HVAC Protection From Solar Power Inverter
BONUS: Doubles As Solar Storm / HEMP E3 Equipment Disconnector

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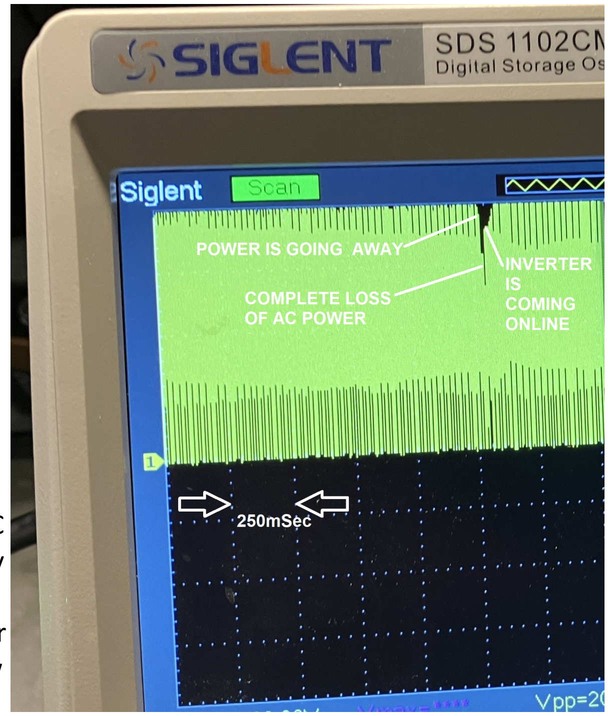
I started out trying to save myself $Thousands of dollars in HVAC repair bills -- and I ended up with a neat homebrew circuit that will possibly end my HVAC troubles, but it can also be used to provide inexpensive protection against the power-line wildness that can result from **GEOMAGNETIC STORMS** (like the Carrington Event) or from High Altitude Electromagnetic Pulse (HEMP).



Captured transition on oscilloscope, between utility power and solar inverter power

The Need: We wanted a comfy living arrangement in grid-down hurricane aftermath

Power to our neighborhood is very tenuous during hurricanes and we almost always lose it -- sometimes for several days. While we have a 9kW solar power system, it simply cannot start our 3-ton sized standard compressor AC systems....so in our little guest space, we went with a pricey "inverter-compressor" heat pump/ac HVAC system that has low startup currents and can easily be powered by our solar system. (Our other solution is 500-watt, 5000 BTU window AC units and we keep those around for storms.)

Comes with a New-Fangled Electric Motor

The fancy HVAC system had a fancy "electronic commutation" blower motor which has multiple push-pull MOSFET drivers sequentially powering three different DC windings to provide infinite speed control. If you have a "variable speed blower" you might have the same. These blowers are $300-$700 and the labor to change them isn't cheap either! (OEM ECM blower motor: $325 Amazon: https://www.amazon.com/dp/B07WC75772)

Ours started ***blowing up***. Again and Again. Toast! And very expensive! A full repair can easily be $1000.

After about the 3rd failure I blew up, too! We had paid extra $thousands of dollars to get this inverter compressor system, and now it was costing us WAY more than cheaper bigger systems. The dealer suggested it had to do with the fact we had solar power -- most of the failures he had seen were similar.

Apparently our solar power inverter kicks in *quickly* when utility power is lost -- but likely with a different PHASE, and that catches the fancy motor's MOSFET drivers with their pants down, facing unexpected L *di/dt* induced voltages from the still-fast-spinning blower....and just like an infinite SWR in a cheap transmitter, it blows the push-pull MOSFETs.....

Trying to Find A Solution

In the beginning, I didn't realize I would also be developing a solution for the wild and wacky utility line voltages that can result from a **geomagnetic storm** that damages power line systems, may knock neutrals out and put amazing voltages on either phase reaching your house.... All I knew was that a good solution would be to detect the loss of utility power **quicker than the inverter** -- and take the HVAC system off-line until the blower comes to a stop and the power is stabile again. I ended up solving BOTH problems!

