Validating Surge Test Standards by Field Experience: High-Energy Tests and Varistor Performance

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ABSTRACT – New, high-energy surge tests are emerging in IEEE and IEC standards. Field experience offers a valuable criterion for validating or invalidating proposed standards. A proposal under consideration by the IEC involves so much energy that a varistor of the voltage rating commonly used in protecting load equipment, if subjected to this test, would almost certainly fail. Yet, reported varistor failure rates do not reflect such a situation. Thus, a re-examination of the premises that led to the proposed test specifications appears necessary. Proposals for high-energy tests as additional waveforms in the new version of IEEE C62.41, on the other hand, lead to current and energy levels that do not place typical varistors in immediate jeopardy. Thus, they appear more consistent with field experience.

INTRODUCTION

A natural approach in defining the surge tests to be performed on any equipment is to attempt duplicating the conditions observed in site measurements. However, this approach would lead to a situation where general conclusions are drawn from limited measurements of specific surge occurrences. It has in fact led to a multitude of proposals for test standards that may subsequently be applied outside of their original, correct context because no other standard is available at the time. An example of this situation may be developing with the proposal by Technical Committee 77 of the International Electrotechnical Commission (IEC) for a high-energy 100/1300-μs surge test.

To evaluate the effects of various proposed or existing high-energy stress tests on commonly used varistors, this paper presents a simple, yet effective, model of a surge generator. The evaluation proceeds by quantifying the current through the varistor and the corresponding energy deposited in the varistor. The computed results are compared to the published device ratings to predict the likelihood of failure. This likelihood is then compared to the available information from field experience on failure rates.

Any immunity test should be conducted with an objective which is more subtle than the 'duplicate the environment' goal. A test stress is applied to a device, not to demonstrate that it can survive any of the stresses that it will encounter in nature, but only to demonstrate for the benefit of both manufacturer and purchaser that the device can survive an agreed-upon, simple, and reproducible stress. From surviving the test stress, the inference is made, *subject to confirmation by field experience*, that the device does have the ability to survive the infinite variety of stresses that it will encounter during its life in the real world. In other words, simple test stresses are useful because they can be reproduced over a period of time at the same facility, and between facilities, providing a common language and a standard of comparison that is essential to conduct orderly transactions. Test standards should not, however, be misconstrued as representing natural phenomena. They are effective only if they discriminate between those devices with a potential for long field survival and those which are likely to fail.

The proposed 100/1300-μs IEC test should be re-examined with this philosophy in mind, because it appears that commonly used varistors would be expected to fail when subjected to this test. Anecdotal field experience does not support that prediction, raising questions on the general validity of this test. On the other hand, high-energy tests derived from new proposals contained in the revised version of IEEE Std C62.41 (under consideration by the IEEE Standards Board as PC62.41) do not lead to contradiction between field experience and predicted test results.

PROPOSED IEEE AND IEC HIGH-ENERGY TESTS

Metal-oxide varistors that suppress surges by absorbing energy have proliferated in low-voltage ac power circuits. Consequently, new high-energy tests have been proposed to assess the ability of these varistors to withstand the corresponding stress. In a major revision of the IEEE Guide C62.41 [1], emerging as a Recommended Practice, an additional waveform has been proposed to assess this ability. The proposal is a 10/1000-μs surge, with three "System Exposure" levels, defined below. The IEC Technical Committee TC77 is considering a surge test requirement based on the scenario of current-limiting fuses clearing a fault at the end of a cable, where the energy trapped in the system inductance causes a large transient at the time the fuse interrupts the current [2]. That scenario was first described and quantified by Meissen [3], and incorporated in German Standard VDE 0160 [4].

The PC62.41 Recommended Practice draft proposes among other waveforms, a high-energy stress defined by an open-circuit voltage and a source impedance, at three "System Exposure" levels. For the "Low Exposure" level, no high-energy stress is proposed; for the "Medium Exposure" level, the surge environment involves a crest of 2 times the system peak voltage, with a source impedance of 1 Ω. For the "High Exposure" level, the crest is 2.3 times the system peak voltage, while the source impedance is only 0.25 Ω.

