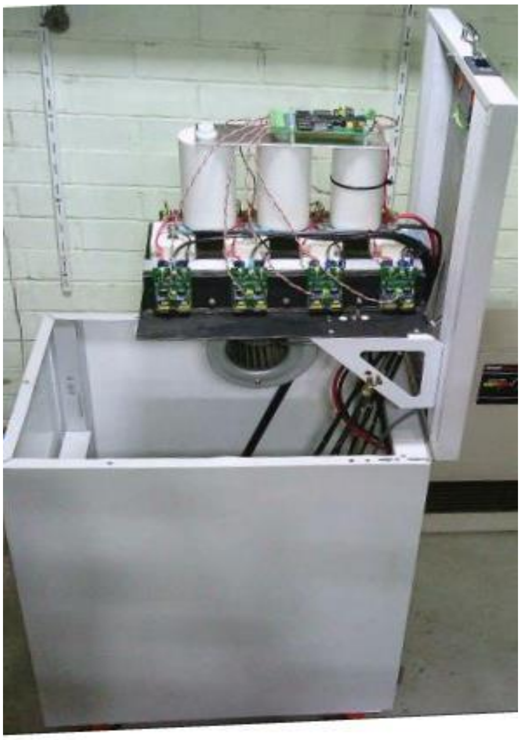
The 'WarpStepInverter' .

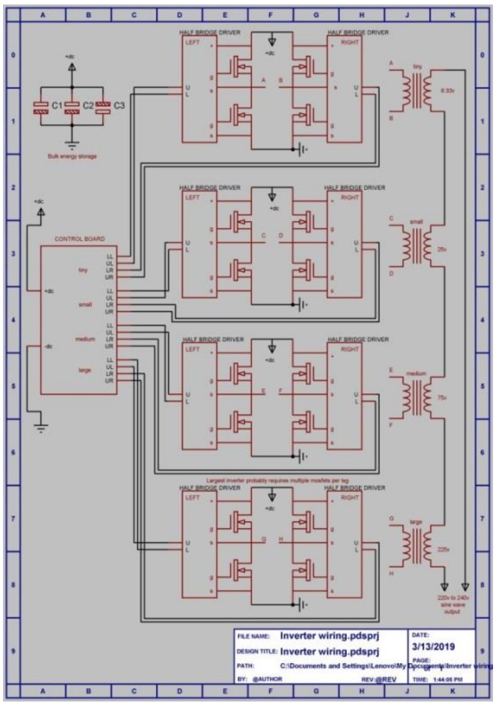


'Warpspeed,' Tony LeGrip, Australia, (retired power electronics engineer), has successfully been using the step inverter principle. Many thanks Tony for letting me show your Inverter work and your comments.

"The first of these step inverters I ever built (now almost forty years ago) used a 68H05C8 processor with 16K of internal eprom. It used three inverters giving 27 voltage steps peak to peak, with fifteen 1K lookup tables. I still have that original inverter around here somewhere.

It worked very well for what it was, only 500 watts with 10v to 15v dc input. It was just a toy really, but it certainly proved the original concept to be sound.

Thirty two lookup tables should be very workable, and 1K lookup tables provide more than adequate 20uS time resolution for 50Hz.



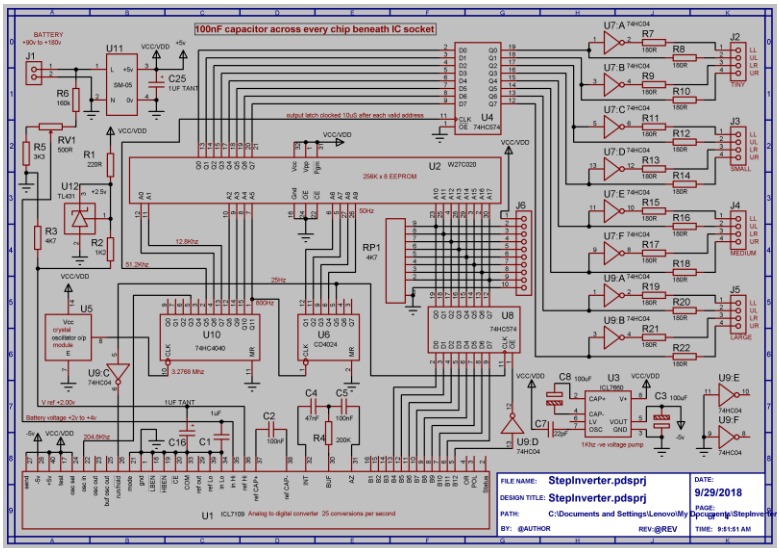
My latest effort powering my house right now uses 256 individual 1K lookup tables which is more than are really necessary. Experience now suggests 64 or 128 lookup tables might be about optimum.

