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DETECTION AND CONTROL OF
POWER-LINE TRANSIENTS AFFECTING
TESTER AND GAGE PERFORMANCE

PDO 6989240, Final Report

J. W. Hill, Project Leader

Published August 1976

Prepared for the United States Energy
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**Kansas City
Division**

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Project Leader:
J. W. Hill
Department 142

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Final Report

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AND GAGE PERFORMANCE

BDX-613-1421, UNCLASSIFIED Final Report, Published August 1976

Prepared by J. W. Hill, D/142, under PDO 6989240

Monitoring of power lines in the Bendix Kansas City Division facility has indicated that common transients have peak amplitudes of less than 50 volts. Electrical storms produce large numbers of transients with peaks exceeding 100 volts. Bendix-built testers were found to be immune to transients having peaks in excess of 600 volts; commercial testers were found to be sensitive to transients with peaks from 100 to 250 volts. Transient-protection devices are discussed, and a preventive-maintenance program is recommended.

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Contract Number E(29-1)-613 USERDA

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SUMMARY

Certain indications of product failure obtained from product testers have been suspected to be the result of short-duration power-line transients. A project therefore was initiated to monitor power lines and thus determine the type of transients that are most prevalent, to perform transient-immunity tests on product testers and other sensitive instruments, and to make a survey of transient-protection methods that might be adopted.

A Programmed Power Inc. Model 3200 power-line monitor was rented and evaluated. It performed all functions within specifications, but it proved to be subject to errors caused by power-line transients in its own power input.

The monitoring of power lines indicated that common transients were small in amplitude, with peaks of 50 volts, or less. Electrical storms were found to produce large numbers of transients with peaks exceeding 100 volts. A complete characterization, which would show the probability of the occurrence of large transients, was beyond the scope and resources of the project.

Transient-immunity tests were performed on several product testers. Those that were Bendix-built proved to be immune to transients with peaks exceeding 600 volts, while those purchased from outside sources were sensitive to transients with peaks in the 100- to 250-volt range.

Recommendations for the control of transient problems include routine verification of transient-immunity for product testers and other instruments, the use of transient suppressors as insurance against large transients, and the acquisition of equipment for a permanent transient-monitoring capability.

DISCUSSION

SCOPE AND PURPOSE

Certain indications of product failure obtained from product testers have been suspected to be the result of short-duration power-line transients. Studies of this problem reported in trade journals appear to support this contention.

At the request of Quality Process Engineering, this project was initiated to monitor power lines and thus determine the type of transients that are most prevalent, to perform transient-immunity tests on product testers and other sensitive instruments, and to make a survey of transient-protection methods that might be adopted.

PRIOR WORK

Although no prior work has been reported in the Bendix Kansas City facility, industrial studies have been performed to determine the nature and prevalence of line transients in order to improve the reliability of solid-state electronic devices that are line-powered. These studies have indicated that, in residential areas, one transient in excess of 200 volts each day and one transient in excess of 1000 volts each year can be expected. Between 50 and 75 percent of all television failures are attributed to line transients.¹

ACTIVITY

Transient Monitoring

The Power-Line Monitor

A survey of commercially available power-line monitors indicated that the Programmed Power Inc. Model 3200 offered the greatest flexibility and utility for monitoring power-line transients. One of these instruments therefore was rented for evaluation and for accumulating transient data for the study.

The Model 3200 power-line monitor records deviations in line frequency, high and low short-duration transients, and high and low excursions of the rms line voltage. All of these parameters have adjustable threshold controls, and the output is recorded on a printer along with the time and date. The number of events in each category are accumulated on separate, resettable counters.

Upon evaluation, the instrument was found to perform all functions in a satisfactory manner. However, it was found to record transients on its own power input as well as those on the sensing input. An external transient-suppression network was provided to prevent the recording of erroneous data.

Survey Results

Because the monitor was available for only a limited time and several areas had to be monitored, necessary time-histories could not be compiled to establish probability distributions of the occurrence of significant events. Data accumulated showing the nature of common, day-to-day events are shown in the Appendix. The indicated *Number of Events* is the number of times in which the thresholds determined by the *Window Setting* were exceeded.

From the data obtained, the peak value of typical transients generally was less than 30 volts, although transients in excess of 50 volts were common where machine tools were being operated.

During electrical storms, transients having peak values in excess of 100 volts were very common. This is significant because an operator inside the plant normally would have no knowledge that an electrical storm was in progress. Later power-line transient-immunity tests indicated that some instruments in the plant can be affected by spikes of this magnitude.

Since the acquisition of the Model 3200 power-line-transient monitor was beyond the scope and the resources of this project, the instrument was returned to the vendor.