The IEC proposal appears to be based on the VDE 0160 standard which specifies the direct discharge of a large capacitor – thousands of microfarads – into the equipment under test (EUT). The VDE test procedures are not quite clearly outlined at this point but might be interpreted as re-adjusting the capacitor charging voltage after connecting the EUT to the surge generator, in order to maintain the specified test voltage across the EUT. That approach would be diametrically opposed to the generally-accepted practice of performing a surge test with a generator having the capability of delivering a well-defined open-circuit voltage and short-circuit current, or an open-circuit voltage associated with a specified source impedance (Fisher & Martzloff, 1976 [5]; IEEE Guide on Surge Testing, 1987 [6]).

Another ambiguity in the VDE 0160 test specification is that it might be acceptable to perform a test where the voltage waveform is less than the specification, provided that 80% of the energy stored in the surge generator capacitor be delivered to the EUT. However, there is no provision in the test procedure for measuring

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this energy, and it is doubtful that this condition can be achieved with a surge generator containing the parallel resistor which is necessary to achieve the specified rate of decay (or duration of the tail of the wave) when the EUT offers a high impedance.

Metal-oxide varistors offered by manufacturers include ratings of 130 V rms for applications in 120 V systems and 250 V rms for application in 220 V systems. The motivation for using these varistor ratings is, of course, the desire to provide the lowest possible clamping voltage to protect sensitive equipment. A paper presented at the Zürich EMC Symposium suggests that premature varistor aging may result from this close clamping (Martzloff & Leedy, 1989 [7]). However, the 130-V and 250-V varistor ratings are still widely used by equipment manufacturers who take the position that they are not afflicted by unacceptable failure rates. Thus, the authors accept that position as reflecting actual field experience, and will apply it as a criterion for validating or questioning the proposed high-energy test standards.

SUMMARY OF RESULTS

This paper reports the results of modeling the application of a surge test to a family of commonly used varistor sizes (14, 20 and 32-mm diameter). For each varistor size, the computations were performed for three levels of manufacturing tolerances on the varistor: nominal value, -10%, and +10%. A varistor with its clamping voltage at the maximum acceptable tolerance level (the level shown on published I-V curves) will tend to absorb less energy than a varistor with a lower clamping voltage because it will divert current for a smaller part of the surge. The maximum energy deposition in the varistor will occur for a varistor having the lowest acceptable clamping voltage, typically 20% below the maximum, as indicated by the ±10% tolerance on varistor nominal voltages. Should the test generator parameters be at the most severe conditions within its uncertainties (higher peak voltage and longer duration than nominal, within allowable tolerances), the stress on the varistor would be even greater.

The circuit model used in the computations reported in this paper is a simple capacitor-discharge circuit that can produce the 10/1000-μs waveform of PC62.41 or the 100/1300-μs waveform of VDE 0160, each with appropriate selection of the components values. The modeling results, discussed in detail below with supporting information in the Appendix, indicate that the smaller size varistors would not be damaged at the "Medium Exposure" level of PC62.41, but would be damaged at the "High Exposure" level. The 32-mm varistor would easily accept several applications of the "High Exposure" level, while the 20-mm varistor would have a limited life. On the other hand, few varistors will survive the VDE 0160 stress.

Table 1 presents this information in the form of the number of surges that a varistor can survive, for the three sizes and three tolerance values of varistors, and for the three type of tests, VDE 0160, PC62.41 "High Exposure" and PC62.41 "Medium Exposure". The results with PC62.41 are in good agreement with anecdotal (unpublished) field experience, that is, 14-mm varistors installed at the service entrance are often in jeopardy, 20 mm varistors have a better chance, and 32 mm varistors are generally successful. Failure rates are not reported formally in the literature, but anecdotal information does circulate. The response of industry to the Zürich paper alerting the community to the risk of premature aging caused by repeated swells [7] was that 20-mm and 32-mm varistors do not suffer from an unacceptable or alarming failure rate.

The predicted survival rates of Table 1 appear consistent with the actual field experience, thus validating the stress levels proposed by IEEE PC62.41. In contrast, for the VDE 0160 stress, the predicted survival rate is so low that a conclusion appears inescapable: the VDE 0160 stress involves an exceptionally high energy level, making the application of the test questionable if interpreted as a general requirement. The authors do not question the scenario leading to this stress level, but do question the IEC proposal to require an across-the-board test at that level for all equipment.

