Averaged Switch Modeling with Switching Loss

This problem explores the effect of switching loss on the averaged switch model. For clarity, other losses are neglected. The PWM switch network illustrated in Fig. 1 operates with the waveforms illustrated in Fig. 2. Switching loss is induced by the reverse recovery process of the diode.

(a) Derive a large-signal averaged switch model for the switch network defined by Figs. 1 and 2. Give analytical expressions for all elements in your equivalent circuit, in terms of the quantities identified in Figs. 1 and 2. Your model will include one or more current sources that depend on $I_{on}$, so be sure that your model explicitly contains a branch that conducts current $I_{on}$.

(b) The indirect power of a PWM converter is the power that flows through its switch network as defined by Fig. 1. The transistor converts this power $P_{indirect} = P_1 = \langle v_1 \rangle \langle i_1 \rangle$ from dc to ac. The diode rectifies the ac power back to dc, and it then flows out of Port 2 of the switch network as the dc power $P_2 = \langle v_2 \rangle \langle i_2 \rangle$. Derive an expression for the efficiency $\eta_{pw} = P_2 / P_1$ by which the switch network processes this indirect power. Express your result in the form:

$$\eta_{pw} = \frac{1 - \frac{x}{d}}{1 + \frac{x}{d}}$$  (1)

Give an expression for $x$. Note that the switching loss is directly related to this process of converting the indirect power from dc to ac and back to dc.

(c) The above switch network is employed in the boost converter illustrated in Fig. 3. The input
power of this converter, \( P_{\text{in}} = V I_g \), can be decomposed into two components: \( P_{\text{in}} = P_{\text{direct}} + P_{\text{indirect}} \) where \( P_{\text{indirect}} = \langle v_1 \rangle \langle i_1 \rangle \) as discussed in part (b). \( P_{\text{direct}} \) is the “direct power” that flows directly from the dc source \( V_g \) to the dc load, without the intermediate step of being converted to ac form by the switch network.

Derive an expression for the converter efficiency \( \eta_{\text{converter}} = \frac{VI}{VgIg} \), in terms of \( \eta_{\text{sw}} \) and \( P_{\text{direct}}/P_{\text{indirect}} \). Give expressions for \( P_{\text{direct}} \) and \( P_{\text{indirect}} \) in terms of \( V_g, I_g, \) and \( V \). Show that \( \eta_{\text{converter}} = \eta_{\text{sw}} \) when all of the power is indirect, and that \( \eta_{\text{converter}} \) increases as the fraction of direct power increases.