11.5 Transformer Design for Flyback Converter in CCM

11.5.1 Practical Design Considerations of Transformers

The transformer is the most important component of the flyback converter. It provides DC isolation, AC coupling, voltage level change, and magnetic energy storage. The current flows only in the primary winding when the magnetic energy in the transformer is increased and in the secondary winding while the magnetic energy is decreased. Thus, the physical transformer in the flyback converter serves as an inductor to store and transfer the magnetic energy and as a transformer to provide DC isolation, AC coupling, and voltage and current level transformation. The transformer in a flyback converter is often described as a coupled inductance.

The primary winding should start from the innermost layer of the bobbin. This reduces the length of wire, minimizing the copper loss of the primary winding. In addition, the electromagnetic interference (EMI) noise radiation is reduced because the secondary windings act as Faraday's shields. The innermost layer of the primary winding should be connected to the drain of a power metal-oxide-semiconductor field-effect transistor (MOSFET). Therefore, the shielding of the winding with the highest voltage is maximized by the secondary windings. In multiple-output transformers, the secondary winding with the highest output power should be placed closest to the primary winding to ensure good coupling and to reduce leakage inductance. If the secondary winding has small number of turns, the turns of this winding should be spread along the entire window breadth to maximize the coupling coefficient. If the secondary winding has a low number of turns and is made of strands, the strands should form one flat layer along the window breadth to increase the coupling coefficient and to reduce the proximity effect loss.

11.5.2 Area Product A_p for Transformer Square Wave Voltages

The window area limited by the maximum current density in the winding wire is given by

$$W_a = \frac{N_p A_{wp} + N_s A_{ws}}{K_u} \tag{11.68}$$

Assuming the winding allocation is such that $N_p A_{wp} = N_s A_{ws}$, the window area is

$$W_a = \frac{2N_p A_{wp}}{K_u} = \frac{2N_p I_{Lpmax}}{K_u J_{pm}} = \frac{2N_p I_{Lprms}}{K_u J_{prms}}. \tag{11.69}$$

From Chapter 1, the required core cross-sectional area is given by

$$A_c = \frac{\lambda_m}{N_p B_{pk}} = \frac{L_p I_{Lpmax}}{N_p B_{pk}}. \tag{11.70}$$

Hence, the core area product is obtained as

$$A_p = W_a A_c = \frac{2N_p I_{Lpmax}}{K_u J_{pm}} \times \frac{L_p I_{Lpmax}}{N_p B_{pk}} = \frac{2L_p I_{Lpmax}^2}{K_u J_{pm} B_{pk}} = \frac{4W_m}{K_u J_{pm} B_{pk}}. \tag{11.71}$$

The core cross-sectional area for transformer square voltage waveforms is

$$A_c = \frac{V_{Lprms}}{4 f_s N_p B_{pk}}. \tag{11.72}$$

Thus, the core area product is

$$A_p = W_a A_c = \frac{2N_p I_{Lprms}}{K_u J_{prms}} \times \frac{V_{Lprms}}{4 f_s N_p B_{pk}} = \frac{I_{Lprms} V_{Lprms}}{2K_u f_s J_{prms} B_{pk}}. \tag{11.73}$$

11.5.3 Area Product A_p Method

The inductor for pulse-width modulated (PWM) converters in continuous conduction mode (CCM) should satisfy the following conditions:

1. $L > L_{min}$ required for CCM operation.
2. $B_{max} < B_s$ or $\lambda_{max} < \lambda_s$. For ferrite cores, $B_s < 0.5$ T at room temperature and $B_s = 0.3$ T at $T = 100\,^{\circ}$C.
3. $P_L < P_{L(max)}$. Since $P_L \approx P_w = P_{rL}$, $r_L < r_{Lmax}$.
4. $J_{max} < J_{max}$. Typically, $J_{max} = 0.1$–5 A/mm^2.

The magnitude of the AC magnetic flux is caused by the peak-to-peak value Δi_L of the AC component of the inductor current and is normally only a fraction of the DC flux. In many cases, the AC inductor current riding on top of the DC current I_L is small enough that it does not affect the overall current density of the single wire used.

Example 11.1

A flyback PWM converter is operated in the CCM and has the following specifications: $V_I = 28 \pm 4$ V, $V_O = 5$ V, $I_O = 2$–10 A, and $f_s = 100$ kHz.

Solution: Figure 11.3 shows a circuit of the flyback converter and its models for CCM. Figure 11.4 shows waveforms in the flyback converter for CCM. The maximum and minimum output powers are

$$P_{Omax} = V_O I_{Omax} = 5 \times 10 = 50 \text{ W} \tag{11.74}$$

and

$$P_{Omin} = V_O I_{Omin} = 5 \times 2 = 10 \text{ W}. \tag{11.75}$$

The minimum and maximum load resistances are

$$R_{Lmin} = \frac{V_O}{I_{Omax}} = \frac{5}{10} = 0.5\ \Omega \tag{11.76}$$

and

$$R_{Lmax} = \frac{V_O}{I_{Omin}} = \frac{5}{2} = 2.5\ \Omega. \tag{11.77}$$

The minimum and maximum DC voltage transfer functions are

$$M_{VDCmin} = \frac{V_O}{V_{Imax}} = \frac{5}{32} = 0.15625\ \Omega \tag{11.78}$$

and

$$M_{VDCmax} = \frac{V_O}{V_{Imin}} = \frac{5}{24} = 0.2083\ \Omega. \tag{11.79}$$

Assume the converter efficiency $\eta = 0.92$ and the maximum duty cycle $D_{max} = 0.5$. The transformer turns ratio is

$$n = \frac{\eta D_{max}}{(1 - D_{max}) M_{VDCmax}} = \frac{0.92 \times 0.5}{(1 - 0.5) \times 0.2083} = 4.4167. \tag{11.80}$$

The minimum duty cycle is

$$D_{min} = \frac{n M_{VDCmin}}{n M_{VDCmin} + \eta} = \frac{4.414 \times 0.15625}{4.4167 \times 0.15625 + 0.92} = 0.4286. \tag{11.81}$$

The minimum inductance of the primary winding is determined by the operation in CCM

$$L_p \approx L_{m(min)} = \frac{n^2 R_{Lmax} (1 - D_{min})^2}{2 f_s} = \frac{4.4167^2 \times 2.5 \times (1 - 0.4286)^2}{2 \times 10^5} = 79.61\ \mu\text{H}. \tag{11.82}$$