TABLE 1

PREDICTED NUMBER OF HIGH-ENERGY SURGES THAT VARISTOR CAN SURVIVE, AS A FUNCTION OF SIZE AND CLAMPING VOLTAGE TOLERANCE

Varistor		VDE 0160 Class 2	PC62.41 High	PC62.41 Medium
Size mm	Clamping Voltage Tolerance			
14	−10%	none	none	80
	0%	none	1	3000
	+10%	none	8	$> 10^6$
20	−10%	none	1	500
	0%	none	3	8000
	+10%	1	20	"indefinite"
32	−10%	none	8	20 000
	0%	1	80	200 000
	+10%	5	800	"indefinite"

The dramatic effect of the tolerance value on survival rate is also apparent. Greater reliability can be achieved if users would accept – better yet, request – a slightly higher clamping voltage than the lowest clamping voltage offered by the manufacturers of varistors and by the manufacturers of packaged suppressors.

MODELING A SURGE TEST

The normal practice in surge testing, as described in the IEEE Guide on Surge Testing [6], is to specify an open-circuit voltage and a short-circuit current to be delivered by the surge generator. With these two parameters specified, the surge generator is considered to be defined for any test involving a specimen of high impedance (typically insulation) or low impedance (typically a surge diverter). For the unidirectional surges of 10/1000 μs and 100/1300 μs, a simple, four-component model circuit can produce these waveforms. An actual surge generator, of course, requires careful attention to avoid problems of parasitic impedances, but the simple circuit model of Figure 1 can deliver the required waveforms, as shown in Figure 2 for the case of the nominal PC62.41 10/1000-μs waveform.

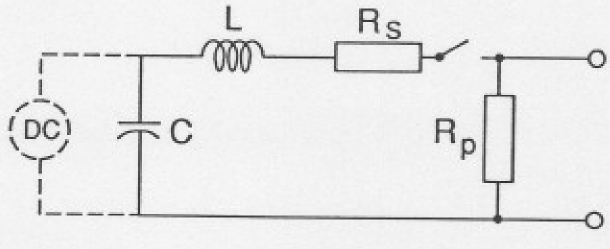

Figure 1. Four-component circuit for 10/1000-μs and 100/1300-μs surge modeling

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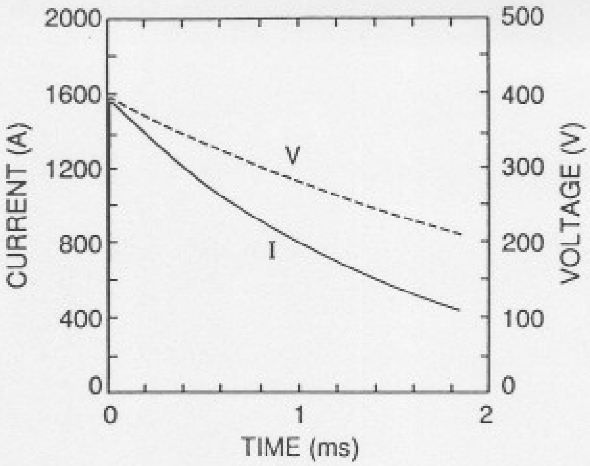

Figure 2. The open-circuit voltage, V, and short-circuit current, I, produced by the circuit model with its parameters set for the PC62.41 10/1000-μs waveform

In the specification of that waveform, the tolerances allowed by PC62.41 recognize the fact that the open-circuit voltage will inescapably have a longer duration but shorter rise time than the short-circuit current. Because the high-energy aspect of this test makes the current waveform the most significant parameter, the values of the components in the model were selected to most closely approximate the nominal 10/1000 μs for the short-circuit current, while allowing the open-circuit voltage to go to the longest duration permitted by the tolerances. For the VDE 0160 model, the values of the components were selected to comply with the 6000-μF requirement while producing the specified open-circuit voltage.

In predicting varistor failure rates, the model can take into consideration the possible combinations of manufacturing tolerances on the varistors and the uncertainties of the test (something which is more difficult to do by tests on random samples). In the simple computations reported here, three cases have been computed with the varistor at the mid-point and the two extremes of its manufacturing tolerance. The surge generator parameters were set to produce the nominal current waveform in order to make a mid-range rather than a worst case prediction. The conclusions on survival rates and validation of the proposed tests presented above would not be dramatically affected if the surge generator parameter tolerances were included in the computation.

