1 Outline of Power Supply

Regulated DC voltage is required for semiconductor devices such as ICs and Transistors to function. Regulated voltage can be generated from commercial AC lines with an AC to DC power supply or from DC power source (such as Batteries) with a DC to DC converter.

Each type is further classified to one that is isolated between primary (Input) circuit and secondary (Output) circuit or non-isolated.

Over the past 15 years, there have been significant changes in the design of power supplies. The most important of these has been widespread change from linear regulator to switch mode power supplies (SMPS). The principal reason for the move to switch mode power supplies is their much greater efficiency typically 65 - 90% as opposed to 25 - 50% for the linear regulator. This greatly reduces the cooling requirement, and allows a much higher power density.

Table 1.1 Compares some of the features of Switch mode Power Supplies with Linear Regulators

Mode / Item	Switch mode Power Supply	Linear Regulator
Efficiency	65 - 90%	25 - 50%
Stabilization	Normal	Excellent
Ripple Noise	10 - 200mV	Less than 10mV
Response speed	0.5 - 10mS	10μS - 1mS
EMI	Wide interference spectrum	Magnetic interference for source frequency
Input voltage	Wide input range	Narrow input range
Circuit	Complicated	Simple
Size	Small(1/4 - 1/10 of Linear regulator)	Large
Weight	Light (1/4 - 1/10 of Linear regulator)	Heavy

2 Circuit Method of Switch mode Power Supply

The method of switch mode power supply is classified by circuit method of DC-DC converter. There are 2 methods for oscillator: self-oscillating converter where positive feedback from the power transformer to provide the oscillatory behavior, and separate-course oscillator with PWM control IC.

Self-oscillator changes operating frequency depending on input voltage and load, but separate-course oscillator does not change operating frequency.

Forward converter and flyback converter are methods of transfer of energy from primary to secondary source. The forward converter transfers energy when the switching transistor is ON (ON-ON converter), but flyback converter transfers the energy when transistor is OFF (ON-OFF converter).

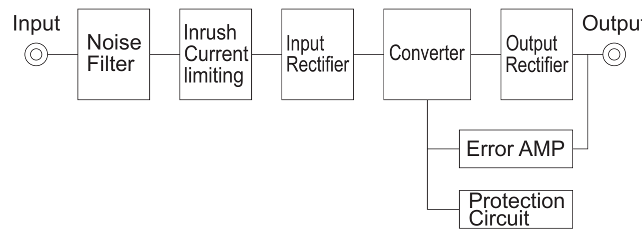


Fig.2.1 Circuit diagram of Switch mode Power Supply

1) Forward converter

Fig.2.2 shows the power stage of a typical single-ended forward converter. Since the output inductor L_1 carries a large DC current component, the term "choke" will be used to describe this component.

Although the general appearance of the power stage is similar to that of the flyback unit, the mode of operation is entirely different. The secondary winding S_1 is phased so that energy will be transferred to the output circuits when the power transistor TR_1 is ON. The power transformer T_1 operates as a true transformer with a low output resistance, and therefore a choke L_1 is required to limit the current flow in the output rectifier D_1, the output capacitor C_1, and the load.

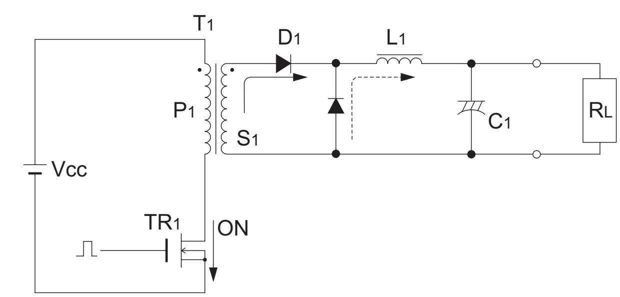


Fig.2.2 Forward converter

2) Push-pull converter

A power switching circuit which uses a centertapped transformer and two power switches which are driven ON and OFF alternatively. This circuit does not provide regulation by itself.

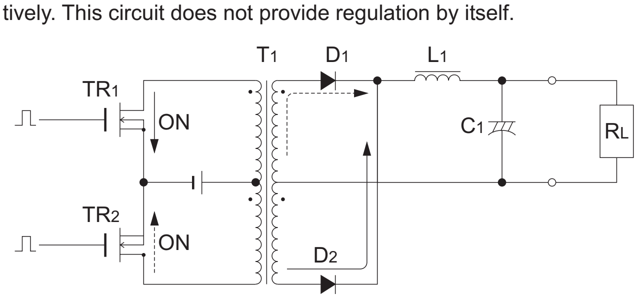


Fig.2.3 Push-pull converter

3) Half-bridge converter

A power switching circuit similar to the full bridge converter except that only two transistors are used, with the other two replaced by capacitors.

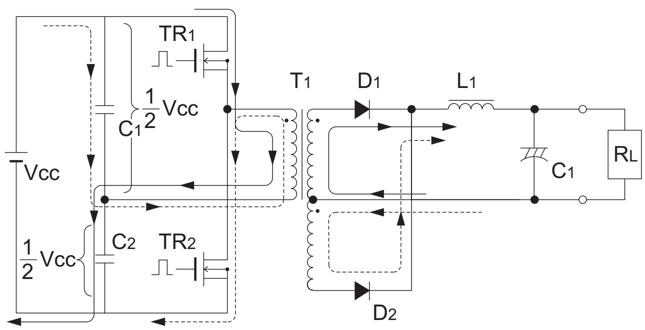


Fig.2.4 Half-bridge converter

4) Full-bridge converter

A power switching circuit in which four transistors are connected in a bridge configuration to drive a transformer primary.

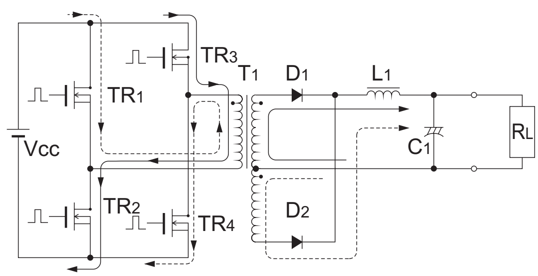


Fig.2.5 Full-bridge converter

5) Flyback converter

A power supply switching circuit which normally uses a single transistor. During the first half of the switching period the transistor is ON and energy is stored in a transformer primary; during the second half period this energy is transferred to the transformer secondary and the load.

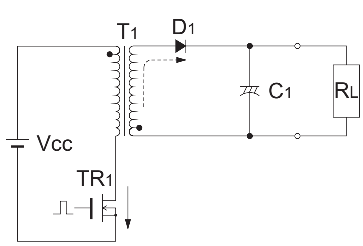


Fig.2.6 Flyback converter

6) Buck regulator

In buck regulators, the output voltage will be of the same polarity but always lower than the input voltage. One supply line must be common to both input and output. This may be either the positive or negative line, depending on the regulator design.

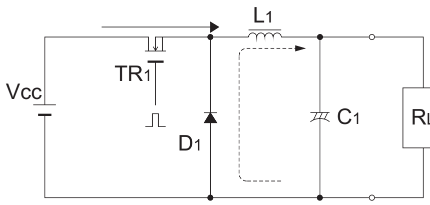


Fig.2.7 Buck regulator

7) Boost regulator

In boost regulators, the output voltage will be of the same polarity but always higher than the input voltage. One supply line must be common to both input and output. This may be either the positive or negative line, depending on the design.

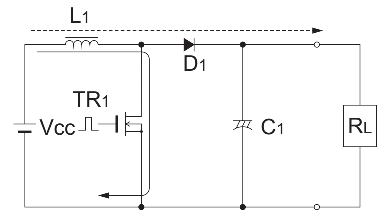


Fig.2.8 Boost regulator

8) Buck-boost regulator

In buck-boost regulators, the output voltage is of opposite polarity to the input, but its value may be higher, equal, or lower than that of the input. One supply line must be common to both input and output, and either polarity is possible by design.

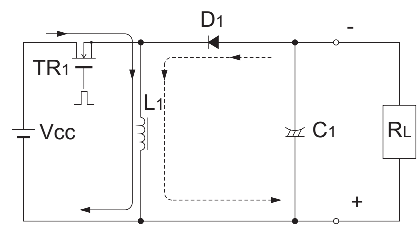


Fig.2.9 Buck-boost regulator

3 Glossary of term

1) Input voltage range

The high and low input voltage limits within which a power supply or DC-DC converter meets its specifications.

