

TRANSIENT VOLTAGE SURGE SUPPRESSION DESIGN AND CORRELATION

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Abstract. The purpose of the TVSS application will influence the design. This may be to clamp voltage, shunt current, filter frequency, dissipate energy or a combination. The elements may consist of air gaps, passive elements, or semiconductor electronics. The verification and performance testing is an area often overlooked. Proper installation, including grounding, is critical to success of the circuit.

INTRODUCTION

Protection systems for electrical systems have progressed far from the traditional lightning arrester. Most standards and traditional works address classical protection without detailed considerations of component design [1,2,3,4,5].

There are numerous devices on the market that make various claims. Most engineers do not have the instrumentation, equipment, laboratory, or resources to validate these devices for their application.

Numerous different components and systems were tested. Custom designs that can be applied in the field were evaluated after analyzing the response, or lack thereof, for commercial devices to standard IEEE waveforms.

The paper will discuss various approaches to protection system design. It is a very hands-on discussion of protection systems, eliminating the commercial concerns of vendors. This is a follow-on and result of research for several previous grounding papers [6,7,8].

STANDARD TESTS

There are various inexpensive instruments that detect the trigger level for protection networks. However, determination of the current capacity and wave response requires very sophisticated laboratory instruments. If these tests are performed, they are done off-site in a laboratory environment.

Any comparison requires a standardized test procedure. ANSI C62 describes the industry-accepted waveform, applications and test procedures [9,10,11,12]. A 1.2 / 50 wave-shape is used to evaluate open circuit or voltage responses. This is shown as channel 1 (Volts) of the oscillographs. For short circuit or current responses, an 8 / 20 wave-shape is used. This is channel 2 (Amps). Some oscillographs show an output voltage from inline devices on a third channel.

A 1.2/50 wave-shape describes an impulse signal that rises from virtually zero to its crest in 1.2 μ s and declines to one-

half crest value in 50 μ s. The microsecond units are not usually applied to the designation of the wave.

The test equipment applied both of these signals to the circuit. The resulting wave-shape was displayed, and captured, on a quad-channel digital recording oscilloscope.

The maximum deliverable voltage is selected prior to the test. After firing, the voltage and current maximum and minimums passed through the suppressor were captured.

Figure 1 is a standard voltage waveform in response to an open circuit. The voltage peaks and dissipates in the standard period of time. There is no current flow.

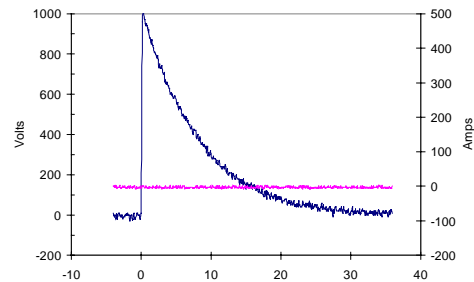


Figure 1 - Standard 1.2/50 Voltage

Figure 2 is the response to a short circuit. The voltage is very limited, while the current peaks and dampens very quickly with a very minor ringing, or oscillation.

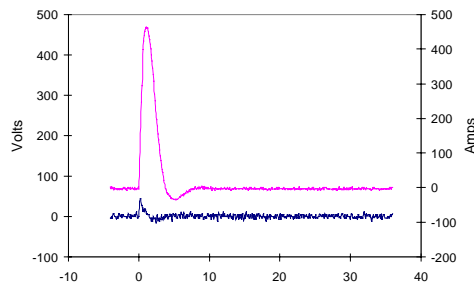


Figure 2 - Standard 8/20 Current

PROTECTION DEVICES

Protection devices are added to an electrical system to aid in managing surges. The devices may shunt current, block

energy from traveling down the wire, filter certain frequencies, clamp voltage levels, or perform a combination of these tasks [7].