The transformers must be designed to provide the required voltages, and the output voltages for each transformer will be different depending on the number of inverters you eventually plan to have. Assuming we are designing for a nominal 235v rms final output, which is 333v peak.

The actual final regulated output voltage can be readily potentiometer adjusted but we need a design goal to start from when designing our transformers initially.

If you only plan to build a single transformer inverter of the infamous "modified sinewave" type, it will need to have a single 333 volt rated secondary. A two transformer inverter will need to reach the same 333v peak with both secondary's aiding, and have a 1:3 voltage relationship. So the large transformer might be 249v and the small one 83v.
A three transformer inverter would also need to add together to provide 333v peak, in ratios of 1:3:9. So the large one will need to be 231v, medium transformer 77v, and the small one about 25.6v.

A four transformer inverter, large one 225v, medium 75v, small 25v, tiny one 8.3v. That also adds up to 333v with relative secondary ratios of 1:3:9:27



So before you start winding transformers you need to pretty much decide right at the start how many inverters you plan to eventually have. Three work perfectly well for all practical purposes, but four give a much smoother final waveform. As your rom will have eight bits, and the fourth inverter is very low power, may as well include it.

I would also suggest the fitting of an electrostatic screen between primary and secondary to eliminate the possibility of voltage spikes on the square wave output of each transformer. I did that, and all my steps were very clean. I originally worried about switching spikes on the output from primary to secondary capacitive coupling , but have no idea if that problem is real or imagined.

I have now built several quite different versions of these step inverters over the years, and each one has become simpler , better, and requiring fewer parts.

The current 5Kw inverter control board uses an Intersil twelve bit dual slope A/D converter to address the high order eight bits in rom. Low order ten bits of rom are continuously clocked from a 3.2768Mhz crystal oscillator module. The A/D converter starts a conversion every 40mS and its output is latched into the rom every second cycle right at the zero crossing.

The dual slope measurement technique is extremely accurate and consistent, and gives very high noise immunity to inverter ripple voltage on the incoming dc bus. Its not really possible to filter this before measurement without introducing some time delay, and I wanted to measure the exact dc input voltage without any uncertainty or delay for the most accurate input voltage correction each alternate inverter cycle.

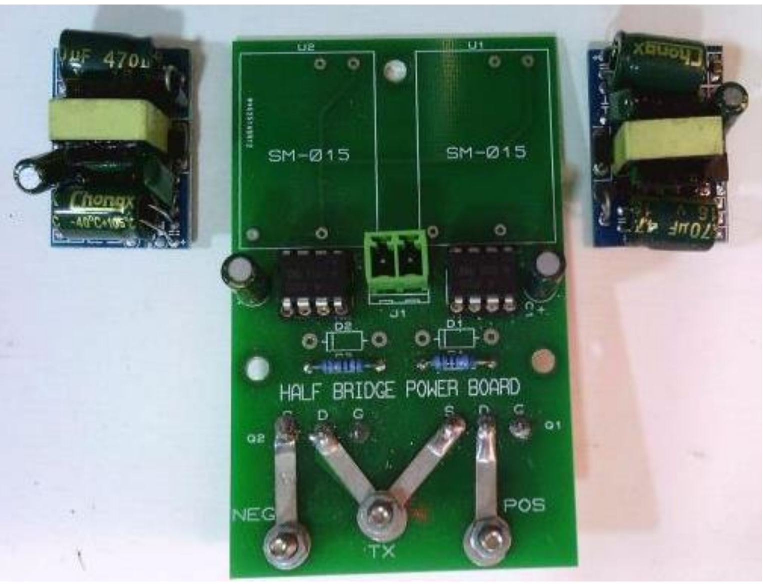
Rom output data is latched after the data is completely stable, and that is about it.
Each latched data bit drives an opto isolated gate driver direct through a 180 ohm resistor, and the opposite complimentary output comes straight off a 74HC04 inverter.

Four bridge inverters, sixteen opto isolator outputs from the driver board on four different plugs.

Five volt positve supply comes from one of those two dollar Chinese postage stamp sized switching power supplies, and minus five volts (for the A/D) from a voltage pump chip.

