L_{\min} = \frac{D(1-D)^2 T \times R}{2}$$

$$= \frac{D(1-D)^2 R}{2f}$$

If the desired value of the inductor L and the load resistance R are established, the minimum switching frequency required for CCM is

$$f_{\min} = \frac{D(1-D)^2 R}{2L}$$

If the desired switching frequency and the value of the inductor L are established, the minimum load resistance required for CCM is

$$R_{\min} = \frac{2fL}{D(1-D)^2}$$

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