Power-Factor Control

The European standards EN61000-3-2 define limits for the harmonics of the line current. This concerns appliances, which may be sold to public customers and have an input power of $\geq 75\,\mathrm{W}$ (special regulations see EN61000-3-2). Some limit values from this standard are given in table 6.1. In practice this standard means that for many applications a mains rectifier with smoothing is not allowed because of the amount of harmonics (see figure 6.1).

harmonic-order n	input power75 to 600W maximum value of harmonic current per Watt (mA/W) / maximum (A)	input power >600W maximum value of harmonic current (A)
3	3,4 / 2,30	2,30
5	1,9 / 1,14	1,14
7	1,0 / 0,77	0,77
9	0,5 / 0,4	0,40
11	0,35 / 0,33	0,33

table 6.1: RMS limits for the harmonics of the line current

To keep the line current approximately sinusoidal, a boost converter can be used (see figure 6.2). In this case the boost converter is called **Power Factor Pre-regulator (PFC)**. In comparison to the boost converter the PFC is controled in a different way: The output voltage is higher than the input voltage as for the boost converter, but the transistor is turned on and off in a way that a sinusoidal input current is achieved instead of a exact constant output voltage. The transistor is driven in such a way, that the inductor current $I_L(t)$ follows the shape of the rectified mains $V_{in}(t)$. The output voltage of the PFC is controled to approximately $\overline{U_a} \approx 380\,\mathrm{V}$.

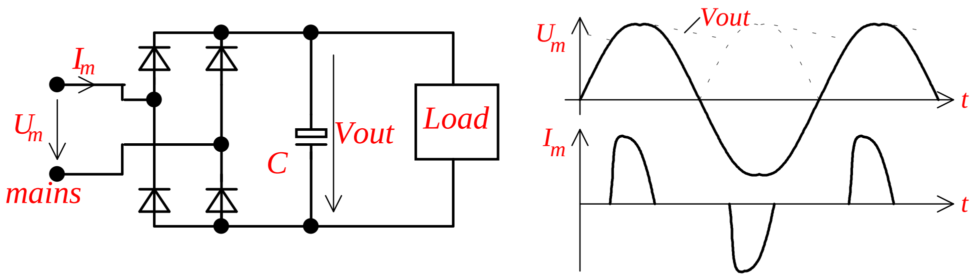

Figure 6.1: Usual rectifieing and smoothing of the mains and its mains current

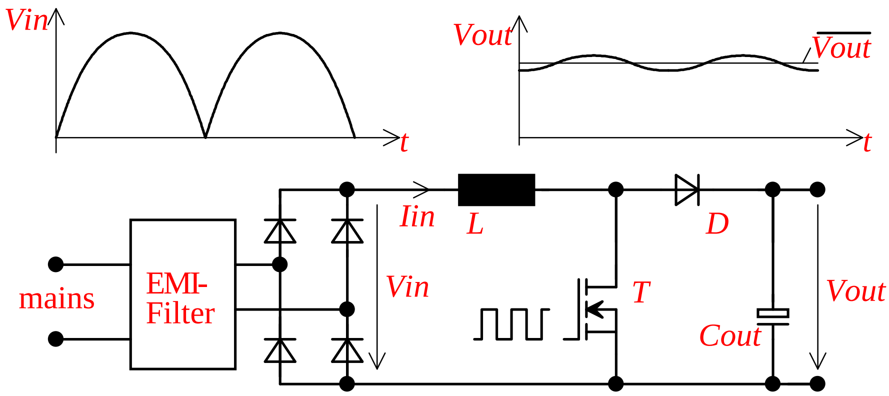

Figure 6.2: boost converter as a power-factor preregulator

Currents, Voltages and Power of the PFC:

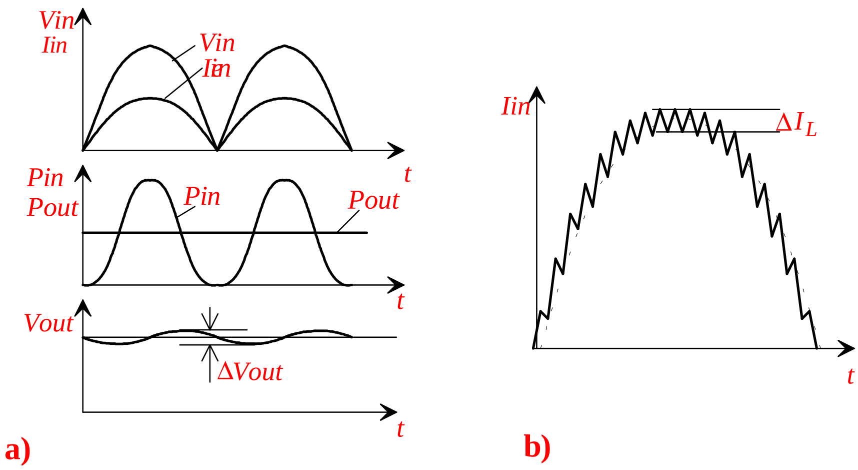

Figure 6.3: Currents, voltages and Power of the PFC

For the following calculations, it is assumed that the output power is constant:

$$\boxed{P_{out} = V_{out} \cdot I_{out} = const.}$$

The input current should be controled to a sinusoidal shape and should be in phase with the input voltage. The input power is now pulsating and can be calculated as follows:

$$\boxed{P_{in}(t) = \frac{\hat{V}_{in} \cdot \hat{I}_{in}}{2} \cdot (1 - \cos 2\omega t)}$$

