14. Technical Information. **(my 2nd edition OzInverter 92 page A4 size booklet, I release this PDF copy, Leslie Bryan.**

In this chapter I will show discussions and further in depth information, on what is going on in the OzInverter and its necessary components and fittings.
Also **'oztules' Notes and explanations……..** This Chapter of the book is relevant information that necessarily accompanies this OzInverter project, and is mostly dedicated to 'oztules', John Tulloch's technical comments, I have also added relevant comments from 'Warpspeed,' Tony LeGrip, Australia, (retired power electronics engineer), many thanks Tony for your valued information.

Most of the following is from forum members on https://www.thebackshed.com/forum/forum_topics.asp?FID=4&PN=1 , many thanks guys for allowing me to openly publish your comments.
Later in the Chapter I will briefly discuss other Inverters and also show Tony's interesting 'WarpStepInverter', again, my thanks for your contributions Tony.

The OzInverter evolves. My reply to a question**.**
Hi 'theoldwizard1', "You ask a question that I answer a lot, so here is the History".

" 'wiseguy' has answered a bit of your question and on other RE forums around the World you will find other answers from the likes of 'Oztules', and 'Warpspeed' our delightful Professor on toroids.

In truth the original concept of the OzInverter was to have a real Inverter that could from 48vdc give me and 'Oztules' and a few others. a real 6kW 50HZ 240vac running capacity, and stand surges up in the 50kW regions, and adequately power a large normal domestic dwelling. ie, we wanted a real Off Grid Inverter that was Simple, Robust, and very importantly Very Cost Effective.

In 2015 .... I had purchased a very expensive German Inverter, it was rubbish, it would only do half its rated value running continually before it would overheat, and only 10 minutes at its so called full rated value. It certainly could not handle backcharging, AC coupling and DC coupling all at once. All the tech department of the German company could say was that I needed lots of their expensive supplementary equipment to get my RE generation to work properly.

The German machine went back to Germany and I got my money back. But I had to use the EU Trading Standards, stating that the makers did not inform the purchaser, that their own propriety ancillary equipment was necessary.

So with 'Oztules' help we moved forward with getting an Inverter that handled Backcharging through it,..... AC Coupling (Using GTI's to feed back into the OzInverter created mini grid),...... DC Coupling, (the batteries that run the OzInverter can also be charged by a DC charging source) , and very importantly our New Inverter has a Low running/working power loss, ie, in the 35watts region.
I have had 4kW EI type Inverters that have a loss of nearly 200 watts!!!! that's a waste of your batteries at night time.

At first the Power Jack boards were used, and with a decent size and especially wound toroid, it would work very well. But the Chinese boards were bad on QC, and getting them became an issue. With the P J boards on the OzInverter when AC coupled, the AC voltage would rise when the batteries were reaching full capacity and pushing back, and this knocks off the GTI's because of the GTI internal settings.
The 8010 PWM SMD Chip.......
I had noticed the EGS002 board but the response's from folk were not good. Yes it worked well on normal EI transformers, but only up to about 3kW with toroid transformers. Some preliminary stuff here......
http://www.anotherpower.com/board/index.php?PHPSESSID=h7jd5l4edljl6k4ls18pgfj4i1&topic=1116.0

'Oztules' further investigated, and Like me we really wanted to get away from relying on a particular manufacturers products. The 8010 chip was removed from the EGS002 board and the OzInverter evolved with mostly 'Oztules' endeavours.
"*Looking good.. now with just off the shelf components, we can finally make a real inverter.. that is easy to fix as well. utopia indeed for remote living I don't think any other unit on the market can say that.... usually you have to replace propriety boards... if you can get them.* . 'oztules.'

Now the OzInverter original design has evolved with folk like 'Madness', 'Tinker' and others going their own particular way with their inverters using the 8010 chip.

'Oztules' and then Madness have added a GTI control circuit as the 8010 chip holds a rock steady constant AC output whatever the AC load is doing. Because of this rock steady AC, a normal GTI without control will backcharge to the batteries and over charge them, and that's not good.!
'Madness' now has some of his MadInverter boards that have a lot of ancillary control and data output visual stuff using MEGA's and his specialized written software.

I still use a simple Voltage comparators to shut down the GTI's as the battery voltage rises.

I have documented the OzInverters progress and published this book, on 'How to make a 6kW OzInverter' and hopefully it fully explains and documents the up-todate progress. And with permission from 'wiseguys' and 'gaspo' also add in their latest findings and works.

VERY IMPORTANTLY, we are dealing with an output of at least 6kW with this OzInverter, so its important that certain protocols must be adhered too.
REMEMBER, Its Power Electrics, its Power Electronics, its Mechanical Engineering, so any poor quality build skills, straying or shortcuts from the build road will lead to the OzInverter failing to work correctly.
OzInverter Mantra ...... KEEP IT SIMPLE, MAKE IT ROBUST, KEEP IT COST EFFECTIVE."

A Brief synopsis of other Inverter types.

6 types of Inverter have been discussed since 2015, and there build process shown here on the Back Shed Forum, Au.

1. '**Oztules**' work, 'OzInverter' formed from the Australian Powerstar and the Chinese PowerJack Inverters. Uses a Toroid and H Bridge, and now uses the PWM 8010 SMD Chip..
2. '**Tinker**', Klaus, has developed his own particular H Bridge Inverter. Uses a toroid.
3. '**Madness**' Gary Hoffmann, has designed his own design of H Bridge Inverter, uses a toroid, and has moved towards using Mega/Arduino micros to control, and he loves writing code. He has also extended and designed new boards for GTI control on the PV. Although 'Oztules' concept, Madness has done a clever circuit that controls the PV before it goes into the GTI and keeps the battery charging under very strict control. ...
4. '**Warpspeed**' Tony LeGrip, Has done a 'WarpStepInverter' that runs without the need of one large transformer he uses 4 small ones. Its very simple and rather clever. See later in this Chapter.
5. "**podia**'s", Peter Birtles, interesting nanoverter, using his own PWM code, so the 8010 chip is not used.........
6. Interestingly '**Midnite**' in the US, are at this very moment about to launch Beta units on a range of Inverters and GTI's that use a non toroid design and High Frequency switching. They will stack there individual 2kW Inverter circuits to obtain a good power output. Note, Their original design showed the use of lithium Ion NMC INR 18650 cells stacked in each 2kW unit, however, 2019, Midnite are saying that they will use a separate battery pack. The other day a few friends and i worked out that with all their engineers on the task since 2015, we reckon they have invested about $14,000,000

'Warpspeed' on Commercial transformers.

"Commercial transformer designers take a whole different approach to transformer design.
For them its a business, and the idea is to manufacture the smallest transformer with the least amount of steel and copper at the lowest cost.
Many transformer applications are for inside equipment, and will never be run at anything other than full maximum load.

So what I am getting at here, is that for them the most efficient transformer is the lowest COST solution. They do not give a damn about no load idling power, or even how hot it gets at flat out full load. Kva per dollar is the holy grail.
The generally accepted flux levels for commercially wound toroidal transformers is around 1.6T, and that allows a bit of allowance for a slightly high mains voltage.
And many budding inverter enthusiasts have reverse engineered commercial designs and just assumed 1.6T is the correct design figure, and argue that, as just about all transformers work at that level it must be correct !

Warpspeed' on Commercial transformers, continued:-

Inverters are very different beasts, and there is a lot to be gained by running our toroids at far lower flux densities. For a start, our inverters run continuously, and for a domestic application usually at a small fraction of the full rated power. ***Battery capacity is a very expensive commodity, so anything we can do to reduce idling power will be a giant step forward.*** *If we are recycling old or free material, and size and weight are no deterrent, we can gain hugely by lowering the flux density to around 1.0T"*

'Warpspeeds' comments on limitations of HF (high Frequency) Inverters.

"If you build say a 2Kw high frequency switching power supply to first generate a high dc voltage, and then use PWM to generate a sine wave from that high dc voltage, you are always going to be limited by that 2Kw dc to dc converter.

You cannot suddenly draw 3Kw from it to supply some momentary power surge. There will only ever be 2Kw of dc available.
Now a great steel lump of a transformer driven with PWM straight from a battery is only limited in power by heating of the wire in the transformer, and by the maximum safe current capacity of the mosfets driving that transformer.

Although constant continuous long term power output may still be limited to 2Kw (in this example) you could draw short term power surges of multiples of 2Kw for very short periods without any problem at all.
If you want an inverter that has some real peak surge load grunt, a big lump of iron for the transformer core has all the advantages for a practical inverter."

'Warpspeed' on a Chinese G…..l brand of High Frequency Inverters.

"*A High frequency Inverter …………….It's the crappy high frequency type that uses five small dc to dc converters in parallel to generate several hundred volts of dc, and then turns that into a modified sine wave. It's all very highly stressed with light duty parts, and just looking at it the advertised power rating is just a complete total joke.*

High frequency inverters are rather fragile and very prone to blowing up. Not necessarily G…..l, but high frequency inverters in general are definitely best avoided.

