Chapter 7

DC-DC Switch-Mode Converters

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- dc-dc converters for switch-mode dc power supplies and dc-motor drives

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Block Diagram of DC-DC Converters

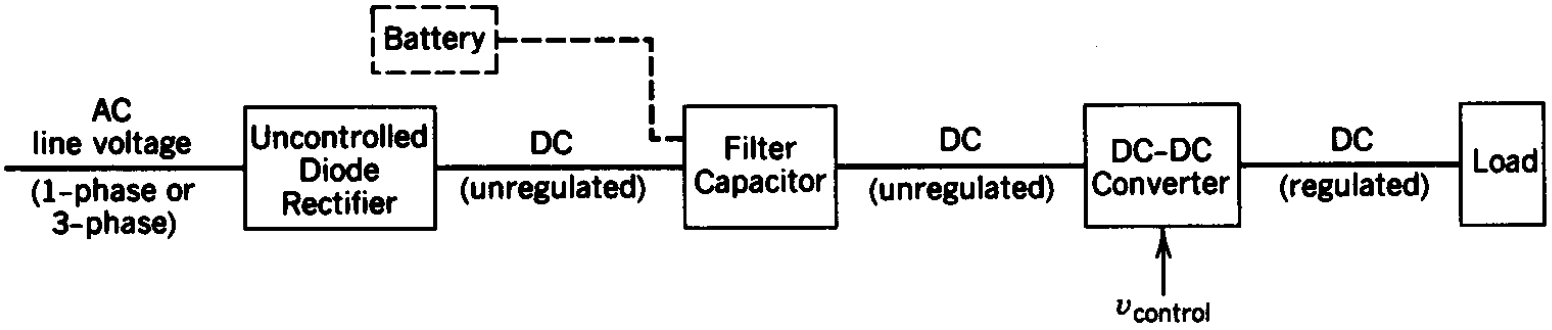

Figure 7-1 A dc–dc converter system.

- Functional block diagram

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Stepping Down a DC Voltage

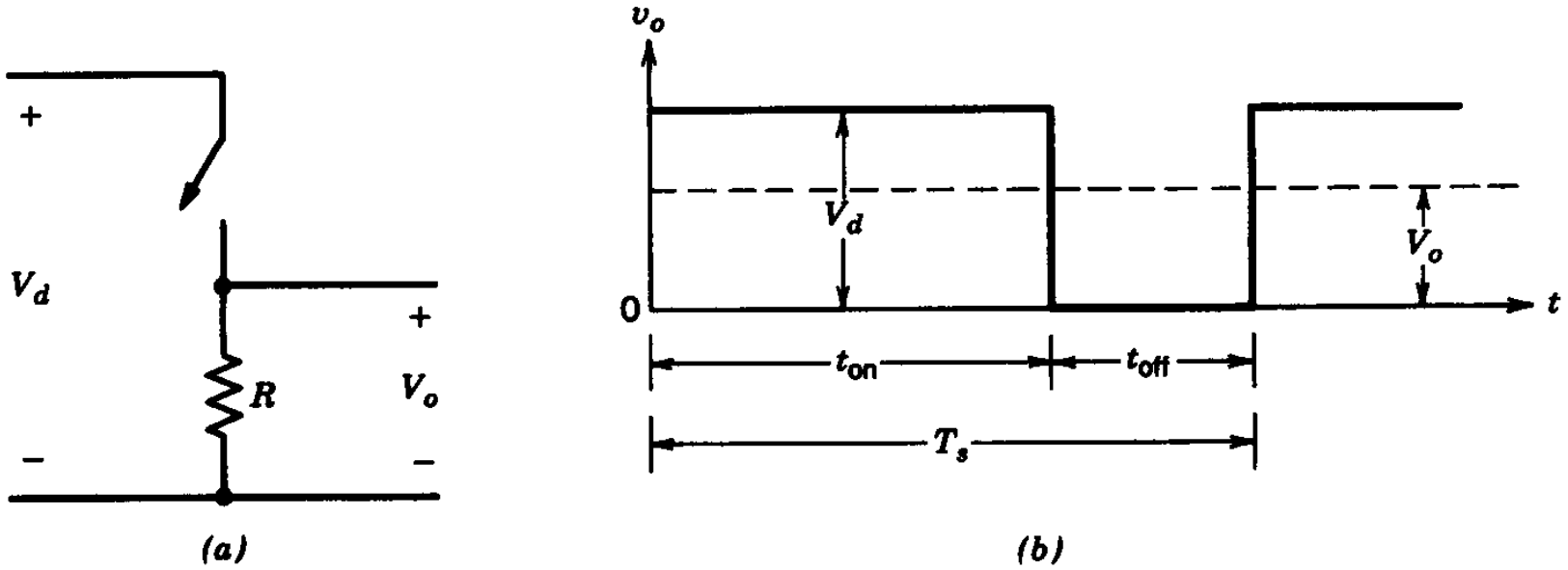

Figure 7-2 Switch-mode dc–dc conversion.

- A simple approach that shows the evolution

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Pulse-Width Modulation in DC-DC Converters

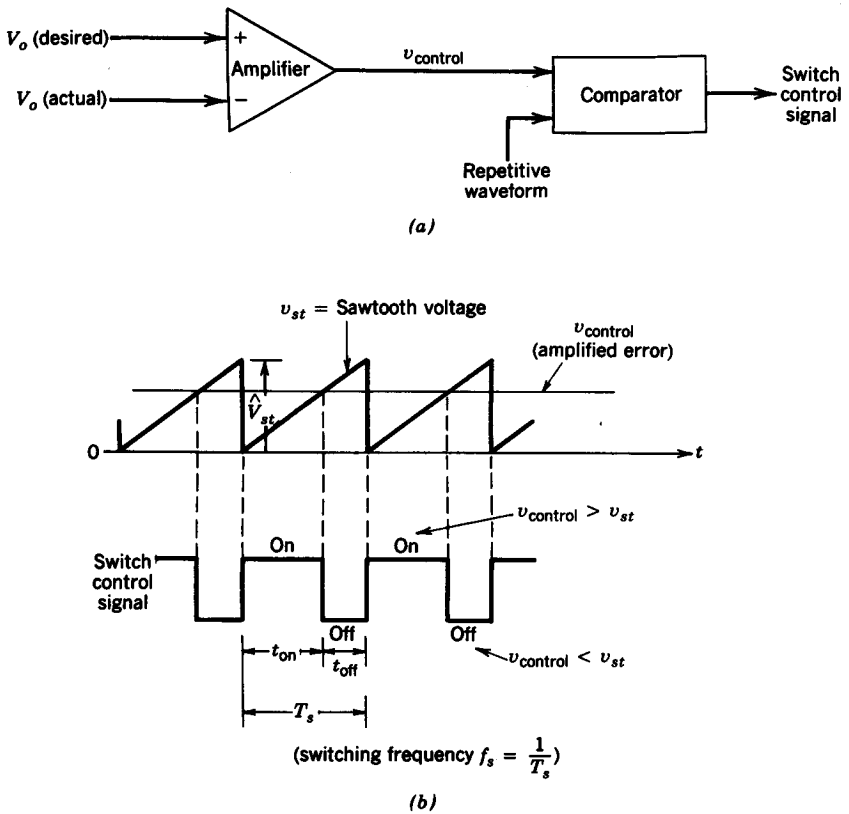

Figure 7-3 Pulse-width modulator: (*a*) block diagram; (*b*) comparator signals.

- Role of PWM

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Step-Down DC-DC Converter

- Pulsating input to the low-pass filter

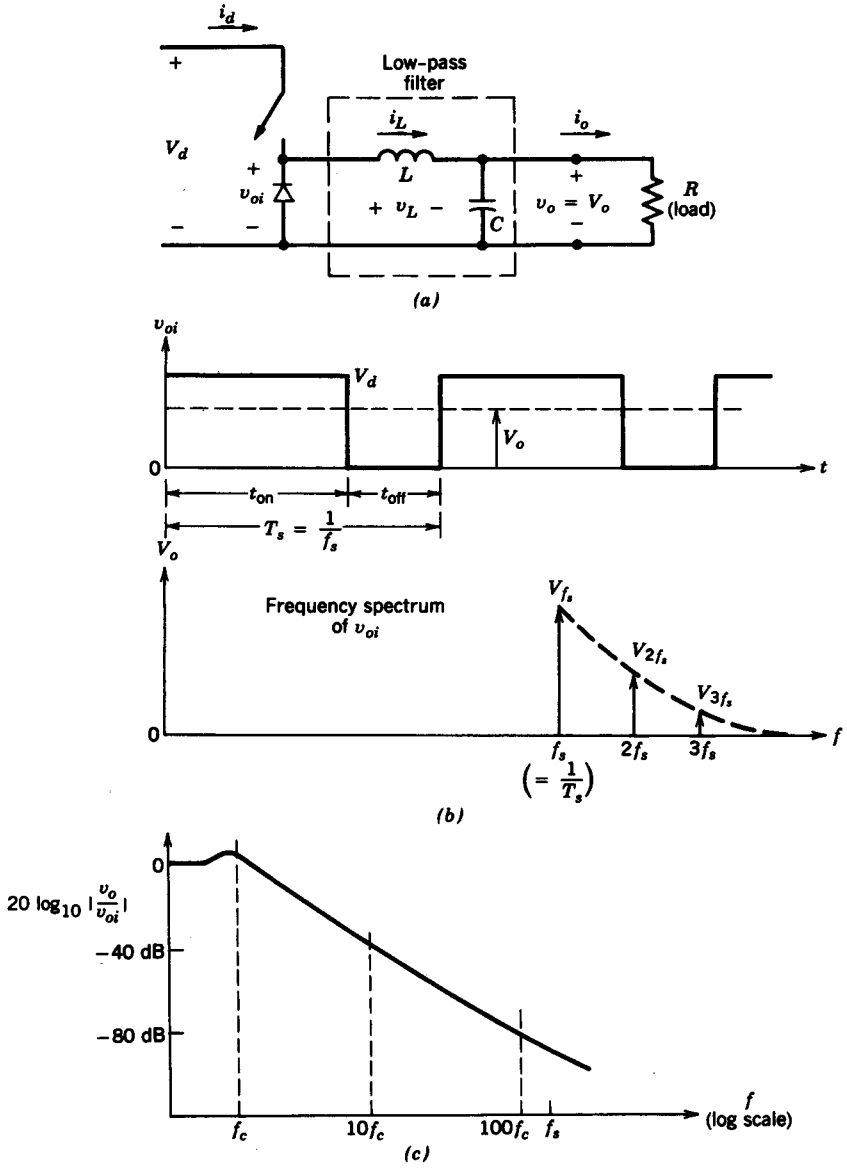

Figure 7-4 Step-down dc–dc converter.

