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Back to Basics: Power Management Impacts All Electronic Systems

Power management plays a major role in virtually every piece of electronic equipment. An effective power-management subsystem can affect the reliability, performance, and time to market of associated electronic equipment.

A power-management subsystem controls, regulates, and distributes power in an electronic system. The specific type of power management depends on the power input, which includes:

- **Battery input** (portable equipment) – Because of the size and weight restrictions of portable equipment, this power-management subsystem is usually integrated with the rest of the electronic system. Generally, battery power-management subsystems employ power conversion ICs that minimize power consumption. Battery types can also affect these designs. Some of these systems also include an ac adapter that plugs into a wall outlet and provides a dc output voltage. Usually, the ac adapter can be used to power the unit and also to recharge its battery.
- **AC input** – This subsystem employs a power supply that accepts a utility power ac input, rectifies and filters it, then applies the dc voltage to a regulator circuit that maintains a constant dc output voltage. There are a wide variety of ac-dc supplies; some have an output voltage of less than 1 V, whereas others produce thousands of volts. This power-management subsystem usually employs a switch-mode power supply, although some linear supplies are available.
- **DC input** – This type uses a power supply that accepts a dc voltage input—typically 5, 12, 24, or 48 V—and produces a dc output voltage. At the low end, some supplies of this type can produce less than1 Vdc, whereas other dc-dc supplies can produce up to thousands of volts. This power-management subsystem usually employs a switch-mode power supply.
- **Power over Ethernet** (PoE) – Power over Ethernet enables data terminal equipment (DTE) to receive power over the same cabling used for data in an Ethernet network. This standard specifies the protocol for delivery of a nominal 48 Vdc over unshielded twisted-pair cables (such as CAT-5), eliminating the need for a local power source for the remote device. IEEE 802.3af and IEEE 802.3at present the requirements for providing and receiving power over existing Ethernet cabling. It involves power sourcing equipment (PSE) that provides the power on the cable for the powered device (PD).
- **Ultra-low-voltage input** (energy harvesting) – Energy harvesting can provide the power to charge, supplement, or replace batteries. In operation, the energy harvester captures minute amounts of energy, accumulates it, stores it, and then maintains the stored energy as a power source. A key component in energy harvesting is a power converter that can operate with ultra-low-voltage inputs. These ultra-low-voltage inputs include solar power, thermal energy, wind energy, or kinetic energy.

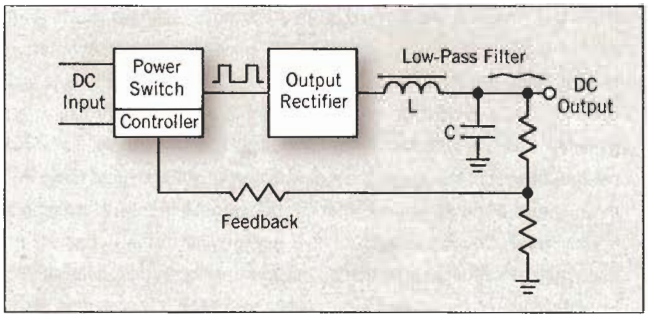

Fig. 1. Switch-mode power supplies convert dc voltage to a switched voltage, and then rectify and filter the switched voltage to obtain a dc output voltage.

LINEAR VS. SWITCH-MODE

All the power-management subsystems listed above use power sources that are either linear, switch-mode, or a combination of both configurations. Linear power supplies always conduct current, whereas switch-mode supplies switch output power on and off at a high frequency. Differences between the two include size and weight, power-handling capability, EMI, and regulation.

THE LDO REGULATOR

The most widely-used linear regulator is the low-dropout (LDO) voltage regulator, which is usually a single IC with external resistors and capacitors. Its main components are a pass transistor, error amplifier, and voltage reference.

Low dropout refers to the difference between the input and output voltages that allows the IC to regulate output voltage. That is, the LDO regulates the output voltage until its input and output approach each other at the dropout voltage. Ideally, the dropout voltage should be as low as possible to minimize power dissipation and maximize efficiency.

