PFC-Fundamentals

2. Active Power Factor Correction – Principle of Operation

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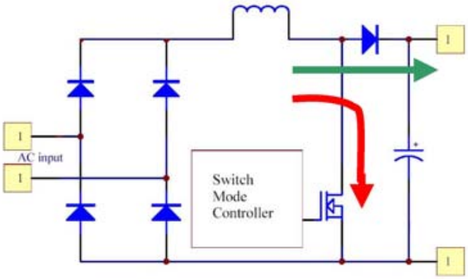
For the development of applications with sinusoidal current consumption more design work will be required than ever before. New national and international standards and laws demand increased activities. And compliance of the applicable standards is a must today. But an active PFC also generates additional advantages, which does not generally lead to additional costs. Precondition is a system design that uses the advantages of an active PFC as smaller DC-link capacitor, loss reduction in the application connected to the output achieved by the increased and constant output voltage. Application examples of active PFC solutions are inverter welding machines, as by application of a PFC, the performance can be increased without affecting the mains fuse. Also converter-controlled fans for clean rooms should be mentioned. In clean room production facilities typically hundreds or thousands of such ventilators are used and the current drain from the mains have to be controlled in order to keep the system in function.

General Requirements

Some general requirements are mandatory for all these applications: compact design, low interference level, and power loss optimization. To realize an optimally compact PFC design, the switching frequency must be maximized so that extremely small PFC choke coils can be applied. To control by this caused increased power loss, the coil should have a high-performance core with thermal contact to the cooling element. New semiconductors must be suited for higher performance in order to gain smaller space requirements. At the same time it has to be prevented that the advantage is lost by the demand for a larger cooling element. Here new technologies of the semiconductor industry are opening doors. High switching frequencies are leading to considerable cost savings. A compact design leads to completely new mechanic concepts for an application, which may also lead to considerable savings in system costs. Also a positive interlinking effect can be utilized. Higher switching frequencies allow the application of smaller components for choke and EMC filter. By its compact design, EMC compatibility will be easier. And this will lead to further savings in system costs and development time.

Fundamentals of Active Power Factor Correction

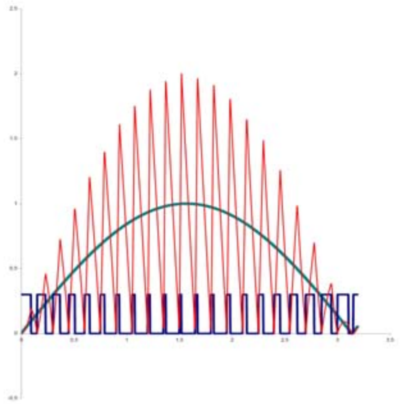
An active PFC switch is basically an AC/DC converter, as its core is a standard SMPS (Switch Mode Power Supply) structure, which controls the current supplied to the consumer via a "Pulse Width Modulation" (PWM). The PWM triggers the power switch, which separates the intermediate DC voltage in constant pulse sequences. This pulse sequence will then be smoothened by the intermediate DC capacitor, which generates DC output voltage.



Two different modulation procedures can be applied, the continuous mode and the discontinuous mode.

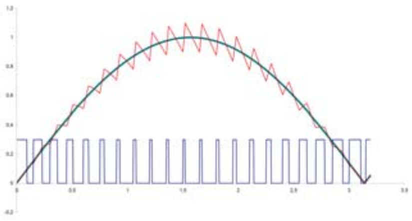
Discontinuous Mode

In the discontinuous mode the transistor is switched on only then, when the energy contained in the choke coil is completely transferred via the diode to the electric DC output circuit. When switching on the transistor the choke contains neither energy nor current. This operation principle has therefore the advantage that switch-on losses will not be generated. Another benefit is that the choke can be very small. But this principle generates strongly increased waviness and switch off losses.



Continuous Mode

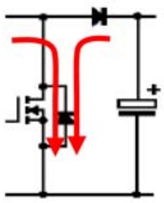
The topology is the same as in the discontinuous mode, but here varies the current in the choke closed to the sinusoidal average. In the continuous mode these large upper waves and the very high switch-off losses (caused by the double as high switch-off current) can be avoided. Therefore, this process will be preferably be used for capacities from about 250W.



Design of a Continuous Mode PFC

Switch-On Losses

In standard PFC switches normally relatively low flow losses are generated compared to the switching losses. Consequently mainly the transistor switching losses are limiting the maximal switching frequency. On the other hand, the reverse current of the diode has a great influence on these switching losses generated in the power switch.

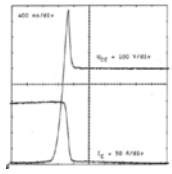


Reverse currents of the diode increase the switch-on losses of the transistor and the application of a fast boost diode with a low reverse recovery charge (Q_{rr}) can thus be of great importance. The boost diode has a significant influence into the switch on losses of the power transistor in the boost circuit.

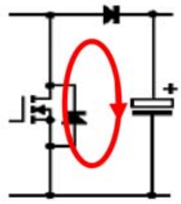
Switch-Off Losses

Any parasitic inductance in the output causes a voltage-overshot witch endangers the semiconductors and increases the switch off losses. Switching-off the transistor results in a current change. This causes a voltage spike by the current change in the parasitic inductances according to:

$$V_{CE}(peak) = V_{CE} + L \times di/dt$$



To minimize switch-off losses, prevention of parasite induction loops at the PFC output is of great importance. A particularly elegant solution is to short the inductive loop with a capacitor attached as closed as possible. A fast capacitor integrated into the power component would be the optimum.



MOSFET vs. IGBT

IGBT or MOSFET? To answer this question, the efficiency of a frequency-dependent technology isn't a suitable standard. The reason is the switching of variable currents. In the range of the sinus maximum, only a short pulse will be required to increase the voltage from e.g. 325 V (V_{Peak} at 230 V_{AC}) to 400 V DC. In the zero flow range the pulse frequency is higher, but the current to be switched is then lower. For 230 V_{AC} / 400 V_{DC} applications and switching frequencies of 60 kHz and more the MOSFET seems to be the better and cheaper solution. Applications with focus on a wide input range (e.g. 90 V_{AC} .. 240 V_{AC}) generate a completely different result. When applying 90 V_{AC} at the input and 400 V_{DC} at the output, also in the sinus maximum, a relatively long pulse will be required for the transformation from 127 V (V_{Peak} at 90 V_{AC}) to 400 V_{DC}. For such applications the static losses are more decisive for the performance balance of the PFC level. For switching frequencies up to nearly 100 kHz, application of very fast IGBT´s seems to be more attractive. To optimize the system costs, switching and flow-through losses shall always be nearly equal.

As a rule, P_{Stat}/P_{Switch} = 1 shall apply. Balancing of switching losses with flow-through losses shall always be the target for a design to cost.