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Step-Down DC-DC Converter: Waveforms

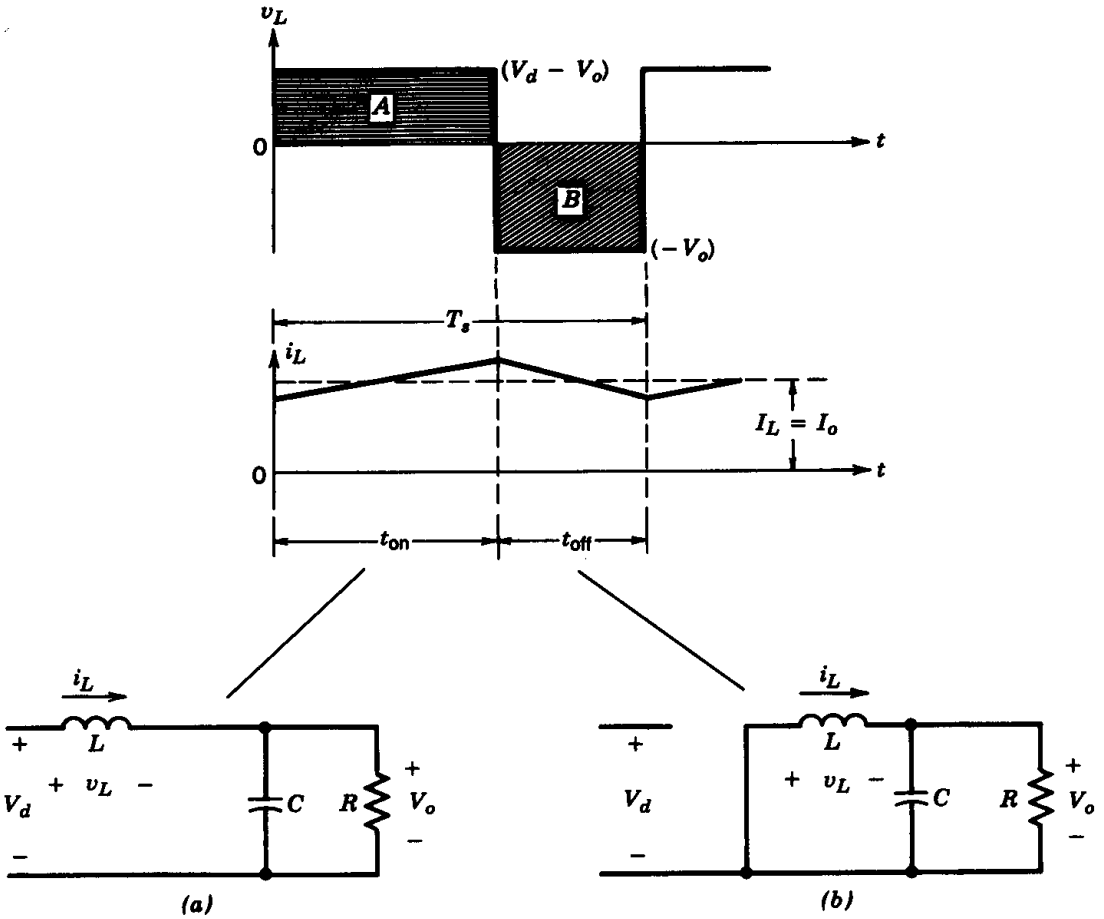

Figure 7-5 Step-down converter circuit states (assuming i_L flows continuously): (*a*) switch on; (*b*) switch off.

- Steady state; inductor current flows continuously

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Step-Down DC-DC Converter: Waveforms at the boundary of Cont./Discont. Conduction

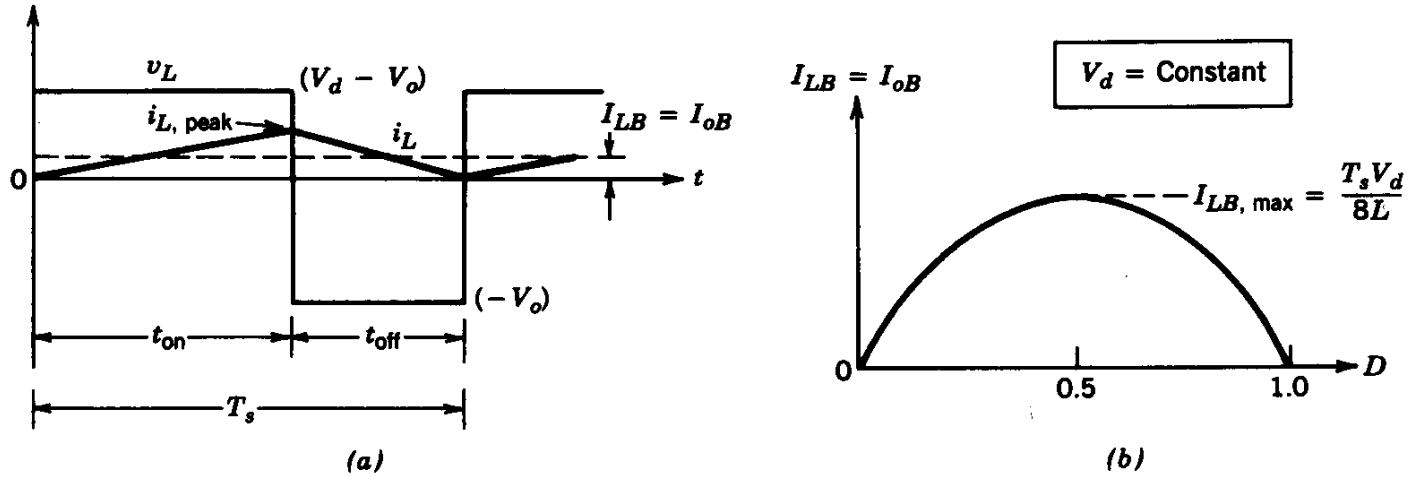

Figure 7-6 Current at the boundary of continuous–discontinuous conduction: (*a*) current waveform; (*b*) I_{LB} versus D keeping V_d constant.

- Critical current below which inductor current becomes discontinuous

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Step-Down DC-DC Converter: Discontinuous Conduction Mode

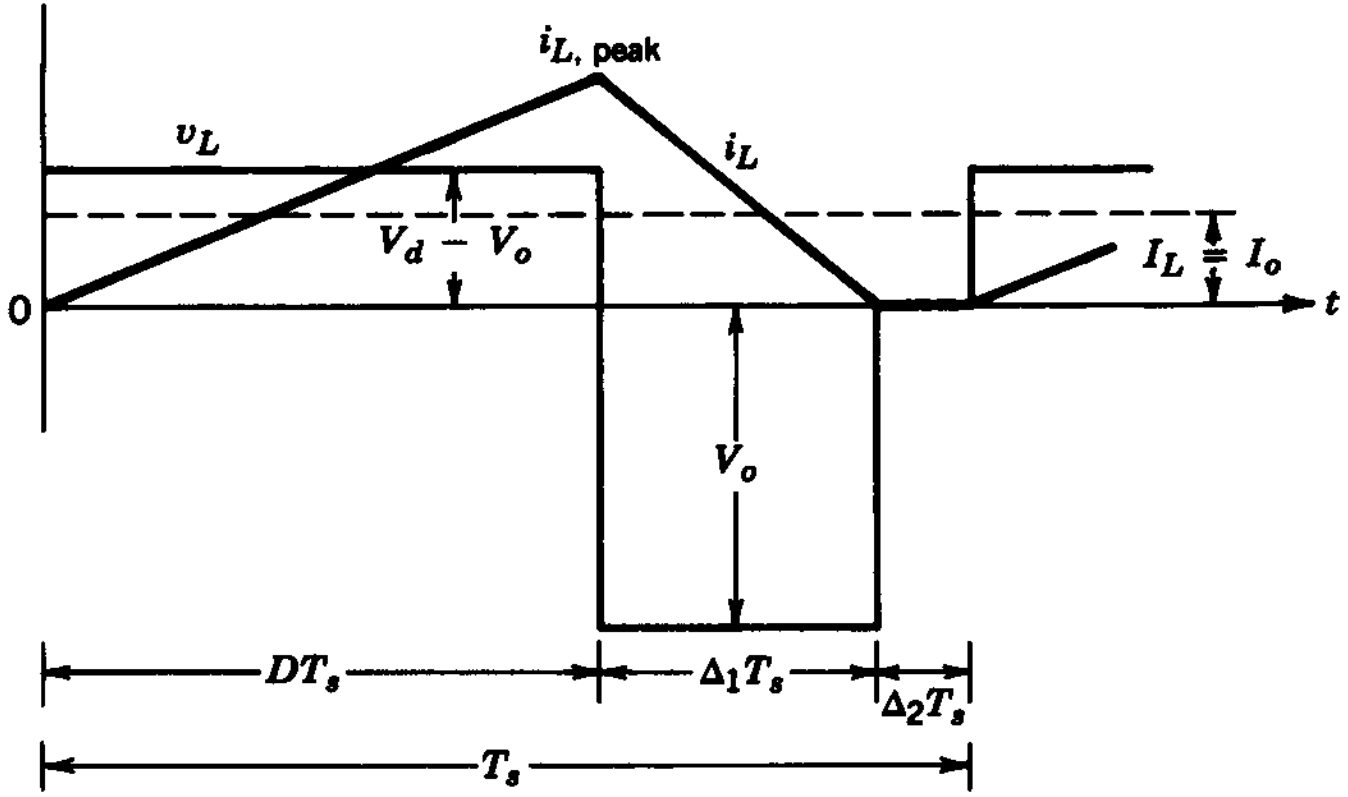

Figure 7-7 Discontinuous conduction in step-down converter.