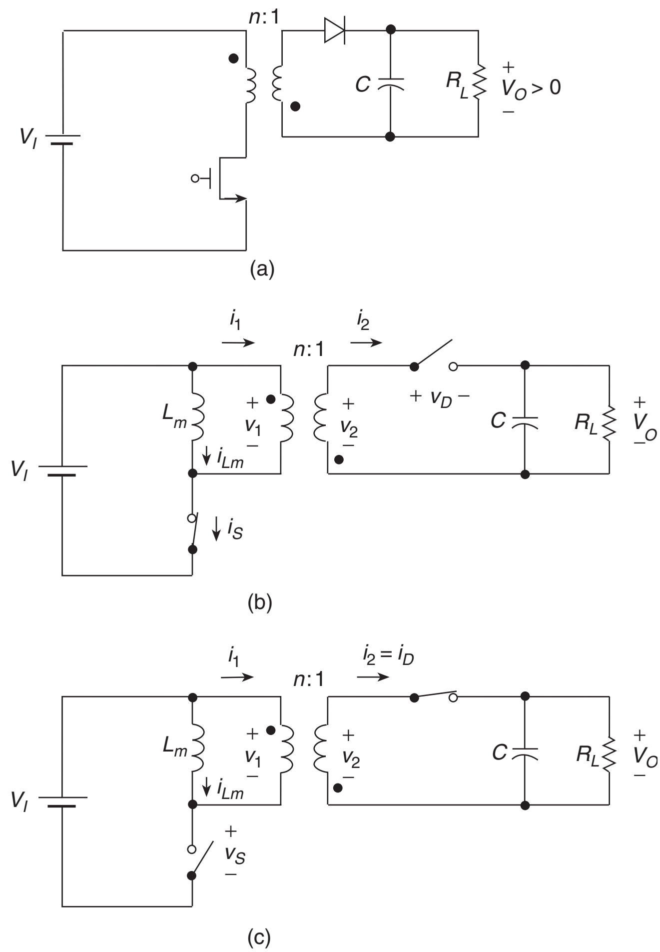

Figure 11.3 Flyback PWM converter and its models for CCM. (a) Circuit. (b) Model when MOSFET is on. (c) Model when MOSFET is OFF

Pick $L_p = 82\ \mu$H. The inductance of the secondary winding is

$$L_s = \frac{L_p}{n^2} = \frac{82 \times 10^{-6}}{4.4167^2} = 4.2036\ \mu\text{H}. \tag{11.83}$$

Pick $L_s = 4.7\ \mu$H.

The maximum peak-to-peak value of the magnetizing current and the primary current ripple is

$$\Delta i_{Lp(max)} = \Delta i_{Lm(max)} = \frac{nV_O(1 - D_{min})}{f_s L_p} = \frac{4.4167 \times 5 \times (1 - 0.4286)}{10^5 \times 82 \times 10^{-6}} = 1.5387\ \text{A}. \tag{11.84}$$

The minimum peak-to-peak value of the magnetizing current and the primary current ripple at full power is

$$\Delta i_{Lp(min)} = \Delta i_{Lm(min)} = \frac{nV_O(1 - D_{max})}{f_s L_p} = \frac{4.4167 \times 5 \times (1 - 0.5)}{10^5 \times 82 \times 10^{-6}} = 1.346\ \text{A}. \tag{11.85}$$

The maximum DC input current is

$$I_{Imax} = \frac{P_O}{\eta V_{Imin}} = \frac{M_{VDCmax} I_{Omax}}{\eta} = \frac{0.2083 \times 10}{0.92} = 2.2641\ \text{A}. \tag{11.86}$$

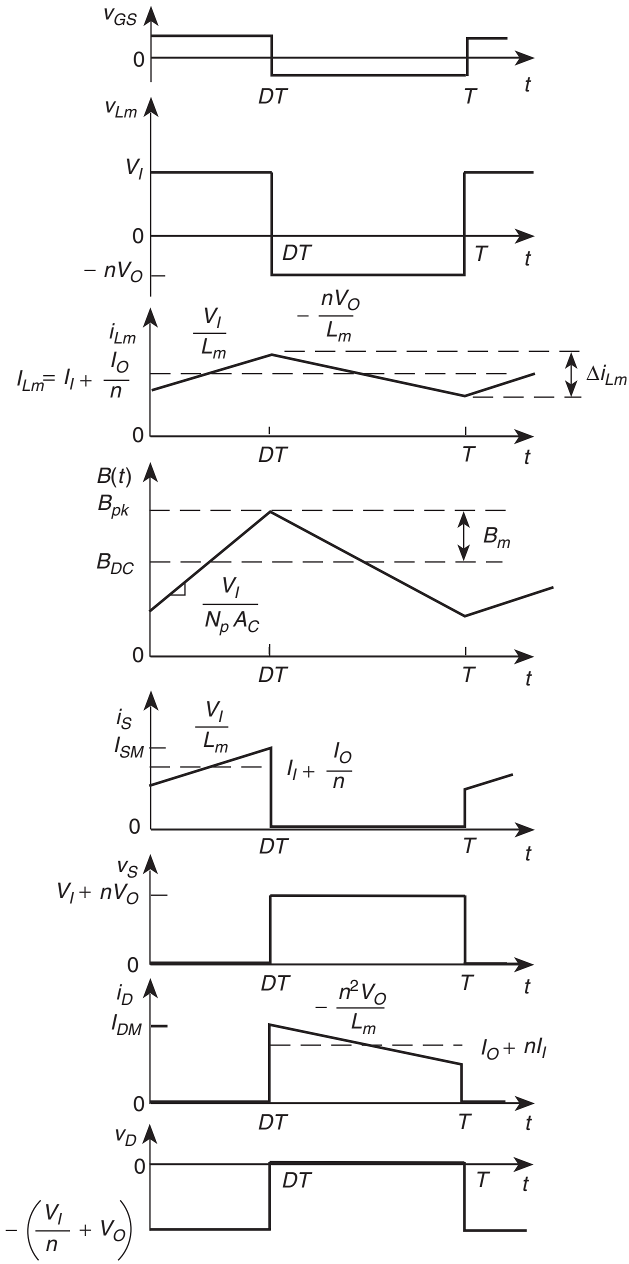

Figure 11.4 Waveforms in flyback PWM converter for CCM

The maximum peak value of the primary winding current is

$$I_{pmax} = \frac{I_{Omax}}{n(1 - D_{max})} + \frac{nV_O(1 - D_{max})}{f_s L_p}$$
$$= \frac{10}{4.4167 \times (1 - 0.5)} + \frac{4.4167 \times 5 \times (1 - 0.5)}{10^5 \times 82 \times 10^{-6}} = 5.874 \text{ A}. \quad (11.87)$$

