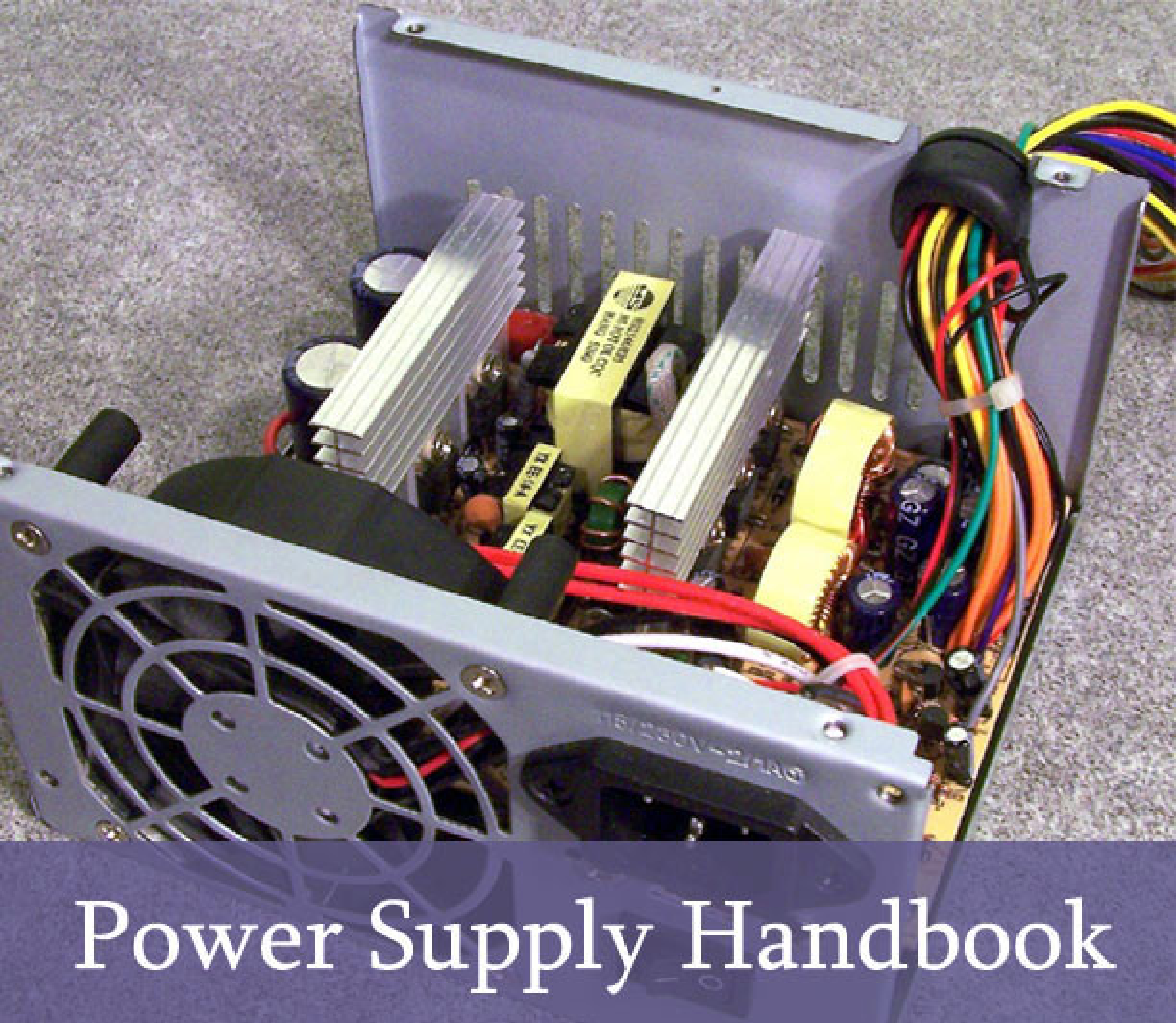

Power Supply Handbook

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Chapter-1

Power Supply

A **power supply** is a device that supplies electrical energy to one or more electric loads. The term is most commonly applied to devices that convert one form of electrical energy to another, though it may also refer to devices that convert another form of energy (e.g., mechanical, chemical, solar) to electrical energy. A regulated power supply is one that controls the output voltage or current to a specific value; the controlled value is held nearly constant despite variations in either load current or the voltage supplied by the power supply's energy source.

Every power supply must obtain the energy it supplies to its load, as well as any energy it consumes while performing that task, from an energy source. Depending on its design, a power supply may obtain energy from:

- Electrical energy transmission systems. Common examples of this include power supplies that convert AC line voltage to DC voltage.
- Energy storage devices such as batteries and fuel cells.
- Electromechanical systems such as generators and alternators.
- Solar power.

A power supply may be implemented as a discrete, stand-alone device or as an integral device that is hardwired to its load. In the latter case, for example, low voltage DC power supplies are commonly integrated with their loads in devices such as computers and household electronics.

Constraints that commonly affect power supplies include:

- The amount of voltage and current they can supply.
- How long they can supply energy without needing some kind of refueling or recharging (applies to power supplies that employ portable energy sources).
- How stable their output voltage or current is under varying load conditions.
- Whether they provide continuous or pulsed energy.

Power supplies types

Power supplies for electronic devices can be broadly divided into linear and switching power supplies. The linear supply is usually a relatively simple design, but it becomes increasingly bulky and heavy for high-current equipment due to the need for large mains-frequency transformers and heat-sinked electronic regulation circuitry. Linear voltage regulators produce regulated output voltage by means of an active voltage divider that consumes energy, thus making efficiency low. A switched-mode supply of the same rating as a linear supply will be smaller, is usually more efficient, but will be more complex.

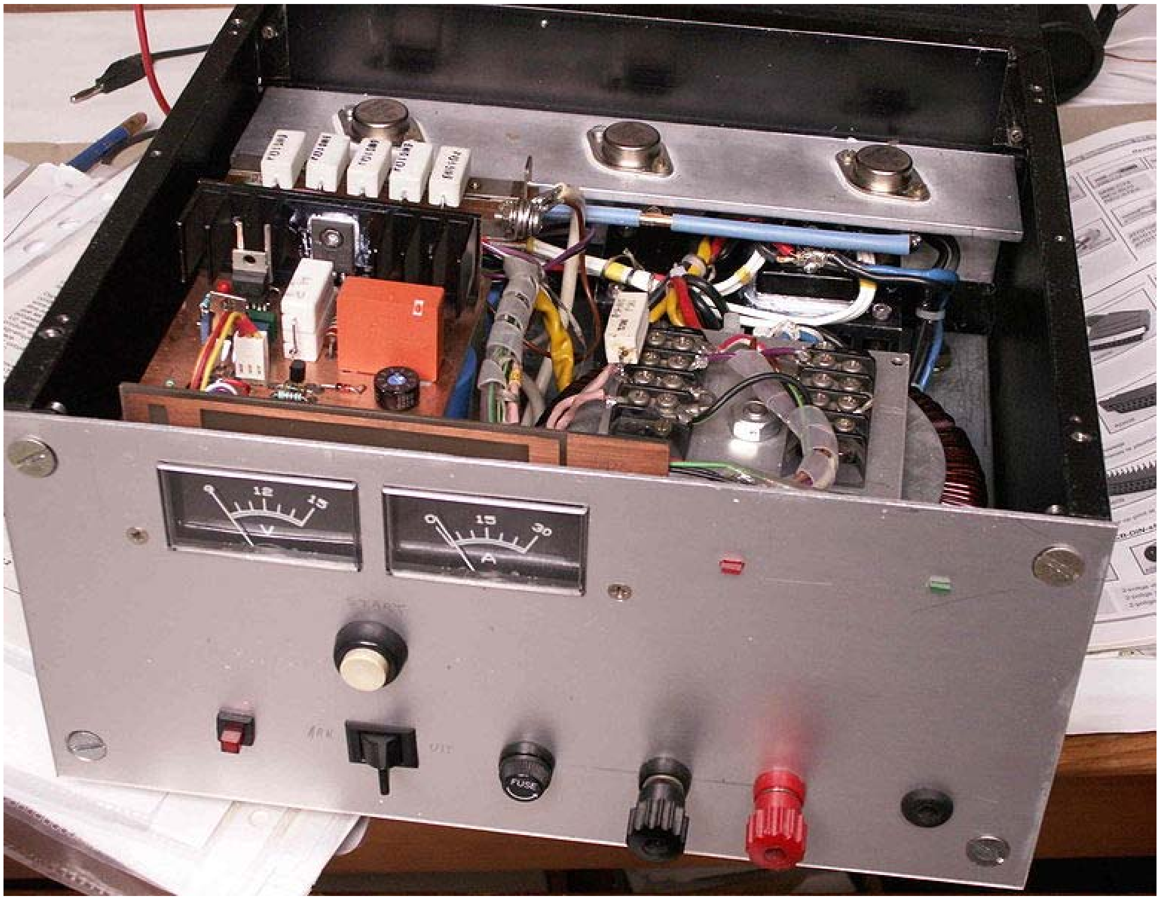
Battery

A battery is an alternative to a line-operated power supply; it is independent of the availability of mains electricity, suitable for portable equipment and use in locations without mains power. A battery consists of several electrochemical cells connected in series to provide the voltage desired. Batteries may be primary (able to supply current when constructed, discarded when drained) or secondary (rechargeable; can be charged, used, and recharged many times)

The primary cell first used was the carbon-zinc dry cell. It had a voltage of 1.5 volts; later battery types have been manufactured, when possible, to give the same voltage per cell. Carbon-zinc and related cells are still used, but the alkaline battery delivers more energy per unit weight and is widely used. The most commonly used battery voltages are 1.5 (1 cell) and 9V (6 cells).

Various technologies of rechargeable battery are used. Types most commonly used are NiMH, and lithium ion and variants.

DC power supply



A home-made linear power supply (used here to power amateur radio equipment)

An AC powered unregulated power supply usually uses a transformer to convert the voltage from the wall outlet (mains) to a different, nowadays usually lower, voltage. If it is used to produce DC, a rectifier is used to convert alternating voltage to a pulsating direct voltage, followed by a filter, comprising one or more capacitors, resistors, and sometimes inductors, to filter out (smooth) most of the pulsation. A small remaining unwanted alternating voltage component at mains or twice mains power frequency (depending upon whether half- or full-wave rectification is used)—ripple—is unavoidably superimposed on the direct output voltage.

For purposes such as charging batteries the ripple is not a problem, and the simplest unregulated mains-powered DC power supply circuit consists of a transformer driving a single diode in series with a resistor.

Before the introduction of solid-state electronics, equipment used valves (vacuum tubes) which required high voltages; power supplies used step-up transformers, rectifiers, and filters to generate one or more direct voltages of some hundreds of volts, and a low alternating voltage for filaments. Only the most advanced equipment used expensive and bulky regulated power supplies.

AC power supply

An AC power supply typically takes the voltage from a wall outlet (mains supply, often 230v in Europe) and lowers it to the desired voltage (eg 9vac). As well as lowering the voltage some filtering may take place. An example use for an AC power supply is powering certain guitar effects pedals (e.g. the Digitech Whammy pedal) although it is more common for effects pedals to require DC.

Linear regulated power supply

The voltage produced by an unregulated power supply will vary depending on the load and on variations in the AC supply voltage. For critical electronics applications a linear regulator may be used to set the voltage to a precise value, stabilized against fluctuations in input voltage and load. The regulator also greatly reduces the ripple and noise in the output direct current. Linear regulators often provide current limiting, protecting the power supply and attached circuit from overcurrent.

Adjustable linear power supplies are common laboratory and service shop test equipment, allowing the output voltage to be adjusted over a range. For example, a bench power supply used by circuit designers may be adjustable up to 30 volts and up to 5 amperes output. Some can be driven by an external signal, for example, for applications requiring a pulsed output.

AC/DC supply

In the past, mains electricity was supplied as DC in some regions, AC in others. Transformers cannot be used for DC, but a simple, cheap unregulated power supply could run directly from either AC or DC mains without using a transformer. The power supply consisted of a rectifier and a filter capacitor. When operating from DC, the rectifier was essentially a conductor, having no effect; it was included to allow operation from AC or DC without modification.

Switched-mode power supply

A computer's switched mode power supply unit.

A switched-mode power supply (SMPS) works on a different principle. AC input, usually at mains voltage, is rectified without the use of a mains transformer, to obtain a DC voltage. This voltage is then switched on and off at a high speed by electronic switching circuitry, which may then pass through a high-frequency, hence small, light, and cheap, transformer or inductor. The duty cycle of the output square wave increases as power output requirements increase. Switched-mode power supplies are always regulated. If the SMPS uses a properly-insulated high-frequency transformer, the output will be electrically isolated from the mains, essential for safety.

The input power slicing occurs at a very high speed (typically 10 kHz — 1 MHz). High frequency and high voltages in this first stage permit much smaller transformers and smoothing capacitors than in a power supply operating at mains frequency, as linear supplies do. After the transformer secondary, the AC is again rectified to DC. To keep output voltage constant, the power supply needs a sophisticated feedback controller to monitor current drawn by the load.

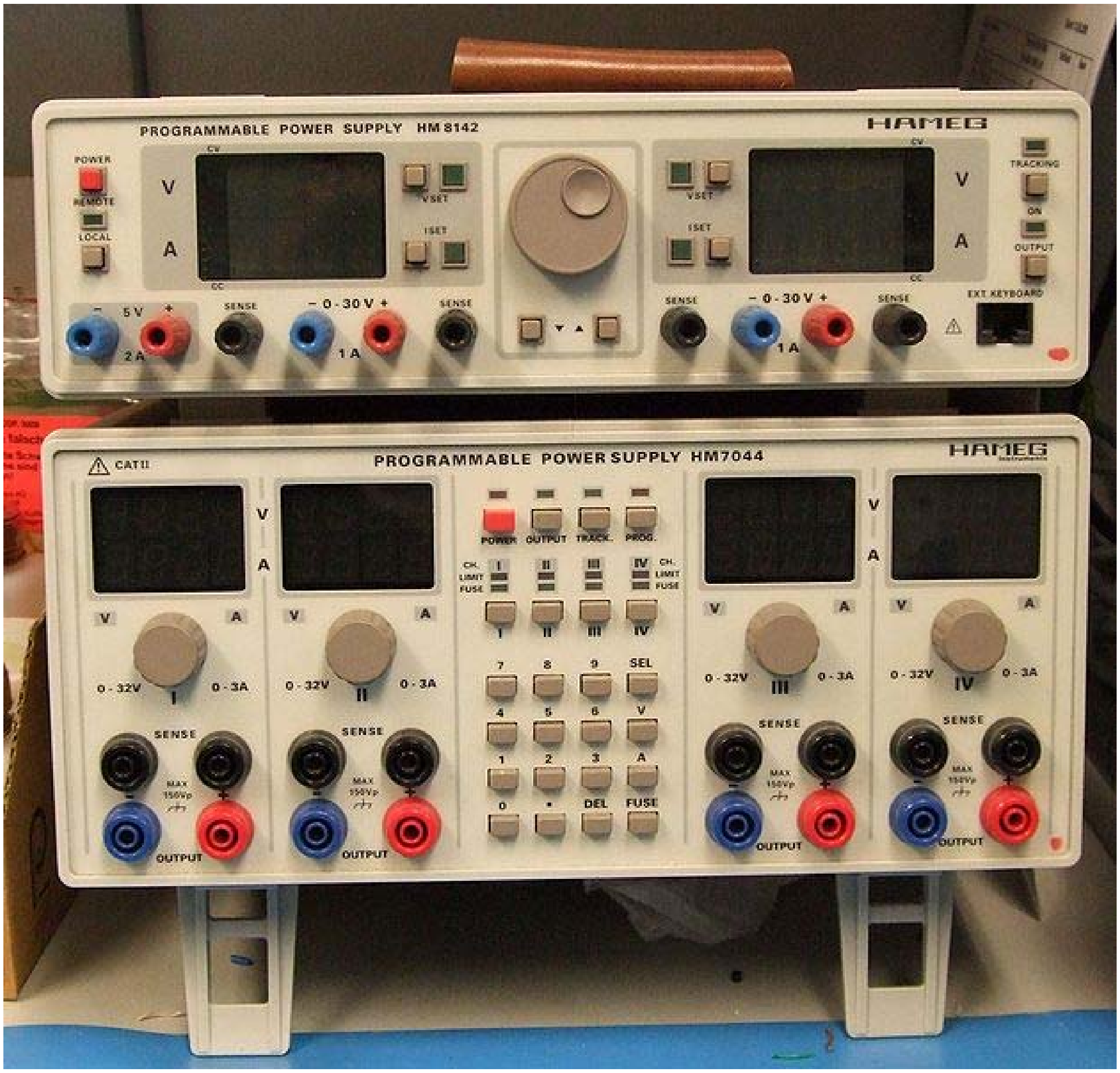
SMPSs often include safety features such as current limiting or a crowbar circuit to help protect the device and the user from harm. In the event that an abnormal high-current power draw is detected, the switched-mode supply can assume this is a direct short and will shut itself down before damage is done. For decades PC power supplies have provided a *power good* signal to the motherboard whose absence prevents operation when abnormal supply voltages are present.

SMPSs have an absolute limit on their minimum current output. They are only able to output above a certain power level and cannot function below that point. In a no-load condition the frequency of the power slicing circuit increases to great speed, causing the isolated transformer to act as a Tesla coil, causing damage due to the resulting very high voltage power spikes. Switched-mode supplies with protection circuits may briefly turn on but then shut down when no load has been detected. A very small low-power dummy load such as a ceramic power resistor or 10-watt light bulb can be attached to the supply to allow it to run with no primary load attached.

Power factor has become a recent issue of concern for computer manufacturers. Switched mode power supplies have traditionally been a source of power line harmonics and have a very poor power factor. Many computer power supplies built in the last few years now include power factor correction built right into the switched-mode supply, and may advertise the fact that they offer *1.0 power factor*.

By slicing up the sinusoidal AC wave into very small discrete pieces, a portion of unused alternating current stays in the power line as very small spikes of power that cannot be utilized by AC motors and results in waste heating of power line transformers. Hundreds of switched mode power supplies in a building can result in poor power quality for other customers surrounding that building, and high electric bills for the company if they are billed according to their power factor in addition to the actual power used. Filtering capacitor banks may be needed on the building power mains to suppress and absorb these negative power factor effects.

Programmable power supply



Programmable power supplies

Programmable power supplies allow for remote control of the output voltage through an analog input signal or a computer interface such as RS232 or GPIB. Variable properties include voltage, current, and frequency (for AC output units). These supplies are composed of a processor, voltage/current programming circuits, current shunt, and voltage/current read-back circuits. Additional features can include overcurrent, overvoltage, and short circuit protection, and temperature compensation. Programmable power supplies also come in a variety of forms including modular, board-mounted, wall-mounted, floor-mounted or bench top.

Programmable power supplies can furnish DC, AC, or AC with a DC offset. The AC output can be either single-phase or three-phase. Single-phase is generally used for low-voltage, while three-phase is more common for high-voltage power supplies.

Programmable power supplies are now used in many applications. Some examples include automated equipment testing, crystal growth monitoring, and differential thermal analysis.

Uninterruptible power supply

An uninterruptible power supply (UPS) takes its power from two or more sources simultaneously. It is usually powered directly from the AC mains, while simultaneously charging a storage battery. Should there be a dropout or failure of the mains, the battery instantly takes over so that the load never experiences an interruption. Such a scheme can supply power as long as the battery charge suffices, e.g., in a computer installation, giving the operator sufficient time to effect an orderly system shutdown without loss of data. Other UPS schemes may use an internal combustion engine or turbine to continuously supply power to a system in parallel with power coming from the AC . The engine-driven generators would normally be idling, but could come to full power in a matter of a few seconds in order to keep vital equipment running without interruption. Such a scheme might be found in hospitals or telephone central offices.

High-voltage power supply

High voltage refers to an output on the order of hundreds or thousands of volts. High-voltage supplies use a linear setup to produce an output voltage in this range.

Additional features available on high-voltage supplies can include the ability to reverse the output polarity along with the use of circuit breakers and special connectors intended to minimize arcing and accidental contact with human hands. Some supplies provide analog inputs (i.e. 0-10V) that can be used to control the output voltage, effectively turning them into high-voltage amplifiers albeit with very limited bandwidth.

Voltage multipliers

Voltage multipliers, as the name implies, are circuits designed to multiply the input voltage. The input voltage may be doubled (voltage doubler), tripled (voltage tripler), quadrupled (voltage quadrupler), etc. Voltage multipliers are also power converters. An AC input is converted to a higher DC output. These circuits allow high voltages to be obtained using a much lower voltage AC source.

Typically, voltage multipliers are composed of half-wave rectifiers, capacitors, and diodes. For example, a voltage tripler consists of three half-wave rectifiers, three capacitors, and three diodes. Full-wave rectifiers may be used in a different configuration to achieve even higher voltages. Also, both parallel and series configurations are available. For parallel multipliers, a higher voltage rating is required at each consecutive multiplication stage, but less capacitance is required. The voltage capability of the capacitor limits the maximum output voltage.

Voltage multipliers have many applications. For example, voltage multipliers can be found in everyday items like televisions and photocopiers. Even more applications can be found in the laboratory, such as cathode ray tubes, oscilloscopes, and photomultiplier tubes.

Power supply applications

Computer power supply

A modern computer power supply is a switch with on and off supply designed to convert 110-240 V AC power from the mains supply, to several output both positive (and historically negative) DC voltages in the range + 12V,-12V,+5V,+5VBs and +3.3V. The first generation of computers power supplies were linear devices, but as cost became a driving factor, and weight became important, switched mode supplies are almost universal.

The diverse collection of output voltages also have widely varying current draw requirements, which are difficult to all be supplied from the same switched-mode source. Consequently most modern computer power supplies actually consist of several different switched mode supplies, each producing just one voltage component and each able to vary its output based on component power requirements, and all are linked together to shut down as a group in the event of a fault condition.