- Steady state; inductor current discontinuous

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Step-Down DC-DC Converter: Limits of Cont./Discont. Conduction

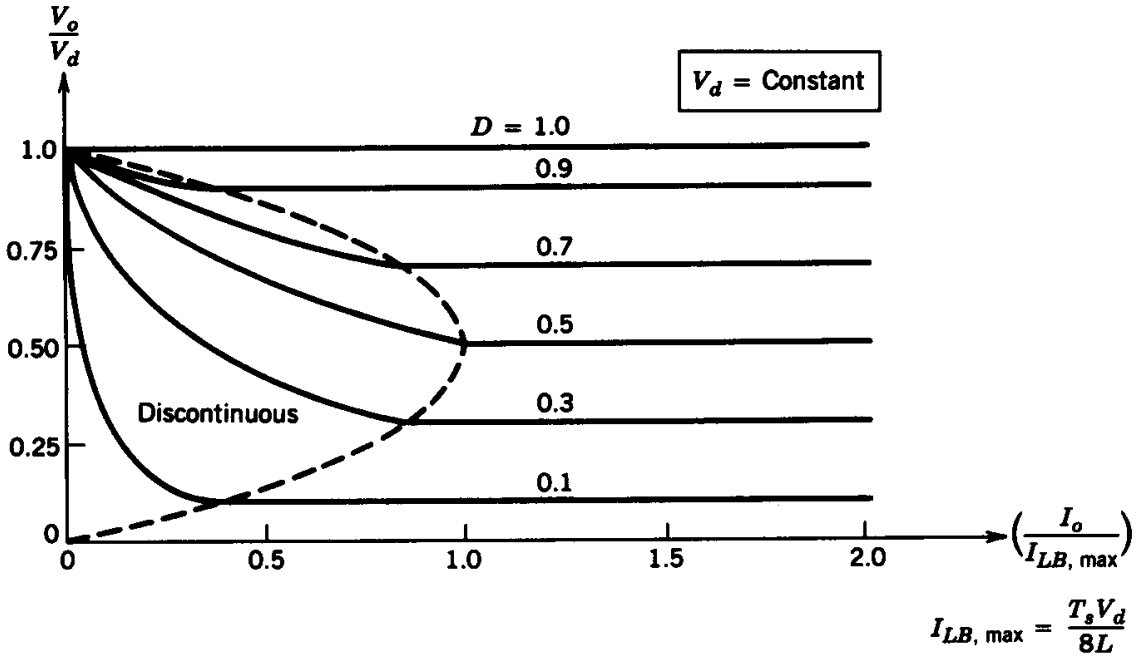

Figure 7-8 Step-down converter characteristics keeping V_d constant.

- The duty-ratio of 0.5 has the highest value of the critical current

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Step-Down DC-DC Converter: Limits of Cont./Discont. Conduction

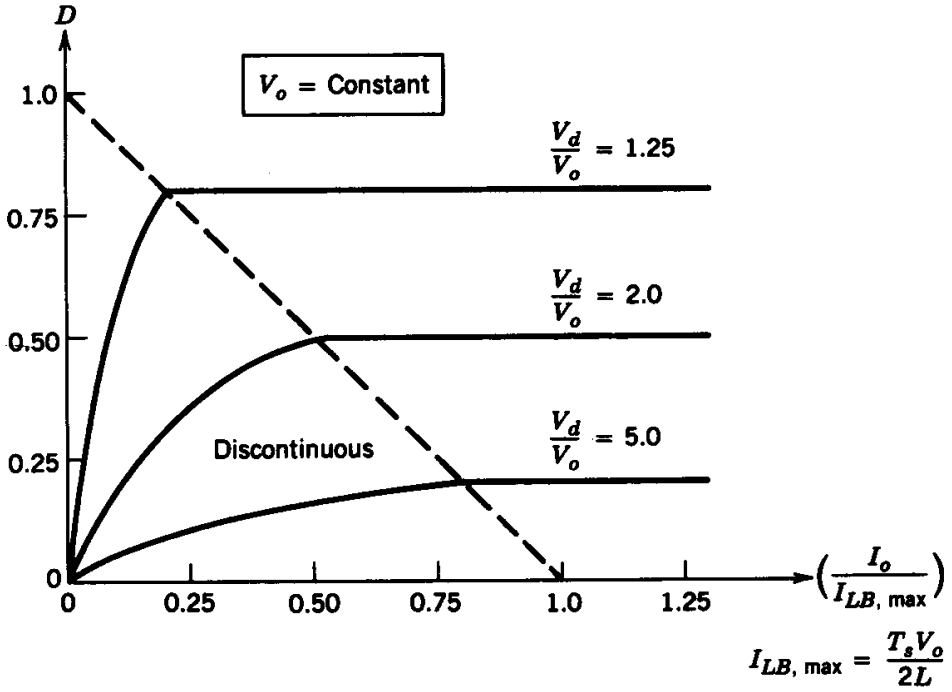

Figure 7-9 Step-down converter characteristics keeping V_o constant.

- Output voltage is kept constant

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Step-Down Conv.: Output Voltage Ripple

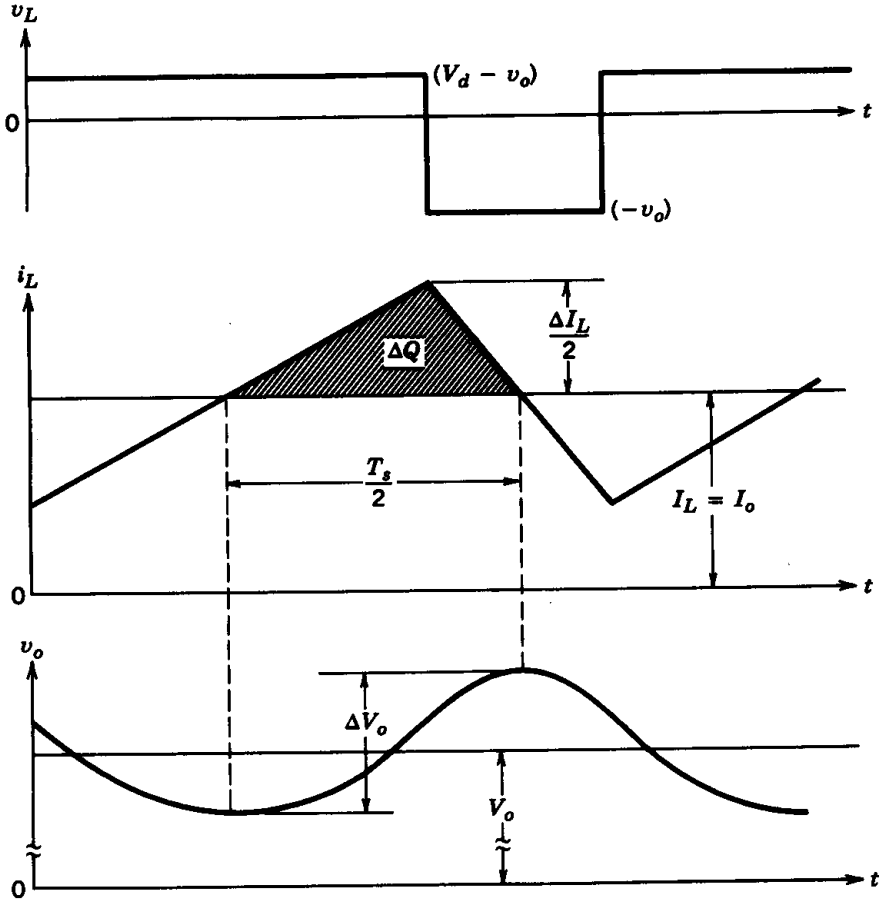

Figure 7-10 Output voltage ripple in a step-down converter.

- ESR is assumed to be zero

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Step-Up DC-DC Converter

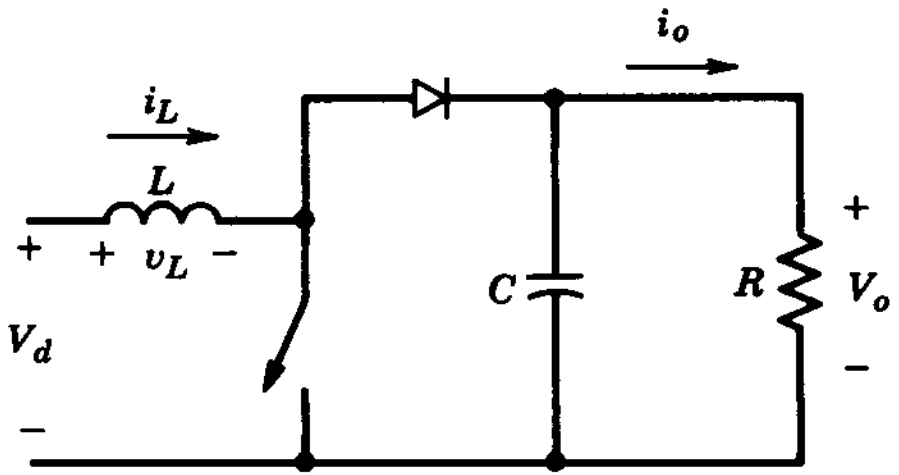

Figure 7-11 Step-up dc–dc converter.

- Output voltage must be greater than the input

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Step-Up DC-DC Converter Waveforms

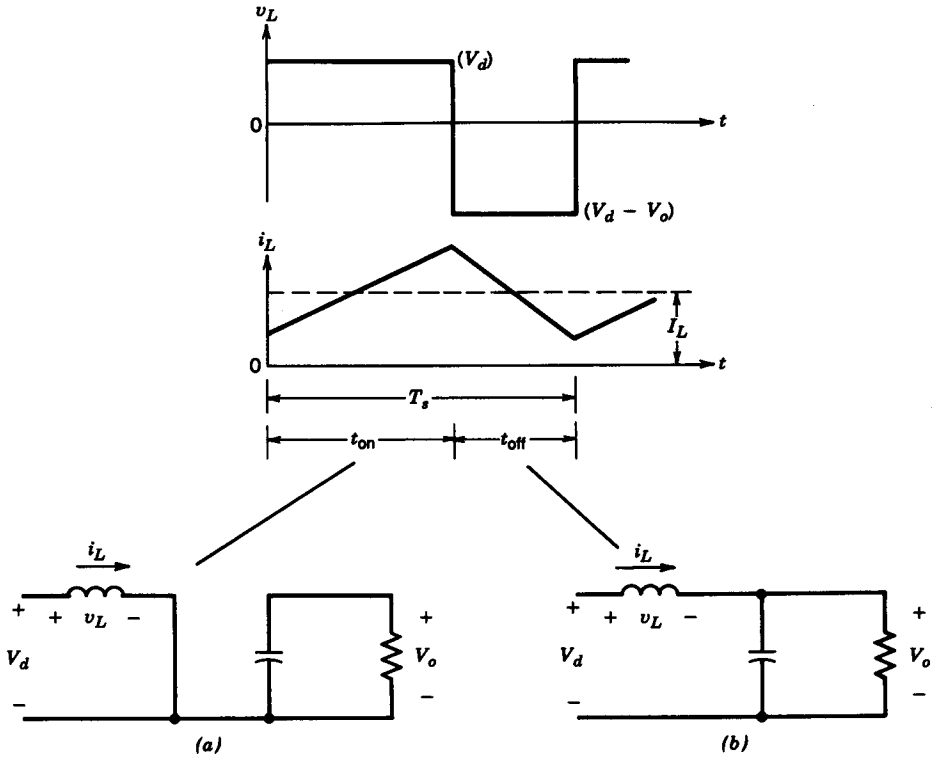

Figure 7-12 Continuous-conduction mode: (*a*) switch on; (*b*) switch off.

