SMPS: a crucial component of the "system Data Center"

By Francesco Di Domenico

IMPROVING THE STANDARD of living requires ever-increasing demand for energy, particularly in electrical forms. People do not use directly electrical energy, but mainly IT and telecommunication equipment, transportation vehicles, white goods, light, mechanical work or media: these are all the tangible effects of the electrical energy.

Power electronics is the science studying the ways to convert electrical energy into the forms typically used in the daily life. A modern power conversion system consists of an energy source, an electrical load, a power electronic circuit, and control functions: the control circuits take information from source and load, determining how the switches must operate to achieve the desired conversion.

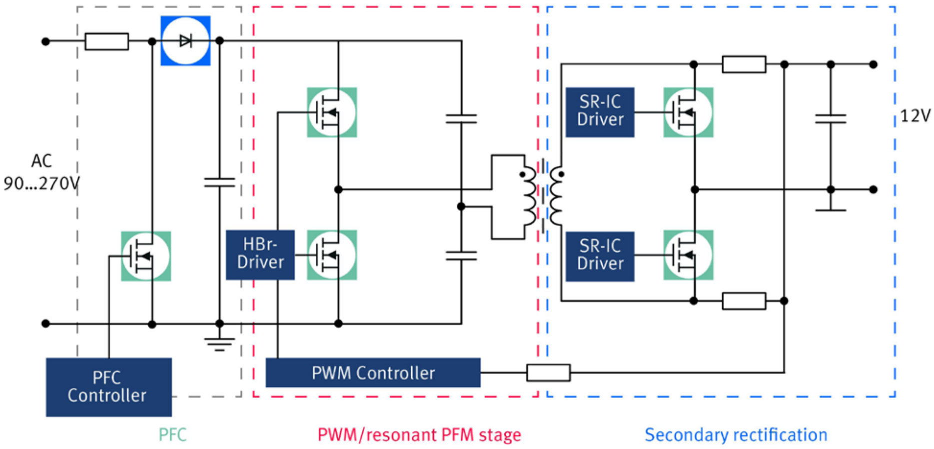

Fig. 1: An AC/DC SMPS system consisting of three main stages.

This is exactly the principle of operation of the SMPS (Switch Mode Power Supply), which uses a high frequency switch (in practice a transistor) with varying duty cycle to maintain regulated output voltage.

An AC/DC SMPS is a system consisting of three main stages, as shown in figure 1 in the case of a typical IT server application.

In each of these 3 stages the role of power or logic components based on semiconductors is fundamental: high voltage power MOSFETs, diode and controllers in the PFC and PWM/resonant stages, Low Voltage power MOSFETs or diodes in the rectification stage.

More recently the focus has been moving from a "device-driven" to an "applications-driven" scenario, in a "system engineering" approach. This transition has been mainly triggered by the fact that advanced semiconductors with suitable power ratings already exist for almost every application of wide interest, so designers show an increasing interest in a more flexible, reliable and of course efficient way to use them.

According to the new "system" approach, efficiency and power density are definitely more and more in the focus of SMPS design, especially in IT computing applications. Figure 2 shows the most popular efficiency standard followed in this environment, the 80Plus, which fixes the minimum efficiency requirements in typical operating condition (20, 50 and 100% loading).

The most recent one, the Titanium, imposes the requirement even at 10% loading, so at very light load: this is consistent with the operation of modern computing systems, where each power supply is typically used in a paralleled N+1 redundant configuration, so it will work most of the time at load much closer to 10% than to 100%.

In fact in the past the increasing efficiency need was mainly driven by the capability of heat dissipation at full load without excessive impact on fan's acoustic noise generation: as a result, maximizing the full load efficiency was more in the focus.

However, more recently the explosive growth of consumer electronics and data processing equipment had pushed to the introduction of various requirements aimed at the optimization of light-load operation. For example, the workload of Web services can significantly vary based on diurnal cycles, application weights, external events, etc. And this is mostly valid even for High Performance Computing (HPC) and cloud servers.

Meeting this stringent light-load efficiency poses major design challenges to power supply manufacturers and huge effort has been dedicated by both power semiconductors and control ICs providers in developing technologies able to comply with these specifications and making SMPS efficiency plot as much as possible "flat" in the entire load range.