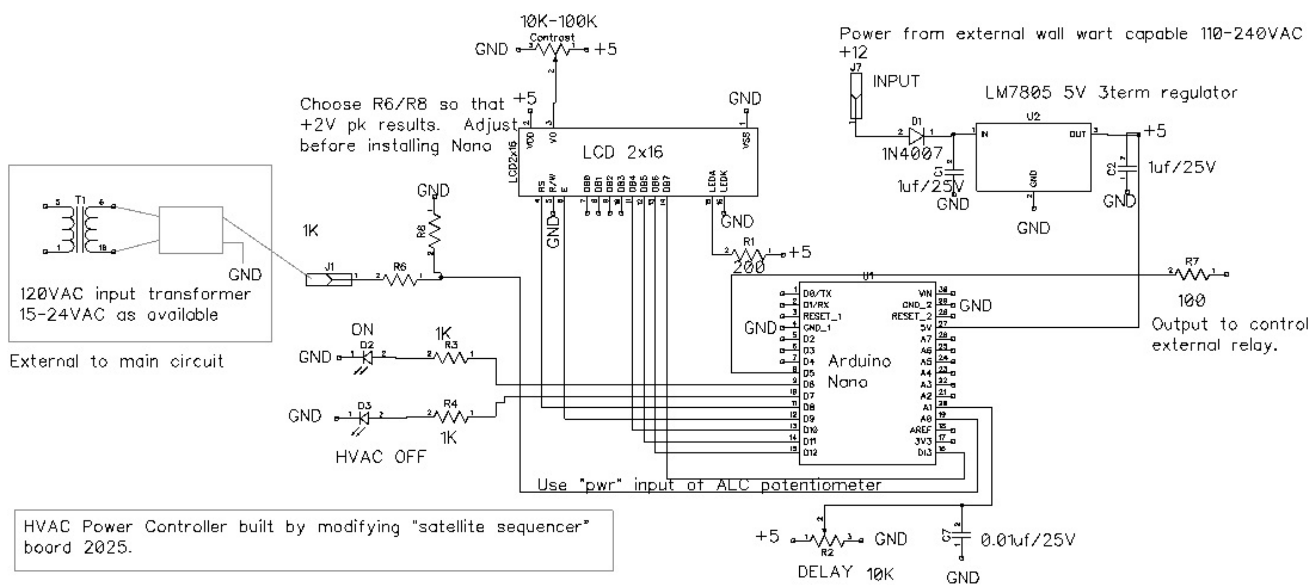
Details are slim on the exact operation of my grid-connected OUTBACK inverter that is so smart that it can sell power to the grid every day.   I looked through online forums and studied available literature, but the details of possible solutions involving inverter settings to prevent phase disruptions are MURKY. It is possible that setting the inverter to "0" cycles inspection might cause it to continuously synchronize and prevent phase changes during transition--but I can't easily test or guarantee that and the $1000 cost of a mistake is daunting....   So I set it to at least make the inverter study the income AC for a longer period of time (20 cycles instead of 6) to give my circuit additional "space."   However, in the case of loss of power, it appears to respond in just over ONE CYCLE (I don't know why).

> If you build in **solar backup power** and automated fast switchover and also have an **inverter-compressor HVAC system with electronically commutated variable speed motors**.....you may similarly be at risk of losing ECM motors due to abrupt phase changes.   If you can't arrange for your solar inverter to perfectly track and align with utility power, this system may save your ECM motors.

I discovered the incredibly fast switchover, by doing a slow-speed storage scope tracing of rectified DC from a 15VAC spare transform and observed the switchover -- which is VERY VERY FAST. (See first photo in this paper.) I created this by flipping off the utility circuit breaker to that part of the house, simulating a power loss.   There is basically only ONE CYCLE of complete loss.   The available literature suggests the Outback Inverter switches in 10-16 mS -- less than one cycle of 60Hz power!

