3. Function of the Power Factor Correction Circuit (PFC)

The mains input current of Switched Mode Power Supplies (SMPSs) with a capacitor input filter is not sinusoidal like the mains voltage but has a pulsed shape. The power factor correction circuit must make the mains input current more sinusoidal like the mains voltage. This is necessary to comply with the requirements of the new line-harmonics regulation EN 61000-3-2. The TDA 1684X is specialized for controlling the Charge Pump Circuit for PFC.

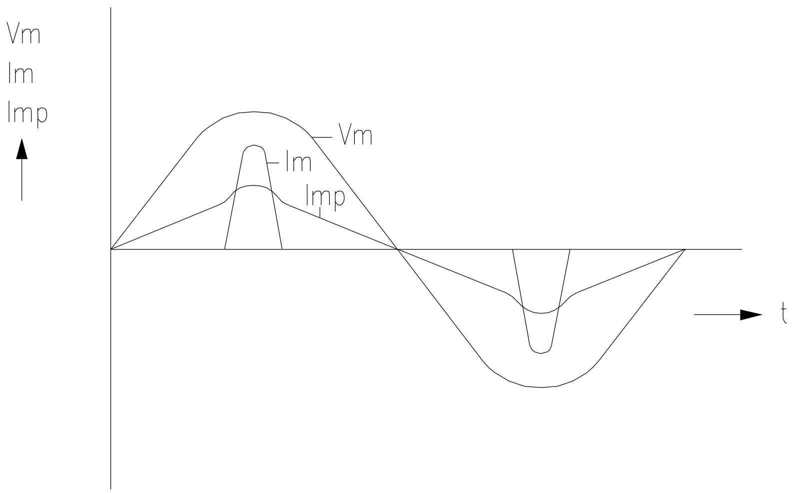

Fig. 5: Course of voltage and current
in the Standard and PFC Power Supply

In Fig. 5 can be seen that the input current Im of a standard power supply without PFC flows only during a short time near the pos. and neg. maximums of the mains voltage. No current is flowing outsides of the maximums. The reason is that the rectifier diode is only forward biased by the AC line voltage being higher than the voltage at the primary capacitor for a short time at the peak of the waveform.

To remedy this, a charge pump circuit is inserted between the bridge rectifier and the primary capacitor, which “pumps” current from a lower voltage up to a higher voltage to get a current shape like the curve Imp in Fig. 5. The current transfer of the charge pump is dependent on the load due to the frequency and pulse width modulation of the TDA16846, and by selection of the pasive L and C charge pump components.

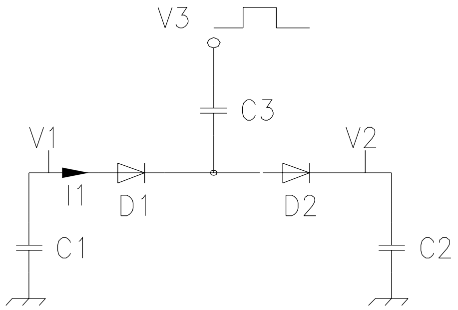

Fig. 6: Charge Pump Circuit

Fig. 6 shows a simple charge pump circuit. The capacitor C1 is charged with a DC voltage V1 and the capacitor C2 is charged with a DC voltage V2. V1 is a low voltage and V2 is a comparative high voltage. The charge pump circuit between V1 and V2 consists of the 2 diodes D1 and D2 and the capacitor C3. The capacitance of C3 is small compared with C1 and C2. Pulses from a voltage source V3 are transfered across the capacitor C3 to the connection point between D1 and D2. If the amplitude of the pulses V3 is higher than the difference V2 - V1, then a current flow is possible from voltage V1 up to the voltage V2. The charge Q3 which is transfered within each period across C3 is: Q3 = C3 * (V3 - (V2 - V1)) = C3 * (V3 + V1 - V2). When the pulse frequency is f3, then the current I1 of the charge pump is:

$$I1 = C3 \times f3 \times (V3 - V2 + V1)$$

If the voltage V1 is no DC voltage but a rectified AC voltage and if V3 = V2, then the current I1 becomes the same shape as V1.

