Application of "Surge and Ring" Test in Qualifying Solar PV Inverters

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A Recent Event…

In early December (2013) North Texas experienced an ice storm with many electrical service interruptions due to "lines down".

One of our solar PV field trial sites experienced a "<u>surge</u>" event…

…and inspired me to speak about Surge Testing at this workshop!

http://2.bp.blogspot.com/-VTuwwSJLBPo/UqCBqeYwvKI/AAAAAAAAXQM/iN1nfbJ-QZk/s1600/Ice+Storm.jpg

The Phenomenon of Surge

Surge is a word used to describe a sudden rise in voltage, beyond the normal system voltage, that lasts less than one cycle. There are two main causes for surge:

- A high voltage is induced in a conductor because of a nearby, extreme electrical current (to ground) related to a lightning strike
- A high voltage occurs due to switching within the electrical utility network. Inductive energy can be left in a circuit and, when the field collapses, a high voltage is produced.

The Phenomenon of Surge (cont.)

The consequence of a Surge can be a loss of functionality in an electrical device:

- **Permanently, due to arcing damage within circuits**
- **Temporarily, due to microcontroller "crash"**

Increased Interest in "Surge Withstand Capability" of Products

Quote from forward to IEEE C62.41-1991
(Standard Entitled: IEEE Recommended Practice on Surge Voltages in Low-Voltage AC Power Circuits)

"These problems have received increased attention in recent years because of the widespread application of complex semiconductor devices that are more sensitive to voltage surges than vacuum tubes, relays and earlier generations of semiconductor devices."

See also International Standard: IEC/EN 61000-4-5, Surge Immunity Test

IEEE C62.41 Recommended Practice on Surge Voltages…

The IEEE C62.41 organizes range of situations according to:
1) Location (within the electrical network), and
2) Exposure (both for frequency/intensity of lightning activity and also load-switching activity.)

Each has three levels:

Location

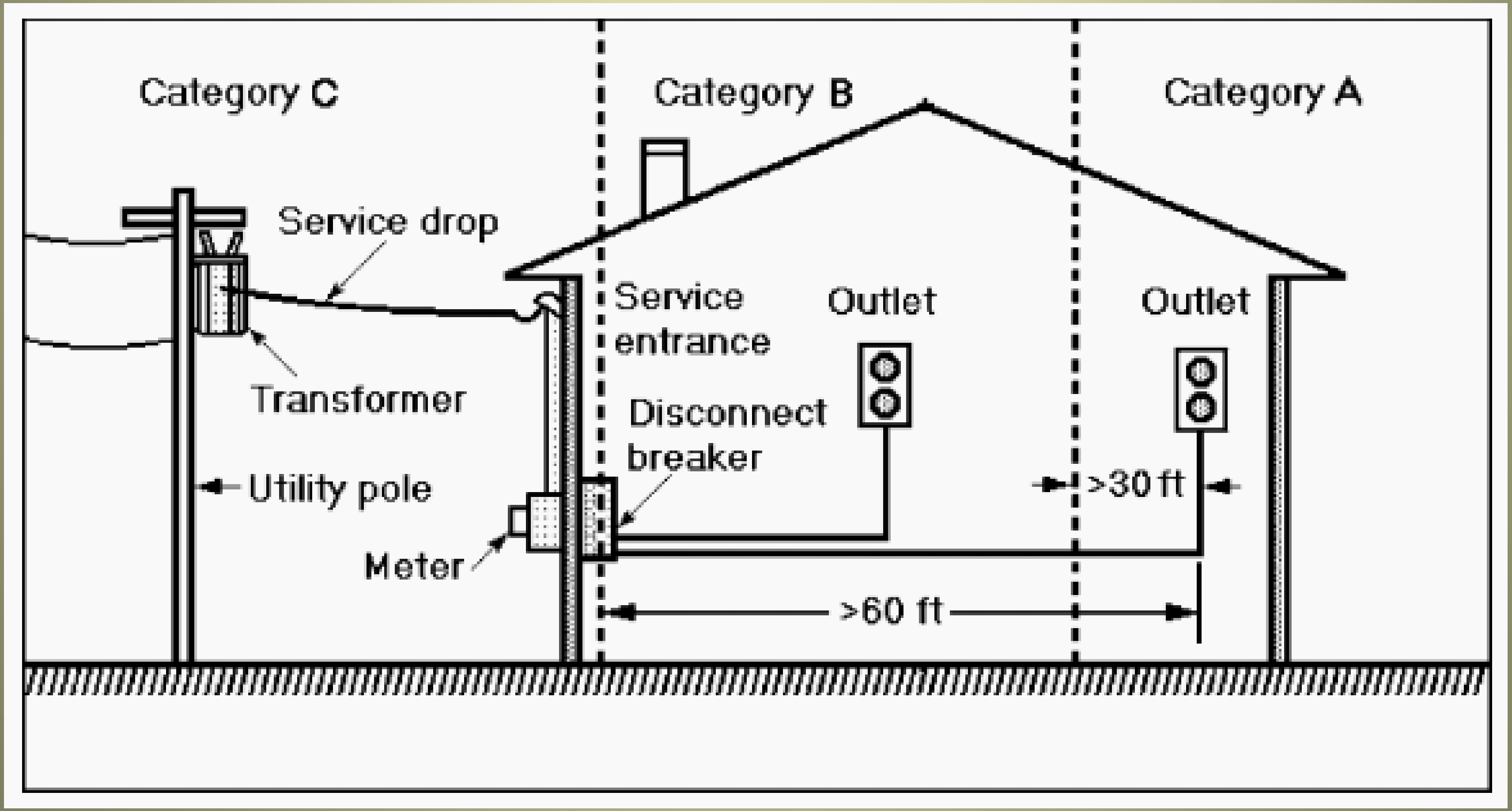
Category A: Long branch circuits, receptacles (indoor)
Category B: Major feeders, short branch circuits, service panel (indoor)
Category C: Outdoor overhead lines, service entrance

