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AN APPROACH TO SETTING PERFORMANCE REQUIREMENTS FOR AUTOMATED EVALUATION OF THE PARAMETERS OF HIGH-VOLTAGE IMPULSES*

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Abstract

This paper reports the present status of an ongoing study of digital signal processing applied to various impulse waveforms. In a round-robin study, twelve laboratories are using their own software to evaluate the parameters of impulse waveforms in a data base of thirty-one waveforms with the objective of establishing minimum performance requirements. This paper presents the results obtained for smooth full impulses and some examples of results on more complex waveforms.

1. Introduction

Present standards for digital waveform recorders used in high-voltage impulse measurements clearly specify tests to demonstrate that the recorder has sufficient measurement accuracy. Indeed, because the testing of digital recorders can be automated, more stringent testing has been specified for digital recorders than is practical for oscilloscopes and this has led to the accuracy of digital recorders being more clearly demonstrated.

The question of how the digital record should be processed was left to the parties concerned in the test, with the only specified condition being that the raw data should be retained and compared with processed data. However, since the parameters of the test impulse (including the test value) may be determined from the processed data, it is important to establish tests to ensure the evaluation of parameters is performed adequately. The problem is how to do this while at the same time permitting users to develop and apply a wide range of techniques which may give enhanced accuracy. This problem is further complicated by the different needs of various users ranging from single-purpose test laboratories (e.g., a cable manufacturer who may only test a few test objects which are capacitive and do not cause significant distortion) to large high-voltage test/research laboratories (which may perform tests on a very wide range of test objects which have a correspondingly wide range of impedances, some of which distort the waveform).

An approach under consideration is to provide reference waveforms together with their parameters: peak value, front time, etc., /1/. The users would evaluate the parameters of the appropriate waveforms using their own software packages and test if the parameters are within specified limits. To reduce the amount of time required for evaluation the waveforms would be divided into groups and the users need only use those groups which are appropriate to the high voltage tests performed in their own laboratories.

In a first step to establish reference waveforms this round-robin test was initiated in November, 1987 and participation was invited from interested members of Working Group 33.03 of Conférence Internationale des Grands Réseaux Électriques (CIGRÉ WG 33.03), Working Group 08 of Technical Committee 42 of the International Electrotechnical Commission (IEC TC42 WG08) and Working Group on P1223 of the Institute of Electrical and Electronics Engineers (IEEE WG P1223). A data base of test waveforms of lightning impulses was selected from calculated data and measured impulses contributed by various laboratories. The calculated waveforms were: 1) a smooth double exponential, (1.2/50) and 2) a set of nine records derived from this smooth double exponential by adding nine different randomly-generated noise files, whose peak amplitude was 1% of the peak value of the impulse. Measured data from impulse tests were contributed by the laboratories listed in Table 1.

All of these organizations except PTB also contributed to the analysis of the records using various software packages. In addition the organizations listed in Table 2 also contributed to the analysis.

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Table 1. Sources of Impulse Records.

Organization	Contributors
Centro Elettrotecnico Sperimentale Italiano (CESI) (Italy)	G. Rizzi, C. Cherbaucich
Georgia Power Research Center (U.S.A.)	L. Coffeen, J. McBride
Les Renardières Électricité de France	J.J. Ribot, M.F. Deschamps
National Institute of Standards and Technology(NIST) (U.S.A.)	G.J. Fitzpatrick
National Research Council (Canada)	T.R. McComb
Physikalische Technische Bundesanstalt (PTB) (Germany)	K. Schon
Siemans, Nürnberg (Germany)	R. Maier
Smit Transformers and N.V. Tot Keuring Van Electrotechnische Materialen (KEMA) (Netherlands)	E. Hanique, P. Vaessen

Table 2. Additional Contributors to the Analysis.

Organization	Contributors
Eidgenössische Technische Hochschule, Zurich (ETH) (Switzerland)	K. Lehmann, W. Zaengl
Hipotronics (U.S.A.)	W. Larzelere, Y. Zhang
U. of Padova (Italy)	G. Pesavento

Four organizations plotted some of the files and read them as oscillograms thus giving a link to the old techniques: Nicolet, U.S.A. (A. Metalka), NRC, Mississippi State University, U.S.A. (D. Miller) and Smit/KEMA.