The major advantage of an LDO IC is its relatively quiet operation, since it does not involve switching. LDOs with an internal pass transistor can provide outputs in the 50-mA to 1-A range. The LDO's low dropout voltage, low quiescent current, and low EMI make it a good fit for portable and wireless applications. However, its efficiency is in the 50% to 70% range.

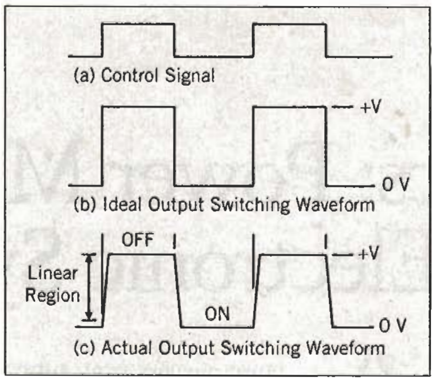

Fig. 2. The power switch has three operating modes: off, on, and the transition through the linear region.

LDOs provide either an adjustable or fixed-output voltage. Some LDO families provide a full range of outputs in 100- or 50-mV steps; for example, 2 to 6 V in 100-mV steps. This wide range of output voltages is made possible by laser trimming the ICs during their manufacture.

The LDO's internal bandgap voltage reference can be a source of noise, usually specified as microvolts rms over a specific bandwidth, such as 30 µVrms from 1 to 100 kHz. This low-level noise is much less of a problem than the switching transients and harmonics from a switch-mode converter. An external capacitor from its voltage-reference bypass pin to ground minimizes this noise.

WHAT ARE A POWER SUPPLY'S CHARACTERISTICS?

Drift: The variation in dc output voltage as a function of time at constant line voltage, load, and ambient temperature.

Efficiency: Ratio of output-to-input power (in percent), measured at a given load current with nominal line conditions (Pout/Pin).

Hold-Up Time: Time during which a power supply's output voltage remains within specifications following the loss of input power.

Inrush Current: Peak instantaneous input current drawn by a power supply at turn-on.

International Standards: Specify a power supply's safety requirements and allowable EMI levels.

Isolation: Electrical separation between the input and output of a power supply, measured in volts. A non-isolated supply has a dc path between the input and output of supply, whereas an isolated power supply uses a transformer to eliminate the dc path between input and output.

Line Regulation: Change in value of dc output voltage resulting from a change in ac input voltage, specified as the change in ±mV or ±%.

Load Regulation: Change in value of dc output voltage resulting from a change in load from open circuit to maximum rated output current, specified as the change in ±mV or ±%.

Noise: A power supply's output may consist of short bursts of high-frequency pulses caused by charging and discharging parasitic capacitances. This noise contributes to the supply's total instantaneous output voltage as well as being fed to the supply's input, and can be coupled into nearby circuits and other equipment operating on the same ac line.

Peak Current: The maximum current that a power supply can provide over brief periods.

Peak Power: The absolute maximum output power that a power supply can produce without damage. It is typically well beyond the continuous reliable output-power capability and should only be used infrequently.

Periodic and Random Deviation (PARD): Unwanted periodic (ripple) or aperiodic (noise) deviation of the power-supply output voltage from its nominal value. PARD is expressed in mV peak-to-peak or rms, at a specified bandwidth.

Tracking: When using multiple output power supplies, whereby one or more outputs follow another with changes in line, load, and temperature, so that each maintains the same proportional output voltage, within specified tracking tolerance, with respect to a common value.

Ripple: Rectifying and filtering a switching power supply's output results in an ac component (ripple) that rides on its dc output. Ripple frequency is some integral multiple of the converter's switching frequency, which depends on the converter topology. Ripple is relatively unaffected by load current, but can be decreased by external capacitor filtering.