Welding power supply

Arc welding uses electricity to melt the surfaces of the metals in order to join them together through coalescence. The electricity is provided by a *welding power supply*, and can either be AC or DC. Arc welding typically requires high currents typically between 100 and 350 amps. Some types of welding can use as few as 10 amps, while some applications of spot welding employ currents as high as 60,000 amps for an extremely short time. Older welding power supplies consisted of transformers or engines driving generators. More recent supplies use semiconductors and microprocessors reducing their size and weight.

AC adapter

Switched mode mobile phone charger

A linear or switched-mode power supply (or in some cases just a transformer) that is built into the top of a plug is known as a "plug pack", "plug-in adapter", "adapter block", "domestic mains adapter" or just "power adapter". Slang terms include "wall wart" and "power brick". They are even more diverse than their names; often with either the same kind of DC plug offering different voltage or polarity, or a different plug offering the same voltage. "Universal" adapters attempt to replace missing or damaged ones, using multiple plugs and selectors for different voltages and polarities. Replacement power supplies must match the voltage of, and supply at least as much current as, the original power supply.

The least expensive AC units consist solely of a small transformer, while DC adapters include a few additional diodes. Whether or not a load is connected to the power adapter, the transformer has a magnetic field continuously present and normally cannot be completely turned off unless unplugged.

Because they consume standby power, they are sometimes known as "electricity vampires" and may be plugged into a power strip to allow turning them off. Expensive switched-mode power supplies can cut off leaky electrolyte-capacitors, use powerless MOSFETs, and reduce their working frequency to get a gulp of energy once in a while to power, for example, a clock, which would otherwise need a battery.

Overload protection

Power supplies often include some type of overload protection that protects the power supply from load faults (e.g., short circuits) that might otherwise cause damage by overheating components or, in the worst case, electrical fire. Fuses and circuit breakers are two commonly used mechanisms for overload protection.

Fuses

A fuse is a piece of wire, often in a casing that improves its electrical characteristics. If too much current flows, the wire becomes hot and melts. This effectively disconnects the power supply from its load, and the equipment stops working until the problem that caused the overload is identified and the fuse is replaced.

There are various types of fuses used in power supplies.

- fast blow fuses cut the power as quick as they can
- slow blow fuses tolerate more short term overload
- wire link fuses are just an open piece of wire, and have poorer overload characteristics than glass and ceramic fuses

Some power supplies use a very thin wire link soldered in place as a fuse.

Circuit breakers

One benefit of using a circuit breaker as opposed to a fuse is that it can simply be reset instead of having to replace the blown fuse. A circuit breaker contains an element that heats, bends and triggers a spring which shuts the circuit down. Once the element cools, and the problem is identified the breaker can be reset and the power restored.

Thermal cutouts

Some PSUs use a thermal cutout buried in the transformer rather than a fuse. The advantage is it allows greater current to be drawn for limited time than the unit can supply continuously. Some such cutouts are self resetting, some are single use only.

Current limiting

Some supplies use current limiting instead of cutting off power if overloaded. The two types of current limiting used are electronic limiting and impedance limiting. The former is common on lab bench PSUs, the latter is common on supplies of less than 3 watts output.

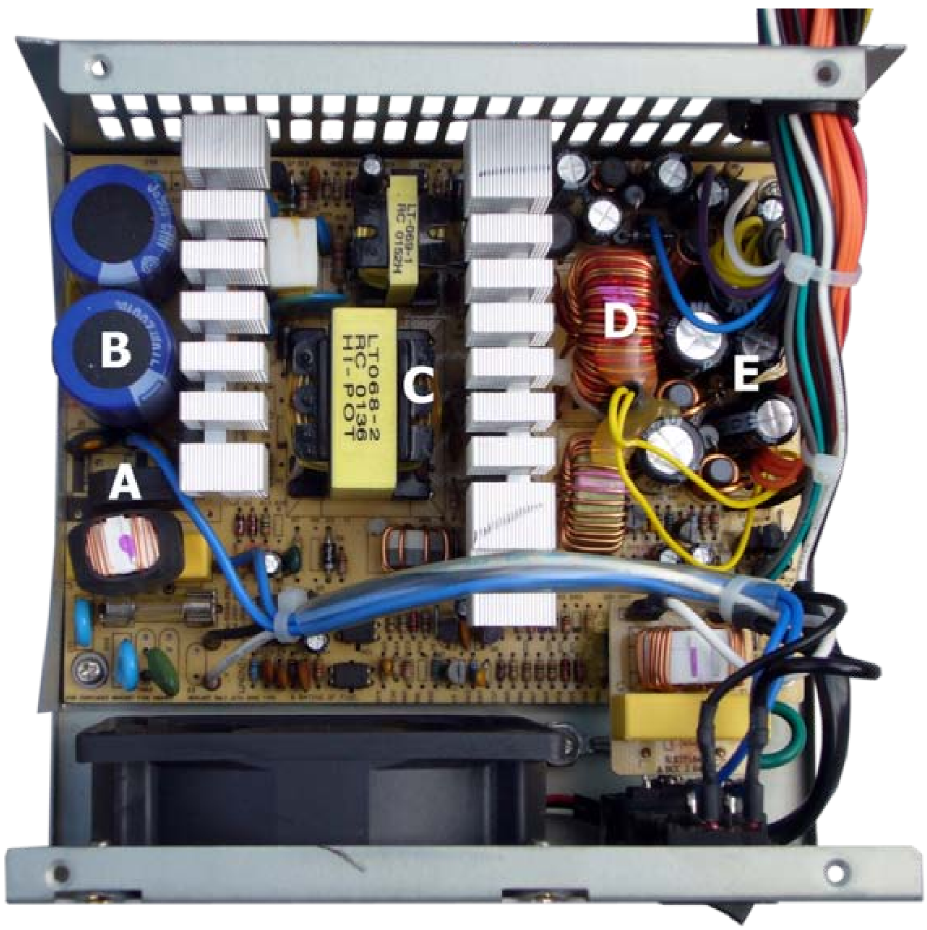
A foldback current limiter reduces the output current to much less than the maximum non-fault current.

Power conversion

The term "**power supply**" is sometimes restricted to those devices that *convert* some other form of energy into electricity (such as solar power and fuel cells and generators). A more accurate term for devices that convert one form of electric power into another form (such as transformers and linear regulators) is power converter. The most common conversion is from AC to DC.

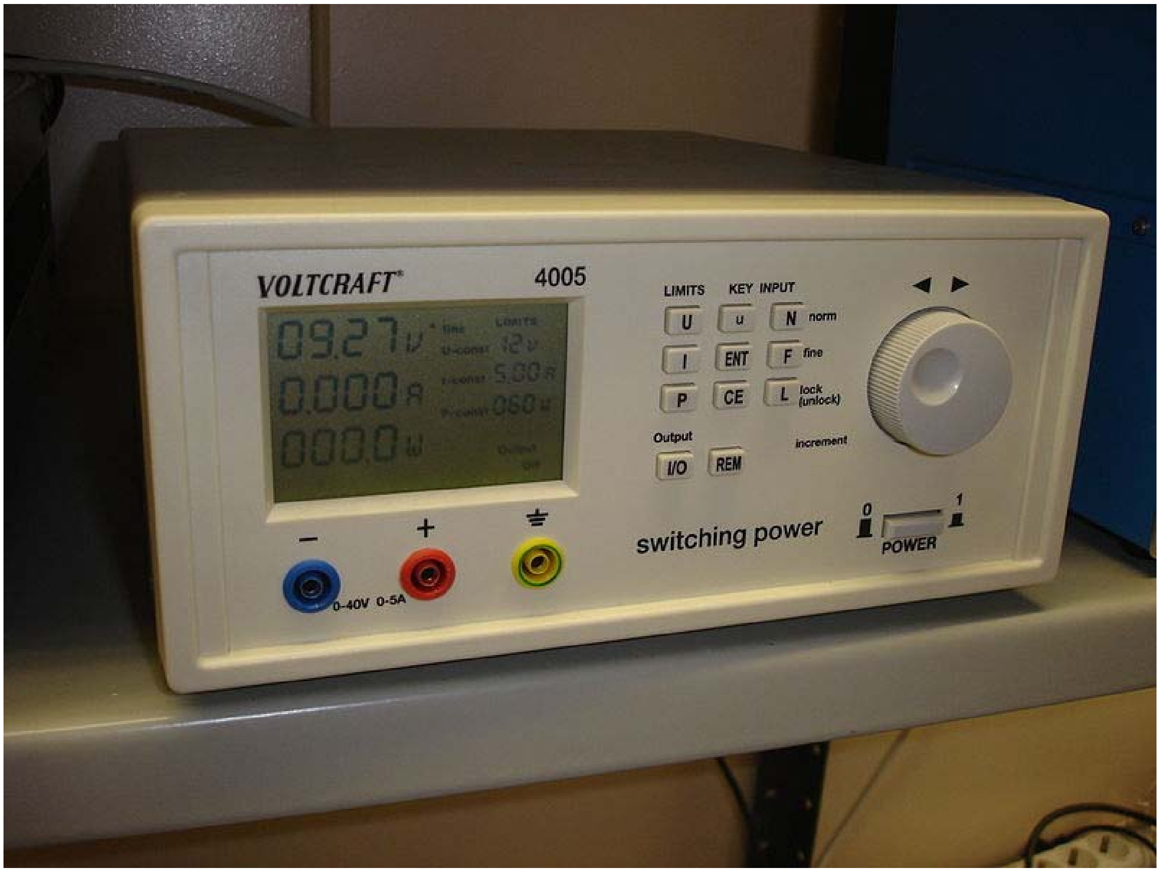
Chapter-2

Switched-mode Power Supply



Interior view of an ATX SMPS: below
A: input EMI filtering; A: bridge rectifier;
B: input filter capacitors;
Between B and C: primary side heat sink;
C: transformer;
Between C and D: secondary side heat sink;

D: output filter coil;
E: output filter capacitors.
The coil and large yellow capacitor below E are additional input filtering components that are mounted directly on the power input connector and are not part of the main circuit board.



An adjustable switched-mode power supply for laboratory use

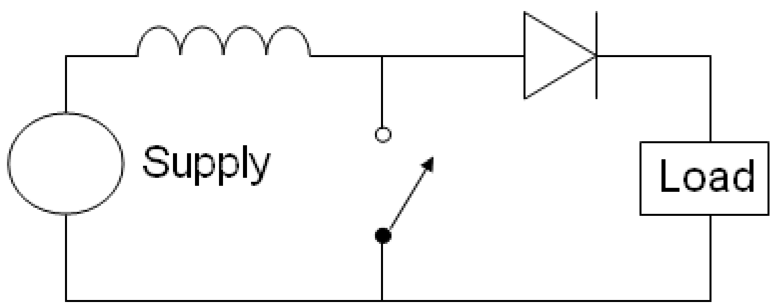
A **switched-mode power supply** (**switching-mode power supply**, **SMPS**, or simply **switcher**) is an electronic power supply that incorporates a switching regulator in order to be highly efficient in the conversion of electrical power. Like other types of power supplies, an SMPS transfers power from a source like the electrical power grid to a load (e.g., a personal computer) while converting voltage and current characteristics. An SMPS is usually employed to efficiently provide a regulated output voltage, typically at a level different from the input voltage.

Unlike a linear power supply, the pass transistor of a switching mode supply switches very quickly (typically between 50 kHz and 1 MHz) between full-on and full-off states, which minimizes wasted energy. Voltage regulation is provided by varying the ratio of on to off time. In contrast, a linear power supply must dissipate the excess voltage to regulate the output. This higher efficiency is the chief advantage of a switch-mode power supply.

Switching regulators are used as replacements for the linear regulators when higher efficiency, smaller size or lighter weight are required. They are, however, more complicated, their switching currents can cause electrical noise problems if not carefully suppressed, and simple designs may have a poor power factor.

Explanation

A linear regulator provides the desired output voltage by dissipating excess power in ohmic losses (e.g., in a resistor or in the collector–emitter region of a pass transistor in its active mode). A linear regulator regulates either output voltage or current by dissipating the excess electric power in the form of heat, and hence its maximum power efficiency is voltage-out/voltage-in since the volt difference is wasted. In contrast, a switched-mode power supply regulates either output voltage or current by switching ideal storage elements, like inductors and capacitors, into and out of different electrical configurations. Ideal switching elements (e.g., transistors operated outside of their active mode) have no resistance when "closed" and carry no current when "open", and so the converters can theoretically operate with 100% efficiency (i.e., all input power is delivered to the load; no power is wasted as dissipated heat).



The basic schematic of a boost converter.

For example, if a DC source, an inductor, a switch, and the corresponding electrical ground are placed in series and the switch is driven by a square wave, the peak-to-peak voltage of the waveform measured across the switch can exceed the input voltage from the DC source. This is because the inductor responds to changes in current by inducing its own voltage to counter the change in current, and this voltage adds to the source voltage while the switch is open. If a diode-and-capacitor combination is placed in parallel to the switch, the peak voltage can be stored in the capacitor, and the capacitor can be used as a DC source with an output voltage greater than the DC voltage driving the circuit. This boost converter acts like a step-up transformer for DC signals. A buck–boost converter works in a similar manner, but yields an output voltage which is opposite in polarity to the input voltage. Other buck circuits exist to boost the average output current with a reduction of voltage.

In an SMPS, the output current flow depends on the input power signal, the storage elements and circuit topologies used, and also on the pattern used (e.g., pulse-width modulation with an adjustable duty cycle) to drive the switching elements. Typically, the spectral density of these switching waveforms has energy concentrated at relatively high frequencies. As such, switching transients, like ripple, introduced onto the output waveforms can be filtered with small LC filters.

Hydraulic analogy explains the basic principle.

Advantages and disadvantages

The main advantage of this method is greater efficiency because the switching transistor dissipates little power when it is outside of its active region (i.e., when the transistor acts like a switch and either has a negligible voltage drop across it or a negligible current through it). Other advantages include smaller size and lighter weight (from the elimination of low frequency transformers which have a high weight) and lower heat generation due to higher efficiency. Disadvantages include greater complexity, the generation of high-amplitude, high-frequency energy that the low-pass filter must block to avoid electromagnetic interference (EMI), and a ripple voltage at the switching frequency and the harmonic frequencies thereof.

Very low cost SMPSs may couple electrical switching noise back onto the mains power line, causing interference with A/V equipment connected to the same phase. Non-power-factor-corrected SMPSs also cause harmonic distortion.

Classification

SMPSs can be classified into four types according to the input and output waveforms:

- AC in, DC out: rectifier, off-line converter input stage
- DC in, DC out: voltage converter, or current converter, or DC to DC converter
- AC in, AC out: frequency changer, cycloconverter, transformer, phase converter
- DC in, AC out: inverter

SMPS and linear power supply comparison

There are two main types of regulated power supplies available: SMPS and linear. The following table compares linear regulated and unregulated AC-to-DC supplies with switching regulators in general:

Comparison of a linear power supply and a switched-mode power supply

	Linear power supply	Switching power supply	Notes
Size and weight	Heatsinks for high power linear regulators add size and weight. Transformers, if used, are large due to low	Smaller transformer (if used; else inductor) due to higher operating frequency (typically 50 kHz – 1 MHz). Size and weight of adequate RF shielding may be	A transformer's power handling capacity of given size and weight increases with frequency

	operating frequency (mains power frequency is at 50 or 60 Hz); otherwise can be compact due to low component count.	significant.	provided that hysteresis losses can be kept down. Therefore, higher operating frequency means either higher capacity or smaller transformer.
Output voltage	With transformer used, any voltages available; if transformerless, not exceeding input. If unregulated, voltage varies significantly with load.	Any voltages available, limited only by transistor breakdown voltages in many circuits. Voltage varies little with load.	A SMPS can usually cope with wider variation of input before the output voltage changes.
Efficiency, heat, and power dissipation	If regulated: efficiency largely depends on voltage difference between input and output; output voltage is regulated by dissipating excess power as heat resulting in a typical efficiency of 30–40%. If unregulated, transformer iron and copper losses may be the only significant sources of inefficiency.	Output is regulated using duty cycle control; the transistors are switched fully on or fully off, so very little resistive losses between input and the load. The only heat generated is in the non-ideal aspects of the components and quiescent current in the control circuitry.	Switching losses in the transistors (especially in the short part of each cycle when the device is partially on), on-resistance of the switching transistors, equivalent series resistance in the inductor and capacitors, and core losses in the inductor, and rectifier voltage drop contribute to a typical efficiency of 60–70%. However, by optimizing SMPS design (such as choosing the optimal switching frequency, avoiding saturation of inductors, and active

			rectification), the amount of power loss and heat can be minimized; a good design can have an efficiency of 95%.
Complexity	Unregulated may be simply a diode and capacitor; regulated has a voltage regulating IC or discrete circuit and a noise filtering capacitor; usually a simpler circuit (and simpler feedback loop stability criteria) than switch-mode circuits.	Consists of a controller IC, one or several power transistors and diodes as well as a power transformer, inductors, and filter capacitors. Some design complexities present (reducing noise/interference; extra limitations on maximum ratings of transistors at high switching speeds) not found in linear regulator circuits.	In switch-mode mains (AC-to-DC) supplies, multiple voltages can be generated by one transformer core, but that can introduce design/use complications: for example it may place *minimum* output current restrictions on one output. For this SMPSs have to use duty cycle control. One of the outputs has to be chosen to feed the voltage regulation feedback loop (Usually 3.3 V or 5 V loads are more fussy about their supply voltages than the 12 V loads, so this drives the decision as to which feeds the feedback loop. The other outputs usually track the regulated one pretty well). Both need a careful selection of their transformers. Due to the high

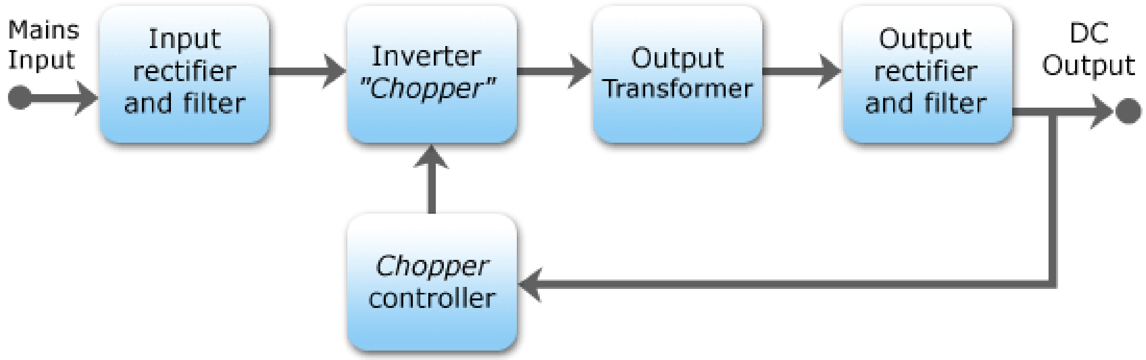
			operating frequencies in SMPSs, the stray inductance and capacitance of the printed circuit board traces become important.
Radio frequency interference	Mild high-frequency interference may be generated by AC rectifier diodes under heavy current loading, while most other supply types produce no high-frequency interference. Some mains hum induction into unshielded cables, problematical for low-signal audio.	EMI/RFI produced due to the current being switched on and off sharply. Therefore, EMI filters and RF shielding are needed to reduce the disruptive interference.	Long wires between the components may reduce the high frequency filter efficiency provided by the capacitors at the inlet and outlet. Stable switching frequency may be important.
Electronic noise at the output terminals	Unregulated PSUs may have a little AC ripple superimposed upon the DC component at twice mains frequency (100–120 Hz). Can cause audible mains hum in audio equipment or brightness ripples or banded distortions in analog security cameras.	Noisier due to the switching frequency of the SMPS. An unfiltered output may cause glitches in digital circuits or noise in audio circuits.	This can be suppressed with capacitors and other filtering circuitry in the output stage. With a switched mode PSU the switching frequency can be chosen to keep the noise out of the circuits working frequency band (e.g., for audio systems above the range of human hearing)
Electronic noise at the input terminals	Causes harmonic distortion to the input AC, but relatively little or no high frequency noise.	Very low cost SMPS may couple electrical switching noise back onto the mains power line, causing interference with A/V equipment connected to the same phase. Non power-factor-corrected SMPSs also	This can be prevented if a (properly earthed) EMI/RFI filter is connected between the input terminals and the bridge rectifier.

		cause harmonic distortion.	
Acoustic noise	Faint, usually inaudible mains hum, usually due to vibration of windings in the transformer and/or magnetostriction.	Usually inaudible to most humans, unless they have a fan or are unloaded/malfunctioning, or use a switching frequency within the audio range, or the laminations of the coil vibrate at a subharmonic of the operating frequency.	The operating frequency of an unloaded SMPS is sometimes in the audible human range, and may sound subjectively quite loud for people who have hyperacusis in the relevant frequency range.
Power factor	Low for a regulated supply because current is drawn from the mains at the peaks of the voltage sinusoid, unless a choke-input or resistor-input circuit follows the rectifier (now rare).	Ranging from very low to medium since a simple SMPS without PFC draws current spikes at the peaks of the AC sinusoid.	Active/passive power factor correction in the SMPS can offset this problem and are even required by some electric regulation authorities, particularly in Europe. The internal resistance of low-power transformers in linear power supplies usually limits the peak current each cycle and thus gives a better power factor than many switch-mode power supplies that directly rectify the mains with little series resistance.
Inrush current	Large current when mains-powered linear power supply equipment is switched on until magnetic flux of transformer stabilises and	Extremely large peak "in-rush" surge current limited only by the impedance of the input supply and any series resistance to the filter capacitors.	Empty filter capacitors initially draw large amounts of current as they charge up, with larger capacitors drawing

	capacitors charge completely, unless a slow-start circuit is used.		larger amounts of peak current. Being many times above the normal operating current, this greatly stresses components subject to the surge, complicates fuse selection to avoid nuisance blowing and may cause problems with equipment employing overcurrent protection such as uninterruptible power supplies. Mitigated by use of a suitable soft-start circuit or series resistor.
Risk of electric shock	Supplies with transformers allow metalwork to be grounded, safely. Dangerous if primary/secondary insulation breaks down, unlikely with reasonable design. Transformerless mains-operated supply dangerous. In both linear and SM the mains, and possibly the output voltages, are hazardous and must be well-isolated.	Common rail of equipment (including casing) is energised to half mains voltage, but at high impedance, unless equipment is earthed/grounded or doesn't contain EMI/RFI filtering at the input terminals.	Due to regulations concerning EMI/RFI radiation, many SMPS contain EMI/RFI filtering at the input stage before the bridge rectifier consisting of capacitors and inductors. Two capacitors are connected in series with the Live and Neutral rails with the Earth connection in between the two capacitors. This forms a capacitive divider that energises the