Protection devices are selected based on the voltage, frequency, and ground system of the circuit. Regardless of the function, only a few basic components are available to economically protect an electrical system. Figure 3 shows a system with all types of components. Most protection schemes use only parts of the system. An effective device will have multiple combinations of the elements.

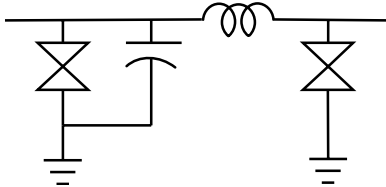


Figure 3 - Protection Scheme

The simplest protection arrangement is physical separation. Gaps may be used to provide arc paths above a certain level. These may be air gaps or may have a dielectric material between conductors. Classical lightning arresters fit in this category. The cross symbols in Figure 3 represent these components.

Often the devices are built so that the path will become a low impedance once breakdown occurs. Silicon carbide (SiC) is traditionally used in high-energy devices [10,13]. The results of tests on several different devices are shown in the Table at the end of the paper.

The test signal is an impulse while power system devices are rated RMS. To compare results, the peak voltage from a power circuit is $\sqrt{2}$ RMS.

The most significant observation is that most devices do not provide any substantial current limitation and protection until two times the rated voltage or $\sqrt{2}$ times the peak is reached. As the impulse level is increased, the let through voltage is as much as $2\sqrt{2}$ times the rated peak voltage.

One brand uses a unique insulation material. It is essentially sand with spaced out probes. This device provides virtually no protection.

Gas tubes and other break-over materials also fit in this air-gap category [12]. This is the slowest class of protection equipment, but the energy handling capability is very large for the cost. A performance curve for a 120-volt device is shown in Figure 4.

PASSIVE ELEMENTS

The next common arrangement uses passive electrical elements (capacitors and inductors) in the circuit.

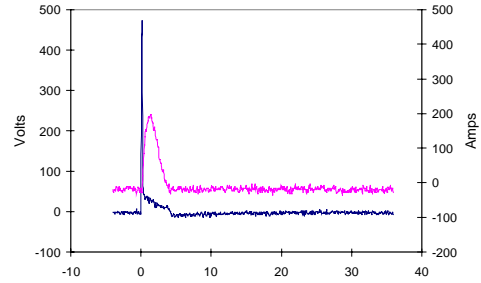


Figure 4 - Gas Tube Response 500V Test

Capacitors shunt voltage to ground. The size of the capacitor is very important in determining the speed of energy dissipation. As can be seen in Figure 5, a large capacitor greatly lengthens the time it takes for the voltage to return to zero. Capacitors store the energy when hit with a surge. The energy must dissipate once the impulse has passed.

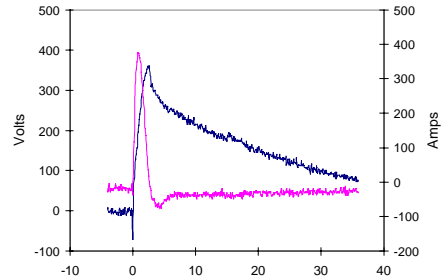


Figure 5 - Capacitor Response

In-line filtering uses inductors, which block current changes. The inductor also provides a conductive, low resistance path.

Figure 6 shows the response of an inductor. The basic shape is very similar to the short circuit of Figure 2. A voltage is built-up and the substantial current is damped very quickly. Larger inductance permits a greater voltage build-up while the current is more limited because of the $L di/dt$ effects.

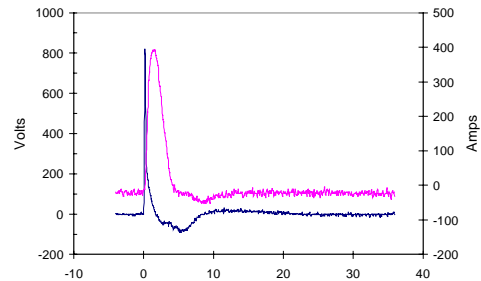


Figure 6 - Inductor Response

Air core is preferred to ferrite core inductors. The air core inductor has less attenuation, a higher cutoff frequency, and is larger. However, it is preferred because ferrite core inductors have a non-linear response to the magnitude and frequency of the current to be dissipated.