The component values of the circuit shown in Figure 1 may be selected so as to generate the desired waveforms of the various standards. The selection method is described below. In order to determine the response of the circuit with the nonlinear varistor, numerical techniques are used as shown in the second step below.

In the circuit of Figure 1, the capacitance, C, is charged to an initial voltage V_c. The surge generator has a series resistance, R_s, and a parallel resistance, R_p. A small inductance, L, is tuned to provide the specified rise time. This simple LRC circuit is described by a characteristic equation

$$L\lambda^2 + R\lambda + \frac{1}{C} = 0$$

where R is defined below. The two decay constants are

$$\lambda^{\pm} = -\frac{R}{2L} \pm \sqrt{\left(\frac{R}{2L}\right)^2 - \frac{1}{LC}}.$$

The response of the circuit is a "double exponential" waveform[8].

Using the allowed tolerances of PC62.41 for the model, the wave shape of the short-circuit current (in which case R is R_s) was set at 10/1000 μs. For the open-circuit voltage (in which case R is $R_s + R_p$), the maximum duration allowed by PC62.41 is 2000 μs. The decay times, expressed as full width at half maximum (FWHM) for these two waveforms are designated as t_I and t_V, respectively. The effective source impedance is defined in PC62.41 as the ratio of the peak open-circuit voltage, V_p, to the peak short-circuit current, I_p. Its value, $Z = V_p/I_p$, has the dimension of an impedance.

Because the time constants are widely separated, the determination of the circuit component values from the values of t_I, t_V, Z, and V_p can be simplified to produce approximate values. The characteristic decay values λ^+ and λ^- are given by

$$\lambda^+ \cong -\frac{1}{RC}$$

$$\lambda^- \cong -\frac{R}{L}.$$

In particular, for long times t, the short circuit current, I_{sc}, and open-circuit voltage, V_{oc}, are given by

$$I_{sc}(t) \cong I_p e^{-t/R_s C}$$

$$V_{oc}(t) \cong V_p e^{-t/(R_s+R_p)C}.$$

At half maximum, one has

$$t_I = \log 2 \cdot R_s \cdot C$$

and

$$t_V = \log 2 \cdot (R_s + R_p) \cdot C.$$

With a small value of the inductance,

$$V_p \cong V_c \frac{R_p}{R_s + R_p}$$

and

$$\frac{1}{R_s} + \frac{1}{R_p} = \frac{1}{Z}.$$

These relations lead to the four equations:

$$R_p = \frac{t_V}{t_I} \cdot Z \tag{1}$$

$$R_s = \frac{t_V}{t_V - t_I} \cdot Z \tag{2}$$

$$C = \frac{t_I}{\log 2 \cdot R_s} \tag{3}$$

$$V_c = \frac{t_V}{t_V - t_I} \cdot V_p. \tag{4}$$

The inductance is determined by considering the 10-90% rise time, t_R. The widely separated time constants allow estimating the fast component of the current to be estimated by

$$I_{sc} \cong I_p e^{-Rt/L}$$

at short times t.

Applying a logarithm yields

$$L \cong \frac{R \cdot t_R}{\log .9 - \log .1} = \frac{R \cdot t_R}{\log 9}. \tag{5}$$

The expressions (1)-(5) uniquely define the characteristics of the circuit for given values of the time constants, the source impedance, and the peak open-circuit voltage.

With the parameters of the model test circuit thus defined, the solution of the response of the current and energy in the varistor is obtained numerically using the ordinary differential equation package PLOD [9]. The varistor is presumed to contain an internal series resistance, R_m, and have the I-V relationship

$$V_m = \left(\frac{I_m}{k}\right)^{1/\alpha} + R_m I_m. \tag{6}$$

The first-order system of equations to be solved is given by the definition of the capacitor current, I, and by Ohm's Law

$$\frac{dQ}{dt} = -I \tag{7}$$

$$L\frac{dI}{dt} = \frac{Q}{C} - R_s I - V_m. \tag{8}$$

The varistor current, I_m, and I are related by (6) and by

$$I = I_m + \frac{V_m}{R_p}. \tag{9}$$

By exploiting this relationship, a direct numerical solution for the varistor current is possible. In addition, the energy in the varistor, E_m, is found by integrating

$$\frac{dE_m}{dt} = I_m \cdot V_m. \tag{10}$$

The initial charge is given by $C \cdot V_c$ and the initial current and energy in the varistor are zero. The computations were performed for the two PC62.41 exposure levels and for the maximum VDE 0160 stress, as described below.