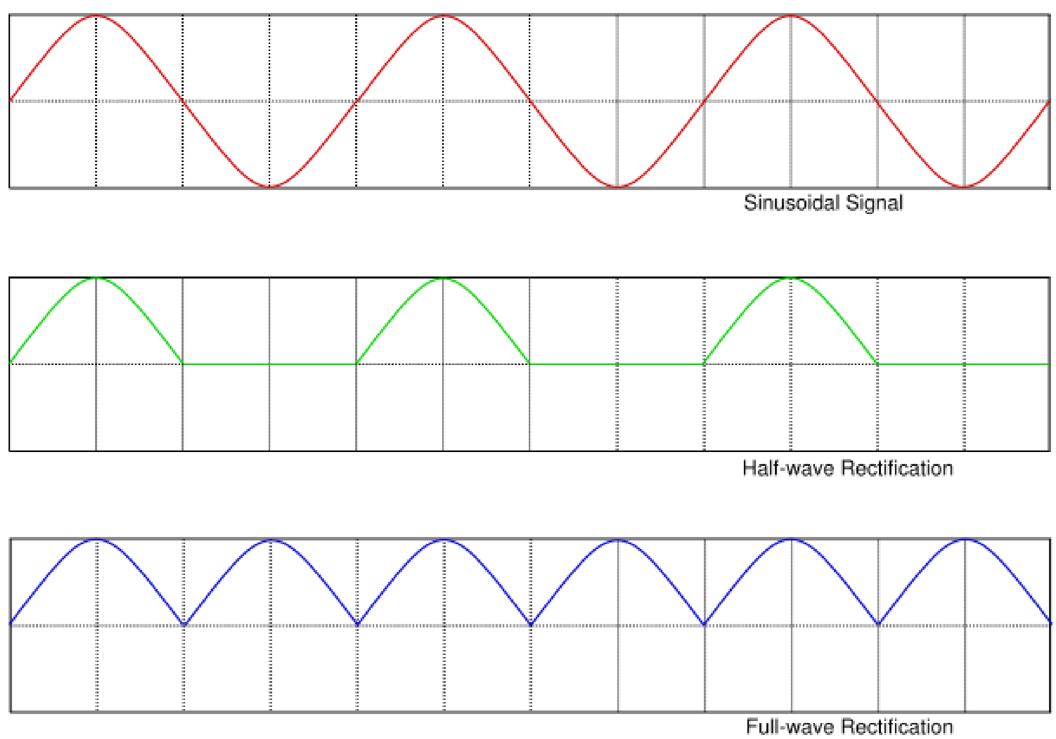
			common rail at half mains voltage. Its high impedance current source can provide a tingling or a 'bite' to the operator or can be exploited to light an Earth Fault LED. However, this current may cause nuisance tripping on the most sensitive residual-current devices.
Risk of equipment damage	Very low, unless a short occurs between the primary and secondary windings or the regulator fails by shorting internally.	Can fail so as to make output voltage very high. Stress on capacitors may cause them to explode. Can in some cases destroy input stages in amplifiers if floating voltage exceeds transistor base-emitter breakdown voltage, causing the transistor's gain to drop and noise levels to increase. Mitigated by good failsafe design. Failure of a component in the SMPS itself can cause further damage to other PSU components; can be difficult to troubleshoot.	The floating voltage is caused by capacitors bridging the primary and secondary sides of the power supply. A connection to an earthed equipment will cause a momentary (and potentially destructive) spike in current at the connector as the voltage at the secondary side of the capacitor equalises to earth potential.

Theory of operation



Block diagram of a mains operated AC–DC SMPS with output voltage regulation

Input rectifier stage



AC, half-wave and full-wave rectified signals.

If the SMPS has an AC input, then the first stage is to convert the input to DC. This is called *rectification*. The rectifier circuit can be configured as a voltage doubler by the addition of a switch operated either manually or automatically. This is a feature of larger supplies to permit operation from nominally 120 V or 240 V supplies. The rectifier produces an unregulated DC voltage which is then sent to a large filter capacitor. The current drawn from the mains supply by this rectifier circuit occurs in short pulses around the AC voltage peaks. These pulses have significant high frequency energy which reduces the power factor. Special control techniques can be employed by the following SMPS to force the average input current to follow the sinusoidal shape of the AC input voltage thus the designer should try correcting the power factor. An SMPS with a DC input does not require this stage. An SMPS designed for AC input can often be run from a DC supply (for 230 V AC this would be 330 V DC), as the DC passes through the rectifier stage unchanged. It's however advisable to consult the manual before trying this, though most supplies are quite capable of such operation even though nothing is mentioned in the documentation. However, this type of use may be harmful to the rectifier stage as it will only use half of diodes in the rectifier for the full load. This may result in overheating of these components, and cause them to fail prematurely.

If an input range switch is used, the rectifier stage is usually configured to operate as a voltage doubler when operating on the low voltage (~120 V AC) range and as a straight rectifier when operating on the high voltage (~240 V AC) range. If an input range switch is not used, then a full-wave rectifier is usually used and the downstream inverter stage is simply designed to be flexible enough to accept the wide range of DC voltages that will be produced by the rectifier stage. In higher-power SMPSs, some form of automatic range switching may be used.

Inverter stage

The inverter stage converts DC, whether directly from the input or from the rectifier stage described above, to AC by running it through a power oscillator, whose output transformer is very small with few windings at a frequency of tens or hundreds of kilohertz (kHz). The frequency is usually chosen to be above 20 kHz, to make it inaudible to humans. The output voltage is optically coupled to the input and thus very tightly controlled. The switching is implemented as a multistage (to achieve high gain) MOSFET amplifier. MOSFETs are a type of transistor with a low on-resistance and a high current-handling capacity.

Voltage converter and output rectifier

If the output is required to be isolated from the input, as is usually the case in mains power supplies, the inverted AC is used to drive the primary winding of a high-frequency transformer. This converts the voltage up or down to the required output level on its secondary winding. The output transformer in the block diagram serves this purpose.

If a DC output is required, the AC output from the transformer is rectified. For output voltages above ten volts or so, ordinary silicon diodes are commonly used. For lower voltages, Schottky diodes are commonly used as the rectifier elements; they have the advantages of faster recovery times than silicon diodes (allowing low-loss operation at higher frequencies) and a lower voltage drop when conducting. For even lower output voltages, MOSFETs may be used as synchronous rectifiers; compared to Schottky diodes, these have even lower conducting state voltage drops.

The rectified output is then smoothed by a filter consisting of inductors and capacitors. For higher switching frequencies, components with lower capacitance and inductance are needed.

Simpler, non-isolated power supplies contain an inductor instead of a transformer. This type includes *boost converters*, *buck converters*, and the *buck-boost converters*. These belong to the simplest class of single input, single output converters which use one inductor and one active switch. The buck converter reduces the input voltage in direct proportion to the ratio of conductive time to the total switching period, called the duty cycle. For example an ideal buck converter with a 10 V input operating at a 50% duty cycle will produce an average output voltage of 5 V. A feedback control loop is employed to regulate the output voltage by varying the duty cycle to compensate for variations in input voltage. The output voltage of a boost converter is always greater than the input voltage and the buck-boost output voltage is inverted but can be greater than, equal to, or less than the magnitude of its input voltage. There are many variations and extensions to this class of converters but these three form the basis of almost all isolated and non-isolated DC to DC converters. By adding a second inductor the Ćuk and SEPIC converters can be implemented, or, by adding additional active switches, various bridge converters can be realised.

Other types of SMPSs use a capacitor-diode voltage multiplier instead of inductors and transformers. These are mostly used for generating high voltages at low currents (*Cockcroft-Walton generator*). The low voltage variant is called charge pump.

Regulation

A feedback circuit monitors the output voltage and compares it with a reference voltage, which shown in the block diagram serves this purpose. Depending on design/safety requirements, the controller may contain an isolation mechanism (such as opto-couplers) to isolate it from the DC output. Switching supplies in computers, TVs and VCRs have these opto-couplers to tightly control the output voltage.

Open-loop regulators do not have a feedback circuit. Instead, they rely on feeding a constant voltage to the input of the transformer or inductor, and assume that the output will be correct. Regulated designs compensate for the impedance of the transformer or coil. Monopolar designs also compensate for the magnetic hysteresis of the core.

The feedback circuit needs power to run before it can generate power, so an additional non-switching power-supply for stand-by is added.

Transformer design

SMPS transformers run at high frequency. Most of the cost savings (and space savings) in off-line power supplies come from the fact that a high frequency transformer is much smaller than the 50/60 Hz transformers formerly used. There are additional design tradeoffs.

Transformer size

The higher the switching frequency, the lesser the amount of energy that needs to be stored intermediately during the time of a single switching cycle. Because this energy is stored in form of magnetic energy in the transformer core material (like ferrite), less of such material is needed.

However, higher frequency also means more energy lost during transitions of the switching semiconductor. Furthermore, much more attention to the physical layout of the circuit board is required, and the amount of electromagnetic interference will be more pronounced.

Core loss

There are several differences in the design of transformers for 50 Hz vs 500 kHz. Firstly a low frequency transformer usually transfers energy through its core (soft iron), while the (usually ferrite) core of a high frequency transformer limits leakage.

Copper loss

At low frequencies (such as the line frequency of 50 or 60 Hz), designers can usually ignore the skin effect. At line frequencies, the skin effect becomes important when the conductors have a diameter larger than about 0.3 inches (7.6 mm).

Switching power supplies must pay more attention to the skin effect because it is a source of power loss. At 500 kHz, the skin depth is about 0.003 inches (0.076 mm) – a dimension smaller than the typical wires used in a power supply.

The skin effect is exacerbated by the harmonics present in the switching waveforms. The appropriate skin depth is not just the depth at the fundamental, but also the skin depths at the harmonics.

Since the waveforms in a SMPS are generally high speed (PWM square waves), the wiring must be capable of supporting high harmonics of the base frequency due to skin effect.

In addition to the skin effect, there is also a proximity effect, which is another source of power loss.

Power factor

Simple off-line switched mode power supplies incorporate a simple full wave rectifier connected to a large energy storing capacitor. Such SMPSs draw current from the AC line in short pulses when the mains instantaneous voltage exceeds the voltage across this capacitor. During the remaining portion of the AC cycle the capacitor provides energy to the power supply.

As a result, the input current of such basic switched mode power supplies has high harmonic content and relatively low power factor. This creates extra load on utility lines, increases heating of the utility transformers and standard AC electric motors, and may cause stability problems in some applications such as in emergency generator systems or aircraft generators. Harmonics can be removed through the use of filter banks but the filtering is expensive, and the power utility may require a business with a very low power factor to purchase and install the filtering onsite.

Unlike displacement power factor created by linear inductive or capacitive loads, this distortion cannot be corrected by addition of a single linear component. Additional circuits are required to counteract the effect of the brief current pulses.

In 2001, the European Union put into effect the standard IEC/EN61000-3-2 to set limits on the harmonics of the AC input current up to the 40th harmonic for equipment above 75 W. The standard defines four classes of equipment depending on its type and current waveform. The most rigorous limits (class D) are established for personal computers, computer monitors, and TV receivers. In order to comply with these requirements modern switched-mode power supplies normally include an additional power factor correction (PFC) stage.

Putting a current regulated boost chopper stage after the off-line rectifier (to charge the storage capacitor) can correct the power factor, but increases the complexity (and any cost).

Types

Switched-mode power supplies can be classified according to the circuit topology. The most important distinction is between isolated converters and non-isolated ones.

Non-isolated topologies

Non-isolated converters are simplest, with the three basic types using a single inductor for energy storage. In the voltage relation column, *D* is the duty cycle of the converter, and can vary from 0 to 1. V_{in} is assumed to be greater than zero; if it is negative, negate V_{out} to match.

Type	Power [W]	Typical efficiency	Relative cost	Energy storage	Voltage relation	Features
Buck	0–1,000	80–90%	1.0	Single inductor	0 ≤ Out ≤ In, $V_2 = DV_1$	Current is continuous at output.
Boost	0–150	70%	1.0	Single inductor	Out ≥ In, $V_2 = \frac{1}{1-D}V_1$	Current is continuous at input.
Buck-boost	0–150	78%	1.0	Single inductor	Out ≤ 0, $V_2 = -\frac{D}{1-D}V_1$	Current is dis-continuous at both input and output.

Split-pi (or, boost-buck)	0–2,000	96%	>2.0	Two inductors and three capacitors	Up or down	Bidirectional power control; in or out
Ćuk				Capacitor and two inductors	Any inverted, $V_2=-\frac{D}{1-D}V_1$	Current is continuous at input *and* output
SEPIC				Capacitor and two inductors	Any, $V_2=\frac{D}{1-D}V_1$	Current is continuous at input
Zeta				Capacitor and two inductors	Any, $V_2=\frac{D}{1-D}V_1$	Current is continuous at output
Charge pump				Capacitors only		Low performance. Like a CW multiplier, the disadvantages of charge pumps for power conversion can be somewhat mitigated through proper component sizing and drive frequency, since output energy is proportional to capacitance and frequency.

When equipment is human-accessible, voltage and power limits of <42.5 V and 8.0 A limit apply for UL, CSA, VDE approval.

The buck, boost, and buck-boost topologies are all strongly related. Input, output and ground come together at one point. One of the three passes through an inductor on the way, while the other two pass through switches. One of the two switches must be active (e.g., a transistor), while the other can be a diode. Sometimes, the topology can be changed simply by re-labeling the connections. A 12 V input, 5 V output buck converter can be converted to a 7 V input, −5 V output buck-boost by grounding the *output* and taking the output from the *ground* pin.

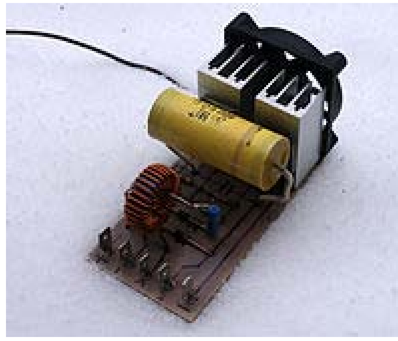
Likewise, SEPIC and Zeta converters are both minor rearrangements of the Ćuk converter.

Switchers become less efficient as duty cycles become extremely short. For large voltage changes, a transformer (isolated) topology may be better.

Isolated topologies

All isolated topologies include a transformer, and thus can produce an output of higher or lower voltage than the input by adjusting the turns ratio. For some topologies, multiple windings can be placed on the transformer to produce multiple output voltages. Some converters use the transformer for energy storage, while others use a separate inductor.

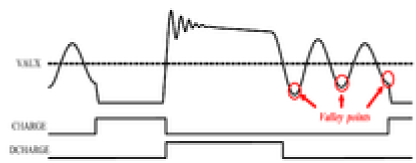
Type	Power [W]	Typical efficiency	Relative cost	Input range [V]	Energy storage	Features
Flyback	0–250	78%	1.0	5–600	Transformer	Isolated form of the buck-boost converter.[1]
Ringing choke converter (RCC)	0–150	78%	1.0	5–600	Transformer	Low-cost self-oscillating flyback variant.
Half-forward	0–250	75%	1.2	5–500	Inductor	
Forward[2]	100-200	78%		60–200	Inductor	Isolated form of buck converter
Resonant forward	0–60	87%	1.0	60–400	Inductor and capacitor	Single rail input, unregulated output, high efficiency, low EMI.
Push-pull	100–1,000	72%	1.75	50–1,000	Inductor	
Half-bridge	0–2,000	72%	1.9	50–1,000	Inductor	
Full-bridge	400–5,000	69%	>2.0	50–1,000	Inductor	Very efficient use of transformer, used for highest powers.
Resonant, zero voltage switched	>1,000		>2.0			
Isolated Ćuk					Two capacitors and two inductors	



Zero voltage switched power supplies require only small heatsinks as little energy is lost as heat. This allows them to be small too; this ZVS can handle powers in excess of 1 kilowatt. Transformer is not shown.

- **^1** Flyback converter logarithmic control loop behaviour might be harder to control than other types.
- **^2** The forward converter has several variants, varying in how the transformer is "reset" to zero magnetic flux every cycle.

Quasi-resonant zero-current/zero-voltage switch



Quasi-resonant switching switches when the voltage is at a minimum and a valley is detected

A quasi-resonant zero-current/zero-voltage switch (ZCS/ZVS) where "each switch cycle delivers a quantized 'packet' of energy to the converter output, and switch turn-on and turn-off occurs at zero current and voltage, resulting in an essentially lossless switch." Quasi-resonant switching, also known as *valley switching*, reduces EMI in the power supply by two methods:

1. By switching the bipolar switch when the voltage is at a minimum (in the valley) to minimize the hard switching effect that causes EMI.
2. By switching when a valley is detected, rather than at a fixed frequency, introduces a natural frequency jitter that spreads the RF emissions spectrum and reduces overall EMI.

Efficiency and EMI

Higher input voltage and synchronous rectification mode makes the conversion process more efficient; the power consumption of the controller also has to be taken into account. Higher switch frequency allows component sizes to be shrunk, but can produce more radio frequency (RF) interference. A resonant forward converter produces the lowest EMI of any SMPS approach because it uses a soft-switching resonant waveform compared with conventional hard switching.

Failure modes

Power supplies which use capacitors suffering from the capacitor plague may experience premature failure when the capacitance drops to 4% of the original value. This usually cause the switching semiconductor to fail in a conductive way. That may expose connected loads to the full input volt and current, and precipitate wild oscillations in output.

Failure of the switching transistor is common. Due to the large switching voltages this transistor must handle (around 325 V for a 230 V_{AC} mains supply), these transistors often short out, in turn immediately blowing the main internal power fuse.

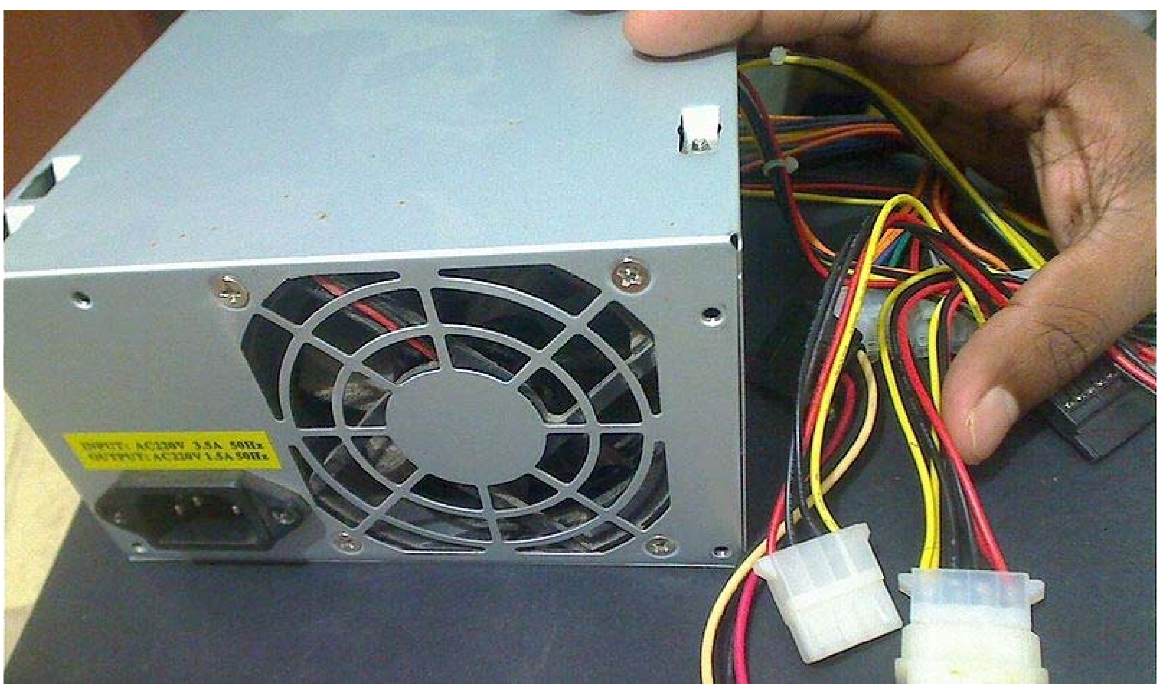
Precautions

The main filter capacitor will often store up to 325 V long after the power cord has been removed from the wall. Not all power supplies contain a small "bleeder" resistor to slowly discharge this capacitor. Any contact with this capacitor may result in a severe electrical shock.

The primary and secondary side may be connected with an capacitor to reduce EMI and compensate for various capacitive couplings in the converter ciruit, where the transformer is one. This may result in electric shock in some cases. The current flowing from line or neutral through a 2000 Ω resistor to any accessible part must according to IEC 60950 be less than 250 μA for IT equipment.

Applications

Switched mode mobile phone charger



A 450 Watt SMPS for use in personal computers with the power input, fan, and output cords visible

Switched-mode power supply units (PSUs) in domestic products such as personal computers often have universal inputs, meaning that they can accept power from most mains supplies throughout the world, with rated frequencies from 50 Hz to 60 Hz and voltages from 100 V to 240 V (although a manual voltage range switch may be required). In practice they will operate from a much wider frequency range and often from a DC supply as well.

In 2006, at an Intel Developers Forum, Google engineers proposed the use of a single 12 V supply inside PCs, due to the high efficiency of switch mode supplies directly on the PCB.

Most modern desktop and laptop computers also have a voltage regulator module—a DC–DC converter on the motherboard to step down the voltage from the power supply or the battery to the CPU core voltage, which is as low as 0.8 V for a low voltage CPU to 1.2–1.5 V for a desktop CPU as of 2007. Some motherboards have a setting in the BIOS that allows overclockers to set a new CPU core voltage; other motherboards support dynamic voltage scaling which constantly adjust the CPU core voltage. Most laptop computers also have a DC–AC converter to step up the voltage from the battery to drive a CCFL backlight in the flat-screen monitor, which typically requires around 1 kV_{RMS}.

