UNDERSTANDING & USING DC-AC INVERTERS

DC-AC inverters are electronic devices used to produce 'mains voltage' AC power from low voltage DC energy (from a battery or solar panel). This makes them very suitable for when you need to use AC power tools or appliances but the usual AC mains power is not available. Examples include operating appliances in caravans and mobile homes, and also running audio, video and computing equipment in remote areas.

Most inverters do their job by performing two main functions: first they convert the incoming DC into AC, and then they step up the resulting AC to mains voltage level using a transformer. And the goal of the designer is to have the inverter perform these functions as *efficiently* as possible — so that as much as possible of the energy drawn from the battery or solar panel is converted into mains voltage AC, and as little as possible is wasted as heat.

Modern inverters use a basic circuit scheme like that shown in Fig.1. As you can see the DC from the battery is converted into AC very simply, by using a pair of power MOSFETs (Q1 and Q2) acting as very efficient electronic switches. The positive 13.8V DC from the battery is connected to the centre-tap of the transformer primary, while each MOSFET is connected between one end of the primary and earth (battery negative). So by switching on Q1, the battery current can be made to flow through the 'top' half of the primary and to earth via Q1. Conversely by switching on Q2 instead, the current is made to flow the opposite way through the 'lower' half of the primary and to earth.

Therefore by switching the two MOSFETs on alternately, the current is made to flow first in one half of the primary and then in the other, producing an alternating magnetic flux in the transformer's core. As a result a corresponding AC voltage is induced in the transformer's secondary winding, and as the secondary has about 24 times the number of turns in the primary, the induced AC voltage is much higher: around 650V peak to peak.

By the way if you're wondering why MOSFETs are used as the electronic switches, to convert the DC into AC, it's because they make the most efficient high-current switches. When they're 'off' they are are virtually an open circuit, yet when they're 'on' they are very close to a short circuit (only a few milliohms). So very little power is wasted as heat.

(In DC-AC inverters designed to deliver high power, there are actually quite a few MOSFETs connected to each side of the transformer primary, to share the heavy current. However because they're essentially connected in parallel, you can still think of them as behaving very much like the single transistors shown in Fig.1. They just behave like very high-power MOSFETs, able to switch many tens of amps...)

Note that because the switching MOSFETs are simply being turned on and off, this type of inverter does not produce AC of the same 'pure sinewave' type as the AC power mains. The output waveform is essentially alternating rectangular pulses, as you can see from Fig.2. However the width of the pulses and the spacing between them is chosen so that the ratio between the RMS value of the output waveform and its peak-to-peak value is actually quite similar to that of a pure sinewave. The resulting waveform is usually called a 'modified sinewave', and as the RMS voltage is close to 230V many AC tools and appliances are able to operate from such a waveform without problems.

It's true, though, that this kind of waveform is not close enough to a sinewave for some appliances. That's mainly because the rectangular pulses contain not just the fundamental mains frequency, but quite a lot of its harmonics as well. So if the inverter is operating at the Australia/New Zealand mains frequency of 50Hz, the output will also contain components at 100Hz, 150Hz, 200Hz, 250Hz and so on. These harmonics can disturb the operation of some appliances.

It's because of this shortcoming that manufacturers have come up with a more complex type of inverter, which *does* deliver a pure sinewave output. More about these later.

Output regulation

We take for granted the fact that our mains power is very well *regulated* — so you can plug almost any appliance into a standard point outlet, and it will operate correctly. That's because the electricity supplier has enormous generating plants, with automatic regulation systems to keep the mains voltage and frequency very close to constant, despite load variations of many megawatts.

Inevitably you can't get this kind of performance from a much smaller electronic inverter, connected to a modest battery or solar panel as the energy source. However most modern inverters can provide reasonably good regulation for loads of up to their rated capacity (given in watts) — assuming of course that they're running from a well-charged battery.

In this type of inverter it isn't feasible to control the peak-to-peak output, because this is largely fixed by the battery voltage and the transformer's step-up ratio. So in most cases the regulation is achieved in a different way: by varying the width of the rectangular pulses, to control the 'form factor' and hence the RMS value of the output voltage.