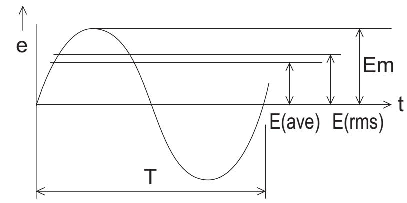


Fig.3.1 Sinusoidal voltage wave form

Maximum Value Em

Effective Value $E\,(rms) = \sqrt{\frac{1}{T}\int_0^T e^2\,dt} = \frac{1}{\sqrt{2}}Em$

Average Value $E\,(ave) = \frac{2}{T}\int_0^{\frac{T}{2}} e\,dt = \frac{2\sqrt{2}}{\pi}Em$

2) Input current of SMPS

Fig.3.2 shows the typical voltage and current wave forms at the input to a SMPS. Current only flows to charge the capacitors when the rectified input voltage exeeds the voltage stored. Pulses of current are drawn from the supply near the peak point of the AC voltage sinewave.

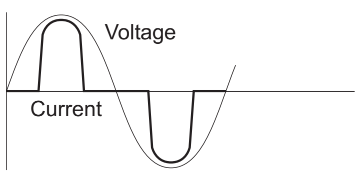


Fig.3.2 Input wave form of SMPS

$$\text{Input Current (rms)} = \frac{\text{Output Power}}{\text{Input Voltage (rms)} \times \text{Efficiency} \times \text{Power Factor}}$$

3) Input Power

It can be seen that the input voltage is only slightly distorted by the very non-linear load presented by the capacitor input filter. The sinusoidal input is maintained because the line input resistance is very low. The input current however, is very distorted and discontinuous, but superficially would appear to be a part sine wave in phase with the voltage. This leads to a common error: The product $V_{in\ (rms)} \times I_{in\ (rms)}$ is assumed to give input power. This is not so! The product is the input volt-ampere product; it must be multiplied by the power factor (typically 0.6 for a capacitor input filter) to get true power.

The reason for the low power factor is that the nonsinusoidal current wave form contains a large odd harmonic content, and the phase and amplitude of all harmonics must be included in the measurement.

Apparent Power = E(rms) × I(rms)

Active Power = Apparent Power × Power Factor

4) Efficiency

The ratio of total output power to active power, expressed in percent. This is normally specified at full load and nominal input voltage.

$$\text{Efficiency} = \frac{\text{Output Power}}{\text{Active Power}} \times 100\ (\%) = \frac{\text{Output Power}}{E(rms) \times I(rms) \times \text{Power Factor}} \times 100\ (\%)$$

5) Inrush current

The peak instantaneous input current drawn by the SMPS at switch ON.

a. The Series Resistor Technique

For low-power applications, simple series resistor may be used. However, a compromise must be made, as a high value of resistance, which will give a low inrush current, will also be very dissipative under normal operating conditions. Consequently, a compromise selection must be made between acceptable inrush current and acceptable operating losses.

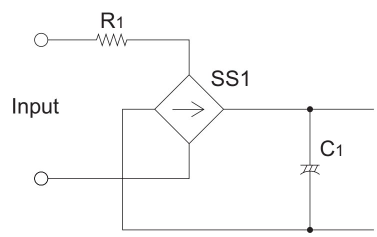


Fig.3.3 Series Resistor Technique

b. The Thermistor Technique

Negative temperature coefficient thermistors (NTC) are often used in the position of TH1 in low-power applications. The resistance of the NTCs is high when the supply is first switched ON, giving them an advantage over normal resistors. They may be selected to give a low inrush current on initial switch-on, and yet, since the resistance will fall when the thermistor self-heats under normal operating conditions, excessive dissipation is avoided.

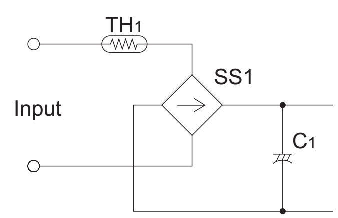


Fig.3.4 Thermistor Technique

c. The Resistor-Thyristor Technique

For high-power converters, the limiting device is better shorted out to reduce losses when the unit is fully operating. Position R1 will normally be selected for the start resistor so that a single triac or relay may be used. R1 can be shunted by a triac or relay after start-up, as shown in Fig.3.5. Although Fig.3.5 shows an active limiting arrangement in which a resistor is shunted by a triac, other combinations using thyristors or relays are possible. On initial switch-on, the inrush current is limited by the resistor. When the input capacitors are fully charged, the active shunt device is operated to short out the resistor, and hence the losses under normal running conditions will be low.

In the case of the triac start circuit, the triac may be conveniently energized by a winding on the main converter transformer. The normal converter turn-on delay and soft start will provide a delay to the turn-on of the triac. This will allow the input capacitors to fully charge through the start resistor before converter action starts. This delay is important, because if the converter starts before the capacitors are fully charged, the load current will prevent full charging of the input capacitors, and when the triac is energized there will be a further inrush current.

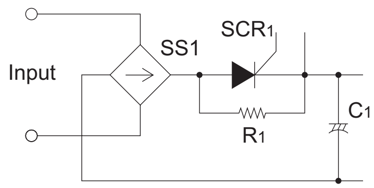


Fig.3.5 Resistor-Thyristor Technique

6) Safety Leakage Current

When the input voltage is at nominal, the current flowing from the input lines to the protective earth conductor.

The UL, CSA, EN allows the following leakage values, measured at 1.06 times rated voltage through a 1500Ω resistor in pararell with an 220nF capacitor: for portable office equipment (<25kg), 0.5mA; for nonportable office equipment, 3.5 mA; and for data processing equipment, 3.5mA, maximum.

It is interesting to note that Japan allows a maximum leakage current of 1mA, measured through an 1000Ω resistor, for line frequencies up to 1kHz. For higher leakage currents an isolation transformer at the installation is required. For line frequencies above 1kHz the maximum leakage current is logarithmically increasing to a value of 20mA at 30kHz.

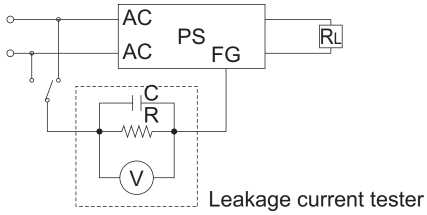


Fig.3.6 Leakage Current Measuring Circuit

7) Output Voltage

The nominal value of the DC voltage at the output terminals of a power supply.

8) Rated Output Current

The maximum load current which a power supply was designed to provide at a specified ambient temperature.

9) Minimum Load

Minimum output current required for voltages to be in specified range. Generally in multiple output power supplies, a minimum load is required on the main output to ensure regulation of auxiliary outputs.

10) Line Regulation

The change in output voltage as the input voltage is varied over its specified limits, with load and temperature constant.

11) Load Regulation

The change in output voltage as the load is changed from minimum to maximum, at constant line and constant temperature.

12) Overshoot

A transient change in output voltage, in excess of specified output accuracy limits, which can occur when a power supply is turned ON or OFF, or when there is a step change in line or load.

13) Ripple and Noise

The amplitude of AC voltage on the output of a power supply, expressed in millivolts peak-to-peak, at a specified band width. This is the result of feed through of the rectified line frequency, internal switching transients and other random noise.

14) Temperature Regulation

A change in output voltage (mV) in ambient temperature over a specified temperature range.

15) Drift

The change in output voltage of a power supply over a specified period of time, following a warm-up period, with all other operating parameters such as line, load, and ambient temperature held constant.

16) Start-up Time (Turn-on Delay Time)

The time in seconds after switch ON for the output (s) to reach their nominal voltage (s) within regulation limits.

17) Hold-up Time

The time during which a power supply's output voltage remains within specification following the loss of input power.

18) Output Voltage Adjustment Range

The range over which the output voltage can be adjusted (and the means of adjustment).

19) Overcurrent Protection

An output protection feature which limits the output current to a predetermined value in order to prevent damage to the power supply or the load under overcurrent conditions. The supply is automatically restored to normal operation following removal of the overcurrent.