Due to their high volumes mobile phone chargers have always been particularly cost sensitive. The first chargers were linear power supplies but they quickly moved to the cost effective ringing choke converter (RCC) SMPS topology, when new levels of efficiency were required. Recently the demand for even lower no load power requirements in the application has meant that flyback topology is being used more widely; primary side sensing flyback controllers are also helping to cut the bill of materials (BOM) by removing secondary-side sensing components such as optocouplers.

Where integration of capacitors for stabilization and batteries as a energy storage or hum and interference needs to be avoided in the power distribution, SMPS may be essential for efficient conversion of electric DC energy. For AC applications where frequency and voltage can't be produced by the primary source an SMPS may be essential as well. Applications may be found in the automobile industry where ordinary trucks uses nominal 24 V_{DC} but may need 12 V_{DC}. Ordinary cars use nominal 12 V_{DC} and may need to convert this to drive equipment. In industrial settings, DC supply is sometimes chosen to avoid hum and interference and ease the integration of capacitors and batteries used to buffer the voltage that makes SMPS essential.

Terminology

The term switchmode was widely used until Motorola claimed ownership of (but did not register) the trademark SWITCHMODE, for products aimed at the switching-mode power supply market, and started to enforce their trademark. *Switching-mode power supply*, *switching power supply*, and *switching regulator* refer to this type of power supply.

Chapter-3

AC Adapter

AC adapter plugged into Australian wall socket

The **AC adapter**, **AC/DC adapter** or **AC/DC converter** is a type of external power supply, often enclosed in what looks like an over-sized AC plug. Other names include **plug pack**, **plug-in adapter**, **adapter block**, **domestic mains adapter**, **line power adapter**, or **power adapter**. Informal terms include **wall wart**, **wall cube** and **power brick**. AC adapters are typically used with electrical devices that do not contain their own internal power supply. The internal circuitry of an external power supply is very similar to the design that would be used for a built-in or internal supply, but there are several advantages of separating the power supply from the main body of the electronic device, as explained below.

Modes of operation

An AC adapter disassembled to reveal a simple unregulated DC supply circuit.

Originally, AC adapters were linear power supplies, containing a transformer to convert the mains electricity voltage to a lower voltage, a rectifier to convert it to pulsating DC, and a filter to smooth the pulsating waveform to DC, with residual ripple variations small enough not to affect the device being powered. Size and weight of the device was largely determined by the transformer, which in turn was determined by the power output and mains frequency. Ratings over a few watts made the devices too large and heavy to be physically supported by a wall outlet. The output voltage of these adapters varied with load; for equipment requiring a more stable voltage, linear voltage regulator circuitry was added. Losses in the transformer and the linear regulator were considerable; efficiency was relatively low, and significant power dissipated as heat even when not driving a load.

More recently, switched-mode power supplies (SMPSs) have become almost ubiquitous for this purpose. Mains voltage is rectified to a high direct voltage driving a switching circuit, which has a transformer operating at a high frequency and outputs direct current at the desired voltage. The high-frequency ripple is more easily filtered out than mains-frequency. The high frequency allows the transformer to be small, which reduces its losses; and the switching regulator is more efficient than a linear regulator. The result is a much more efficient, smaller, and lighter device. Safety is ensured, same as in the older circuit, because the transformer electrically isolates the output from the mains.

Unless very carefully designed and using suitable components, switching adapters can be more likely to fail than the older type, due in part to complex circuitry and the use of semiconductors. Unless designed well, these adapters may be easily damaged by overloads, even transient ones, which can come from lightning, brief mains overvoltage (sometimes caused by an incandescent light failing), component degradation, etc. A very common mode of failure is due to the use of electrolytic capacitors whose equivalent series resistance (ESR) increases with age; switching regulators are very sensitive to high ESR (the older circuit also used electrolytic capacitors, but the effect of degradation is much less dramatic). Well-designed circuits pay attention to the ESR, ripple current rating, pulse operation, and temperature rating of capacitors Sometimes circuit designers design SMPSs, and accountants then cut the cost by replacing components such as capacitors with cheaper ones with the same headline characteristics but worse ESR, etc. The cost-reduced power supply may appear to be just as functional as before, but then suffers a high failure rate after a few years.

Advantages

External AC adapters are widely used to power small or portable electronic devices, because of a number of advantages:

- Safety — External power adapters can free product designers from worrying about some safety issues. The designer builds a product to run off a low voltage (usually supplied through a coaxial power connector) and does not have to worry about hazardous voltages inside the product enclosure. External power supplies tested and certified by safety agencies such as Underwriters Laboratories (UL) and DIN allow a low-power electronic product to be produced and later modified as needed, without requiring expensive and time-consuming recertification each time a design is changed. Nevertheless, care should be taken if more than a few watts are supplied to a product, even at low voltages, since a malfunction could still start a fire. Thus, an internal fuse, circuit breaker, or thermal limiter may be useful in a powered product, even when a safety-certified external power supply is used. An external, removable AC adapter can be used to help achieve a design with intrinsic safety.

- Heat reduction — Heat reduces reliability and longevity of electronic components, and can cause sensitive circuits to drift or malfunction. A separately-enclosed power supply moves what is often the primary source of heat to a cables-length distance.

- Electrical noise reduction — Because radiated electrical noise falls off with the inverse square of the distance, it is advantageous to convert potentially-noisy AC line power or automotive power to "clean", filtered DC in an external adapter, at a safe distance from noise-sensitive circuitry.

- Weight reduction — When most power adapters were simple transformer-based designs, they were quite heavy, and would have added considerably to the weight of portable or hand-held devices. Even modern light-weight switching circuits for AC line power still would add appreciable weight to hand-held devices, whose design weight budget is often denominated in grams. Moving these heavy power-handling components to a separate power supply reduces the dead weight of parts that are only in use during a battery charging cycle.

- Size reduction — The physical bulk of power supply components can be shed from portable or handheld devices, slimming them considerably.

- Ease of replacement — Power supplies are prone to failure, due to their exposure to power spikes and their internal generation of waste heat. External power supplies exemplify the design principle of modularity, in that they can be easily unplugged and replaced if they should fail.

- Configuration versatility — Externally-powered electronic products can be used with different power sources as needed (e.g. 120VAC, 240VAC, 12VDC, or external battery pack), for convenient use in the field, or when traveling.

- Simplified product inventory and distribution — An electronic product that is sold and used internationally must be powered from a wide range of power sources, and must meet product safety regulations in many jurisdictions. The configuration modularity enabled by a separate, external power supply and/or power cord allow satisfying these diverse power requirements with a small number of product SKUs, reducing product inventory costs and overhead costs of warehousing and distribution.

Problems

"Power brick" in-line configuration, with detachable AC cord at left

Whilst useful for many purposes, some external AC adapters have attracted criticism. Problems with this type of power supply may include:

- Size — The power supply may obscure other power sockets; some power strips attempt to relieve this problem by varying the spacing between their sockets.
- Weight — Some AC adapters can be heavy, exerting excess weight on the plug socket (this depends on the socket design of the country in question). Some external power supplies are "power bricks" having a short AC cord so they can lie on the floor, thus relieving strain, at the expense of clutter. Other wall-hanging types are made long and thin, minimizing the leverage of their weight vector that pulls the plug out, at the expense of exacerbating the size problem. Heavy adapters are a burden on travelers, especially if several different ones must be carried for various equipment.
- Inefficiency — Some AC adapters, especially older linear power supplies, waste significant electrical energy while in use, or even when the powered device is not in use or disconnected.
- Confusion — Some consumers are unable to choose or obtain a suitable replacement AC adapter for a given small appliance. This can result in the large scale discarding of "orphaned" adapters and equipment which have been separated from each other. The sheer number of partially incompatible adapters in use can be overwhelming, especially in the absence of clear labeling. Still worse, mismatching of adapters can cause severe equipment damage, or even fire.

Efficiency

Millions of still-usable AC power adapters are thrown out annually, because of poor compatibility with new equipment.

The issue of inefficiency of some power supplies has become more well known, with US president George W. Bush referring in 2001 to such devices as "Energy Vampires". Legislation is being enacted in the EU and a number of states, including California, to reduce the level of energy wasted by some of these devices.

But others have argued that these inefficient devices are low powered, e.g., devices that are used for small battery chargers, so even if they have a low efficiency, the amount of energy they waste is less than 1% of household consumption of electric energy.

Considering the total efficiency of power supplies for small electronic equipment, the older mains-frequency linear transformer-based power supply was found in a 2002 report to have efficiencies from 20–75%, and have considerable energy loss even when powered up but not supplying power. Switched-mode power supplies (SMPSs) are much more efficient; a good design can be 80–90% efficient, and is also much smaller and lighter. In

2002 most external plug-in "wall wart" power adapters commonly used for low-power consumer electronics devices were of linear design, as well as supplies built into some equipment. External supplies are usually left plugged in even when not in use, and consume from a few watts to 35 watts of power in that state. The report concluded that about 32 billion kilowatt-hours (kWh) per year, about 1% of total electrical energy consumption, could be saved in the United States by replacing all linear power supplies (average efficiency 40–50%) with advanced switching designs (efficiency 80–90%), by replacing older switching supplies (efficiencies of less than 70%) with advanced designs (efficiency of at least 80%), and by reducing standby consumption of supplies to not more than 1 watt.

Since the report was published, SMPSs have indeed replaced linear supplies to a great extent, even in wall warts. The 2002 report estimated that 6% of electrical energy used in the US "flows through" power supplies (not counting only the wall warts). The website where the report was published said in 2010 that despite the spread of SMPSs, "today's power supplies consume at least 2% of all U.S. electricity production. More efficient power supply designs could cut that usage in half"

Since wasted electrical energy is released as heat, an inefficient power supply is hot to the touch, as is one that wastes power without an electrical load. This waste heat is itself a problem in warm weather, since it often requires additional air conditioning to remove the unwanted heat.

Reuse

"Universal" DC power adapter, with a cigarette lighter power plug for obtaining power from an automobile.

AC adapters are often reused on other appliances, but there are 5 parameters which all must suit the appliance:

- Voltage
- Current capacity
- Polarity (or AC)
- Voltage regulation (or stabilization)
- Connector type

"Universal" adapters are available on which the user can adjust these parameters.

Universal power adapters

A six-way connector on a "universal" DC power supply, consisting of a 4-way X connector and two separate individual connectors. The X-connector here provides 3.5 and 2.5 mm phone plugs and two sizes of coaxial power connector

One inherent disadvantage of *external* power adapters is that they can get separated from the product they are intended to power. Consequently, there is a market for replacement adapters. In addition, failed power supplies must be replaced. Not only must the replacement match voltage, current, and polarity requirements, but it must also match the connector. Many electrical products are poorly labeled with information about the power supply they require, so it is prudent to record the specifications of the original power supply in advance, to ease replacement if the original is later lost. Careful labeling of power adapters can also reduce the likelihood of a disastrous mixup which could cause equipment damage.

Some so-called "universal" replacement power supplies allow the voltage and polarity to be switched, which can ease the matching problem. In addition, the power connector must be matched.

Four-way **X connectors** or six-way **star connectors**, also known as **spider connectors**, with multiple plug sizes and types are common on generic power supplies. Other replacement power supplies have arrangements for changing the power connector, with from four to nine different alternatives available when purchased in a set. RadioShack sells universal AC adapters of various capacities, branded as "Enercell Adaptaplug", and fitted with 2-pin female sockets compatible with their Adaptaplug connector lineup. This allows many different configurations of AC adapters to be put together, without requiring soldering. Philmore and other competing brands offer similar AC adapters with interchangeable connectors.

A suitable power supply for a particular use must have the matching plug dimensions, the matching DC (or AC) voltage and polarity, and the ability to supply at least the required current. The input voltage must match the wall socket (115/230 VAC at 60/50 Hz) or other power source, such as 12VDC automotive battery power.

But the label on a power supply may not be a reliable guide to the actual voltage it supplies under varying conditions. Most low-cost power supplies are "unregulated", in that their voltage can change appreciably with load. If they are lightly loaded, they may put out much more than the nominal "name plate" voltage, which could damage the load. If they are heavily loaded, the output voltage may droop appreciably, in some cases well below the nominal label voltage even within the nominal rated current, causing the equipment being supplied to malfunction or be damaged. Cheap external power supplies of traditional design with undersized transformers tend to have poor regulation, whether originally-supplied or replacement units.

In general, more modern high-quality switched-mode power supplies (SMPSs) are smaller, more efficient, and put out a much more constant voltage even as the input voltage and the load current may vary. Configurable switched-mode power supplies have come down considerably in price, and they are especially convenient for use when traveling because of their decreased weight and size.

Standards

AC adapters capable of powering USB devices. Automotive 12VDC models are also available (not shown).

A de facto standard has emerged in low-power AC adapters, namely the USB connector. Although the original purpose of this design was to enable serial digital data exchange, the USB standard also provided the option of providing 5VDC power, up to 500mA per device. This standard has been become sufficiently widespread that numerous accessory gadgets ("USB decorations") are available which connect to USB only for DC power, and not for data interchange. Electric fans, lamps, alarms, coffee warmers, battery chargers, and even toys have been designed to tap power from a USB connector. Plug-in adapters are widely available to convert 115VAC or 230VAC power or 12VDC automotive power to 5VDC USB power.

Portable "USB chargers" are available which convert energy from an internal battery to deliver DC power via a standard USB connnector, which can used to power a variety of portable electronics (e.g. MP3 player, cellphone). There is even a popular DIY Open Hardware USB charger which can be built from a kit. Also, pocket-sized portable "USB battery packs" are available which can charge from a powered USB port, and can later in turn provide power from their own USB port.

The trend towards more-compact electronic devices has driven a shift towards the micro-USB connector, which is identical in function to the original USB connector but physically smaller. In 2009, the International Telecommunication Union (ITU) announced adoption of a world standard based on the micro-USB connector and interchangeable chargers for standards-compliant cellphones. This should markedly reduce the profusion of non-interchangeable power adapters previously needed for each year's new crop of cellphone models.

Note that the previous assertions regarding USB power and the micro-USB charger standards are fairly-well documented in the USB article, and interested readers are referred there for much more detailed information.

Substitutes

A "Green Plug" system has been proposed, based on USB technology, by which the consuming device would tell the external power supply what kind of power is needed. Some commercial adapters, for example those by iGo, already automatically set their output according to which of a range of interchangeable tips is fitted; tips are available to fit and supply appropriate power to many notebook computers and mobile devices. Adapters can be manufactured to operate from any AC mains supply anywhere in the world (however iGo products are not available in many countries, including Australia) with an appropriate interchangeable plug and voltage-tolerant circuitry, and also operate from 12V DC vehicle supplies—a truly universal device.

Larry Page, a founder of Google, has proposed a 12V 15A standard for almost all equipment requiring an external converter. New buildings would also have 12V DC wiring, so that in effect the AC adapter would be built into the wall.

Chapter-4

80 PLUS

80 PLUS is an initiative to promote energy efficiency in computer power supply units (PSU). It certifies products that have more than 80% energy efficiency at 20%, 50% and 100% of rated load, and a power factor of 0.9 or greater at 100% load. That is, PSUs that waste 20% or less electric energy as heat at the specified load levels, thus reducing electricity use and bills compared to less efficient PSUs. Sometimes rebates are given for manufacturers who use 80 PLUS-certified PSUs.

History

- Ecos & EPRI develop the Generalized Internal Power Supply Efficiency Test Protocol for desktop derived multi-output power supplies
- In March 2004 the 80 PLUS idea was presented as an initiative at the ACEEE Market Transformation Symposium.
- In February 2005 the first market ready power supply was created by Seasonic.
- In 2006 Energy Star added 80 PLUS requirements to their upcoming (in effect since July 2007) Energy Star 4.0 computer specifications.
- In November and February 2006 HP and Dell certify their PSUs to the 80 PLUS spec.
- July 20, 2007 — ENERGY STAR Computer Specification 4.0 goes into effect. The specification includes 80 PLUS power supply efficiency levels for desktop computers.
- December 2007 — over 200 PSUs on the market are 80 PLUS certified and it is becoming the market standard.
- First quarter 2008 — Standards revised to add Bronze, Silver and Gold higher efficiency level certifications.
- October 2009 - Added specification for Platinum efficiency level.

Efficiency level certifications

80 PLUS Test Type	115V Internal Non-Redundant			230V Internal Redundant		
Fraction of Rated Load	20%	50%	100%	20%	50%	100%
80 PLUS	80%	80%	80%	Not defined		
80 PLUS Bronze	82%	85%	82%	81%	85%	81%
80 PLUS Silver	85%	88%	85%	85%	89%	85%
80 PLUS Gold	87%	90%	87%	88%	92%	88%
80 PLUS Platinum	90%	92%	89%	90%	94%	91%

Redundant are typically used in data centers.

For the higher certification levels, the requirement of 0.9 or better power factor was extended to apply to 20% and 50% load levels, as well as at 100% load. The Platinum level requires 0.95 or better power factor for servers.

The Climate Savers Computing Initiative efficiency level targets for workstations for 2007 through 2011, correspond to the 80 PLUS certification levels. From July 2007 through June 2008, basic 80 PLUS level (Energy Star 4.0). For next year target is, 80 PLUS bronze level, the following year 80 PLUS silver, then 80 PLUS gold, and finally platinum.

Misleading power supply advertising

There have been a few instances where companies claim or imply that their supplies are 80 PLUS when they haven't been certified, and in some cases do not meet the requirements. When a company resells an OEM power supply under a new name it must be certified under the new name and company, even if the OEM supply is certified. In some instances a reseller has claimed a higher wattage than the supply can deliver - in which case the reseller's supply would not meet 80 PLUS requirements. The 80 PLUS web site has a list of all certified supplies, so it is possible to confirm that a supply really meets the requirements.

Although some power supply manufacturers name their products with similar names, like "85 Plus," there is no such official certification or standard.

What it means

The efficiency of a computer power supply is its output power divided by its input power. The remaining power is converted into heat. For instance, a 600-watt power supply with 60% efficiency running at full load would draw 1000W from the mains and would therefore waste 400W as heat. On the other hand a 600-watt power supply with 80%

efficiency running at full load would draw 750W from the mains and would therefore waste only 150W as heat.

For a given power supply, efficiency varies depending on how much power is being delivered. Supplies are typically most efficient at between half and three quarters load, much less efficient at low load, and somewhat less efficient at maximum load. Older ATX power supplies were typically 60% to 75% efficient. To qualify for 80 PLUS, a power supply must achieve at least 80% efficiency at three specified loads (20%, 50% and 100% of maximum rated power). However, 80 PLUS supplies may still be less than 80% efficient at lower loads. For instance, an 80 PLUS, 520 watt supply could still be 70% or less efficient at 60 watts (a typical idle power for a desktop computer). Thus it is still important to select a supply with capacity appropriate to the device being powered.

It is easier to achieve the higher efficiency levels for higher wattage supplies, so gold and platinum supplies may be less available in consumer level supplies of reasonable capacity for typical desktop machines.

Typical computer power supplies may have power factors as low as 0.5 to 0.6. The higher power factor reduces the peak current draw, reducing load on the circuit or on an uninterruptible power supply.

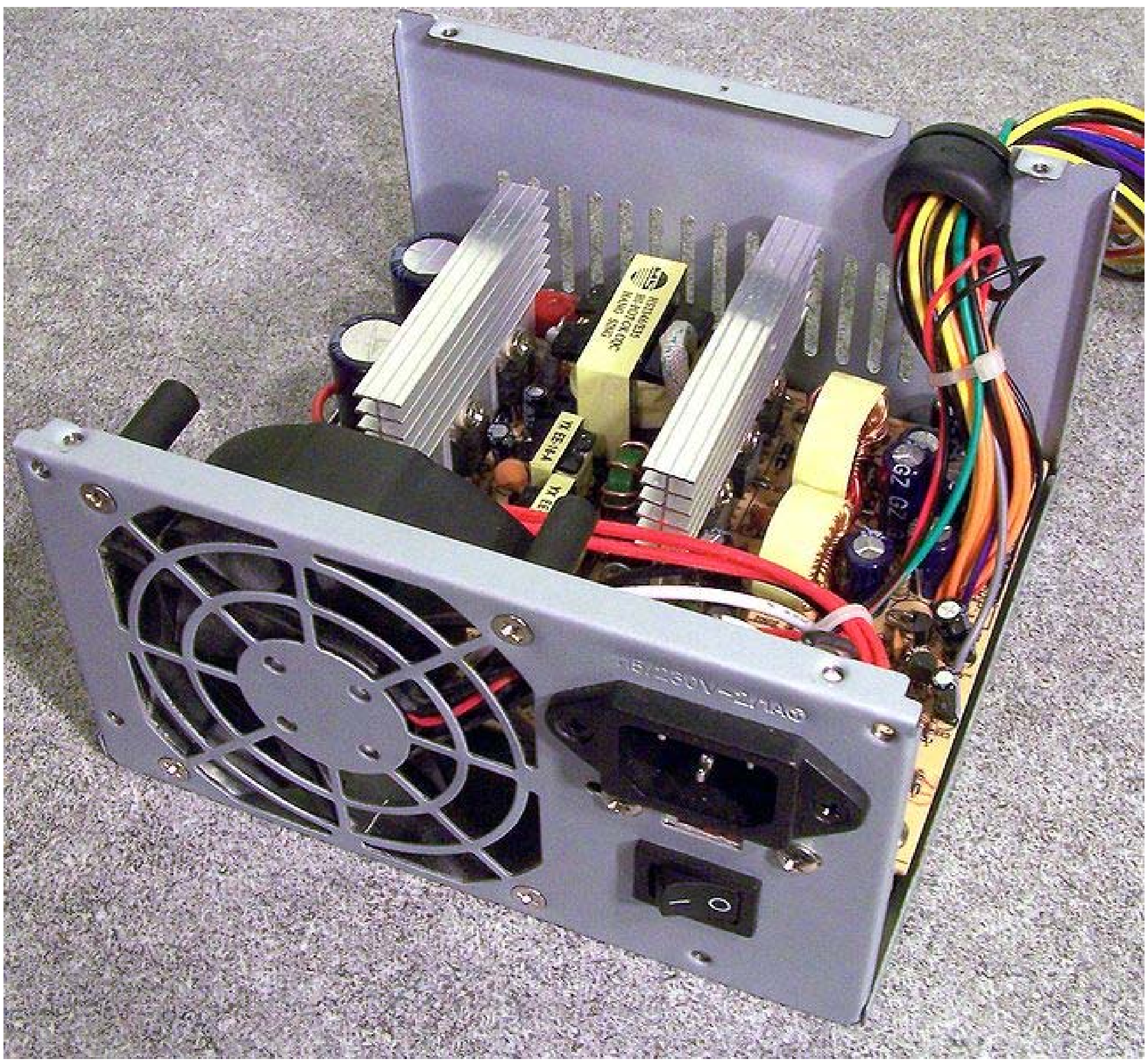
Reducing the heat output of the computer helps reduce noise, since fans do not have to spin as fast to cool the computer. Reduced heat and resulting lower cooling demands may increase computer reliability.

