Operating Technical Electronics, Inc.

POWER CONVERSION SPECIALISTS

PRINCIPLES OF POWER CONVERSION

THE POWER CIRCUIT

Power flows in a circuit when a power source is connected via a wire to a load, then through a second wire back to the source. Mains cables have three wires but only two of these - named live and neutral - carry the power and the third wire - the earth wire - is there for safety purposes only.

AC & DC

There are two types of power source - alternating current (AC) and direct current (DC). They have quite different properties and uses:

AC

Alternating current sources, as the name suggests, have a voltage and current which flows in one direction around the circuit for a short period then stops and flows in the other direction for an equal period. The common form of AC power is the domestic power supply which repeats this cycle of events 50 times per second, or 50 Hertz (abbreviated to 50 Hz.) . AC power is not restricted to 50 Hz. and much higher frequencies are used within the power conversion products which will be described later. Alternating current has two main features. Firstly, it is easy to generate AC with rotating machines, i.e. generators. Secondly, AC voltage can easily be changed to a lower or higher voltage by means of a transformer - a very simple and reliable component. The disadvantage of AC is that it is impossible to store AC power.

DC

DC power can be conveniently stored in a battery. The most familiar type is the lead-acid battery as found in automobiles. Many other types of battery exist but they all store energy by converting power put into the battery to chemical energy. This can then be converted back into electrical energy whenever needed. DC power can also be stored by an electronic component called a capacitor but a battery can store over 1000 times more energy for a given size. A capacitor stores energy as electrical charge between two foils and is used for short-term storage within electronic equipment.

POWER CONVERSION

An entire industry exists for the purpose of designing products which convert one type of power to another, one voltage into several different voltages, or store energy ready to convert it back into electricity when needed. The three basic conversions are:

1. AC-DC

This is generally known as a "power supply". The input power usually will be 230V AC in Europe (110V AC in the USA) at 50 Hz (60 Hz in the USA), although it can also be other inputs, for example 28V AC at 400 Hz is sometimes used on aircraft.

2. DC-DC

This is known as a "converter" and changes the input voltage to one or more different DC voltages.

3. DC-AC

This is called an "inverter" and usually changes the DC power source into the equivalent of a domestic AC power source, i.e. 230V AC at 50 Hz. (or 110V AC 60 Hz.).

These three basic conversions are then combined to form a more complex product:

4. STANDBY SYSTEM

The AC mains supply in Europe is generally of a very high quality. Its voltage is quite stable, its frequency is well-defined and its reliability is usually very good. Some applications, however, need complete protection against the AC mains failing for either safety (e.g. chemical plants, hospitals), security (e.g. banks, computing), or commercial reasons (e.g. shops). Outside Europe, the AC mains is often of much poorer quality and less reliable. A standby system overcomes these problems by storing energy in a battery and turning the DC voltage into AC output when the incoming supply fails. The battery has to be re-charged when the mains supply returns using a specialised form of AC-DC converter called a battery charger. The combination of AC-DC charger, battery, DC-AC inverter and the necessary switching between the parts of the system is called a STANDBY SYSTEM.

The electronic standby system reacts immediately when the incoming mains fails, but energy storage in a battery is very expensive. For long-term standby power, therefore, the electronic system is often used to provide power whilst a diesel generator is started up (this could take a few minutes), at which point the electronic system shuts down and the generator supplies the load using diesel fuel or petrol as the energy source. The energy content of diesel or petrol is about 100 times greater than the equivalent weight of battery can store, therefore they are far more suitable where extended periods of power provision are needed.

POWER, VOLTS AND AMPS.

Generally, in a system, the voltage is fixed (e.g. 12 volts from a battery, 230V AC from the mains) and the current is determined by the load. Power is voltage multiplied by current, therefore the higher the load current - the higher the power.

Batteries are rated in amp-hours (abbreviated Ah). This means, for example, that a 40 Ah battery can supply either 40 amps for 1 hour, or 20 amps for 2 hours, or 10 amps for 4 hours etc. (this is a simplification for the purpose of clarity).

Watts are volts multiplied by amps., therefore a 12 volt 40 Ah battery can supply 480 watt-hours of power. A 48 watt load on the fully-charged battery will therefore run for up to 10 hours, or a 480 watt load for just one hour. It is actually quite damaging to completely discharge a lead-acid battery and it is generally recommended to only use one half of the full capacity before re-charging.

FREQUENCY

Transformers, motors and similar magnetically-based components are designed for a limited range of frequencies. This frequency is quite critical and a transformer designed for 60 Hz may well over-heat if run at 50 Hz.

The frequency of operation affects the size of magnetic components. A 1000 watt transformer designed for 50 Hz weighs about 15 kg. The same 1000 watt transformer for use at 50,000 Hz (abbreviated 50 kHz) weighs about 0.5 kg.