20) Overvoltage Protection

A circuit which detects output overvoltages above a specified level and shuts down the converter to protect load circuits.

21) Remote Sensing

A technique of regulating the output voltage of a power supply at the load by means of sensing leads which go from the load back to the regulator. This compensates for voltage drops in the load leads.

22) Remote ON/OFF

(1) Converter shutdown into a standby or idle mode by application of an external signal to the remote ON/OFF terminal.
(2) Converter shut down by an external logic signal.

23) Isolation

The electrical separation between input and output of a power supply by means of the power transformer. The isolation resistance (normally in megohms) is generally specified and is a function of materials and spacings employed throughout the power supply. The maximum AC or DC voltage which may be applied from input to output and/or chassis of a power supply.

24) Operating Temperature

The range of ambient or baseplate temperature in ℃ over which a converter can be operated safely at either rated or derated output power.

25) Operating Humidity

The range of ambient or baseplate humidity in % over which a converter can be operated safely at either rated or derated output power.

26) Operating Altitude

The altitude at which a power supply can be operated safely. Expressed in m (feet).

27) Storage Temperature

The range of ambient temperature over which a converter may be stored long term without damage. Expressed in ℃.

28) Storage Humidity

The range of ambient humidity over which a converter may be stored long term without damage. Expressed in %.

29) Storage Altitude

The altitude at which a power supply may be stored in the long term without damage. Expressed in m (feet).

30) Vibration Standards

Definition of acceleration of mechanical vibration that can be applied to the converter without damage.

31) Impact Standards

Definition of acceleration of mechanical impact that can be applied to the converter without damage.

4 Notes on operation

1) Input voltage

a. Applicable voltage in the world

Confirm AC power supply voltage, frequency, and phase because they can differ from area to area. If more than the specified amount of voltage is applied, damage to power supply can result. If the input voltage has a big distorted wave, unit will either not operate normally or will suffer a shortened life time.

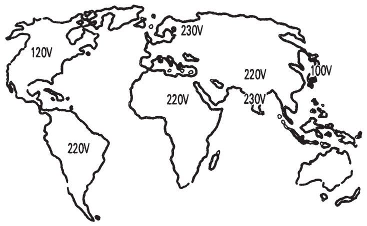


Fig.4.1 Applicable input voltage in the world

b. Applying square wave

AC voltage sinusoidal wave is expressed in effective value, and square wave is expressed in maximum value. Switch mode power supply, which will rectify input voltage by rectifying capacitor input, produces DC voltage close to maximum value and operates inverter. When applying square wave, 1.4 times more than specified input voltage is required. If input is applied keeping indicated maximum value, unit will either not operate normally or suffer shortened life time. If there are questions, please contact us before operation.

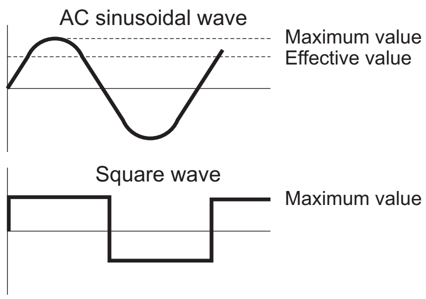


Fig.4.2 Sinusoidal and square wave form

c. Influence of line filter or choke coil

When a large inductance value of line filter or choke coil is used at input, counter-electromotive force is occured by inductance when switched OFF, and high voltage is applied to input, causing stress and damage to power supply.

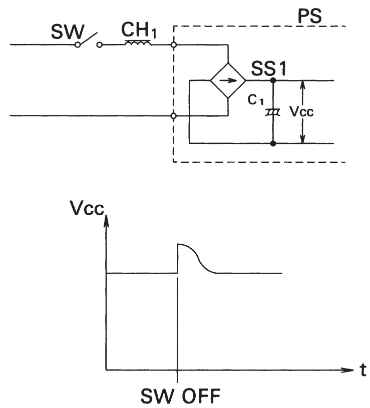


Fig.4.3 Influence of choke coil to input

d. Influence of a phase advance capacitor

Phase advance capacitor is used because phase lag of current is corrected by 3 phase AC. If phase advance capacitor is connected after the input switch, voltage in capacitor at switch OFF is charged in input voltage at next switch ON. Because this causes to power supply, close attention is required.

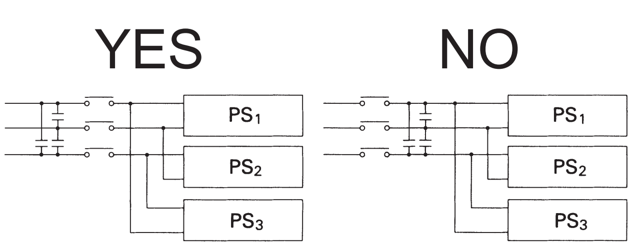


Fig.4.4 Connecting point of phase advance capacitor

2) Auto ranging input power supply

Since autoranging input power supply detects peak values of input voltage, be sure rectangler or DC voltage is not applied.

3) Input current, capacitor ripple, peak currents, and power factor

It will be clear that even if the input voltage remains sinusoidal, the input current will be very distorted, with large peak values. This distorted current wave form results in low input power factors. Further, a large ripple current will flow in the filter capacitors. The rms input, peak, and ripple currents are all given as a ratio to a "Calculated effective input current" I_e:

$$I_e = \frac{P_{in}}{V_{in}}$$

Where I_e = Calculated effective input current, A rms

P_{in} = Calculated (or measured) input power, W

V_{in} = Supply voltage rms

Note: I_e is thus the calculated "real" component of input current (the component which produces the real power). Because of the large harmonic component in the distorted input current, the measured input rms current will be larger by an amount defined by the power factor P_f (approximately 0.5 - 0.7) in the case of a capacitor input filter.

Note: Although Power Factor is normally defined as

$$\text{Power Factor} = \frac{\text{True input Power}}{\text{Input V} \cdot \text{A product}} = \frac{\text{Active Power}}{\text{Apparent Power}}$$

In the case of the "direct-off-line" rectifier capacitor input filter, the low source resistance of the supply ensures that the input voltage remains near constant and free of distortion. Hence the power factor may be defined as the ratio of the effective input current to the rms input current, i.e.,

$$\text{Power Factor} = \frac{I_e}{I_{in\ (rms)}}$$

4) Selecting fuses

The initial fuse selection will be made as follows:

For the line input fuse, study the turn-on characteristics of the supply and the action of the inrush-limiting circuitry at maximum and minimum input voltages and full current-limited load. Choose a normal-blow or slow-blow fuse that provides sufficient current margin to give reliable operation and satisfy the inrush requirements. Its continuous current rating should be low enough to provide good protection in the event of a genuine failure. However, for long fuse life, the current rating should not be too close to the maximum rms equipment input current measured at minimum input voltage and maximum load (perhaps 150% of I_{rms} maximum). Use measured or calculated rms currents, and allow for the form factor (approximately 0.6 for capacitor input filters) when calculating rms currents.

5) Selecting switches

Use the switches within their rating, including inrush current rating. Check particularly the inrush current using a switch with a set. Since voltage fluctuation occurs depending on geographical region, review the derating for using a switch.

6) Lightning transients

The major mechanisms by which lightning produces surge voltages are the following.

- A direct lightning stroke to an external circuit (outdoor) injecting high currents producing voltages by either flowing through earth resistance or flowing through the impedance of the external circuit;
- An indirect lightning stroke (i.e. a stroke between or within clouds or to nearby objects which produces electromagnetic fields) that induces voltages/currents on the conductors outside and/or inside a building;
- Lightning earth current flow resulting from nearby direct-to-earth discharges coupling into the common earth paths of the earthing system of the installation.

a) Transient suppression devices

The ideal transient suppression device would be an open circuit at normal voltages, would conduct without delay at some slight voltage above normal, would not allow the voltage to increase during the clamping period, would handle unlimited currents and power, would revert back to an open circuit when the stress has gone, and would never wear out.