The input power consists of a DC-part $P_{in=} = \frac{\hat{V}_{in} \cdot \hat{I}_{in}}{2}$ and of an AC-part $P_{in\sim} = \frac{\hat{V}_{in} \cdot \hat{I}_{in}}{2} \cdot \cos 2\omega t$. The DC-part is equal to the output power P_{out}, providing a loss-free PFC .

$$\boxed{P_{in} = \frac{\hat{V}_{in} \cdot \hat{I}_{in}}{2} = V_{out} \cdot I_{out} = P_{out}}$$

In practice an efficiency of about $\eta = 95\%$ is realistic which means that $P_{in} \approx \frac{P_{out}}{0.95}$.

The output capacitor C_{out} is charged by the pulsating input power P_{in} and discharged by the constant output power P_{out}. This causes a voltage ripple ΔV_{out} at C_{out}, which depends on the value of C_{out}. For the 230V/50Hz-mains, providing $V_{out} = 380\,\mathrm{V}$ and $\Delta V_{out}/V_{out} = 10\%$, C_{out} can be calculated to:

$$\boxed{C_{out} \approx 0,5; \frac{\mu F}{W}}$$

The choke L determines the high frequency ripple of the input current ΔI_L (figure 6.3b). The higher the inductance and the higher the clock frequency f, the lower this current ripple. If $\Delta I_L = 20\%$ of the peak value of the input current $\hat{I}_{in}$ and assuming that the 230V/50Hz-mains voltage is a minimum of $V_{in\,\min} = 200\mathrm{V}$, it follows that:

$$\boxed{L \approx \frac{50 \cdot 10^3}{f \cdot P_{in}};\; L\,(\mathrm{H}),\, f(\mathrm{Hz}),\, P\,(\mathrm{W})}$$

and for the maximum inductor current:

$$\boxed{I_{Lmax} = \hat{I}_{in\,\max} + \frac{1}{2}\Delta I_L = 1,1 \cdot \frac{2P_{in}}{\hat{U}_{in\,\min}}}$$

Controlling the PFC:
Two feedback circuits are required:

- One to control the input current to be sinusoidal (input current control)

and

- one to keep the average output voltage constant, which means keeping it independent from the load power consumption (output voltage control)

The input current control loop is lead by the input voltage. In this case the input current aquires the same shape as the input voltage and consequently the power factor of the mains current will be unity.

The output voltage is controled by comparing it to a constant reference voltage.

The multiplier links the two loops. The output of the multiplier is sinusoidal and its magnitude depends on the output voltage control loop. If the output voltage decreases from its nominal value, the output voltage of the voltage control amplifier increases which causes the magnitude of the multiplier output to increase and consequently the RMS-value of the input current also increases.

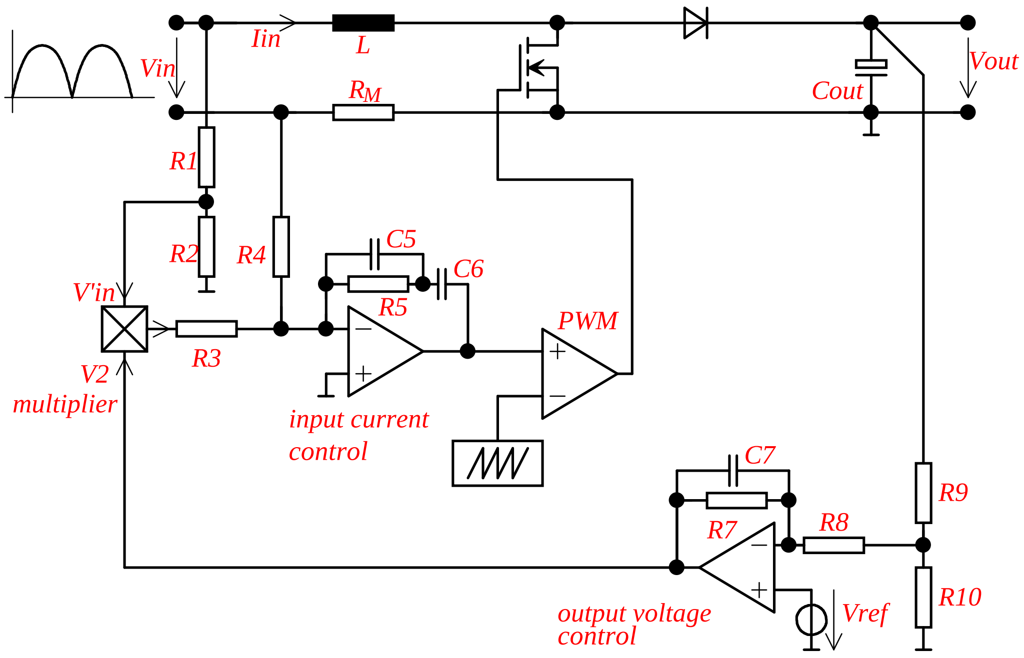

Figure 6.4: The control loops of the PFC

- The RMS value of the input current is controled by the output voltage control loop while the input current control loop drives the input current to be sinusoidal.