Control of switch mode power supplies

The output voltage of a switch mode power supply is kept constant with the help of closed loop control. The value of the output voltage (actual value) is compared with a reference voltage (nominal voltage). The difference between actual and nominal value controls the duty cycle of the transistor drive. The function of the control loop is to regulate the variation of the mains and of the change of the output current. This is called **line regulation** and **load regulation**.

There are two different methods of regulation: **voltage-mode** and **current-mode control**. The voltage-mode control is the "traditional" method of regulation. Most modern systems use current-mode control which is the basis of nearly all IC current-mode controllers.

Both controller types can be explained using a boost converter shown in fig 4.1:

Voltage-mode control:

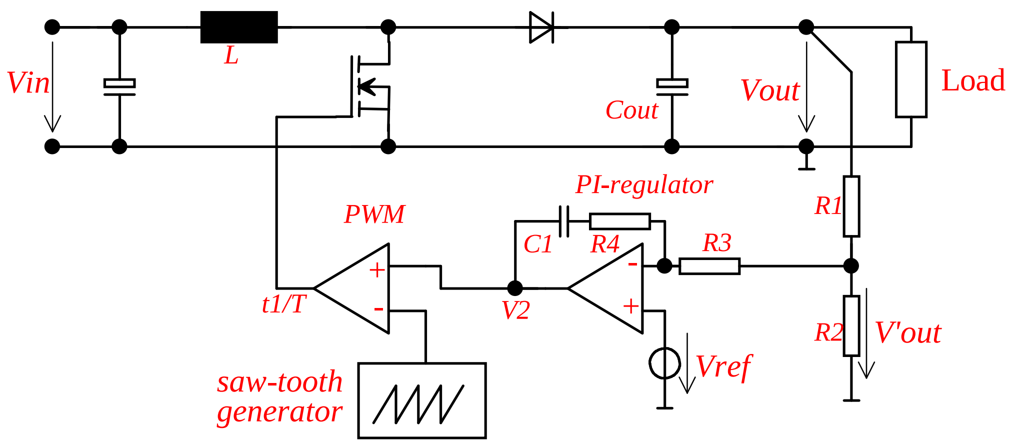

Figure 4.1: voltage-mode-control for a boost converter

The output voltage V_{out} is compared to the reference voltage V_{ref} via a voltage divider R_1, R_2 and amplified by the PI-regulator. A pulse width modulator (PWM, see Fig.4.1a) converts the output voltage of the PI-regulator V_2 into a pulse width modulated voltage t_1/T . The output of the pulse width modulator (PWM) controls the transistor of the boost converter (see also Chapter 1.2: "boost converter").

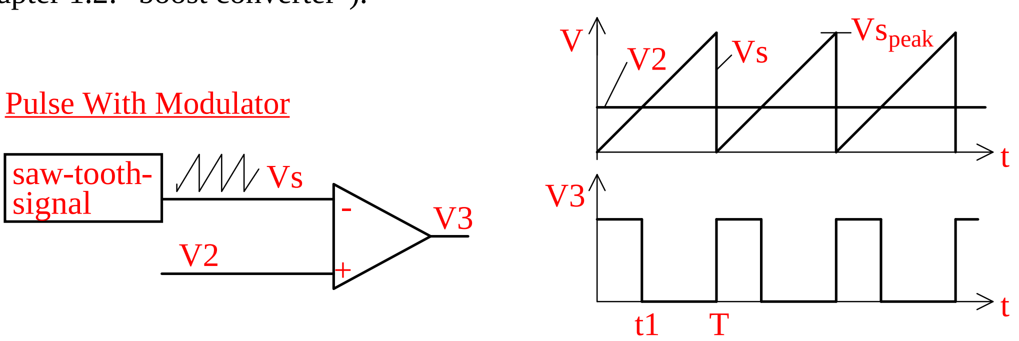

Figure 4.1a:Pulse width modulator

The closed loop operates as follows: If the output voltage V_{out} is to low, the voltage V'_{out} will be lower than the reference voltage V_{ref}, this will cause the output voltage V_2 of the PI-regulator to increase. In the PWM circuit V_2 is compared with a saw tooth signal and as it increases the duty cycle t_1/T also increases, this causes the output voltage to increase until $V'_{out} = V_{ref}$.

