Lecture 16 - Forward converters

Forward Converter (Derived from Buck Converter)

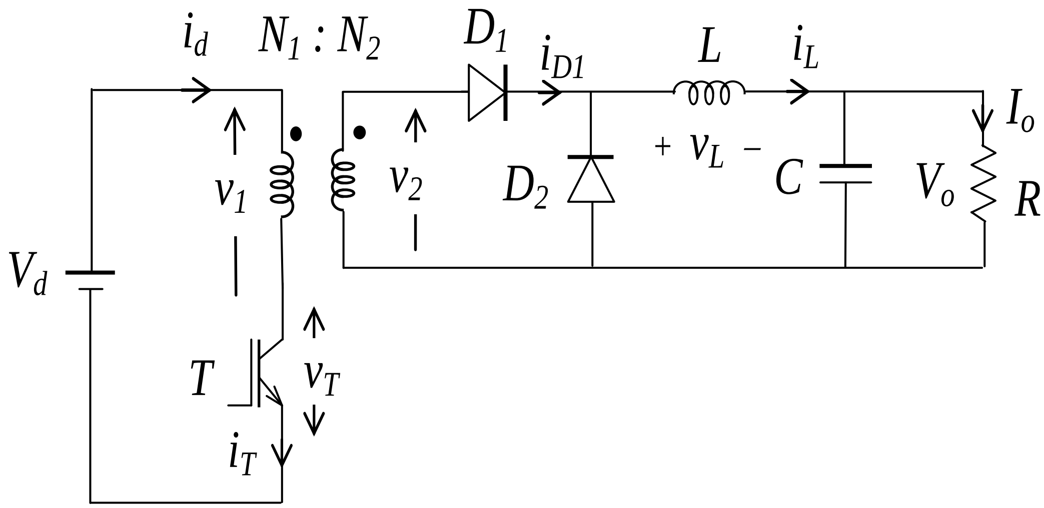

Figure 16.1

During $0 < t < t_{on}$: D_2 is reverse biased (i.e., OFF), D_1 is forward biased (i.e., ON) and

$$v_L = \frac{N_2}{N_1} V_d - V_0 \tag{16.1}$$

During t_{off} i.e., $t_{on} < t < T_s$: D_1 is reverse biased (i.e., OFF), D_2 is forward biased (i.e., ON) and

$$v_L = -V_{0.} \tag{16.2}$$

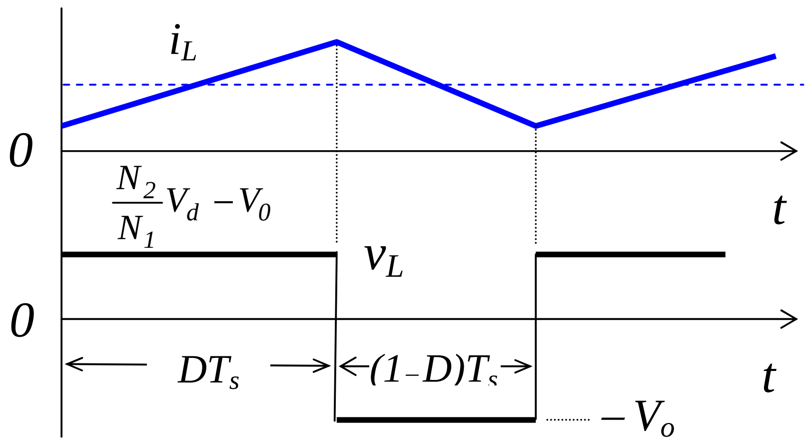

Figure 16.2

$$\frac{\frac{N_2}{N_1}V_d - V_0}{L} DT_s - \frac{V_0}{L}(1-D)T_s = 0 \tag{16.3}$$

$$\therefore \frac{V_o}{V_d} = \frac{N_2}{N_1} D \tag{16.4}$$

Note that the minimum value of inductor L for continuous conduction can be found in the same way as for the buck converter (see earlier analysis).

$$I_L = I_o = \frac{V_o}{R} \tag{16.5}$$

$$\Delta i_L = \frac{\left(\frac{N_2}{N_1}\right)V_d - V_o}{L} DT_s \tag{16.6}$$

$$\therefore i_{L\,min} = I_L - \frac{\Delta I_L}{2} = \frac{V_o}{R} - \frac{\dfrac{N_2}{N_1} \times \dfrac{N_1 V_o}{N_2 D} - V_o}{2L} DT_s$$

$$= \frac{V_o}{R} - \frac{V_o\left(1-D\right)T_s}{2L} \qquad (16.7)$$

Therefore, for operation at the boundary between continuous and discontinuous conduction, the minimum value of L is given by,

$$Lf_s\big|_{\min} = \frac{\left(1-D\right)R}{2} \qquad (16.8)$$

which is the same formula for the buck converter as found earlier.