The testing conditions may give an unrealistic expectation of efficiency for heavily loaded, high power (rated much larger than 300W) supplies. A heavily loaded power supply and the computer it is powering generate significant amounts of heat, which may raise the power supply temperature, which is likely to decrease its efficiency. Since power supplies are certified at room temperature, this effect is not taken into account.

80PLUS does not set efficiency targets for very low load. For instance, generation of standby power may still be relatively inefficient, and may not meet requirements of the One Watt Initiative. Testing of 80 PLUS power supplies shows that they vary considerably in standby efficiency. Some consume half a watt or less in standby with no load, where others consume several times as much at standby, even though they may meet higher 80PLUS certification requirement levels. Inefficiencies in generating standby power are magnified by the amount of time that computers spend turned off.

Chapter-5

Power Supply Unit (Computer)



The top cover has been removed to show the internals of a computer Power supply unit.

A **power supply unit** (**PSU**) is the component that supplies power to the other components in a computer. More specifically, a power supply unit is typically designed to convert general-purpose alternating current (AC) electric power from the mains (100-127V in North America, parts of South America, Japan, and Taiwan; 220-240V in most of the rest of the world) to usable low-voltage direct current (DC) power for the internal components of the computer. Some power supplies have a switch to change between 230 V and 115 V. Other models have automatic sensors that switch input voltage automatically, or are able to accept any voltage between those limits.

The most common computer power supplies are built to conform to the ATX form factor. This enables different power supplies to be interchangeable with different components inside the computer. ATX power supplies also are designed to turn on and off using a signal from the motherboard, and provide support for modern functions such as the standby mode available in many computers. The most recent specification of the ATX standard PSU as of mid-2008 is version 2.31.

Power rating

Computer power supplies are rated based on their maximum output power. Typical power ranges are from 500 W to lower than 300 W for small form factor systems intended as ordinary home computers, the use of which is limited to web-surfing and burning and playing DVDs. Power supplies used by gamers and enthusiasts mostly range from 450 W to 1400 W. Typical gaming PCs feature power supplies in the range of 500-800 W, with higher-end PCs demanding 800-1400 W supplies. The highest-end units are up to 2 kW strong and are intended mainly for servers and, to a lesser degree, extreme performance computers with multiple processors, several hard disks and multiple graphics cards. The power rating of a PC power supply is not officially certified and is self-claimed by each manufacturer. A common way to reach the power figure for PC PSUs is by adding the power available on each rail, which will not give a true power figure. Therefore it is possible to overload a PSU on one rail without having to use the maximum rated power.

This may mean that if:

- PSU A has a **peak** rating of **550 watts at 25°C**, with **25 amps** (300 W) **on** the **12 volt** line, and
- PSU B has a **continuous** rating of **450 watts at 40°C**, **with 33 amps** (400 W) **on** the **12 volt** line,

and if those ratings are accurate, then PSU B would have to be considered a vastly superior unit, despite its lower overall power rating. PSU A may only be capable of delivering a fraction of its rated power under real world conditions.

This tendency has led in turn to greatly overspecified power supply recommendations, and a shortage of high-quality power supplies with reasonable capacities. Very few computers require more than 300–350 watts maximum. Higher end computers such as servers and gaming machines with multiple high power GPUs are among the few exceptions, although in recent years the power demand of "video cards" in the ability to watch high definition (HD) media has led to even the average ATX computer to consume between 400 and 500 watts.

Appearance

Most computer power supplies are a square metal box, and have a large bundle of wires emerging from one end. Opposite the wire bundle is the back face of the power supply, with an air vent and C14 IEC connector to supply AC power. There may optionally be a power switch and/or a voltage selector switch. A label on one side of the box lists technical information about the power supply, including safety certifications maximum output power. Common certification marks for safety are the UL mark, GS mark, TÜV, NEMKO, SEMKO, DEMKO, FIMKO, CCC, CSA, VDE, GOST R and BSMI. Common certificate marks for EMI/RFI are the CE mark, FCC and C-tick. The CE mark is required for power supplies sold in Europe and India.

A RoHS or 80 PLUS can also sometimes be seen.

Dimensions of an ATX power supply are 150 mm width, 86 mm height, and typically 140 mm depth, although the depth can vary from brand to brand.

Connectors

Various connectors from a computer PSU.

Typically, power supplies have the following connectors:

- **PC Main** power connector (usually called **P1**): This is the connector that goes to the motherboard to provide it with power. The connector has 20 or 24 pins. One of the pins belongs to the PS-ON wire (it is usually green). This connector is the largest of all the connectors. In older AT power supplies, this connector was split in two: **P8** and **P9**. A power supply with a 24-pin connector can be used on a motherboard with a 20-pin connector. In cases where the motherboard has a 24-

pin connector, some power supplies come with two connectors (one with 20-pin and other with 4-pin) which can be used together to form the 24-pin connector.

- **ATX12V** 4-pin power connector (also called the **P4 power connector**). A second connector that goes to the motherboard (in addition to the main 24-pin connector) to supply dedicated power for the processor. For high-end motherboards and processors, more power is required, therefore EPS12V has an 8 pin connector.
- **4-pin Peripheral** power connectors (usually called **Molex** for its manufacturer): These are the other, smaller connectors that go to the various disk drives of the computer. Most of them have four wires: two black, one red, and one yellow. Unlike the standard mains electrical wire color-coding, each *black wire* is a ground, the *red wire* is +5 V, and the *yellow wire* is +12 V. In some cases these are also used to provide additional power to PCI cards such as FireWire 800 cards.
- **4-pin Berg** power connectors (usually called **Mini-connector** or "mini-Molex"): This is one of the smallest connectors that supplies the floppy drive with power. In some cases, it can be used as an auxiliary connector for AGP video cards. Its cable configuration is similar to the Peripheral connector.
- **Auxiliary** power connectors: There are several types of auxiliary connectors designed to provide additional power if it is needed.
- **Serial ATA** power connectors: a 15-pin connector for components which use SATA power plugs. This connector supplies power at three different voltages: +3.3, +5, and +12 volts.
- **6-pin** Most modern computer power supplies include 6-pin connectors which are generally used for PCI Express graphics cards, but a newly introduced 8-pin connector should be seen on the latest model power supplies. Each PCI Express 6-pin connector can output a maximum of 75 W.
- **6+2 pin** For the purpose of backwards compatibility, some connectors designed for use with high end PCI Express graphics cards feature this kind of pin configuration. It allows either a 6-pin card or an 8-pin card to be connected by using two separate connection modules wired into the same sheath: one with 6 pins and another with 2 pins.
- A **C14 IEC connector** with an appropriate C13 cord is used to attach the power supply to the local power grid.

AT vs. ATX

A typical installation of an ATX form factor computer power supply.

There are two basic differences between AT and ATX power supplies: The connectors that provide power to the motherboard, and the soft switch. On older AT power supplies, the Power-on switch wire from the front of the computer is connected directly to the power supply.

On newer ATX power supplies, the power switch on the front of the computer goes to the motherboard over a connector labeled something like; PS ON, Power SW, SW Power, etc. This allows other hardware and/or software to turn the system on and off.

The motherboard controls the power supply through pin #14 of the 20 pin connector or #16 of the 24 pin connector on the motherboard. This pin carries 5V when the power supply is in standby. It can be grounded to turn the power supply on without having to turn on the rest of the components. This is useful for testing or to use the computer ATX power supply for other purposes.

AT stands for **A**dvanced **T**echnology when ATX means **A**dvanced **T**echnology e**X**tended.

Laptops

Most portable computers have power supplies that provide 25 to 200 watts. In portable computers (such as laptops) there is usually an external power supply (sometimes referred to as a "power brick" due to its similarity, in size, shape and weight, to a real brick) which converts AC power to one DC voltage (most commonly 19 V), and further

DC-DC conversion occurs within the laptop to supply the various DC voltages required by the other components of the portable computer.

Servers

Some web servers use a single-voltage 12 volt power supply. All other voltages are generated by voltage regulator modules on the motherboard.

Energy efficiency

Computer power supplies are generally about 70–75% efficient. That means in order for a 75% efficient power supply to produce 75 W of DC output it would require 100 W of AC input and dissipate the remaining 25 W in heat. Higher-quality power supplies can be over 80% efficient; higher energy efficient PSU's waste less energy in heat, and requires less airflow to cool, and as a result will be quieter. Google's server power supplies are more than 90% efficient. HP's server power supplies have reached 94% efficiency. Standard PSUs sold for server workstations have around 90% efficiency, as of 2010.

It's important to match the capacity of a power supply to the power needs of the computer. The energy efficiency of power supplies drops significantly at low loads. Efficiency generally peaks at about 50-75% load. The curve varies from model to model (examples of how this curve looks can be seen on test reports of energy efficient models found on the 80 PLUS website). As a rule of thumb for standard power supplies it is usually appropriate to buy a supply such that the calculated typical consumption of one's computer is about 60% of the rated capacity of the supply provided that the calculated maximum consumption of the computer does not exceed the rated capacity of the supply. Note that advice on overall power supply ratings often given by the manufacturer of single component, typically graphics cards, should be treated with great skepticism. These manufacturers want to minimize support issues due to under rating of the power supply specifications and advise customers to use a more powerful power supply to avoid these issues.

Various initiatives are underway to improve the efficiency of computer power supplies. Climate savers computing initiative promotes energy saving and reduction of greenhouse gas emissions by encouraging development and use of more efficient power supplies. 80 PLUS certifies power supplies that meet certain efficiency criteria, and encourages their use via financial incentives. On top of that the businesses end up using less electricity to cool the PSU and the computer's themselves and thus save an initially large sum(i.e. incentive + saved electricity = higher profit).

Facts

Redundant power supply.

- Life span is usually measured in mean time between failures (MTBF). Higher MTBF ratings are preferable for longer device life and reliability. Quality construction consisting of industrial grade electrical components and/or a larger or higher speed fan can help to contribute to a higher MTBF rating by keeping critical components cool, thus preventing the unit from overheating. Overheating is a major cause of PSU failure. MTBF value of 100,000 hours (about 11 years continuous operation) is not uncommon.

- Power supplies may have passive or active power factor correction (PFC). Passive PFC is a simple way of increasing the power factor by putting a coil in series with the primary filter capacitors. Active PFC is more complex and can achieve higher PF, up to 99%.

- In computer power supplies that have more than one +12V power rail, it is preferable for stability reasons to spread the power load over the 12V rails evenly to help avoid overloading one of the rails on the power supply.
    - Multiple 12V power supply rails are separately current limited as a safety feature; they are not generated separately. Despite widespread belief to the contrary, this separation has no effect on mutual interference between supply rails.
    - The ATX12V 2.x and EPS12V power supply standards defer to the IEC 60950 standard, which requires that no more than 240 volt-amps be present between any two accessible points. Thus, each wire must be current-limited to no more than 20 A; typical supplies guarantee 18 A without triggering the current limit. Power supplies capable of delivering more than 18 A at 12 V connect wires in groups to two or more current sensors which will shut down the supply if excess current flows. Unlike a fuse or circuit breaker, these limits reset as soon as the overload is removed.
    - Because of the above standards, almost all high-power supplies claim to implement separate rails, however this claim is often false; many omit the necessary current-limit circuitry, both for cost reasons and because it is an irritation to customers. (The lack is sometimes advertised as a feature under names like "rail fusion" or "current sharing".)

- When the computer is powered down but the power supply is still on, it can be started remotely via Wake-on-LAN and Wake-on-Ring or locally via Keyboard Power ON (KBPO) if the motherboard supports it.

- Early PSUs used a conventional (heavy) step-down transformer, but most modern computer power supplies are a type of switched-mode power supply (SMPS) with a ferrite-cored High Frequency transformer.

- Computer power supplies may have short circuit protection, overpower (overload) protection, overvoltage protection, undervoltage protection, overcurrent protection, and over temperature protection.

- Some power supplies come with sleeved cables, which is aesthetically nicer, makes wiring easier and cleaner and have less detrimental effect on airflow.

- There is a popular misconception that a greater power capacity (watt output capacity) is always better. Since supplies are self-certified, a manufacturer's claims may be double or more what is actually provided. Although a too-large power supply will have an extra margin of safety as far as not over-loading, a larger unit is often less efficient at lower loads (under 20% of its total capability) and therefore will waste more electricity than a more appropriately sized unit. Additionally, computer power supplies generally do not function properly if they are too lightly loaded. (less than about 15% of the total load.) Under no-load conditions they may shut down or malfunction.For this reason the no-load protection was introduced in some power supplies.

- Another popular misconception is that the greater the total watt capacity is, the more suitable the power supply becomes for higher-end graphics cards. The most important factor for judging a PSUs suitability for certain graphics cards is the PSUs total 12V output, as it is that voltage on which modern graphics cards operate. If the total 12V output stated on the PSU is higher than the suggested minimum of the card, then that PSU can fully supply the card. It is however recommended that a PSU should not just cover the graphics cards' demands, as there are other components in the PC that depend on the 12V output, including the CPU , disk drives and optical drives.

- Power supplies can feature magnetic amplifiers or double-forward converter circuit design.

Wiring diagrams

AT power connector (Used on older AT style mainboards)

Color	Pin	Signal
	P8.1	Power Good
	P8.2	+5 V
	P8.3	+12 V
	P8.4	−12 V
	P8.5	Ground
	P8.6	Ground
	P9.1	Ground
	P9.2	Ground
	P9.3	−5 V
	P9.4	+5 V
	P9.5	+5 V
	P9.6	+5 V

24-pin ATX12V 2.x power supply connector
(20-pin omits the last four: 11, 12, 23 and 24)

Color	Signal	Pin	Pin	Signal	Color
Orange	+3.3 V	1	13	+3.3 V	Orange

				+3.3 V sense	Brown
Orange	+3.3 V	2	14	−12 V	Blue
Black	Ground	3	15	Ground	Black
Red	+5 V	4	16	Power on	Green
Black	Ground	5	17	Ground	Black
Red	+5 V	6	18	Ground	Black
Black	Ground	7	19	Ground	Black
Grey	Power good	8	20	Reserved	N/C
Purple	+5 V standby	9	21	+5 V	Red
Yellow	+12 V	10	22	+5 V	Red
Yellow	+12 V	11	23	+5 V	Red
Orange	+3.3 V	12	24	Ground	Black

- Pins 8, 13, and 16 (shaded) are control signals, not power:
  - "Power On" is pulled up to +5V by the PSU, and must be driven low to turn on the PSU.
  - "Power good" is low when other outputs have not yet reached, or are about to leave, correct voltages.
  - The "+3.3 V sense" line is for remote sensing.
- Pin 20 (formerly −5V, white wire) is absent in current power supplies; it was optional in ATX and ATX12V ver. 1.2, and deleted as of ver. 1.3.
- The right-hand pins are numbered 11–20 in the 20-pin version.

Modular power supplies

A **modular power supply** is a relatively new approach to cabling, allowing users to omit unused cables. Whereas a conventional design has numerous cables permanently connected to the power supply, a modular power supply provides connectors at the power supply end, allowing unused cables to be detached from the power supply, producing less clutter, a neater appearance and less interference with airflow. It also makes it possible to supply a wider variety of cables, providing different lengths of Serial ATA power connectors instead of Molex connectors.

While modular cabling can help reduce case clutter, they have often been criticized for creating electrical resistance. Some third party websites that do power supply testing have confirmed that the quality of the connector, the age of the connector, the number of times it was inserted/removed, and various other variables such as dust can all raise resistance. However, this is somewhat inconsequential as the amount of this resistance in a good connector is small compared to the resistance generated by the length of the wire itself.

Chapter-6

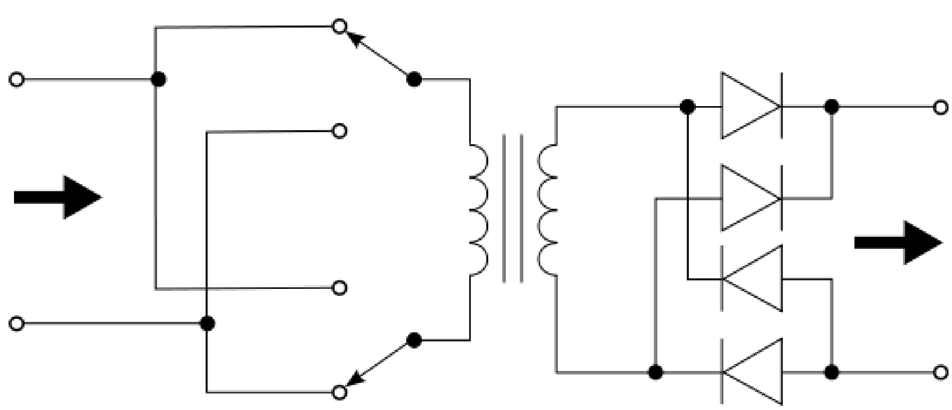
Push–pull Converter and Single-ended Primary-inductor Converter

Push–pull converter

A **push–pull converter** is a type of DC to DC converter that uses a transformer to change the voltage of a DC power supply. The transformer's ratio is arbitrary but fixed; however, in many circuit implementations the duty cycle of the switching action can be varied to effect a range of voltage ratios. The primary advantages of push–pull converters are their simplicity and ability to scale up to high power throughput, earning them a place in industrial DC power applications.

The push–pull converter is similar to the flyback converter and especially the forward converter.

Circuit operation



The term *push–pull* is sometimes used to generally refer to any converter with bidirectional excitation of the transformer. For example, in a full-bridge converter, the switches (connected as an H-bridge) alternate the voltage across the supply side of the transformer, causing the transformer to function as it would for AC power and produce a voltage on its output side.

However, *push–pull* more commonly refers to a two-switch topology with a split primary winding.

In any case, the output is then rectified and sent to the load. Capacitors are often included at the output to buffer against the inevitable switching noise.

In practice, it is necessary to allow a small interval between powering the transformer one way and powering it the other: the "switches" are usually pairs of transistors (or similar devices), and were the two transistors in the pair to switch simultaneously there would be a risk of shorting out the power supply. Hence, a small wait is needed to avoid this problem. This wait time is called "Dead Time" and is necessary to avoid transistor shoot-through.

Transistors

N-type and P-type power transistors can be used. Power MOSFETs are often chosen for this role due to their high current switching capability and their inherently low ON resistance. The gates (base) of the power transistors are tied via a resistor to one of the supply voltages. A P-type transistor is used to pull up the N-type power transistor gate (common source) and an N-type transistor is used to pull down the P-type power transistor gate.

Alternatively, all power transistors can be N-type, which offer around three times the gain of their P-type equivalents. In this alternative the N-type transistor used in place of the P-type has to be driven in this way: The voltage is amplified by one P-type transistor and one N-type transistor in common base configuration to rail-to-rail amplitude. Then the power transistor is driven in common drain configuration to amplify the current.

In high frequency applications both transistors are driven with common source.

The operation of the circuit means that both transistors are actually pushing, and the pulling is done by a low pass filter (coil) in general, and by a center tap of the transformer in the converter application. But because the transistors push in an alternating fashion, the device is called a push–pull converter.

Timing

If both transistors are in their on state, a short circuit results. On the other hand if both transistors are in their off state, high voltage peaks appear due to back EMF.

If the driver for the transistors is powerful and fast enough, the back EMF has no time to charge the capacity of the windings and of the body-diode of the MOSFETs to high voltages.

If a microcontroller is used, it can be used to measure the peak voltage and digitally adjust the timing for the transistors, so that the peak only just appears. This is especially useful when the transistors are starting from cold with no peaks, and are in their boot phase.

The cycle starts with no voltage and no current. Then one transistor turns on, a constant voltage is applied to the primary, current increases linearly, and a constant voltage is induced in the secondary. After some time T the transistor is turned off, the parasitic capacities of the transistors and the transformer and the inductance of the transformer form an LC circuit which swings to the opposite polarity. Then the other transistor turns on. For the same time T charge flows back into the storage capacitor, then changes the direction automatically, and for another time T the charge flows in the transformer. Then again the first transistor turns on until the current is stopped. Then the cycle is finished, another cycle can start anytime later. The S-shaped current is needed to improve over the simpler converters and deal efficiently with remanence.

Single-ended primary-inductor converter

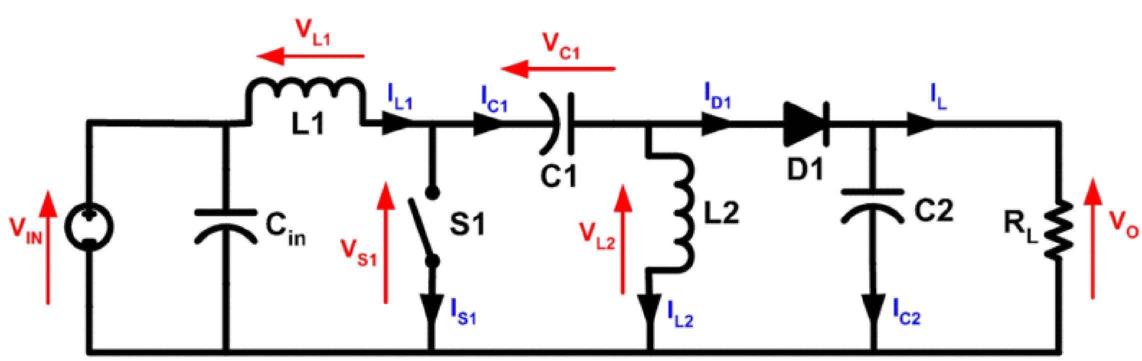


Figure 1: Schematic of SEPIC

Single-ended primary-inductor converter (**SEPIC**) is a type of DC-DC converter allowing the electrical potential (voltage) at its output to be greater than, less than, or equal to that at its input; the output of the SEPIC is controlled by the duty cycle of the control transistor.