TYPES OF POWER CONVERSION

1. AC-DC CONVERSION

1.1 the un-regulated plug-top power supply

Most electronic equipment runs from the AC mains supply, therefore the most common type of power conversion is from AC to DC and will be referred to as a "mains power supply" or "off-line power supply". The simplest form of AC-DC power supply consists of a 50 Hz transformer (which changes, or "transforms", the voltage to required output voltage) followed by an electronic component called a bridge rectifier (this uses four diodes to re-route the AC voltage into uni-directional current flow) and a large capacitor (which stores the pulses of energy from the rectified mains and smoothes them into a DC output. This is cheap and simple but the output voltage varies with changes in the input voltage and also with changes in load current and is only used for very low powers - typically up to 10 or 15 watts. They are often housed in "plug-top" plastic boxes which actually plug into the domestic mains socket and supply the DC to the load via an output cable.

1.2 linear regulated power supply

Most electronic circuits require a stabilised power supply (especially digital circuitry). The simplest type of stabilising circuit is the linear regulator. This accepts the varying input from the un-regulated supply and drops the varying portion of the voltage across a transistor in series with the output. Thus, if the un-regulated supply might supply anywhere between 6 and 9 volts but a 5 volt stabilised supply is needed then the series transistor automatically drops between 1 and 4 volts as required. This is very simple to do using a regulator integrated circuit (I.C.) costing about 10 pence. The circuit is very inefficient, however, as up to 9 volts goes in but only 5 comes out. For this reason, the linear regulator is only normally used up to about 50 watts output.

1.3 the secondary switching regulator

The mains side of a transformer is called the primary; the output side is called the secondary. The efficiency of the regulator on the secondary side of the transformer can be greatly increased by using a secondary switching regulator. This is a more complex circuit than the linear regulator because it switches the series transistor off and on very fast (typically at 50 kHz - 50,000 times per second) such that the average voltage equals the required output voltage. For example, if the input is 10 volts and the switch is on for half the time, the average output is 5 volts. If the input is 20 volts and the switch is on for one quarter of the time then the output is still 5 volts. The output from the switch, however, consists of pulses of voltage and a filter must be added to smooth these pulses into the required DC voltage. This filter is called a choke-capacitor or L-C filter. This circuit improves the efficiency compared to the linear regulator but the size and weight are high due to the use of a 50 Hz transformer and this limits its use to 100 watts or less.

1.4 the switch-mode power supply (SMPS)

Strictly speaking, the secondary switching power supply is a "switch-mode power supply" but the term is normally applied to primary switch-mode circuits. These are now used throughout industry due to their low weight, small size and efficiency. They achieve this by using the size reduction of a high-frequency

transformer compared to a 50 Hz transformer mentioned earlier. To do this, the AC mains input is first turned into high voltage DC by a bridge rectifier and is then smoothed by a large capacitor. This DC voltage is then switched off and on at high frequency (typically 50 kHz to 200 kHz) to simulate AC voltage which can then be applied to the primary of a high-frequency transformer. The transformer reduces the high voltage down to the output level required and the low-voltage AC is then turned back into DC by a second bridge rectifier and smoothed by a choke-capacitor filter. The overall circuit is therefore:

AC - high voltage DC ; DC - high freq. AC ; high freq. transformer ; high freq. AC - DC ; L-C filter

This extra circuitry increases the cost but reduces the size by about 5:1 and reduces the weight by about 10:1 over a linear regulated power supply of the same power.

Switch mode power supplies are now used in all computers, televisions and most industrial equipment. Because switching circuits generate high frequency currents which can then radiate and cause radio-frequency interference, high power linear supplies are still used in some very sensitive equipment such as data recorders and audio mixing desks.

The output from a switch mode power supply is not limited to a single voltage. By adding extra output windings to the transformer, multiple outputs can be generated. An example is the typical computer supply with +5 volts, +12 volts and -12 volts outputs. These are three stabilised outputs sharing a common "0 volt" line, with a 5 volt and 12 volt output connected as positive relative to the 0 volt line, and the third output being 12 volts connected as negative relative to the 0 volt line.

A relay can only switch ten or twenty times a second. Switching at 50 kHz or more requires a semi-conductor switch, i.e. a transistor, and several types are now commonly used - bipolar, MOSFET and IGBT are all types of transistor used in switch mode power supplies.

1.5 Battery chargers

A battery charger is a specialised form of AC-DC power supply. A normal power supply generates an output voltage and the output current is determined by the load. In the case of a battery charger, the output voltage is determined by the state of charge of the battery and the output current is controlled by the battery charger. This subtle difference is often overlooked by engineers and results in the standard power supply over-heating and failing when used for battery charging. A battery charger is more expensive than a power supply of the same apparent power rating because the battery charger is designed to run continuously in what would be a fault condition for a standard power supply. The best type of battery charger also includes extra circuitry to re-charge the battery quickly by using a "3 stage charging profile". This charges the battery to a higher "boost" voltage for a limited time and then automatically drops to the safe "float" voltage.

