Evolving high-voltage power delivery through the power process chain

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Do you know how much current your plugged in cellphone adapter leaks when you're not charging your mobile device? Or have you considered that the power supply in your 4K TV leaks when you are not even watching TV? Probably not, if you're like most people, though you may have experienced vague guilt about leaving adapters plugged in when not charging gadgets.

The truth is that a plugged in cellphone adapter or TV that is turned off only leaks a tiny bit of so-called "vampire" current. But collectively, the tiny trickles from *all* cellphone power adapters and internal TV power supplies add up to a river of wasted power. To put some perspective on the issue, we calculated that if adapters for all cellphones sold in a single year could be changed to leak zero current, the savings would power a city of 200,000 people. Think of the power plants that could be saved from year after year of cellphone adapters operating with zero power leakage.

The same reckoning applies for your tablet and notebook adapters, and even more so with ubiquitous electronic appliances such as sound systems and DVD players that are always plugged in – and can't easily be unplugged when you are feeling the tug of guilt to save energy. And the same type of leaks occur in large commercial systems, where power demands – and losses – are much greater.

Now let's talk about how hot your laptop AC adapter gets when you watch a movie, or the loud noise from your desktop PC power supply's fan when you're hard at work. Both of these examples occur due to the power supply's inability to do the job at 100% efficiency. The wasted energy generated makes these devices hot, requiring fans or heatsinks to keep cool.

Traditionally, electronic systems large and small have lost power through their power supplies when they are actively delivering power and when they are idle. The job of a power supply is to convert electric power from energy sources such as high-voltage utility power or unregulated battery voltages to well-regulated low voltages for use by electronic circuits. Power conversion, however, has always carried the penalty of power loss, when the application is not in use but still connected to the power source, and when it is in use at full steam.

Fortunately, new developments in power supplies are having a big effect in saving electricity in applications ranging from day-to-day gadgets like cellphones and digital televisions, to electric vehicles (EVs) and hybrid-electric vehicles (HEVs), industrial-scale equipment such as robots and large installations such as telecom base stations and data centers.

Power supplies are accomplishing so much because they are achieving higher power density. That is, they fit into tighter spaces, and they do so by losing less power and creating less heat and signal noise. Changes in power supply architectures and field-effect transistor (FET) technologies, complemented by ecosystem developments such as better batteries, are quickly making available, and at the same time, increasing the demand for higher power density and efficiency.

As a leading developer of high-voltage power semiconductor solutions, Texas Instruments (TI) is innovating to enable greater power density so system developers can implement smaller, more efficient boards for quick verification and manufacturing. High-voltage innovations benefit virtually all types of electronic applications supplied by high-voltage line power or storage batteries — not to mention the bigger advantages that come with reduced electricity consumption.

High-voltage power supply design requirements

Electronic systems run on power supplied from sources with higher voltages than the circuitry uses. The supply may be alternating current (AC) from the power grid at 110 or 220 volts (V), or it may be direct current (DC) from a battery with a high storage voltage. Car batteries, for instance, traditionally operated at 12 V, but as advanced driver assistance systems continue to pull power, and specific functions such as pumps are electrified, instead of running off the engine, 48-V batteries are entering the landscape to reduce current draw.

For use in electronic systems, these voltages must be converted into much lower voltages, usually ranging from 1 to 5 V. Because lower voltages lose more power in transmission, the challenge is to bring a higher voltage close to the end application, onto the circuit board if possible, before converting it. The savings in space and power bring savings in costs, but also raise the stakes for safety, both for the equipment and for people who may be around it.

To bring high-voltage close to the end application, the key technical problem is how to increase power density. Electricity for data centers was traditionally processed multiple times in a series of stages before it reached the components, such as microprocessors and storage devices that composed the end load. Hence, power supplies have always occupied significant volume of space, with each conversion stage losing power, and the power supply overall producing considerable heat that demands space for cooling.

The solution is to use switched-mode power supplies (SMPSs), which are small, convert power efficiently, and create very little heat in a confined space. However, SMPS designs were traditionally complicated, with a number of component impedances needing balancing and an inherent high-frequency stage that can feed an unwanted signal back onto the line where it may interfere with other equipment. The high frequencies used allow component size reductions but also require different materials from silicon (Si) – gallium-nitride (GaN) or silicon-carbide (SiC) – as well as extremely fast controllers. These are all factors that bring new design challenges most circuit designers view as headaches, since their expertise lies in some other area of the system.

The shrinking switched-mode power supply

To resolve these issues with power supply designs, system developers turn to advanced solutions for high-voltage power, which are quickly becoming easier to design with, as well as offering improved features and greater efficiency. Advances in circuit design and wide bandgap materials such as GaN enable SMPSs to operate at higher frequencies, allowing smaller components and lower power loss. Isolation and electromagnetic interference (EMI) techniques are also improved, making high-voltage technology safer and minimizing noise. As a result, power designs are faster to implement, verify and test for compliance with industry standards.