A significant consideration is the resistance associated with the inductor. Larger inductors have larger resistances. High resistance can cause very large power dissipation for large currents on power circuits. Conversely, the inductor must be

large enough to limit the current. An inductor's power rating must be adequate for continuous operation.

$$P = I^2 R$$

In control circuits, the resistance must be small enough to cause minimal impact on loop compliance. For example, the total loop resistance for a 4-20 ma circuit is typically 600 ohms. The instrument already comprises 250 ohms of this.

Energy storage devices create problems for suppressors, if not used carefully. Capacitors hold elevated voltage on the line. Inductors can create more voltage because of current changes.

FILTERS

Bypass or band-pass filters are a combination of an inline inductor and a shunt capacitor. For power systems, the circuit must pass 60 Hz.

Typical transients may be expected to perform similar to a 1 MHz signal. A filter would be constructed to block this high-frequency signal. Hence, the roll-off of a filter should have little impact on power or dc circuits. However, in control circuits, high frequency counters and analog circuits may be attenuated with this filter.

More surge protection is provided from devices with the lowest throughput energy at a particular frequency. Throughput is the amount of energy that gets past the protector onto the equipment being protected. Most lightning energy can be restricted with devices designed for less than 1 MHz. Above that frequency, there is less throughput.

The combination of inductor and capacitor will create a tuned circuit with a resonant frequency. Care must be exercised to prevent the frequency from matching the frequency of the transients. The frequency of oscillation or ringing of the circuit is determined by the relationship.

$$f = 1 / 2\pi\sqrt{L C}$$

Figure 7 illustrates the response of a device with a filter that resonates. Notice the output has a greater magnitude than the input and it oscillates. There is also substantial noise on the current channel. This is not an acceptable protector. Because this will happen at some transient frequency, filters generally are not recommended.

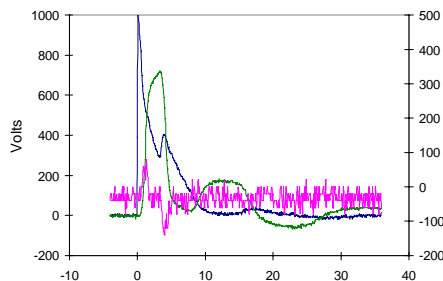


Figure 7 - Resonating Filter Response

SEMICONDUCTORS

Semiconductor devices are the most advanced arrangement. These devices are faster than gap elements, but they generally handle less energy than comparably priced alternatives. Because of the limited range of operation, these devices must be more precisely specified. Silicon devices fit into two groups: voltage and current protective elements.

Metal oxide devices are primarily voltage triggered and are manufactured to handle very precise quantities of energy (joules or watt-sec). The device is selected for a "turn on" voltage that is greater than the peak expected voltage from the power supply. The energy dissipation is based on the standard waveform. Each metal oxide varistor (MOV) will have a resulting surge current rating. Typically the material is a zinc oxide (ZnO).

The current capability is related to voltage by a non-linear modification of the linear Ohm's law.

$$I = k V^\alpha$$

A higher alpha indicates more non-linearity. For silicon carbide arresters (SiC), alpha is in the range of 10. For metal oxide (ZnO), the range is 25 to 60. This indicates MOV devices are much more responsive than silicon carbide arresters. In other words they will conduct high current more quickly.

At very small currents, in the microamps, an MOV behaves like a linear resistor. At very large currents, in kiloamps, the current is fixed. In between, it is non-linear.

The MOV device has an inherent capacitance. Higher energy units tend to have a higher capacitance. This creates a problem with high frequency signals. At high frequency, the high capacitance will increase the impedance of the circuit and attenuate the signal.