Dynamic Response: A power supply may be employed in a system where there is a requirement to provide fast dynamic response, such as the load of high-speed microprocessors with power-management functions. In this case, the microprocessor may be in a standby state and upon command it must start up or turn off immediately, which imposes high dynamic currents with fast ramp rates on the power supply. To accommodate the microprocessor, the supply's output voltage must ramp up or down within a specified time interval, but without excessive overshoot.

Power-Supply Sequencing: Sequential turn-on and turn-off of power supplies may be required in systems with multiple operating voltages. That is, voltages must be applied in a specific sequence otherwise the system can be damaged. For example, after applying the first voltage and before

SWITCH-MODE POWER SUPPLIES

There are also some OEM linear supplies that handle several amperes of current. They are usually bulky benchtop or rack-mounted supplies. Switching technology allows a switch-mode power supply package that is less than half the size and weight of an OEM linear supply.

In most applications, older, high-current linear supplies have been superseded by switch-mode supplies. As seen in *Fig. 1*, the switched output voltage is rectified and low-pass-filtered to obtain a dc output voltage.

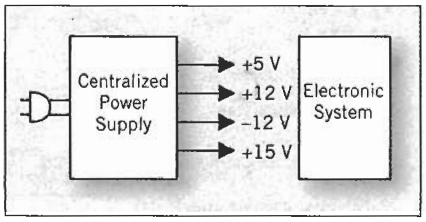

Fig. 3. A power supply with multiple outputs. On some power supplies, output-voltage regulation can be affected by loading on the different output voltages.

The inductor-capacitor low-pass output filter converts the switched voltage to a dc voltage. The filter is not perfect, so there is always some residual output noise, called ripple. The amount of ripple depends on the effectiveness of the low-pass filter at the switching frequency.

Power-supply switching frequencies are usually between 100 kHz to more than 1MHz, but some are even higher. Higher switching frequencies allow the use of lower-value inductors and capacitors in the low-pass filter. However, higher frequencies can also increase power semiconductor losses, reducing power-supply efficiency.

A portion of the dc output voltage is fed back to the power switch controller circuit. If the dc output tends to decrease, the controller causes the power switch to vary its on and off times to maintain a constant dc output voltage. In a similar manner, if the dc output voltage tends to increase, the feedback keeps the output voltage constant.

In terms of power dissipation, the power switch is a key component in the power supply. The switch is usually a power MOSFET that operates in two states: ON and OFF (*Fig. 2*).

In the off-state the power switch draws very little current and dissipates very little power. In the on-state the power switch draws the maximum amount of current, but its on-resistance is low, so in most cases its power dissipation is minimal.

In the transition from the on-state to the off-state—and off-state to on-state—the power switch goes through its linear region so it can consume a moderate amount of power. The total loss for the power switch is, therefore, the sum of the on- and off-state plus the transition through its linear regions. The actual losses depend on the power switch and its operating characteristics. A typical switch-mode power supply is 80% to more than 90% efficient.

The switching power supply can produce switching EMI, whereas the linear supply does not. Therefore, switch-mode power-supply manufacturers must suppress both the conducted and radiated EMI to ensure proper system performance.

it reaches a specific value, a second voltage can be ramped up, and so on. Sequencing works in reverse when power is removed, although speed is not usually as much of a problem as turn-on.

Remote On/Off: This is preferred over switches to turn power supplies on and off. Power-supply data-sheet specifications usually detail the dc parameters for remote on/off, listing the on and off logic levels required.

Remote Sense: A typical power supply monitors its output voltage and feeds a portion of it back to the supply to provide voltage regulation. In this way, if the output tends to rise or fall, the feedback regulates the supply's output voltage. However, to maintain a constant output at the load, the power supply should actually monitor the voltage at the load. But, connections from a power supply's output to its load have resistance and current flowing through them, producing a voltage drop that creates a voltage difference between the supply's output and the actual load. For the optimal regulation, the voltage fed back to the power supply should be the actual load voltage. The supply's two (plus and minus) remote-sense connections monitor the actual load voltage, a portion of which is then fed back to the supply with very little voltage drop, because the current through the two remote sense connections is very low. As a consequence, the voltage applied to the load is regulated.