Much better are the larger transformer inverters, even the modified sinewave types. Better still are the PWM pure sine wave transformer inverters, but all that "goodness" comes at very great extra cost, size, and weight.

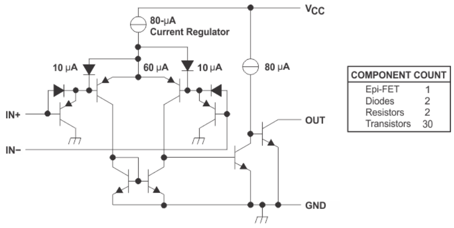
A high frequency inverter takes some low voltage dc (12v for G…..l) and generates high voltage dc, usually about 340 volts. It does that with a high frequency switching supply, the G…..l runs about 40Khz, all fairly typical.
Now that is the problem right there. If your switching power supply is designed to deliver 1Kw of power, that is its maximum. It cannot suddenly supply a peak power of 1.1Kw, or 3Kw or 5Kw for a second or two.

Many loads, in fact most loads have high inrush currents when initially switched on, and a high frequency inverter has absolutely zero short term overload capacity, despite what it claims on the front of the inverter.
So you take your 99,000 watt inverter that has a surge capacity of a gazillion watts and plug in one of your power tools pull the trigger, and the smoke escapes from the inverter. Happens all the time...

Now a transformer inverter has a vastly higher overload capacity. It has multiple huge mosfets to ensure low conduction losses, but that also provide massive short term overload capacity. The large transformer and heatsinks can absorb a lot of flash heat, so the inverter will not complain too much about short term overloads.

Now a tiny high frequency switching power supply will have much smaller parts, and just cannot absorb the same type of short term overloads without going bang. Much more stressed, far more fragile. Just a toy really and best avoided for serious usage."

The Ozcooling fan circuit………. See in the relevant chapter regards the Ozcooling circuit PCB and Breadboard layout……….. *"It is a very simple use of a quad comparator chip I have lots of. We only use 1 in this case, and I was surprised at how well it worked... so I built some more.*



The comparator compares two voltages, and if the + input one is higher than the other the output transistor is turned on, if not then off.
So we have an open collector output to deal with....... which means two things.
1. we need to supply it with voltage on the collector (via 10k)
2. when the +>- then the transistor is turned on and shorts the collector to ground.... so on is off and off is on.

To see how it works,
1. we use a 10k and a 3v zener to establish a fixed reference voltage on pin 7 (+input) This gives us a set point that we can use to compare the temp probe to.
2. We set up a voltage divider using the 47k, the 50k pot and the temp probe all seriesed with Vcc to ground.... fed to pin 6 (-input)
3. When the NTC temp goes up, it's resistance comes down, pulling the output of the 50k pot lower and lower.
4. When it gets lower than pin 7 voltage, then the comparator will switch off the transistor (which was shorted to ground when on), and the 10k pull up resistor (Vcc to pin 1 output) will be able to deliver voltage to the now open circuit collector on pin 1... this voltage then fed to the fet to switch fan on.

Now thats as a comparator, it is on or off..... if we introduce negative feedback into the - input (pin 6) then we alter the stage gain, and the more feedack we introduce, the lower the gain, and the sharp on/ off behaviour of the comparator is made wishy washy.... thats tech talk for it will now switch on and off before and after the set point, with a voltage slope rather than hard on or off..... this translates to the fet as more or less voltage to the fan/s.

The feedback is introduced at pin 6 via the 50k pot on the right. It takes some of the output through a 10k and then a 50k pot back to the input of pin 6.... so we can change how hard and fast the fans turn on.

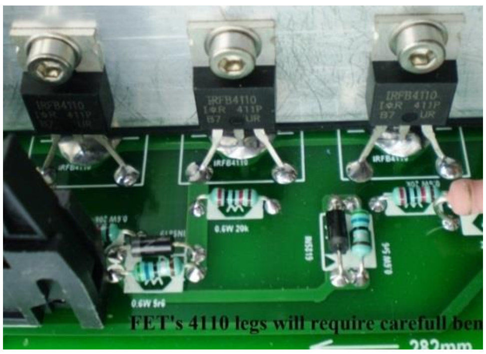
I set mine so that as it approaches the set point, the fans wake up and start rotation, silent and slow, then as the set point gets closer, they speed up , if they can stabilise it at low speed then good, else it gets hotter, the fans spin faster until you can hear them... all the way up to full on at the set point... so feedback pot for slope rate.

So thats as simple a fan control as I can come up with, and still work nicely. It could be made a lot more flashy, but it does the job.
Each comparator looks like the above right photo. It may help to understand the output inversion......"

The Power Board Mosfets.......
"In theory, a single 4110 can carry 150amps@100v... so a single one can actually do 15kw on it's own

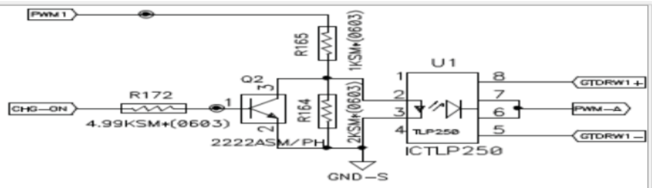
Practice is different, those skinny legs can't handle 100 amps continuous, apparently the silicon can, as it has a resistance of only .003 ohms.... so at 100 amps it will drop E=IR or 100x .003 or .3v losses@100amps.. so the dissipation will be W=ExI or 100 x .3... or only 30 watts.. so that leaves over 340 watts of dissipation spare.

Can you see that the dissipation figures are not the power handling figures, the 370w is the figure it can safely dissipate in losses..... not throughput. It's losses is the Rds on in ohms (.003-.006 for 4110) x the current flowing through it... these losses are dissipated in the mosfet and heat sink.

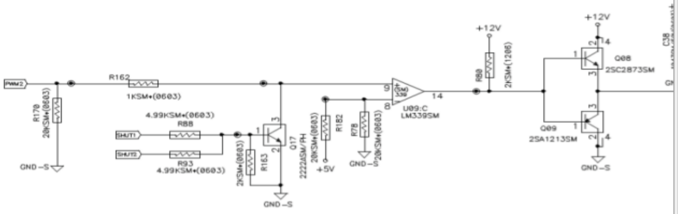


Switching losses are added to the IR losses, (and in anything I build usually outweigh the resistive losses hands down). Getting the switching losses down is a science unto itself... black science almost, add in parasitic oscillations and lots of other gremlins, and we have our work cut out to keep the losses less than the 370 watts. If we fail, it goes up in smoke.

1/Driver of the Up Bridge;

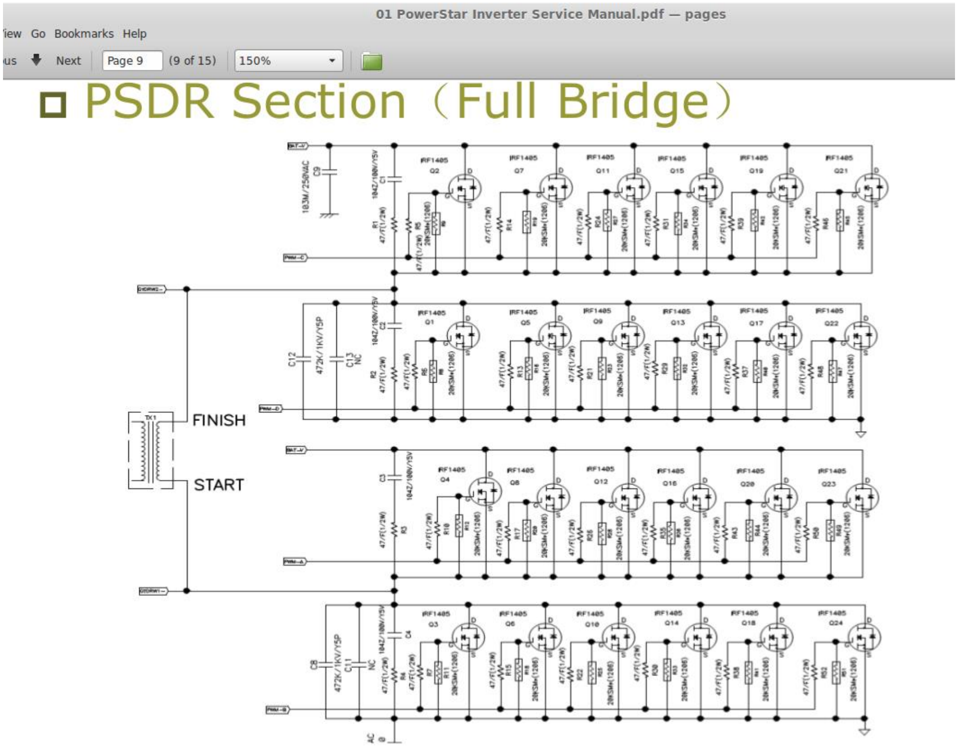


2/Driver of the Down Bridge;



For the most part, if we keep the switching frequency low, stick to the design rules regarding layout etc etc etc... we do pretty darn well.
With 6 fets per leg, we get roughly 150X6=900 amps of capacity X the voltage we switch... 48X900=43000w or more.. my bank is usually 56v so 56X900=50kw. (so it should easily survive transients of this level)

Now these figures are all theoretical, and have no real place in the real world... except for fractions of a second, and there they count.
We switch at high speed........ over 20 thousand times per second... so we don't need to carry these currents for long, and our duty cycle is less than 100% (each leg is turned on only at a max of 40% of the time I suspect).