This is called **pulse width modulation** (PWM), and is usually done by having a feedback system which senses the inverter's output voltage (or load current). When this feedback senses that the load on the inverter's output has increased, the inverter's control circuitry acts to increase the width of the pulses which turn on the MOSFETs. So the MOSFETs turn on for longer each half-cycle, automatically correcting the RMS value of the output to compensate for any droop in peak-to-peak output.

The resulting regulation is usually capable of keeping the RMS value close to constant, for loads up to the inverter's full rated output power. However this

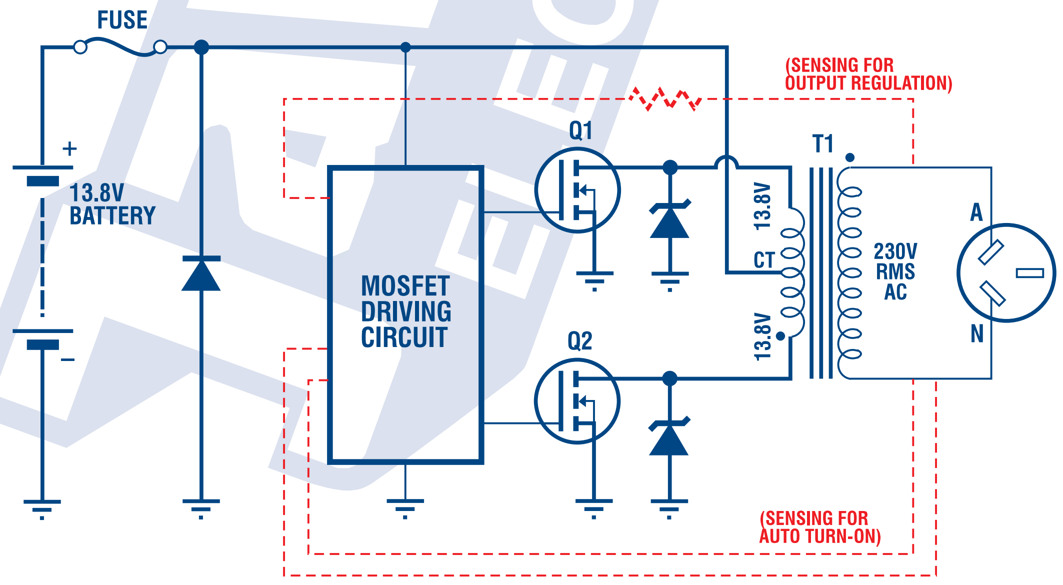

Fig.1: The basic circuit scheme used in many modern DC-AC inverters. MOSFETS Q1 and Q2 are used to convert the battery's low voltage DC into AC, which is then stepped up to 230V RMS by the transformer.

approach does have limitations, mainly because it can generally only increase the pulse width to a certain point. (In the extreme, the output becomes a square wave.) This may not be sufficient to allow the inverter to deliver enough RMS output voltage in short-term overload or 'surge' conditions.

When many types of appliance are first turned on, for example, they draw a 'startup' current which is many times greater than the current drawn when they're running. This type of surge can overload the inverter, and its protection circuitry may 'shut it down' to prevent damage to the transformer and MOSFETs.

Some types of inverter incorporate special 'soft start' circuitry, to allow the inverter to cope with this type of short load current surge. The output voltage and power may drop, but at least the inverter keeps operating and allows the appliance to start up.

Even so, there are some appliances and tools that are simply not compatible with inverters, because of their tendency to draw an extremely high startup current. Examples are refrigerators, freezers, air conditioners or any other appliance where a motor is driving a compressor or pump. As the motor in these appliances often has a *very* heavy load right at switch-on (with the compressor near 'top dead centre'), it can need to draw a huge current simply in order to start rotating.

This type of appliance and tool should really be powered using a suitably rated engine-driven alternator, not a DC-AC inverter.