Output Voltage Trim: Most power supplies have the ability to trim the output voltage, whose adjustment range does not need to be large, usually about ±10%. One common usage is to compensate for the dc distribution voltage drop within the system. Trimming can either be upward or downward from the nominal setting using an external resistor or potentiometer.

MAKE OR BUY YOUR POWER SUPPLY?

The ac- and dc-input power-management subsystems employ a power supply that can either be bought or made by the equipment manufacturer. Therefore, those equipment manufacturers must decide whether to make or buy the power supply for a particular piece of equipment.

The decision to either make or buy a power supply for a particular design can have a major impact on the cost and time to market of the end product. The equipment manufacturer has several challenges to consider before making a power supply in-house:

- Does it want the power-supply design to be proprietary?
- Can it make the power supply cheaper than purchasing it?
- Is time to market a consideration?
- Are the necessary people and resources available to make the power supplies, including design and production facilities?
- Does the design and production include the time, costs, and fees associated with getting safety agency certifications specific to power supplies?

Unless the equipment manufacturer can meet the above challenges, it most likely will buy the power supplies and then implement the power-management subsystem. These supplies may provide a single output or multiple output voltages, as shown in *Fig. 3*.

LOOKING AT THE SPECS

Next, the equipment manufacturer must find a power supply whose characteristics match the system requirements. A tabular presentation, shown in *Fig. 4*, is a good way to present the power supply's requirements on a single page. This information will be presented to the power supply OEM.

The minimum and maximum values show the range of output current and output power required. The average values provide a look at the average output current and output power for the required power supply. If there are available power supplies that suit the application, you would either require a custom-designed unit or pick a different type of power-supply function that can meet your requirements.

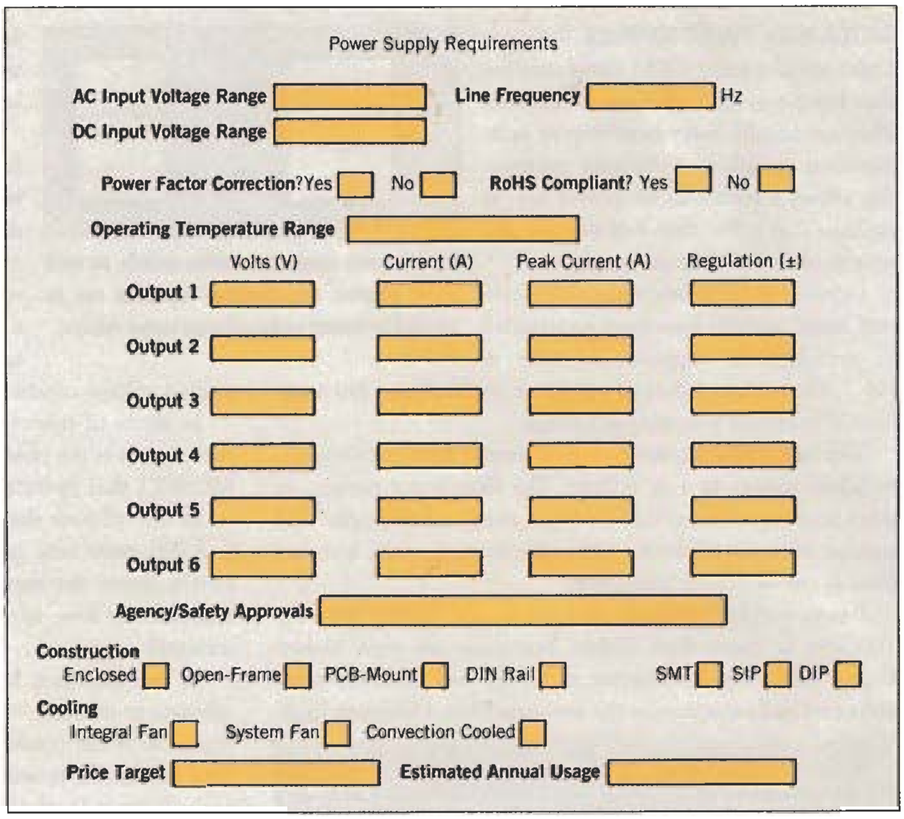

Fig. 4. Using a tabular presentation aids in the selection of a power supply that meets the application requirements.