At the time this is written, there is no single transient suppression device that approaches this ideal for all the stress conditions. Hence, at present efficient transient protection requires the use of a number of devices, carefully selected to complement each other and thus cover the full range of voltage and current stress conditions.

b) Line filter, transient suppressor combinations

If inductors are used, it is expedient to provide additional filtering in the transient suppressor circuit at the same time. This will help to reject line-borne noise and filter out power supply-generated noise. Also, the winding resistance and inductance can provide the necessary series impedance to limit the transient current for efficient transient suppression. Consequently, transient suppression is often combined with the EMI noise filtering circuits typically required with switch mode power supplies.

c) Metal oxide varistors (MOVs, Voltage-dependent resistors)

As the name implies, varistors (MOVs) display a voltage-dependent resistance characteristic. At voltages below the turnover voltage, these devices have high resistance and little circuit loading. When the terminal voltage exceeds the turnover voltage, the resistance decreases rapidly and increasing current flows in the shunt-connected varistor.

The major advantages of the varistor are its low cost and its relatively high transient energy absorption capability. The major disadvantages are progressive degradation of the device with repetitive stress and a relatively large slope resistance.

d) Gas-filled surge arresters

Much larger transient currents can be handled by the various gas-discharge suppressor devices. In such suppressors, two or more electrodes are accurately spaced within a sealed high-pressure inert gas environment. When the striking voltage of the gas tube is exceeded, an ionized glow discharge is first developed between the electrodes. As the current increases, an arc discharge is produced, providing a low-impedance path between all internal electrodes.

When it strikes, the gas arrester effectively short-circuits the supply, with only a small voltage being maintained across the electrodes. Because of the low internal dissipation in this mode, a relatively small device can carry currents of many thousands of amperes. With this type of suppressor, protection is provided not so much by the energy dissipated within the device itself, but by the device's short-circuit action. This forces the transient energy to be dissipated in the series resistance of the supply lines and filter.

A disadvantage of the gas arrester is its relatively slow response to an overvoltage stress.

7) "Lockout" in foldback current limited supplies

A power supply output protection circuit whereby the output current decreases with increasing overload, reaching a minimum at short circuit. This minimizes internal power dissipation under overload conditions. Foldback current limiting is normally used with linear regulators and is unnecessary with switching regulators.

With the resistive load (the straight-line loads depicted in Fig.4.5), there can only be one stable point of operation, defined by the intersection of the load line for a range of given loads with the power supply characteristic (for example, all points P1). Therefore, the reentrant characteristic shown would be swept out as the load resistance is varied from maximum to zero. This characteristic is swept out without instability or "lockout"; however, this smooth shutdown may not occur with non-linear loads.

Fig. 4.5 shows a very non-linear load line R3 (such as may be encountered with tungsten filament lamps) impressed on the power supply reentrant current limit characteristic.

It should be understood that a tungsten filament lamp has a very low resistance when it is first switched ON (because of the low temperature of the filament wire). Consequently, a relative large current flows at low applied voltages. As the voltage and current increase, the temperature and resistance of the filament increase, and the working point changes to a higher resistance. A non-linear characteristic is often found in active semiconductor circuits. It should be noticed that this non-linear load line crosses the power supply reentrant current characteristic at three points. Points P2 and P3 are both stable operating points for the power supply. When such a supply-load combination is first switched ON, the output voltage is only partially established to point P2, and lockout occurs. (It is interesting to note that if the supply is switched ON before the load is applied, it may be expected that the correct working point P3 will be established.) However, point P3 is a stable operating point only for a lamp that was previously working. When the lamp is first switched on, lockout will still occur at point P2, during the lamp power-up phase. This is caused because the slope resistance of the lamp load line at point P2 is less than the slope of the power supply reentrant characteristic at the same point. Since P2 is a stable point, lockout is maintained, and in this example the lamp would never be fully turned ON.

Reentrant lockout may be cured in several ways. The reentrant characteristic of the power supply may be modified to bring it outside the non-linear load line of the lamp, as shown in plots B and C in Fig.4.6. This characteristic now provides only one stable mode of operation at point P1.

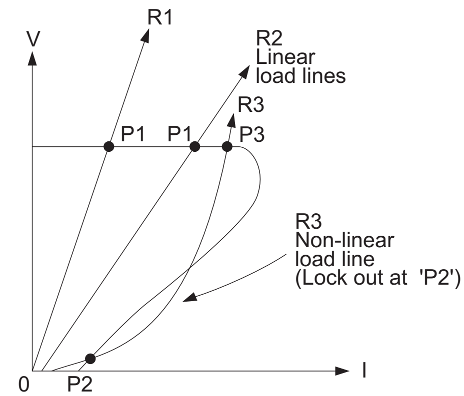


Fig.4.5 Overload and start-up characteristics of a foldback, current-limited supply, showing performance for linear and non-linear load lines.

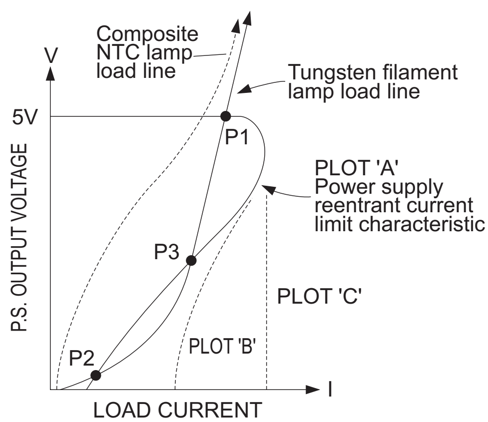


Fig.4.6 Non-linear load line, showing "lockout" and modified characteristics to prevent lockout.

8) Peak loading

a. Peak current in excess of rated current from several hundreds micro seconds to several tenths seconds

Peak current flows until the current limit value. If peak current flows beyond the prescribed duration, power supply may heat up and result in damage, so this must be avoided.

When more peak current is required, it is possible by modification.

Please contact us for the modification.

b. Peak current in excess of rated current from a few micro seconds to several hundreds micro seconds

Peak current flows by adding the capacitor externally to the output.

The formula for calculating the capacitance is as follows.

Please make sure that the ripple current is within the specified value when selecting the capacitor.

$$C\,(\mu F) = \frac{(I_P - I_R)\,tw}{\Delta V} \times 10^6$$

where

C : Capacity of capacitor externally added to output (μF)

I_P : Peak current (A)

I_R : Rated current (A)

tw : Width of peak current (sec.)

ΔV : Acceptable voltage drop (V)

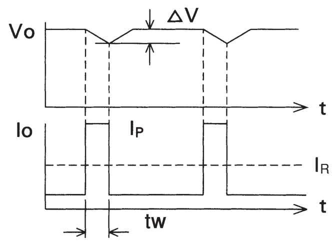


Fig.4.7 Externally added capacitor at peak loading

When the frequency of peak current is from 20Hz to 20MHz, a sound may occur from power supply.

Please evaluate the sound in advance.

For more information, please consult with us.

9) Derating

The specified reduction in an operating parameter to improve reliability. Generally for power supplies, it is the reduction in output power at elevated ambient temperature. Operate units in each specified range shown in Derating Curve.

10) Series Operation

Most power converters can be operated in series if they have overload limitation by either constant current or constant power circuits. With some switching converters series operation is prohibited because one unit upsets the feedback regulation system of the other. With linear and switched mode units using foldback current limiting lock out at switch ON can occur because of the different ramp up times of two units in series. Care must be taken not to exceed the safe working voltage at the outputs of converters in series. This may be considerably lower than the dielectric strength test voltage which is a short-term test between outputs and ground. The output ripple of converters in series is additive but this of course does not change the value of ripple expressed as a percentage of total output voltage. To protect each output from the reverse voltage applied by the other unit in the event of load short circuits, reverse biased diodes are used as shown in Fig.4.8. It is common practice to include these protection diodes in laboratory power supplies.

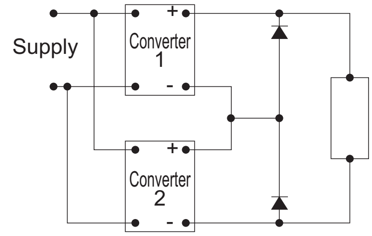


Fig.4.8 Outputs connected in series showing reverse voltage protection diodes

11) Parallel Operation

This is only recommended with power converters specifically designed for parallel connection. A general comment is that it is much lower cost and causes far fewer problems to use a single power converter correctly rated for the application rather than two or more in parallel. However, there are power converters which feature master slave parallel operation. These units are intended for modular expansion schemes and fault tolerant parallel redundant power systems. Where power converters are overload protected by constant current limiting simple parallelling of the outputs can work to an acceptable standard. Output voltages must be set to equality as precisely as possible. In a two unit system the unit with the slightly higher output voltage will reach its current limit and the voltage will drop to equal that of the other unit.