The maximum rms value of the primary winding current is

$$I_{prms(max)} = \frac{I_{Omax}\sqrt{D_{max}}}{n(1 - D_{max})} = \frac{10\sqrt{0.5}}{4.4167 \times (1 - 0.5)} = 3.202 \text{ A}. \tag{11.88}$$

The maximum energy stored in the magnetic field of the transformer is

$$W_m = \frac{1}{2}L_m I_{Lmmax}^2 = \frac{1}{2}L_p I_{pmax}^2 = \frac{1}{2} \times 82 \times 10^{-6} \times 5.874^2 = 1.414 \text{ mJ}. \tag{11.89}$$

Since the saturation flux density B_s decreases as the temperature increases, the high-temperature B–H characteristics should be considered in the design. The typical values of the saturation flux density for ferrites at high temperatures is $B_s = 0.3$–0.35 T.

Assume the core window utilization factor $K_u = 0.3$, $J_m = 5$ A/mm^2, and $B_{pk} = 0.25$ T. The core area product is

$$A_p = \frac{4W_m}{K_u J_m B_{pk}} = \frac{4 \times 1.414 \times 10^{-3}}{0.3 \times 5 \times 10^6 \times 0.25} = 1.1312 \text{ cm}^4. \tag{11.90}$$

A Magnetics ferrite core PC 0F-43622 is selected. The dimensions of this core are $A_p = 1.53$ cm^2, $A_c = 2.02$ cm^2, $l_c = 5.32$ cm, and $V_c = 10.7$ cm^3. The F-type magnetic material is used to make this core. The core parameters are $\mu_{rc} = 3000 \pm 20\%$, $A_L = 10\,000$ mH/1000 turns, and $B_s = 0.49$ T. The coefficients of this material are $k = 0.0573$, $a = 1.66$, and $b = 2.68$.

The core window area is

$$W_a = \frac{A_p}{A_c} = \frac{1.53}{2.02} = 0.757 \text{ cm}^2. \tag{11.91}$$

The skin depth at $f = 100$ kHz is

$$\delta_w = \frac{66.2}{\sqrt{f_s}} \text{(mm)} = \frac{66.2}{\sqrt{10^5}} = 0.209 \text{ mm}. \tag{11.92}$$

To avoid the skin and proximity effects, the diameter of a bare strand should be

$$d_{is} = 2\delta_w = 2 \times 0.209 \times 10^{-3} = 0.418 \text{ mm}. \tag{11.93}$$

The primary and secondary windings will consist of many strands. Select the copper round wire AWG27 for the strands, which has $d_{os} = 0.409$ mm, $d_{is} = 0.3606$ mm, $A_{wst} = 0.1021$ mm^2, and $R_{wDC}/l_w = 0.1687$ Ω/m.

The cross-sectional area of the primary winding wire is

$$A_{wp} = \frac{I_{pmax}}{J_m} = \frac{5.874}{5} = 1.17 \text{ mm}^2. \tag{11.94}$$

The number of strands in the primary winding is

$$S_p = \frac{A_{wp}}{A_{wst}} = \frac{1.17 \times 10^{-6}}{0.1021 \times 10^{-6}} = 11.45. \tag{11.95}$$

Pick $S_p = 10$. The area allocated to the primary winding is

$$W_{ap} = \frac{W_a}{2} = \frac{0.757 \times 10^{-4}}{2} = 0.3785 \text{ cm}^2. \tag{11.96}$$

The cross-sectional area of the insulated strand wire is

$$A_{wpos} = \frac{\pi d_{os}^2}{4} = \frac{\pi \times (0.409 \times 10^{-3})^2}{4} = 0.1313 \text{ mm}^2. \tag{11.97}$$

The number of turns of the primary winding is

$$N_p = \frac{K_u W_{ap}}{S_p A_{wpos}} = \frac{0.3 \times 0.3785 \times 10^{-4}}{10 \times 0.1313 \times 10^{-6}} = 8.648. \tag{11.98}$$

Pick $N_p = 9$. The terminals of the winding in a transformer with a pot core are usually on the opposite sides of the core. The number of turns of the secondary winding is

$$N_s = \frac{N_p}{n} = \frac{9}{4.4167} = 2.03. \tag{11.99}$$

Select $N_s = 2$.

The length of the air gap is

$$l_g = \frac{\mu_0 A_c N_p^2}{L_p} - \frac{l_c}{\mu_{rc}} = \frac{4\pi \times 10^{-7} \times 2.02 \times 10^{-4} \times 9^2}{82 \times 10^{-6}} - \frac{5.32 \times 10^{-2}}{3000} = 0.233 \text{ mm}. \quad (11.100)$$

The maximum peak value of the magnetic flux density is

$$B_{pk} = \frac{\mu_0 N_p I_{pmax}}{l_g + \frac{l_c}{\mu_{rc}}} = \frac{4\pi \times 10^{-7} \times 9 \times 5.874}{0.233 \times 10^{-3} + \frac{5.32\times10^{-2}}{3000}} = 0.2649 \text{ T} < B_s. \quad (11.101)$$

The maximum peak value of the AC component of the magnetic flux density is

$$B_{m(max)} = \frac{\mu_0 N_p \frac{\Delta i_{Lp(max)}}{2}}{l_g + \frac{l_c}{\mu_{rc}}} = \frac{4\pi \times 10^{-7} \times 9 \times \frac{1.5387}{2}}{0.233 \times 10^{-3} + \frac{5.32\times10^{-2}}{3000}} = 0.0347 \text{ T}. \quad (11.102)$$

The minimum peak value of the AC component of the magnetic flux density at full power is

$$B_{m(min)} = \frac{\mu_0 N_p \frac{\Delta i_{Lp(min)}}{2}}{l_g + \frac{l_c}{\mu_{rc}}} = \frac{4\pi \times 10^{-7} \times 9 \times \frac{1.346}{2}}{0.233 \times 10^{-3} + \frac{5.32\times10^{-2}}{3000}} = 0.03035 \text{ T}. \quad (11.103)$$

The core power loss density is

$$P_v = 0.0573 f^{1.66} (10 B_m)^{2.68} = 0.0573 \times 100^{1.66} \times (10 \times 0.0347)^{2.68} = 7.018 \text{ mW/cm}^3. \quad (11.104)$$

The minimum core power loss density at full power is

$$P_{vmin} = 0.0573 f^{1.66} (10 B_{m(min)})^{2.68} = 0.0573 \times 100^{1.66} \times (10 \times 0.03035)^{2.68} = 4.9 \text{ mW/cm}^3. \quad (11.105)$$

The core loss is

$$P_C = V_c P_v = 10.7 \times 7.018 \times 10^{-3} = 75.09 \text{ mW}. \quad (11.106)$$

The minimum core loss at full power is

$$P_{Cmin} = V_c P_{vmin} = 10.7 \times 4.9 \times 10^{-3} = 52.43 \text{ mW}. \quad (11.107)$$

Figure 11.5 shows a plot of the core loss as a function of the DC input voltage V_I for the flyback converter operating in CCM.