Because the transient-susceptibility of new instruments and the spike-output of new machinery generally is not known, a capability for making a transient survey is needed for troubleshooting and preventive-maintenance work. At the present time, this capability does not exist within the plant.

Transient-Immunity Tests

For line-monitoring information to be meaningful, it must be compared to noise-susceptibility data on the instruments under study. Because product testers historically have been suspected of producing occasional erroneous indications, personnel from Test Equipment Engineering were contacted to identify testers that were most suspect. As a result, transient-immunity tests were conducted on the PT2200, PT3028, and PT3030.

For the tests, spikes were introduced into the power line by a Berkely Instruments Model 3020 line-noise generator. None of the product testers listed showed any indication of being affected by spikes having a peak value of 600 volts with 10 kW peak power and a rise-time of approximately 1 μ s.

Transient-immunity tests of the DoAll three-axis measuring machine in Department 143-PM produced erroneous data with 250-peak-volt spikes, and produced a program crash with 450-peak-volt spikes. (The crash occurred only when negative spikes were used.)

Transient-immunity tests also were performed on the AA-Gage Polar Inspection gage in Department 90. Data errors occurred with 100-peak-volt transients, and location lock-in was lost when 300-peak-volt transients were present. A solenoid valve attached to the machine was found to be producing spikes of this magnitude; also, an electrical storm that was in progress while the tests were being conducted in Department 90 produced spikes in this range.

Suppression of Power-Line Transients

Types of Transients

In some cases, either as a remedy for a known transient problem or as insurance against a suspected problem, the use of transient-suppression devices may be desirable. In evaluating these devices, the nature and source of the transients must be considered.

Most high-amplitude, short-duration spikes result from the commutation of an inductive load. When the current is interrupted, a voltage spike is generated by the collapsing magnetic field:

$$e = L \frac{di}{dt}; \quad (1)$$

where

e = the generated voltage;

L = the inductance of the load; and

$\frac{di}{dt}$ = the derivative of the current.

A voltage of this nature sometimes may be damaging to semiconductor appliances on the same line, or it may induce a logic error through the power supply of a digital system. Because short-duration spikes are composed of high-frequency components, they may pass through the interwinding-capacitance of a step-down transformer with little attenuation. For the same reason, they may experience little attenuation from electrolytic capacitors, which tend to act as inductors at high frequencies.

Line transients may be of two general types: normal mode, and common mode. The normal-mode transients generally are the result of a commutated inductive load, while common-mode transients generally result from energy being coupled into the line from an external source such as a lightning discharge. Common-mode disturbances can be isolated by common-mode baluns and shielded isolation transformers. Both of these devices are commonly used to break ground loops in low-noise instrumentation and, in power supplies, for line isolators.²

Types of Suppressors

Both types of transients can be attenuated by nonlinear clamping devices and by filtering techniques. Nonlinear clamps may consist of zener diodes, silicon-carbide thyrectors, metal-oxide varistors, selenium rectifiers, or gas discharge devices. Spark gaps and gas discharge devices have the advantage of high power-handling capability, but the disadvantage of requiring that the current swing through zero before the arc is extinguished. The ignition-voltage of the arc is a function of the rise-time of the pulse as well as the amplitude.

The function of all nonlinear clamps, except gas discharge types, may be expressed by the equation

$$I = KV^{\alpha}, \quad (2)$$

where

I = the current,

K = a constant,

V = the voltage, and

α = an exponent.

Devices having the higher values of α serve as the best clamps. In zener arrays, $\alpha = 35$, and in metal-oxide varistors, $\alpha = 25$.³ Their effective "let-through" voltage, however, also is increased as the energy-level of the pulse increases. Zener arrays and metal-oxide varistors are more commonly used because of their high α and energy-dissipation characteristics.

Evaluation of Suppressors

A James Shielded Power Line Isolation Transformer that was tested exhibited a common-mode attenuation exceeding 60 dB under operating conditions. Under controlled conditions, with external coupling eliminated, these devices are specified by the manufacturer to have a common-mode isolation of 150 dB.

The clamping devices tested were the General Electric metal-oxide varistors and the Transtector Corporation's high-power zener diode arrays. Both devices absorbed 10-kW-peak pulses without significantly raising the nominal let-through voltage. Both devices are highly recommended as a general remedy for transient problems. The high-current versions should always be used.

RC snubbers also were evaluated. Since the energy in a transient is contained principally in the high-frequency components, a capacitive reactance theoretically should provide a short-circuit across the line and thus attenuate the pulse. In reality, the capacitor forms a resonant circuit with the inductive source to produce ringing oscillations. The resistor commonly used in series with the capacitor is intended to dampen these oscillations, but it also tends to counter the shunting-action of the capacitor. This approach therefore is not recommended as a general remedy for transients.