The response of a typical MOV used in a 130-volt power protector is shown in Figure 8. MOVs used in electronics or higher voltages have similar characteristic curves.

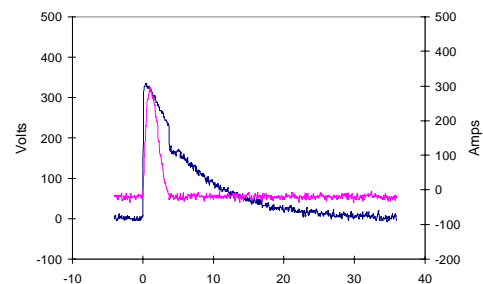


Figure 8 – 130V MOV Response

Zener, avalanche, or silicon junction diodes are much faster devices than varistors and tend to limit voltage surges to a lower level. However, they cannot sustain as much energy without failure. Since the unit has essentially no energy dissipation rating, it is coupled with a primary arrester such as a gas tube. The diode will trigger first, and then the energy will be dissipated through the gas tube. A typical circuit using a zener consists of a resistor or inductor placed in-line and the zener shunting the output [7].

MOVs can handle more energy alone than other semiconductors. Nevertheless, at elevated energy levels, MOVs designed for instrumentation protection failed. Even these must be used in conjunction with a primary arrester [8].

GROUNDS

For transient protection, a uniform, equipotential ground grid is desired under the entire area covered by the electrical system and all its connected equipment. The facility-grounding network provides this reference [6, 7, 8].

For typical systems, the ground terminals of the TVSS are tied together, and only one connection is made to earth. However, two different "grounds" are shown in Figure 3. These are isolated under two conditions.

The first condition is in high-energy power circuits. In this case, the grounds are intentionally isolated in order to dissipate the energy. The distance between connections causes a high inductance. The voltage drop across this inductance isolates feedback from one side to the other. In addition, the inductance blocks high frequency signals, such as a transient.

The second condition is remote instrumentation. The distance between the transmitter and the controller may be far enough that circulating currents become a problem due to different earth potentials on the ends of long conductors. This is particularly the case when a transmitter is outside the ground ring of the plant yard. Under this condition, the grounds must be isolated.

INSTRUMENTATION TVSS

More sophisticated electronics are often protected with in-line devices connected and grounded close to the equipment. An exception is electronic circuits that are fed from multiple cable pairs. The cable pairs share the energy; therefore less energy is imposed on each piece of electronics.

The mode of protection depends on the connection of the protection circuit. Differential mode units are connected between the two signal wires of a circuit. A common mode unit is connected between a signal wire and ground. Usually, as a minimum, a common mode device should be placed on both ends of each conductor. This is shown in the top part of Figure 9.

Many commercial protection modules have differential protection and an inductor to limit current changes. Most of these have a common mode connection to the earth. While this may be acceptable inside the plant ground grid area, it often contributes to failures on transmitters remote from the signal power source.

REMOTE INSTRUMENT TVSS

For remote instrumentation, the primary requirement is to isolate the unshielded cable from both the transmitter and the DCS input card. Isolated in-line protectors should be placed on the transmitter using differential mode. Shunt devices should be placed on the DCS ends of the cables using common mode.

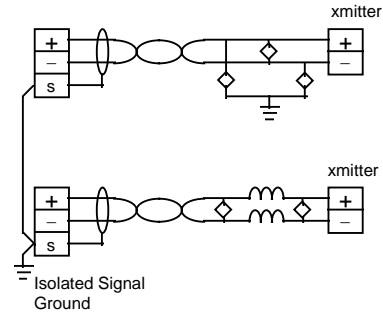


Figure 9 - Remote Transmitter Circuit

A very effective inductor is 20 turns of the circuit wire. This should be on an air core that has a radius at least seven times the wire diameter. For typical instrumentation wire, this can be wrapped around a pencil for shape. The preferred varistor for a 24-volt circuit is a 36v, 160-joule device. With two MOVs across the line, the system shown in Figure 9 has performed better than most commercial systems that were tested. The response of the protection circuit is shown in Figure 10.