Exposure

Low Exposure: areas with low lightning activity & little load-switching activity.
Medium Exposure: medium to high lightning activity, or with significant switching transients, or both.
High Exposure: rare installations that have greater surge exposure

IEEE C62.41 Recommended Practice on Surge Voltages…

Location Categories



IEEE C62.41 Recommended Practice on Surge Voltages…

The Exposure Category is related to annual incidence of thunderstorms and nearby electric utility sources of surge. (Medium Exposure is for systems and geographical areas known for medium to high lightning activity or with significant switching transients or both.)

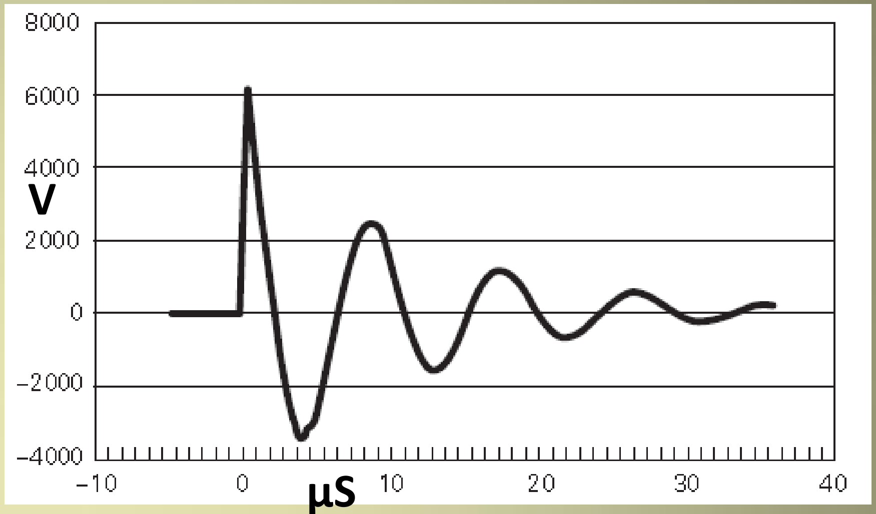
For a microinverter that is designed to be used throughout North America, it is best to choose:

Location Category: B (or C)
Exposure Category: Medium

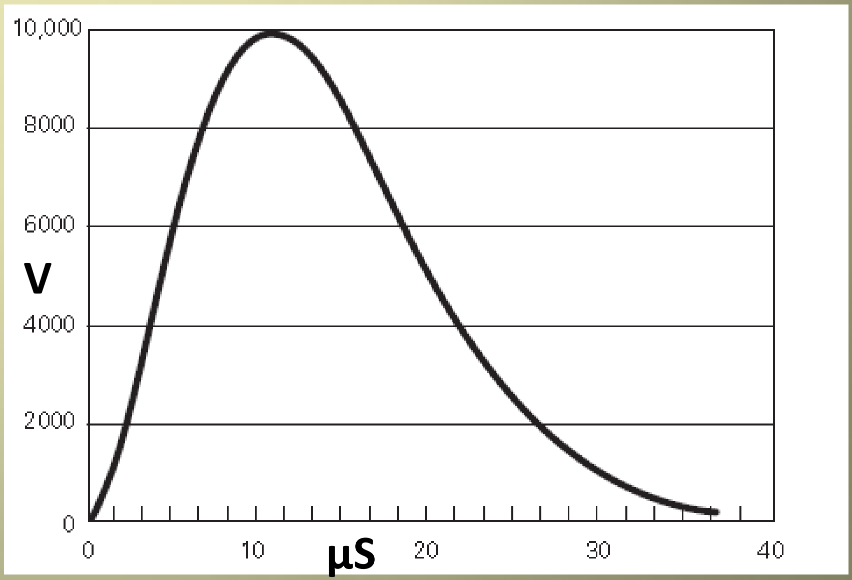
IEEE C62.41 Recommended Practice

Test Waveforms:

- Ring Waves



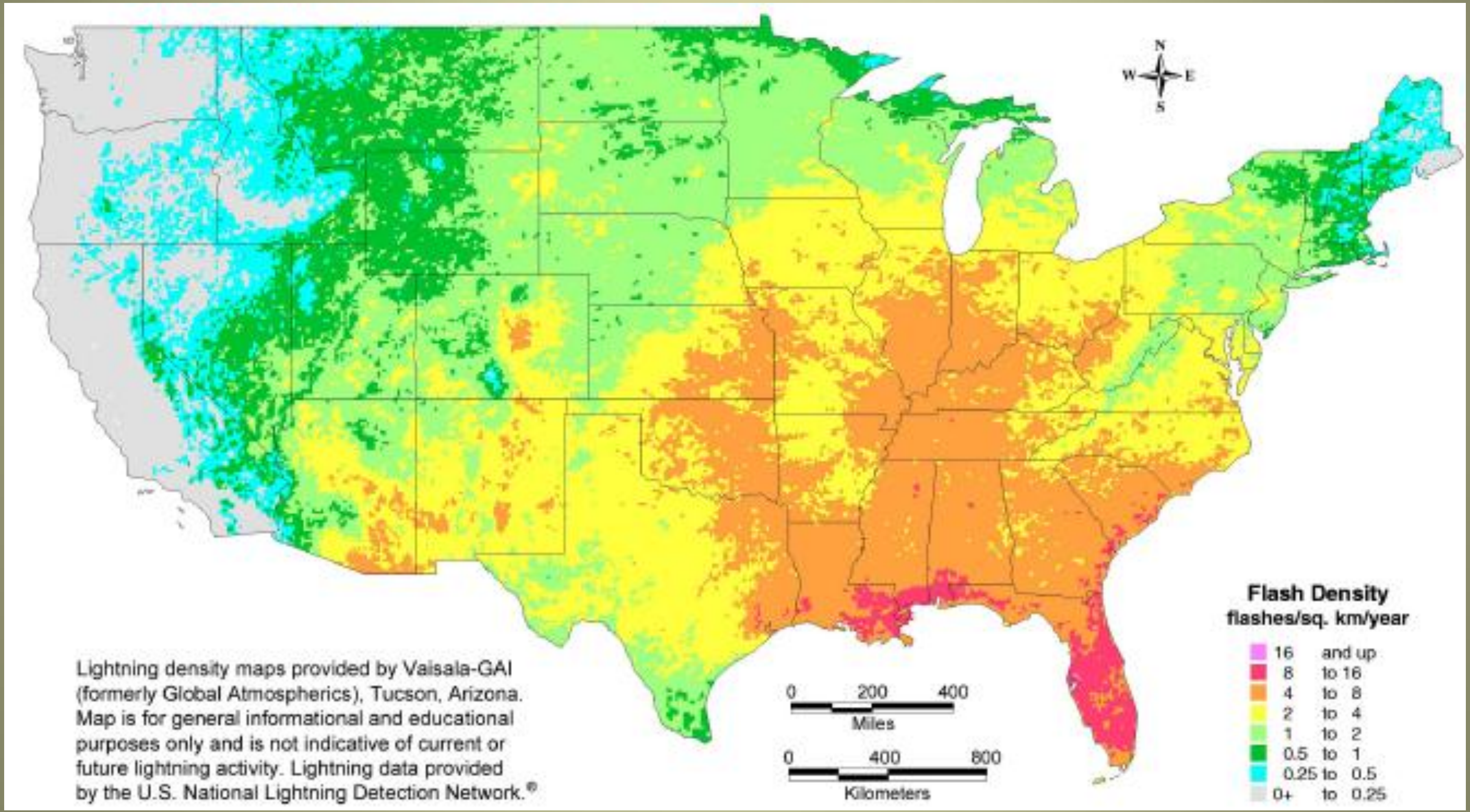
- High Energy (Combination) Waves



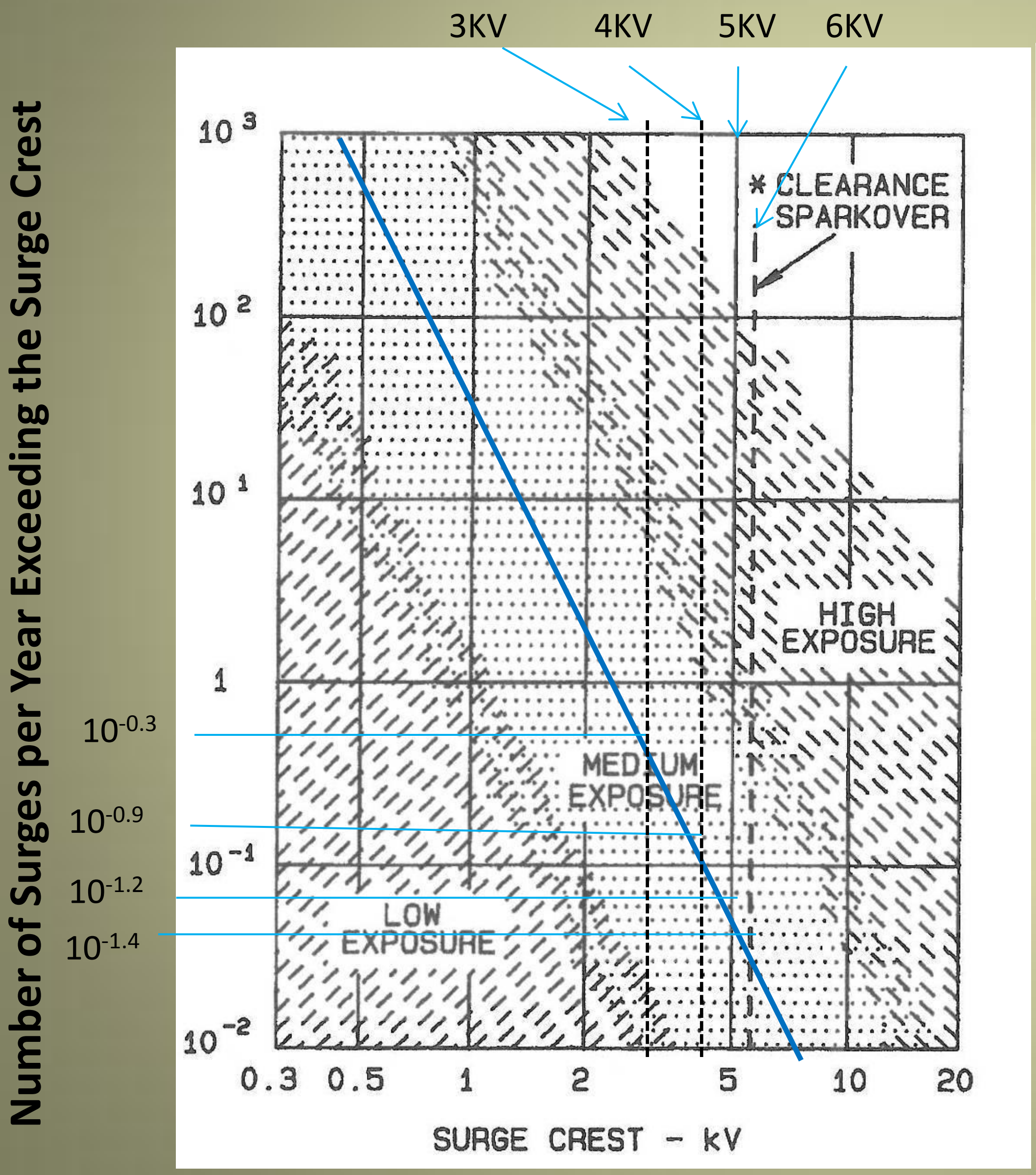
- Other Specialized Waveforms

Lightning Flash Map

Flash Density (per square kilometer per year)



Probabilities…



	Surge Level (KV)				
	3	4	5	6	
Number of Surges /year per 100 Sites	**50**	**12.6**	**6.3**	**4**	

Remember: <u>Medium</u> Exposure is for geographical areas known for medium to <u>high</u> lightning activity.

Establishing a Design Surge Resistance Level

% Failure associated with the arbitrary mid line of previous chart							
Design Surge Resistance	Years in Field at Medium Exposure Sites						
	5	10	15	20	25	30	40
3KV	22.1	39.3	52.8	63.2	71.3	77.7	86.5
4KV	6.1	11.8	17.2	22.3	27.0	31.5	39.6
5KV	3.1	6.1	9.0	11.8	14.6	17.2	22.3
6KV	2.0	3.9	5.8	7.7	9.5	11.3	14.8