- Continuous current conduction mode

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Step-Up DC-DC Converter: Limits of Cont./Discont. Conduction

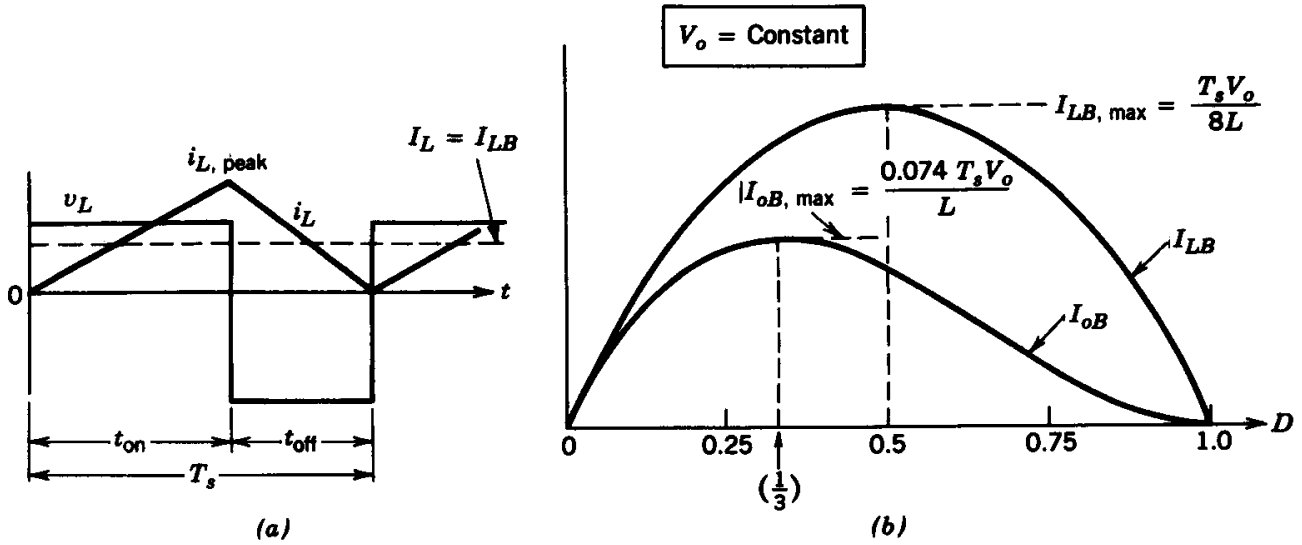

Figure 7-13 Step-up dc–dc converter at the boundary of continuous–discontinuous conduction.

- The output voltage is held constant

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Step-Up DC-DC Converter: Discont. Conduction

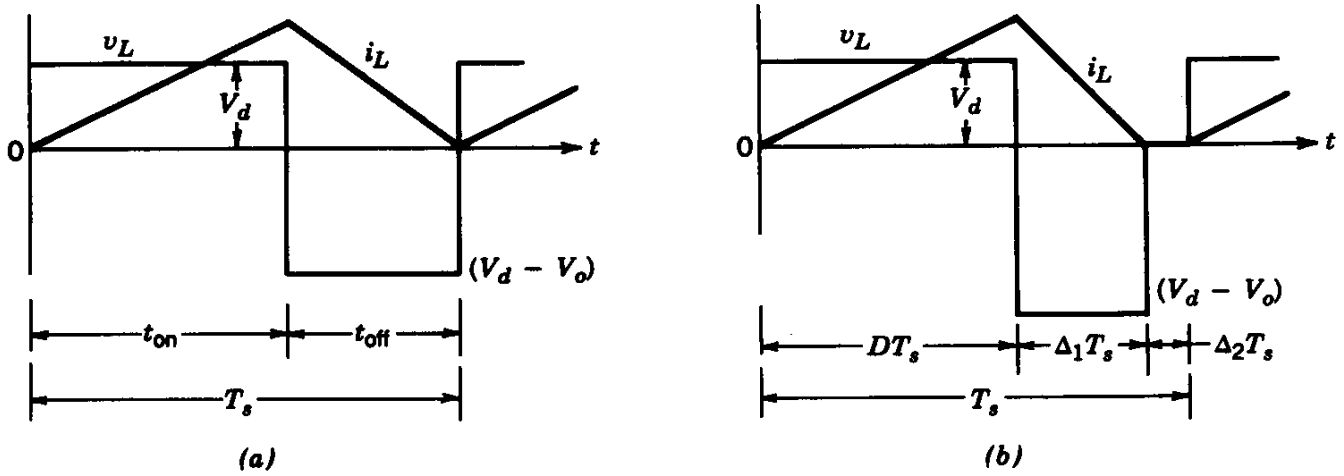

Figure 7-14 Step-up converter waveforms: (*a*) at the boundary of continuous–discontinuous conduction; (*b*) at discontinuous conduction.

- Occurs at light loads

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Step-Up DC-DC Converter: Limits of Cont./Discont. Conduction

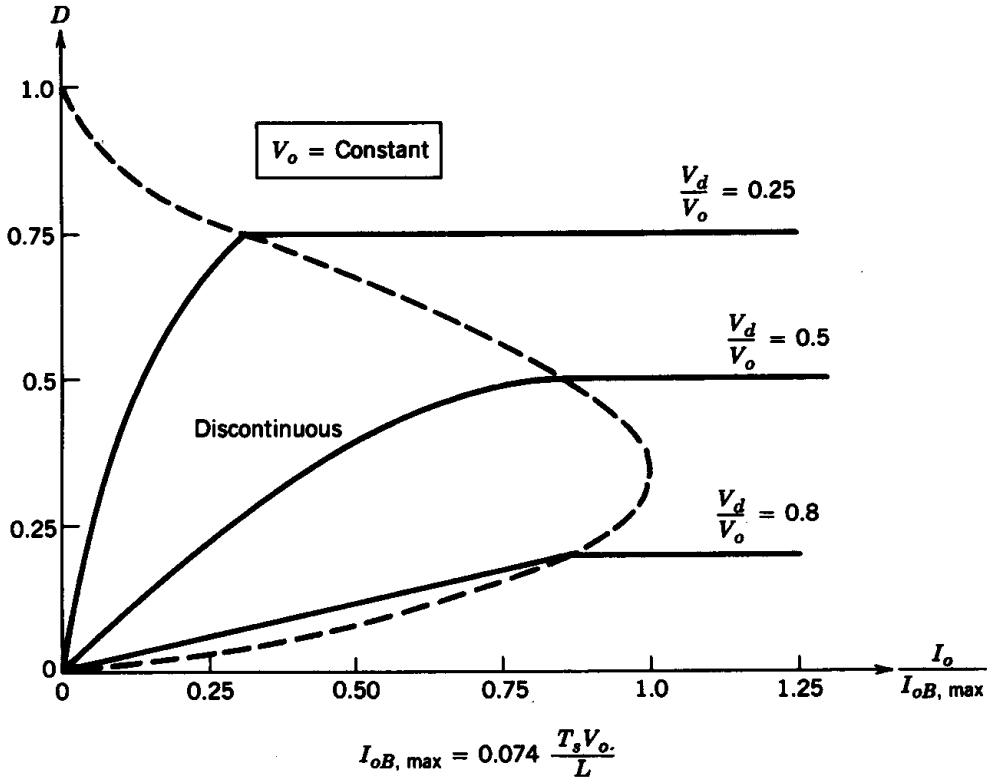

Figure 7-15 Step-up converter characteristics keeping V_o constant.

- The output voltage is held constant

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Step-Up DC-DC Converter: Effect of Parasitics

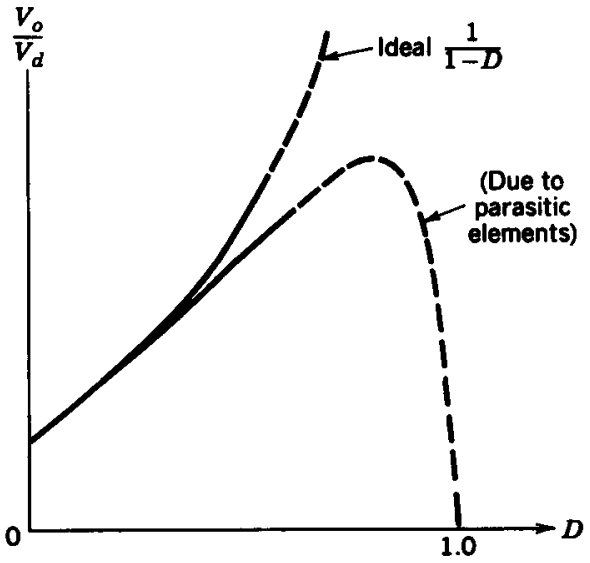

Figure 7-16 Effect of parasitic elements on voltage conversion ratio (step-up converter).

