Flyback converter

The **Flyback converter** belongs to the primary switched converter family, which means there is isolation between in and output. Flyback converters are used in nearly all mains supplied electronic equipment for low power consumption, up to approximately 300W. Examples of which are televisions, personal computers, printers, etc..

Flyback converters have a remarkably low number of components compared to other SMPSs, they also have the advantage that several isolated output voltages can be regulated by one control circuit.

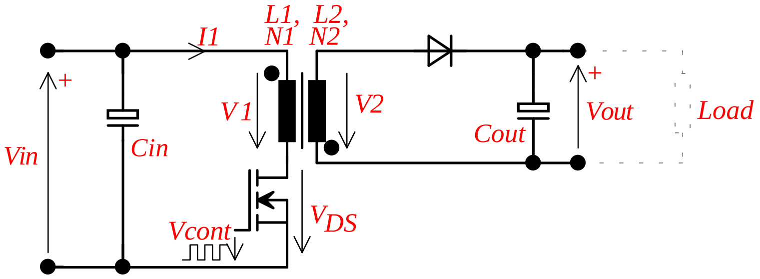

Figure 2.1.1: Flyback converter

Fig. 2.1.1 shows the basic circuit of a flyback converter. The transistor works as a switch, which is turned on and off by the pulse-width-modulated control voltage V_{cont}. During the on-time of the transistor the primary voltage of the transformer V_1 is equal to the input voltage V_{in} which results in the current I_1 increasing linearly. During this phase, energy is stored in the transformer core. During the on-phase the secondary current is zero, because the diode is blocking. When the transistor is turned off the primary current I_1 is interrupted and the voltages at the transformer invert due to Faraday's Law ($v = L\frac{\mathrm{di}}{\mathrm{dt}}$), the diode conducts and the energy moves from the transformer core via the diode to the output capacitor C_{out}.

During the on-phase of the transistor the drain-source voltage V_{DS} is equal to zero. During the off-time of the transistor, the output voltage V_{out} will be transformed back to the primary side and the drain-source voltage theoretically steps up to $V_{DS} = V_{in} + V_{out} \cdot \frac{N_1}{N_2}$. If a mains voltage of 230V/50Hz is used V_{DS} will jump up to approximately 700V. In practice this voltage will be even higher due to the self induction of the leakage inductance of the transformer. To allow for this effect the minimum rated drain-source breakdown voltage of the transistor must be 800V.

The transformer is not a "normal" transformer, because its function is to store energy during the on-time of the transistor and to deliver this energy during the off-time via the diode to the output capacitor. In effect the transformer is a storage inductor (often called a choke) with a primary and secondary winding. To store energy the transformer core needs an air gap (normal transformers do not have an air gap). An important consideration for this transformer is, that primary and secondary windings are closely coupled to achieve a minimum leakage inductance. It should be noted that the energy of leakage inductance cannot be transfered to the secondary side and is therefore disipated as heat on the primary side.