A modern data center looks like an array of racks; in each "drawer" of it we find a server, and in each server a SMPS can be found – see figure 3: therefore a large number of power supplies are expected to be inside such a structure.

Looking at the diagram of the power delivery system of a typical large server farm, for each Watt consumed by data processing, more than two Watts are wasted in power conversion and cooling.

An important parameter used to quantify the server efficiency inside a data center is the so called Total Cost of Ownership (TCO), defined as the cost to equip and run the servers. In fact, TCO consists of two main components, the CAPEX (Capital Expenditure, so equipment costs) and the OPEX (Operating Expenditure, so the energy cost). With steadily decreasing prices of IT equipment, the cost of electricity over the equipment lifetime has become a significant fraction of the initial acquisition cost, especially for low-end equipment such as "blade", 1U, and 2U servers (where "U" is a unit of height measuring 1.75 inches or 4.45 cm), where the cost of power and cooling

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exceeds the acquisition cost in approximately three years. As a result of the increasing impact of energy cost on the TCO, efficiency considerations have started to have a significant influence on equipment acquisition decisions, starting of course from the SMPS selection.

In addition, the increasing power consumption of IT equipment and in particular that of fast-growing large data center facilities has started to have a serious environmental impact, especially in terms of CO^2 emission.

A third important component affecting the TCO is the reliability of components, since repairs can be costly in labor and reserve-capacity provisioning. A similar but maybe less tangible element affecting the TCO is the serviceability of the servers, which involves the time, and therefore the cost of repairs and upgrades. The size and weight of the components, especially the SMPS, may significantly influence this parameter. For this reason the trend in increasing efficiency goes hand in hand with the increasing power density. Figure 4 gives a short overview of the specific impact on SMPS requirements.

	Standard			Bronze			Silver			Gold			Platinum		
Percent Loading	20%	50%	100%	20%	50%	100%	20%	50%	100%	20%	50%	100%	20%	50%	100%
115 V_{AC}	80%	80%	80%	82%	85%	82%	85%	88%	85%	87%	90%	87%	90%	92%	89%
230 V_{AC}	-	-	-	81%	85%	81%	85%	89%	85%	88%	92%	88%	90%	94%	91%

80 PLUS TITANIUM

Load Efficiency

Fig. 2: The most popular efficiency standards: the 80Plus fixes the minimum efficiency requirements in typical operating condition (20, 50 and 100% loading).

In fact, SMPS did not see a dramatic change in power density until the beginning of the rapid growth of the Internet: while a typical power density of server front-end power supplies was in the 10 W/in³ range just 10 years ago, the power density requirement is today in the 40 W/in³ range. As this trend continues, SMPS with more than 50W/in³ will be commonly available in few years. These dramatic power density gains have been primarily enabled by the availability of better components (both semiconductors and magnetics), advanced packaging techniques, but also design optimization and consequent new advanced control techniques.

An important contribution to the future efficiency and power

Fig. 4: A short overview of the specific impact on SMPS requirements.

density is expected to come mostly from system architecture and power management optimization. For this reason, the digital power management bus has been already standardized by the PMBus Consortium. In addition to PMBus compliance, digital control techniques become increasingly popular in power conversion.

Generally, while digital power management can optimize performance at the system level, digital control contributes to optimize the converter-level efficiency in the entire load range by implementing adaptive, load-dependent control algorithms, or phase-shedding in interleaved structures in order to achieve almost flat efficiency plots. In addition, within the digital control, monitoring, protection, and house-keeping features of power are shifted from hardware to software, which significantly shortens product design time, reduces the cost, and also allows for easy adjustment ("tweaking") of parameters even during the mass production.

Regarding the circuital topologies used inside SMPS, the opportunity to significantly reduce the size of power converters by increasing the switching frequency created by the MOSFET technology has focused topologies studies on the reduction of switching losses of the semiconductor devices, which is typically perceived as the major obstacle to maximizing the switching frequency of PWM converters. This has given big emphasis to the resonant power conversion, which led to the development of new families of resonant converters, based on the zero-voltage-switching (ZVS), zero-current-switching (ZCS), quasi-resonant (QR) and multi-resonant concepts.