The mean turn length (MTL) is

$$l_T = \frac{\pi(F + E)}{2} = \frac{\pi(15.9 + 30.4)}{2} = 72.728 \text{ mm} = 7.2728 \text{ cm}, \quad (11.108)$$

where $F = 15.9$ mm is the inner diameter of the winding window and $E = 30.4$ mm is the outer diameter of the winding window. The length of the primary winding wire is

$$l_{wp} = N_p l_T = 9 \times 7.278 = 65.502 \text{ cm}. \quad (11.109)$$

Pick $l_{wp} = 68$ cm. The DC and low-frequency resistance of each strand of the primary winding is

$$R_{wpDCs} = \left(\frac{R_{wDC}}{l_w}\right) l_{wp} = 0.1687 \times 0.68 = 0.1147\ \Omega. \quad (11.110)$$

Hence, the DC and low-frequency resistance of the primary winding is

$$R_{wpDC} = \frac{R_{wpDCs}}{S_p} = \frac{0.1147}{10} = 0.01147\ \Omega. \quad (11.111)$$

The DC and low-frequency power loss in the primary winding is

$$P_{wpDC} = R_{wpDC} I_{Imax}^2 = 0.01147 \times 2.2641^2 = 0.05879 \text{ W}. \quad (11.112)$$

Using (7.234), we obtain $F_{Rph} = 2.6$. Figure 11.6 shows a plot of F_{Rph} as a function of the DC input voltage V_I for the flyback converter operating in CCM.

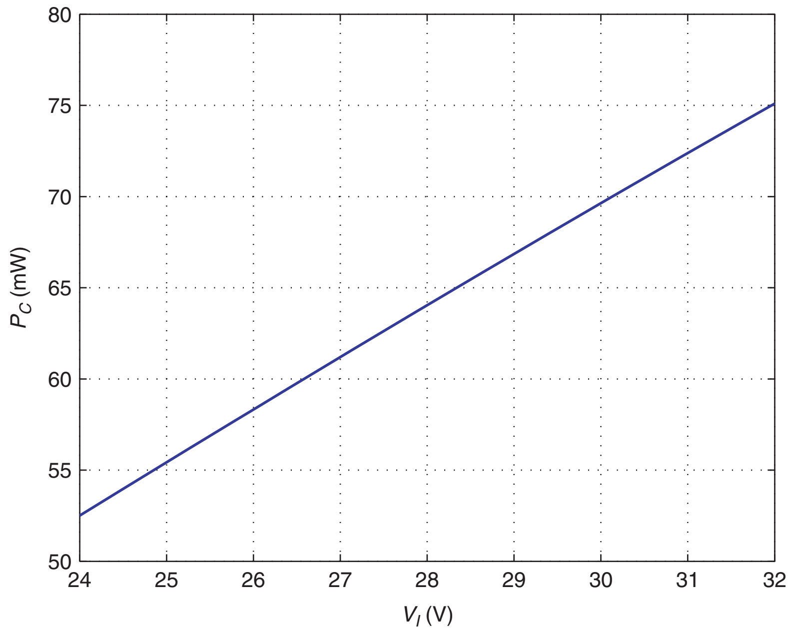

Figure 11.5 Core power loss P_C as a function of the DC input voltage V_I for the flyback converter operating in CCM

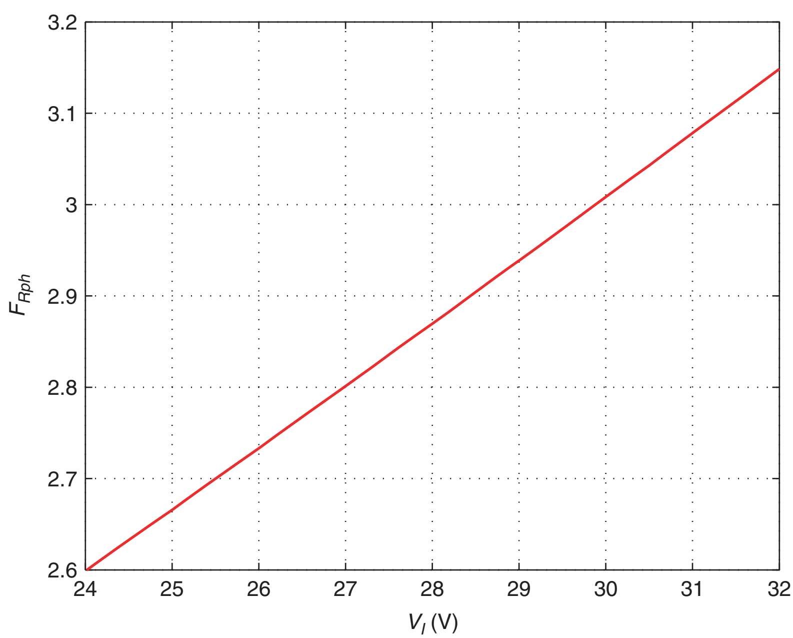

Figure 11.6 F_{Rph} as a function of the DC input voltage V_I for the flyback converter operating in CCM