A SEPIC is similar to a traditional buck-boost converter, but has advantages of having non-inverted output (the output voltage is of the same polarity as the input voltage), the isolation between its input and output (provided by a capacitor in series), and true shutdown mode: when the switch is turned off, its output drops to 0 V.

SEPICs are useful in applications in which a battery voltage can be above and below that of the regulator's intended output. For example, a single lithium ion battery typically discharges from 4.2 volts to 3 volts; if other components require 3.3 volts, then the SEPIC would be effective.

Circuit operation

The schematic diagram for a basic SEPIC is shown in Figure 1. As with other switched mode power supplies (specifically DC-to-DC converters), the SEPIC exchanges energy between the capacitors and inductors in order to convert from one voltage to another. The amount of energy exchanged is controlled by switch S1, which is typically a transistor such as a MOSFET; MOSFETs offer much higher input impedance and lower voltage drop than bipolar junction transistors (BJTs), and do not require biasing resistors (as MOSFET switching is controlled by differences in voltage rather than a current, as with BJTs).

Continuous mode

A SEPIC is said to be in continuous-conduction mode ("continuous mode") if the current through the inductor L1 never falls to zero. During a SEPIC's steady-state operation, the average voltage across capacitor C1 (V_{C1}) is equal to the input voltage (V_{in}). Because capacitor C1 blocks direct current (DC), the average current across it (I_{C1}) is zero, making inductor L2 the only source of load current. Therefore, the average current through inductor L2 (I_{L2}) is the same as the average load current and hence independent of the input voltage.

Looking at average voltages, the following can be written:

$$V_{IN} = V_{L1} + V_{C1} + V_{L2}$$

Because the average voltage of V_{C1} is equal to V_{IN}, $V_{L1} = -V_{L2}$. For this reason, the two inductors can be wound on the same core. Since the voltages are the same in magnitude, their effects of the mutual inductance will be zero, assuming the polarity of the windings is correct. Also, since the voltages are the same in magnitude, the ripple currents from the two inductors will be equal in magnitude.

The average currents can be summed as follows:

$$I_{D1} = I_{L1} - I_{L2}$$

When switch S1 is turned on, current I_{L1} increases and the current I_{L2} increases in the negative direction. (Mathematically, it decreases due to arrow direction.) The energy to increase the current I_{L1} comes from the input source. Since S1 is a short while closed, and the instantaneous voltage V_{C1} is approximately V_{IN}, the voltage V_{L2} is approximately $-V_{IN}$. Therefore, the capacitor C1 supplies the energy to increase the magnitude of the current in I_{L2} and thus increase the energy stored in L2. The easiest way to visualize this is to consider the bias voltages of the circuit in a d.c. state, then close S1.

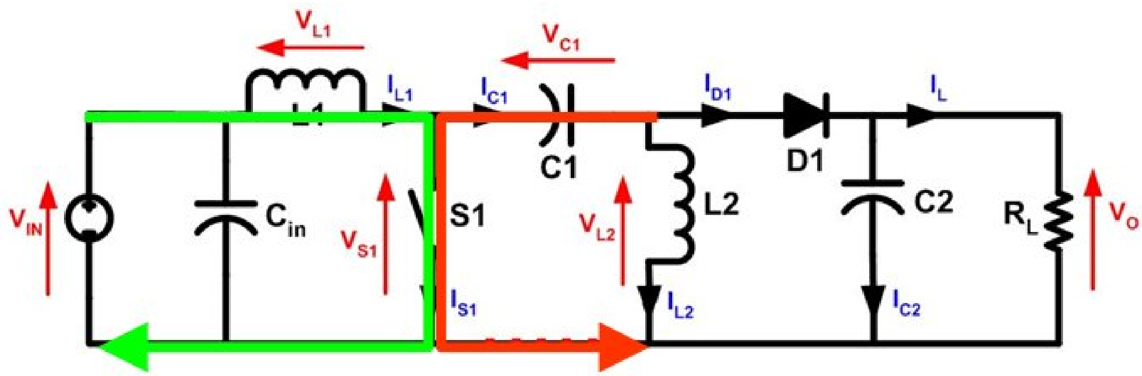


Figure 2: With S1 closed current increases through L1 (green) and C1 discharges increasing current in L2 (red)

When switch S1 is turned off, the current I_{C1} becomes the same as the current I_{L1}, since inductors do not allow instantaneous changes in current. The current I_{L2} will continue in the negative direction, in fact it never reverses direction. It can be seen from the diagram that a negative I_{L2} will add to the current I_{L1} to increase the current delivered to the load. Using Kirchoff's Current Law, it can be shown that $I_{D1} = I_{C1} - I_{L2}$. It can then be concluded, that while S1 is off, power is delivered to the load from both L2 and L1. C1, however is being charged by L1 during this off cycle, and will in turn recharge L2 during the on cycle.

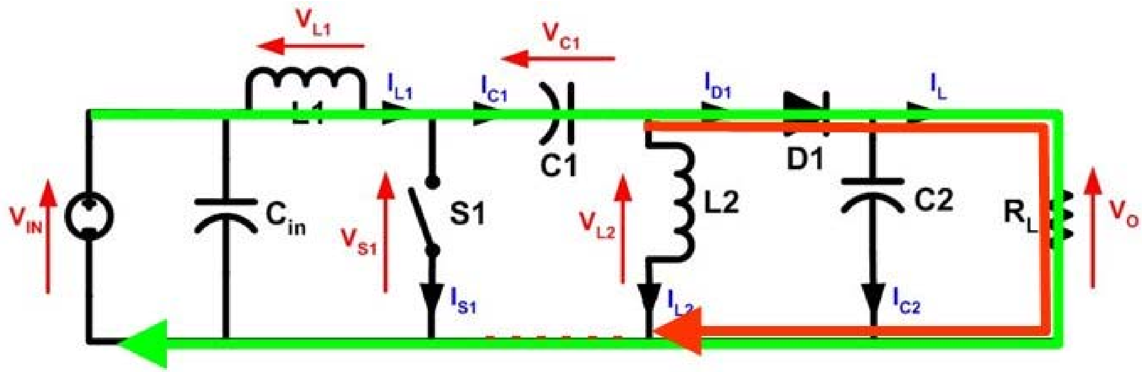


Figure 3: With S1 open current through L1 (green) and current through L2 (red) produce current through the load

Because the potential (voltage) across capacitor C1 may reverse direction every cycle, a non-polarized capacitor should be used. However, a polarized tantalum or electrolytic capacitor may be used in some cases, because the potential (voltage) across capacitor C1 will not change unless the switch is closed long enough for a half cycle of resonance with inductor L2, and by this time the current in inductor L1 could be quite large.

The capacitor C_{IN} is required to reduce the effects of the parasitic inductance and internal resistance of the power supply. The boost/buck capabilities of the SEPIC are possible because of capacitor C1 and inductor L2. Inductor L1 and switch S1 create a standard boost converter, which generate a voltage (V_{S1}) that is higher than V_{IN}, whose magnitude is determined by the duty cycle of the switch S1. Since the average voltage across C1 is V_{IN}, the output voltage (V_O) is V_{S1} - V_{IN}. If V_{S1} is less than double V_{IN}, then the output voltage will be less than the input voltage. If V_{S1} is greater than double V_{IN}, then the output voltage will be greater than the input voltage.

The evolution of switched-power supplies can be seen by coupling the two inductors in a SEPIC converter together, which begins to resemble a Flyback converter, the most basic of the transformer-isolated SMPS topologies.

Discontinuous mode

A SEPIC is said to be in discontinuous-conduction mode (or, discontinuous mode) if the current through the inductor L1 is allowed to fall to zero.

Reliability and Efficiency

The voltage drop and switching time of diode D1 is critical to a SEPIC's reliability and efficiency. The diode's switching time needs to be extremely fast in order to not generate high voltage spikes across the inductors, which could cause damage to components. Fast conventional diodes or Schottky diodes may be used.

The resistances in the inductors and the capacitors can also have large effects on the converter efficiency and ripple. Inductors with lower series resistance allow less energy to be dissipated as heat, resulting in greater efficiency (a larger portion of the input power being transferred to the load). Capacitors with low equivalent series resistance (ESR) should also be used for C1 and C2 to minimize ripple and prevent heat build-up, especially in C1 where the current is changing direction frequently.

Chapter-7

Ćuk Converter and Grid Tie Inverter

Ćuk converter

The **Ćuk converter** is a type of DC-DC converter that has an output voltage magnitude that is either greater than or less than the input voltage magnitude.

The non-isolated Ćuk converter can only have opposite polarity between input and output. It uses a capacitor as its main energy-storage component, unlike most other types of converters which use an inductor. It is named after Slobodan Ćuk of the California Institute of Technology, who first presented the design.

Non-isolated Ćuk converter

Operating Principle

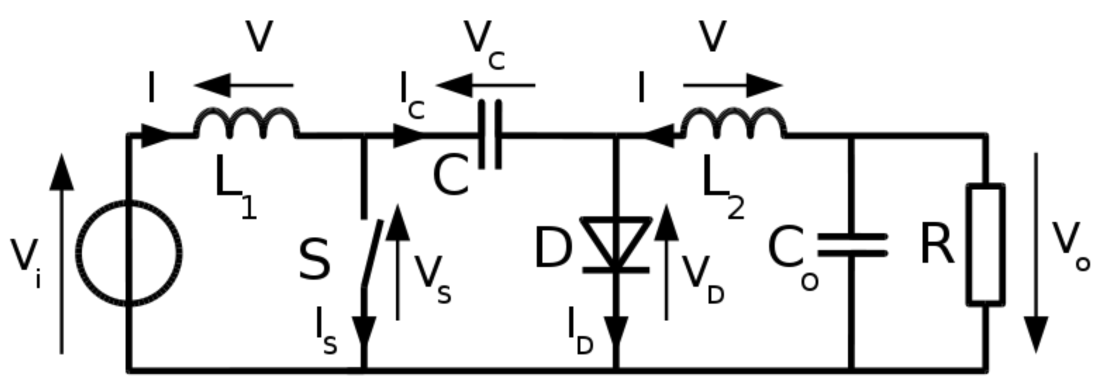


Fig 1: Schematic of a non-isolated Ćuk converter.

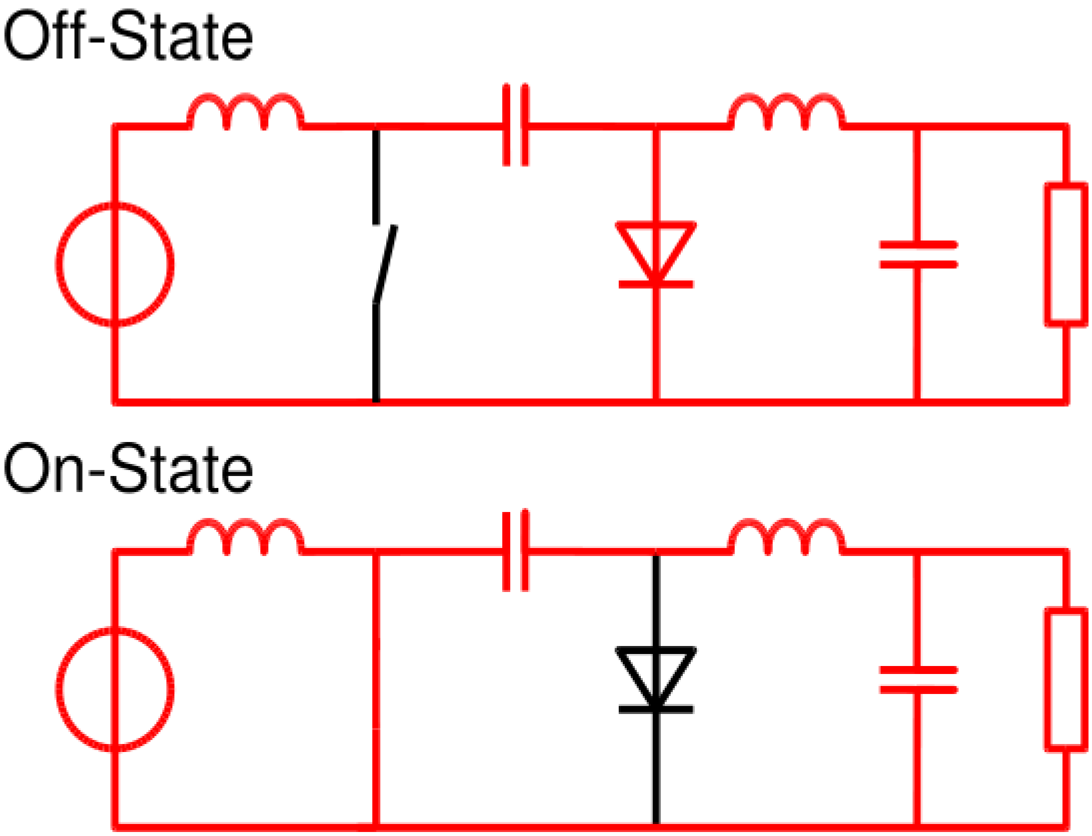


Fig 2: The two operating states of a non-isolated Ćuk converter.

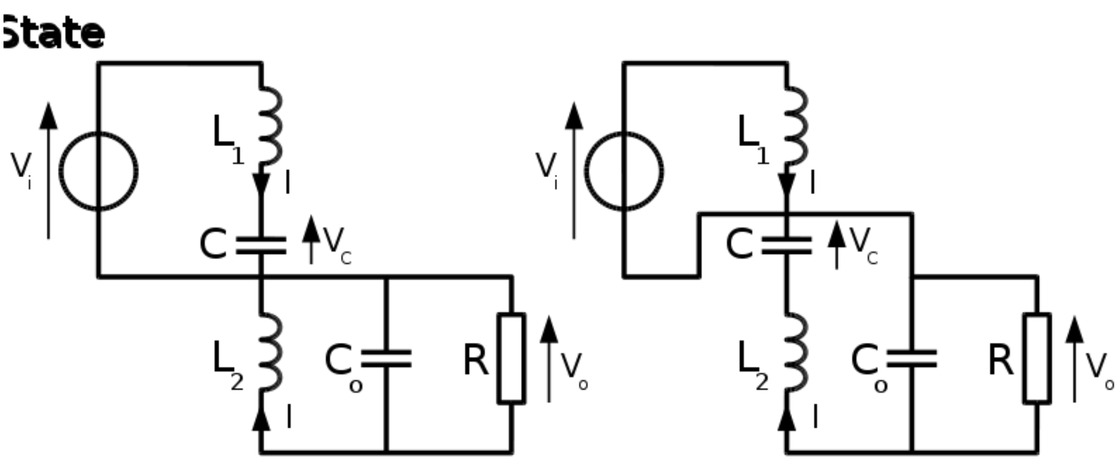


Fig 3: The two operating states of a non-isolated Ćuk converter. In this figure, the diode and the switch are either replaced by a short circuit when they are on or by an open circuit when they are off. It can be seen that when in the Off state, the capacitor C is being charged by the input source through the inductor L_1. When in the On state, the capacitor C transfers the energy to the output capacitor through the inductance L_2.

A non-isolated Ćuk converter comprises two inductors, two capacitors, a switch (usually a transistor), and a diode. Its schematic can be seen in figure 1. It is an inverting converter, so the output voltage is negative with respect to the input voltage.

The capacitor C is used to transfer energy and is connected alternately to the input and to the output of the converter *via* the commutation of the transistor and the diode.

The two inductors L_1 and L_2 are used to convert respectively the input voltage source (V_i) and the output voltage source (C_o) into current sources. Indeed, at a short time scale an inductor can be considered as a current source as it maintains a constant current. This conversion is necessary because if the capacitor were connected directly to the voltage source, the current would be limited only by (parasitic) resistance, resulting in high energy loss. Charging a capacitor with a current source (the inductor) prevents resistive current limiting and its associated energy loss.

As with other converters (buck converter, boost converter, buck-boost converter) the Ćuk converter can either operate in continuous or discontinuous current mode. However, unlike these converters, it can also operate in discontinuous voltage mode (i.e., the voltage across the capacitor drops to zero during the commutation cycle).

Continuous mode

In steady state, the energy stored in the inductors has to remain the same at the beginning and at the end of a commutation cycle. The energy in an inductor is given by:

$$E = \frac{1}{2}LI^2$$

This implies that the current through the inductors has to be the same at the beginning and the end of the commutation cycle. As the evolution of the current through an inductor is related to the voltage across it:

$$V_L = L\frac{dI}{dt}$$

it can be seen that the average value of the inductor voltages over a commutation period have to be zero to satisfy the steady-state requirements.

If we consider that the capacitors C and C_o are large enough for the voltage ripple across them to be negligible, the inductor voltages become:

- in the off-state, inductor L_1 is connected in series with V_i and C. Therefore $V_{L1} = V_i - V_C$. As the diode D is forward biased (we consider zero voltage drop), L_2 is directly connected to the output capacitor. Therefore $V_{L2} = V_o$

- in the on-state, inductor L_1 is directly connected to the input source. Therefore $V_{L1} = V_i$. Inductor L_2 is connected in series with C and the output capacitor, so $V_{L2} = V_o + V_C$

The converter operates in on-state from t=0 to t=D·T (D is the duty cycle), and in off state from D·T to T (that is, during a period equal to (1-D)·T). The average values of V_{L1} and V_{L2} are therefore:

$$\bar{V}_{L1} = D \cdot V_i + (1 - D) \cdot (V_i - V_C) = (V_i - (1 - D) \cdot V_C)$$

$$\bar{V}_{L2} = D\,(V_o + V_C) + (1 - D) \cdot V_o = (V_o + D \cdot V_C)$$

As both average voltage have to be zero to satisfy the steady-state conditions we can write, using the last equation:

$$V_C = -\frac{V_o}{D}$$

So the average voltage across L_1 becomes:

$$\bar{V}_{L1} = \left(V_i + (1 - D) \cdot \frac{V_o}{D}\right) = 0$$

Which can be written as:

$$\frac{V_o}{V_i} = -\frac{D}{1 - D}$$

It can be seen that this relation is the same as that obtained for the Buck-boost converter.

Related structures

Inductor coupling

Instead of using two discrete inductor components, many designers implement a *coupled inductor Ćuk converter*, using a single magnetic component that includes both inductors on the same core. The transformer action between the inductors inside that component gives a *coupled inductor Ćuk converter* lower output ripple than a Ćuk converter using two independent discrete inductor components.

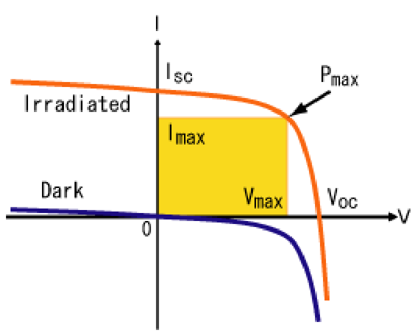
Single-ended primary-inductance converter (SEPIC)

A SEPIC converter is able to step-up or step-down the voltage.

Grid tie inverter

Inverter for grid connected PV

Example of large 3-phase inverter for commercial and utility scale grid-tied PV systems



Schematic drawing of current-voltage characteristics of a solar cell The area of the yellow rectangle gives the output power. Pmax denotes the maximum power point

A **grid-tie inverter** (**GTI**) is a special type of inverter that converts direct current electricity into alternating current electricity and feeds it into an existing electrical grid. GTIs are often used to convert direct current produced by many renewable energy sources, such as solar panels or small wind turbines, into the alternating current used to power homes and businesses. The technical name for a grid-tie inverter is "grid-interactive inverter". They may also be called synchronous inverters. Grid-interactive inverters typically cannot be used in standalone applications where utility power is not available.

Residences and businesses that have a grid-tied electrical system are permitted in many countries to sell their energy to the utility grid through a policy known as "net metering", whereby the entity that owns the renewable energy power source receives compensation from the utility for its net outflow of power. So for example, if during a given month a power system feeds 500 kilowatt-hours into the grid and uses 100 kilowatt-hours from the grid, it would receive compensation for 400 kilowatt-hours. In the US, net metering policies vary by jurisdiction.

In the United States, grid-interactive power systems are covered by specific provisions in the National Electric Code, which also mandates certain requirements for grid-interactive inverters.

Typical operation

Inverters take DC power and invert it to AC power so it can be fed into the electric utility company grid. The grid tie inverter must synchronize its frequency with that of the grid (e.g. 50 or 60 Hz) using a local oscillator and limit the voltage to no higher than the grid voltage. A typical modern GTI has a fixed unity power factor, which means its output voltage and current are perfectly lined up, and its phase angle is within 1 degree of the AC power grid. The inverter has an on-board computer which will sense the current AC grid waveform, and output a voltage to correspond with the grid.

Grid-tie inverters are also designed to quickly disconnect from the grid if the utility grid goes down. This is an NEC requirement that ensures that in the event of a blackout, the grid tie inverter will shut down to prevent the energy it produces from harming any line workers who are sent to fix the power grid.

Properly configured, a grid tie inverter enables a home owner to use an alternative power generation system like solar or wind power without extensive rewiring and without batteries. If the alternative power being produced is inadequate, the deficit will be sourced from the electricity grid.

Technology

Grid-tie inverters that are available on the market today use a number of different technologies. The inverters may use the newer high-frequency transformers, conventional low-frequency transformers, or no transformer. Instead of converting direct current directly to 120 or 240 volts AC, high-frequency transformers employ a computerized multi-step process that involves converting the power to high-frequency AC and then back to DC and then to the final AC output voltage. Transformerless inverters, which boast lighter weight and higher efficiencies than their counterparts with transformers, are popular in Europe. However, transformerless inverters have been slow to enter the US market. Until 2005, NEC code required all solar electric systems to be negative grounded, an electrical configuration that interferes with the operation of transformerless inverters. The issue at stake currently is that there are concerns about having transformerless electrical systems feed into the public utility grid since the lack of galvanic isolation between the DC and AC circuits could allow the passage of dangerous DC faults to be transmitted to the AC side.

