Homework
Lesson 39
Isolated DC / Dc Converters

1. Problem 7.1 The flyback converter of Figure 7.2a has the following parameters:

$V_S := 36 \cdot V$ $D := 0.40$ $N12 := 1$ $R_0 := 20 \cdot \Omega$ $L_m := 240 \cdot \mu H$ $C := 100 \cdot \mu F$ $f_{sw} := 30 \cdot kHz$

$$T := \frac{1}{f_{sw}} = 33.333 \cdot \mu s$$

$$N21 := \frac{1}{N12} = 1$$

a. Determine the output voltage
b. Determine the average, maximum, and minimum inductor currents
c. Determine the output voltage ripple.

First, we determine whether we are in continuous conduction. Using the first form of (7.9) in the text because we don't yet know $V_0$, the average current in the inductance $L_m$ is

$$I_{LM} := \frac{V_S \cdot D}{(1 - D)^2 \cdot R_0} \cdot \frac{1}{N12^2} = 2\,A$$

The peak to peak current ripple in $L_m$ is

$$\Delta I_{LM} := \frac{V_S}{L_m} \cdot D \cdot T = 2\,A$$

This current ripple indicates continuous conduction. It is an average value of 2A with a 1A devation in each direction (up and down) from that average. Finding the average voltage in this case,

$$V_0 := V_S \cdot N21 \cdot \frac{D}{1 - D} = 24\,V$$

Average inductor current is already found above: $I_{LM} = 2\,A$

The maximum current is

$$I_{LMmax} := I_{LM} + \frac{\Delta I_{LM}}{2} = 3\,A$$

The falling current returns to

$$I_{LMmin} := I_{LM} - \frac{\Delta I_{LM}}{2} = 1\,A$$

Output voltage ripple in continuous conduction is approximately

$$\Delta V_0 := V_0 \cdot \frac{D}{R_0 \cdot C \cdot f_{sw}} = 0.16\,V \qquad \frac{\Delta V_0}{V_0} = 0.00667$$

2. Problem 7.2 The flyback converter of Figure 7.2a has an input of 48V, and output of 30V, a duty ratio of 0.45, and a switching frequency of 25kHz. the load resistor is 15Ω.

a. Determine the transformer turns ratio

b. Determine the transformer magnetizing inductance $L_m$ such that the minimum inductor current is 25% of the average.

$V_S := 48 \cdot V$ $\quad V_0 := 30 \cdot V$ $\quad D := 0.45$ $\quad f_{sw} := 25 \cdot kHz$ $\quad R_0 := 15 \cdot \Omega$ $\quad T := \frac{1}{f_{sw}} = 40 \cdot \mu s$

The second part of the problem assumes continuous conduction in the magnetizing inductance. We assume the same for the first part of the problem. Finding the output voltage expression:

$$V_0 = V_S \cdot N \cdot \frac{D}{1 - D}$$

Rearranging to solve for the turns ratio,

$$N := \frac{1 - D}{D} \cdot \frac{V_0}{V_S} = 0.764 \qquad \frac{1}{N} = 1.309$$

The turns ratio is N1:N2 = 1.309:1 or 1:0.764.

Checking the continuous current assumption,

$$\Delta i_{Lm} := \frac{V_S \cdot D \cdot T}{L_m} = 3.6\,A \qquad I_{Lm} := \frac{V_0^{\,2}}{V_S \cdot D \cdot R_0} = 2.778\,A$$

The average current is greater than half of the ripple, so the current is continuous.

The minimum current will be 25% of the average inductor current, per the part b problem statement,

$$I_{Lmmin} := 0.25 \cdot I_{Lm} = 0.694\,A$$

Finding the ripple current

$$\Delta i_{Lm} := 2 \cdot \left(I_{Lm} - I_{Lmmin}\right) = 4.167\,A$$

We know that the rising part of the current ripple may be found from the following

$$\Delta i_{Lm} = \frac{V_S \cdot D \cdot T}{L_m}$$

Rearranging,

$$L_m := \frac{V_S \cdot D \cdot T}{\Delta i_{Lm}} = 207.36 \cdot \mu H$$

Problem 7.3 Design a flyback converter for an input of 24V and an output of 40W at 40V. Specify the transofrmer turns ratio and magnetizing inductance, the switching frequency, and the capacitor to limit the ripple to less than 0.5%.