This converter will then supply the remaining current demanded by the load. So regulation can never be better than the difference between the output voltage settings of the two converters, and one unit will always be operating in current limit, therefore above its rating. Where current limits are adjustable to below maximum rating simple parallelling is satisfactory if the degradation of regulation can be tolerated. To improve load current sharing precisely equal series resistors can be used as shown in Fig.4.9.

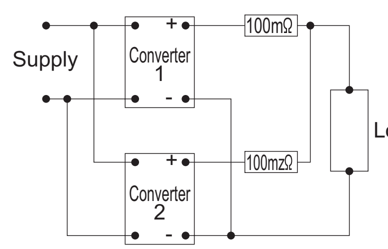


Fig.4.9 Current sharing resistors used to parallel two converters

For the best results the wiring resistance must also be exactly balanced. Small differences in the output voltage settings of the converter outputs still creates considerable current unbalance. In the example illustrated (Fig. 4.9), the load is 5V to 2A. Converter output voltage setting are 5V and if they are unequal by 0.1V, the current out of balance from the nominal 1A is ±0.5A. This requires that each unit individually rated at 1.5A. It is clearly not a cost effective method of providing 5V 2A of stabilized power. Also that the 100mΩ series resistors degrade the regulation to worse than 2%.

In critical applications where continuous operation is essential, parallel redundant power systems are often specified. The system has to keep running even when a power unit fails. Current sharing is not such an important criterion since each power unit must be rated to supply the total load. But to enable both units to be continuously monitored for faults it is advisable that some measure of current sharing takes place. Both units are then always operating. Isolating series diodes which are continuously rated at the full load current allow either power converter to continue operation unaffected by a fault in the other. Matching the forward resistance of the diodes and balancing the wiring resistance helps with the current sharing. However, these series impedance degrade the regulation. Some power converters, which are specifically designed for use in fault tolerant systems allow remote sensing downstream of the parallelling diodes to maintain full regulation at the load. In the parallel redundant scheme illustrated in Fig. 4.10 one of the power converters could be replaced by a battery followed by a DC-DC converter to provide a no-break power system in the event of main supply failure.

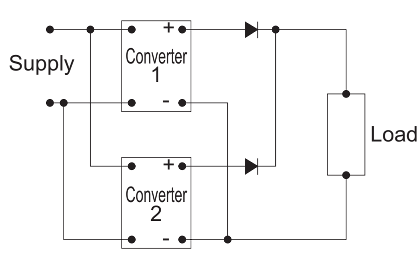


Fig.4.10 Isolating diodes used for parallel redundant connection of two converters

12) Remote sensing

Remote sense terminals are connected to a high-gain part of the power amplifier loop. Consequently, any noise picked up in the remote sense leads will be translated as output voltage noise to the power supply terminals, degrading the performance. Further, the additional phase shifts caused by lead inductance and resistance can have a destabilizing effect. Therefore, it is recommended that remote sense leads be twisted to minimize inductance and noise pickup.

13) Remote ON/OFF

For system control, it is often necessary to turn the power supply ON or OFF by external electronic means. Typically a TTL high signal will define the ON condition and a TTL low the OFF condition. Of course, opposite case is also available, so please read catalogue carefully before operation. Activation of this electronic inhibit should invoke the normal soft-start sequence of the power supply when it is turned ON. Power supplies for which this remote ON/OFF function is required will often need internal auxiliary supplies which are common to the output. The auxiliary supply must be present irrespective of main converter operation. This apparently simple requirement may define the complete design strategy for the auxiliary supplies.

5 Electromagnetic Interference

5.1 Introduction

Electromagnetic interference (EMI), otherwise referred to as radio-frequency interference (RFI), the unintentional generation of conducted or radiated energy, is indefatigable in all switch mode power supplies. The fast rectangular switching action required for good efficiency also produces a wide interference spectrum which can be a major problem.

Further, for proper operation of any electronic system, it is important that all the elements of the system be electromagnetically compatible. Also, the total system must be compatible with other adjacent systems. As the SMPS can be such a rich source of interference, it is vital that this aspect of the design be carefully considered. Normal good design practice requires that the RF interference allowed to be conducted into the supply or output lines, or permitted to be radiated away from any power equipment, be minimized to prevent RF pollution. Further, national, federal, and international regulations limit by law the permitted interference levels.

5.2 EMI/RFI propagation modes

There are two forms of propagation of interest to the power supply designer: electromagnetic radiated E and H waves and conducted interference on supply lines and interconnecting wires.

Radiated interference is normally minimized as a natural result of the layout and wiring practices required to reduce leakage inductance and improve performance. Typically the high-frequency current loops will be short, and twisted pairs will be used where possible. Transformers and chokes with air gaps will be screened to reduce radiated magnetic fields, screened boxes or equipment enclosures will often be used.

The techniques applied to minimize conducted interference will also reduce radiated noise. The following sections concentrate on the conducted aspect of power supply interference, as once the conducted limits have been met, the radiated limits will normally be satisfied as well.

5.3 Power line conducted mode interference

Two major aspects of conducted interference will be considered: differential mode conducted noise and common mode conducted noise. These will be considered separately.

Differential mode interference

Differential or series mode interference is that component of RF noise which exists between any two supply or output lines. In the case of off-line SMPS, this would normally be live and neutral AC supply lines or positive and negative output lines. The interference voltage acts in series with the supply or output voltage.

Common mode interference

Common mode interference is that component of RF noise which exists on any or all supply or output lines with respect to the common ground plane (chassis, box, or ground return wire).

5.4 RFI filtering in power supplies

Nearly all switch mode power supplies intended for use on mains supplies are filtered to be compliant with either level A or level B RFI standards when driving steady state loads. When power units are used in "real" situations, driving active electronic circuits, especially those featuring high speed and/or high power switching, the characteristics of the interference generated can change dramatically, thereby reducing the effectiveness of the line filter. It is the final equipment as an entity, that is required to conform to the regulations, not the individual internal sub assemblies. So, specifying a power supply which meets the required RFI level does not remove the need for testing of the completed equipment for conformity.

Internal AC wiring between power unit input terminals and the equipment AC input receptacle, or between the receptacle and other AC driven units (fans, motors, lamps etc.) may well pick up interference which totally bypasses the power units line filters. The employment of RFI compliant power units is not a guarantee of system compliance.

1) Design for EMC

Electronic systems must be designed from the outset with EMC considerations in mind. To ensure system conformity to the necessary standards an AC input line filter should be located in an optimum position adjacent to, or integrated with the AC input receptacle. Internal AC and DC distribution wiring should be in twisted pairs, taking the shortest possible routes, should not be bundled together in looms, and should cross other internal wiring at right angles. The most susceptible wires need to be shielded within a grounded conductive sheath. To keep radiated noise within bounds, known sources of RFI, such as CRTs, HF ballasts and switched mode converter transformers must not be sited adjacent to vent holes or other openings in metal enclosures.

2) Switch mode power supplies

All varying electric currents and magnetic fields generate Electro Magnetic Interference. The more rapid the variation, the higher the amplitude and the broader is the frequency band of the noise emissions generated. Because they employ fast switching transitions at high power, switch mode power supplies are a major source of broad band noise. In consequence they tend to incorporate comprehensive line input filters. Typically these filters are similar to those illustrated in Fig.5.1 and 5.2 for level A and level B compliance respectively.

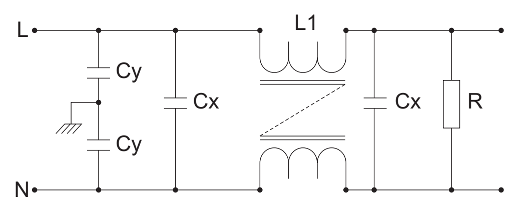


Fig.5.1 Typical line filter used in SMPS for VDE0871 Level A compliance

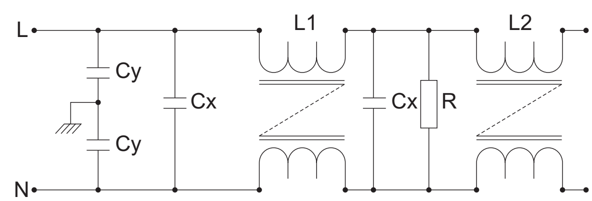


Fig.5.2 Typical line filter used in SMPS for VDE0871 Level B compliance

5.5 Limits for mains terminal interference

Power conversion product manufacturers and users are mainly concerned with the following standards.