10KV	0.002	0.004	0.006	0.008	0.010	0.012	0.016
Note: assuming 10 surges required to accumulate sufficient damage for failure							

Testing

The IEEE standard provides different parameters according to the Location and Exposure categories. We use 6 KV as the amplitude limit for surges due to the flash-over clearance in building wiring systems.

Ring Wave:	6000V, 12 ohm	0.5 µs, 100 kHz
Combination Wave:	6000V, 2 ohm	1.2x50 µs - 8x20 µs

Must check all line-to-line and line-to-ground possibilities in forward and reverse polarity.

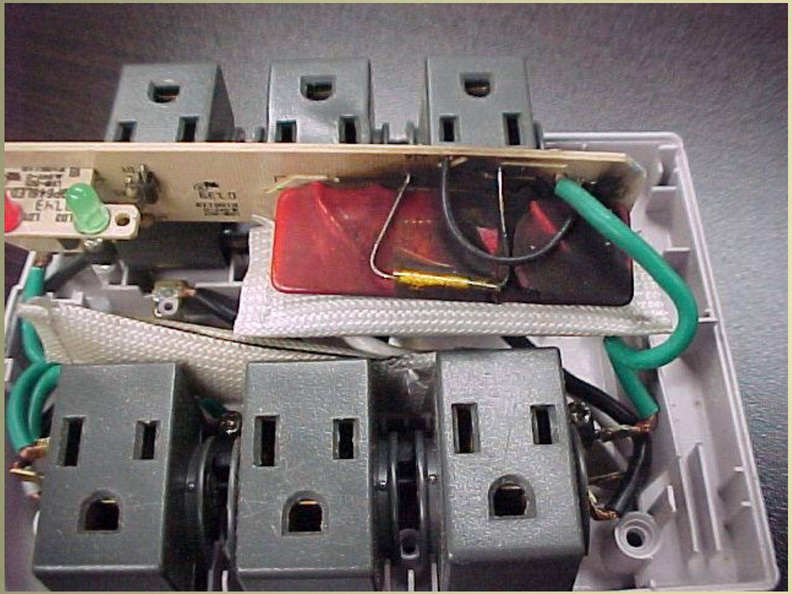
The surge is introduced at different phase-angles of the AC power since it has been found that it can make a difference. (24 pulses of the Combination Wave are applied and 48 Ring Waves are applied for a 240V split-phase product.)