So in fractional times, 60kw is not out of the question... and surviving it is possible too. Remember of your 24 fets, you can only calculate for 6, as each leg only has 6fets..... not 24.
I use the 15kw boards because the fet spacing is greater, and so cooling is better..... mostly not of interest, but more surface is always better than less.
...........oztules

The Chinese PJ boards are just W7 boards in disguise.

The OzInverters Development.

The OzInverter H Bridge concept is nothing new, however utilising the 8010 PWM chip and re-designing the Power Board and Control board, The OzInverter is SIMPLE, very ROBUST and extremely COST EFFECTIVE as a DO IT YOURSELF BUILD.

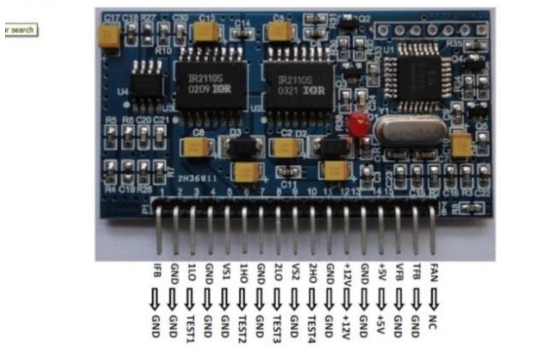

EGS002 Driver Board Testing

Figure 4-1. EGS002 Driver Board Connection Diagram

EGS002 Driver Board Testing

1) Connect IFB, VS1, VS2, VFB and TFB to the ground during testing.
2) Connect DC 5V to pin +5V and DC 12V (voltage can be between 12V and 15V) to pin +12V

How it evolved, ...
In 2015 it was a concern that just relying on the Chinese PJ boards could leave us without the PCB's required, especially if PowerJack withdrew them from being retailed as just one set.

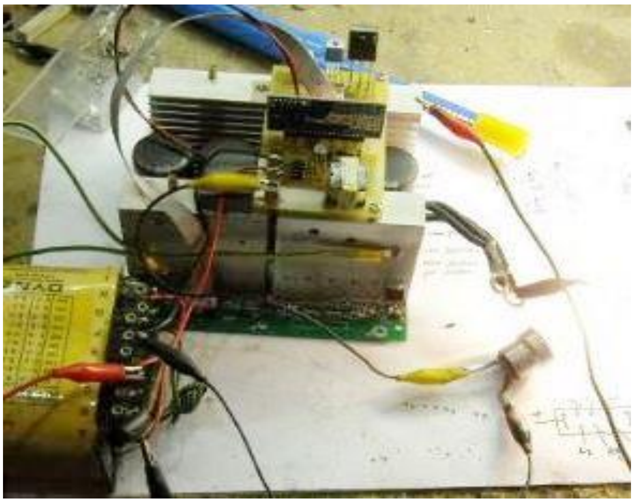
However, In 2015, I was interested in a 3kW Inverter working with a new EGS002 control card, and 'oztules' took up experimentation with this new control board and designed and made a simple connection and power board.

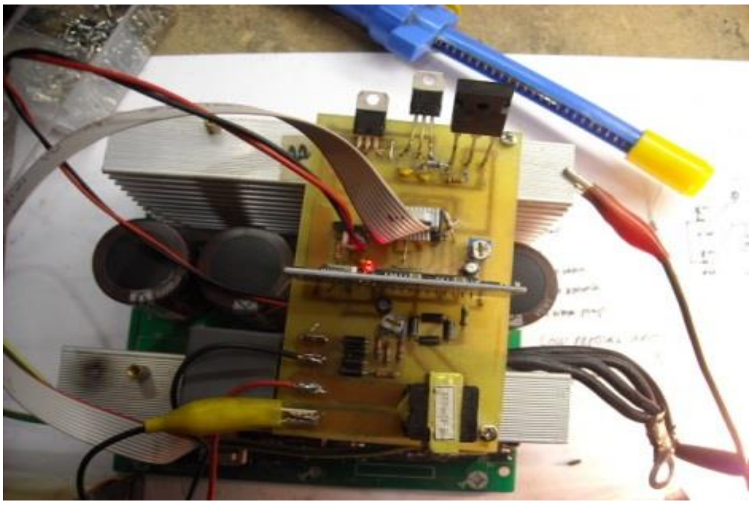
I have included these experiments from
http://www.thebackshed.com/forum/forum_posts.asp?TID=8220&PN=1
………here in this book.

EGS002 sub board containing the SMD 8010 PWM Chip. Manufacturers comments………”***To prevent output voltage is too low or too high when supply to the load, EG8010 has integrated overvoltage and undervoltage protection. Overvoltage protection is set at 3.15V with 300mS delay.***

Undervoltage protection is set at 2.75V with 3S delay. When either situation happens, depending on pin (9)PWMTYP’s setting, EG8010 will set the level of SPWMOUT1 to SPWMOUT4 at “0” or “1”, and shut down all power MOSFET to decrease the voltage to zero. Eight seconds after overvoltage or undervoltage protection activates, EG8010 will turn on power MOSFET for 100ms to re-determine output voltage. If overvoltage or undervoltage issue still exists, EG8010 will repeat the process above every eight seconds. If EG8010 runs regularly for more than one minute, it will zero the counter of overvoltage and undervoltage. However, if EG8010 does not function regularly after five 8-second cycle, it will complete turn off the output of SPWM unit. It needs a hard reset to start again”.

‘Oztules’ Inverter experiment pure sine EGS002…… *”This may interest those toying with making a low frequency pure sine inverter.. of whatever voltage you choose for input and output.*

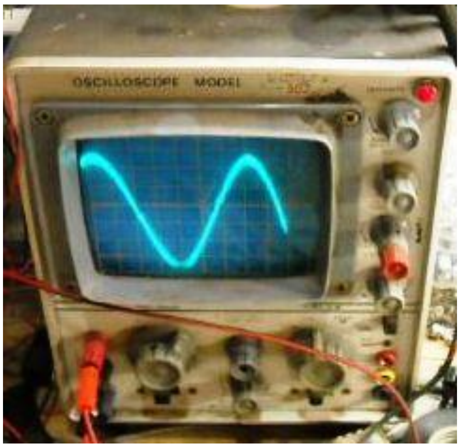




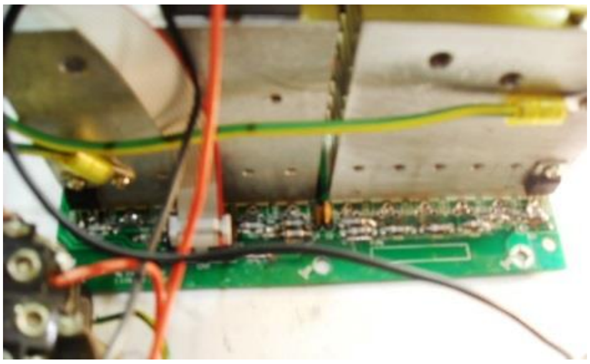
This will be fairly brief, as it is experimental at this stage.
This involves a EGS002 board which can be had for around the $7 mark on aliexpress and ebay.
The test board looks like this.. a simple dual voltage output stage to keep the volts to 12v and 5v for the EGS002, with a transistor for the main step down voltage stage.”

‘Oztules’ continues his comments ……
“I made a quick h bridge to use for the initial test, but designed the control card to interface with the PJ power board.. it has the caps and heat sinks already. Once that found out a few flaws (voltage regulator went west for no apparent reason) we then plugged it into the PJ board. The PJ had only 1 mosfet per leg... now there's confidence (less to replace) like so: Then fired it up, with a 40w load.. it was the only filament bulb thing in the place....so it was pressed into service...

Well it worked.. The voltage control went from 68acv to over 260vac. Transformer was 32:240v.
The temp probe was heated up, and the unit stopped, restarted 8 seconds or so later, the current transformer will have to wait until I have it connected to the battery bank, and a big transformer attached. Suffice to say I was pleased to see it running at all. didn't expect it to be so easy I must admit.
Fets stayed cold (touching the front of them, there was no heat)... so.. Put 2x 560r 20w ceramic resistors as well as the load. Unit started smoothly, constant frequency, and soft start voltage... straight to the 240v mark.... nice so far”.