2. DC-DC CONVERSION

2.1 non-isolated outputs

If the source (or input) voltage is higher than the required output voltage, then a simple, cheap but inefficient linear regulator can be used. If higher efficiency is wanted, a switching regulator (called, in this case, a "buck" regulator) will give 80 to 90% efficiency at a reasonable cost, small size and low weight.

If the input voltage is lower than the required output voltage then the linear regulator is no longer an option - the linear regulator can only drop voltage and cannot increase it. There is, however, a switching regulator circuit called a "boost" regulator which will turn the input voltage into a higher output voltage. The efficiency is still 80 to 90% and the cost, size and weight are similar to the "buck" regulator.

2.2 isolated outputs

Most systems are earthed for reasons of safety and screening against radio frequency radiation. If the input and output of a DC-DC converter share a common 0 volt line and both the battery and load are earthed (sometimes referred to as grounded) then the earth can become part of a large "earth loop" which can generate large amounts of radio frequency interference. This problem is avoided if the input and output of the DC-DC converter are isolated from each other. This isolation can only be achieved with a transformer and transformers only work on AC, so the circuit becomes:

DC - high freq.AC ; high frequency transformer ; high freq.AC - DC ; L-C filter

These extra stages increase the cost of the converter but eliminate the earth loop problem. Extra windings can be added to the transformer to generate multiple output voltages.

3. DC-AC CONVERSION

3.1 Square-wave inverter

The DC-AC inverter is usually taking a 12 volt or 24 volt battery power source and turning it into 230V AC 50 Hz (or 110V AC 60 Hz in the USA). Because the output voltage is higher than the battery voltage, a transformer must be used to step it up. The cheapest type of inverter uses transistors to switch the battery voltage at 50 Hz AC which is then fed into a heavy and bulky 50 Hz transformer. The transformer steps the voltage up to 230 volts which can then power the load. The output waveform (or shape) is a square wave rather than the sinusoid of the mains supply but most loads can accept this.

3.2 Quasi-sinewave inverter

If the square-wave inverter is too big or heavy, or the load needs a waveform closer to a sinusoid, then the quasi-sinewave (or modified square-wave) inverter offers better characteristics but at a higher price. The sequence of circuitry here is:

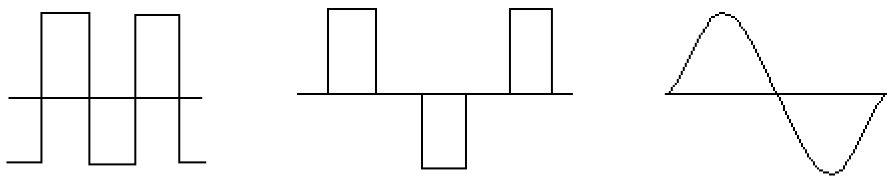
DC - high freq.AC ; high freq. transformer ; AC - high voltage DC ; DC - 50 Hz AC

The DC to 50 Hz AC conversion is accomplished with transistor switches and the width of the square wave is controlled to more-closely approximate to a sine-wave. The use of the high frequency transformer makes this inverter small and light-weight, but the output is not a true sinusoid and is unsuitable for very noise-sensitive loads.

3.3 The sinewave inverter

It is possible to add extra stages to the quasi-sinewave inverter to make it produce a true sinusoidal waveform. There are several ways of achieving this, but the general method is to vary (or modulate) the width of the high frequency pulses in such a way that, when they are averaged with a choke-capacitor filter, they produce a half-sinusoid at 100 Hz which is then switched with transistors to produce a 50 Hz bi-directional sinewave output. This is then suitable to power any kind of load but is, of course, the most expensive type of inverter.

Inverter waveforms



Square Wave Quasi-sine wave Sine wave

Custom specials

When an electronics engineer designs a new product, he naturally concentrates on the circuitry which he is designing. At this stage, the circuitry is usually powered by bench power supplies. When the product is functioning perfectly, the design is handed over to the printed circuit and mechanical designers to build

into the final enclosure. This is often the first time in the project that the power supply is seriously considered. Time is running short and often the space left over when the rest of the product is fitted into the box is where the power supply has to fit. If they are lucky, a standard power supply might fit into the space. Quite often, the only solution is a custom-designed power supply to fit the available space. We have a wide range of proven circuits available and can produce prototypes based on these designs in 4 to 6 weeks. This is considerably quicker than most of the big power supply manufacturers.

Open-frame power supplies

These are low-power units for building into the customer's enclosure. High voltages are exposed on this type of power supply and it is the customer's responsibility to consider the safety of maintenance personnel etc. We import these from a Taiwanese company. Due to the vast numbers in which these are made in Taiwan, and other factors such as labour rates, this type of power supply is not made by many European manufacturers. The range covers 20 watts to 65 watts and one to four outputs.

Enclosed power supplies

These also are imported from Taiwan and offer exceptional value for money and excellent quality. Being fully boxed, they are easier to mount safely within an enclosure. The standard range covers 40 watts to 320 watts and one to four outputs. In addition, we can modify the products to customise them. An example is an additional circuit added to the S-100 series which allows it to become a fan speed controller with an external control input.