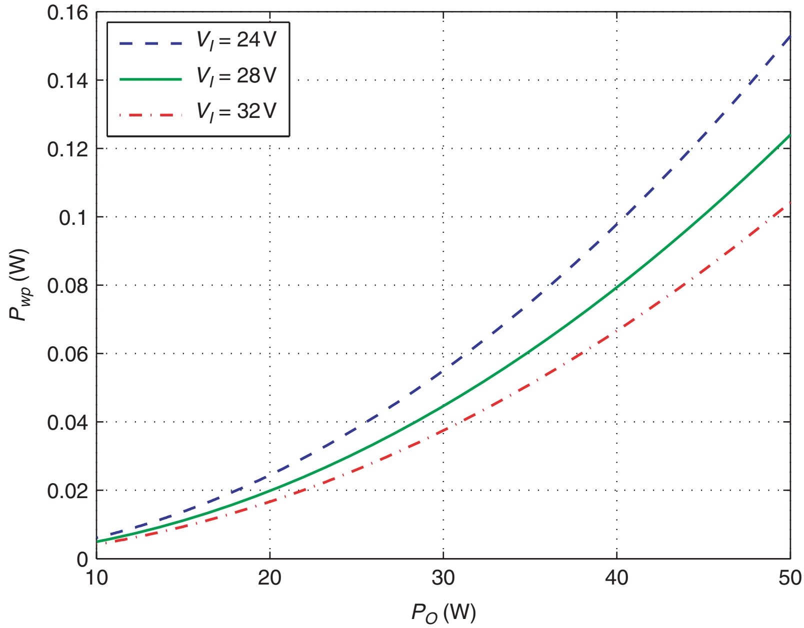

Figure 11.7 Primary winding power loss P_{wp} as a function of the output power P_O at fixed values of the DC input voltage V_I for the flyback converter operating in CCM

The primary winding power loss is

$$P_{wp} = F_{Rph} P_{wpDC} = 2.6 \times 0.05879 = 0.1528 \text{ W}. \tag{11.113}$$

Figure 11.7 shows the plots of the power loss in the primary winding P_{wp} as a function of the output power P_O at fixed values of the DC input voltage V_I for the flyback converter operating in CCM. Figure 11.8 shows the plots of the power loss in the primary winding P_{wp} as a function of the DC input voltage V_I at fixed values of the output power P_O for the flyback converter operating in CCM.

The maximum current through the secondary winding is

$$I_{smax} = \frac{I_{Omax}}{1 - D_{max}} + \frac{n \Delta i_{Lpmax}}{2} = \frac{10}{1 - 0.5} + \frac{4.4167 \times 1.5387}{2} = 23.398 \text{ A}. \tag{11.114}$$

The maximum rms value of the secondary winding current is

$$I_{srms(max)} = \frac{I_{Omax}}{\sqrt{1 - D_{max}}} = \frac{10}{\sqrt{1 - 0.5}} = 14.142 \text{ A}. \tag{11.115}$$

The cross-sectional area of the total secondary winding wire is

$$A_{ws} = \frac{I_{smax}}{J_m} = \frac{23.398}{5} = 4.68 \text{ mm}^2. \tag{11.116}$$

The number of strands of the secondary winding is

$$S_s = \frac{A_{ws}}{A_{wst}} = \frac{4.68 \times 10^{-6}}{0.1021 \times 10^{-6}} = 45.83. \tag{11.117}$$

Pick $S_s = 45$. The length of the secondary winding is

$$l_{ws} = N_s l_T = 2 \times 7.27 = 14.54 \text{ cm}. \tag{11.118}$$

Pick $l_{ws} = 16$ cm. The DC and low-frequency resistance of each strand of the secondary winding is

$$R_{wsDCs} = \left(\frac{R_{wsDCs}}{l_w} \right) l_{ws} = 0.1687 \times 0.16 = 0.027\ \Omega. \tag{11.119}$$

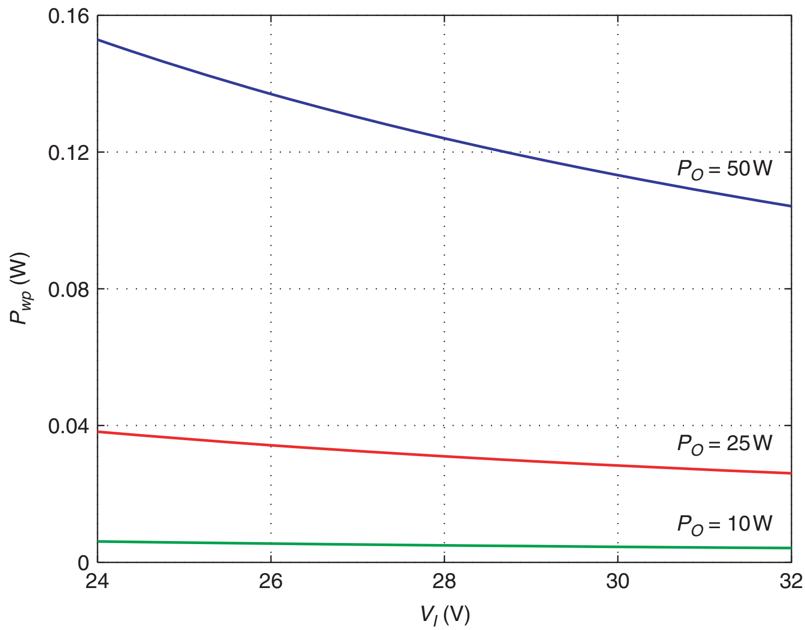

Figure 11.8 Primary winding power loss P_{wp} as a function of the DC input voltage V_I at fixed values of the output power P_O for the flyback converter operating in CCM

The DC and low-frequency resistance of all strands in the secondary winding is

$$R_{wsDC} = \frac{R_{wsDCs}}{S_s} = \frac{0.027}{45} = 0.0006\ \Omega. \tag{11.120}$$

The DC and low-frequency power loss in the secondary winding is

$$P_{wsDC} = R_{wsDC} I_{Omax}^2 = 0.0006 \times 10^2 = 0.06\ \text{W}. \tag{11.121}$$

Using (7.238), we compute $F_{Rsh} = 2.6$. Figure 11.9 shows a plot of F_{Rsh} as a function of the DC input voltage V_I for the flyback converter operating in CCM.

The secondary winding power loss is

$$P_{ws} = F_{Rsh} P_{wsDC} = 2.6 \times 0.06 = 0.156\ \text{W}. \tag{11.122}$$

Figure 11.10 shows the plots of the power loss in the secondary winding P_{ws} as a function of the output power P_O at fixed values of the DC input voltage V_I for the flyback converter operating in CCM. Figure 11.11 shows the plots of the power loss in the secondary winding P_{ws} as a function of the output power P_O at fixed values of the DC input voltage V_I for the flyback converter operating in CCM.