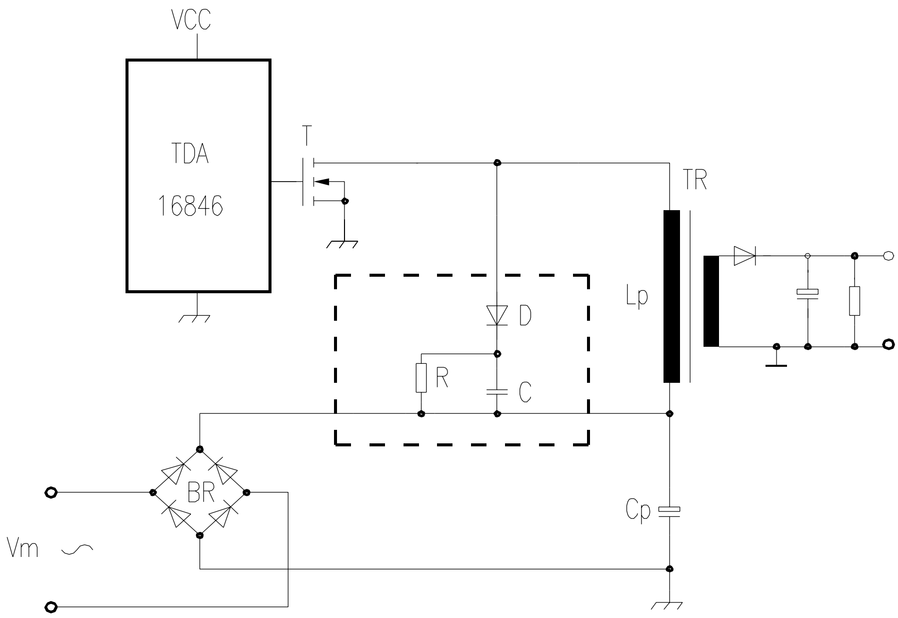

Fig. 7: RCD Snubber Circuit

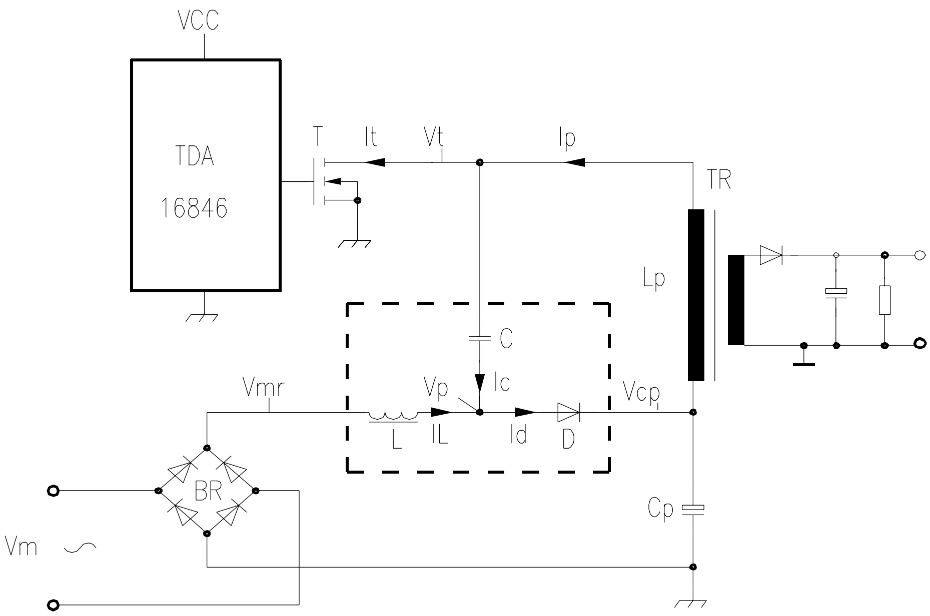

Fig. 8: PFC Charge Pump Circuit

In Fig. 7 a snubber circuit is shown which is generally used in standard SMPSs. It consists of a diode D, a resistor R, and a capacitor C. This snubber circuit cuts off the voltage overshoots at the drain of the switching transistor T. It can be replaced by a charge pump circuit consisting of an inductor L, a diode D and a capacitor C. Fig. 8 shows the charge pump circuit which is connected between the bridge rectifier BR, the positive terminal of the primary capacitor Cp and the drain of the switching transistor T. The bridge rectifier replaces the diode D1 in Fig. 6. The inductor L is put in to avoid high current pulses when the capacitor C charges after switching on the power transistor T. The pulsed voltage source V3 in Fig. 6 is replaced by the drain voltage of the switching transistor T. The snubber circuit shown in Fig. 7 is no longer necessary because the charge pump circuit fulfills not only the PFC- but also the snubber function.