It is a good idea to select a power supply that provides a safety margin for the future. Too often, electronic systems expand from their initial requirements and need additional current, power, and sometimes even a new output voltage. A new output voltage usually requires an additional power supply or one with an adjustable output voltage.

IS THIS POWER SUPPLY THE RIGHT FIT?

You have to make sure the power supply will fit in the space provided for it. Therefore, make sure the package type you want will fit in the allocated space.

In addition, make sure there is enough room adjacent to the power supply to allow it to be coolec if you are using natural convection cooling. Some supplies have built-in fans; if not, use external forced air cooling and make sure that there is sufficient air movement around the supply.

Many rack-mounted power systems are specified as being 1U, 2U, 3U, etc. The term 1U defines one rack unit of height that, or 1.75-in. of rack height. A 2U rack-mount height would be 2 x 1.75-in., or 3.5-inches high, and so on.

The 1U, 2U, 3U heights are maximum dimensions. Individual rack-mounted power supplies must be a bit shorter than the equipment's overall height to allow for the top and

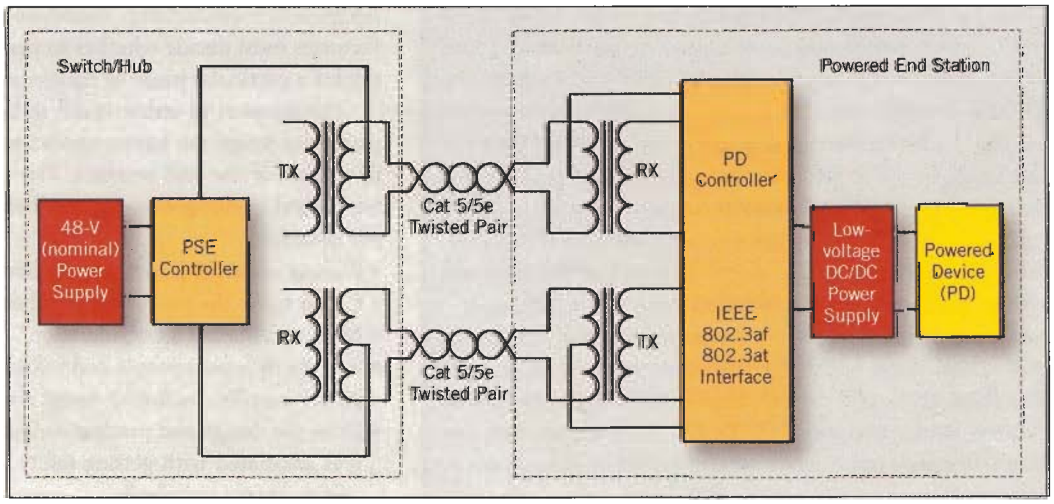

Fig. 5. Power management for PoE systems involves the distribution of power over existing data lines using CAT5 cable.

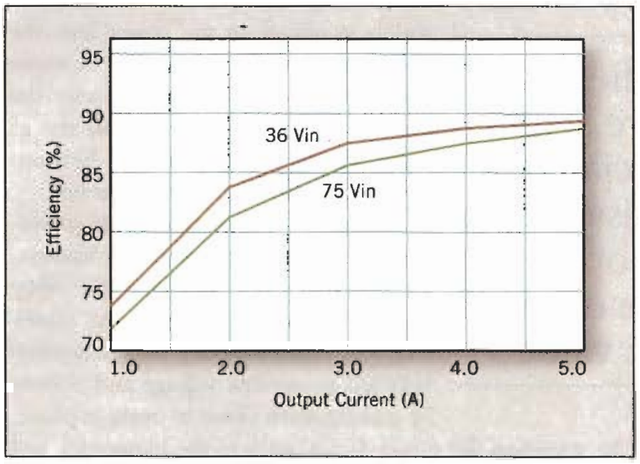

Fig. 6. This plot shows that efficiency varies with the power supply's applied voltage as well as the output load current.