"Ran for a few minutes, until the load resistors started to smoke....checked the fets, and with 240 watts, the temp was barely warm on the front of the fets... so I guess that 600 or more watts on a single h bridge is well within reach... but my 56v power supply was topped out at 300w... so that will have to wait until I get it all better resourced.

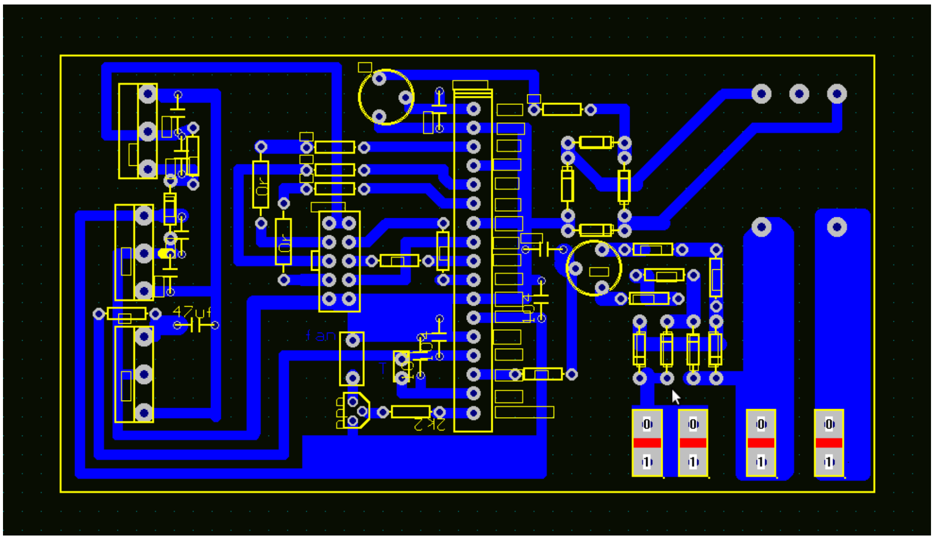


It didn't change even as I dropped the load on off on off etc.... until I got tired of trying to fool it. I am hoping that this translates into the high power phase as well, we'll see."

Above Left….. *"The wave looked like this: "* *"It is looking promising. Next step is to put 6 fets on each leg, and see how the switching transitions degenerate, or if the drivers can handle it nicely without further conditioning... I live in hope.... but not confidence.*

I would prefer to use galvanically isolated supplies for the high side drivers, rather than the pump, and if this is necessary, will probably end up just buying the chips, and designing the power supply with pwm for the drives and logic separately. and then driving with high current totems.... but we'll see. ....oztules"

12/02/16…. *"Wound a small 3kw torroid. Put in another fet in the h bridge legs. We ended up with this little beauty. Oven element with about 2100watts load. The heat sinks stayed pretty cool over the 10 min test. Voltage was stable... very stable. …..oztules"*



The EGS002 board was discarded when a limitation was found when driving a toroid over 3kW load. 'Oztules' put together a control board with the 8010 PWM chip on its own sub board, and I am now, 2019, at a Mk16 OzControl Board.

'Wapspeed' comments on Toroid's and there cooling…..

"The steel does vary from batch to batch and from different suppliers, that is to be expected, and the differences can be quite significant. It only really effects the zero load idling current, flat out at full power it won't make as much difference.

The voltages induced in each turn "should" be identical but there will always be some sneaky magnetic lines of flux that take short cuts through the air instead of going only through the steel core. The difference in voltage will be very small, much less than the voltage of one complete full turn, and is quite normal and nothing to worry about.

The more copper you can stuff into the thing with fatter wire, the cooler it will run and the more power you will be able to safely get out of the transformer before it gets dangerously hot. Its those 40++C days where the airconditioner burns up your transformer.

Power is only limited by safe temperature rise. My mate with the transformer winding business tells me my largest transformer will take about six hours running at full rated continuous power for the temperature to level out at its full rated maximum.

Its probably pretty comparable to what you guys have, 50Kg total of steel and copper and a 4.5Kva continuous rating in still air. I don't know of anyone that has an oil filled inverter transformer.

One final thought. If you use the tunnel heatsink method of construction, the heatsink should be mounted vertical for best convective airflow. That is pretty obvious.

'Warpspeed' some ideas on the PWM inverter Choke,

"O/k let's look at our large efficient inverter output transformer (toroid or E core) that probably has a step up turns ratio of about 8:1 (30v to 240v).
Its a wonderful thing at 50Hz, and if there are enough turns to keep the flux density low, the magnetizing current should remain nice and low (when driven by a 50Hz sine wave).
Now what happens if we connect this DIRECT to a very low impedance PWM switching bridge switching at 23 Khz?
The secondary of our transformer will have a lot of capacitance between turns, between layers, and between the secondary and the core. The secondary inductance will be very high, but there will be a self-resonance of only a very few Khz with all that self-capacitance.
The combined capacitance across the secondary is reflected back into the primary at a rate of turns ratio squared. So there will be x64 the secondary capacitance that the bridge sees as a direct load. That capacitance has to be charged and discharged 23,000 times per second.
If the transformer connects directly to the bridge there are going to be some pretty fearsome current spikes every PWM switching cycle, even with no external load on the transformer. This will definitely increase idling current, but worse, its going to really stress the mosfets as the current spikes will be almost unlimited with such a low source and load impedances. So we fit a series choke into the primary to vastly reduce the rate of current rise each time the bridge switches.
With sufficient inductance the voltage at the bridge can switch very fast while the voltage across the transformer and its capacitance hardly changes.

You will see a very fast high frequency rail to rail waveform on one end of the choke, and a smooth 50Hz sine wave on the other end of the choke with only a very slight high frequency ripple feeding the transformer.
Now in the early days of all this inverter development, it was discovered that a ferrite choke would greatly reduce the idling current, and it will certainly do that. The problem with ferrite is that it saturates very easily, and although it will reduce idling power, above a few amps through the choke and primary, it will saturate and have no effect at higher power.
We really need a choke that will keep on working up to full rated inverter power and ideally beyond, to greatly reduce the switching losses in the mosfet bridge. This will create far lower switching current spikes, reduce the stresses and heating on the mosfets and heat sinks, and generally improve inverter robustness and efficiency.
How big ? Well minimum might be something like 50uH would certainly work at 48v and 2-3Kw but something a fair bit larger would be better if you can arrange it. It really cannot be made too big, either in inductance or saturation current. Its rather like the decoupling electrolytics. More is always better.
When you have a really nice big non saturating high inductance choke working, it will effectively decouple the transformer from the bridge, and it allows the transformer to "do its own thing" as far as any self-resonant behaviour goes.
Expect to see some wobbles develop in the 50Hz waveform due to transformer self-resonance, especially at zero load.
With higher loading the wobbles usually become slightly less.
The wobbles are not caused by the choke, but actually indicate that the choke is working properly.

Some people get alarmed by the now distorted sine wave output, and assume fitting a much large choke is the wrong thing to do. Fixing one problem has just created another problem, but it's definitely a BIG step forward fitting a large non saturating steel cored choke.
One sneaky solution to the waveform distortion is to lower the self-resonant frequency of the transformer down to exactly x1.5 times the inverter frequency. That is 75Hz transformer resonance for a 50Hz inverter, and that usually takes around 4uF to 10uF across the secondary, but that varies a lot from transformer to transformer. This also sounds a bit suspect.... But try it and see, it definitely works!
The magic of exactly x1.5 times the inverter operating frequency produces a self-damping effect, where any resonant build-up on one cycle will be exactly out of phase the following cycle. If it's not tuned exactly right, resonant energy can build up causing even worse waveform distortion, and the inverter output voltage may do some very strange things at zero load.

Voltage feedback may lose control. But if you get the transformer tuning exactly right (ideally +/- 1Hz) after fitting a really nice large non saturating steel cored choke into the primary, a great many problems will have been solved, and you will then have a sweet running and efficient inverter with a good clean low distortion sine wave at the output".

