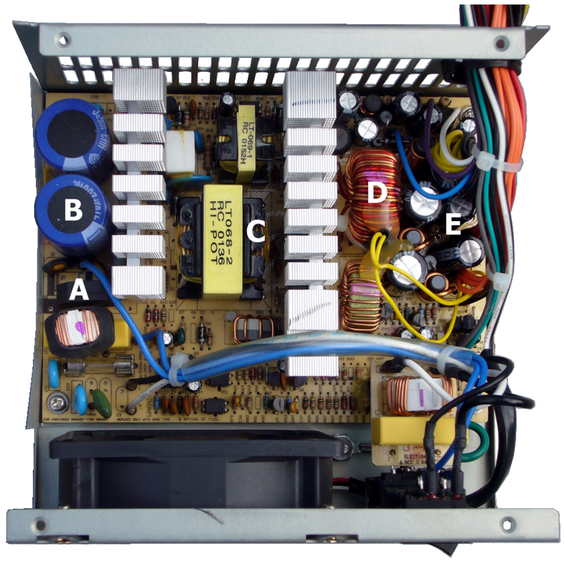
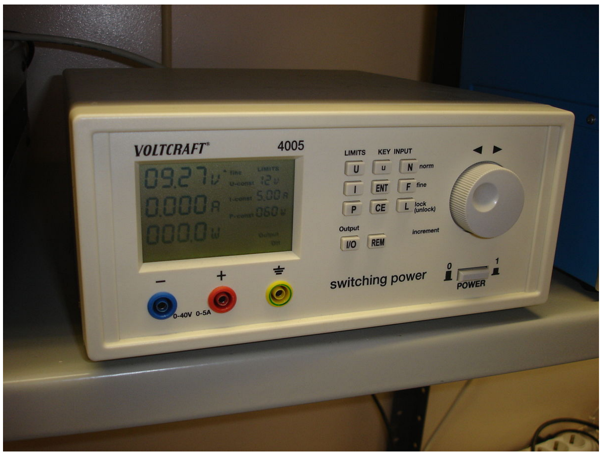
Switched-mode power supply

A **switched-mode power supply** (**switching-mode power supply**, **SMPS**, or **switcher**) is an electronic power supply that incorporates a switching regulator to convert electrical power efficiently. Like other power supplies, an SMPS transfers power from a source, like mains power, to a load, such as a personal computer, while converting voltage and current characteristics. Unlike a linear power supply, the pass transistor of a switching-mode supply continually switches between low-dissipation, full-on and full-off states, and spends very little time in the high dissipation transitions, which minimizes wasted energy. Ideally, a switched-mode power supply dissipates no power. Voltage regulation is achieved by varying the ratio of on-to-off time. In contrast, a linear power supply regulates the output voltage by continually dissipating power in the pass transistor. This higher power conversion efficiency is an important advantage of a switched-mode power supply. Switched-mode power supplies may also be substantially smaller and lighter than a linear supply due to the smaller transformer size and weight.



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.

Switching regulators are used as replacements for 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.



An adjustable switched-mode power supply for laboratory use

History

1926: "Electrical Condensors" by Coursey[1] mentions high frequency welding[2] and furnaces.

ca 1936: Car radios used electromechanical vibrators to transform the 6 V battery supply to a suitable B+ voltage for the vacuum tubes.[3]

1959: Transistor oscillation and rectifying converter power supply system U.S. Patent 3,040,271 [4] is filed.[5]

1970: High-Efficiency Power Supply produced from about 1970 to 1995.[6][7][8][9]

1972: HP-35, Hewlett-Packard's first pocket calculator, is introduced with transistor switching power supply for light-emitting diodes, clocks, timing, ROM, and registers.[10]

1976: "Switched mode power supply" U.S. Patent 4,097,773 [11] is filed.[12]

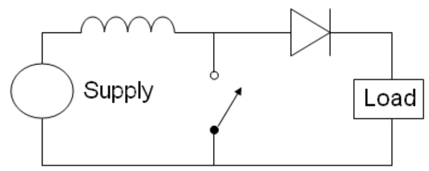
1977: Apple II is designed with a switching mode power supply. "*For its time (1977) it was a breakthrough, since until then switching mode power supplies weren't used. Designed by Rod Holt,*".[13] "*Rod Holt was brought in as product engineer and there were several flaws in Apple II that were never publicized. One thing Holt has to his credit is that he created the switching power supply that allowed us to do a very lightweight computer*".[14]

1980: The HP8662A 10 kHz – 1.28 GHz synthesized signal generator went with a switched power supply.[15]

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. The spectral density of these switching waveforms has energy concentrated at relatively high frequencies. As such, switching transients and ripple introduced onto the output waveforms can be filtered with small LC filters.

