Block diagram of regulated power supply pdf

Power-supply is an electronic circuit that is used for the purpose of providing the electrical-power to appliances or loads such as machines, computers, & so on. These electrical & electronic appliances require various types of power at different ranges & also with different characteristics. Therefore, for this reason the power is converted into the recommended forms (with desired qualities) by using some electronic power converters or power converters. In this project we'll show you a circuit diagram of smps power supply alongwith description. Electrical & electronic loads work with various forms of power supplies, such as AC power supply, High-voltage power supply, AC- to-DC power supply, Uninterruptable power supply (UPS) , Programmable power supply & Switch-mode power supply. It is actually the electronic power supply integrated with the switching regulator for converting the electrical power efficiently from one form to another form with desired characteristics & is called as switch-mode power supply (in short smps). It is used to attain regulated DC output voltage from an unregulated AC or DC input voltage. Circuit Diagram Of Smps Power Supply Like other power supplies, switch-mode power supply is a complicated circuit that supplies the power from a source to loads. Switch-mode power supply is necessary for power consuming electrical & electronic appliances & even for preparing electrical & electronic projects. Topologies of Switch Mode Power Supply There are several types of topologies for SMPS, among those, a few are as follows DC to DC converter AC to DC converter Fly back converter Forward-converter Switch Mode Power Supply's Working Principle Here is the working of a few types of topologies of switch mode power supply: 1. DC to DC Converter SMPS Working Principle Primarily a high-voltage DC power is directly obtained from a DC power source in a DC to DC converter. Then, this hig- voltage DC-power is switched at an extremely high switching speed usually in the range of 15 KHz to 50 KHz. And then it's fed to a step-down transformer that is comparable to the weight & size of a transformer unit of 50Hz. The output of the step down transformer is then further provided to the rectifier. This filtered & rectified output DC power is utilized as a source for loads & a sample of this output power is used as a feedback for controlling the output voltage.The ON time of the oscillator is controlled with this feedback voltage, & a closed-loop regulator is formed. Circuit Diagram Of Smps Power Supply DC-DC The output of the smps is regulated by means of PWM (Pulse-Width-Modulation). As given in the circuit above, the switch can be driven by the PWM-oscillator, such that the power delivered to the step-down transformer is controlled indirectly, & hence, the output is controlled by the pulse-width-modulation, as this pulse-width signal & the output-voltage are inversely related to each other. If the duty cycle is 50%, the maximum power is transported through the step-down transformer & if duty cycle decreases, the power transferred will also decrease by decreasing the dissipation of power. 2. Working Principle of AC to DC Converter SMPS: There is an AC input in an AC to DC converter SMPS. It is converted into DC by rectification process using a rectifier & filter. This unregulated DC voltage is fed to the large-filter capacitor or Power Factor Correction (PFC) circuits for correction of power factor as it is affected. This is because around voltage peaks, a short current is drawn through the rectifier, these current pulses have appreciably high-frequency energy which causes the power factor to decrease. Circuit Diagram Of Smps Power Supply AC-DC It is somewhat similar to the above explained DC to DC converter, but instead of direct DC power supply, here AC input is used. So, the combination of the rectifier & filter, shown in the block diagram is used to convert the AC into DC & switching is done by using a power 'MOSFET' amplifier with which very high gain can be obtained. This MOSFET transistor has low on-resistance & can withstand high current. The switching-frequency is chosen such that it must be placed inaudible to normal human beings (mostly above 20KHz) & switching action is controlled by a feedback using the PWM-oscillator. The AC voltage is again fed to the output transformer. The output of this transformer is then rectified & smoothed by using the output rectifier & filter.In order to control the output voltage a feedback circuit is used by comparing it with the reference voltage. 3. Fly back Converter type SMPS Working Principle The switch mode power supply circuit with very low output power of less than 100W (watts) is commonly a type of Fly back converter SMPS & it is very simple & low cost circuit compared to other SMPS circuits. Hence, it is used for low-power applications. Circuit Diagram Of Smps Power Supply Fly-Back Converter The unregulated input-voltage with a constant value is converted into a required output voltage by fast switching with the help of a 'MOSFET'; the switching frequency is around 100 kHz. The isolation of voltage can be achieved by means of a transformer. The switch operation can be controlled by means of a PWM control while implementing a practical fly back converter. Fly back transformer displays different characteristics as compared to general transformer. The two windings of the fly back transformer come into play as magnetically coupled inductors. The