RESULTS

PC62.41 - 10/1000 μs Stresses

To evaluate the effects of the test on varistors, a simple equivalent circuit of the varistor is connected to the terminals of the model generator. The charging voltage of the generator is, of course, left unchanged. For the range of frequencies involved in these waveforms, the only two significant elements of the varistor equivalent circuit (Figure 3) are the pure varistor, R_X, ($I = kV^\alpha$) and the series resistance, R_{ON}. The parallel resistance, R_{OFF}, and capacitance, C, and the series inductance, L, of the complete equivalent circuit can be neglected. Three diameters of 130-V rated varistors were considered, each with its characteristic clamping at -10%, 0% and +10% of the nominal value published by one manufacturer. Figure 4 shows the type of plots obtained from the model where the current through the varistor and the cumulative energy deposited in the varistor are computed as a function of time. Showing the complete set of results for all combinations would require excessive space; a summary of the results is presented in the Appendix. In the typical example of Figure 5, three curves show the cumulative energy for a 14-mm varistor with nominal rating of 130 V rms, and three tolerance values: -10%, 0%, and +10% clamping voltage, when exposed to the PC62.41 "High Exposure" stress level.

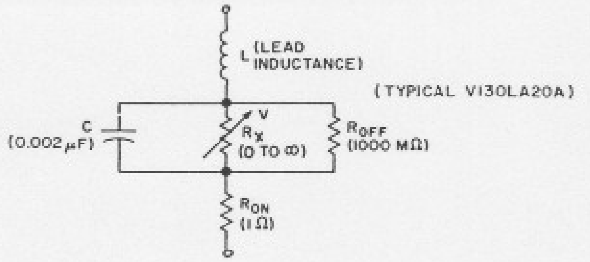

Figure 3. Equivalent circuit of a varistor. Source: Reference [13].

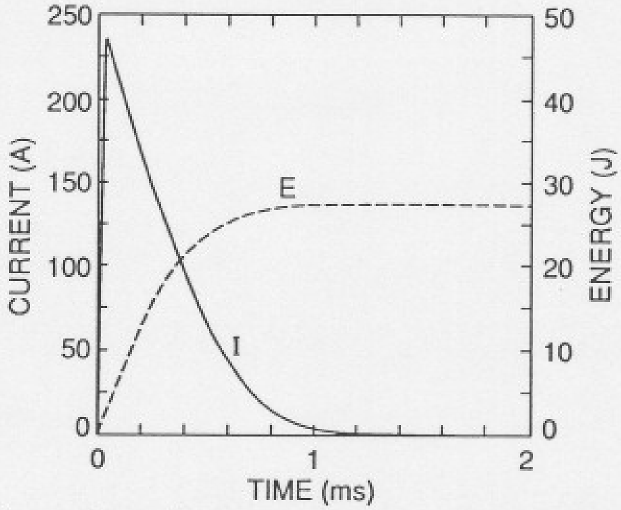

Figure 4. Energy deposition, E, and current, I, in a 20 mm varistor with nominal clamping characteristic (0% tolerance) during the "High Exposure" 10/1000-μs PC62.41 surge

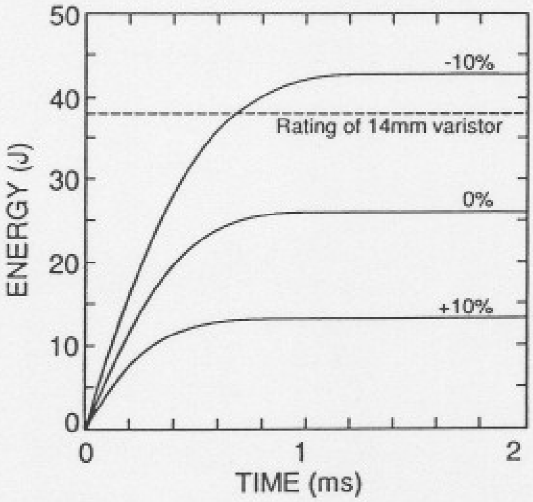

Figure 5. Energy deposition in 14 mm varistors at -10%, 0%, and +10% values of clamping characteristics during a "High Exposure" 10/1000-μs PC62.41 surge