EN55022 (CISPR22) : European standard for Information Technology Equipment (ITE)
FCC part 15 sub part J : USA standard for ITE
VDE0871 : German standard for ITE

The German standards VDE0871 level A and B have for many years been used as a world wide benchmark especially for line conducted interference levels. This is partly because authorities in Germany have been able to enforce the regulations successfully as a result of legal backing, and partly because they are more stringent than CISPR standards at lower frequencies. They include limits for line conducted noise in the 10kHz to 150kHz frequency band which are of particular concern to designers of switch mode power supplies. EN55022 has no requirements below 150kHz, although from 150kHz class B limits are slightly lower (see Fig.5.3) than VDE0871. For class A equipment they coincide from 150kHz to 30MHz. FCC class A and class B limits cover the frequency spectrum from 450kHz to 30MHz, and as can be seen from Fig.5.3 the requirements are less stringent.

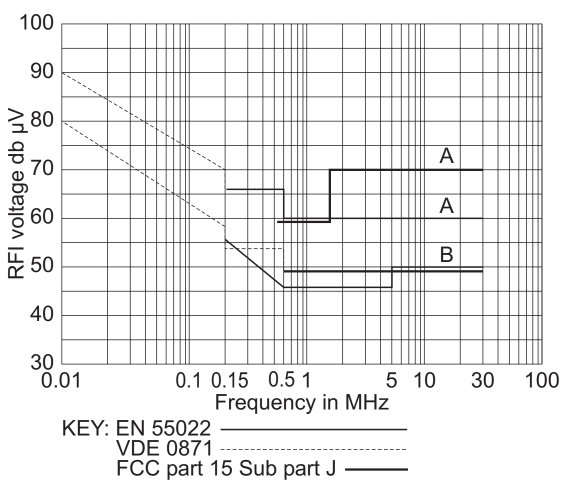


Fig.5.3 Limits of Mains Terminal Interference Voltage for Class A and Class B Equipment for compliance with EN, VDE and FCC standards

(Note: (i)Above 150kHz class A limits are the same for EN & VDE
(ii) FCC limits are only specified above 450kHz)

In common with other EC member states Germany will have to harmonize its national standards with the EN standards. The equivalent to EN55022 has been published as VDE0878 part 3 but with a national supplement part 30 which retains the low frequency conducted noise limits per VDE0871.

6 Power Factor Correction

6.1 Introduction

EN61000-3-2 is main standards to limit distortion of the supply current wave form by equipment powered by the AC mains supply. This standard comes with the scope of the EMC Directive, and imposes specific limits on the amplitudes of the harmonics in the wave form. This standard will have a significant effect upon the design and use of equipment containing switch mode AC/DC power supplies.

The benefits of power factor corrected power supplies are very obvious in some applications at higher power levels (typically >1kw) especially where equipment is specified for operation from standard low power (<15A) AC main sockets, or from UPS and standby generator sources.

6.2 Power in AC circuit

6.2.1 Sinewave current

The formula for power in AC circuits with sinusoidal wave forms is

Instantaneous Power = $E \sin\omega t \times I \sin(\omega t + \phi)$

where E and I are the peak amplitudes of the voltage and current sinewaves and is the phase difference between them.

This leads to the following expression:

$$P = \frac{EI}{2}\left[\cos\phi - \cos(2\omega t+\phi)\right]$$

Thus the power wave form is a cosine wave at twice the frequency with an offset equal to

$$\frac{EI}{2}\cos\phi = \frac{E}{\sqrt{2}} \dagger \frac{I}{\sqrt{2}}\cos\phi \text{ (Fig.6.1)}$$

To obtain average power the above wave form is integrated with respect to time and since cos $(2\omega t+\phi)$ integrates to zero,

$$\text{Average Power} = \frac{E}{\sqrt{2}} \times \frac{I}{\sqrt{2}}\cos\phi = E_{rms} \cdot I_{rms}\cos\phi \text{ (W)}$$

$$\text{Power Factor} = \frac{\text{Active Power}}{\text{Apparent Power}} = \frac{\text{Watts}}{\text{Volts} \times \text{amps}} = \cos\phi$$

for no phase difference, Power Factor = 1, and in circuits with sinewaves Power Factor depends only on the phase difference between the voltage and current wave forms.

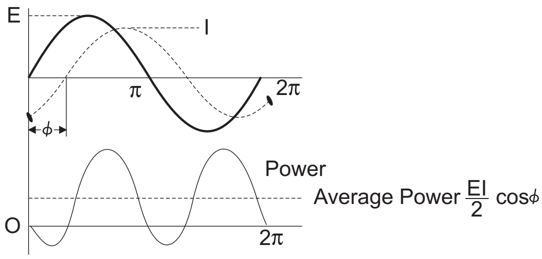


Fig.6.1 Voltage, Current and Power Curves in Single Phase AC Circuits with Sinusoidal Wave forms

6.2.2 Non-Sinewave current

However, when the current wave form is not a sinewave (as in the case with switch mode power supply input circuits) a more general expression must be derived.

Voltage is as above = $E \sin \omega t$, but the current is made up of a fundamental plus harmonics and is expressed as $\Sigma I_n \sin(n\omega t + \phi)$

for n = 1, 2, 3, 4 ......

$$\therefore P = E \sin \omega t \, (\Sigma I_n \sin n \cdot \omega t + \phi n) \quad \text{for } n = 1, 2, 3, 4.....$$

$$= \frac{\Sigma EI}{2} (\cos[(n-1)\,\omega t - \phi n] - \cos[(n+1)\,\omega t + \phi n]) \quad \text{for } n = 1, 2, 3, 4.....$$

Except when n = 1(the fundamental) every other term in this expression integrates to zero with respect to time, so the harmonic components of current add nothing to the average power which remains

$$\text{Average Power} = \frac{I}{2} EI_1 \cos\phi_1$$

Unfortunately, each harmonic of current adds to the rms value

$$I_{rms} = \Sigma \frac{I_n}{\sqrt{2}} \quad \text{for } n = 1, 2, 3, 4.....$$

$$\text{and Power Factor} = \frac{EI_1\cos\phi}{\Sigma EI_n} \quad \text{for } n = 1, 2, 3, 4.....$$

Even when the fundamental component of the current is in phase with the applied voltage, making $\cos\phi_1 = 1$ the Power Factor is less than unity, and where the harmonics are a large proportion of the fundamental, PF is much less than unity.

6.3 Input Wave form of SMPS

A typical SMPS input circuit functions just like a peak detector. Current only flows to charge the capacitors when the rectified input voltage exceeds the voltage stored. Pulses of current are drawn from the supply near the peak point of the AC voltage sinewave. The larger the stored energy in the capacitors relative to the continuous power the shorter are the current pulses. Power supplies designed for long hold-up times, and power supplies used at a low fraction of their rated power exhibit current wave forms with higher harmonic content and therefore worse power factor.

6.4 Power Factor Correction Technique

The simplest solution to the problem is to use a passive component LC filter between the AC supply and the SMPS input. This filter will behave as a buffer energy store to provide the current pulses demanded. Because it functions at mains frequency and transmits all the power used by the SMPS, this filter is heavy and expensive, and typically between one third and one half the volume of the power unit. The main advantage of these filters is their relative simplicity and ruggedness-they will not degrade the MTBF of the power unit. If the energy buffer can be made to operate at high frequency, the inductor in the filter can be very much smaller. Active PFC schemes using a high frequency switching pre-regulator are now possible, and there are a number of integrated circuits available to implement the necessary control functions. A typical scheme uses a current mode boost regulator to pre regulate the output of the input bridge rectifier/storage capacitor. The full wave rectified input voltage sinewave is used as a current reference signal. Power factors between 0.95 and 0.99 are claimed for this technique. A further advantage is that the universal input operation from 90V through 264V is easily accomplished. But it does not add considerably to the cost and complexity of the power unit and is very difficult to justify for anything other than high power units.