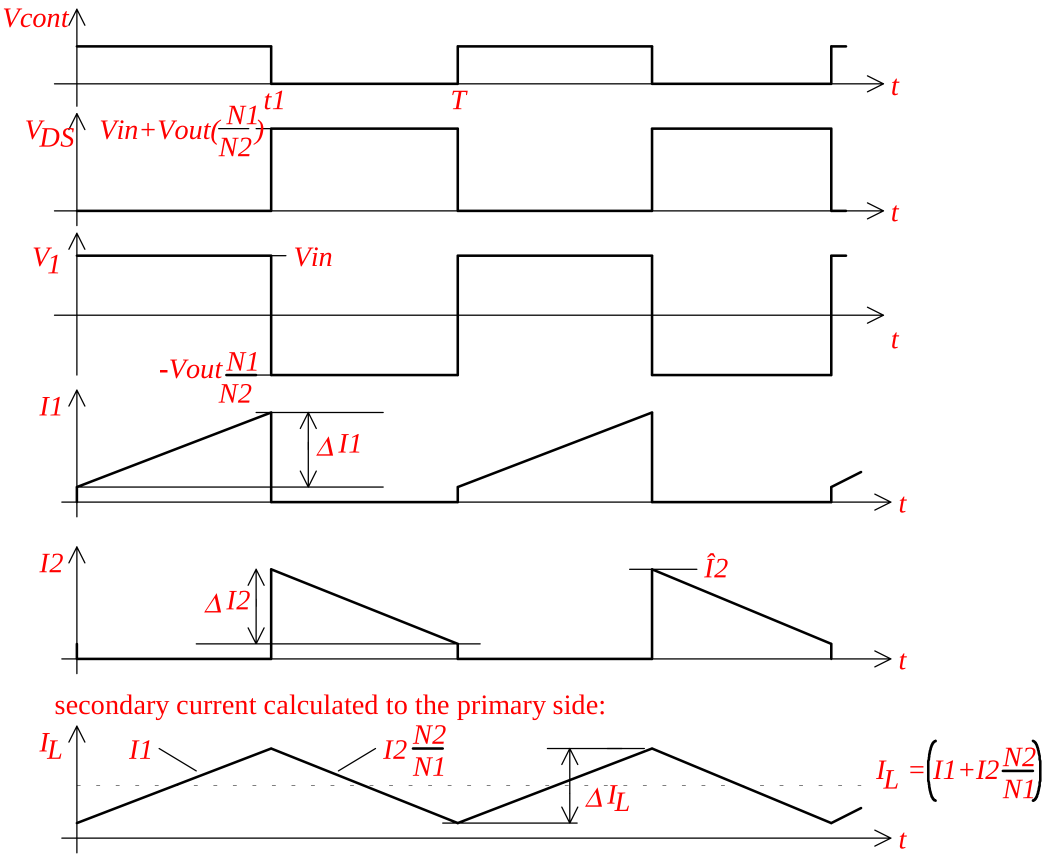

Figure 2.1.2: Voltages and currents at the flyback converter

Design of the flyback converter:

For the primary voltage of the transformer V_1 the average $\overline{V_1}$ must be equal to zero for steady state conditions (if not, the current will increase to infinity).
This leads to: $V_{in} \cdot t_1 = V_{out} \cdot \frac{N_1}{N_2} \cdot (T - t_1)$ and:

$$\boxed{V_{out} = V_{in} \cdot \frac{N_2}{N_1} \cdot \frac{t_1}{T - t_1}}$$

The turns ratio of the transformer should be choosen so that for the rated output power the on-time (energy charge time) t_1 is equal to the off-time (energy discharge time) $T - t_1$. This leads to the turns ratio:

$$\boxed{\frac{N_1}{N_2} = \frac{V_{in}}{V_{out}}}$$

The breakdown voltage of the transistor and the reverse voltage of the diode must be for this case:

$$\boxed{\begin{array}{ll}\text{Transistor:} & V_{DS} = V_{in} + V_{out}\cdot\frac{N_1}{N_2} \approx 2V_{in} \\ \text{Diode:} & V_R = V_{out} + V_{in}\cdot\frac{N_2}{N_1} \approx 2V_{out}\end{array}}$$

It should be noted that the rated breakdown voltage of the transistor must be chosen significantly higher, because at the turn-off instant the energy of the leakage inductance L_s will not be taken over by the secondary winding. To keep the overvoltage in an acceptable range a **snubber circuit** is required, see Fig 2.1.3. At the instant of turn-off the current of the leakage inductance L_s is diverted through by the diode D and charges the capacitor C. The power is dissipated in resistor R.
If R and C are required to operate at 230$\mathrm{V}_{\mathrm{AC},}$, a value of R has to be determined experimentally to ensure that the dc voltage across C falls within the region of 350V to 400V.

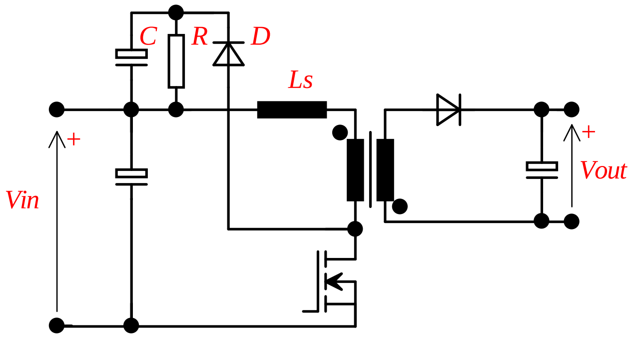

Figure 2.1.3: Snubber circuit to limit the peak voltage across the transistor

To design the transformer the primary inductance L_1 has to be calculated first.
L_1 has to store energy during the on-time of the transistor, which is the energy required at the output. This energy is given by: $W = P_{out}\cdot T$, where T is the periodic time of the switching frequency and P_{out} is the rated power. This energy is stored in the primary inductance during the first half of the period time and is transfered to the output capacitor during the second half of the switching period. As before the switching period is divided into two equal parts, one part to store the energy and the other part to transfer the energy.