The DC and low-frequency power loss in both the windings is

$$P_{wDC} = P_{wpDC} + P_{wsDC} = 0.05879 + 0.06 = 0.11879\ \text{W}. \tag{11.123}$$

The sum of the power loss in both the windings is

$$P_w = P_{wp} + P_{ws} = 0.1528 + 0.156 = 0.3088\ \text{W}. \tag{11.124}$$

Figure 11.12 shows the plots of the total winding power loss P_w as a function of the output power P_O at fixed values of the DC input voltage V_I for the flyback converter operating in CCM. Figure 11.13 shows the plots of the power loss in both primary and secondary windings P_w as a function of the DC output voltage V_I at fixed values of the output power P_O for the flyback converter operating in CCM. The sum of the core loss and the resistance winding loss in the transformer is

$$P_{cw} = P_C + P_w = 0.07509 + 0.3088 = 0.3839\ \text{W}. \tag{11.125}$$

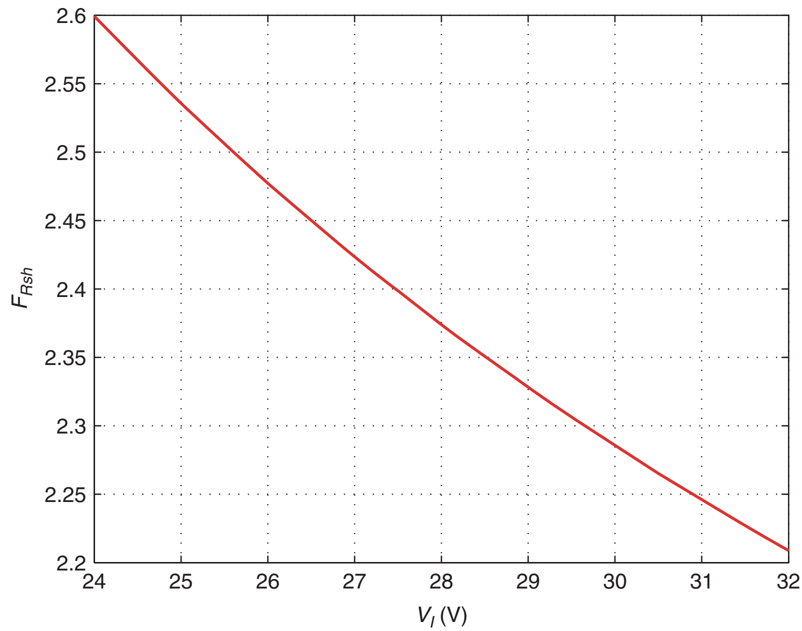

Figure 11.9 F_{Rsh} as a function of the DC input voltage V_I for the flyback converter operating in CCM

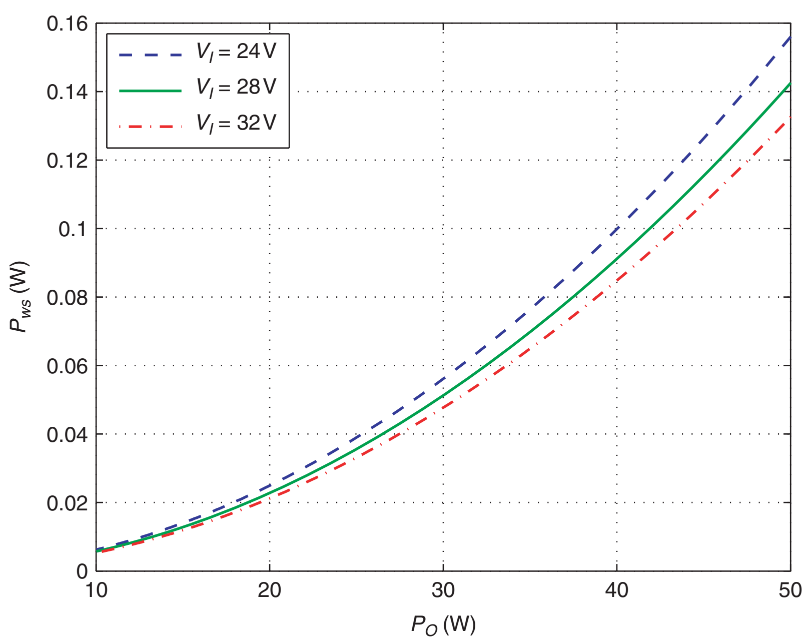

Figure 11.10 Secondary winding power loss P_{ws} as a function of the output power P_O at fixed values of the DC input voltage V_I for the flyback converter operating in CCM

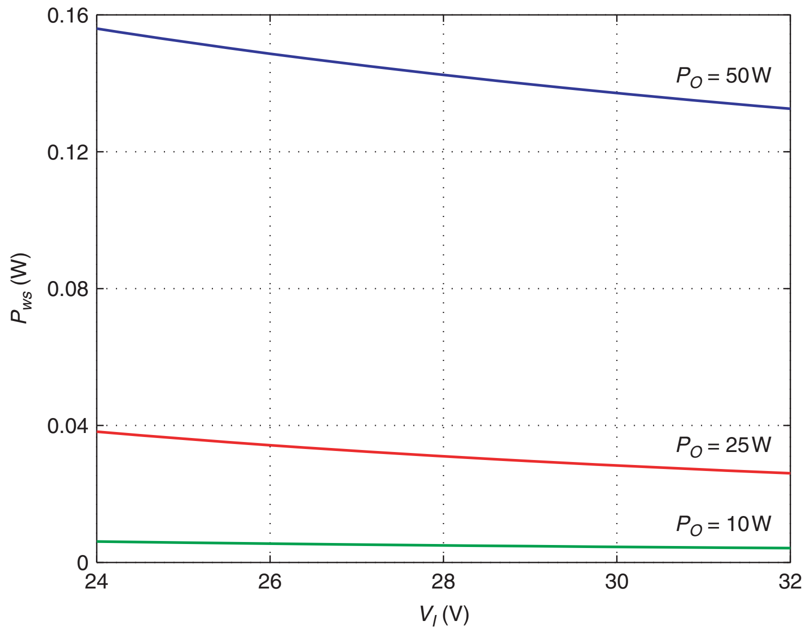

Figure 11.11 Secondary winding power loss P_{ws} as a function of the DC input voltage V_I at fixed values of the output power P_O for the flyback converter operating in CCM