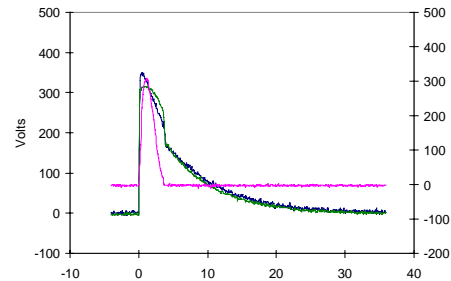


Figure 10 - Remote Protector Response

Two significant points are noted. The inductor causes the rounding of the output voltage and the output performance curve is almost identical to the MOV performance curve. It is especially significant that the scheme dissipates the energy without any ground connection.

POWER TVSS

Protection for power systems depends on the load. The voltage, number of phases and configuration describe the type protection. Generally, non-electronics can be protected with shunt type protectors.

Inline devices either failed or were ineffective in performance or packaging. Most inline devices actually had more voltage applied to the load than the voltage at the input

of the protection circuit. The circuits would have been more effective as a shunt rather than an inline device.

For high-energy power systems, all components in Figure 3 may be used. Often, the inductor can be removed from the circuit with little impact. It is difficult to both match the frequency and get low enough resistance for large currents. This is particularly important since inline inductors are very expensive when built for low resistance and high current.

A 130-volt device is shown in Figure 11. The protection line to neutral is quiet good, the line to ground voltage was twice as high as seen in Figure 12.

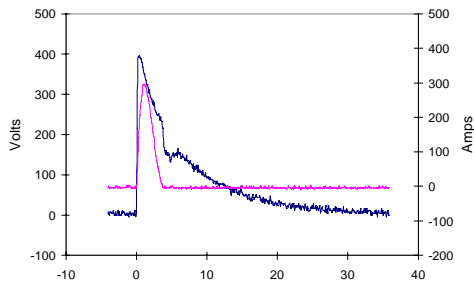


Figure 11 - Power TVSS Response L-N

This approach is common. Apparently the assumption in the design is that there will never be a voltage difference between the neutral and ground. Many papers on harmonics and other topics have illustrated that this is not the case [14].

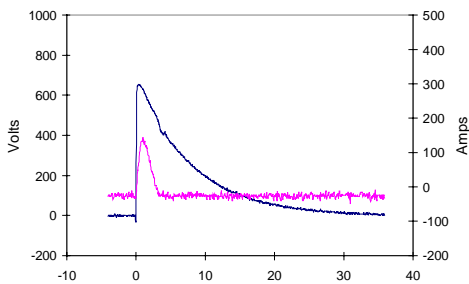


Figure 12 - Power TVSS Response L-G

The most detailed design TVSS tested had a very sophisticated circuit. The device had MOV, gas tube, and capacitor across the line to neutral with an iron core inductor in the line. On the output side, it had MOVs across the line to neutral, line to ground, and neutral to ground. In addition it had a current limiting transorb across the line to neutral.

Theoretically, this should be the highest performing device. The voltage surge was clamped just slightly higher than other MOV devices. The ringing was less than other filter devices apparently because of the transorb.

MOTOR TVSS

A variety of single-phase and three-phase devices have been previously evaluated for telephone and motor power systems. The results of those tests compare with recent technology devices [15].

A complete system, including filters, designed for three-phase motor load was analyzed. With a 6000-volt surge

applied, both the line-to-neutral and the line-to-line voltage were about 5900 volts. The current discharge was only 12 amps. The system did little to protect the 480-volt load.

With the grounds shorted together, there was a ringing for one cycle in both the current and voltage waveforms. It took 350 microseconds for the oscillation to stabilize. The peak voltage was 5679 volts with a current of 544 amps. It is very obvious that common grounds can cause a coupling back to the filter.