Most grid-tie inverters on the market include a maximum power point tracker on the input side that enables the inverter to extract an optimal amount of power from its intended power source. Since MPPT algorithms differ for solar panels and wind turbines, specially made inverters for each of these power sources are available.

Characteristics

Inverter manufacturers publish datasheets for the inverters in their product line. While the terminology and content will vary by manufacturer, datasheets generally include the information listed below.

- *Rated output power*: This value will be provided in watts or kilowatts. For some inverters, they may provide an output rating for different output voltages. For instance, if the inverter can be configured for either 240 VAC or 208 VAC output, the rated power output may be different for each of those configurations.
- *Output voltage(s)*: This value indicates to which utility voltages the inverter can connect. For smaller inverters that are designed for residential use, the output voltage is usually 240 VAC. Inverters that target commercial applications are often compatible with 208, 240, 277, and/or 480 VAC.
- *Peak efficiency*: The peak efficiency represents the highest efficiency that the inverter can achieve. Most grid-tie inverters on the market as of July 2009 have peak efficiencies of over 94%, some as high as 96%. The energy lost during inversion is for the most part converted into heat. This means that in order for an inverter to put out the rated amount of power it will need to have a power input that exceeds the output. For example, a 5000 W inverter operating at full power at 95% efficiency will require an input of 5,263 W (rated power divided by efficiency). Inverters that are capable of producing power at different AC voltages may have different efficiencies associated with each voltage.
- *CEC weighted efficiency*: This efficiency is published by the California Energy Commission on its GoSolar website. In contrast to peak efficiency, this value is an average efficiency and is a better representation of the inverter's operating profile. Inverters that are capable of producing power at different AC voltages may have different efficiencies associated with each voltage.

- *Maximum input current*: This is the maximum amount of direct current that the inverter will use. If a DC power source, such as a solar array, produces an amount of current that exceeds the maximum input current, that current will not be used by the inverter.
- *Maximum output current*: The maximum output current is the maximum continuous alternating current that the inverter will supply. This value is typically used to determine the minimum current rating of the over-current protection devices (e.g., breakers and fuses) and disconnects required for the output circuit. Inverters that are capable of producing power at different AC voltages will have different maximum outputs for each voltage.
- *Peak power tracking voltage*: This represents the DC voltage range in which the inverter's maximum point power tracker will operate. The system designer must configure the strings optimally so that during the majority of the year, the voltage of the strings will be within this range. This can be a difficult task since voltage will fluctuate with changes in temperature.
- *Start voltage*: This value is not listed on all inverter datasheets. The value indicates the minimum DC voltage that is required in order for the inverter to turn on and begin operation. This is especially important for solar applications, because the system designer must be sure that there is a sufficient number of solar modules wired in series in each string to produce this voltage. If this value is not provided by the manufacturer, system designers typically use the lower band of the peak power tracking voltage range as the inverter's minimum voltage.
- *NEMA rating* (US only): The NEMA rating indicates the level of protection the device has against water intrusion. Most inverters are NEMA 3R which means they are outdoor rated for most situations.
- *IP56 rating* (rest of the world): This is similar to the above NEMA rating which indicates suitability for outdoor use and installation.

Chapter-8

Power Supply Rail

A **power supply rail** or **voltage rail** refers to a single voltage provided by a power supply unit (PSU) relative to some understood ground. Although the term is generally used in electronic engineering, most people encounter it in the context of personal computer power supplies.

Original IBM PC standard

The original IBM PC power supply unit (PSU) supplied two main voltage rails: +5 V and +12 V. It supplied two other voltages, −5 V and −12 V, but with limited amounts of power.

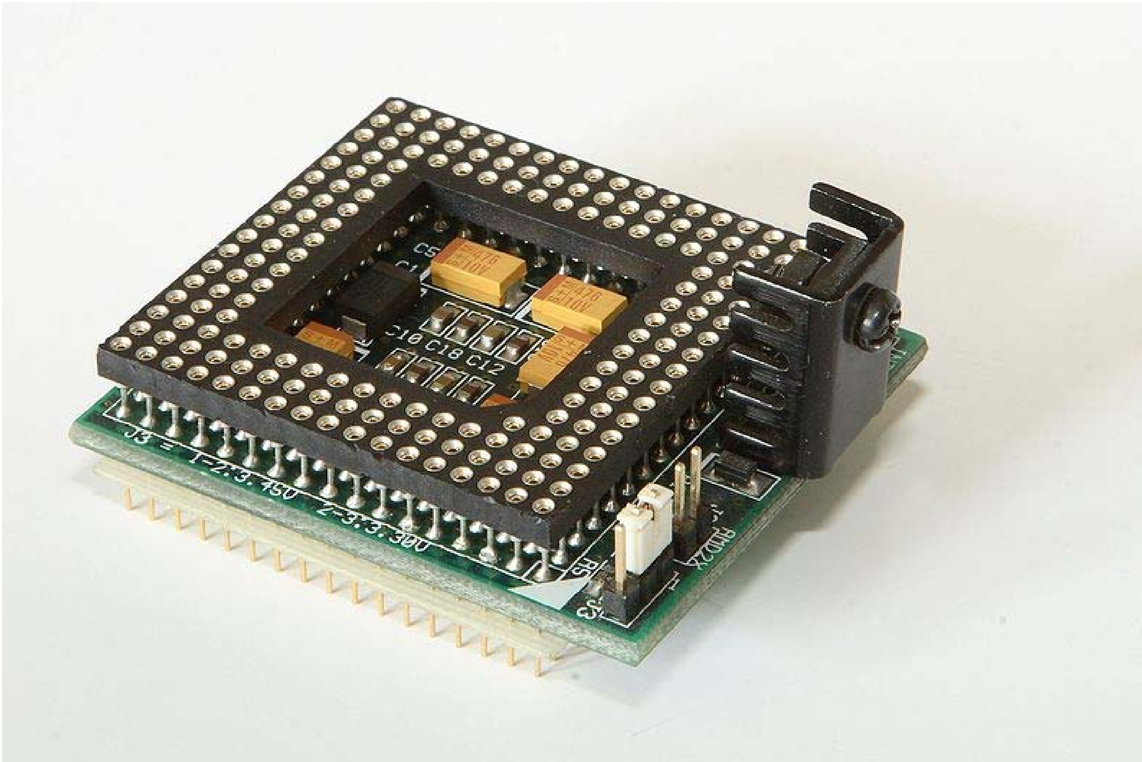
Most of the standard silicon microchips of the time operated on 5 V power. Of the 63.5 watts these PSUs could deliver, most of it was on this +5 V rail.

The +12 V supply was used primarily to operate motors. Fan motors, floppy disk drives and later, hard disk drives. As more peripherals were added, more power was delivered on the 12 V rail. However, since most of the power is consumed by chips, the 5 V rail still delivered most of the power.

The −12 V rail was used primarily to provide the negative supply voltage to the RS-232 serial ports.

An additional wire referred to as *Power Good* is used to prevent digital circuitry operation during the initial microseconds of power supply turn-on, where output voltages and currents are rising but not yet sufficient or stable for proper device operation. Once the output power is ready to use, the Power Good signal tells the digital circuitry that it can begin to operate.

ATX standard



Voltage converter for 80486DX4 processors (5 V to 3.3 V). Note the heat sink on the linear regulator, required to dissipate the wasted power.

When Intel developed the ATX standard power supply connector (published in 1995), microchips operating on 3.3 V were becoming more popular, beginning with the Intel 80486DX4 microprocessor in 1994, and the ATX standard supplies three positive rails: +3.3 V, +5 V, and +12 V. Earlier computers which wished to operate on 3.3 V typically used a simple but inefficient linear regulator to generate it from the +5 V rail.

The ATX connector provides multiple wires and power connections for the 3.3 V supply, because it is most sensitive to voltage drop in the supply connections.

Another ATX addition was the +5sb rail for providing a small amount of standby power, even when the computer was nominally "off".

Increase in +12 V demand

As transistors become smaller on chips, it becomes preferable to operate them on lower supply voltages, and the lowest supply voltage is often desired by the densest chip, the central processing unit. In order to supply large amounts of low-voltage power to the Pentium and subsequent microprocessors, a special power supply, the voltage regulator module began to be included on motherboards.

Initially, this was supplied by the main +5 V supply, but as power demands increased, the high currents required to supply sufficient power became problematic. To reduce the power losses in the 5 V supply, with the introduction of the Pentium 4 microprocessor, Intel changed the processor power supply to operate on +12 V, and added the separate P4 connector to the new ATX12V 1.0 standard to supply that power.

Modern high-powered graphics processing units do the same thing, resulting in the vast majority of the power requirements of a modern personal computer being on the +12 V rail.

When high-powered GPUs were first introduced, typical ATX power supplies were "5 V-heavy", and could only supply 50–60% of their output in the form of 12 V power. Thus, GPU manufacturers, to ensure 200–250 watts of 12 V power (peak load, CPU+GPU), recommended power supplies of 500–600 W or higher.

More modern ATX power supplies can deliver almost all (typically 80–90%) of their total rated capacity in the form of +12 V power.

Because of this change, it is important to consider the +12 V supply capacity, rather than the overall power capacity, when using an older ATX power supply with a more recent computer.

Low-quality power supply manufacturers sometimes take advantage of this overspecification by assigning unrealistically high power supply ratings, knowing that very few customers fully understand power supply ratings.

+3.3 V and +5 V rails

As mentioned above, these supplies are rarely a limiting factor when selecting a power supply for a modern personal computer; generally any supply with a sufficient +12 V rating will have adequate capacity at lower voltages. However, a large quantity of hard drives or PCI cards will create a greater load on the +5 V rail. A linear regulator could be used to convert the +12 V rail into a +5 V rail for each hard drive if the +5 V rail is overloaded.

It is worth noting that most PSUs create their 3.3 V output by regulating down their 5 V rail. As such, 3.3 V and 5 V typically have a combined limit as well. For example, a 3.3 V rail may have a 10 A rating by itself (33 W), and the 5 V rail may have a 20 A rating (100 W) by itself, but the two together may only be able to output 110 W. In this case, loading the 3.3 V rail to maximum (33 W), would leave the 5 V rail only be able to output 77 W.

As all of the rails come from one transformer and primary-side switching components, there is also an overall maximum power limit.

Multiple +12 V Rails

As power supply capacity increased, the ATX power supply standard was amended (beginning with version 2.0) to include:

3.2.4. Power Limit / Hazardous Energy Levels

Under normal or overload conditions, no output shall continuously provide more than 240 VA under any conditions of load including output short circuit, per the requirement of UL 1950/ CSA 950/ EN 60950/ IEC 950.

—ATX12V Power Supply Design Guide, version 2.2

This is a safety limit on the amount of power that may pass, in case of a fault, through any one wire. That much power can significantly overheat a wire, and would be more likely to melt the insulation and possibly start a fire.

Ideally, there would be one current limit per wire, but that would be prohibitively expensive. Since the limit is far larger than the reasonable current draw through a single wire, manufacturers typically group several wires together and apply the current limit to the entire group. Obviously, if the group is limited to 240 VA, so is each wire in it. Typically, a power supply will guarantee at least 17 A at 12 V by having a current limit of 18.5 A, plus or minus 8%. Thus, it is guaranteed to supply at least 17 A, and guaranteed to cut off before 20 A.

These groups are the so-called "multiple power supply rails". They are not fully independent; they are all connected to a single high-current 12 V source inside the power supply, but have separate current limit circuitry. The current limit groups are documented so the user can avoid placing too many high-current loads in the same group.

This works in the same way, and for the same reason, as the many small circuit breakers in a circuit breaker panel as well as the main supply breaker. And just like typical domestic wiring, multiple outlets are connected to each circuit breaker for reasons of cost.

Originally, a power supply featuring "multiple +12 V rails" implied one able to deliver more than 20 A of +12 V power, and was seen as a good thing. However, people found the need to balance loads across many +12 V rails inconvenient. This problem was exacerbated by the fact that the assignment of connectors to rails is done at manufacturing time, and it is not always possible to move a given load to a different rail.

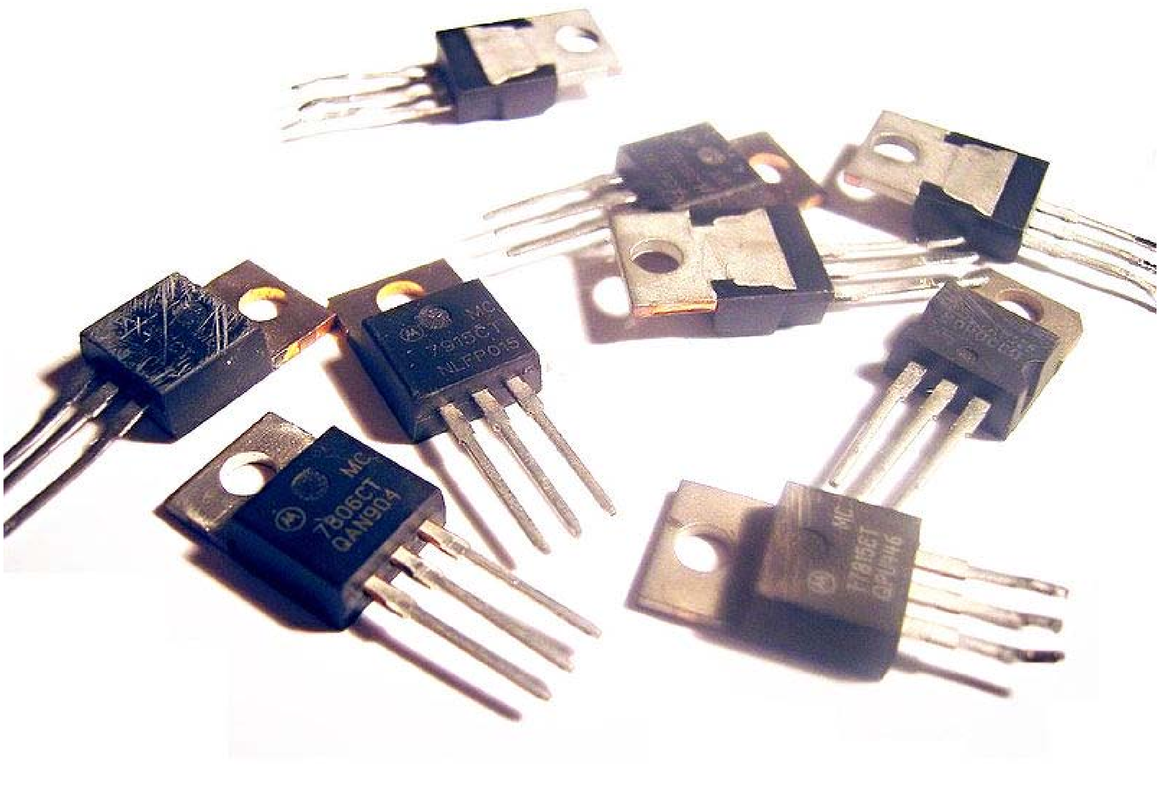
Rather than add more current limit circuits, many manufacturers have chosen to ignore the requirement and increase the current limits above 20 A per rail, or provide "single-rail" power supplies that omit the current limit circuitry. (In some cases, in violation of their own advertising claims to include it.) The requirement was deleted from version 2.3 (March 2007) of the ATX12V power supply specifications.

Operation of overcurrent protection

When a power supply has multiple-rail overcurrent protection, if any rail reaches that limit, the entire power supply will shut down. This is not associated with any overheating or increase in ripple voltage by the power supply as a whole, as might be caused by an overall overload. The only reliability penalty from operating a rail close to its current limit comes from the risk of triggering the shutdown.

Chapter-9

DC-to-DC Converter



An assortment of 78xx series ICs, linear DC-DC converters

A **DC-to-DC converter** is an electronic circuit which converts a source of direct current (DC) from one voltage level to another. It is a class of power converter.

Usage

DC to DC converters are important in portable electronic devices such as cellular phones and laptop computers, which are supplied with power from batteries primarily. Such electronic devices often contain several sub-circuits, each with its own voltage level requirement different from that supplied by the battery or an external supply (sometimes higher or lower than the supply voltage). Additionally, the battery voltage declines as its stored power is drained. Switched DC to DC converters offer a method to increase voltage from a partially lowered battery voltage thereby saving space instead of using multiple batteries to accomplish the same thing.

Most DC to DC converters also regulate the output voltage. Some exceptions include high-efficiency LED power sources, which are a kind of DC to DC converter that regulates the current through the LEDs, and simple charge pumps which double or triple the input voltage.

Conversion methods

Electronic

Linear

Linear regulators can only output at lower voltages from the input. They are very inefficient when the voltage drop is large and the current is high as they dissipate heat equal to the product of the output current and the voltage drop; consequently they are not normally used for large-drop high-current applications.

The inefficiency wastes power and requires higher-rated, and consequently more expensive and larger, components. The heat dissipated by high-power supplies is a problem in itself as it must be removed from the circuitry to prevent unacceptable temperature rises.

They are practical if the current is low, the power dissipated being small, although it may still be a large fraction of the total power consumed. They are often used as part of a simple regulated power supply for higher currents: a transformer generates a voltage which, when rectified, is a little higher than that needed to bias the linear regulator. The linear regulator drops the excess voltage, reducing hum-generating ripple current and providing a constant output voltage independent of normal fluctuations of the unregulated input voltage from the transformer / bridge rectifier circuit and of the load current.

Linear regulators are inexpensive, reliable if good heat sinking is used and much simpler than switching regulators. As part of a power supply they may require a transformer, which is larger for a given power level than that required by a switch-mode power supply. Linear regulators can provide a very low-noise output voltage, and are very suitable for powering noise-sensitive low-power analog and radio frequency circuits. A popular design approach is to use an LDO, Low Drop-out Regulator, that provides a local "point of load" DC supply to a low power circuit.

Switched-mode conversion

Electronic switch-mode DC to DC converters convert one DC voltage level to another, by storing the input energy temporarily and then releasing that energy to the output at a different voltage. The storage may be in either magnetic field storage components (inductors, transformers) or electric field storage components (capacitors). This conversion method is more power efficient (often 75% to 98%) than linear voltage regulation (which dissipates unwanted power as heat). This efficiency is beneficial to increasing the running time of battery operated devices. The efficiency has increased since the late 1980s due to the use of power FETs, which are able to switch at high frequency more efficiently than power bipolar transistors, which incur more switching losses and require a more complicated drive circuit. Another important innovation in DC-DC converters is the use of synchronous rectification replacing the flywheel diode with a power FET with low "On" resistance, thereby reducing switching losses.

Most DC to DC converters are designed to move power in only one direction, from the input to the output. However, all switching regulator topologies can be made bi-directional by replacing all diodes with independently controlled active rectification. A bi-directional converter can move power in either direction, which is useful in applications requiring regenerative braking.

Drawbacks of switching converters include complexity, electronic noise (EMI / RFI) and to some extent cost, although this has come down with advances in chip design.

DC to DC converters are now available as integrated circuits needing minimal additional components. DC to DC converters are also available as a complete hybrid circuit component, ready for use within an electronic assembly.

Magnetic

In these DC to DC converters, energy is periodically stored into and released from a magnetic field in an inductor or a transformer, typically in the range from 300 kHz to 10 MHz. By adjusting the duty cycle of the charging voltage (that is, the ratio of on/off time), the amount of power transferred can be controlled. Usually, this is applied to control the output voltage, though it could be applied to control the input current, the output current, or maintain a constant power. Transformer-based converters may provide isolation between the input and the output. In general, the term "DC to DC converter" refers to one of these switching converters. These circuits are the heart of a switched-mode power supply. Many topologies exist. This table shows the most common.

Forward	Flyback
• Energy goes from the input, through the magnetics and to the	**• Energy goes from the input and stored in the magnetics • Later, it is released from**

<table>
<tr><td></td><td>load, simultaneously</td><td>the magnetics to the load</td></tr>
<tr><td>No transformer
• Non-isolated</td><td>Step-down (Buck) - The output voltage is lower than the input voltage, and of the same polarity</td><td>• Non-inverting: The output voltage is the same polarity as the input
    o Step-up (Boost) - The output voltage is higher than the input voltage
    o SEPIC - The output voltage can be lower or higher than the input
• Inverting: the output voltage is of the opposite polarity as the input
    o Inverting (Buck-Boost)
    o Ćuk - Output current is continuous</td></tr>
<tr><td></td><td colspan="2">True Buck-Boost - The output voltage is the same polarity as the input and can be lower or higher
Split-Pi (Boost-Buck) - Allows bidirectional voltage conversion with the output voltage the same polarity as the input and can be lower or higher</td></tr>
<tr><td>With transformer
• May be isolated</td><td>• Half bridge - 2 transistors drive
• Full bridge - 4 transistor drive</td><td>Flyback - 1 or 2 transistor drive</td></tr>
</table>

In addition, each topology may be:

- **Hard switched** - transistors switch quickly while exposed to both full voltage and full current
- **Resonant** - an LC circuit shapes the voltage across the transistor and current through it so that the transistor switches when either the voltage or the current is zero

Magnetic DC to DC converters may be operated in two modes, according to the current in its main magnetic component (inductor or transformer):

- **Continuous** - the current fluctuates but never goes down to zero
- **Discontinuous** - the current fluctuates during the cycle, going down to zero at or before the end of each cycle

A converter may be designed to operate in Continuous mode at high power, and in Discontinuous mode at low power.

The Half bridge and Flyback topologies are similar in that energy stored in the magnetic core needs to be dissipated so that the core does not saturate. Power transmission in a flyback circuit is limited by the amount of energy that can be stored in the core, while forward circuits are usually limited by the I/V characteristics of the switches.

Although MOSFET switches can tolerate simultaneous full current and voltage (although thermal stress and electromigration can shorten the MTBF), bipolar switches generally can't so require the use of a snubber (or two).