Dc input both powers the board and also provides the dc input voltage measurement for the A/D converter.
There is an absolute minimum of external wiring to the control board and absolute simplicity.

There are ceramic bypass capacitors across every chip located directly under each chip, the sockets have enough height to allow that.
Its all very basic. no soft start, no over current protection, no dead time in the waveforms from the control board, no voltage feedback and no microprocessor.
And it works perfectly well direct from the solar panels without having anything in between except 36,000uF of energy storage capacitance.



Voltage swings from solar can be quite large direct off the panels, as you might expect, but the inverter output voltage remains rock solid . In fact its better than a PID feedback control, simply because its much faster reacting and completely stable.

Correction to dc input voltage changes are total every 40mS without the slow ramping correction that occurs with a PID voltage feedback system. If there are some sufficiently large electrolytics placed across the inverter dc input, any sudden inverter step load changes will produce a relatively slow enough dc voltage change at the input, that the input voltage correction can easily follow. This results in negligible light flicker with very heavy refrigerator compressor starting loads for example.

Another feature is that there can be some large step amplitude corrections, but if those are carried out right at the zero crossing point, there will be no waveform discontinuity.

Overload just trips the ac circuit breaker on the output. The whole thing has enough grunt to do that very safely. I have been completely off grid now for eight months without a single issue, and the inverter worked very first time it was powered up without a single problem.

Each inverter consists of a pair of modular half bridge power boards.” (**see photo above right**), *“these just connect to the control board via a single twisted pair for the optio isolators. Upper and lower mosfet opto isolator inputs are connected in inverse parallel. It’s impossible for both to be on simultaneously, and that provides very effective cross conduction protection. There are eight of these small half bridge power boards. These also are as basic as can be, with just a 15v isolated gate supply and an opto isolated gate driver chip (with inbuilt undervoltage shutdown) for each upper and lower mosfet.*

A small capacitor across the inverse connected opto isolator led’s provide dead time. 1nF about 300nS for the mosfets, and 10nF about 2.5uS for the large IGBT power blocks.
The whole inverter has eight of these small half bridge power boards.

The two smaller inverters just use individual mosfets fitted to screw terminal blocks, and the PCB tracks have been reinforced with solder lugs fitted both sides to make the PCB just about indestructible if the mosfets ever go bang. The two larger inverters use 200 amp IGBT modules that plug into the same identical half bridge power boards.

Every mosfet has its own fully isolated 15v gate driver supply. This prevents any blowups from escaping beyond the power board, it isolates the grounds on the low side, reduces potential noise problems, and minimises external wiring, as gate drive power comes from directly across the higher voltage bridge power rails.
It provides a very simple easy to repair system if the unthinkable ever happens.

These particular IGBT modules are rated to carry 1,000 amps of fault current for one full 10mS half mains cycle, which is much more than is required to very quickly trip a normal C curve thermal/magnetic circuit breaker. That is something mosfets just cannot do as well as an IGBT.

It would be very easy to scale this up to 10Kw or 50Kw without any of the high frequency problems the PWM guys are plagued with. No primary chokes required either. And its much more straightforward to build and get going even though there are more individual parts to it.

Only really two obstacles to overcome, winding the four transformers is a bit of a pain, but its fairly straightforward, just work. The other is getting suitable lookup tables organized.

I just wrote a program in assembler to burn an EEPROM directly. That is no more difficult or complex than having a working microcontroller in the inverter. But a bare basic rom design has the advantage of not having any software timing constraints in generating the waveforms, it just cycles through sequential addresses repetitively without any drama.

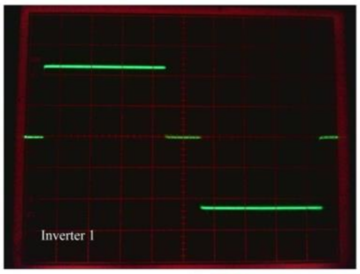
A bare hardware rom is a lot more robust , than running a live software program in an inverter. If software crashes, the inverter inevitably goes bang. Much less to go wrong with just a crystal, an address counter and a rom.

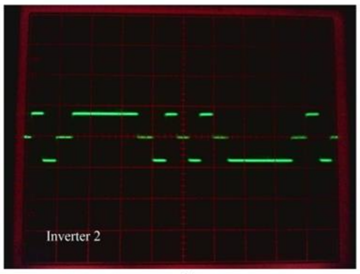
If it ever does go bang, everything just unplugs or readily unscrews, and I have spare boards ready to go. Accessibility is particularly good too in this version, although its physically rather large. I should be able to fix a blow up very fast without requiring either mains power or a soldering iron.