A pure resistive load was applied to the output. This caused harmonic spikes every 10 microseconds. This reflects the earlier discussion of sensitivity of the filter to tuned frequencies.

After a number of different scenarios, a very interesting observation was found. A TVSS with MOV arresters was as effective for a 60 Hz, 480 VAC circuit as the circuit with filters. In a more advanced design, primary arresters enhance the ability of the MOV to sustain large surges.

TVSS CHALLENGES

Follow-through: Follow-through current is a side effect of protection schemes. When a protector device fires, the arrester will continue conducting for an extended time. The follow-through disturbs the protected system. The protector shorts the circuit during the triggered time. Consequently the system experiences false alarms and shutdowns.

Gas tubes are particularly susceptible to this problem. In some conditions, the tube may never shut-off. Specific arc extinguishing circuits are required. By comparison, zener diodes clear very quickly while MOVs may take up to 15 seconds to clear.

Degradation: An MOV degrades with time as it ages. Each surge that it takes will cause small holes to be punched in the substrate. When enough of these holes are punched, the device will fail.

Manufacturers grade MOVs on the amount of energy the MOV can withstand after so many hits. Select devices with the desired energy rating with a lifetime hit to exceed 100,000.

As long as a zener's range is not exceeded, the device does not significantly age. However, because of the very limited current capability, a zener without a primary arrester will fail often.

Catastrophe: Silicon semiconductors, metallic oxide varistors, and gas tubes will fail in a shorted mode when at the end of their life or when overpowered.

The short becomes very obvious if it occurs on the positive or hot lead. The short will cause a large current to flow that should trip the overcurrent protection. However, a short in the negative or neutral may not be initially detected, but it could cause problems with circulating currents.

At very excessive power levels, the device may melt and become an open circuit. Open circuits are seldom found until the device did not do its job. However, open circuits can be tested quickly with a simple pulse instrument.

For gas tubes, the open occurs at power levels that deteriorate the elements so the gas will not ignite. Properly designed gas tube circuits can work to the limits of lightning levels.

TRANSIENT SOURCES

There are a variety of sources of transients and surges that can interfere with the operation of electrical equipment [16]. The type of transient influences the design and selection of the protection systems.

Transients can be caused by the way electrical equipment is operated. Electromagnetic interference is generated by switched mode power supplies in computers, SCR controllers, and variable frequency drives [6]. The interference caused by switched mode power supplies must be corrected by increasing wire sizes, changing transformer design and configuration, and using active filters. Single frequency passive filters composed of capacitors and inductors are not generally effective. The cutoff frequency of the filter is physically too close to the fundamental to allow a good filter design [14,17].

The switching of large motor loads and the switching of transmission lines and power factor correction capacitors can create spikes. The breaking of large currents can cause surges on the line that damage electronics and even some machines. The surges may be in the form of voltage spikes, voltage dips, or current transients. Although the energy levels for these disturbances are not as great as those from lightning, they can create problems for equipment connected to the same power lines. Some surge arresters (protectors) may compensate for problems caused by the switching surges on the power line.

Radio frequency interference (RFI) can be caused by communications transmissions. However, interference is more often a problem from the spurious emissions from electronics that are operating at high frequency. Both digital and analog circuits can cause these emissions. Furthermore, the RFI may be fairly broadband since it will often result from multiple sub-circuits operating at the same time. Shielding is the preferred way to handle RFI. The best approach is to shield the noise from escaping the source device.

Electromagnetic induction (EMI) is noise that is picked up from a stray source and converted to a voltage on the electrical system. The sources are often the same as those generating RFI. However, appropriate isolated grounding is an additional tool used to handle this noise.

Electromagnetic pulse (EMP) interference is derived from nuclear detonation. This is a radiated broadband electromagnetic pulse with a very high energy. The energy form is very similar to lightning but is approximately 10 times faster. The radiation is induced on all conductors and is converted into a voltage. Protectors designed for EMP will work for lightning. However, they are expensive and do not work substantially better than devices specifically designed for lightning [6].