output of this transformer is passed through a diode & a capacitor for filtering & rectification. As shown in the figure, the voltage across this filter capacitor is taken as the output voltage of the SMPS. 4. Forward-Converter type SMPS Working Forward-converter type SMPS is almost same as the Fly back converter type SMPS, but in the forward-converter type, a control is connected for controlling the switch & at the output of transformer's secondary winding & the rectification & filtering circuit is complex as compared to the fly back converter. It can be called as a DC to DC buck converter, alongwith a transformer used for isolation & scaling. In addition to the diode D1 & capacitor C, a diode D2 & an inductor L are interfaced at the output end. If switch S is switched ON, then the input is given to the primary winding of the transformer & hence, a scaled-voltage is produced at transformer's secondary winding. Circuit Diagram Of Smps Power Supply Forward Converter This is how, the diode D1 gets forward-biased & the scaled-voltage is moved through the low pass filter preceding the loads. If the switch S is turned off then currents from the primary & secondary winding reach to zero, but the current through the inductive filter & load can not be changed at once, & a path is provided to this current by the freewheeling diode D2. By means of the filter inductor, the desired voltage across the diode D2 & to maintain the EMF needed for maintaining the continuity of the current at inductive filter. Different types of topologies are there in which SMPS can be realized such as Buck converter, Buck-boost converter, Boost converter: Self oscillating fly back converter, Boost-buck, Cuk, Sepic. But only a few are discussed in this article, namely DC to DC converter, AC to DC converter, Fly back converter & Forward-converter. Read>> Electrical Appliances Over Under Volt Protection Circuit Diagram Power supply with switching regulator Interior view of an ATX SMPS: below A: input EMI filtering and 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 in the lower right corner are additional input filtering components that are mounted directly on the power input connector and are not part of the main circuit board. ATX power supplies provide at least 5 independent voltage outputs. An adjustable switched-mode power supply for laboratory use A switched-mode power supply (switching-mode power supply, switch-mode power supply, switched 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 DC or AC source (often mains power, see AC adapter) to DC loads, 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. A hypothetical ideal switched-mode power supply dissipates no power. Voltage regulation is achieved by varying the ratio of on-to-off time (also known as duty cycles). In contrast, a linear power supply regulates the output voltage by continually dissipating power in the pass transistor. The switched-mode power supply's higher electrical efficiency is an important advantage. Switched-mode power supplies can also be substantially smaller and lighter than a linear supply because the transformer can be much smaller. This is because it operates on a high switching frequency which ranges from several hundred kHz to several MHz in contrast to the 50 or 60 Hz mains frequency. Despite the reduced transformer size, the power supply topology and the requirement for electromagnetic interference (EMI) suppression in commercial designs result in a usually much greater component count and corresponding circuit complexity. Switching regulators are used as replacements for linear regulators when higher efficiency, smaller size or lighter weight is required. They are, however, more complicated; switching currents can cause electrical noise problems if not carefully suppressed, and simple designs may have a poor power factor. History 1836 Induction coils use switches to generate high voltages. 1910 An inductive discharge ignition system invented by Charles F. Kettering and his company Dayton Engineering Laboratories Company (Delco) goes into production for Cadillac.[1] The Kettering ignition system is a mechanically switched version of a fly back boost converter; the transformer is the ignition coil. Variations of this ignition system were used in all non-diesel internal combustion engines until the 1960s when it began to be replaced first by solid-state electronically switched versions, then capacitive discharge ignition systems. 1926 On 23 June, British inventor Philip Ray Coursey applies for a patent in his country and United States, for his "Electrical Condenser".[2][3] The patent mentions high frequency welding[4] and furnaces, among other uses.[3] c. 1932 Electromechanical relays are used to stabilize the voltage output of generators. See Voltage regulator#Electromechanical regulators.[5][6] c. 1936 Car radios used electromechanical vibrators to transform the 6 V battery supply to a suitable B+ voltage for the vacuum tubes.[7] 1959 The MOSFET (metal-oxide-semiconductor field-effect transistor) is invented by Mohamed M. Atalla and Dawon Kahng at Bell Labs.[8] The power MOSFET later became the most widely used power device for switching power supplies.[9] 1959 Transistor oscillation and rectifying converter power supply system U.S. Patent 3,040,271 is filed by Joseph E. Murphy and Francis J. Starzec, from General Motors Company[10] 1960s The Apollo Guidance Computer, developed in the early 1960s by the MIT Instrumentation Laboratory for NASA's ambitious moon missions (1966-1972), incorporated early switched mode power supplies.