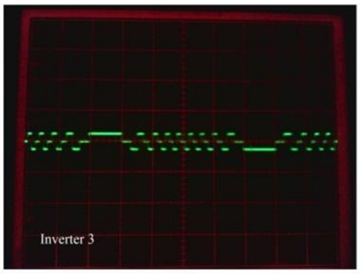
This Inverter system does not require a battery, it uses solar power direct off the panels during the day, but reverts to dc from a grid powered rectifier at night. All achieved with a single diode.
During an Australian summer I get about 80% of my total power from solar. During winter it falls to about 55% from solar.

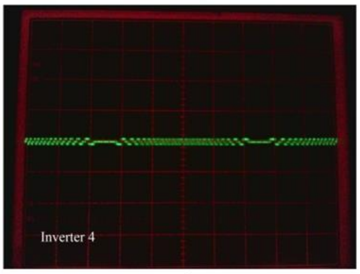
I have now installed a battery for complete off grid operation, but for over a year it ran from a dc rectifier at night without a battery. During the day there is easily sufficient total solar power, even in mid-winter, it's just that it drops to zero at night no matter how many solar panels there are.

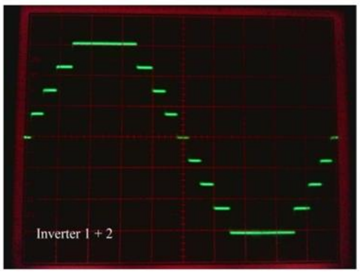
A three inverter stepped system with 27 steps produces about 4% harmonic distortion, about the same as measured off the the grid here. A four inverter stepped system with 81 steps peak to peak produces just slightly below 1% measured harmonic distortion without any filtering."

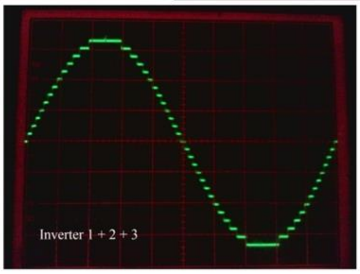


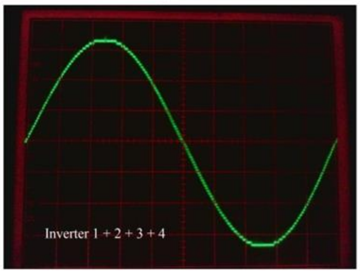








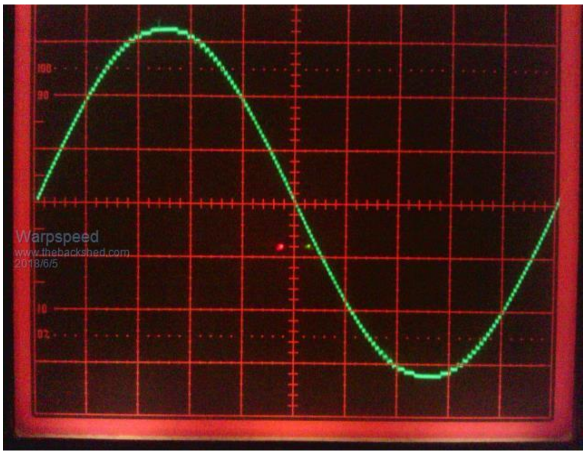




Here is 'Warpspeeds', Tony's explanation, what's happening……..

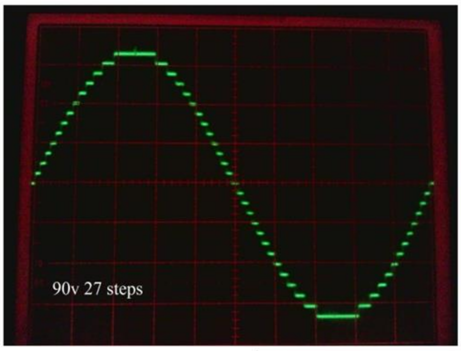
"The seven pictures above, show the individual output waveforms of the four square wave inverters in correct relative amplitude, and the effect produced when the secondary voltages are combined.