Finally, lightning is a source of tremendous electric, magnetic, and thermal energy from nature. It is generally the predominant motivator for designing a protection system.

REPRESENTATION

TVSS devices were provided by a number of vendors and users. A few opted not to provide test units. In some cases, units were purchased. In others, after analyzing the literature, it was determined the devices fit a particular design. During tests, the shape of the waveforms could usually be used to

determine the circuits, even in potted units. Therefore, the results of the analyses appear to be representative of the state of the art.

SUMMARY

There are numerous different considerations for each type system. Nevertheless, there is a key concern for each. The goal is to make these seemingly conflicting requirements compatible.

A complete TVSS system consists of shunt protectors on the input and output. Other components may include the input shunted with a capacitor and an inductor placed inline. The grounds are isolated on the input and output.

For low energy systems, an MOV is often the only device used. This may be effective if it is adequately sized and has not deteriorated. For circuits exposed to higher energy and for power circuits, another primary arrester should be included.

The fastest system uses avalanche diodes with a primary arrester to dissipate the larger energy.

For adequate protection, three conditions are critical. A semiconductor device is required. A high-energy primary arrester is used in conjunction. The configuration is arranged for all possible scenarios.

Finally, protection will generally be inappropriate without a very effective ground grid.

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Test	Device	Rating	Units	Test Voltage	Peak V	Min V	Peak I	Min I	Peak V Out
1	Open Circuit			1000	1011	8	11	4	
2	Open Circuit			1000	1009	3	13	-6	
3	Short Circuit			1000	99	-4	458	-31	
4	Short Circuit			1000	48	-2	468	-25	
5	1200V	88 μ F		1000	140	-11	435	-48	
6	1200V	88 μ F		6000	686	-113	2704	-316	
7	1600V	2200 μ F		1000	54	-24	458	-29	
8	1600V	2200 μ F		6000	306	-185	2846	-200	
9	440V	20 μ F		1000	372	-23	401	-54	
10	440V	20 μ F		6000	2172	-163	2519	-429	
11	480V	20 μ F		1000	370	-24	422	-83	
12	480V	20 μ F		6000	2190	-167	2617	-533	
13	50V	22 μ F		1000	385	-22	305	-3	
14	50V	22 μ F		6000	339	-190	2853	-185	
15	Gas Tube Neon	125V		500	495	-21	1	-20	
16	Gas Tube Neon	125V		6000	Catastrophic Failure				
17	L - 100 turn, pen.			1000	533	-69	339	-31	
18	L - 100 turn, pen.			6000	2969	-473	2077	-229	
19	L - 20 turn, pen.			1000	164	-9	438	-27	
20	L - 20 turn, pen.			6000	752	-204	2740	-191	
21	L - Ferrite Core, 10 T			1000	372	-35	459	-35	
22	L - Ferrite Core, 10 T			6000	852	-230	2831	-251	
23	L - Ferrite Core, 6 T			1000	54	-20	469	-27	
24	L - Ferrite Core, 6 T			6000	305	-174	2914	-231	
25	L - Toroid			1000	864	-74	426	-26	
26	L - Toroid			6000	2625	-529	2604	-234	
27	L-Clamp-on,Data Sup.	SC		1000	86	-25	462	-32	
28	Zener			1000	75	-17	443	-48	
29	MOV	510V		1500	1224		108		
30	MOV	1000V		6000	2861		1482		
31	MOV	39V		1000	133	-19	406	-21	
32	MOV/Resistor	130V		1000	346	-18	296	-20	
33	MOV-20J	130V		1000	345	-16	298	-20	
34	MOV-20J	130V		6000	348	-117	2834	-146	
35	Device Not Reusable								
36	Arr - SiC, G 3Phase	650V		1000	1015	2	12	-3	
37	Arr - SiC, G 3Phase			3000	1744	-36	594	-1	
38	Arr - SiC, G 3Phase			6000	2361	-101	1802	6	
39	Arr-DE	600V		1000	1018	-27	11	-6	
40	Arr-DE	600V		6000	6017	-130	16	-6	
41	Arr-JO(9200)	650V		1000	1014	-20	13	-7	
42	Arr-JO(9200)	650V		6000	2538	-173	1733	6	
43	Arr-JO(Z650)	650V		1000	1019	-20	14	-4	
44	Arr-JO(Z650)	650V		6000	2552	-175	1717	7	
45	Arr-OB	3kV		1000	1018	-20	10	-5	
46	Arr-OB	3kV		6000	6024	-142	16	-5	
47	Arr-SD	600V		1000	1015	-20	13	-6	
48	Arr-SD	600V		6000	2132	-185	1951	9	