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), 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.

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:

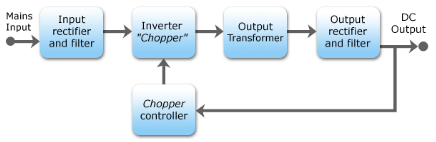
Comparison of a linear power supply and a switched-mode power supply

	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 operating frequency (mains power frequency is at 50 or 60 Hz); otherwise can be compact due to low component count.	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 significant.	A transformer's power handling capacity of given size and weight increases with frequency 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 circuit and a noise-filtering capacitor; usually a simpler circuit (and simpler feedback loop stability criteria) than switched-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 switched-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). It can cause audible mains hum in audio equipment, 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 cause harmonic distortion.	This can be prevented if a (properly earthed) EMI/RFI filter is connected between the input terminals and the bridge rectifier.
Acoustic noise	Faint, usually inaudible mains hum, usually due to vibration of windings in the transformer 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 the EU. 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 switched-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 capacitors charge completely, unless a slow-start circuit is used.	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 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.

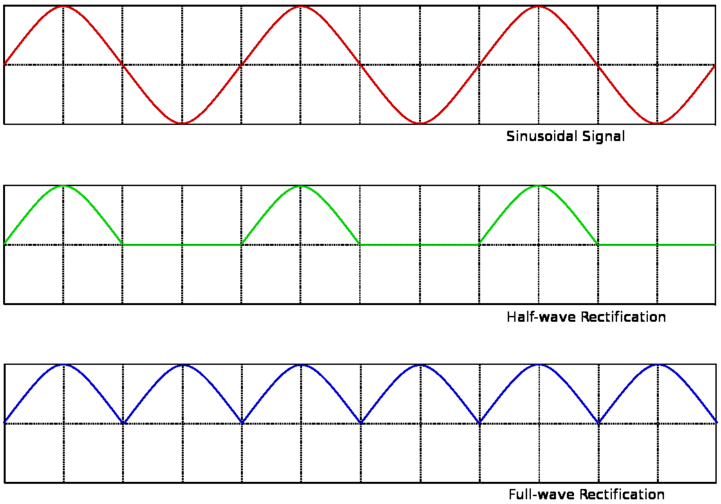
Risk of electric shock	Supplies with transformers isolate the incoming power supply from the powered device and so allow metalwork of the enclosure to be grounded safely. Dangerous if primary/secondary insulation breaks down, unlikely with reasonable design. Transformerless mains-operated supply dangerous. In both linear and switch-mode the mains, and possibly the output voltages, are hazardous and must be well-isolated.	Common rail of equipment (including casing) is energized to half the 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 energizes 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.[16] 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 equalizes 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*. A SMPS with a DC input does not require this stage. In some power supplies (mostly computer ATX power supplies), the rectifier circuit can be configured as a voltage doubler by the addition of a switch operated either manually or automatically. This feature permits operation from power sources that are normally at 115 V or at 230 V. 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. To correct for this, many newer SMPS will use a special PFC circuit to make the input current follow the sinusoidal shape of the AC input voltage, correcting the power factor. Power supplies that use Active PFC usually are auto-ranging, supporting input voltages from ~100 VAC – 250 VAC, with no input voltage selector switch.

A SMPS designed for AC input can usually be run from a DC supply, because the DC would pass through the rectifier unchanged.[17] If the power supply is designed for 115 VAC and has no voltage selector switch, the required DC voltage would be 163 VDC (115 × √2). This type of use may be harmful to the rectifier stage, however, as it will only use half of diodes in the rectifier for the full load. This could possibly result in overheating of these components, causing them to fail prematurely. On the other hand, if the power supply has a voltage selector switch for 115/230V (computer ATX power supplies typically are in this category), the selector switch would have to be put in the 230 V position, and the required voltage would be 325 VDC (230 × √2). The diodes in this type of power supply will handle the DC current just fine because they are rated to handle double the nominal input current when operated in the 115 V mode, due to the operation of the voltage doubler. This is because the doubler, when in operation, uses only half of the bridge rectifier and runs twice as much current through it.[18] It is uncertain how an Auto-ranging/Active-PFC type power supply would react to being powered by DC.