Any transformer overshoots are intercepted by the charge pump, by forming a tuned circuit from the capacitor C and the transformer´s primary inductive resistance Lp, at the beginning of the transformer demagnetization period with a conducting diode D. This reduces the frequency and the amplitude of the overshoot to an acceptable level. This type of pulse snubbing has the advantage that no energy is lost, and this increases the efficiency level of the power supply.

The advantages of the PFC charge pump circuit are its simplicity, and the ease with which its transfer function can be controlled by dimensioning its components. A switched mode power supply can quickly be converted to PFC by selecting the appropriate configuration (as an alternative to the snubber circuit). Since the capacitor in the charge pump circuit is a differentiator, the charge transfer can be controlled effectively by means of the frequency. For example, the transfer function of the input current can be shaped by means of power supply phase dependent frequency modulation of the SNT frequency.

Next the function of the PFC charge pump circuit is explained in detail using the pulse diagram of Fig. 9. The voltage and current characteristics are depicted for a 230 V mains voltage. At the time t0 the switching transistor T is turned on by the control circuit TDA 1684X. The drain voltage Vt falls from about 600 V to 0 V. The primary current Ip begins to rise simultaneously due to the voltage imposed across the primary inductance. The voltage fall of Vt is also transfered accross the capacitor C to the junction between L and D (Fig. 8), so that the voltage Vp drops from 400 V to approx. -200 V. Due to the negative voltage Vp the current IL in the choke L is increasing. As this current charges the capacitor C the voltage Vp climbs likewise during t0 and t1.

After the charge phase of the flyback transformer TR and the choke L has been completed at time t1, the power transistor T is turned off by the control circuit TDA 1684X. The voltage Vt and with it the voltage Vp will rise rapidly until Vp has reached the potential Vcp (400V). The voltage Vp stays at the Vcp level while Vt slows its rise.

At the same time the current IL, which previouly charged the capacitor C, flows through the diode D into the capacitor Cp. The energy stored in L is then transferred to Cp. This causes a flow of current from the lower instantaneous value of the mains voltage to the higher voltage Vcp of the capacitor Cp.

Because of the conducting diode D an RC circuit is built of the primary inductance Lp and the capacitor C. The primary current is flowing through Lp, C and D until the moment t2, when the secondary diodes become conducting and the discharging of the transformer to the secondary side begins.

During the discharge phase from t2 to t3 the current IL is decreasing. The voltage Vp is clamped at one diode drop above Vcp.

The current through the choke L becomes higher with longer switch on time of the transistor T. The on time of T increases with an increasing secondary load and also with a decreasing mains voltage. At the same time the current increases through the PFC charge pump circuit.

Due to the stored energy in the capacitor Cp the power supply is also completely capable of stabilizing the power line ripple voltage during mains voltage´s zero crossing.

Fig. 9 shows also another period of the PFC charge pump circuit. This kind of sequence occurs near the maximum of the mains voltage. Vp is rising and reaches the potential Vcp during the switch on time from t3 to t5 at the time t4. So the current Ic stops at t4. The drain current It has 2 maxima. It consists between t3 and t4 of the sum of Ip and -Ic, after t4 only of Ip. In this kind of sequence the current IL doesn’t periodically return to zero.

There is no problem when the core of the PFC choke L gets nearly into saturation, because the current through L is limited by a charge of the capacitor C.

Attention: Because of the higher voltage at the primary capacitor which is necessary for the demagnetization of the PFC choke, a 450 V type instead of a 385 V type should be used.

To avoid that a current flows backwards through the PFC choke, the diodes for the bridge rectifier should be fast types, at least the two diodes at the output of the bridge rectifier should have a small reverse recovery time. Otherwise the function of the charge pump circuit can be heavy affected and the PFC diode can get an overvoltage.