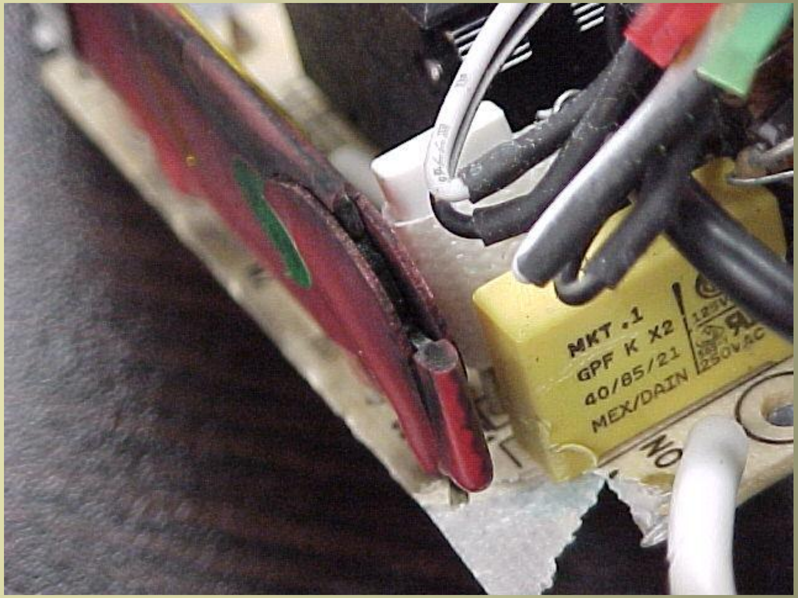
The device must function* throughout this testing and show no signs of damage at the end.

* A “pass” is sometimes a matter of judgment.

That Recent Event…

Solar PV field trial site in Red Oak, Texas had surge event, due to "power anomalies", during ice storm on Dec. 5-6, 2013.





Items ruined:

- **electric blanket control**
- **power strips**
- **microwave oven**
- **computer (power supply)**
- **thermostat**

Some items that survived:

- **All solar PV microinverters**
- **2 heat pump outdoor units**
- **2 heat pump indoor units**

Conclusions

- 9 out of 10 components that had been qualified according to Surge and Ring Test (Lennox Procedure E99-5) survived this event…while many consumer products within the home did not!

- There will always be a surge that can defeat any protection scheme, but, by design, we can assure that most surges will not.

Un-Concluded

- Could there be a lightning-induced surge failure mode on the dc side of the inverter?

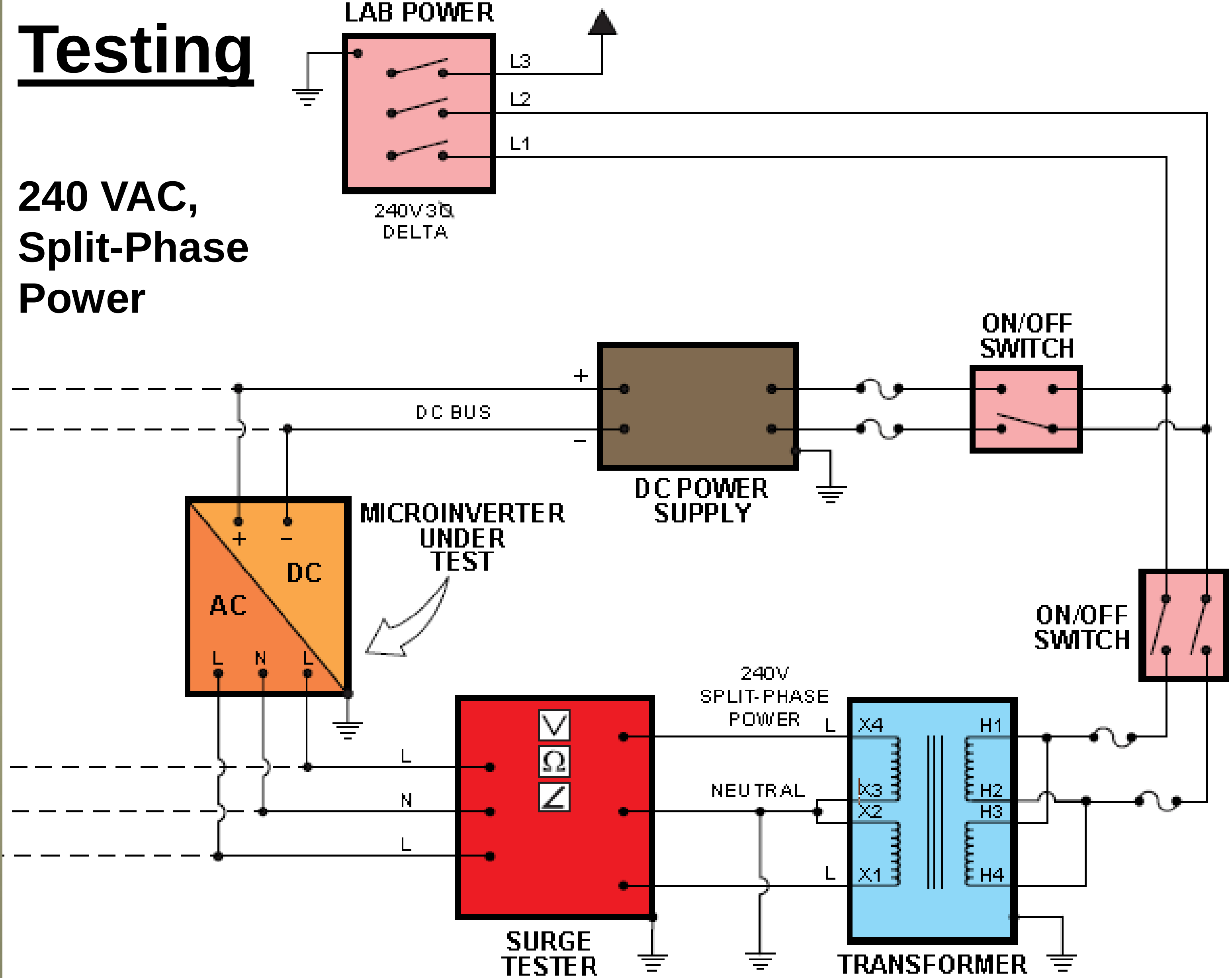
- Damage to MOVs is cumulative and this equipment is expected to last a long time. Should solar PV inverters be evaluated according to Location C rather than B?