[11] c. 1967 Bob Widlar of Fairchild Semiconductor designs the µA723 IC voltage regulator. One of its applications is as a switched mode regulator.[12] 1970 Tektronix starts using High-Efficiency Power Supply in its 7000-series oscilloscopes produced from about 1970 to 1995.[13][14][15][16] 1970 Robert Boschert develops simpler, low cost circuits. By 1977, Boschert Inc. grows to a 650-person company.[17][18] After a series of mergers, acquisitions, and spin offs (Computer Products, Zytec, Artesyn, Emerson Electric) the company is now part of Advanced Energy.[19][20][21] 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.[22] 1973 Xerox uses switching power supplies in the Alto minicomputer [23] 1976 Robert Mammano, a co-founder of Silicon General Semiconductors, develops the first integrated circuit for SMPS control, model SG1524.[17] After a series of mergers and acquisitions (Linfinity, Symetricom, Microsemi), the company is now part of Microchip Technology.[24] 1977 Apple II is designed with a switching mode power supply. "Rod Holt ... created the switching power supply that allowed us to do a very lightweight computer".[25] 1980 The HP8662A 10 kHz – 1.28 GHz synthesized signal generator went with a switched mode power supply.[26] Explanation A linear power supply (non-SMPS) uses a linear regulator to provide the desired output voltage by dissipating 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 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 SMPS changes output voltage and current by switching ideally lossless storage elements, such as inductors and capacitors, between different electrical configurations. Ideal switching elements (approximated by transistors operated outside of their active mode) have no resistance when "on" and carry no current when "off", and so converters with ideal components would operate with 100% efficiency (i.e., all input power is delivered to the load; no power is wasted as dissipated heat). In reality, these ideal components do not exist, so a switching power supply cannot be 100% efficient, but it is still a significant improvement in efficiency over a linear regulator. 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 a 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 a small LC filter. Advantages and disadvantages The main advantage of the switching power supply is greater efficiency (up to 96%) than linear regulators because the switching transistor dissipates little power when acting as a switch. Other advantages include smaller size, lower noise, and lighter weight from the elimination of heavy line-frequency transformers, and comparable heat generation. Standby power loss is often much less than transformers. The transformer in a switching power supply is also smaller than a traditional line frequency (50 Hz or 60 Hz depending on region) transformer, and therefore requires smaller amounts of expensive raw materials, like copper. 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 devices connected to the same phase, such as A/V equipment. 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 with switching power supplies 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 a higher capacity or smaller transformer. Output voltage With transformer used, any voltages available; if transformerless, limited to what can be achieved with a voltage doubler. Any voltages available, limited only by transistor breakdown voltages in many circuits. Voltage varies little with load. An SMPS can usually cope with wider variation of input before the output voltage changes. Universal or "wide input" power supplies, which work with mains voltages from 90 to 250 V, are common. Efficiency, heat, and power dissipation 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%.[27] 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 [de] 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 Linear voltage-regulating circuit and usually noise-filtering capacitors; 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 Linear regulators generally have excellent rejection of AC line ripple and are generally lower noise than switched-mode converters. 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 whose hearing is very sensitive to the relevant frequency range. Power factor Low 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 stabilizes 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 are not isolated and therefore dangerous when exposed. 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 consisting of capacitors and inductors before the bridge rectifier. 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. In power supplies without a ground pin (like USB charger) there is EMI/RFI capacitor placed between primary and secondary side.[28] It can also provide some very mild tingling sensation but it's safe to the user.[29] 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[quantify]. 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.[30] 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. Connection to 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'. An 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 VAC or at 230 VAC. 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 power factor correction (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. An SMPS designed for AC input can usually be run from a DC supply, because the DC would pass through the rectifier unchanged.