The output voltages which are not regulated by the optocoupler can have a slightly higher mains voltage ripple because the PFC charge pump circuit effects an additionally modulation of the SMPS frequency with the mains frequency. This effect is higher with a weak coupled transformer.

A complete circuit diagram of a SMPS with the PFC charge pump circuit can be seen in Fig. 16. The PFC charge pump circuit consists of the components L08, D08, and C08.

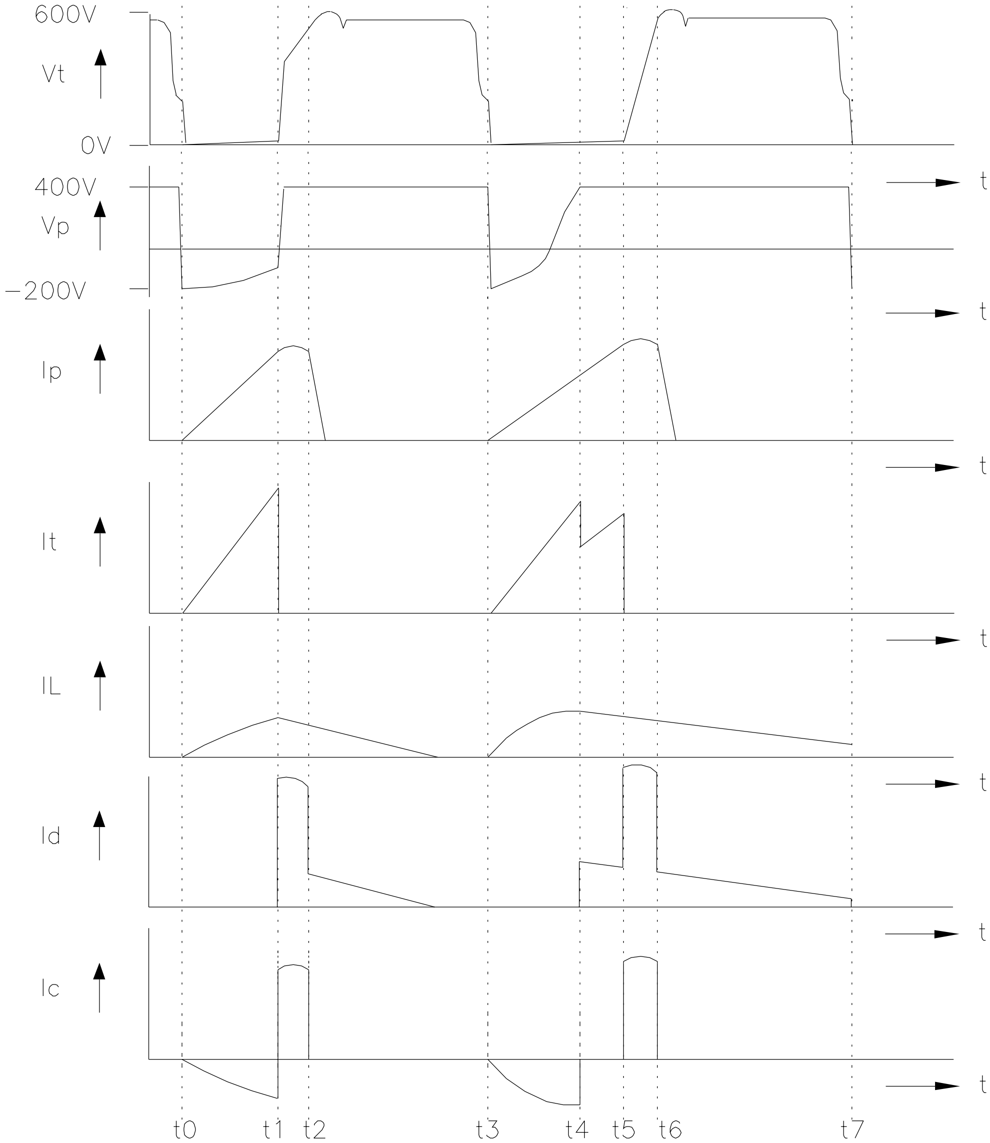

Fig. 9: Voltages and currents in the PFC Charge Pump Circuit