- The duty-ratio is generally limited before the parasitic effects become significant

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Step-Up DC-DC Converter Output Ripple

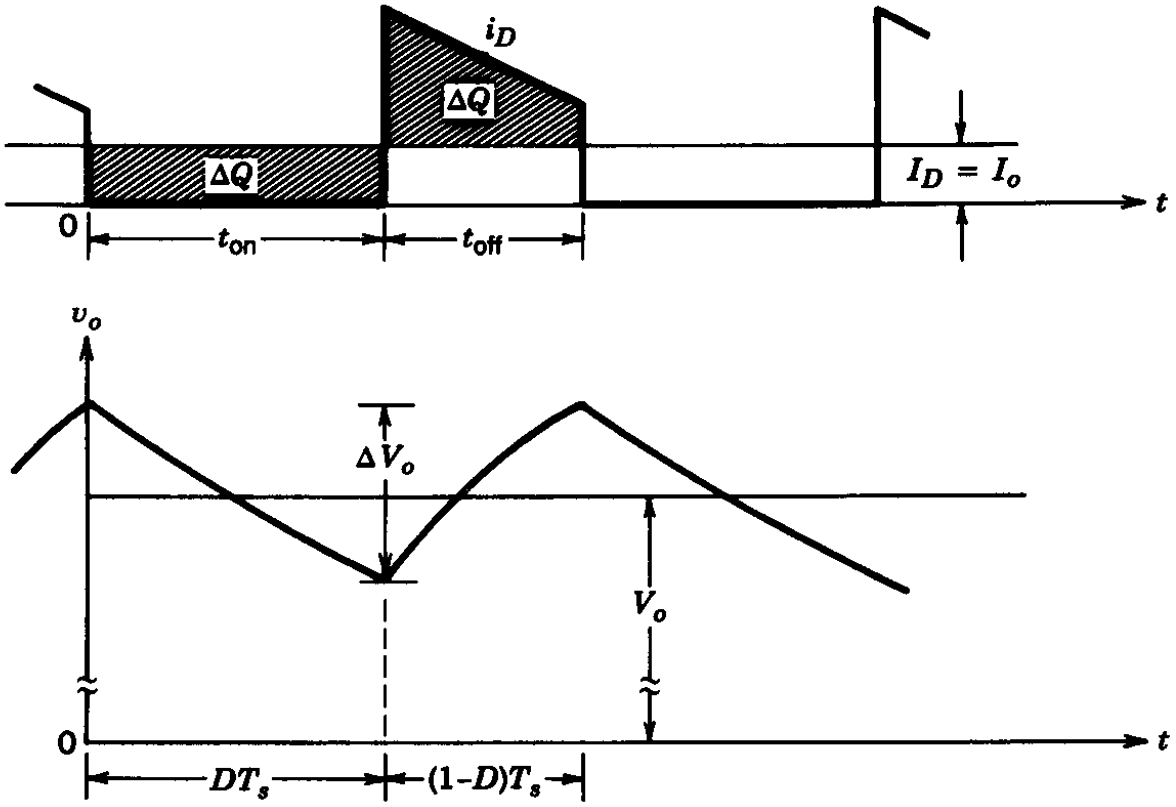

Figure 7-17 Step-up converter output voltage ripple.

- ESR is assumed to be zero

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Step-Down/Up DC-DC Converter

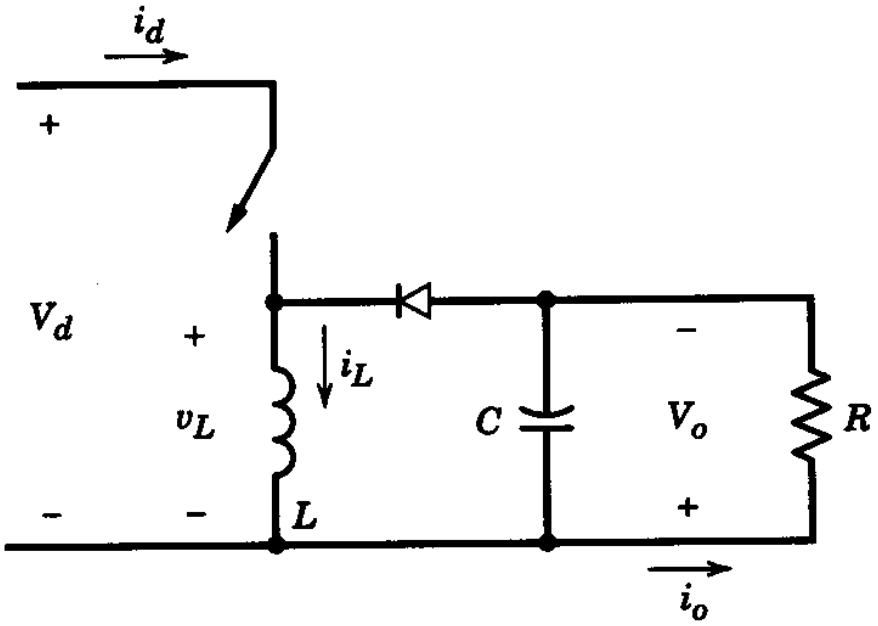

Figure 7-18 Buck–boost converter.

- The output voltage can be higher or lower than the input voltage

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Step-Up DC-DC Converter: Waveforms

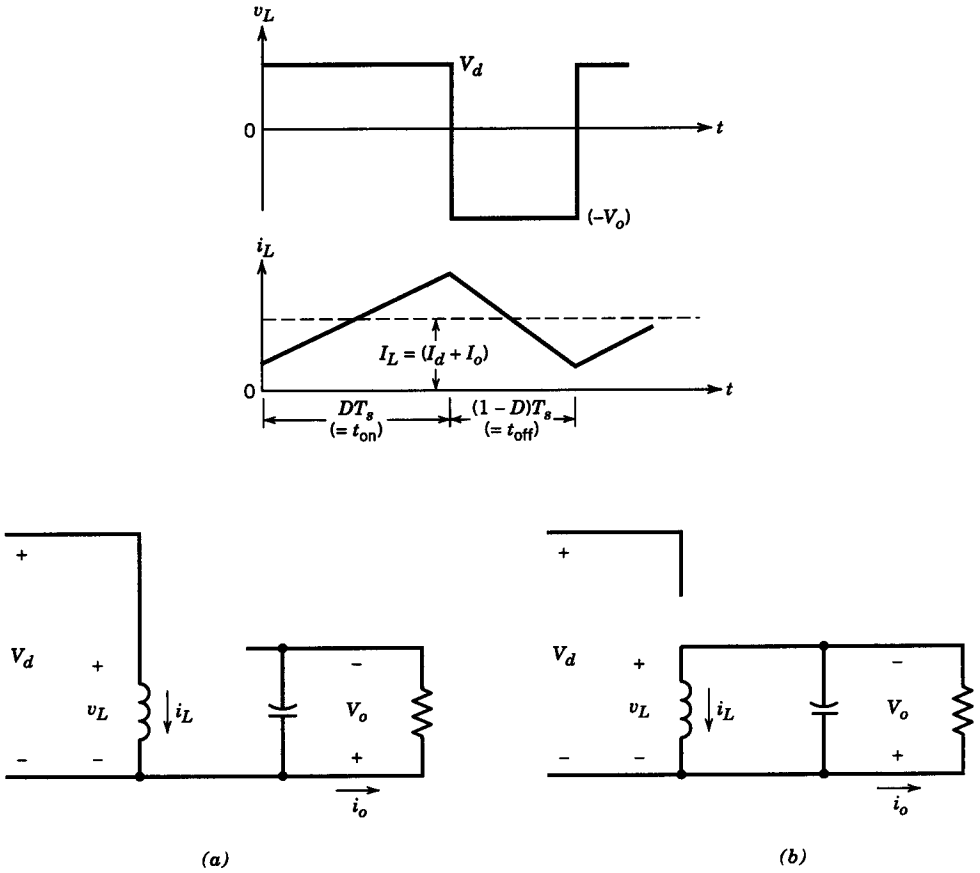

Figure 7-19 Buck–boost converter ($i_L > 0$): (*a*) switch on; (*b*) switch off.

- Continuation conduction mode

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Step-Up DC-DC Converter: Limits of Cont./Discont. Conduction

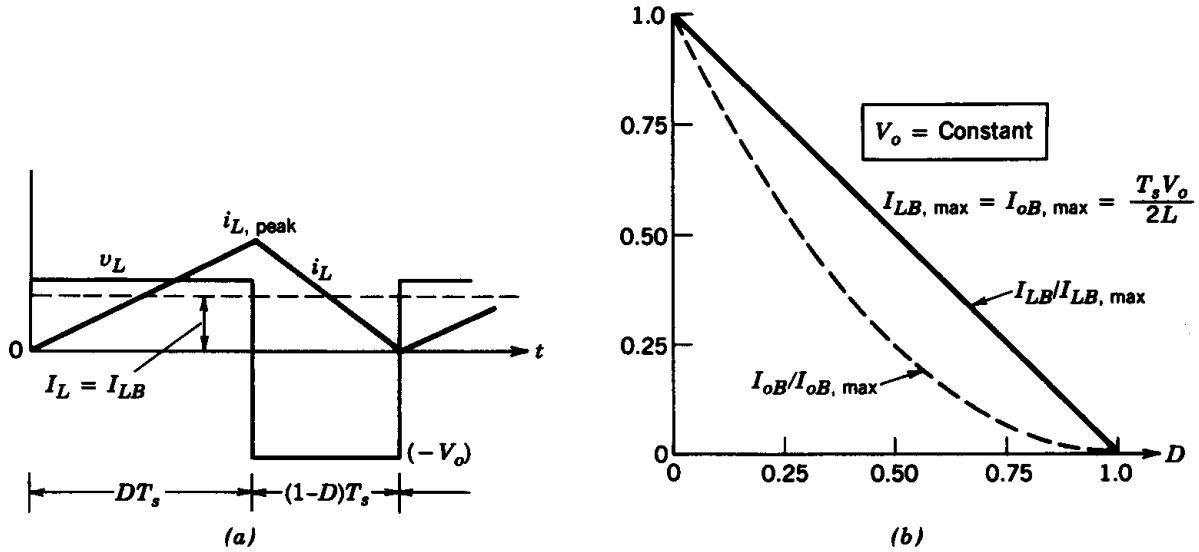

Figure 7-20 Buck–boost converter: boundary of continuous–discontinuous conduction.

- The output voltage is held constant

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Step-Up DC-DC Converter: Discontinuous Conduction Mode

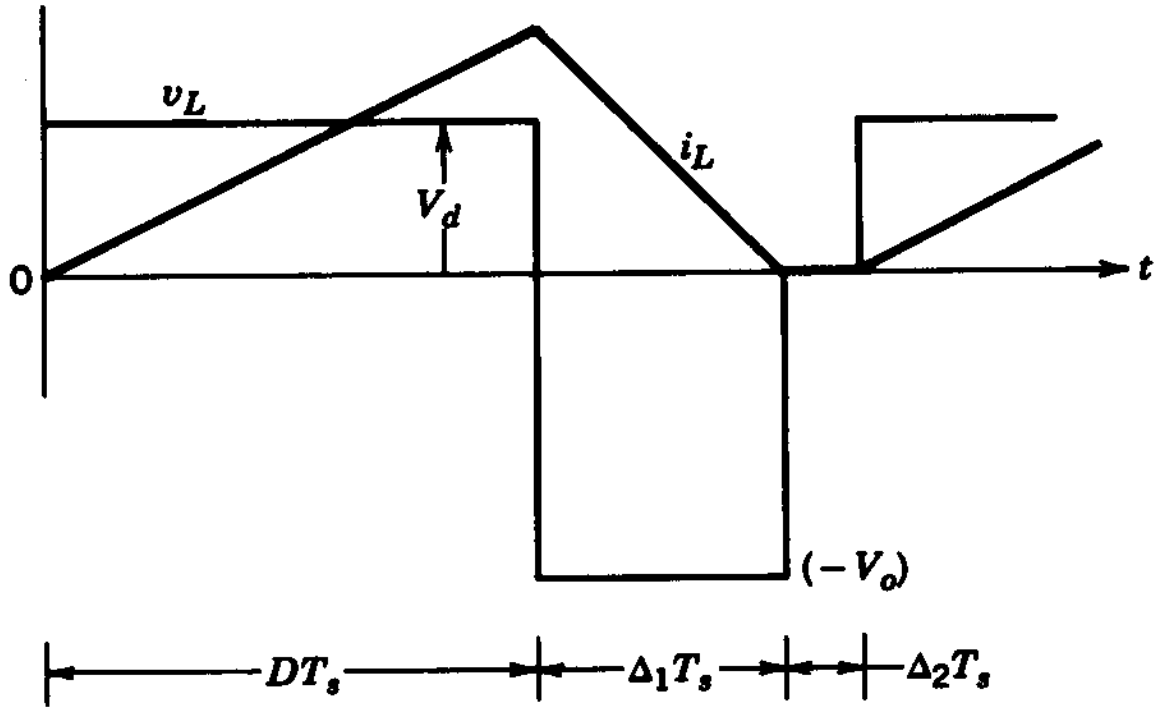

Figure 7-21 Buck–boost converter waveforms in a discontinuous-conduction mode.