ACCOMPLISHMENTS

A Programmed Power Model 3200 power-line monitor was evaluated. Although it performed all specified functions, it proved to be sensitive to transients in its own power input.

The magnitude of common transients was established; however, obtaining the data necessary to predict the prevalence of serious transients is beyond the scope and resources of this project. The surveys indicate that the peaks of common transients are generally less than 50 volts in amplitude.

Several product testers were subjected to transient-immunity tests. Those built by Bendix proved to be immune to 600-peak-volt transients with 10 kW peak power and rise-times of approximately 1 μ s. The DoAll three-axis measuring machine in Department 143-PM showed data errors at 250 peak volts and experienced a program crash at -450 peak volts. The AA Polar Inspection Gage in Department 90 showed data errors when subjected to 100-volt spikes and lost its position lock-in when subjected to 300-volt spikes.

Four types of transient suppressors were evaluated. A James Shielded Power Line Isolation Transformer was found to have 60 dB of attenuation for common-mode transients, rather than the 150 dB specified. High-current metal-oxide varistors and zener diode arrays effectively clipped pulses having 10 kW of peak power without significantly increasing their nominal let-through voltages. RC snubbers were found to be unsatisfactory for many applications because of a tendency to produce ringing oscillations.

FUTURE WORK

Although no further work in the study of transients is planned, the following preventive-maintenance program is recommended.

- All new instruments and testers should be subjected to a transient-immunity test to pinpoint any tester in which problems are likely to occur so that repairs can be made, if necessary. Since the Bendix-built product testers using standard power supplies were unaffected by 600-volt spikes, a similar immunity figure should be obtained from other well-designed equipment.
- Nonlinear clamping devices of the types recommended in this report should be installed across power-line inputs. From published data,⁴ a General Electric V130PA20C varistor is estimated to require peak-pulse power of approximately 10^{11} W for the peak let-through voltage to exceed 600 volts. Because most commutation spikes contain from 10^3 to 10^6 W of peak power, verified spike-immunity of the instrument, combined with the application of nonlinear clamps, can be considered good insurance against errors induced from line spikes.

The actions described require little labor and expense, and they should provide the most cost-effective solution to the transient problem. This type of preventive maintenance should eliminate many manhours of diagnostic work and greatly reduce the amount of uncertain test data obtained.

In addition to these recommendations, a transient-monitoring capability is needed for diagnostic purposes. Sources of transients should be located because they may directly affect unprotected instruments, and because spikes may be associated with, or the cause of, high-frequency electromagnetic interference. A clamped transient contains high-frequency components, and the interaction of clamped or unclamped transients with system components may produce ringing oscillations.

REFERENCES

¹Richard W. Fox, "Six Ways to Control Transients," *Electronic Design*, Volume 22, Number 11, May 24, 1975.

²Ralph Morrison, *Grounding and Shielding Techniques in Instrumentation*. New York: Wiley and Sons, 1967.

³David Kay, "Transient Suppression," *Machine Design*, Volume 47, Number 3, February 6, 1975.

⁴Fox.

Appendix

TRANSIENT-SURVEY RESULTS

Table A-1. Survey Results by Facility Area

Area Surveyed	Number of Events	Window Setting (Volts)	Time of Day (24-Hour Clock)
Data Center*	4	±5	0938
	5	±5	1100
	5	±7	1131
	6	±7	0019
	6	±10	1318
	30	±12	1353 to 0743
	6	±16	1056 to 0025
	3	±20	1300 to 1407
	4	±22	0048 to 2329
	3	±22	1830 to 1215
	4	±24	1013 to 1555
	2	±24	0446 to 0848
	1	±26	0046
D/54 Regulated Line**	4	±10	0609 to 0721
	1	±10	1529
	4	±10	0814 to 0948
	4	±20	0634 to 0936
	5	±20	1840 to 1922
D/90***	738	±100	
D/143-PM Regulated Line†	83	+50,-30	0903 to 1317
	0	±50	
D/812D Laboratory††	2	±50	1622 to 1635
D/142A Laboratory†††	0	±30	

*Total data-collection time was 1-1/2 weeks.

**Quiet for a three-day period. Total data-collection time was 1-1/2 weeks.

***Because ±50-volt transients appeared common,

±100 volts was chosen for the window-setting.
The time distribution is not known because
the printer jammed during the weekend of
5/10/75 to 5/12/75 while a thunderstorm was
in progress.

†Total data-collection time was 5 days.

††Total data-collection time was 2 days.

†††Total data-collection time was 1 week.

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