$V_S := 24 \cdot V \qquad V_0 := 40 \cdot V \qquad P_0 := 40 \cdot W \qquad \Delta V_{pu} := 0.5 \cdot \%$

Calculate the load resistance. We will need it.

$$R_0 := \frac{V_0^{\,2}}{P_0} = 40\,\Omega$$

There are many solutions to this problem. Our job is to find one that seems reasonable. We specify the turns ratio and the switching frequency. A 1:1 turns ratio is reasonable and a switching frequency above audio and, in fact, as high as practicable, would be reasonable. Switching losses limit us, but that is difficult to discern from the small amount of information given in the problem Therefore, we will use 1MHz as a reasonable frequency that is in common use today.

$N_2 := 1 \qquad N_1 := 1 \qquad f_{sw} := 1.0 \cdot MHz$

Calculate the duty cycle, as is done in Example 7-2 n page 244.

$$D := \frac{1}{\frac{V_S}{V_0} \cdot \frac{N_2}{N_1} + 1} = 0.625$$

Calculate the capacitance, as is done in the same example. Any capacitance larger than this will do the job well. Tantalum capacitors are readily available in this range for equivalent series resistance (ESR) and high frequency capability.

$$C_{BIG} := \frac{D}{R_0 \cdot \Delta V_{pu} \cdot f_{sw}} = 3.125 \cdot \mu F$$

Calculate the inductance, as is likewise done in the same example. Any magnetizing inductance greater than this will be fine for this task. A 1:1 transformer with this mangetizing inductance is possible to wind, as a previous homework problem showed us.

$$L_m := \frac{(1 - D)^2 \cdot R_0}{2 \cdot f_{sw}} \cdot \left(\frac{N_1}{N_2}\right)^2 = 2.813 \cdot \mu H$$

3. Problem 7.6. The forward converter of Figure 7-5a has the following parameters:

$V_S := 100 \cdot V \quad N_{12} := 1 \quad N_{13} := 1 \quad L_x := 200 \cdot \mu H \quad L_m := 5 \cdot mH$

$R_0 := 20 \cdot \Omega \quad C_f := 100 \cdot \mu F \quad D := 0.35 \quad f_s := 50 \cdot kHz$

a. Determine the output voltage and the output voltage ripple.

The forward converter is a buck converter with a transformer.

$$V_0 := V_S \cdot D \cdot \frac{1}{N_{12}} = 35\,V$$

Ripple is

$$\Delta V_0 := V_0 \cdot \frac{1 - D}{8 \cdot L_x \cdot C_f \cdot f_s^2} = 0.057\,V \qquad \frac{\Delta V_0}{V_0} = 0.163 \cdot \%$$

b. Determine the average, maximum , and minimum value of the current in the inductor.

Average current in the inductor is the same as the average current in the load because the capacitor's average current must be zero for any complete cycle.

$$I_0 := \frac{V_0}{R_0} = 1.75\,A \qquad I_{Lx} := I_0 = 1.75\,A$$

Change in the inductor current is determined from the part of the cycle when inductor Lx current decreases.

$$\Delta I_{Lx} := \frac{V_0 \cdot (1 - D)}{L_x \cdot f_s} = 2.275\,A$$

Maximum Lx inductor current is

$$I_{Lxmax} := I_{Lx} + \frac{\Delta I_{Lx}}{2} = 2.888\,A$$

Minimum Lx inductor current is

$$I_{Lxmin} := I_{Lx} - \frac{\Delta I_{Lx}}{2} = 0.613\,A$$

c. Determine the peak current in Lm in the transformer model.

This is easiest found from the part of the switching cycle when magnetizing current increases. The rise in magnetizing current is

$$\Delta I_{Lm} := \frac{V_S \cdot D}{L_m \cdot f_s} = 0.14\,A$$

Because magnetizing current starts at zero, this change is its peak value.

$$I_{Lmmax} := \Delta I_{Lm} = 0.14\,A$$

d. Determine the peak current in the switch and the physical transformer primary.

Peak switch current(which is the same as physical transformer primary current) is the sum of the peak magnetizing current and the peak reflected secondary current.

Recall

$$I_{Lxmax} = 2.888\,A$$

Reflecting to get the ideal primary winding current,

$$I_{1max} := I_{Lxmax} \cdot \frac{1}{N_{12}} = 2.888\,A$$

Add these two components to get the physical transformer primary current.

$$I_{swmax} := I_{1max} + I_{Lmmax} = 3.028\,A$$