The magnetizing current i_m rises to its maximum value at t_{on}. Even with continuous conduction in L, the primary current in the transformer, which is $-i_m$ during t_{off}, should be brought down to zero before the end of the switching period T_s. Otherwise flux build up may take place leading to failure of operation. Furthermore, energy trapped in L_m when the transistor is turned off must have a path to flow. Clearly, for a forward converter, a large L_m, meaning small air-gap, low magnetizing current and low energy storage in L_m is preferred.

Forward converter with demagnetizing winding and energy return diode

The purpose of the third winding of turns N_3 and the energy return diode D_3 is to return the trapped energy in L_m at the end of t_{on} to the DC source. This also helps reset the transformer core flux quickly.

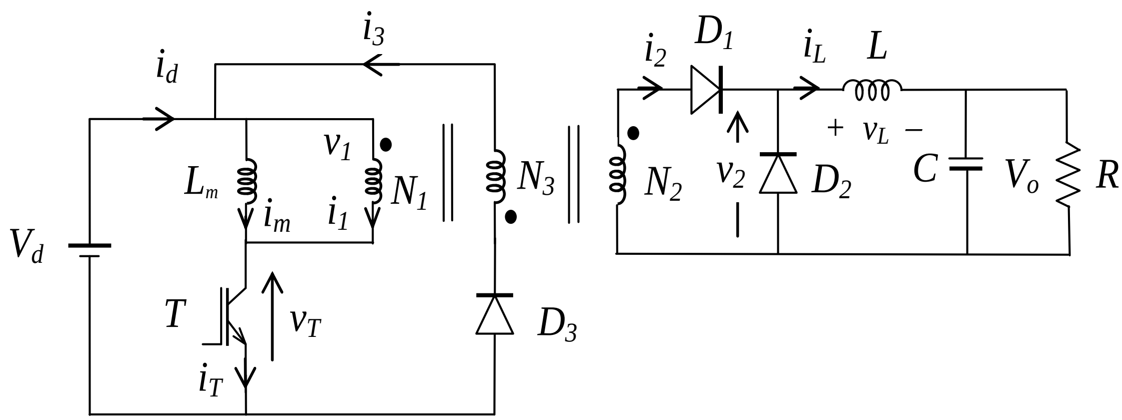

Figure 16.3

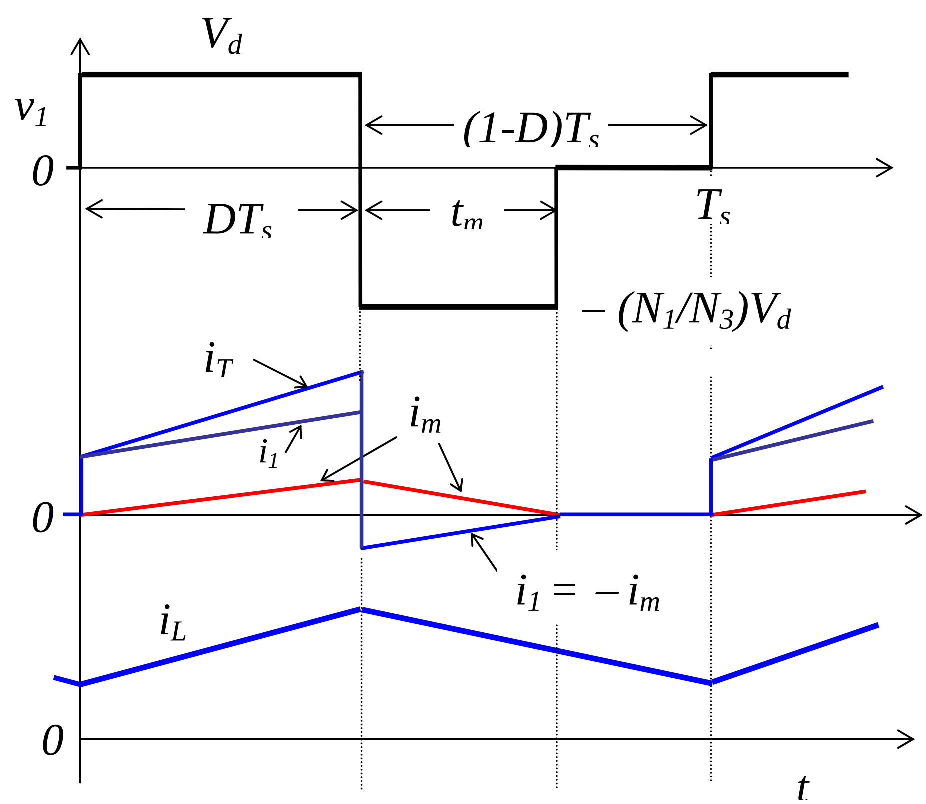

Figure 16.4

Operation with core flux reset

For $0 < t < t_{on}$ $\quad V_1 = V_d$ (16.9)