- This occurs at light loads

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Step-Up DC-DC Converter: Limits of Cont./Discont. Conduction

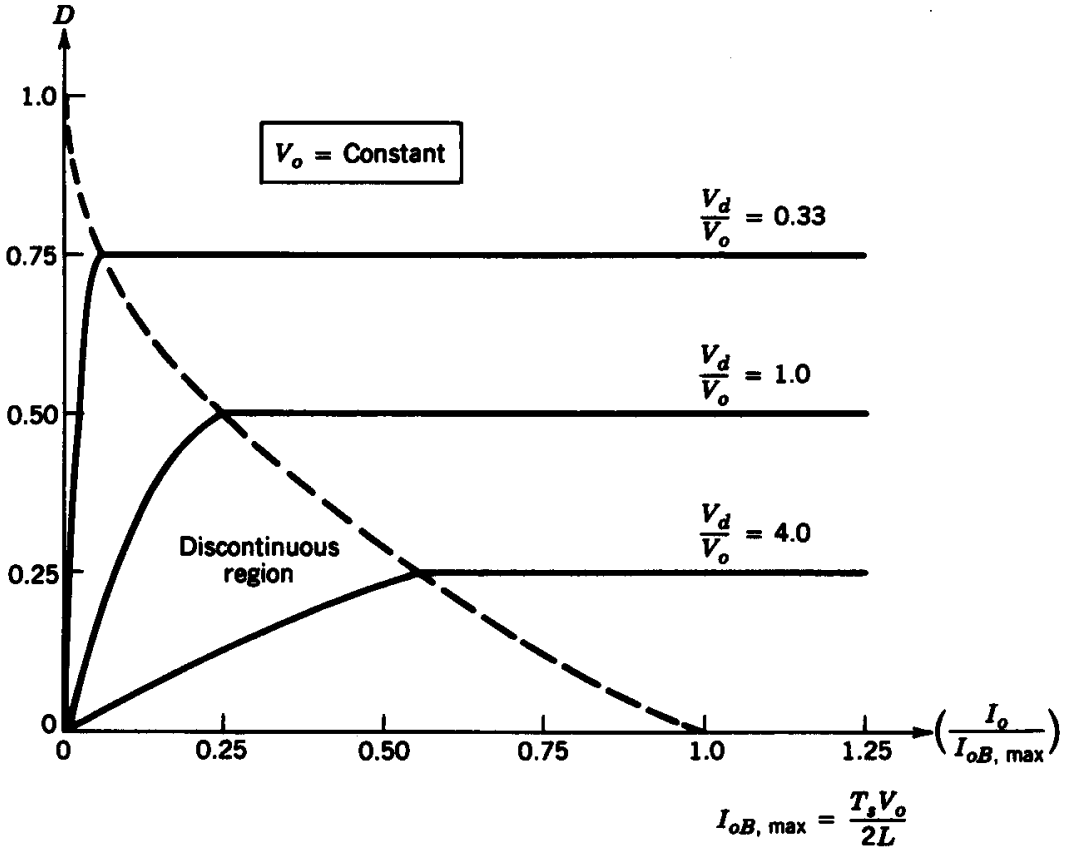

Figure 7-22 Buck–boost converter characteristics keeping V_o constant.

- The output voltage is held constant

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Step-Up DC-DC Converter: Effect of Parasitics

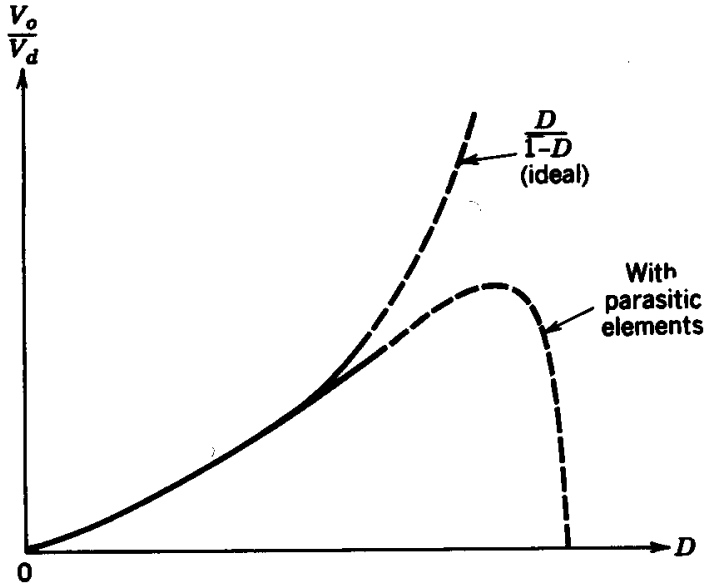

Figure 7-23 Effect of parasitic elements on the voltage conversion ratio in a buck–boost converter.

- The duty-ratio is limited to avoid these parasitic effects from becoming significant

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Step-Up DC-DC Converter: Output Voltage Ripple

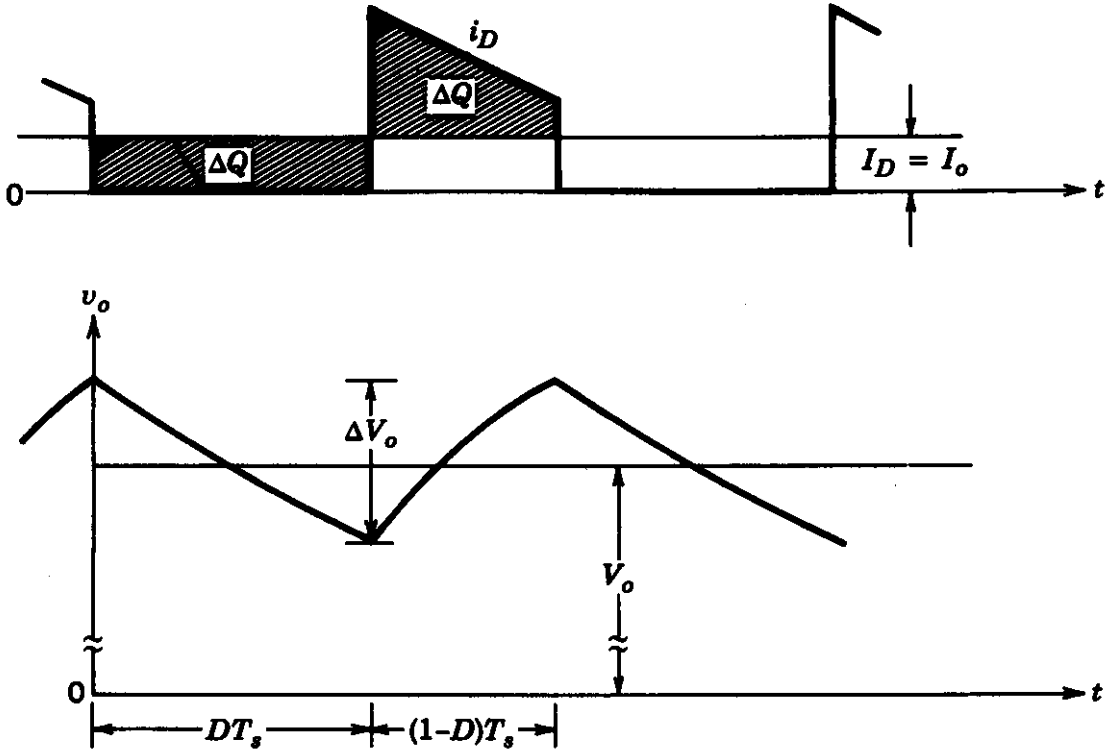

Figure 7-24 Output voltage ripple in a buck–boost converter.

- ESR is assumed to be zero

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Cuk DC-DC Converter

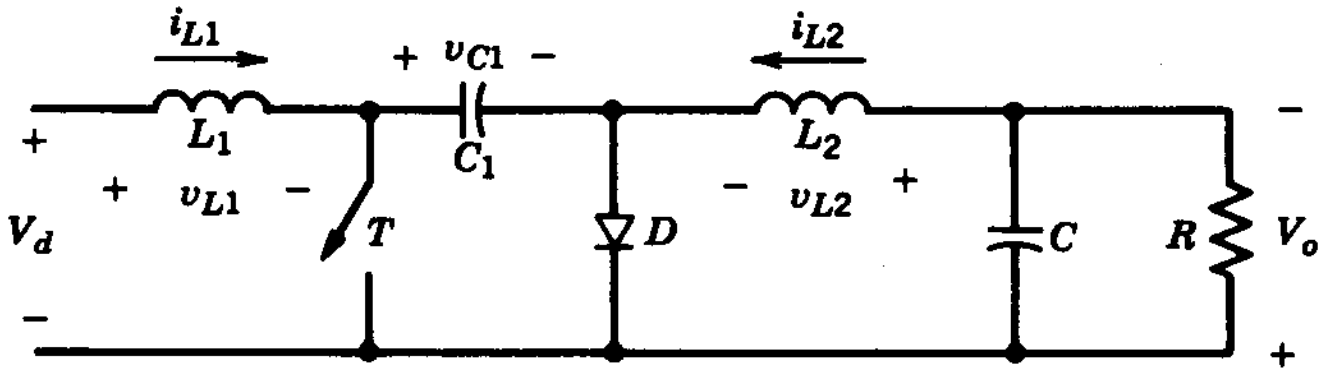

Figure 7-25 Cúk converter.