VDE 0160 - 100/1300 μs Stress

Figure 6 shows the parameters of the 100/1300-μs surge, Class 2 described in the most recent amendment to VDE 0160 [10] and in the IEC proposal [2] . The voltage level is specified as 2.3 times the peak of the ac power system voltage. (The amendment also cites a Class 1 category with a level of only 2.0 times the peak of the ac power system voltage, and a shorter duration). Accepting for the moment the premises that led to the specification of this test, the authors applied the same circuit model used for the IEEE waveforms to produce the specified VDE waveform, with an energy storage capacitor having the value specified in the latest amendment to VDE 0160. (Earlier versions of the VDE 0160 standard suggested a 25 000-μF capacitor. In the amendment, this value has been scaled down to a range of 700 to 6000 μF, perhaps implying that the issue is still unsettled and thus the IEC proposal is still open to feedback from users.)

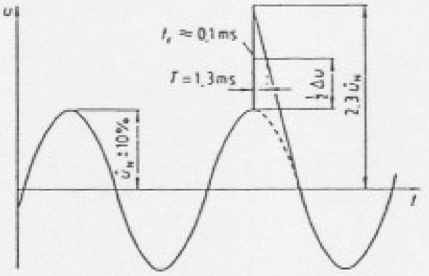

Figure 6. Voltage waveform of the 100/1300-μs surge specified by VDE 0160 and proposed by IEC. Source: Reference [4].

In this case, because the VDE places emphasis on maintaining the voltage waveform, the model parameters were set to obtain an open-circuit voltage close to the 100/1300-μs values, accepting the resulting short-circuit current, for which VDE 0160 does not specify a value. Figure 7 shows the open-circuit voltage and short-circuit current computed by the model.

The computations were performed for the 250-V rms rating, because the VDE 0160 does not provide specifications for system voltages of less than 220 V rms. Details of the results are presented in the Appendix, together with the corresponding results from the PC62.41 stress levels.

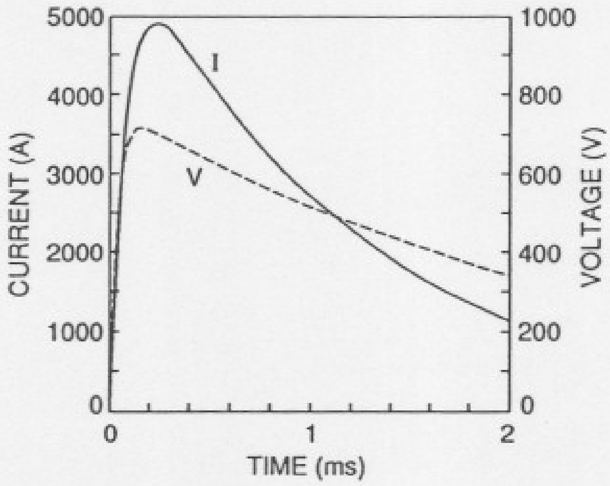

Figure 7. The open-circuit voltage, V, and short-circuit current, I, produced by model with parameters set to approximate the VDE 0160 voltage waveform.

COMPARISONS OF RESULTS FROM MODEL WITH VARISTOR RATINGS

Typical manufacturer specifications [11] include a joules rating for maximum single pulses; however, industry standards (Section 6, IEEE Standard on varistor tests [12]) raise some questions on the application of such a simple criterion.

The cumulative energy levels for the three varistor sizes, each at three tolerance levels, were computed with the model for the PC62.41 and VDE 0160 stress levels. The results are shown in Table 2, together with the typical, single-pulse joule rating published for these sizes. By using this somewhat oversimplified joule criterion (more than 10% change in nominal voltage may occur if joule rating is exceeded), it would appear that only the 14-mm and 20-mm varistor, for the low values of tolerance, might be in jeopardy.