From what is mentioned above, the role played in SMPS advancement by semiconductors companies like Infineon looks really crucial: power devices, drivers, ICs, analog and digital controllers, everything inside Infineon portfolio, are all fundamental parts of such a system. For this purpose, figure 5 shows the typical internal structure of a Server AC/DC SMPS and the several families of Infineon components which are used in each of its stages.

In fact, the outstanding improvements in SMPS performance achieved in the past 10 years have been primarily brought by the dramatic reduction of the on-resistance achieved in high-voltage MOSFETs using the revolutionary Super Junction principle, introduced by Infineon at the end of the nineties in the CoolMOSTM series and equally impressive improvements in reverse-recovery characteristics of high voltage SiC (Silicon Carbide) diodes. In applications with a low output voltage, further efficiency improvements have been made possible by continuous reduction of on-resistance of low-voltage MOSFETs, like Infineon OptiMOS series, used as synchronous rectifiers. Introduction of innovative devices based on GaN (Gallium Nitride) material promises further revolutionary advancements in this field.

An important contribution to the progress of SMPS technology comes in particular from the packaging techniques, having the main goal of minimizing parasitics and improving thermal performances. The need of increased power density has been also triggering more and more advanced component integration: monolithic integration and/or chip co-packaging of semiconductor components such switches, drivers, and control circuits looks promising in order to shrink the system size. For the same reason the use of magnetics with integrated PCB winding(s), allowing more functional integration, will find more extensive use.

Unfortunately, it is commonly recognized that the fast progress in semiconductor technologies has been not followed at the same pace by magnetics and capacitors technology. The major effort of magnetics manufacturers has been focused on the optimization of the existing materials in certain frequency ranges and expanding the portfolio of core shapes and sizes, in particular low-profile planar cores, which is surely helpful for the designers. However, more innovative solutions would be needed in order to further minimize the copper losses due to skin and proximity effects, still considered as the actual major trouble in high-frequency applications. Finally, some progresses have been made in the field of low voltage capacitors technology, but no significant changes have been introduced in the high-voltage electrolytic capacitors used as energy-storage (bulk) capacitors: in fact, despite the introduction of some miniaturized series, their typical capacitance/volume ratio is still relatively low.

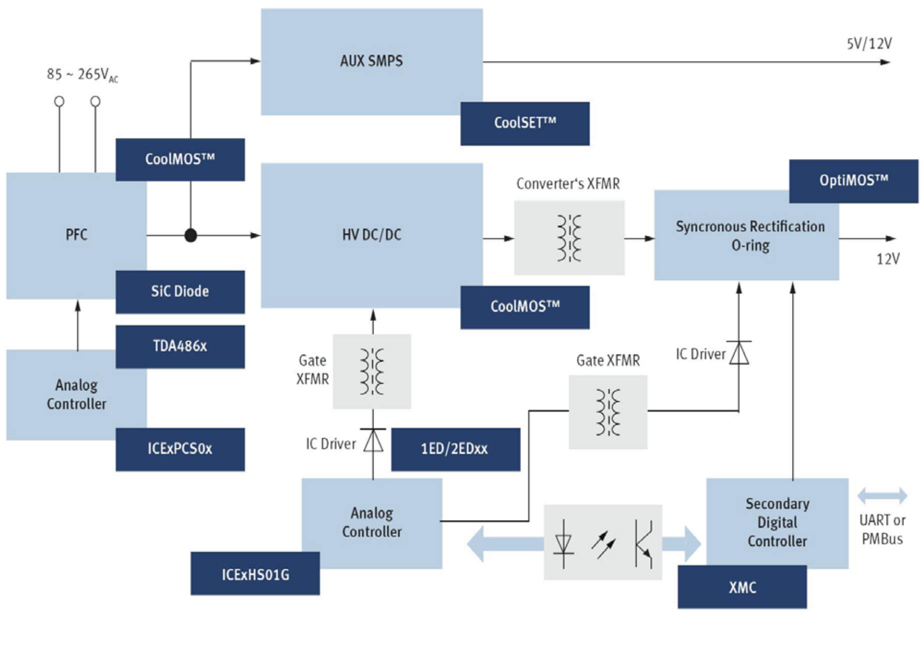

Fig. 5: The typical internal structure of a Server AC/DC SMPS, showing Infineon's solutions.