- The output voltage can be higher or lower than the input voltage

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Cuk DC-DC Converter: Waveforms

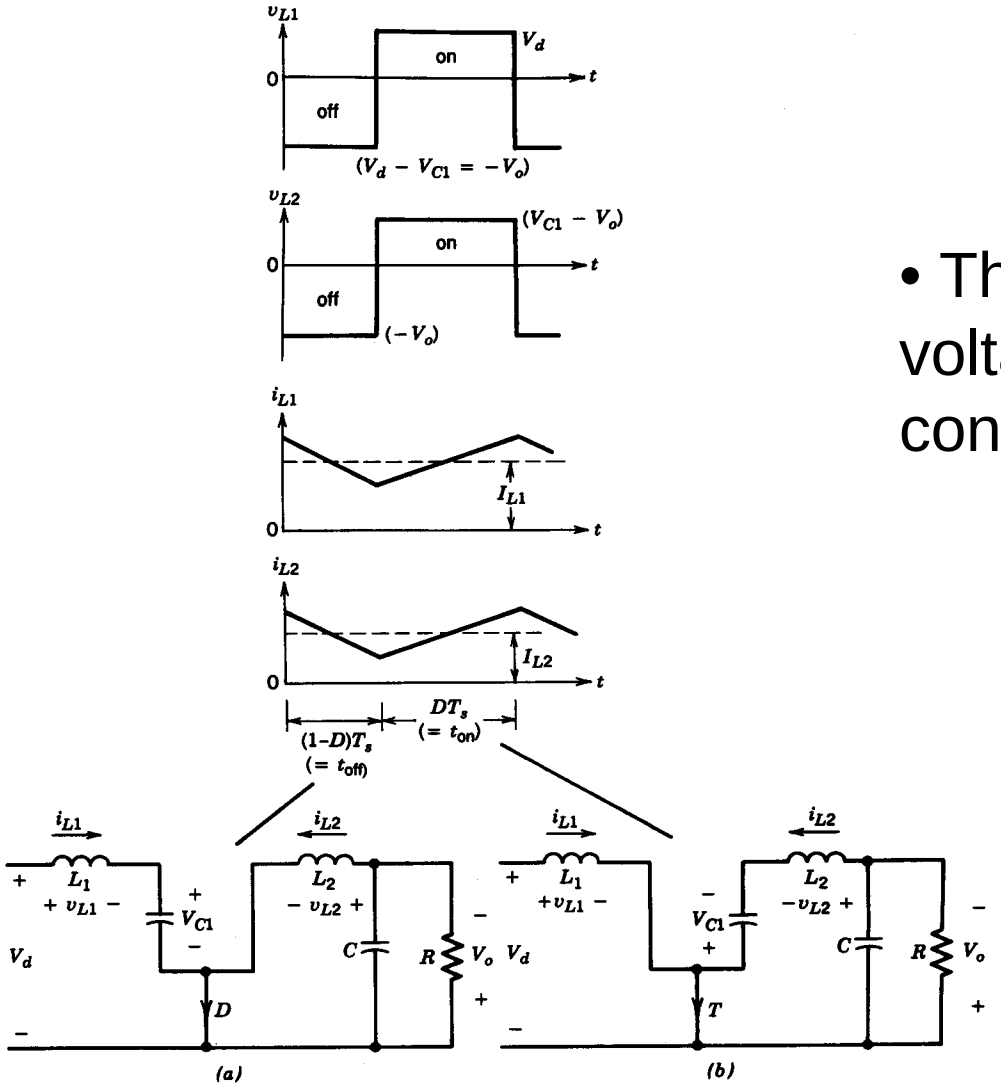

Figure 7-26 Cúk converter waveforms: (*a*) switch off; (*b*) switch on.

- The capacitor voltage is assumed constant

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Converter for DC-Motor Drives

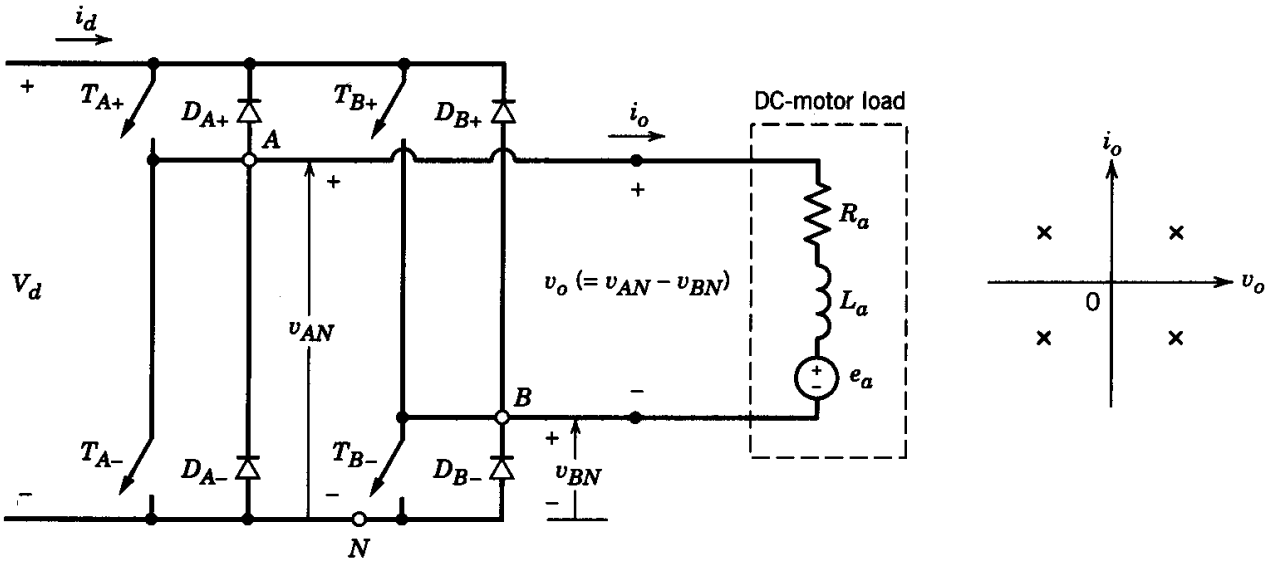

Figure 7-27 Full-bridge dc–dc converter.

- Four quadrant operation is possible

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Converter Waveforms

- Bi-polar voltage switching

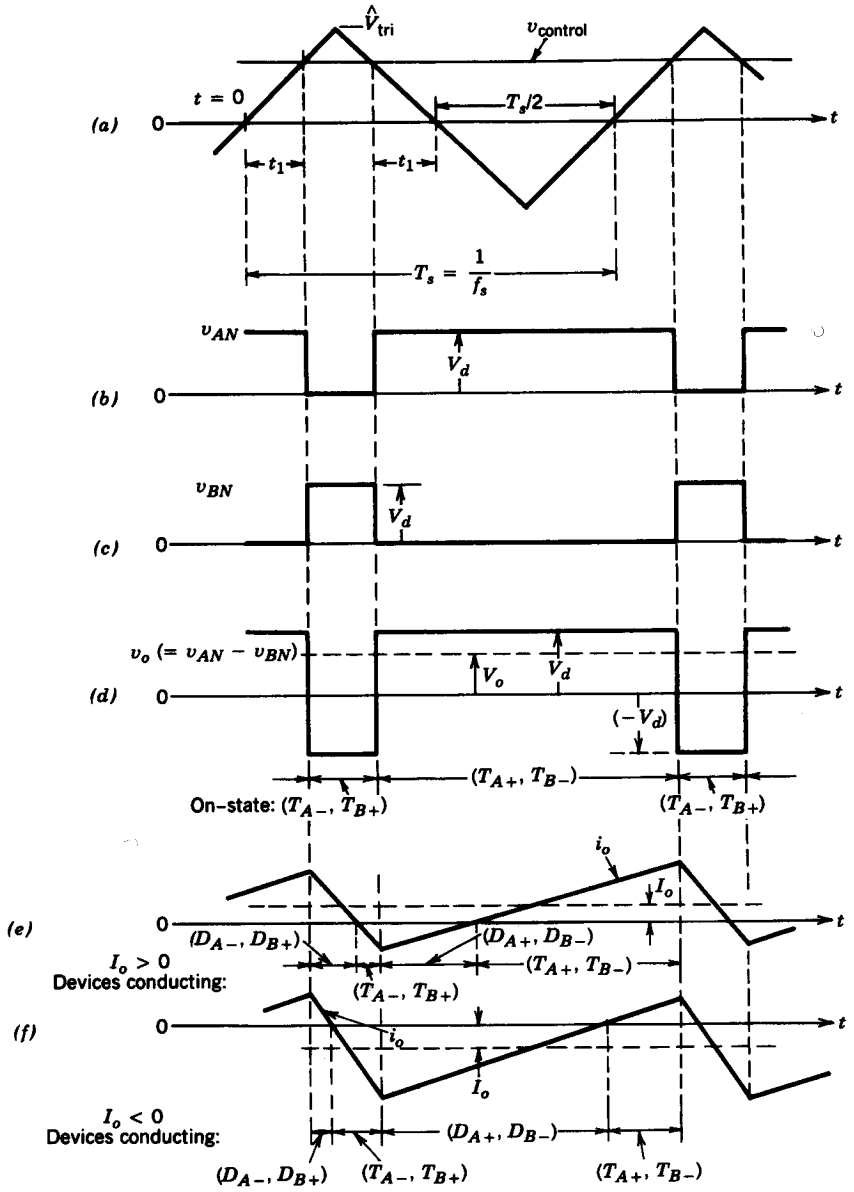

Figure 7-28 PWM with bipolar voltage switching.