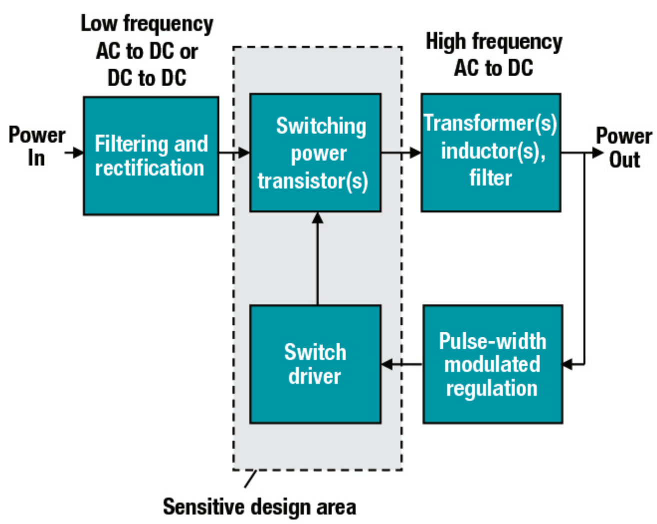

Figure 1. *Generic functions of a switched-mode power supply.*

Figure 1 shows the main functional blocks of a SMPS. The input energy source, which could be either AC or DC, is first filtered to a "clean" DC and applied to an high-voltage power transistor. For AC sources, additional rectification and/or boosting steps may be involved to generate the "clean" DC. The high-voltage power transistor (the switch) turns the DC signal on and off at a high frequency, creating a pulsed AC output, which is fed into a voltage translation component, the transformer. A few additional steps ultimately result in the lower-voltage DC level that is appropriate for operating the main system circuitry. This DC level must be well-regulated when there are any changes in the load or input disturbances. To this end, a feedback signal of the output is fed to a power management controller, which employs techniques such as pulse-width modulation (PWM) to produce a high-frequency pulsed signal that helps achieve regulation when applied to the transistor. A driver transmits the pulsed signal to the high-voltage switch, turning it on and off quickly.

As the diagram indicates, the high-voltage switch and its driver form a part of the SMPS that is extremely sensitive and can be disrupted easily in the case of poor design and/or external interference. The higher the frequency, the greater the sensitivity in this area, which creates a challenge for power supply designers and requires the greatest care in design. Another area of note is the transformer in the upper right block, which not only "steps down" voltages but also isolates the system circuitry from transient disturbances in the external supply. Although essential to the circuit for these reasons, the transformer traditionally carries with it a design penalty – traditionally, it is always an extremely bulky item. The filters in the upper left block are also important in protecting external circuitry from high frequencies feeding back from the high-voltage switch.

These areas of the SMPS are much improved over recent years, due to a broad range of semiconductor and integrated circuit (IC) developments. Wide bandgap semiconductor technology, such as SiC and GaN power transistors, is a key enabler for running SMPSs at increasingly higher switching frequencies while reducing the power loss, which is an absolute necessity for shrinking their size. Switch drivers for GaN transistors integrate passive components ready-tuned to simplify design difficulties, and modules integrating both GaN switches and switch drivers provide the ultimate in design simplification. High-frequency switching reduces the size of external power transformers, and new technology may ultimately enable integration of transformers into the module package. New power conversion concepts with readily available controller solutions enable great reductions in power losses during the switching events in SMPSs, while other innovations provide minimal noise and EMI.

A high-voltage power supply can now fit onto an application board, whereas in the past it may have needed its own board or box. Advanced SMPS design and thermal packaging create far less heat, along with less need for special cooling provisions. With the SMPS shrinking and freeing up valuable real estate, developers seize the extra board space for added functionality. For instance, uninterrupted power supplies (UPSs) are indispensable sources of battery backup power in base stations, data centers and other network-critical installations. At the minimum, a UPS provides sufficient operating time for the system to perform a routine shutdown, and it may provide an extensive charge for prolonged operation. But since centralized UPSs require a lot of space and capital expenditure, some system developers are beginning to look at distributing UPS functionality to individual boards, where it can fit along with the high-voltage SMPS as a complete power unit for the application.

Innovations driving high-voltage power

Power supply technical requirements and application trends continue to drive high-voltage power development at TI. The company possesses extensive power design and IC manufacturing expertise, together with a long history of offering industry-leading power solutions encompassing the complete package of power transistors, integrated circuits and intellectual property (IP) for control. The sum of TI's expertise and history put the company in a strong position for developing advanced high-voltage products that save space, use power efficiently and optimize system costs. TI's portfolio also includes technologies for inverters, which operate similarly to power supplies, except that they supply AC output from DC sources, such as batteries and solar panels.