"Podia's" nanoverter,

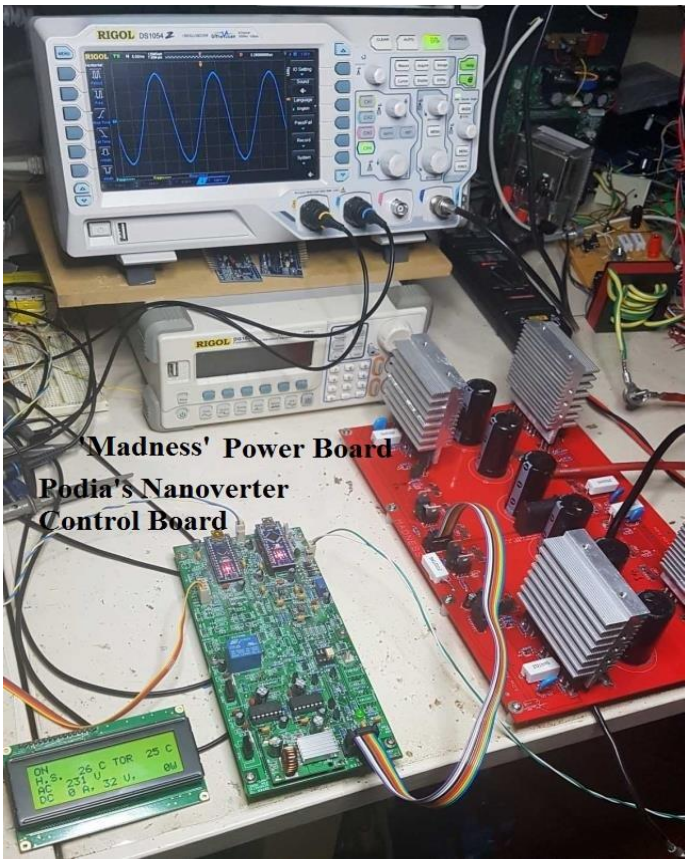
Using his own PWM code, in a Arduino (ATMega 328) so the 8010 chip is not used.........

'Poida' , Peter Birtles, c*omments, …….   "The inverter uses a closed loop control design which takes a DC sample of the output AC voltage on the transformer secondary.*

This DC voltage (Vfb) may have a lot of 100Hz ripple (if a full bridge rectifier is used, else 50Hz ripple), and unknown amounts of much higher frequency noise mostly coming from the full bridge mosfet switching of the DC supply. We need to filter Vfb to only let DC into the control loop.

In another post I showed that the EG8010 IC only samples Vfb during a very short time compared to the 20 ms period of 50Hz output. I think I wrote that Vfb is sampled at the top of one half of the 50Hz output waveform, and the sample window is of the order of 10us. For the rest of the (20milliseconds - 10us) period, Vfb is not sampled.

This means that we need to have Vfb reflect accurately what the output voltage is during that sample time.   Vfb may go all over the place during times when the EG8010 is not sampling it's value.



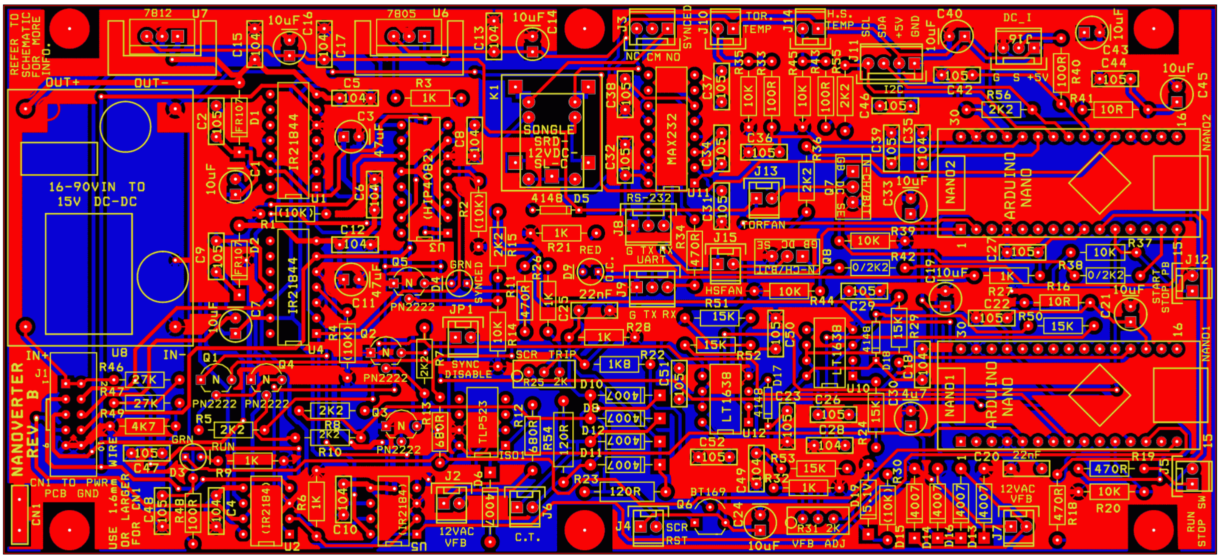
The fact that Vfb is sampled synchronously with the output waveform might lead us to simple Vfb filtering designs which work fine on the test bench, usually with purely resistive loads. In the real world the current and voltage can be way out of whack.   This will upset the closed loop control leading to over/under voltage of the output.

So we have to low pass filter Vfb quite heavily to allow for large disturbances from various load types (switching power supplies, SCR controlled lights, motors, flouro lights etc).

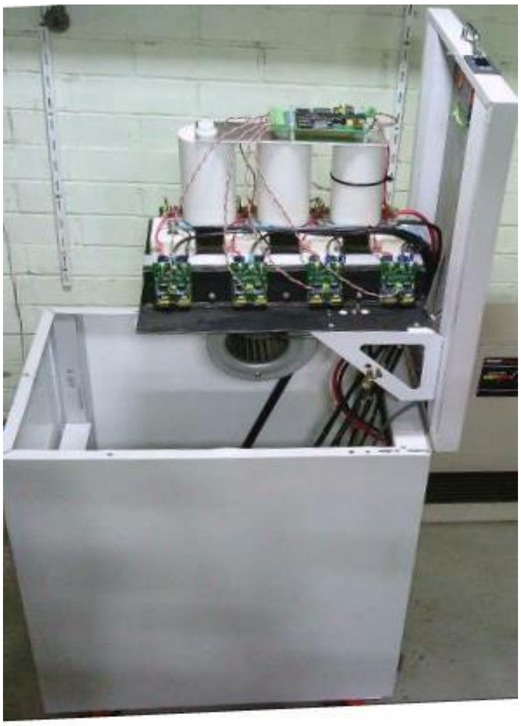
I have built a custom inverter prototype using the Arduino (ATMega 328) so as to permit complete control over all aspects of the inverter function. I can use any sort of digital low pass filtering of Vfb I choose. I could do the filtering in hardware but I prefer the flexibility of software. At last it's time to look at some results of the closed loop output voltage control.

I use a simple design: Vfb is fed into one of the ADC ports and is filtered to remove all the high frequency stuff. The 100Hz ripple is quite high, about 0.3V p/p riding on a 2.5V DC signal.

I then sample this voltage about 2,200 or 8,000 times a second and apply some digital filtering to it. Then at the zero Voltage point in the beginning of each 50Hz output, I apply this filtered Vfb value to the PID control loop to calculate the needed PWM duty cycle %."



<u>**The ‘WarpStepInverter’ .**</u>

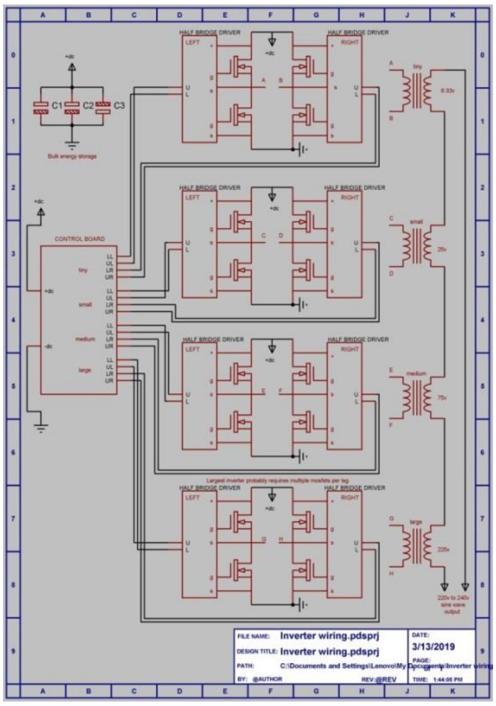


‘Warpspeed,’ Tony LeGrip, Australia, (retired power electronics engineer), has successfully been using the step inverter principle. Many thanks Tony for letting me show your Inverter work and your comments.

“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.