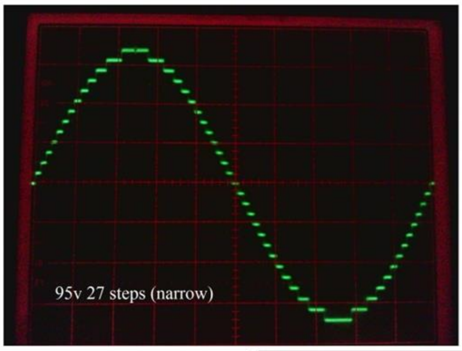
Each inverter has three possible output states, positive, zero, and negative. If we combine the outputs of four inverters, with every possible switching combination we can generate 3x3x3x3 = 81 possible voltage steps peak to peak. That is forty steps up, forty steps down, with a zero step in the middle.

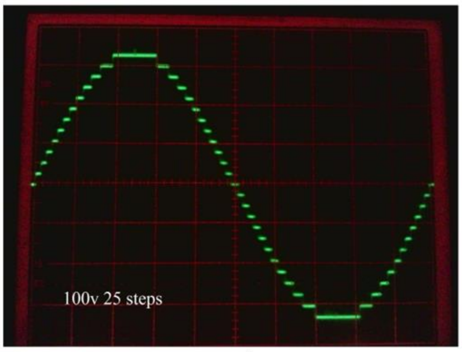


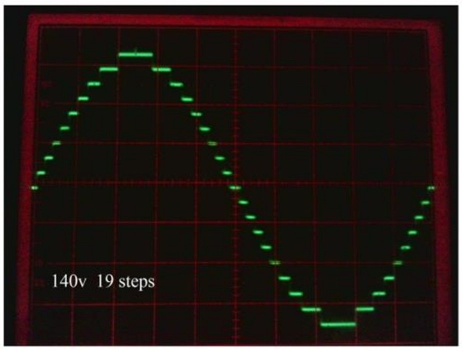
Left photo is taken from the active of a power point (after the final emc filter) with all the house wiring and loads connected to the inverter."

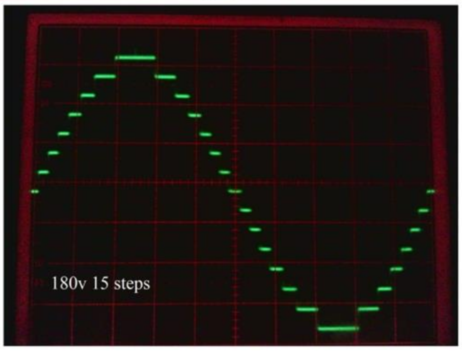
"The five pictures above show how voltage regulation can be achieved.











I have shown this with only three of the four inverters connected, to make the steps much larger and much more clear to see what is actually changing.

It should be appreciated that with the fourth inverter running, the real final output waveform will have far finer steps and a much smoother output. As shown on the previous page. But it’s more difficult to see what is actually happening with dc input voltage changes with such fine steps.

As the dc input voltage increases, the steps all grow proportionally in height, but we can correct for that by making the steps very slightly narrower. The greatest change will always be up near the peaks, with hardly any change at all near the zero crossings.

The first picture above is for a 90v dc input, which is the minimum input voltage in this example, with the smallest step amplitude and the maximum (3x3x3) of 27 steps peak to peak.

Second picture a slight increase to 95v input, still the full 27 steps, but you can see that the top step has become noticeably narrower. If we increase further to 100v input, the top steps have disappeared completely, and we now have only 25 steps peak to peak, but with the same output amplitude as with only 90v.”

“Higher still, 140v dc input and we are down to 19 steps.

Flat out full input voltage 180v and there will be only 15 steps. With the fourth inverter reconnected that increases to 45 steps and the real output waveform will be far smoother than it appears in this basic demonstration.

The inverter never has to operate right up at maximum input voltage, it’s always down closer to the minimum, especially with a lithium battery, so there are always near the maximum number of steps and the lowest harmonic distortion.

That is the basic idea behind combining four very simple low frequency square wave inverters to create a low distortion sine wave, and how we can adjust the output amplitude in very fine increments to create a constant amplitude output over a 2:1 dc input voltage range.

The power stage of each inverter is just a basic four mosfet switching bridge, each directly driving the primary of a transformer.

Primary voltage of the output transformers will all need to be wound to suit the lowest expected dc input voltage. The secondary voltages must go up in exact ratio steps of 1:3:9:27 and these voltages must all be pretty exact if the small final steps are going to be completely even. As these are square wave inverters, the turns ratios will reflect directly the dc input versus the required peak output voltages.

All four secondary windings will be placed in series to generate our required sine wave output voltage, and the secondary currents will all obviously be equal.