Using the criterion of "Pulse Rating" proposed by manufacturers, [11,13] where the current peak and duration are taken into consideration, leads to more detailed and reliable conclusions, which also agree with field experience (Martzloff, 1985 [14]).

Therefore, the current peak and its duration (FWHM) were also computed for the nine combinations of varistor parameters, and compared to the "Pulse rating" corresponding to the duration and peak in each case. The detailed results, which are the basis for the summary of Table 1, are presented in tabular fashion in the Appendix, together with a discussion of the finer points of the analysis.

TABLE 2

SINGLE-PULSE MODELING RESULTS VERSUS VARISTOR RATINGS (JOULES)

Varistor Size mm	Tolerance %	VDE 0160 Class 2 250 V varistor Result	Rating	PC62.41 High 130 V varistor Result	Rating	PC62.41 Medium 130 V varistor Result	Rating
14	−10	212		43		6	
	0	126	72	26	38	3	38
	+10	62		13		1	
20	−10	257		45		6	
	0	181	130	27	70	3	70
	+10	86		14		1	
32	−10	306		46		6	
	0	181	330	28	200	3	200
	+10	86		15		1	

NOTES:

1. Five numbers are located in the shaded area of the results columns for two values of tolerances in the 14-mm and 20-mm varistors. These numbers are greater than the rating of the varistor, and thus would indicate a high likelihood of failure at that stress level.
2. The varistor model postulates the same $I = kV^{\alpha}$ relation for the three ratings, with a series resistance that decreases as the diameter of the varistor increases. The lower series resistance invites a greater current diversion into the varistor in the upturn region of the I-V characteristic, where its effect is more noticeable, especially for the VDE 0160 and the lower tolerance case for the varistors.

CONCLUSIONS

1. Predictions of the impact of the 100/1300-μs surge test proposed by IEC and based on the VDE 0160 standard, were it required for the millions of varistors in service, show that these varistors should experience a greater failure rate than that indicated by available information on actual field failures. This inconsistency raises serious questions on the proposed requirement of such a severe test to a wide range of equipment.

Furthermore, the lingering ambiguity in the VDE 0160 standard (and consequently in the IEC proposal) on whether to set constant open-circuit voltage or to adjust the voltage while the specimen is connected needs to be clarified. A constant, specified open-circuit voltage combined with a well-defined source impedance is the generally accepted practice in surge testing.

2. The energy levels and currents resulting from application of a waveform described in the proposed revision of IEEE C62.41, on the other hand, range from benign for typical large varistors to severe for small varistors. Thus, this set of stress levels appears to be more consistent with field experience, at least as inferred from anecdotal information.

3. While the authors do not question the validity of the fuse-blowing scenario, the basis for the VDE 0160 and proposed IEC test, they recommend a critical review of the statistics of the occurrence of fuse blowing, of the use of varistors with low clamping voltage, and of the distribution of actual clamping voltage within manufacturing tolerances. They also urge all users to share information on the observed failure rates and thus attain a broader perspective on these issues.

ACKNOWLEDGEMENT

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(Appendix overleaf)

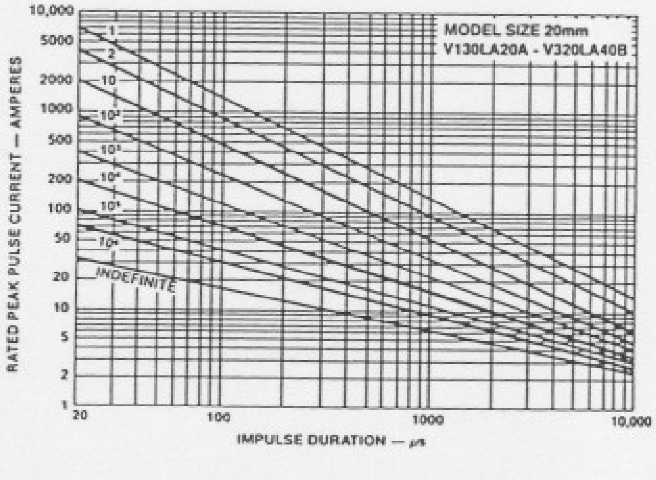
APPENDIX
DETAILED RESULTS FOR CURRENT PEAKS AND DURATIONS

This appendix provides a summary of the 54 separate computations made to determine the current in the varistor resulting from the three high-energy tests discussed in the paper. Three varistor sizes were considered: 14 mm, 20 mm, and 32 mm, and their "Pulse Rating" obtained from References [11] and [13]. The 32 mm size has been dropped from the current product line of Ref [11] and might appear obsolete. However, it was selected because it has been applied in the past [13] and thus more field experience is available for that size, than for the 40-mm size which is the present offering.