6.5 Standards for Limiting Harmonic Distortion

The relevant standard is IEEE519. This in the course of revision and although it is unlikely to the backed by legislation it is thought that the public utilities concerned with the supply of electrical power will require consumers to comply. The standard relates the maximum harmonic content allowed to the ratio of load current to short circuit current. As an instance, for a ratio of 20 the maximum 3rd harmonic is 4% of the fundamental amplitude.

The European standard is EN61000-3-2 (IEC61000-3-2). The precise application of this regulation is still not settled but when it is, it will be backed by the force of a law in the Member States.

6.6 IEC61000-3-2 Ed2.1

Four classes of equipment are defined as follows.

Class A:

- balanced three-phase equipment;
- household appliances, excluding equipment identified as class D;
- tools, excluding portable tools;
- dimmers for incandescent lamps;
- audio equipment.

Equipment not specified in one of the three other classes shall be considered as class A equipment.

Class B:

- portable tools;
- arc welding equipment which is not professional equipment.

Class C:

- lighting equipment.

Class D:

Equipment having a power less than or equal to 600W, of the following types:

- personal computers and personal computer monitors;
- television receivers.

Table 6.1 Limits for class A equipment

No.	ODD Harmonics		EVEN Harmonics	
	Harmonic order n	Max. permissible harmonic current A	Harmonic order n	Max. permissible harmonic current A
1	3	2.30	2	1.08
2	5	1.14	4	0.43
3	7	0.77	6	0.30
4	9	0.40	8≦n≦40	0.23x8/n
5	11	0.33		
6	13	0.21		
7	15≦n≦39	0.15x15/n		

Table 6.2 Limits for class C equipment

No.	Harmonic order n	Max. permissible harmonic current expressed as a percentage of the input current at the fundamental frequency %
1	2	2
2	3	30 × λ
3	5	10
4	7	7
5	9	5
6	11≦n≦39 (Odd harmonic only)	3

＊λ is the circuit power factor.

Table 6.3 Limits for class D equipment

No.	Harmonic order n	mA/W	Max.permissible harmonic current A
1	3	3.4	2.30
2	5	1.9	1.14
3	7	1.0	0.77
4	9	0.5	0.40
5	11	0.35	0.33
6	13≦n≦39	3.85/n	0.15x15/n

For the following categories of equipments, limits are not specified in IEC61000-3-2 Ed2.1.

＊ Limits may be defined in a future amendment or revision of the standard.

- equipment with a total power of 75W or less, other than lighting equipment;

  ＊ This value may be reduced from 75W to 50W in the future, subject to approved by National Committers at that time.

- professional equipment with a total rated power greater than 1kW;

- symmetrically controlled heating elements with a rated power less than or equal to 200W;

- independent dimmers for incandescent lamps with a rated power less than or equal to 1kW.

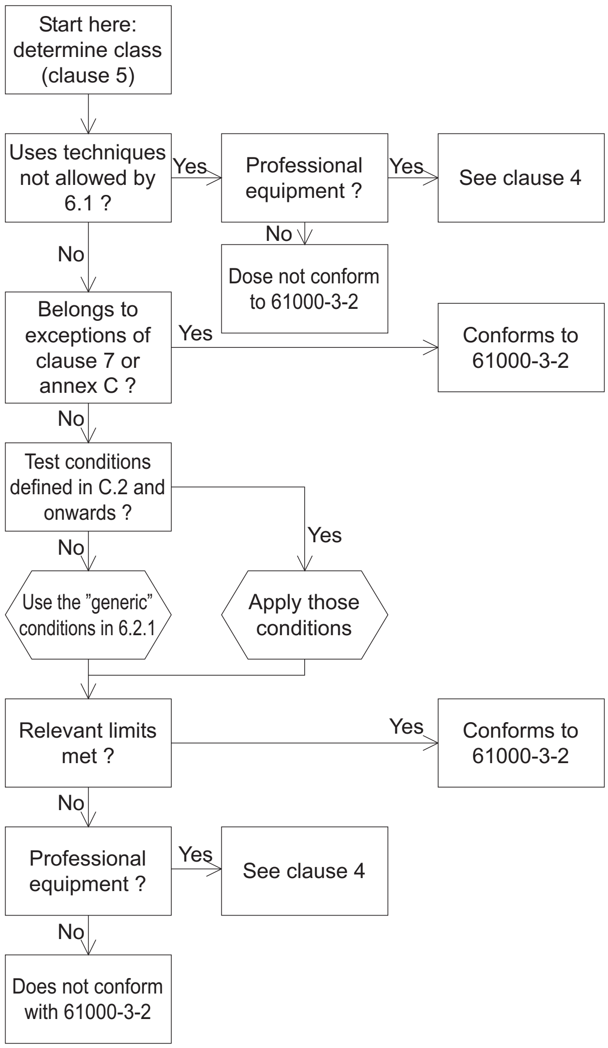


Fig.6.2 Flowchart for determining conformity

6.7 Applications of Power Factor Corrected Power Supplies

Without reference to impending standards there are some applications where PFC is essential. Typical of these power supplies for public telephone networks, where the power units may be either driven from mains AC or from standby generators. To keep the current ratings of the generators and power distribution circuits down, these power supplies (usually≦1.5kW) must have 0.95 or better power factor.

Another important application is the use of UPS systems. A UPS may have to be rated at three to five times the equipment rating in order to provide the very high peak currents demanded by uncorrected power supplies. In such cases, it is extremely cost effective to use PFC power units.

It is necessary to plug 1.5kW plus equipment into normal power distribution sockets which are rated up to 15A (13A UK), without PFC the peak currents will be either blow fuses or cause circuit breakers to trip.

Another problem which has been highlighted is the use of large numbers of low power (<300W) loads in office complexes. There may be upwards of a hundred PCs, word processors, copiers and printers all on the same distribution network all drawing peak currents in sync., causing major problems with overload trips and with cable and circuit breaker ratings. This is the kind of problem that the new regulations will be expected to solve.

7 Reliability

1) Failure mode

It is generally known that the failure rate λ (t) for electronic appliances and components which require no particular maintenance follows their time transition and shows "Bathtub Curve" as illustrated in Fig.7.1, consisting of three stages, i.e., initial failure period, random failure period and wear-out failure period.

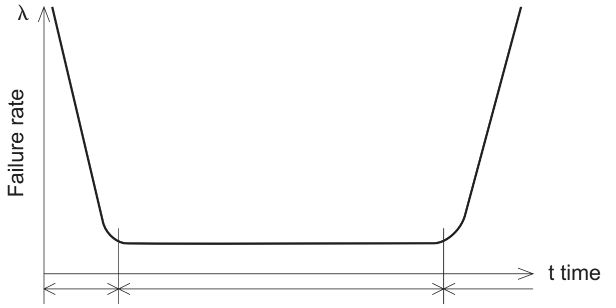


Fig.7.1 Bathtub Curve

2) MTBF

Mean Time Between Failure. The failure rate of a power supply, expressed in hours, established by the actual operation or calculation from a known standard such as MIL-HDBK-217 or RCR9102 (EIAJ Standard ... Standard of Electric Industries Association of Japan).

$$MTBF = \frac{1}{\text{Failure rate}} \text{ (h)}$$

3) Operating temperature and Life expectancy

Expected life is affected by operating temperature. Generally, each 10℃ reduction in temperature will double the expected life. Use capacitors at the lowest possible temperature below the maximum guaranteed temperature.

The formula for calculating expected life at lower operating temperatures is as follows.

$$L2 = L_1 \times 2^{\frac{T_1 - T_2}{10}}$$

where,

L_1 : Guaranteed life (h) at temperature, T_1℃

L_2 : Expected life (h) at temperature, T_2℃

T_1 : Maximum operating temperature (℃)

T_2 : Actual operating temperature, ambient temperature (℃)

8 Safety Standards

There are many national and international standards which deal with the safety aspects of electrical and electronic products.

These standards aim to ensure that products are designed, manufactured and tested to eliminate hazards, so that users get equipment which can be installed and used with complete safety.