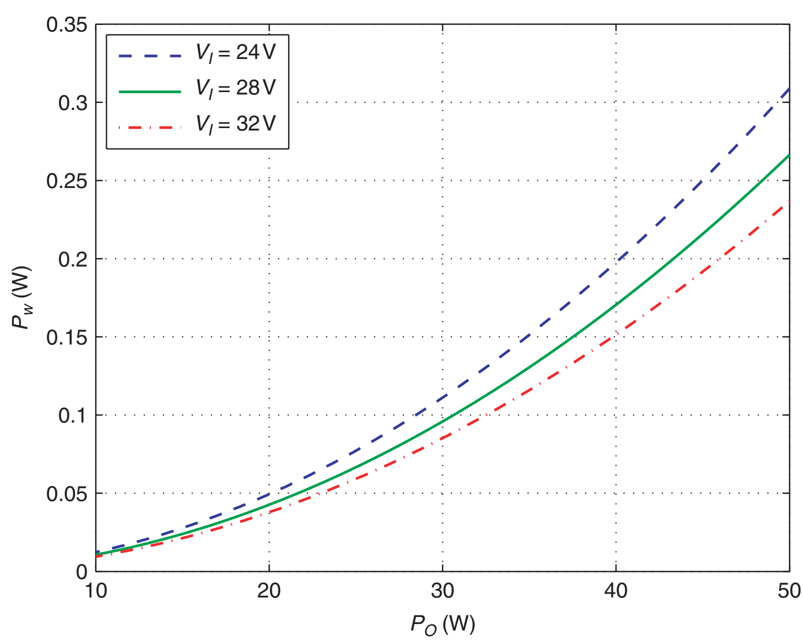

Figure 11.12 Power loss in both primary and secondary windings P_w as a function of the output power P_O at fixed values of the DC input voltage V_I for the flyback converter operating in CCM

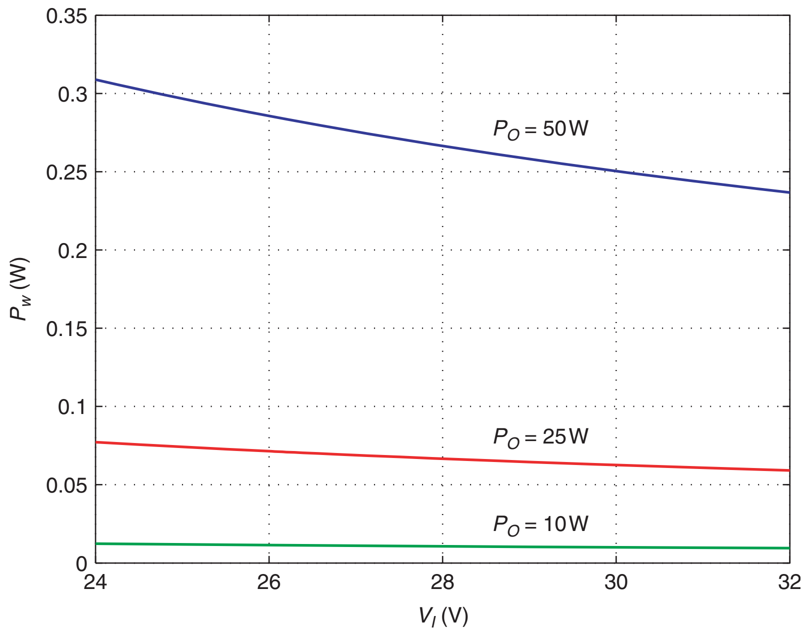

Figure 11.13 Power loss in both primary and secondary windings P_w as a function of the DC input voltage V_I at fixed values of the output power P_O for the flyback converter operating in CCM

Figure 11.14 shows the plots of core and winding power loss P_{cw} as a function of the output power P_O at fixed values of the DC input voltage V_I for the flyback converter operating in CCM. Figure 11.15 shows the plots of the core and winding power loss P_{cw} as a function of the DC input voltage V_I at fixed values of the output power P_O for the flyback converter operating in CCM.

The transformer efficiency at full power can be estimated as

$$\eta_t = \frac{P_O}{P_O + P_{cw}} = \frac{50}{50 + 0.3839} = 99.23\%. \tag{11.126}$$

Figure 11.16 shows the plots of transformer efficiency η_t as a function of the output power P_O at fixed values of the DC input voltage V_I for the flyback converter operating in CCM. Figure 11.17 shows the plots of transformer efficiency η_t as a function of the DC input voltage V_I at fixed values of the output power P_O for the flyback converter operating in CCM.

The total surface area of the core is

$$A_t = 2\left(\frac{\pi A^2}{4}\right) + (\pi A)(2B) = 2\left(\frac{\pi \times 3.56^2}{4}\right) + \pi \times 3.56 \times 2.19 = 44.4\ \text{cm}^2, \tag{11.127}$$

where A is the outer diameter of the core and $2B$ is the total height of both halves of the core. The surface power loss density is

$$\psi = \frac{P_{cw}}{A_t} = \frac{0.3839}{44.4} = 0.008646\ \text{W/cm}^2. \tag{11.128}$$

The temperature rise of the inductor (the core and the winding) is

$$\Delta T = 450\psi^{0.826} = 450 \times 0.008646^{0.826} = 8.89\ ^\circ\text{C}. \tag{11.129}$$

The core window utilization is

$$K_u = \frac{(N_p S_p + N_s S_s)A_{wpo}}{W_a} = \frac{(9 \times 10 + 2 \times 45) \times 0.1313 \times 10^{-6}}{0.757 \times 10^{-4}} = 0.3122. \tag{11.130}$$

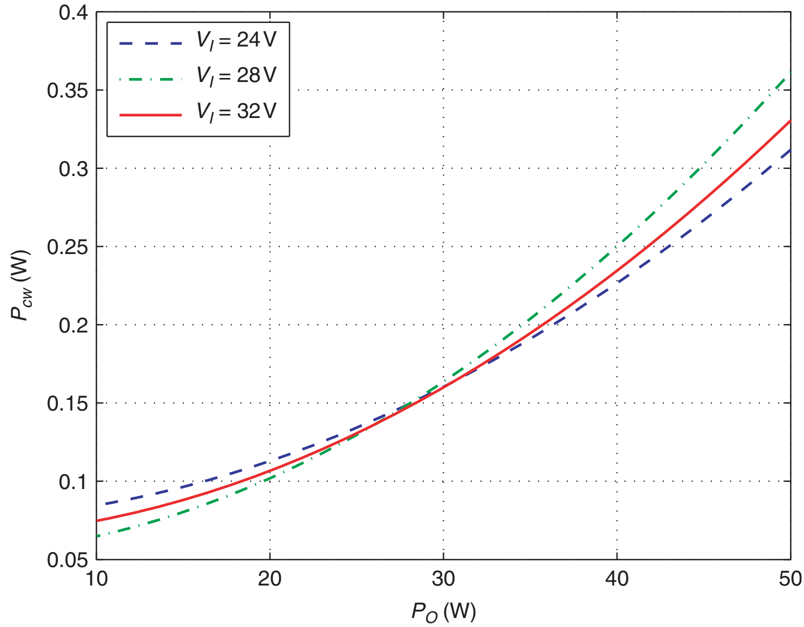

Figure 11.14 Core and winding power loss P_{cw} as a function of the output power P_O at fixed values of the DC input voltage V_I for the flyback converter operating in CCM