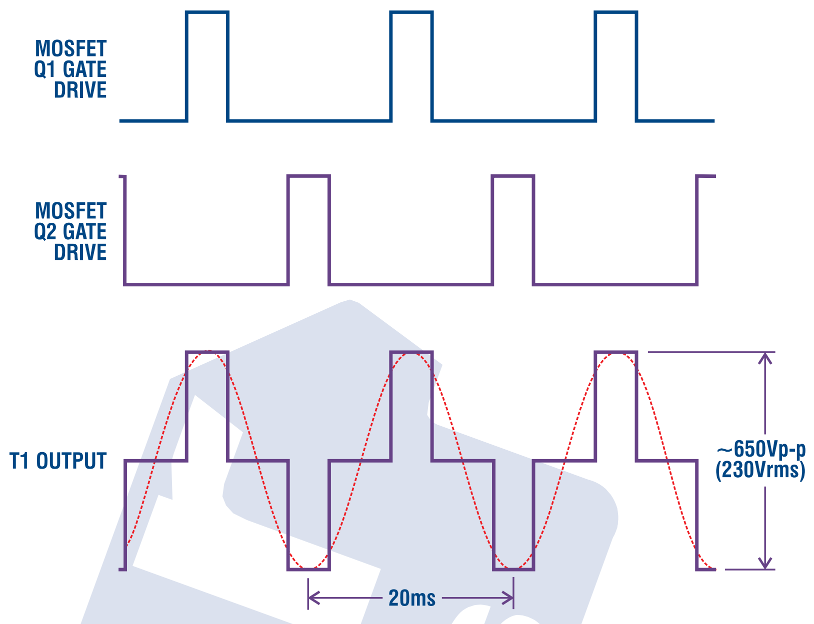

Fig.2: In most DC-AC inverters the switching MOSFETs are turned on alternately for short pulses, as shown, at the same repetition rate as the AC power mains. As a result the transformer produces a 'modified sinewave' output (blue), rather than a true sinewave (red).

Voltage spikes

Another complication of the fairly high harmonic content in the output of 'modified sinewave' inverters is that appliances and tools with a fairly inductive load impedance can develop fairly high voltage *spikes* due to inductive 'back EMF'. These spikes can be transformed back into the primary of the inverter's transformer, where they have the potential to damage the MOSFETs and their driving circuitry.

The risk of damage is fairly small during the actual power pulses of each cycle, because at these times one end of the primary is effectively earthed. Transformer action thus prevents the 'other' end from rising higher than about twice the battery voltage. However as you can see from Fig.2, there are times during every cycle of operation when *neither* of the switching MOSFETs is conducting: the 'flats' between the rectangular pulses. It's at these times that the spikes can produce excessive voltage across the MOSFETs, and potentially cause damage.

It's for this reason that many inverters have a pair of high-power zener diodes connected across the MOSFETs, as shown in Fig.1. The zeners conduct heavily as soon as the voltage rises excessively, protecting the MOSFETs from damage.

Another approach is to have high-power standard diodes connected from each end of the primary to a large electrolytic capacitor, which becomes charged up to twice the battery voltage. When the ends of the primary attempt to rise higher than this voltage, the diodes conduct and allow the capacitor to absorb the spike energy.

Thanks to this type of protection, most inverters are fairly tolerant of *moderately* inductive loads. However they may not be able to cope with heavy loads that are also strongly inductive — like heavy duty tools and machinery, or more than one or two fluorescent lights.

Quite apart from the generation of voltage spikes, heavily inductive loads tend to demand current which is strongly shifted in phase relative to the inverter's output voltage pulses. This makes it hard for the inverter to cope, because the only energy available to the load between the pulses is that stored in the transformer.

Capacitive loading

Actually there's a different kind of problem with many kinds of fluorescent light assembly: not so much inductive loading, but *capacitive* loading.

Although a standard fluoro light assembly represents a very inductive load due to its ballast choke, most are designed to be operated from standard AC mains power. As a result they're often provided with a shunt capacitor designed to correct their *power factor* when they're connected to the mains and driven with a 50Hz sinewave.

The problem is that when these lights are connected to a DC-AC inverter with its 'modified sinewave' output, rich in harmonics, the shunt capacitor doesn't just 'correct' the power factor, but drastically **over corrects** — because its impedance is much lower at the harmonic frequencies. As a result, the fluoro assembly draws a heavily capacitive load current, and can easily overload the inverter.

In cases where fluorescent lights must be run from an inverter, and the lights are not going to be run from the mains again, usually the best solution is to either remove their power factor correction capacitors altogether or replace them with a much smaller value.