TI's GaN technology enables leading-edge high-voltage switching solutions and precision controllers. For ease of development, complete GaN solutions integrate the switch and driver in a single pre-optimized package, backed by reference designs. In addition, TI developed a wide range of Si power FETs, along with gate drivers, controllers and other components. As SiC technology further develops for use in power switches at even higher voltages, TI intends to support developers with SiC switch drivers and controllers.

Two techniques making high-voltage systems even more power-efficient are power factor correction (PFC) and soft switching. PFC is a technique that allows power supplies to draw only the required

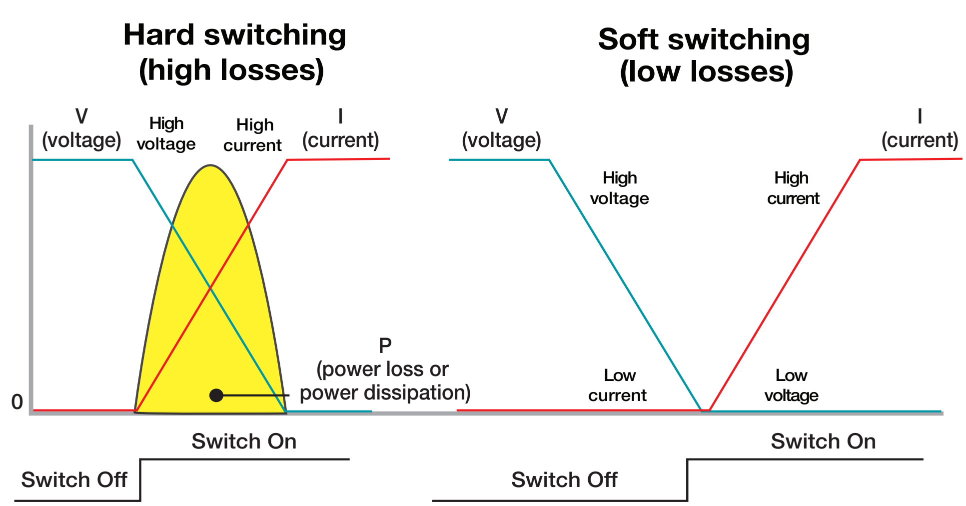

Figure 2*. Soft-switching power savings.*

amount of power from the energy source and avoid excess consumption. By ensuring that the power drawn is predominantly active power and very little reactive power, PFC ensures that all energy derived from the source is usefully transmitted to the system circuitry for performing useful work. Regulatory standards in place in many regions of the world mandate that the equipment sold in that region be power factor corrected. For compliance with these standards, TI has pioneered the development of many varieties of active PFC controllers specifically optimized for different applications and covering a broad power spectrum. Notable among TI's PFC controllers are the interleave multiphase offerings that have enabled smaller inductors and filter components resulting in slimmer televisions, lighter air-conditioners, more compact LED lighting fixtures and denser data-center power supplies.

When a power switch is turned on or off (hard switching), the system inevitably suffers some power loss. As **Figure 2** shows, current and voltage do not change simultaneously, creating a time period in which the power drawn from the source is greater than the useful power available. At the high frequencies of an SMPS, the period in which this occurs is extremely brief, but since it occurs often, the loss can be significant. Soft switching, also known as zero-voltage switching (ZVS), is a technique used to time the voltage on or off so it corresponds with the zero point of the current, thus creating and wasting less power. The circuitry employed to support soft switching can employ either phase-shifted full bridge (PSFB) control or a resonant LLC circuit. TI, noted for its in-depth expertise in soft switching, has developed several power management controller devices and designs that support both of these techniques.

Power design is notably a difficult area of expertise to master, and few board designers make a specialty of it. Recognizing the inherent difficulties of power supply design, TI is focused on innovating to deliver complete, optimized solutions, then supporting its customers with evaluation modules (EVMs), reference designs, software tools, training and extensive documentation.

Power savings for a greener world

Improved power supplies by themselves may or may not bring enough savings in electricity to save us from building new power generation plants, but they are an important factor, along with new developments in energy generation, battery storage and energy-optimizing applications. All these advances are enabled by innovative IC technology that makes equipment more power-efficient while extending its functionality.

High-voltage developments, such as new high-frequency wide-bandgap materials, innovative SMPS design, improved isolation techniques, and thermal packaging advances are bringing about major reductions in electricity losses in transmission and conversion. By developing innovative IC solutions that both feature and enable these advances, TI brings space, heat, cost and power savings to a wide variety of applications that are powered by high-voltage line and battery voltage. Design by design, the future of electronics is becoming greener, and TI's commitment to innovation plays an important role in bringing about this change.

For more information:

- Explore TI's high-voltage GaN and Power Factor Correction offerings
- Read the white paper: Redefining power management through high voltage innovation
- Read the blog: Let's GaN reliably
- Explore TI's complete spectrum of power design training and support resources

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