Inverter stage

This section refers to the block marked *chopper* in the block diagram.

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. The frequency is usually chosen to be above 20 kHz, to make it inaudible to humans. 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.

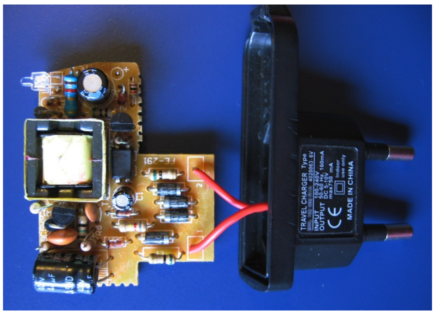
The rectified output is then smoothed by a filter consisting of inductors and capacitors. For higher switching frequencies, components with lower capacitance and inductance are needed.

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 realized.

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.



This charger for a small device such as a mobile phone is a simple off-line switching power supply in a European plug.

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

Any switched-mode power supply that gets its power from an AC power line (called an "off-line" converters) requires a transformer for galvanic isolation. Some DC-to-DC converters may also include a transformer, although isolation may not be critical in these cases. SMPS transformers run at high frequency. Most of the cost savings (and space savings) in off-line power supplies result from the smaller size of high frequency transformer compared to the 50/60 Hz transformers formerly used. There are additional design tradeoffs.

The terminal voltage of a transformer is proportional to the product of the core area, magnetic flux, and frequency. By using a much higher frequency, the core area (and so the mass of the core) can be greatly reduced. However, core losses increase at higher frequencies. Cores generally use ferrite material which has a low loss at the high frequencies and high flux densities used. The laminated iron cores of lower-frequency (<400 Hz) transformers would be unacceptably lossy at switching frequencies of a few kilohertz. Also, more energy is lost during transitions of the switching semiconductor at higher frequencies. Furthermore, more attention to the physical layout of the circuit board is required as parasitics become more significant, and the amount of electromagnetic interference will be more pronounced.

Copper loss

At low frequencies (such as the line frequency of 50 or 60 Hz), designers can usually ignore the skin effect. For these frequencies, the skin effect is only significant when the conductors are large, more than 0.3 inches (7.6 mm) in diameter.

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 in copper is about 0.003 inches (0.076 mm) – a dimension smaller than the typical wires used in a power supply. The effective resistance of conductors increases, because current concentrates near the surface of the conductor and the inner portion carries less current than at low frequencies.

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

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 building wiring, 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 by filtering, but the filters are expensive. 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. 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 cost.

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. To comply with these requirements, modern switched-mode power supplies normally include an additional power factor correction (PFC) stage.

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. The input voltage (V_1) is assumed to be greater than zero; if it is negative, for consistency, negate the output voltage (V_2).

Type	Typical Power [W]	Relative cost	Energy storage	Voltage relation	Features
Buck	0–1,000	1.0	Single inductor	0 ≤ Out ≤ In, $V_2 = DV_1$	Current is continuous at output.
Boost	0–5,000	1.0	Single inductor	Out ≥ In, $V_2 = \frac{1}{1-D} V_1$	Current is continuous at input.
Buck-boost	0–150	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)	0–4,500	>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 / Switched capacitor			Capacitors only		No magnetic energy storage is needed to achieve conversion, however high efficiency power processing is normally limited to a discrete set of conversion ratios.

When equipment is human-accessible, voltage and power limits of <=42.4 V peak/60 V dc and 250 VA apply for Safety Certification (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.

The Neutral Point Clamped (NPC) topology is used in power supplies and active filters and is mentioned here for completeness.

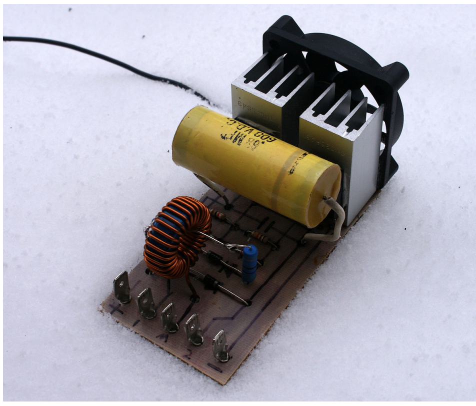
Switchers become less efficient as duty cycles become extremely short. For large voltage changes, a transformer (isolated) topology may be better.