Supplemental Information

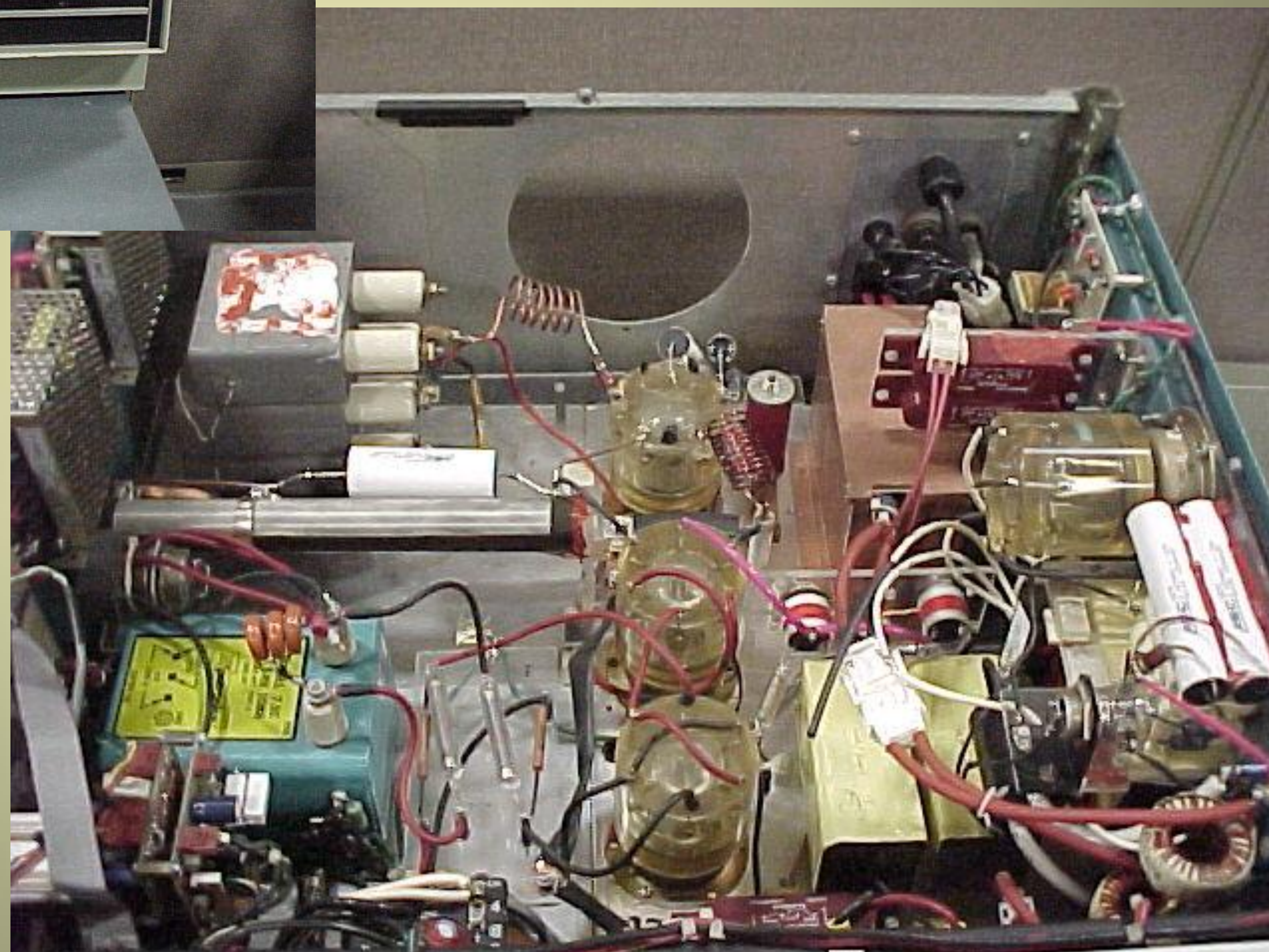
- Schematic of surge test laboratory arrangement
- Photos of original Lennox Surge Tester (built in 1988 – 1989)
- Ring Wave and Combination Wave Circuit Schematics from UL Standard 991
- Its not just electronic components…
- Information on some technologies used to protect electronic circuits from surge