Auto starting

Many inverters are provided with a power switch, and must be turned on before they supply AC power. However some models are provided with 'auto turn-on', so they stop working when the AC load is removed, but turn on again automatically when a load is connected. This allows the power switch of an appliance or tool to be used to control the inverter's operation as well, conserving battery energy while still allowing the appliance to be operated in exactly the same way as when it's connected to the mains.

In most cases this auto turn-on system uses a sensing circuit connected into the inverter's output loop, and designed to detect when the appliance switch is closed — to complete the high voltage circuit. This allows a small DC sensing current to flow, and this current is used to turn on the inverter's MOSFET drive circuitry.

When no DC flows in the output loop, the drive circuitry is disabled and no pulses are fed to the gates of the MOSFETs. As a result they don't conduct, and the inverter doesn't operate. Only a very small 'standby' current is drawn from the battery.

Note, however, that because this kind of auto turn-on circuit uses a small direct current to sense when the appliance has been turned on, it relies on the appliance providing a DC path when its mains switch is closed. If the appliance *doesn't* provide such a path, the auto turn-on circuit won't work.

So with some appliances, the inverter may still need to be turned on and off manually when it's needed.

Frequency stability

Although most appliances and tools designed for mains power can tolerate a small variation in supply frequency, they can malfunction, overheat or even be damaged if the frequency changes significantly. Examples are electromechanical timers, clocks with small synchronous motors, turntables in older 'vinyl' record players and many reel-to-reel tape recorders.

To avoid such problems, most DC-AC inverters include circuitry to ensure that the inverter's output frequency stays very close to the nominal mains frequency: 50Hz in the case of Australia, New Zealand and most European countries, or 60Hz in North America.

In some inverters this is achieved by using a quartz crystal oscillator and divider system to generate the master timing for the MOSFET drive pulses. Others simply use a fairly stable oscillator with R-C timing, fed via a voltage regulator to ensure that the oscillator frequency doesn't change even if the battery voltage varies quite widely.

Sinewave inverters

As explained earlier, most DC-AC inverters deliver a 'modified sinewave' output voltage, because they convert the incoming DC into AC by using MOSFET transistors as electronic switches. This gives very high conversion efficiency, but the 'alternating pulses' output waveform is also relatively rich in harmonics.

Some appliances are less than happy with such a supply waveform, however — examples include light dimmers, variable speed drills, sewing machine speed controls and some laser printers. Because of this, inverter manufacturers *do* make a small number of models which are designed to deliver a pure sinewave output. Generally speaking these inverters use rather more complex circuitry than the 'modified sinewave' type, because it's hard to produce a pure sinewave output while still converting the energy into AC efficiently. As a result pure sinewave inverters tend to be significantly more expensive, for the same output power rating.

The most common type of pure sinewave inverter operates by first converting the low voltage DC into high voltage DC, using a high frequency DC-DC converter. It then uses a high frequency PWM system to convert the high voltage DC into 'chopped' AC, which is passed through an L-C lowpass filter to produce the final clean 50Hz sinewave output. This is like a high-voltage version of the single-bit digital to analog conversion process used in many CD players.

Don't reverse polarity!

A lot of electronic equipment designed to be operated from a battery is fitted with an internal diode in series with one battery lead, to protect the equipment from damage if the connections to the battery are accidentally reversed. But this type of reverse polarity is generally not fitted to DC-AC inverters, because of the heavy current drain involved. The additional voltage drop introduced by a diode would degrade the inverter's regulation too much, quite apart from wasting power and hence reducing the overall efficiency.

If reverse polarity protection *is* provided, this is usually in the form of a protective fuse or circuit breaker in series with the battery leads, plus a reversed-polarity power diode connected across the inverter's DC input (after the fuse: see Fig.1). This means that when the battery leads are connected with the correct polarity, the diode is reverse biased and remains dormant. But if the battery connections are accidentally reversed, the diode is forward biased and suddenly conducts — blowing the fuse and hopefully protecting the inverter itself.

This system generally does provide protection against reversed-polarity damage to most of the inverter circuitry, without degrading its efficiency or output regulation. However the price you pay is that an accidental reversal of the battery connections still blows a fairly expensive high-current fuse, and sometimes also destroys the protective shunt diode as well.