Current-mode control:

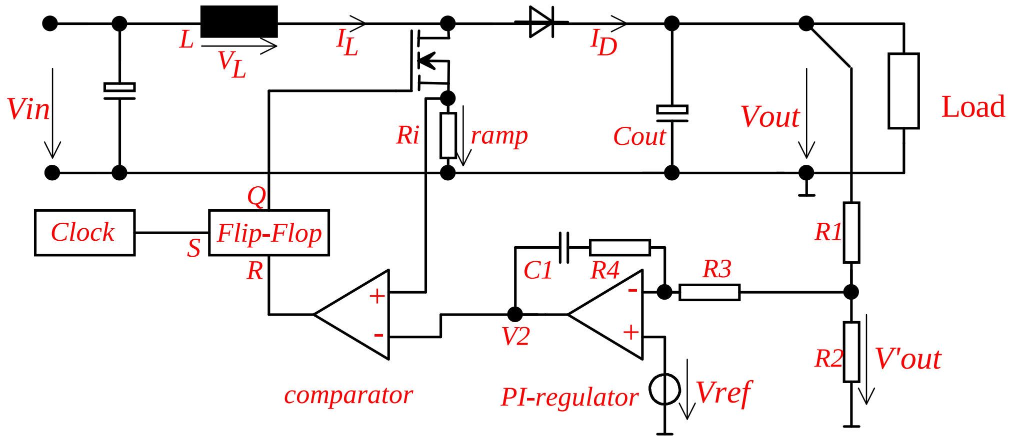

Figure 4.2: current-mode control for a boost converter

The output voltage V_{out} is compared to a reference voltage V_{ref} via the voltage divider R_1, R_2 and amplified by the PI-regulator. The output voltage of the PI-regulator V_2 is compared with ramp voltage across the current measuring resistor R_i. When the voltage across R_i exceeds V_2 the output of the comparator resets a RS-flip-flop and turns the transistor off. The RS-flip-flop is set before by the clock. The transistor is turned on by the clock and turned off, when the ramp voltage (which means the inductor current) reaches a certain value. In this way the PI-regulator directly controls the inductor current.

The closed loop operates as follows: If the output voltage V_{out} is too low, the voltage V'_{out} will be lower than the reference voltage V_{ref}. This causes the output voltage of the PI-regulator V_2 increases. The comparator compares the voltage V_2 with the ramp voltage across R_i. In this way V_2 determines the value to which the ramp voltage across R_i increases (which means the value to which the inductor current I_L increases) until the transistor is turned off. If V_2 increases because the V'_{out} is lower than V_{ref}, the inductor current will increase until V'_{out} is exactly equal to the reference voltage.

Comparision of voltage-mode to current-mode control:

The PI-regulator of the current-mode control regulates the inductor current directly. This current feeds the output capacitor C_{out} and the load resistance R_L. C_{out} and R_L form a first order system and the step response is an an exponential function.

The voltage-mode control regulates the duty cycle t_1/T, which means that the voltage across L is controlled. This voltage operates on a second order system, formed by L, C_{out} and R_L. The step response of such a system is a sinusoidal transient approaching a fixed value.

The current-mode control has therefore a better control response, for this reason most controllers are current-mode types.

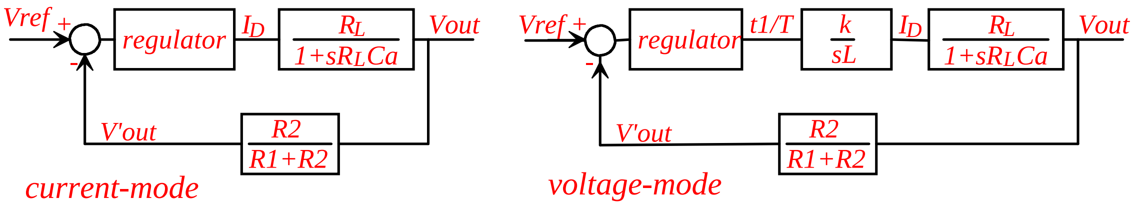

Fig 4.3: Block-diagramms for current-mode- and voltage-mode control

Design of the PI-regulator:

The PI regulated system tends to oscillate, if the capacitance C_1 is selected at too small a value and if the resistor R_4 is too high a value. To alleviate this problem C_1 should initially be selected high (A 1 F foil capacitor is normal in most control circuits). R_4 should be selected so that the cut-off frequency of the PI-regulator stays well below the cut-off frequency of L and C_{out}:

$$\frac{1}{2\pi\sqrt{LC_a}} \geq 10\frac{1}{2\pi R_4 C_1}$$

The controller should now operate in a stable mode (if not, internal interference or an unfit architecture of the board might could be a problem). To improve the reaction of the closed loop, C_1 can be decreased step by step with a parallel increase of R_4. If the loop starts to oscillate, C_1 can be increased by the factor of ten and R_4 decreased. Using these design guides the loop will operate in a stable mode with sufficient regulation speed for most applications.

HINT:

> In many control circuits the operational amplifier (normally called the error amplifier) is a transconductance amplifier. It supplies an output current (very high output impedance), which is proportional to the input voltage. In this case R_4 and C_1 are connected from the output to ground to achieve the PI-characteristic of the regulator.