[17] ARTHUR WITULSKI and ROBERT ERICKSON, "Extension of State-Space Averaging to Resonant Switches—and Beyond," *IEEE Transactions on Power Electronics*, Vol. 5, No. 1, pp. 98-109, January 1990.

[18] D. MAKSIMOVIĆ and S. ĆUK, "A Unified Analysis of PWM Converters in Discontinuous Modes," *IEEE Transactions on Power Electronics*, Vol. 6, No. 3, pp. 476-490, July 1991.

[19] D. J. SHORTT and F. C. LEE, "Extensions of the Discrete-Average Models for Converter Power Stages," *IEEE Power Electronics Specialists Conference*, 1983 Record, pp. 23-37, June 1983.

[20] O. AL-NASEEM and R.W. ERICKSON, "Prediction of Switching Loss Variations by Averaged Switch Modeling," *IEEE Applied Power Electronics Conference*, 2000 Record, pp. 242-248, February 2000.

PROBLEMS

7.1 An ideal boost converter operates in the continuous conduction mode.

(a) Determine the nonlinear averaged equations of this converter.

(b) Now construct a small-signal ac model. Let

$$
\begin{aligned}
\left\langle v_g(t) \right\rangle_{T_s} &= V_g + \hat{v}_g(t) \\
d(t) &= D + \hat{d}(t) \\
\left\langle i(t) \right\rangle_{T_s} &= I + \hat{i}(t) \\
\left\langle v(t) \right\rangle_{T_s} &= V + \hat{v}(t)
\end{aligned}
$$

where V_g, D, I, and V are steady-state dc values; $\hat{v}_g(t)$ and $\hat{d}(t)$ are small ac variations in the power and control inputs; and $\hat{i}(t)$ and $\hat{v}(t)$ are the resulting small ac variations in the inductor current and output voltage, respectively. Show that the following model results:

Large-signal dc components

$$
\begin{aligned}
0 &= -D'V + V_g \\
0 &= D'I - \frac{V}{R}
\end{aligned}
$$

Small-signal ac components

$$
\begin{aligned}
L\frac{d\hat{i}(t)}{dt} &= -D'\hat{v}(t) + V\hat{d}(t) + \hat{v}_g(t) \\
C\frac{d\hat{v}(t)}{dt} &= D'\hat{i}(t) - I\hat{d}(t) - \frac{\hat{v}(t)}{R}
\end{aligned}
$$

7.2 Construct an equivalent circuit that corresponds to the boost converter small-signal ac equations derived in Problem 7.1(b).

7.3 Manipulate your boost converter equivalent circuit of Problem 7.2 into canonical form. Explain each step in your derivation. Verify that the elements in your canonical model agree with Table 7.1.

7.4 The ideal current-fed bridge converter of Fig. 2.31 operates in the continuous conduction mode.

(a) Determine the nonlinear averaged equations of this converter.

(b) Perturb and linearize these equations, to determine the small-signal ac equations of the converter.