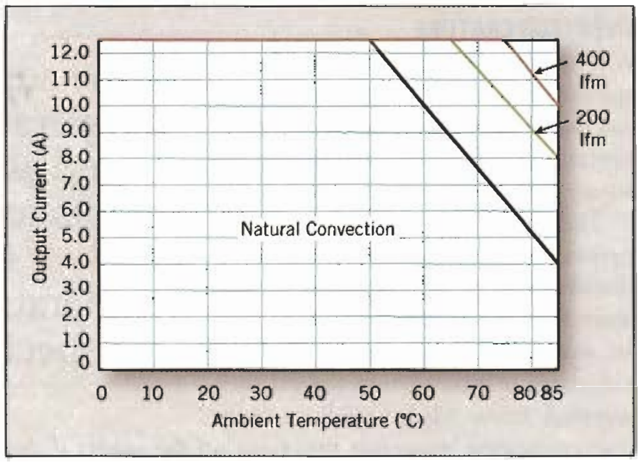

Fig. 7. Derating curve shows how much current the supply can safely handle if it is operating with natural convection, 200 LFM or 400 LFM (linear feet per minute).

bottom covers. So, a 1U high enclosure-mountable power supply needs to be shorter than 1.75 inches; a 2U enclosure-mountable supply needs to be shorter than 3.5 inches, and so forth.

ETHERNET POWER

PoE power-management subsystems are unique because they use existing data cables to distribute power (*Fig. 5*). Typical powered device controllers provide an isolated, low-voltage power source to the remote device. These controllers incorporate all the necessary interface requirements for PoE, which includes detection and classification current signatures required by the PSE.

Initially, PoE was based on the IEEE 802.3af specification that allowed up to 12.95 W for the powered device. IEEE 802.3at changed the powering requirements by allowing higher voltage and current. This requires compatible ICs and also OEM power supplies that meet the "at" spec. Higher power requirements means power supplies will produce more heat, so cooling them properly will become important.

Higher currents may produce more EMI, so PCB layout may become a greater design consideration. In addition, the voltage drop and operating temperature of network cables will increase because of higher currents, so CAT5 cable with four twisted pairs will be required to replace the existing CAT3 cable with two twisted pairs.

Energy-harvesting power-management subsystems are unique because they generally operate with very low voltage and current. In addition, they store accumulated energy and then supply it to their load. Therefore, there is a time delay between first accepting the voltage input and then providing power to the load.

EFFICIENCY AND RELIABILITY

One of the important characteristics in the selection of an OEM power supply is efficiency, which reflects the thermal and electrical losses in the system and impacts the amount of cooling required. Also, it determines the physical package sizes of both the power supply and the final system.

Plus, it will determine the system component operating temperatures and the resultant system reliability. These factors contribute to the determination of the total system cost, both hardware and field support. Power-supply data sheets usually include a plot of efficiency vs. output current, as shown in *Fig. 6*.

Efficiency, reliability, and operating temperature are all related. Power-supply data sheets usually include specific airflow and heat sink requirements.

For example, the ambient operating temperature affects the output load current that the power supply can handle reliably. The derating curves for the power supply that are shown in *Fig. 7* indicate its reliable operating current vs. temperature.

PROTECTING THE SUPPLY

There are several other characteristics to consider when selecting an OEM power supply. Among these are the methods used to protect the supply, which are listed below.

OVERCURRENT

A failure mode caused by output load current that is greater than specified. It is limited by the maximum current capability of the power supply and controlled by internal protection circuits. It can also damage the power supply in some cases.

Short circuits between the supply output and ground can create currents within the system that are limited only by the supply's maximum current capability and internal impedance. This high current can cause overheating and damage the power supply, the load, and interconnects (PCB traces, cables).