In order to succeed, I needed to detect power line abbe rations in under ONE CYCLE of 60 Hz AC.   The same blinding speed could also save your gear from an E3 geomagnetic or HEMP event.....

I realized that the same printed circuit board circuit that I was developing for time-sequencing duplex satellite transmitter / receiver and preamps, would be able to handle this project with its on-board Arduino Nano's A/D converters.   So I built a modified unit for this project.



Catching The Event

Using full-wave (bridge-) rectified DC, I had quasi-sinusoidal pulses at 120Hz, each positive going sinusoid being one half of a full AC cycle. Using a resistive divider, I got them down to about 2 V peak, suitable for the A/D converters on the Arduino Nano. I tried multiple different algorithms to have an Arduino Nano catch failing power. Most failed miserably. Merely following filtered DC doesn't work because it is way too slow. I found you have to literally track individual periods of the full-wave rectified ripple.

By carefully measuring how many measurements the Arduino could make in 8.3 milliseconds (about 74-75) I was able to reliably capture exactly one period of the 120Hz ripple without having to phase-lock. Thus, even if starting from a random point in the cycle, the peak and average remain relatively constant! That allowed me to develop multiple tests that could be carried out on each individual 8.3 mSec epoch. Failure of ANY of these causes the system to declare utility power anomaly:

- Variation of peak voltage by more than 6%
- Variation of DC-averaged voltage by more than 6%
- Lack of any significant voltage through the first 3.3 mSec of measurement (allows even quicker capture of complete loss of voltage if decline in last half-cycle missed)

Testing by flipping the circuit breaker in 7 different tests showed 100% capture by these tests -- and it is catching the FIRST half-cycle of abberant utility AC.

From there it was relatively easy to develop an Arduino algorithm that

- Tests for approximately 90 seconds of continuously good power before ever allowing the HVAC to be powered;
- Turns off AC power ASAP if an abberant cycle detected
- Keeps power off until a full 90 seconds of continuously good power exists
- (If the ciruit itself resets, it's "setup" routine will require the same 90 seconds of good power before allowing a restart -- so it isn't critical that it receive uninterrupted power.)

INPUTS to the Arduino Nano-based Circuit	OUTPUTS
Nominal 12VDC from a wall wart for power Full wave (bridge) rectified ripple AC from a 24VAC wall wart transformer to allow isolated monitoring of the AC voltage	DC output from the Arduino Nano controls a simple relay board, which is able to interrupt 240VAC power to the AC controller and blower motor. (https://www.amazon.com/dp/B085N49S79)

Those requirements allow power to be removed from the blower motor before the inverter comes back on line, and keep it off during the time that the motor is slowing down (reducing L di/dt induced voltages); then a normal power-on restart can occur.

> In the process of the development, I tested a typical solid-state AC relay that is controllable by a 3V DC signal (works well with Arduino outputs). I was surprised to find that sudden application of new AC power to this relay would often result in a momentary conduction even though the DC control voltage was commanding NO CONDUCTION. The solid-state AC relay had to be scrapped in favor of a simple 10A-rated relay board.

I can't guarantee this will always save my expensive ECM blower motor, because it is difficult (and risky) to test, and the actual utility failure profile may be different than my testing profiles -- but this is at least a very reasonable protection system.

HOW THIS RELATES TO GEOMAGNETIC STORM PROTECTION / HEMP

Not everyone recognizes that geomagnetic storms can cause utility power voltages to go way UP or DOWN. Further, in a HEMP most people focus on the E1 high voltage electromagnetic wave, and forget that it too causes an E3 type utility aberration. These events may well escape typical "surge protectors" but still damage voltage-limited components in power supplies and gear built only for single-voltage (120 or 240VAC) power. My circuit can detect both high and low aberrations and shut down power very, very quickly to sensitive communications or other important gear. One or more outputs of the Arduino can be used to drive multiple relays to disconnect utility power.