[31] 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, based on the Delon circuit, for 115/230 V (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.[32] Inverter stage This section refers to the block marked chopper in the 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 This charger for a small device such as a mobile phone is an off-line switching power supply with a European plug, mainly consisting of an opto-coupler, a rectifier and two active components. A feedback circuit monitors the output voltage and compares it with a reference voltage. Depending on design and safety requirements, the controller may contain an isolation mechanism (such as an opto-coupler) 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 Any switched-mode power supply that gets its power from an AC power line (called an "off-line" converter[33]) requires a transformer for galvanic isolation.[citation needed] 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 the high frequency transformer compared to the 50/60 Hz transformers formerly used. There are additional design tradeoffs.[34] 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 (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 = − D 1 − D V 1 {\displaystyle \scriptstyle V_{2}=-{\frac {D}{1-D}}V_{1}} Current is continuous at input and output. SEPIC Capacitor and two inductors Any, V 2 = D 1 − D V 1 {\displaystyle \scriptstyle V_{2}={\frac {D}{1-D}}V_{1}} Current is continuous at input. Zeta Capacitor and two inductors Any, V 2 = D 1 − D V 1 {\displaystyle \scriptstyle 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 limits of ≤ 30 V (r.m.s.) AC or ≤ 42.4 V peak or ≤ 60 V DC and power limits of 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.[37] 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.[38][39] For some topologies, multiple windings can be placed on the transformer to produce multiple output voltages.[40] Some converters use the transformer for energy storage, while others use a separate inductor. Type[36] 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 converter1 Ringing choke converter (RCC) 0–150 1.0 5–600 Transformer Low-cost self-oscillating flyback variant[41] Half-forward 0–250 1.2 5–500 Inductor Forward2 100–200 60–200 Inductor Isolated form of buck converter Resonant forward 0–60 1.0 60–400 Inductor and capacitor Single rail input, unregulated output, high efficiency, low EMI.[42] 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 Zero voltage switched mode 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. ^1 Flyback converter logarithmic control loop behavior might be harder to control than other types.[43] ^2 The forward converter has several variants, varying in how the transformer is "reset" to zero magnetic flux every cycle. Chopper controller: The output voltage is coupled to the input thus very tightly controlled Quasi-resonant zero-current/zero-voltage switch Quasi-resonant switching switches when the voltage is at a minimum and a valley is detected. 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."[44] Quasi-resonant switching, also known as valley switching, reduces EMI in the power supply by two methods: By switching the bipolar switch when the voltage is at a minimum (in the valley) to minimize the hard switching effect that causes EMI. 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.[failed verification] 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.[45] Failure of the switching transistor is common. Due to the large switching voltages this transistor must handle (around 325 V for a 230 VAC 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 volts 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 sides 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 2 kΩ resistor to any accessible part must, according to IEC 60950, be less than 250 µA for IT equipment.[46] 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. 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 VDC cranking supply, 12 V for accessories may be furnished through a DC/DC switch-mode supply. This has the advantage over tapping the battery at the 12 V position (using half the cells) that all the 12 V load is evenly divided over all cells of the 24 V 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. A common use for switched-mode power supplies is as extra-low-voltage sources for lighting, and for this application they are often called "electronic transformers". Examples of SMPSs for extra-low voltage lighting applications, called electronic transformers. Terminology The term switch mode 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.[33] Switching-mode power supply, switching power supply, and switching regulator refer to this type of power supply.[33] See also Electronics portal Energy portal Auto transformer Boost converter Buck converter Conducted electromagnetic interference DC to DC converter Inrush current Joule thief Leakage inductance Resonant converter Switching amplifier Transformer Vibrator (electronic) Notes ^ US 1037492, Kettering, Charles F., "Ignition system", published 2 November 1910, issued 3 September 1912 ^ US 1754265, Coursey, Philip Ray, "Electrical Condenser", published 23 June 1926, issued 15 April 1930 ^ a b "When was the SMPS power supply invented?". electronicspoint.com. ^ "Electrical condensers (Open Library)". openlibrary.org. ^ "First-Hand:The Story of the Automobile Voltage Regulator - Engineering and Technology History Wiki". ethw.org. 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