The computed results are presented in Table A1, for the VDE 0160 Class 2 and the PC62.41 "High Exposure" and "Medium Exposure" stresses. In each major section of the table, the computed current peak and FWHM are tabulated. Next to these computations, the corresponding current peaks are shown, from the "Pulse Ratings" in References [11] or [13] (Figure A1), for the computed duration, and for 1, 10, and 100 applications of that peak of current pulse.

The usual description of a unidirectional surge is based on the FWHM and, therefore, the computations of the current in the varistor were aimed at characterizing this description of the current waveform. However, the "Pulse Rating" curves in both References [11] and [13] are based on an "Impulse Duration" defined as the time from virtual origin of the wave and the virtual time to half value. In the case of the PC62.41, with a front time of 10 μs and a FWHM of 1000 μs, the difference between the FWHM and the "Impulse Duration" is negligible. In the case of the IEC 100/1300-μs waveform, the difference is more significant and, therefore, the comparisons of Table A1 include a 40-μs adjustment in the duration (about half of the rise time).

The peak values of the current shown in the table that exceed the "Pulse Rating" have been identified by shading the area in the columns. At a glance, it becomes apparent that the survival rate to a VDE 0160 exposure can be expected to be extremely low; it will be moderate for the PC62.41 "High Exposure", and will be at its maximum for the PC62.41 "Medium Exposure" stresses.



Source: Ref [13].

Figure A1. Typical published family of "Pulse Rating" curves showing amplitude, duration, and number of allowable pulses.

TABLE A1
MODELING RESULTS VERSUS DEVICE RATINGS – CURRENT AND DURATION

VARISTOR		VDE 0160 – 100/1300 µs 2.3 x 220 x 1.4; 6000 µF; 250-V varistor						IEEE PC62.41 10/1000 µs "High" 2.3 x 120 x 1.4; 0.25 Ω; 130-V varistor					IEEE PC62.41 10/1000 µs "Medium" 2.0 x 120 x 1.4; 1.0 Ω; 130-V varistor				
		RESULTS		RATINGS				RESULTS		RATINGS			RESULTS		RATINGS		
DIA mm	Tolerance %	Peak A	FWHM µs	Virt. Dur. µs*	Allowable Peak Amperes** For Virtual Duration and No. of Pulses in Columns			Peak A	FWHM µs	Allowable Peak Amperes** For FWHM and Number of Pulses in Columns			Peak A	FWHM µs	Allowable Peak Amperes** For FWHM and Number of Pulses in Columns		
					100	10	1			100	10	1			100	10	1
14	-10	520	650	690	30	50	120	305	400	50	75	200	58	322	55	90	240
	0	364	520	560	40	60	150	220	325	55	90	240	35	235	60	110	310
	+10	221	400	440	45	70	180	140	240	60	110	310	116	153	100	160	500
20	-10	558	625	665	45	80	210	325	410	70	120	360	60	325	90	170	410
	0	454	515	555	55	90	250	235	325	90	170	410	36	234	100	200	550
	+10	259	400	440	65	110	300	150	240	100	200	550	16	151	150	300	750
32	-10	825	625	665	100	200	600	345	410	160	340	1000	60	313	200	400	1200
	0	562	500	540	120	250	700	250	320	200	400	1200	36	230	220	500	1700
	+10	325	390	420	150	300	900	155	240	220	500	1700	16	150	400	850	2500

*Adjustment of approximately half of the rise time made to account for the difference between the computed FWHM and the "virtual duration" used in manufacturers specifications. For the short rise time of the PC62.41, the difference is negligible.

**When allowable peak current for the corresponding duration and number of pulses exceeds the rated peak current at that duration, the varistor is deemed in jeopardy; this situation is shown by shading the corresponding area in the rating columns. The unshaded areas represent "survival" of the varistor through the high-energy stress.