During the on-time of the transistor the voltage across the primary inductance is equal to V_{in} and the current I_1 is a ramp waveform. For every cycle of the input energy it follows that :

$$W = V_{in}\frac{\hat{I}_1}{2}\frac{T}{2} \qquad \text{(see Fig. 2.1.4)}$$

This energy is stored in L_1 and can be calculated as:

$$W = \frac{1}{2}L_1\hat{I}_1^2$$

For the size of the primary inductance this leads to:

$$L_1 \approx \frac{V_{in}^2}{8P_{out}\cdot f}.$$

The calculation above assumes an efficiency of 100 %. If we consider an efficiency of η, it means that we have to store more energy in L_1 and not all of this energy is delivered to the output, then L_1 can be calculated as follows:

$$\boxed{L_1 \approx \frac{V_{in}^2}{8\,P_{out}\cdot f}\cdot\eta}$$

η has to be estimated because its value is not known at this point of calculation. ($\eta \approx 0.75$ is normally a good estimate.)

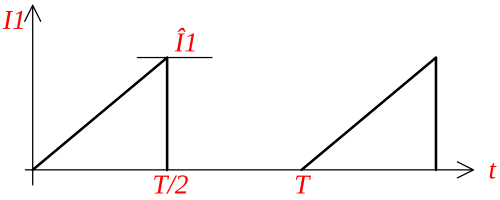

Fig. 2.1.4: Shape of the input current I_1 for rated power

The peak value of the current I_1 is: $\hat{I}_1 = \dfrac{4\cdot P_{out}}{V_{in}\cdot\eta}$

The RMS-value of the current I_1 is: $I_{1RMS} = \dfrac{\hat{I}_1}{\sqrt{6}}$

The core of the transformer and the windings can now be calculated with the help of Chapter 5: "Calculation of inductors and high frequency transformers"

The output capacitor C_{out} is charged by pulses (Ref Fig. 2.1.2). The ripple ΔV_{out} of the output voltage results from the pulsating charge current I_2 and is mainly determined by the impedance $Z_{\max}$ of the capacitor . $Z_{\max}$ can be verified from the capacitor data sheet.

The magnitude of the ripple voltage is given as follows:

$$\boxed{\Delta V_{out} \approx \hat{I}_2 \cdot Z_{\max}}$$

The input capacitor C_{in} can be calculated for 230V/50Hz-mains as follows:

$$\boxed{C_{in} \approx 1\frac{\mu\mathrm{F}}{\mathrm{W}}\cdot P_{in}}$$

A special feature of the flyback converter is the possilbility of controlling several isolated output voltages with only one control circuit (Fig. 2.1.5).

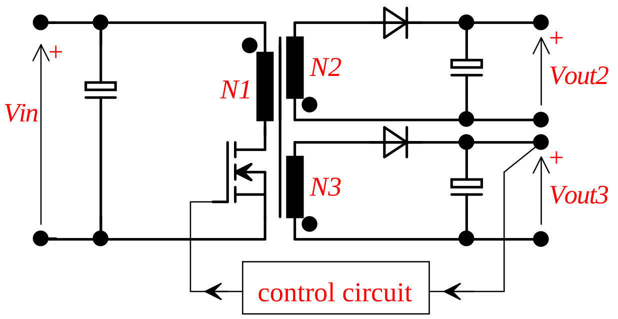

Fig. 2.1.5: Flyback converter for several output voltages

One output voltage is regulated (in Fig. 2.1.5 V_{out3}). Voltage V_{out2} is coupled to V_{out3} via the turns ratio: $\frac{V_{out2}}{V_{out3}} = \frac{N_2}{N_3}$. The energy which is stored in L_1 (N_1) during the on-time of the transistor moves during the off-time to the outputs. These output voltages maintain their values in relationship to the turns ratio. The output voltages in relation to the the turns ratio from the primary side appear to be in parallel. Therefore the energy from the primary side transfers to the output where the lowest voltage appears.