Alternative techniques typically involve very high-dollar Uninterruptible Power Supplies that also monitor incoming voltage, or continuously do double-conversion power generation. Unless you are using a double-conversion UPS, I don't know for sure how FAST those UPS systems will respond; and I do know this circuit can respond VERY quickly to disconnect from utility power and save equipment.

To achieve Level 2 or higher EMP Protection, against the E3 (power line) component, DHS/CISA recommends either using double-conversion ($$$) UPS systems, or "line-interactive" high quality UPS (also $$$, see: https://www.fs.com/blog/comparison-of-ups-topologies-line-interactive-vs-online-vs-offline-3538.html). (See Table 1, Four EMP Protection Levels for Infrastructure and Equipment,(https://www.cisa.gov/sites/default/files/publications/19_0307_CISA_EMP-Protection-Resilience-Guidelines.pdf) This high-speed detection circuit likely fulfills the latter requirement.--and very inexpensively. Critical backup communications centers (such as EOC's) should use either the suggested UPS systems, or some protective system like this. I am not certain that the consumer line-interactive systems would protect adequately against a true E3 event. I believe this circuit could disconnect critical equipment in one cycle from the AC.

Construction

I built a custom 3D printed enclosure and this system is now protecting my expensive HVAC system. It is able to interrupt the low-current 240VAC powering both the electronic control circuitry, and the expensive ECM blower. It now graces a wall in the garage of the guest house.

Implementing at your location would require a bit of custom work, to develop a full wave rectified voltage and observed the measurements the system prints out on the front screen during startup -- then setting the limit parameters in the circuit to the degree of "tightness" that your desire. However, anyone with a modicum of Arduino programming experience should be able to accomplish this. A bit of improvement in the software might automate this part, however. A treasure trove of construction information is provided below including

- Schematic
- Gerbers for the base board
- Arduino Nano .ino file (place in subdirectory of same name)
- STL 3D files for both parts of case

Available Project Construction Information

STL files for custom 3D printed enclosure:
https://qsl.net/nf4rc/Tech/HVACController/my3rdboxwithoutsvg2.stl
https://qsl.net/nf4rc/Tech/HVACController/my3rdboxBOTTOMflangedwithoutsvg2.stl

(use M3 threaded brass inserts and M3 screws: https://www.amazon.com/dp/B0D5V3TZLB)
INO file for Arduino: (version 0.1) https://www.nf4rc.club/how-to-docs/hvac-controller-arduino-code/
Also: http://qsl.net/nf4rc/Tech/HVACController/ArduinoHVACController.ino
Schematic: https://qsl.net/nf4rc/Tech/HVACController/HVACControllerSchematic0.1.jpg
Circuit Board Gerbers: https://qsl.net/nf4rc/Tech/HVACController/SatelliteSequencer_gerberx2.zip

Building Hints:

1. Construct your external AC wall wart transformer and bridge rectifier first, and arrange resistors R6 and R8 anywhere you can on the board to arrive at close to 2.0 V peak DC. Note board error: the case of J1 phono plug jack is not grounded and needs to be jumpered to ground. The external AC transformer must be supplied by the circuit you wish to examine!
2. Next construct the 5V regulator assembly and use an external +9 to + 12 VDC wall wart or other supply to provide power. Verify that this works properly to produce 5VDC before soldering in the Nano. You may wish to add 470uf electrolytic (25V) to the input so that the circuit still receives power during the brief transistions between utility and inverter power, if your wall wart comes from the inverter-supplied circuit.
3. Add the remainder of the circuitry, power up and load software.
4. The system should print out a series of peak (bottom line) and averages (top line) measured values during SETUP. These should remain reasonable constant, within a percent or two. Adjust the software to allow +/- 6-10% of the median of those values by adjusting the values in the comparison statements in lines 294-304 of the code to suit your preferences. Recompile and re-load your custom code for your choice of external transformer and values of R6/R8 and you should be in business!
5. In order to use this to protect against E3 power derangements, set it up to disconnect power from sensitive equipment.
6. Output HIGH should cause your sensitive equipment to be CONNECTED; output LOW disconnects.