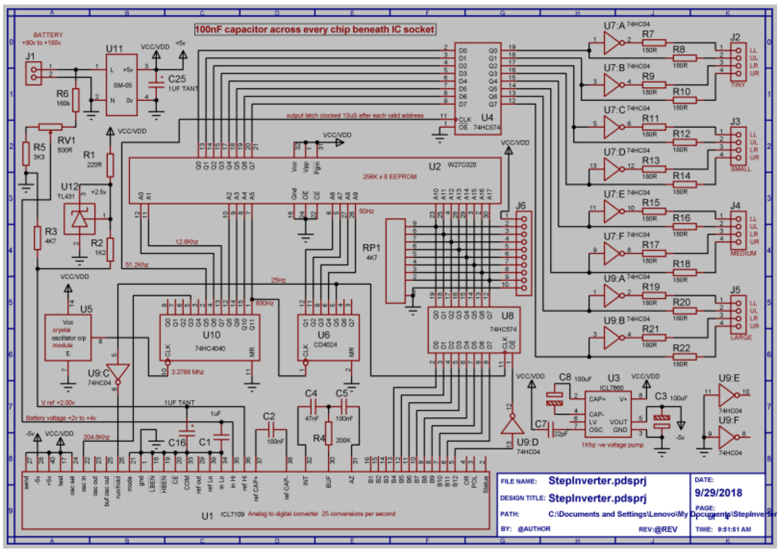
My latest effort powering my house right now uses 256 individual 1K lookup tables which is more than are really necessary. Experience now suggests 64 or 128 lookup tables might be about optimum.

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.

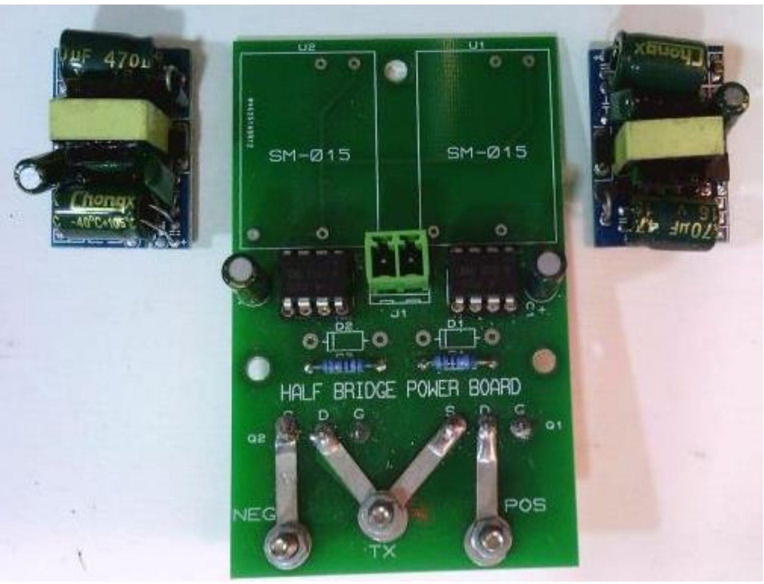
Four bridge inverters, sixteen opto isolator outputs from the driver board on four different plugs.

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 opto 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.

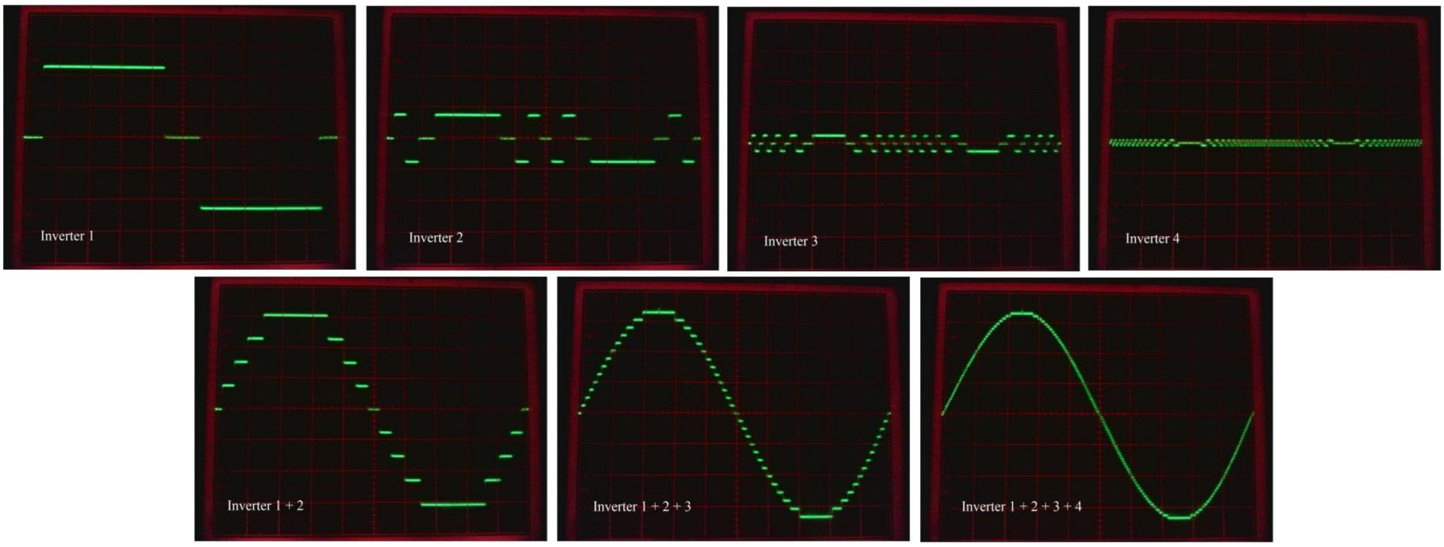
I just wrote a program in assembler to burn an EEPROM directly. That is no more difficult or complex than having a working microcontroller in the inverter. But a bare basic rom design has the advantage of not having any software timing constraints in generating the waveforms, it just cycles through sequential 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.

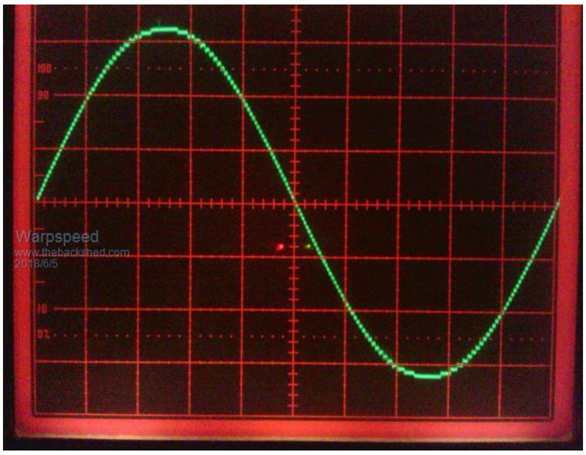
I have now installed a battery for complete off grid operation, but for over a year it ran from a dc rectifier at night without a battery. During the day there is easily sufficient total solar power, even in mid-winter, it's just that it drops to zero at night no matter how many solar panels there are.



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……..

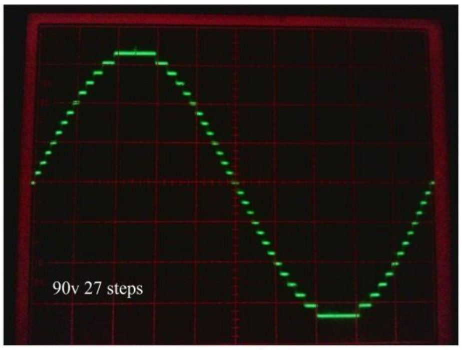
"The seven pictures above, show the individual output waveforms of the four square wave inverters in correct relative amplitude, and the effect produced when the secondary voltages are combined.

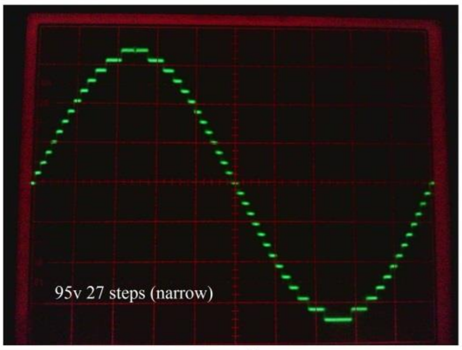


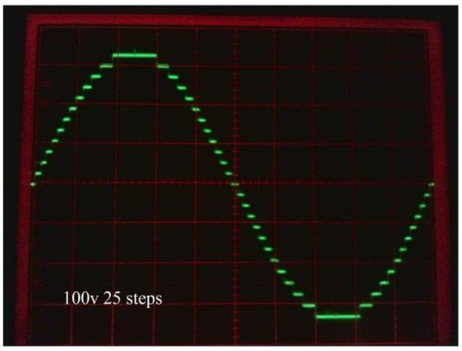
Each inverter has three possible output states, positive, zero, and negative. If we combine the outputs of four inverters, with every possible switching combination we can generate 3x3x3x3 = 81 possible voltage steps peak to peak. That is forty steps up, forty steps down, with a zero step in the middle.