Probably for this reason, some lower priced inverters don't incorporate *any* specific protection against accidental reversal of the battery leads. So with these inverters, you have to be especially careful to connect the battery leads correctly.

Even with inverters which *are* provided with protection, it's still a very good idea to double-check the connections before clipping on the second battery lead. Remember that a mistake will almost certainly mean a blown fuse at least, and possibly a long delay until you can replace it!

Inverters & safety

Finally, there are a couple of important safety aspects to bear in mind whenever you're using a DC-AC inverter.

Many people assume that because an inverter is operating from a nominal 12V battery and it can't deliver as much output as a normal mains power outlet, it's relatively safe. **Nothing could be further from the truth**.

Even a low power inverter rated at a mere 60 watts has an output which is potentially fatal, if you should end up connected across it. Such an inverter can typically deliver up to about 360mA at 230V, which is over TEN TIMES the current level needed to stop your heart and cause fatal fibrillation!

Needless to say higher power inverters are even more dangerous.

There's also another kind of safety risk associated with inverters, which arises from the fact that in many inverters, there's a direct electrical path between the mains-voltage output circuit and the low voltage input circuitry (including the battery leads). This path is usually via the auto turn-on sensing, and possibly also the voltage or current sensing used for output regulation.

When the inverter is being used to power a single tool or appliance, this internal current path normally doesn't pose any safety risk because the complete battery-inverter-appliance system 'floats' above earth. However if the tool or appliance is faulty and develops a short circuit or severe leakage between its mains wiring and its external metal case or frame (which would normally be earthed, when it's plugged into a mains power outlet), there's a risk that the battery connections can become dangerously 'live'.

How can this happen? Think about it: if the leakage path to the appliance's frame happens to be from the side of its mains wiring connected to the 'active' side of the inverter's output, and the frame of the appliance becomes connected to earth, this will immediately raise the 'neutral' side of the inverter's output to the full output voltage above earth — and with it, the low voltage side of the inverter's circuitry **and the battery terminals as well**. So if an unsuspecting person who also happens to be earthed should touch one of those safe-looking 12V battery terminals, they can receive a potentially fatal shock.

It's for this reason that inverter manufacturers and suppliers generally advise strongly **against** connecting an inverter into the permanent wiring of a house, office or factory — especially in a way where the appliances connected to its output tend to become automatically connected to mains earth, and/or linked back to mains neutral (which is ultimately earthed, with the MEN system).

If you want to run a number of appliances from a single high-power inverter, and have the convenience of permanent wiring and mains-type power outlets, the safest approach is to have a wiring system and outlets that are kept totally separate from any wiring that is connected to the AC mains and mains earth. The outlets driven from the inverter output are also best left **unearthed**, and clearly marked as 'INVERTER POWER: FLOATING'.

This totally separate, floating system not only reduces the risk of accidental shocks due to faulty appliances, but also helps to remind users so they don't accidentally plug inappropriate appliances into the inverter outlets.

In any case, always think twice before touching the terminals of a battery that you know is being used to power tools or appliances via a DC-AC inverter. Remember that there's always a risk those battery terminals could deliver you a much greater shock than you'd ever get from 13.8 volts, if one of those tools or appliances should develop a fault.

DC-AC INVERTERS STOCKED BY JAYCAR ELECTRONICS

Jaycar stocks nine different DC-AC inverter models, with continuous output ratings varying from 60 watts to 920 watts at 230V RMS:

MI-5030	60W cont, 80W surge; 10.8-13.2V input, modified sinewave
MI-5036	140W cont, 400W peak; 11-15V input, modified sinewave
MI-5032	200W cont, 500W surge; 10-15V input, modified sinewave
MI-5033	200W cont, 500W surge; 20-30V input, modified sinewave
MI-5035	350W cont, 1000W surge; 10-15V input, modified sinewave
MI-5050	350W cont, 1000W surge; 10-15V input, **pure sinewave**
MI-5040	550W cont, 1500W surge; 10-15V input, modified sinewave
MI-5055	750W cont, 1800W surge; 10-15V input, **pure sinewave**
MI-5045	920W cont, 2600W surge; 10-15V input, modified sinewave

For full details on these products please refer to the latest Jaycar Electronics Engineering Catalogue, or on the website: www.jaycar.com.au