Capacitive

Switched capacitor converters rely on alternately connecting capacitors to the input and output in differing topologies. For example, a switched-capacitor reducing converter might charge two capacitors in series and then discharge them in parallel. This would produce an output voltage of half the input voltage, but at twice the current (minus various inefficiencies). Because they operate on discrete quantities of charge, these are also sometimes referred to as charge pump converters. They are typically used in applications requiring relatively small amounts of current, as at higher current loads the increased efficiency and smaller size of switch-mode converters makes them a better choice. They are also used at extremely high voltages, as magnetics would break down at such voltages.

Electrochemical

A further means of DC to DC conversion in the kiloWatt to many MegaWatts range is presented by using redox flow batteries such as the vanadium redox battery, although this technique has not been applied commercially to date.

Terminology

Step-down - A converter where output voltage is lower than the input voltage. Like a Buck converter.

Step-up - A converter that outputs a voltage higher than the input voltage. Like a Boost converter.

Continuous Current Mode - Current and thus the magnetic field in the inductive energy storage never reach zero.

Discontinuous Current Mode - Current and thus the magnetic field in the inductive energy storage may reach or cross zero.

Noise - Since all properly designed DC to DC converters are completely inaudible, "noise" in discussing them always refers to unwanted electrical and electromagnetic signal noise.

Output noise - The output of a DC to DC converter is designed to have a flat, constant output voltage. Unfortunately, all real DC to DC converters produce an output that constantly varies up and down from the nominal designed output voltage. This varying voltage on the output is the output noise. All DC to DC converters, including linear regulators, have some thermal output noise. Switching converters have, in addition, switching noise at the switching frequency and its harmonics. Some sensitive radio frequency and analog circuits require a power supply with so little noise that it can only be provided by a linear regulator. Many analog circuits require a power supply with relatively low noise, but can tolerate some of the less-noisy switching converters.

Input noise - If the converter loads the input with sharp load edges. Electrical noise can be emitted from the supplying power lines as RF noise. Which should be prevented with proper filtering in the input stage of the converter.

RF noise - Switching converters inherently emit radio waves at the switching frequency and its harmonics. Switching converters that produce triangular switching current, such as the Split-Pi or Ćuk converter in continuous current mode, produce less harmonic noise than other switching converters. Linear converters produce practically no RF noise. Too much RF noise causes electromagnetic interference (EMI).

Chapter-10

Variable-frequency Drive

Small variable frequency drive

A **variable-frequency drive (VFD)** is a system for controlling the rotational speed of an alternating current (AC) electric motor by controlling the frequency of the electrical power supplied to the motor. A variable frequency drive is a specific type of adjustable-speed drive. Variable-frequency drives are also known as adjustable-frequency drives (AFD), variable-speed drives (VSD), AC drives, microdrives or inverter drives. Since the voltage is varied along with frequency, these are sometimes also called **VVVF** (variable voltage variable frequency) drives.

Variable-frequency drives are widely used. In ventilation systems for large buildings, variable-frequency motors on fans save energy by allowing the volume of air moved to match the system demand. They are also used on pumps, elevator, conveyor and machine tool drives.

VFD types

All VFDs use their output devices (IGBTs, transistors, thyristors) only as switches, turning them only on or off. Using a linear device such as a transistor in its linear mode is impractical for a VFD drive, since the power dissipated in the drive devices would be about as much as the power delivered to the load.

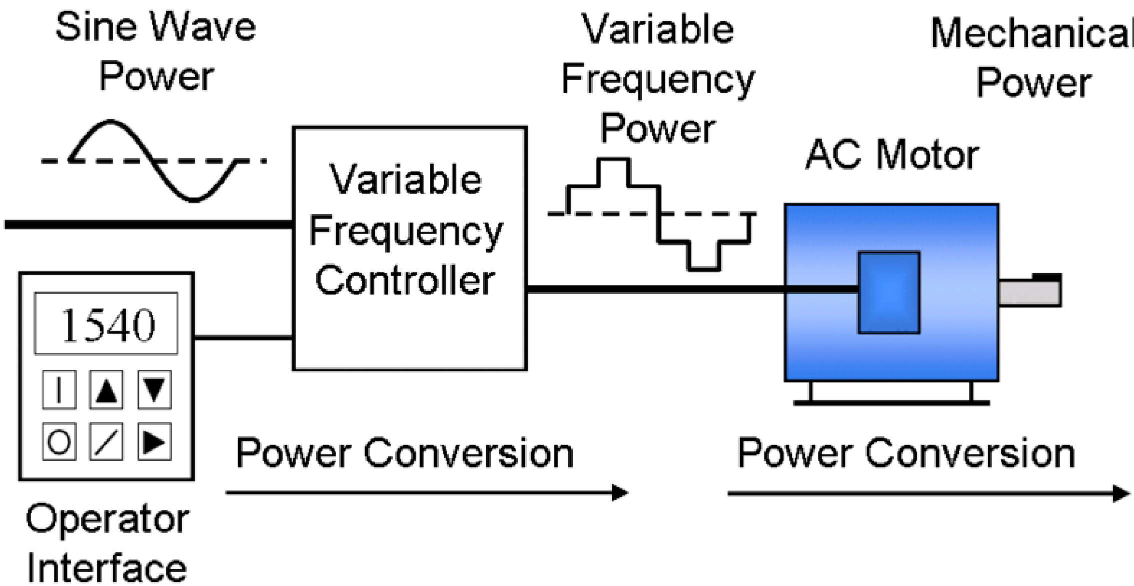
Drives can be classified as:

- Constant voltage
- Constant current
- Cycloconverter

In a constant voltage converter, the intermediate DC link voltage remains approximately constant during each output cycle. In constant current drives, a large inductor is placed between the input rectifier and the output bridge, so the current delivered is nearly constant. A cycloconverter has no input rectifier or DC link and instead connects each output terminal to the appropriate input phase.

The most common type of packaged VF drive is the constant-voltage type, using pulse width modulation to control both the frequency and effective voltage applied to the motor load.

VFD system description



VFD system

A variable frequency drive system generally consists of an AC motor, a controller and an operator interface.

VFD motor

The motor used in a VFD system is usually a three-phase induction motor. Some types of single-phase motors can be used, but three-phase motors are usually preferred. Various types of synchronous motors offer advantages in some situations, but induction motors are suitable for most purposes and are generally the most economical choice. Motors that are designed for fixed-speed operation are often used. Certain enhancements to the standard motor designs offer higher reliability and better VFD performance, such as MG-31 rated motors.

VFD controller

Variable frequency drive controllers are solid state electronic power conversion devices. The usual design first converts AC input power to DC intermediate power using a rectifier or converter bridge. The rectifier is usually a three-phase, full-wave-diode bridge. The DC intermediate power is then converted to quasi-sinusoidal AC power using an inverter switching circuit. The inverter circuit is probably the most important section of the VFD, changing DC energy into three channels of AC energy that can be used by an AC motor. These units provide improved power factor, less harmonic distortion, and low sensitivity to the incoming phase sequencing than older phase controlled converter VFD's. Since incoming power is converted to DC, many units will accept single-phase as well as three-phase input power (acting as a phase converter as well as a speed controller); however the unit must be derated when using single phase input as only part of the rectifier bridge is carrying the connected load.

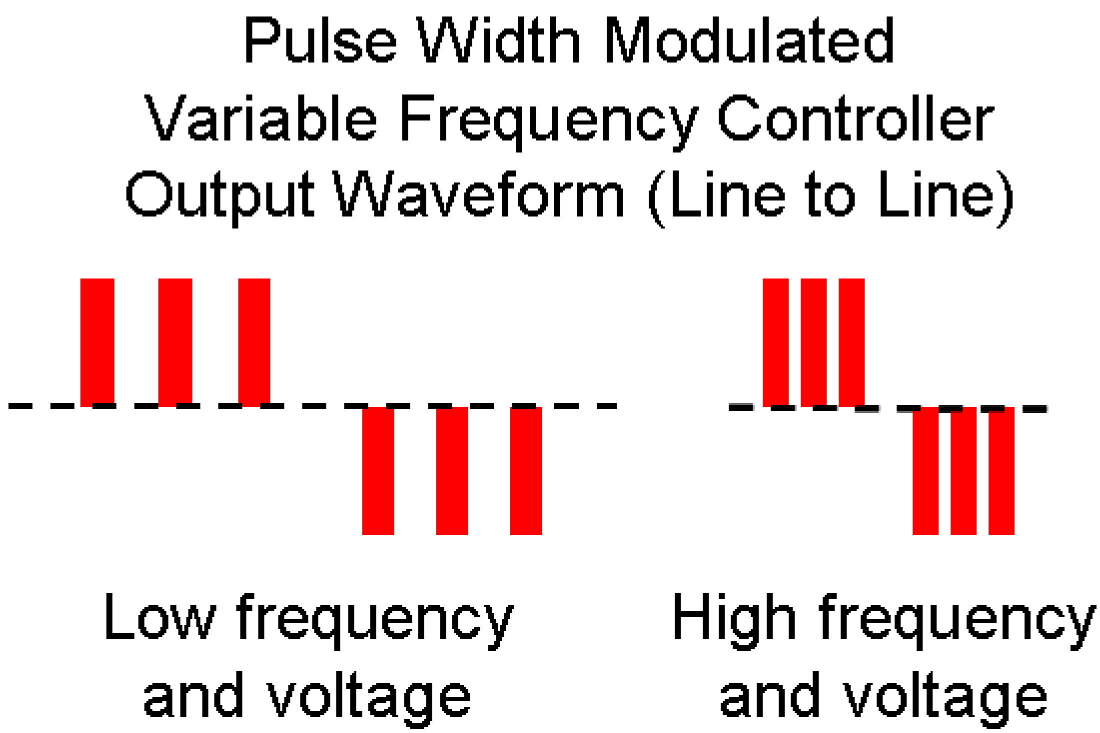
As new types of semiconductor switches have been introduced, these have promptly been applied to inverter circuits at all voltage and current ratings for which suitable devices are available. Introduced in the 1980s, the insulated-gate bipolar transistor (IGBT) became the device used in most VFD inverter circuits in the first decade of the 21st century.

AC motor characteristics require the applied voltage to be proportionally adjusted whenever the frequency is changed in order to deliver the rated torque. For example, if a motor is designed to operate at 460 volts at 60 Hz, the applied voltage must be reduced to 230 volts when the frequency is reduced to 30 Hz. Thus the ratio of volts per hertz must be regulated to a constant value (460/60 = 7.67 V/Hz in this case). For optimum performance, some further voltage adjustment may be necessary especially at low speeds, but constant volts per hertz is the general rule. This ratio can be changed in order to change the torque delivered by the motor.

In addition to this simple volts per hertz control more advanced control methods such as vector control and direct torque control (DTC) exist. These methods adjust the motor voltage in such a way that the magnetic flux and mechanical torque of the motor can be precisely controlled.

The usual method used to achieve variable motor voltage is pulse-width modulation (PWM). With PWM voltage control, the inverter switches are used to construct a quasi-sinusoidal output waveform by a series of narrow voltage pulses with pseudosinusoidal varying pulse durations.

Operation of the motors above rated name plate speed (base speed) is possible, but is limited to conditions that do not require more power than nameplate rating of the motor. This is sometimes called "field weakening" and, for AC motors, means operating at less than rated volts/hertz and above rated name plate speed. Permanent magnet synchronous motors have quite limited field weakening speed range due to the constant magnet flux linkage. Wound rotor synchronous motors and induction motors have much wider speed range. For example, a 100 hp, 460 V, 60 Hz, 1775 RPM (4 pole) induction motor supplied with 460 V, 75 Hz (6.134 V/Hz), would be limited to 60/75 = 80% torque at 125% speed (2218.75 RPM) = 100% power. At higher speeds the induction motor torque has to be limited further due to the lowering of the breakaway torque of the motor. Thus rated power can be typically produced only up to 130...150 % of the rated name plate speed. Wound rotor synchronous motors can be run even higher speeds. In rolling mill drives often 200...300 % of the base speed is used. Naturally the mechanical strength of the rotor and lifetime of the bearings is also limiting the maximum speed of the motor. It is recommended to consult the motor manufacturer if more than 150 % speed is required by the application.



PWM VFD Output Voltage Waveform

An embedded microprocessor governs the overall operation of the VFD controller. The main microprocessor programming is in firmware that is inaccessible to the VFD user. However, some degree of configuration programming and parameter adjustment is usually provided so that the user can customize the VFD controller to suit specific motor and driven equipment requirements.

VFD operator interface

The operator interface provides a means for an operator to start and stop the motor and adjust the operating speed. Additional operator control functions might include reversing and switching between manual speed adjustment and automatic control from an external process control signal. The operator interface often includes an alphanumeric display and/or indication lights and meters to provide information about the operation of the drive. An operator interface keypad and display unit is often provided on the front of the VFD controller as shown in the photograph above. The keypad display can often be cable-connected and mounted a short distance from the VFD controller. Most are also provided with input and output (I/O) terminals for connecting pushbuttons, switches and other operator interface devices or control signals. A serial communications port is also often available to allow the VFD to be configured, adjusted, monitored and controlled using a computer.

VFD operation

When an induction motor is connected to a full voltage supply, it draws several times (up to about 6 times) its rated current. As the load accelerates, the available torque usually drops a little and then rises to a peak while the current remains very high until the motor approaches full speed.

By contrast, when a VFD starts a motor, it initially applies a low frequency and voltage to the motor. The starting frequency is typically 2 Hz or less. Thus starting at such a low frequency avoids the high inrush current that occurs when a motor is started by simply applying the utility (mains) voltage by turning on a switch. After the start of the VFD, the applied frequency and voltage are increased at a controlled rate or ramped up to accelerate the load without drawing excessive current. This starting method typically allows a motor to develop 150% of its rated torque while the VFD is drawing less than 50% of its rated current from the mains in the low speed range. A VFD can be adjusted to produce a steady 150% starting torque from standstill right up to full speed. Note, however, that cooling of the motor is usually not good in the low speed range. Thus running at low speeds even with rated torque for long periods is not possible due to overheating of the motor. If continuous operation with high torque is required in low speeds an external fan is usually needed. The manufacturer of the motor and/or the VFD should specify the cooling requirements for this mode of operation.

In principle, the current on the motor side is in direct proportion of the torque that is generated and the voltage on the motor is in direct proportion of the actual speed, while on the network side, the voltage is constant, thus the current on line side is in direct proportion of the power drawn by the motor, that is U.I or C.N where C is torque and N the speed of the motor (we shall consider losses as well, neglected in this explanation).

(1) n stands for network (grid) and m for motor
(2) C stands for torque [Nm], U for voltage [V], I for current [A], and N for speed [rad/s]
We neglect losses for the moment :
Un.In = Um.Im (same power drawn from network and from motor)
Um.Im = Cm.Nm (motor mechanical power = motor electrical power)
Given Un is a constant (network voltage) we conclude : In = Cm.Nm/Un That is "line current (network) is in direct proportion of motor power".

With a VFD, the stopping sequence is just the opposite as the starting sequence. The frequency and voltage applied to the motor are ramped down at a controlled rate. When the frequency approaches zero, the motor is shut off. A small amount of braking torque is available to help decelerate the load a little faster than it would stop if the motor were simply switched off and allowed to coast. Additional braking torque can be obtained by adding a braking circuit (resistor controlled by a transistor) to dissipate the braking energy. With 4-quadrants rectifiers (active-front-end), the VFD is able to brake the load by applying a reverse torque and reverting the energy back to the network.

Power line harmonics

While PWM allows for nearly sinusoidal currents to be applied to a motor load, the diode rectifier of the VFD takes roughly square-wave current pulses out of the AC grid, creating harmonic distortion in the power line voltage. When the VFD load size is small and the available utility power is large, the effects of VFD systems slicing small chunks out of AC grid generally go unnoticed. Further, in low voltage networks the harmonics caused by single phase equipment such as computers and TVs are such that they are partially cancelled by three-phase diode bridge harmonics.

However, when either a large number of low-current VFDs, or just a few very large-load VFDs are used, they can have a cumulative negative impact on the AC voltages available to other utility customers in the same grid.

When the utility voltage becomes misshapen and distorted the losses in other loads such as normal AC motors are increased. This may in the worst case lead to overheating and shorter operation life. Also substation transformers and compensation capacitors are affected, the latter especially if resonances are aroused by the harmonics.

In order to limit the voltage distortion the owner of the VFDs may be required to install filtering equipment to smooth out the irregular waveform. Alternately, the utility may choose to install filtering equipment of its own at substations affected by the large amount of VFD equipment being used. In high power installations decrease of the harmonics can be obtained by supplying the VSDs from transformers that have different phase shift.

Further, it is possible to use instead of the diode rectifier a similar transistor circuit that is used to control the motor. This kind of rectifier is called active infeed converter in IEC standards. However, manufacturers call it by several names such as active rectifier, ISU (IGBT Supply Unit), AFE (Active Front End) or four quadrant rectifier. With PWM control of the transistors and filter inductors in the supply lines the AC current can be made nearly sinusoidal. Even better attenuation of the harmonics can be obtained by using an LCL (inductor-capacitor-inductor) filter instead of single three-phase filter inductor.

Additional advantage of the active infeed converter over the diode bridge is its ability to feed back the energy from the DC side to the AC grid. Thus no braking resistor is needed and the efficiency of the drive is improved if the drive is frequently required to brake the motor.

Application considerations

The output voltage of a PWM VFD consists of a train of pulses switched at the carrier frequency. Because of the rapid rise time of these pulses, transmission line effects of the cable between the drive and motor must be considered. Since the transmission-line impedance of the cable and motor are different, pulses tend to reflect back from the motor terminals into the cable. The resulting voltages can produce up to twice the rated line voltage for long cable runs, putting high stress on the cable and motor winding and eventual insulation failure. Increasing the cable or motor size/type for long runs and 480v or 600v motors will help offset the stresses imposed upon the equipment due to the VFD (modern 230v single phase motors not effected). At 460 V, the maximum recommended cable distances between VFDs and motors can vary by a factor of 2.5:1. The longer cables distances are allowed at the lower Carrier Switching Frequencies (CSF) of 2.5 kHz. The lower CSF can produce audible noise at the motors. For applications requiring long motor cables VSD manufacturers usually offer du/dt filters that decrease the steepness of the pulses. For very long cables or old motors with insufficient winding insulation more efficient sinus filter is recommended. Expect the older motor's life to shorten. Purchase VFD rated motors for the application.

Further, the rapid rise time of the pulses may cause trouble with the motor bearings. The stray capacitance of the windings provide paths for high frequency currents that close through the bearings. If the voltage between the shaft and the shield of the motor exceeds few volts the stored charge is discharged as a small spark. Repeated sparking causes erosion in the bearing surface that can be seen as fluting pattern. In order to prevent sparking the motor cable should provide a low impedance return path from the motor frame back to the inverter. Thus it is essential to use a cable designed to be used with VSDs.

In big motors a slip ring with brush can be used to provide a bypass path for the bearing currents. Alternatively isolated bearings can be used.

The 2.5 kHz and 5 kHz CSFs cause fewer motor bearing problems than the 20 kHz CSFs. Shorter cables are recommended at the higher CSF of 20 kHz. The minimum CSF for synchronize tracking of multiple conveyors is 8 kHz.

The high frequency current ripple in the motor cables may also cause interference with other cabling in the building. This is another reason to use a motor cable designed for VSDs that has a symmetrical three-phase structure and good shielding. Further, it is highly recommended to route the motor cables as far away from signal cables as possible.

Available VFD power ratings

Variable frequency drives are available with voltage and current ratings to match the majority of 3-phase motors that are manufactured for operation from utility (mains) power. VFD controllers designed to operate at 111 V to 690 V are often classified as low voltage units. Low voltage units are typically designed for use with motors rated to deliver 0.2 kW or 1/4 horsepower (hp) up to several megawatts. For example, the largest ABB ACS800 single drives are rated for 5.6 MW . Medium voltage VFD controllers are designed to operate at 2,400/4,162 V (60 Hz), 3,000 V (50 Hz) or up to 10 kV. In some applications a step up transformer is placed between a low voltage drive and a medium voltage load. Medium voltage units are typically designed for use with motors rated to deliver 375 kW or 500 hp and above. Medium voltage drives rated above 7 kV and 5,000 or 10,000 hp should probably be considered to be one-of-a-kind (one-off) designs.

Medium voltage drives are generally rated amongst the following voltages : 2,3 KV - 3,3 Kv - 4 Kv - 6 Kv - 11 Kv
The in-between voltages are generally possible as well. The power of MV drives is generally in the range of 0,3 to 100 MW however involving a range a several different type of drives with different technologies.

Dynamic braking

Using the motor as a generator to absorb energy from the system is called dynamic braking. Dynamic braking stops the system more quickly than coasting. Since dynamic braking requires relative motion of the motor's parts, it becomes less effective at low speed and cannot be used to hold a load at a stopped position. During normal braking of an electric motor the electrical energy produced by the motor is dissipated as heat inside of the rotor, which increases the likelihood of damage and eventual failure. Therefore, some systems transfer this energy to an outside bank of resistors. Cooling fans may be used to protect the resistors from damage. Modern systems have thermal monitoring, so if the temperature of the bank becomes excessive, it will be switched off.

Regenerative variable-frequency drives

Regenerative AC drives have the capacity to recover the braking energy of an overhauling load and return it to the power system.

Line regenerative variable frequency drives, showing capacitors(top cylinders)and inductors attached which filter the regenerated power.

Cycloconverters and current-source inverters inherently allow return of energy from the load to the line; voltage-source inverters require an additional converter to return energy to the supply.

Regeneration is only useful in variable-frequency drives where the value of the recovered energy is large compared to the extra cost of a regenerative system, and if the system requires frequent braking and starting. An example would be use in conveyor belt during manufacturing where it should stop for every few minutes, so that the parts can be assembled correctly and moves on. Another example is a crane, where the hoist motor stops and reverses frequently, and braking is required to slow the load during lowering.

Regenerative variable-frequency drives are widely used where speed control of overhauling loads is required.

Brushless DC motor drives

Much of the same logic contained in large, powerful VFDs is also embedded in small brushless DC motors such as those commonly used in computer fans. In this case, the chopper usually converts a low DC voltage (such as 12 volts) to the three-phase current used to drive the electromagnets that turn the permanent magnet rotor.