49Duplex EA	120V	1000	478	-19	233	-21	
50Duplex EA	120V	6000	Catastrophic Failure				
51Filter TB-gnds shorted	480V	6000	5679		544		
52Filter TB-power	480V	6000	5966		13		
53TVSS AP L-G	120V	1200	1207	29	13	-2	
54TVSS AP L-G	120V	6000	3573	-401	2542	18	
55TVSS AP L-L	120V	1200	761	16	212	0	
56TVSS AP L-L	120V	6000	1816	30	2323	16	
57TVSS AP L-N	120V	1200	485	14	366	0	
58TVSS AP L-N	120V	6000	1474	-254	2522	12	
59TVSS AP N -G	120V	1200	1215	22	11	-2	
60TVSS AP N -G	120V	6000	1998	-176	2388	13	
61TVSS CC L-L	120V	1000	994	-19	81	-97	720
62TVSS IT L-G	120V	1000	634	-22	149	-21	
63TVSS IT L-G	120V	6000	1823	-6	2330	15	
64TVSS IT L-G	480V	6000	2629	47	1883	15	
65TVSS IT L-L	120V	6000	1760	17	2340	27	
66TVSS IT L-L	480V	6000	2543	49	1921	18	
67TVSS IT L-N	120V	1000	634	-22	149	-21	
68TVSS IT L-N	120V	6000	1503	-271	2495	-1	
69TVSS IT N-G	120V	1000	389	-19	292	22	
70TVSS IT N-G	120V	6000	1583	-258	2515	0	
71TVSS MC L-G	120V	1000	698	-21	159	-23	
72TVSS MC L-N	120V	1000	354	-30	300	-23	394
73TVSS NT L-L	120V	1000	148	-16	548	-41	
74TVSS NT L-L	120V	6000	1163	-201	2671	-247	
75TVSS NT L-N	120V	1000	353	13	448	1	
76TVSS NT L-N	120V	6000	1255	-232	2569	-63	
77TVSS SC L-G	120V	1000	386	-19	282	-21	382
78TVSS SC L-N	120V	1000	385	-18	283	-22	410
79TVSS SC L-N	120V	1000	627	-216	2706	-20	
80TVSS SC N-G	120V	1000	288	-22	286	-21	382
81TVSS SS	120V	1000	348	-21	427	-32	
82TVSS SS	120V	6000	341	-41	2843	-206	
83TVSS TT L-G	120V	6000	5978	83	13	-1	
84TVSS TT L-L	120V	6000	1733	-351	2400	-25	
85TVSS TT L-N	120V	6000	1393	-262	2545	-73	
86TVSS TT N-G	120V	6000	5971	82	14	-1	
87TVSS-remote	4-20ma	1000	351	-18	299	-23	314
88TVSS-remote	4-20ma	6000	558	-243	2723	-20	
89TVSS MT L-N	120V	1000	422	-21	286	-20	-384
90TVSS MT L-G	120V	1000	641	-17	250	-23	244
91TVSS MT N-G	120V	1000	380	-20	2712	-21-110 ss	