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.[19][20] For some topologies, multiple windings can be placed on the transformer to produce multiple output voltages.[21] Some converters use the transformer for energy storage, while others use a separate inductor.

Type	Power [W]	Relative cost	Input range [V]	Energy storage	Features
Flyback	0–250	1.0	5–600	Mutual Inductors	Isolated form of the buck-boost converter.[1]
Ringing choke converter (RCC)	0–150	1.0	5–600	Transformer	Low-cost self-oscillating flyback variant.
Half-forward	0–250	1.2	5–500	Inductor	
Forward[2]	100-200		60–200	Inductor	Isolated form of buck-boost converter
Resonant forward	0–60	1.0	60–400	Inductor and capacitor	Single rail input, unregulated output, high efficiency, low EMI.[22]
Push-pull	100–1,000	1.75	50–1,000	Inductor	
Half-bridge	0–2,000	1.9	50–1,000	Inductor	
Full-bridge	400–5,000	>2.0	50–1,000	Inductor	Very efficient use of transformer, used for highest powers.
Resonant, zero voltage switched	>1,000	>2.0		Inductor and capacitor	
Isolated Ćuk				Two capacitors and two inductors	

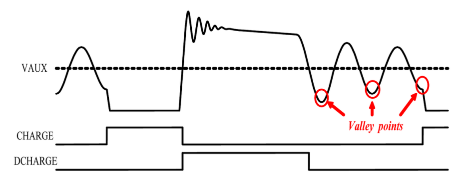
- **^1** Flyback converter logarithmic control loop behavior might be harder to control than other types.[23]
- **^2** The forward converter has several variants, varying in how the transformer is "reset" to zero magnetic flux every cycle.



Zero voltage switched power supplies require only small heatsinks as little energy is lost as heat. This allows them to be small. This ZVS can deliver more than 1 kilowatt. Transformer is not shown.

Quasi-resonant zero-current/zero-voltage switch

In a quasi-resonant zero-current/zero-voltage switch (ZCS/ZVS) "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."[24] Quasi-resonant switching, also known as *valley switching*, reduces EMI in the power supply by two methods:



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

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 switching frequency allows component sizes to be shrunk, but can produce more RFI. 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

For failure in switching components, circuit board and so on read the failure modes of electronics article.

Power supplies which use capacitors suffering from the capacitor plague may experience premature failure when the capacitance drops to 4% of the original value.Wikipedia:Verifiability This usually causes 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.[25]

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.

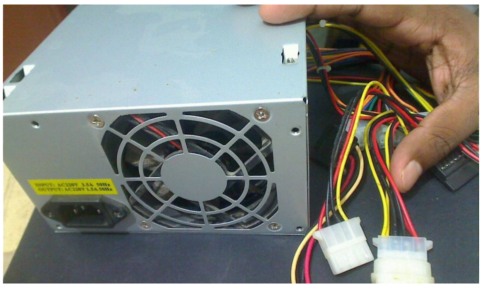
Precautions

The main filter capacitor will often store up to 325 Volt 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 a capacitor to reduce EMI and compensate for various capacitive couplings in the converter circuit, 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.[26]

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 mains supplies throughout the world, although a manual voltage range switch may be required. Switch-mode power supplies can tolerate a wide range of power frequencies and voltages.

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.

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.[*citation needed*]

Switched-mode power supplies are used for DC to DC conversion as well. In automobiles where heavy vehicles use a nominal 24 V_{DC} cranking supply, 12 volts for accessories may be furnished through a DC/DC switch-mode supply. This has the advantage over tapping the battery at the 12 volt position that all the 12 Volt load is evenly divided over all cells of the 24 volt battery. In industrial settings such as telecommunications racks, bulk power may be distributed at a low DC voltage (from a battery back up system, for example) and individual equipment items will have DC/DC switched-mode converters to supply whatever voltages are needed.

Terminology

The term switchmode was widely used until Motorola claimed ownership of 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.

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