They are intended to prevent injury and damage to persons and property from such hazards as electric shock, fire, dangerous temperatures and mechanical instability. The standards are of particular importance to designers and users of power conversion products. Power supplies, especially mains operated power supplies often contain the only barrier separating secondary circuits and accessible metal parts from dangerous AC mains voltages.

Furthermore, they contain components intentionally designed to dissipate heat which may give rise to high temperature risks.

With the exception of low voltage DC/DC converters, the use of power conversion products entails exposure to dangerous high voltages. Personnel concerned with testing or installing such products should be trained in the handling of electrical and electronic equipment and be fully aware of the hazards involved.

With many countries publishing their own safety standards, and with different standards being required dependent on end use the problem of designing internationally acceptable power conversion products has been extremely difficult, since the end use and even the end country of use are usually not known. This has led to expensive and time consuming safety approvals programs either up front to get as many national approval marks as possible, or downstream leading to product modifications and unacceptable delays. Established practice has been to design standard products to the most stringent of published standards and hope that this will be acceptable elsewhere. Consequently the following safety standards have become virtually universal in the power conversion industry.

UL60950-1	USA Safety standard for information technology equipment, including electrical business equipment
UL508	USA Safety standard for industrial control equipment
CSA60950-1	Canadian Safety standard for information technology equipment, including electrical business equipment
EN60950-1	Safety of information technology equipment, including electrical business equipment approved by CENELEC
EN50178	Safety of electric equipment for use in power installations
IEC380	Safety of electrically energized office machines
IEC435	Safety of data processing equipment
IEC60950-1	Safety of information technology equipment, including electrical business equipment
IEC60065	Safety of audio, video, and similar electronic apparatus
IEC60601-1	Safety of medical systems
IEC61010	Safety of electrical equipment for measurement, control and laboratory use

9 Standards and Regulations for Switch mode Power Supply

1) IEC standard

IEC is the International Electrotechnical Commission, a voluntary body, based in Geneva. The standards generated are advisory, nevertheless the IEC has done a great deal towards promoting international harmonization of standards. Many standards issued by national authorities are based on IEC standards with local modifications. For instance, in the UK significant standards have been BS5850 and BS6204, based upon IEC380 and IEC435 respectively.

Fortunately, there is now a strong movement internationally towards harmonization. Firstly, in 1986, IEC950 was published with the title "Safety of information technology equipment including electrical business equipment". In effect this brought IEC380 and IEC435 into a single standard. Since then, CENELEC, the European Committee for Electrotechnical Standardization has adopted IEC950, and published EN60950-1 in 2001.

2) CE marking

Two European Directives are relevant to power supplies :

✻73/23/EEC, the Low Voltage Directive

✻89/336/EEC, the Electromagnetic Compatibility Directive, amended by Directive 92/31/EEC (on the transition period).

Both Directives must be read in conjunction with the amending Directive 93/68/EEC (on CE marking). From January 1, 1995 until December 31, 1996, the Component Power Supply manufacturer has the option of CE marking under the LVD or meeting the requirements of any legal national regulation in force in the country into which the product is supplied. From January 1, 1997, it is mandatory to CE mark under the LVD. The EMC Directive does not apply to Component Power Supplies. For stand alone Power Supplies, the EMC Directive was mandatory and a CE marking was required after December 31, 1995. The CE marking for the LVD is mandatory on January 1, 1997, but in any event, compliance with the LVD itself (or with any legal national regulation) is already mandatory.

a. Machinery Directive (89/392/EEC)

A CPS (Component Power Supplies) is not a machine in the meaning of the Machinery Directive and shall not be CE marked for this Directive. To comply with the requirements necessary to be installed into a ”machine”, a CPS should comply with EN60950-1. Interlocking is the responsibility of the machine manufacturer. A CPS does not require Certificate of Incorporation.

b. EMC Directive

For the purpose of the EMC Directive, a ”component” is defined as any item which is used in the composition of an apparatus and which is not itself an apparatus with a direct function intended for the final user. Therefore, CPS are outside the scope of the EMC Directive.

The onus is on the final equipment manufacturer to ensure that the end product complies with the Directive and to CE mark it.

A CPS is a possible source of electromagnetic interference, but the configuration of the equipment into which it is installed can significantly alter the EMC characteristics as measured on the CPS in isolation. However, the installer may experience difficulties in ensuring that the final equipment is in accordance with the EMC Directive if the design of the Component Power Supply has not taken into account EMC considerations.

CPS for general final use should generally satisfy the generic standards. Full compliance with the requirements of these standards applies only to the final equipment, not to the CPS inside the equipment.

✻For the residential, commercial and light industrial environment:
emission : EN61000-6-3
immunity : EN61000-6-1

✻For the industrial environment:
emission : EN61000-6-4
immunity : EN61000-6-2

CPS intended for a particular application should be designed with the product EMC standards for that application in mind.

c. Low Voltage Directive (LVD)

The LVD came into force in 1974. It applies to most electrical material with a specified AC supply voltage of 50V to 1,000V or DC supply voltage from 75V to 1,500V. CPS with specified supply voltage range outside these limits are not subject to the provisions of the LVD. However, they must be safe and comply with the General Products Safety Directive 92/59/EEC (GPSD). They shall not be CE marked under the LVD (or the GPSD).

CPS for general final use should comply with EN60950-1, with the provision that the installer will be responsible for protection against personal contact with live parts.

Equipment for measurement, control and/or laboratory: CPS intended for this equipment should comply with EN61010-1.

Medical equipment: CPS intended for use in medical equipment covered by the Medical Devices Directive should comply with EN60601-1.

Important note: Although many safety standards are acceptable under the LVD, they do not all have the same flammability requirements as EN60950-1. Manufacturers are well advised to comply with the flammability requirements of EN60950-1.

3) EIAJ Standard

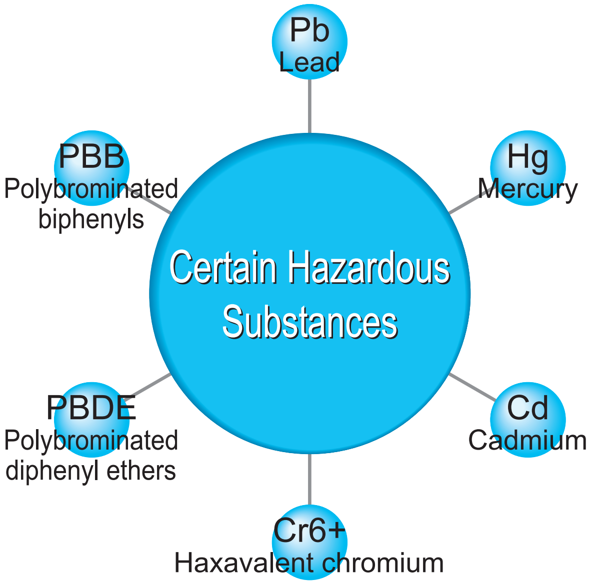
EIAJ standards were established as industry criteria by the Committee of AC Stabilized Power Source of the Electronic Industries Association of Japan. General standards, specific standards, test methods, and terminology, etc. are included, but there is no enforcement power.

4) RoHS Directives

RoHS Directive is an EU directive that will restrict from July, 2006 the use of six substances, Mercury (Hg), Cadmium (Cd), Lead (Pb), Haxavalent chromium (Cr6+), Polybrominated biphenyls (PBB), Polybrominated diphenyl ethers (PBDE) as certain hazardous substances in connection with the Directive on Waste Electrical and Electronic Equipment (WEEE).

It regulates content ratios of these certain hazardous substances on a weight basis in a product by minimum components such as regulated DC power supplies, noise filters.

We have selected, evaluated and changed to alternative RoHS complied components for not only new products but also existing products. Our major models have been already complied with the RoHS Directive since May, 2005. For details about RoHS-complied products, please visit http://www.cosel.co.jp/en/rohs



10 Disclaimer

The contents above are intended as a background guide to assist users of power conversion equipment. They are not intended to be rigorous or complete treatment. Every effort has been made to incorporate information which is up-to-date. Cosel categorically disclaim any responsibility for errors in content or interpretation. Customers are strongly advised to obtain the latest copies of the official documents relevant to the equipment type which they are concerned.