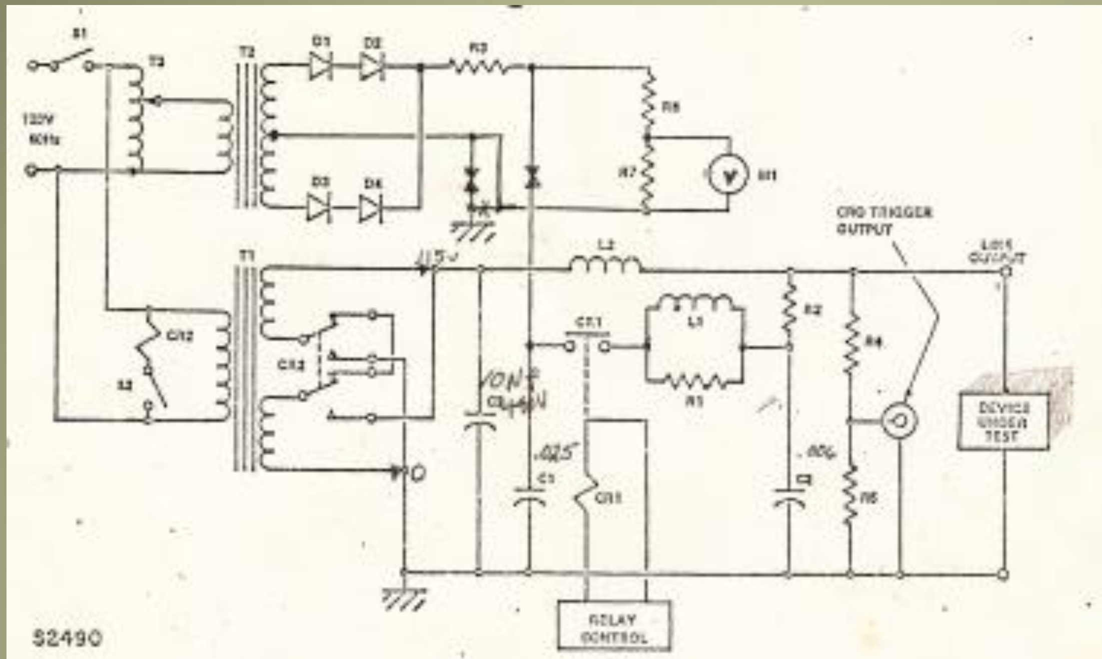
Testing

240 VAC, Split-Phase Power

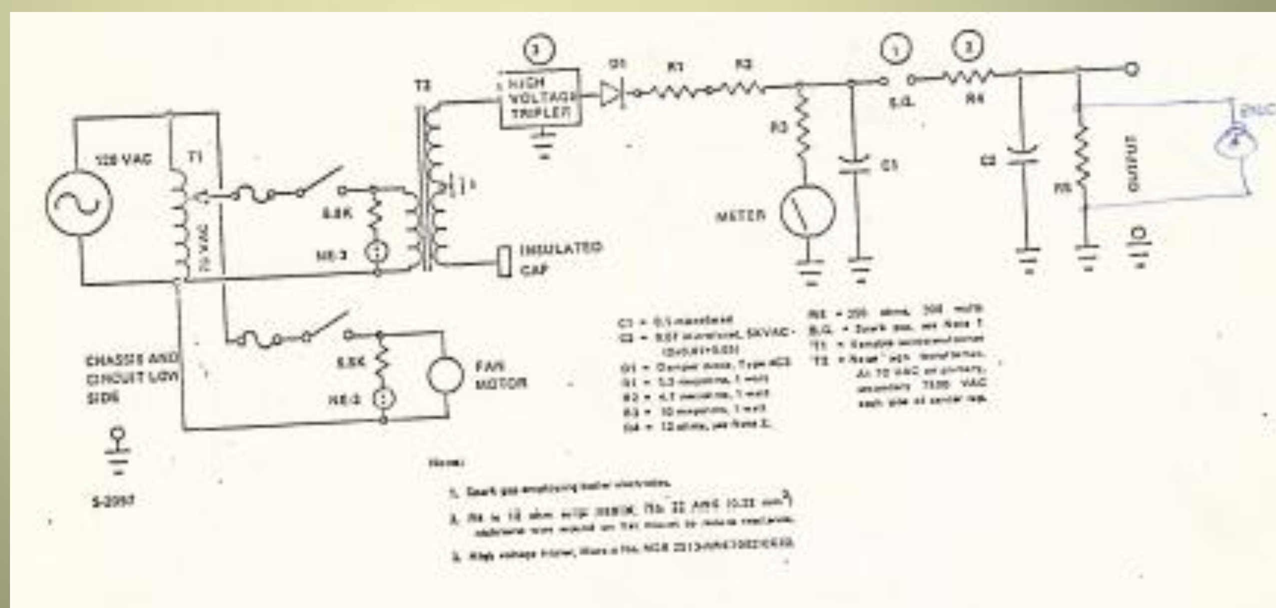


Lennox' Original Surge Tester – Now Retired!