For $t_{on} < t < T_s$ $\quad i_1 = -i_m$ (16.10)

For the three-winding transformer

$$N_1 i_1 + N_3 i_3 = N_2 i_2 \qquad (16.11)$$

During t_{off} , $i_{D1} = i_2 = 0$

$$\therefore i_3 = \frac{N_1}{N_3} i_m \qquad (16.12)$$

We assume that during t_{off}, i_m falls to zero in time $t_m < (1-D)T_s$. During t_m,

$$\therefore \; v_1 = -\frac{N_1}{N_3} V_d \text{ for } t_{on} \le t \le (t_{on} + t_m) \qquad (16.13)$$

From $\displaystyle\int \frac{v_1}{L_m} dt = 0$ for $0 < \mathrm{t} < (t_{on} + t_m)$

$$t_{on} V_d = D T_s V_d = t_m \frac{N_1}{N_3} V_d \qquad (16.14)$$

$$\therefore \frac{t_m}{T_s} = \frac{N_3}{N_1} D \qquad (16.15)$$

The maximum D is given by $t_m = (1-D_{max})T_s$, where t_m is the turn-off time which is available for i_m to fall to zero.

For any $D \le D_{max}$, complete demagnetization will take place. From (16.11)

$$\therefore (1 - D_{max}) = \frac{N_3}{N_1} D_{max} \tag{16.16}$$

$$\therefore D_{max} = \frac{1}{1 + \frac{N_3}{N_1}} \tag{16.17}$$

If $N_3 = N_1$, then $D_{max} = 0.5$. Note that

$$v_T = V_d \left(1 + \frac{N_1}{N_3} \right) \text{ for } t_{on} < t < (t_{on} + t_m) \tag{16.18}$$

$$= V_d \quad \text{for} \quad (t_{on} + t_m) < t < T_s \tag{16.19}$$

Thus,

- With $N_3 = N_1$, if $D < 0.5$, the transformer core flux is guaranteed to reset during every cycle.

- Large L_m makes the demagnetizing winding small. This is in contrast to the Flyback converter for which a small L_m is good for storing higher energy in L_m during T_{on}. Note that the energy stored in L_m is given by $\frac{1}{2} L_m i_m^2$. For the forward converter, the trapped energy in L_m is not useful.

- Low snubber requirement when the core flux is reset.

Filter Capacitor

The filter capacitor for the forward converter is given by the same formula as for the buck converter described earlier.

$$\therefore \frac{\Delta V_o}{V_o} = \frac{(1-D)}{8}\frac{T_s^2}{LC} \qquad (16.20)$$

Two-switch Forward converter

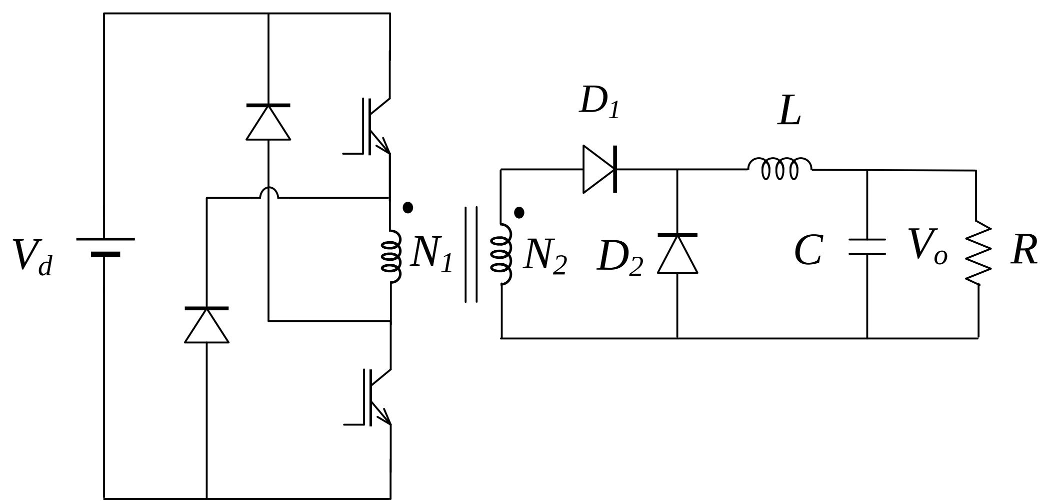

Figure 16.5

In this circuit, the trapped energy in L_m is returned to the DC source via the two diodes on the input side of the transformer, thus requiring no tertiary (third) winding.