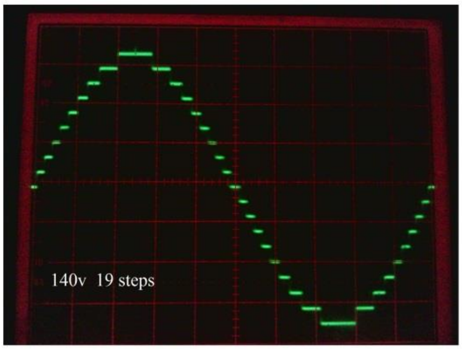
Left photo is taken from the active of a power point (after the final emc filter) with all the house wiring and loads connected to the inverter."

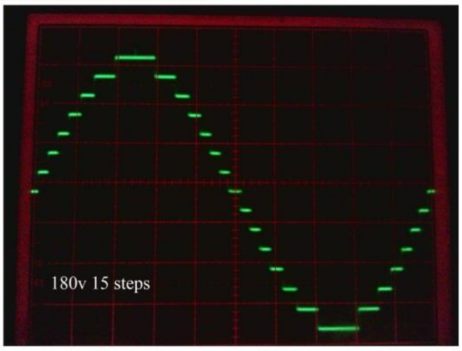
"The five pictures above show how voltage regulation can be achieved.











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.
Convenient transformer secondary voltages might be 225v for the largest #1 inverter, 75v for the #2 inverter (exactly 1/3) 25v for the #3 inverter (exactly 1/9) and 8.33v for #4 inverter (exactly 1/27).

If all inverters switch on together in the same direction we will get 225v + 75v + 25v + 8.33v = 333.33v peak. That equals 235.7v rms, which works out quite nicely.
There are a couple of peculiarities about all this that are fairly important to understand. The first is that some inverters will be switching their output voltage in opposition to other inverters.

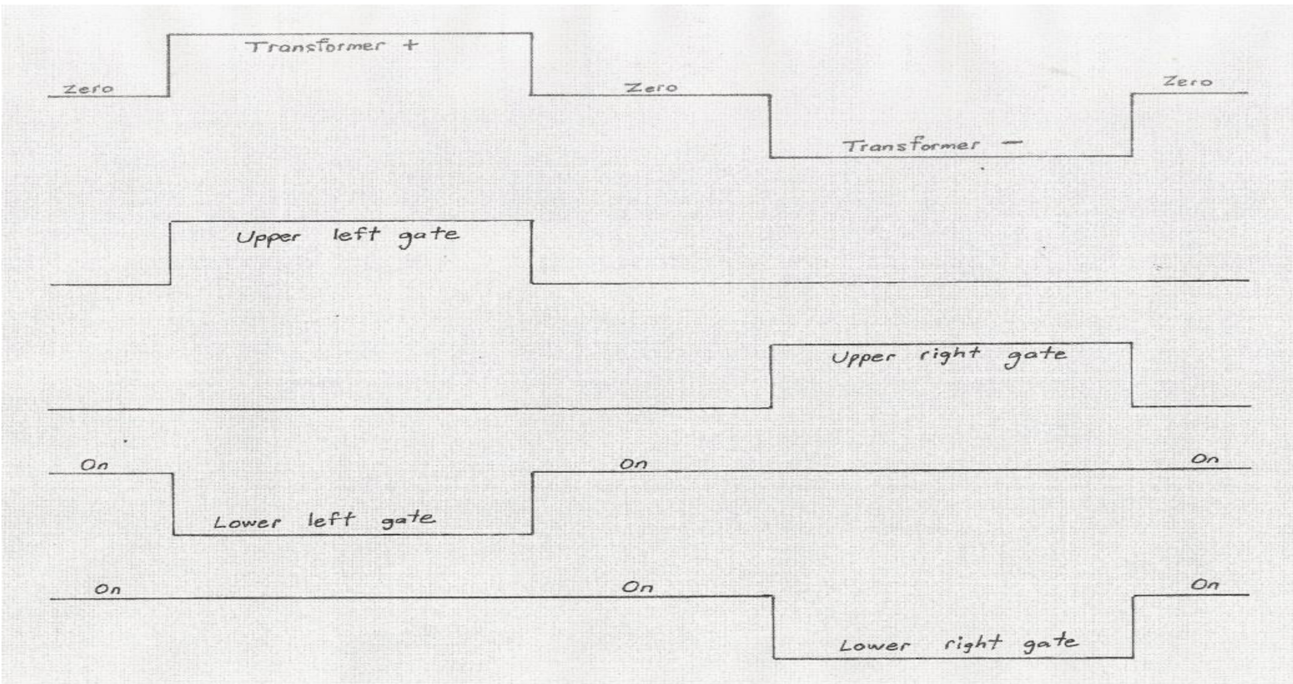
If the 225v inverter switches on positive we get +225v. If at the same time the 75v inverter switches on negative we get -75v, and the combined output produced would be +150v.
What is really weird though is that the 225v inverter will be producing excess power at +225v which then flows backwards through the -75v inverter back onto the dc input power rail. There will be power shuffling back and forth through all four inverters as the complete sinewave is being generated. These mosfet inverters are all bi directional, and heavy out of phase reactive load currents produced by motors, fluorescent lights, and other really nasty reactive loads can feed power backwards onto the dc bus without creating any dramas. So the whole thing is pretty much bullet proof for highly reactive loads.

It's a curious thing, but the voltages throughout the inverter are all square waves, but the currents in the inverter are all sine waves, or chopped up sine waves . All four transformers can be designed as conventional 50Hz sine wave transformers, and it will work fine.

Another other odd thing about this is that each inverter in the zero volt output condition must still carry the final output current of the other inverters as they are all connected in series. So it's not just a case of simultaneously switching off all four mosfets in any zero volt output bridge. That would create an open circuit across the transformer primary, reflected as an open circuit across the transformer secondary.

There absolutely must be a continuous current path through all inverter secondary's even right at the zero crossing where all four are putting out zero voltage.
What we need to do is short out the primaries in the zero output volt condition, and we can do that very easily by turning both lower mosfets on together. So we switch mosfets on in diagonal pairs for either +ve or -ve output in the usual way, and turn on both lower mosfets together for the zero volt shorted output condition. This is a rather unconventional way to drive a bridge, but the gate drive waveforms to do it are really simple.

Please see the mosfet gate drive timing diagram below which is shown without dead time for simplicity."



Discussions on SHOOT THROUGH with 8010 chip.

Possible failure :- …….

A serious short-circuit condition called shoot-through occurs when both the HS and LS power FETs are on at the same time. Shoot-through can happen even if we never intend to have both FETs on simultaneously. For instance, when the HS FET is commanded on and the LS FET is commanded off, logic propagation delay and the time required for charging or discharging the FETs' gate capacitances can cause a short period when the HS FET is half on and the LS FET is half off. If so, current flows directly from VCC to GND through both FETs (shoot-through).

'Poida', Peter Birtles, has analysed the Shoot Through with the 8010…..

"Take output of pin 29, put a 4.7K in series, pin 30 again a 4.7K in series, join these two resistors at a point and again put a 4.7K pulling that point to ground.

When both pins are high, I see approx 3.75V, when one or the other pin is high the voltage is about 1.6V. It has adequate frequency response to confirm 'Wiseguy's', Mike, observations. I needed to attach 4 wires to the emitters of Q2..Q5 to get the raw output of the EG8010.

I saw the shoot-through gate drive after the EG8010 resumes from an over temp signal. Every time. At the start of the first 50Hz cycle. It happens on the SPWM outputs only, not the 50Hz outputs.

I next took the outputs from the EGS002 board with the 8010 on it, pins 8 and 10 which are the gate drive outputs for the SPWM, added them and tried to find the shoot-through situation.
It did not occur. Whether it is prevented by the dead time (IR2110) or the transitors (eg Q2 to Q5) I can't say.
So the EG8010 does in fact generate this unwanted output."

My view is 200ns of shoot-through is too long to permit to occur. HY4008 mosfets are tough in some respects but weak in others. They may survive (for example)100 events of this short period of short circuit but then start failing sometime after.

Much depends on the impedance of the DC bulk capacitors and wire thickness that connects the FET bridge to the capacitors. Some of us here have built inverters with very low impedance, others not so low. My inverters have bulk capacitance about 1/10th or less than what I have seen here become the usual design. So a very low impedance means very high current during shoot-through.
A little higher impedance means less stress on the mosfets during shoot-through and that is why I like my boards to have 1/10 the capacitance. Shoot-through occurs in other circumstances with our inverters.

I am talking about the dV/dT induced voltage spike seen on the gate of the low side mosfet. What happens is the low side mosfet gate voltage rises (or falls..) as a consequence of the fast rate of change of the Drain-Source voltage when the high side mosfet switches ON or OFF really quickly. I have observed repeatedly this effect on my inverter boards.
The voltage rise is just enough to start the low side mosfets conducting. The rise is not enough to make them fully switch on, in my case at least. But the gate does get a short pulse of about 4 or 5V and it comes from WITHIN THE MOSFET ITSELF.