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Converter Waveforms

- Uni-polar voltage switching

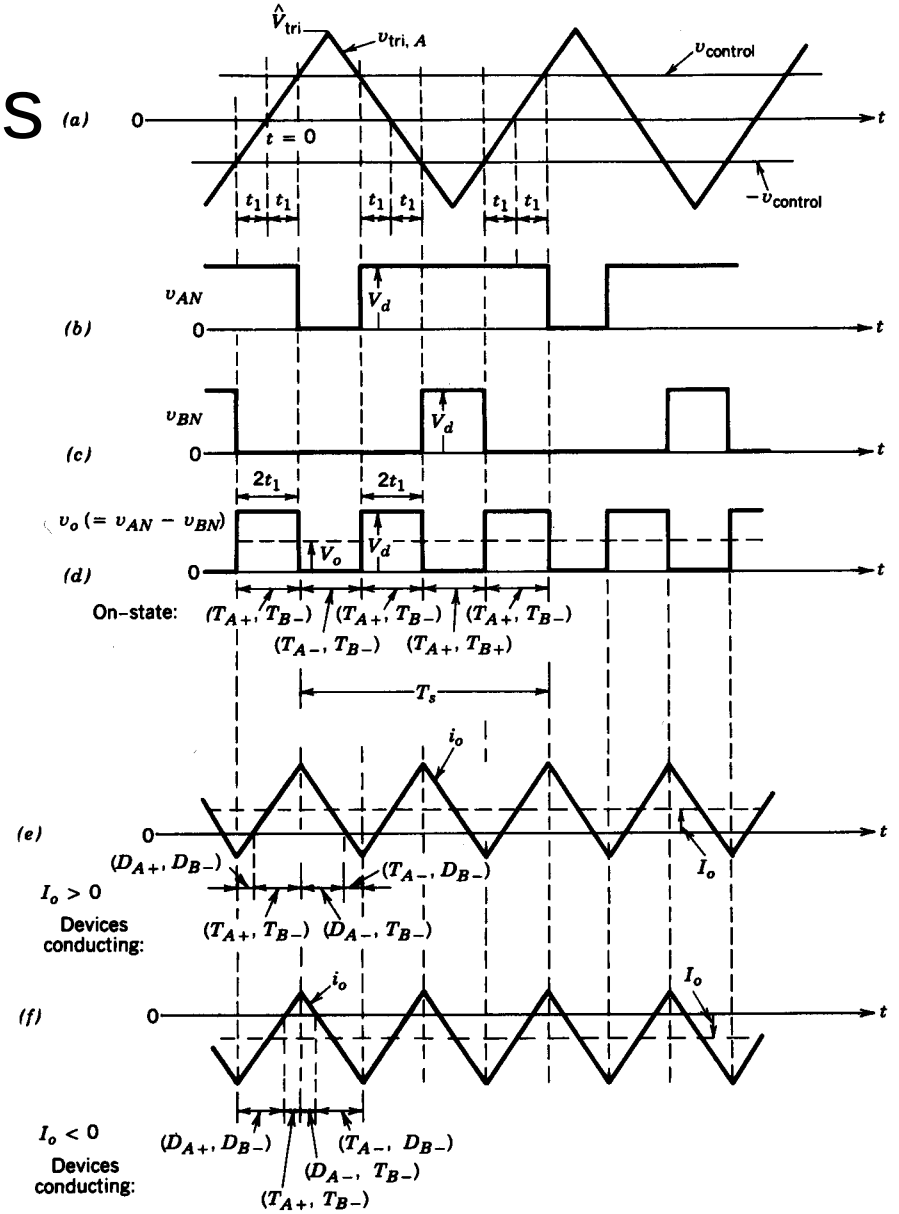

Figure 7-29 PWM with unipolar voltage switching.

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Output Ripple in Converters for DC-Motor Drives

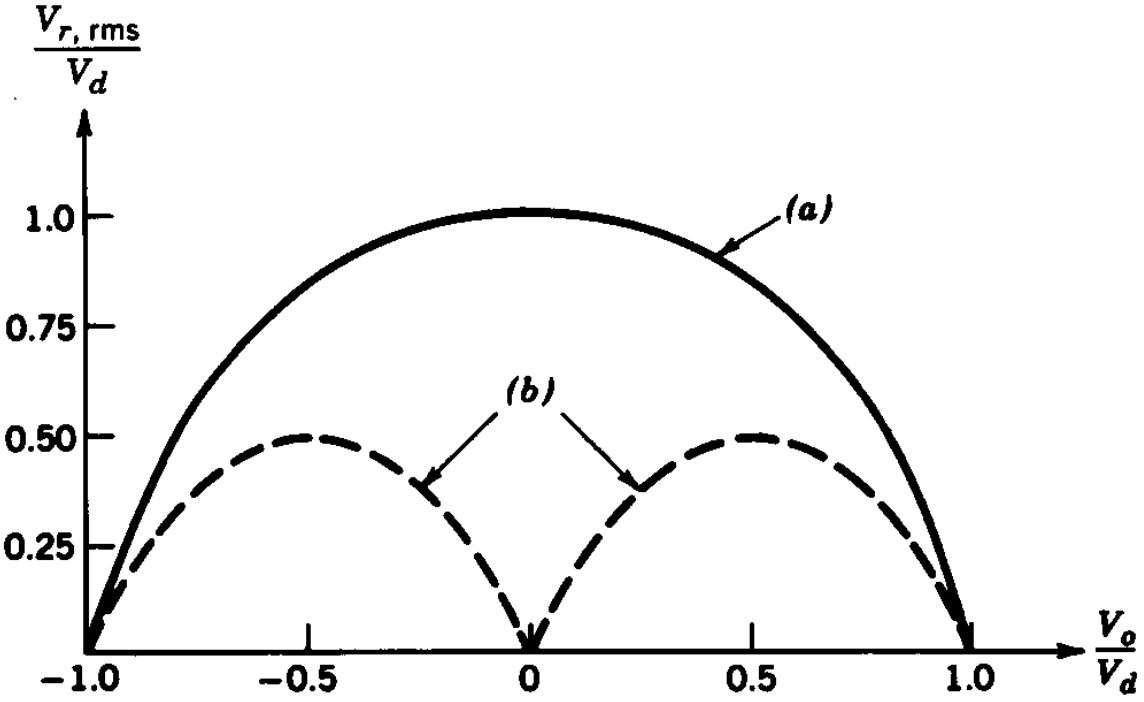

Figure 7-30 $V_{r,\text{rms}}$ in a full-bridge converter using PWM: (*a*) with bipolar voltage switching; (*b*) with unipolar voltage switching.

- bi-polar and uni-polar voltage switching

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Switch Utilization in DC-DC Converters

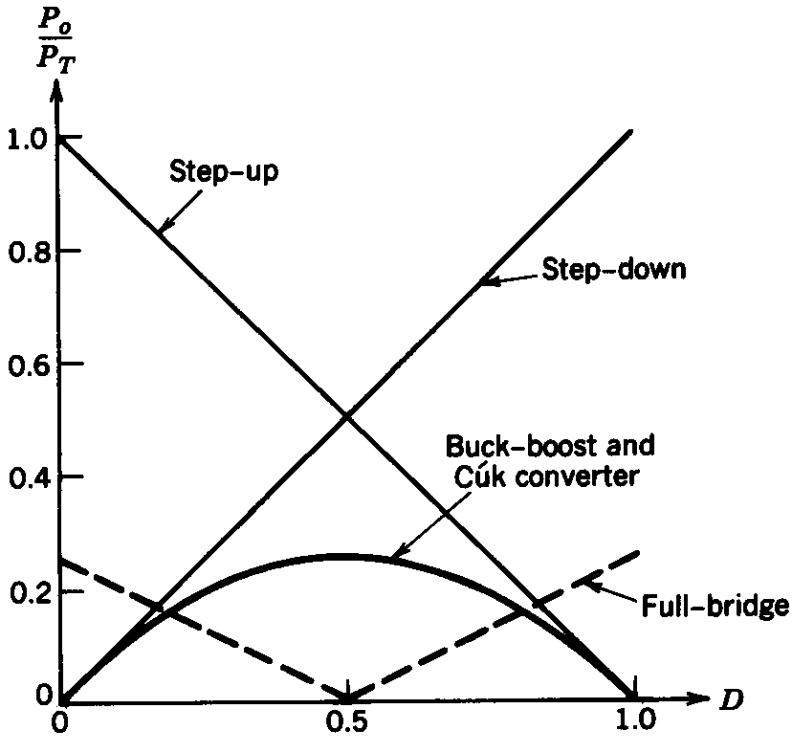

Figure 7-31 Switch utilization in dc–dc converters.

- It varies significantly in various converters

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Equivalent Circuits in DC-DC Converters

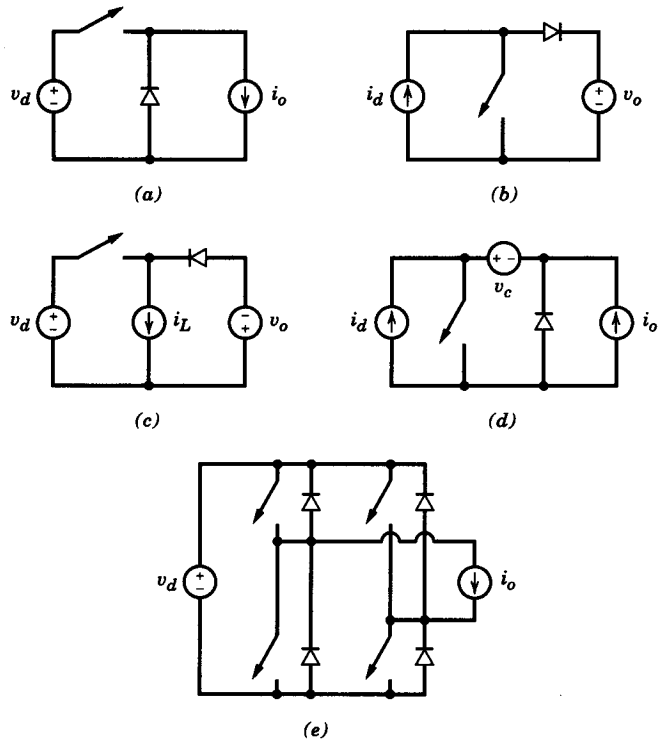

Figure 7-32 Converter equivalent circuits: (*a*) step-down; (*b*) step-up; (*c*) step-down/step-up; (*d*) Cúk; (*e*) full-bridge.

- replacing inductors and capacitors by current and voltage sources, respectively

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Reversing the Power Flow in DC-DC Conv.

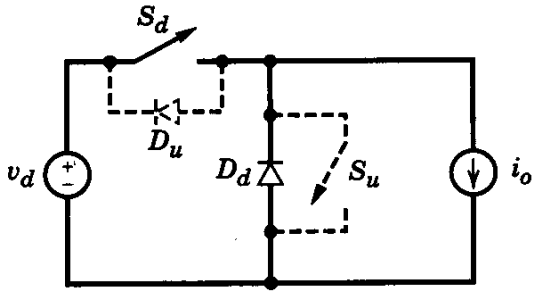

Figure 7-33 Reversible power flow with reversible direction of the output current i_o.

- For power flow from right to left, the input current direction should also reverse

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