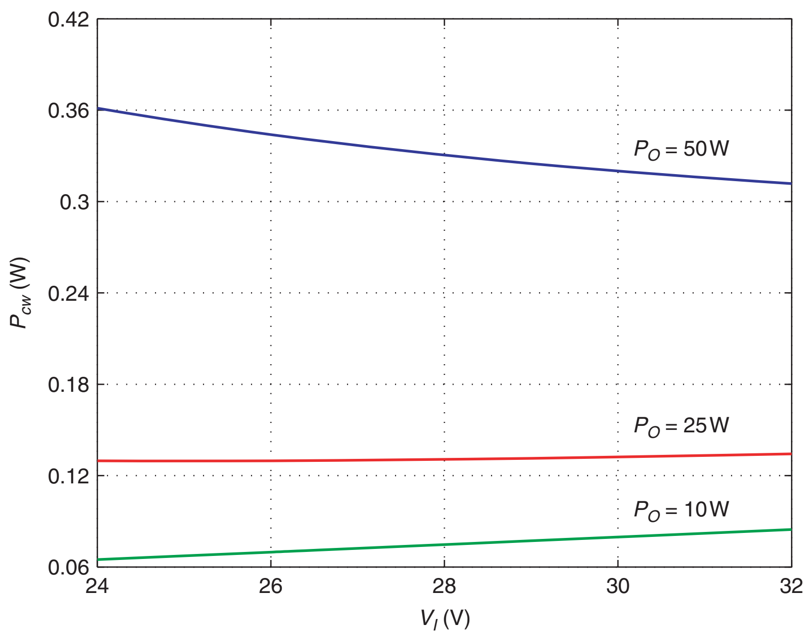

Figure 11.15 Core and winding power loss P_{cw} as a function of the DC input voltage V_I at fixed values of the output power P_O for the flyback converter operating in CCM

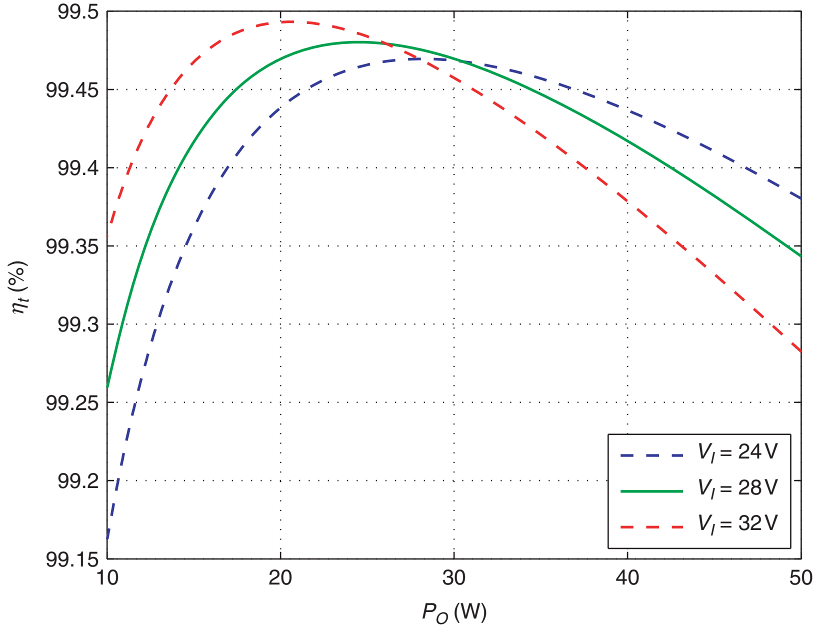

Figure 11.16 Transformer efficiency η_t as a function of the output power P_O at fixed values of the DC input voltage V_I for the flyback converter operating in CCM

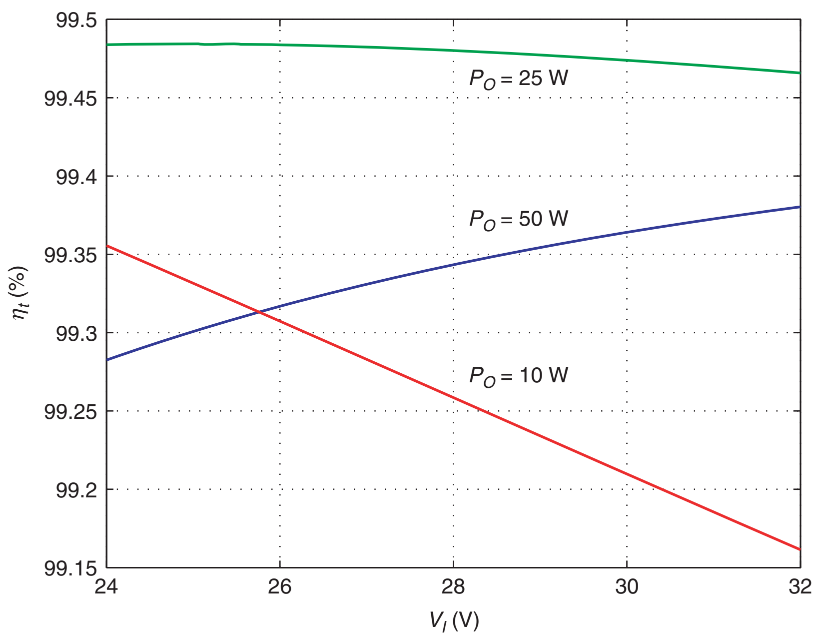

Figure 11.17 Transformer efficiency η_t as a function of the DC input voltage V_I at fixed values of the output power P_O for the flyback converter operating in CCM