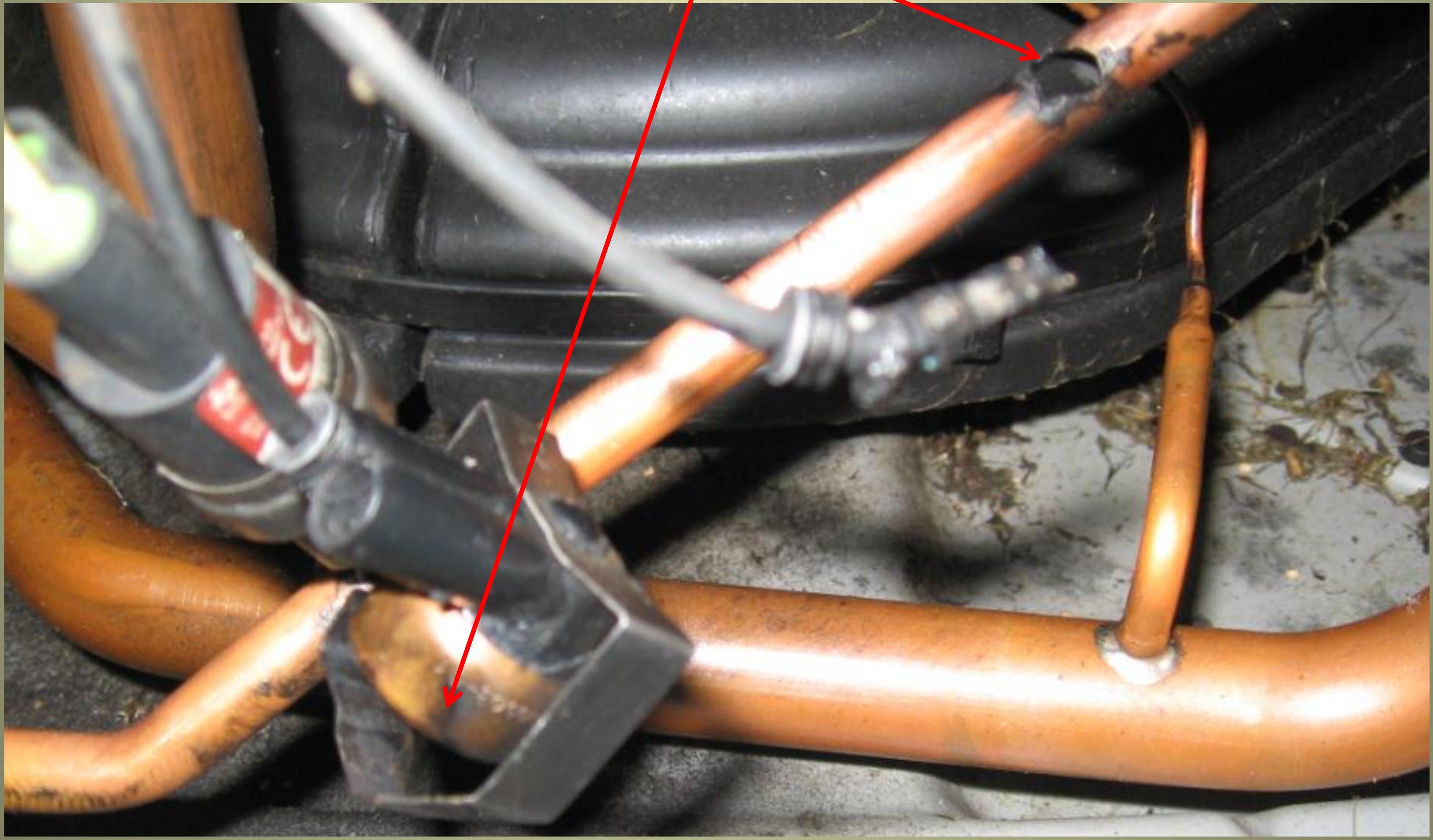


Ring Wave Circuit



Combination Wave Circuit

Its not just electronic components that fail due to surge!
This clamp-on bimetal thermostat arced and ruptured a refrigerant line. This occurred in Washington in winter and is most likely due to power line switching.



Technologies Used to Provide Protection from Surges

Protection: Shorting High Voltage to Ground <u>or</u> Blocking High Voltages from reaching sensitive components. There are several commonly used surge protecting devices of the “shorting high voltage to ground” type. They are developed to have a nominal “clamping voltage”; that is, a voltage above which they conduct electricity to ground. When a surge voltage arrives and the clamping voltage is exceeded, the device provides a short-circuit from a power conductor to the ground conductor. Clearly there would be a limit to the amount of energy that can be handled this way. Fortunately, most surges are short-duration so the actual amount of energy to be handled is small. Most common devices are degraded with each incident. They have a limited life.

Technologies Used to Provide Protection from Surges (continued)

The most common variety is called an MOV (Metal-Oxide Varistor, typically made from sintered zinc oxide). It is relatively low-cost and so has found wide application. As the device experiences many small surges or fewer large ones its clamping voltage begins to drop and it will eventually act as a short circuit even at normal voltages. Because this presents a “thermal runaway” risk, they are usually protected by a thermal fuse. Of course, when the thermal fuse opens, the device no longer acts to protect the circuit from surges. (This is why it is recommended to replace the common electrical power strip/surge protector when your home has experienced a voltage surge.)

Technologies Used to Provide Protection from Surges (continued)

Another technology that is sometimes used is the GDT (Gas Discharge Tube). The GDT has electrodes in a sealed tube filled with a gas mixture. The device is designed to have the gas ionize and begin conducting when an overvoltage condition is reached. The GDT is slower to respond than a MOV. It is able to shunt more current for a given device size. GDTs continue to conduct until the arc extinguishes and this may characteristic may require additional circuit components to assure the GDT stops conducting after the surge event.