In summary, my inverter board has 3 HY4008 per leg of the bridge and at about 24kHz 3 mosfets are switching on, inducing the low side mosfets to conduct a bit at the same time. This state of affairs exists for years. And I find myself wondering why the board failed after 6 months of this abuse?
I expect everyone here also has this dV/dT induced shoot-through. Just how long can a HY4008 put up with one or another type of low level abuse?
That is the question. I think this forum has been in a round about way been working on the answers."

'Warpspeed' comments on Shoot Through.

"That is another very good argument for using a very low impedance gate driver chip right up close to each mosfet, with a very low ohm damping resistor.

Hopefully that should hold the gate sufficiently below the gate threshold during dead time.

A different approach would be to drive the mosfet gate a fair way negative during the off period. There are many suitable IGBT gate driver chips that can do that.
Many factors at work here, what this means is that both upper and lower mosfets (might) be turned on simultaneously for that amount of time, and even if they were the amount of actual fault current flowing is not well defined.

Turning on a mosfet is not easy, there is a lot of gate capacitance to charge up, and it can take several amps per mosfet to do it really fast. Also there is a gate threshold voltage, usually about +3.5v before the thing even begins to conduct at all.

It then begins to conduct and the "on" resistance starts to rapidly fall. That does not happen instantaneously either. So there can be a fairly long time interval between when the control chip output goes logic high, and the particular mosfet wakes up and starts to draw some rapidly increasing current.

There is another completely independent factor. How fast the current can rise and to what value, depending on any series inductance in the power supply to the bridge circuit.
The mosfet drain current cannot rise instantly even if the mosfet could turn on in zero time. There will be series inductance in the bridge circuit, and the large electrolytics also have some internal inductance. So the power souce also limits how fast things can happen.

Combine all these unknown factors together and there may be a very sudden lethal event, or hardly anything at all happens as the whole bridge circuit is just too slow to fully respond. There is an irony here. If you build a really fast highly efficient circuit, its MORE likely to blow up !

On top of that there can be a gradual degradation of the mosfets if they are sufficiently stressed hundreds or thousands of times.   Soft starts will not help in this particular case. Even the smallest narrowest lowest duty cycle turn on may be lethal if both upper and lower mosfets turn hard on simultaneously.
So don't be too hard on us Mark. There are a handful of professional circuit designers here that take all this kind of thing very seriously. Its our bread and butter to design things that work efficiently and are long term completely reliable."

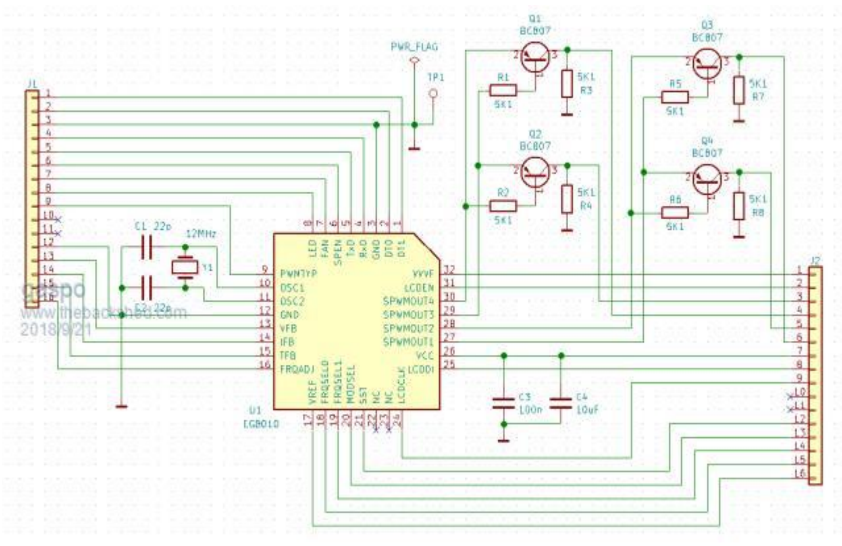
'Warpspeed 'answers a question ……..

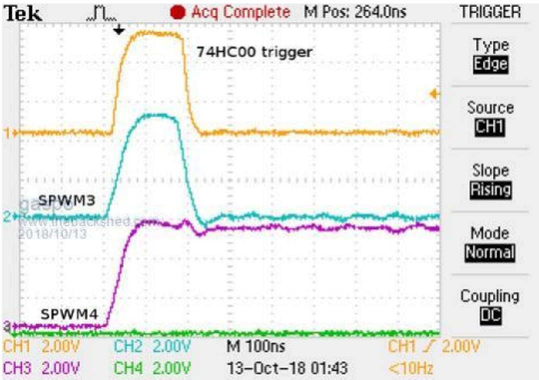
"There are many shades of grey between running sweetly for years and it suddenly blew up and burst into flames. Things can still be be "not quite right" and the inverter still soldiers on in a fashion.
You will know yourself what a big difference adding just the right tuning capacitor across your toroid, and fitting a REAL choke made to your own inverter.

These may seem like really trivial details, but they are not.!
Like going to your doctor, he looks into your eyes, peers down your throat, sticks his finger up your bum, and says you need to take the green pills twice a day.
You just have to trust his judgement that those green pills are really necessary."

Gaspo's, Peter Gasparik, modification to stop Shoot Through on the 8010 sub board.

Gaspo' comments…….   *"I have now received the adapter boards from the PCB manufacturers, so I assembled one and tested it."*
"First I performed the same tests as 'Wiseguy' and 'Poida' did with unmodified adapter board and have observed the same ~200ns shoot through on SPWM pins when coming out of IFB or TFB error condition.



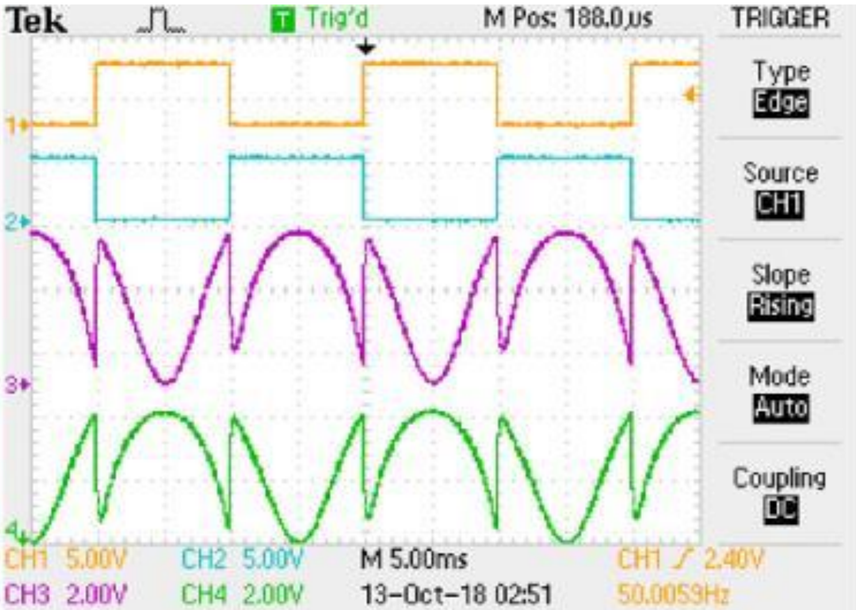


"With the new adapter board the problem did not occur so it looks like the output transistor do their job. The reference voltage with TL431 works fine as well producing 4.96V on the VREF pin."

'Wiseguy' comments, ……… *"Gaspo 's created board can be used without cutting tracks etc. If you get a blank board and load your own parts, by not loading the TL431 and putting a link or zero ohm resistor between the pin 17s (R11?) it works as before. If you don't want to put the crystal & its 2 capacitors on the adaptor board & take advantage of the lower noise pickup you can jumper the 2 crystal connections with 2 short links to the unconnected pins 10 & 11. For the best rejection of noise though having the crystal and capacitors on the adapter board is a good idea. The crystal and caps on the main board would just become unused - you don't have to remove them."*

'wiseguy' wrote: "*'Gaspo' did I miss something ? As it stood with pins 10 & 11 unused, if the crystal is fitted & used on the adaptor board there is no modification to the control board. If the adaptor board has no crystal or capacitors fitted & pins 10 & 11 are linked there is still no modification to the control board ? What modifications were you referring to that could otherwise be necessary for the control board ? "*

'Gaspo', replies…… *"Yes, the C4 is multi-layer ceramic……. What I intend to do was not put permanent tracks from pins*



10,11 on 8010 to connectors but to place jumper pads on the board. So instead of soldering wire links from 8010 pins to connector one would just solder jumper pads together with a drop of tin. A lot simpler then to mess around with soldering tiny wires."

Photos below …. *"The reference voltage parts around the TL43 are not soldered as that would require you to modify the existing OzControl board. Just solder the 2 x 16 pin strips and you have a ready to test and run. Ensure the 8010 works and shows a SPWM waveform on pins 27-30.*