Therefore, most power supplies should have current limiting (overcurrent protection) that activates if the output current exceeds a specified maximum.

OVERTEMPERATURE

A temperature that is above the supply's specified value must be prevented or it can cause power-supply failure. Excessive operating temperature can damage the supply and circuits connected to it.

Therefore, many supplies use a temperature sensor and associated circuits to disable the supply if its operating temperature exceeds a specific value. In particular, semiconductors used in the supply are vulnerable to temperatures beyond their specified limits. Many supplies include overtemperature protection that turns off the supply if the temperature exceeds the specified limit.

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OVERVOLTAGE

This failure mode occurs if the output voltage goes above the specified dc value, which can impose excessive dc voltage that damages the load circuits. Typically, electronic system loads can withstand up to 20% overvoltage without incurring any permanent damage.

If this is a consideration, select a supply that minimizes this risk. Many supplies include overvoltage protection that turns the supply off if the output voltage exceeds a specified amount. Another approach is a crowbar Zener diode that conducts enough current at the overvoltage threshold to activate the power-supply's current limiting and it then shuts down.

SOFT START

Inrush current limitation may be needed when power is first applied or when new boards are hot-plugged. Typically, this is achieved by a soft-start circuit that slows the initial rise of current and then allows normal operation.

If left untreated, inrush current can generate a high peak-charging current that impacts the output voltage. If this is an important consideration, select a supply with this feature.

UNDERVOLTAGE LOCKOUT

Known as UVLO, it turns the supply on when it reaches a high enough input voltage and turns off the supply if the input voltage falls below a certain value. This feature is used for supplies operating from utility power as well as battery power. When operated from battery-based power, UVLO disables the supply (as well as the system) if the battery discharges so much that it drops the supply's input voltage too low to permit reliable operation.

POWER FACTOR CORRECTION (PFC)

Applicable only to ac-dc supplies, the relationship between the ac power-line voltage and current is called power factor. For a purely resistive load on the power line, voltage and current are in phase and the power factor is 1.0. However, when an ac-dc supply is placed on the power line, the voltage-current phase difference increases and power factor decreases because the process of rectifying and filtering the ac input upsets the relationship between voltage and current on the power line.

When this occurs it reduces power-supply efficiency and generates harmonics that can cause problems for other systems connected to the same power line. PFC circuits modify the relationship between power-line voltage and current by making them closer to being in phase. This improves the power factor, reduces the harmonics, and improves the power supply's efficiency. If power-line harmonics are important, choose a supply with PFC that has a power factor of 0.9 and higher.

ELECTROMAGNETIC COMPATIBILITY (EMC)

Manufactured power supplies must ensure EMC by minimizing EMI. In switch-mode power supplies, a dc voltage is converted to a chopped or a pulsed waveform that causes the supply to generate narrow-band noise (EMI) at the fundamental of the switching frequency and its associated harmonics. To contain the noise, manufacturers must minimize radiated or conducted emissions.

OEM power-supply manufacturers minimize EMI radiation by enclosing the supply in a metal box or spray-coating the case. Manufacturers also need to pay attention to the internal layout of the supply and the wiring that goes in and out of the supply.

Most of the conducted interference on the power line is the result of the main switching transistor or output rectifiers. With PFC and proper transformer design, connection of the heat sink, and filter design, the power-supply manufacturer can reduce conducted interference so that the supply can achieve EMI regulatory agency approvals without incurring excessive filter cost.

REGULATORY STANDARDS

Compliance with national or international standards is usually required by individual nations. Different nations can require compliance with different standards that attempt to standardize a product's EMC. Among the regulatory standards are:

- **Electromagnetic disturbance characteristics** – Limits and methods of measurement
- EMC – Requirements for household appliances
- **Radio disturbance characteristics** – Limits and methods of measurement for the protection of receivers except those installed in the vehicle/boat/device itself or in adjacent vehicles/boats/devices.
- **Specification for radio disturbance and immunity measurement apparatus and methods** ⏻