2. The Database and Parameters to be Read

The waveshapes (full and front-chopped impulses) used in this study are defined in /1/. From the records contributed to the study the following were selected:

Group 1: the ten calculated full impulses whose parameters were known (DEXP150, L150N0 to L150N5 and L150N7 to L150N9)

Group 2: two smooth full impulses (measured in two different high-voltage test facilities: B3P and CS2P)

Group 3: six full impulses with oscillations (measured in three different high-voltage test facilities: A1P, A3P, B27P, ES2P, ES3P and ES4P)

Group 4: three full impulses which are slightly-distorted from a double-exponential waveform (measured in a high-voltage test facility: D1P, D2P and D3P)

Group 5: seven full impulses which are highly-distorted from a double-exponential waveform (measured in two different high-voltage test facilities: GS1P, GS4P, F1P, F3P, F5P, F7P and F9P)

Group 6: three front-chopped impulses (calculated(C1P and C3P) and measured (ES1P))

The selection and grouping of impulses was to some extent subjective but is presented as a start to defining groups which can be used to represent various sets of conditions in industrial test facilities. It is expected that these groups will be redefined in an iterative process as more test facilities contribute impulse waveforms which were not covered in the first trial. However these six groups allow the method to be illustrated.

This paper reports on the analysis of the calculated impulses and the measured full impulses which have little or no distortion. It should be noted that this covers the majority of practical measurements. The analysis of the highly-distorted impulses is illustrated: more details will be reported at a later date.

This paper reports the evaluation of the following parameters: the peak value, the front time, and the time to half-value. For those impulses with oscillations on the front, the magnitude of the first oscillation was to be read. For those impulses with oscillations at the peak the amplitude and frequency of the oscillations were to be read. All records were zero-based and normalized to have a maximum value of unity: however the scale factor and zero offset of the originals were supplied for those participants who wished to reconstruct the original records.

3. Measures and Limits

The purpose of this study is to establish a data base of impulses with known parameters and to set practical limits on the errors permitted when a software package is used to evaluate the parameters. For the waveforms calculated from analytical models, the parameters are known exactly. For the measured waveforms, the mean value of each parameter determined in this study is taken as the correct value as a first step. The experimental standard deviation, s, and the range of each parameter are taken as measures of the variations in the analysis software used by the participants to evaluate the waveform parameters /2/.

The limits on the uncertainties in the measurement are set in IEC 60 for smooth impulses as 3% of the peak value and 10% of each time parameter for routine measurements /1/. The overall uncertainty described in /1/ is equivalent to the combined standard uncertainty defined in /3/ with all sensitivity coefficients taken to be unity and all sources of the standard uncertainties assumed to be independent (i.e. the estimated covariances are zero). The corresponding values for Reference Measuring Systems are 1% and 5%. It seems reasonable that the errors contributed by the software used in the analysis should be limited to some fraction of these limits and initial values of 1% of the peak value and 5% of the time parameters are suggested for routine measurements. Lower limits are suggested for comparative measurements against a Reference Measuring System (0.3% of the peak value and 2% of each time parameter).

The limits given in IEC 60 apply only to smooth impulses. For impulses with oscillations and/or overshoot then a smooth curve has to be drawn through the oscillations on the recorded waveform. Originally, this would have been a photograph and the curve would have been hand-drawn by the individual. Because no limits or guidance on method of drawing are given, the "eyeballed" smooth curves would be highly subjective. Software processing appears to offer a way to address this problem and some initial steps are proposed in this work.

4. Evaluation of Calculated Impulses

The parameters of the calculated impulse were: peak value 1, front-time 1202 ns, time-to-peak 2311 ns and time to half-value 50 220 ns. A summary of the values found by the participants are given in Table 3. The range reported here is the difference between the maximum and minimum value for each parameter reported by the participants. These values show that all twelve software packages give excellent results for a smooth double-exponential. Digitization error was simulated by adding randomly-generated noise having peak amplitude of 1% of the waveform peak amplitude to file DEXP150 to produce files L150N* (where * = 0 to 5 and 7 to 9). The results are still very good as is shown in Table 4 where the combined results are within the proposed limits. The results from each participating laboratory (identified by the same letter throughout this paper) are given for each parameter together with the experimental standard deviation (s).

Table 3. Results on a calculated smooth full impulse from Group 1 (DEXP150).

Parameter	Mean Value (population)	Experimental Standard Deviation, s	Error (Range)
Peak value	0.9999 (11)	0.0004	-0.0001 (0.0014)
Front time (ns)	1202.4 (11)	4.9	+0.4 (13.7)
Time to half-value (ns)	50327 (7)	95	+107 (203)

5. Evaluation of Measured Smooth Full Impulses

Results for two measured impulses are given in Table 5. The experimental standard deviation and the range of each parameter are small compared to the proposed limits. This shows that the approach works sufficiently well to be used to qualify software for either routine measurements or for comparative measurements with a Reference Measuring System provided a smooth full impulse is used.

Table 4. Results on calculated full impulses with added noise from Group 1 (L150N*, * = 0 to 5 and 7 to 9).

Test Facility	Peak value	Front time (ns)	Time-to half-value[1] (ns)
N	1.0013 (0.003)[2]	1206 (20)	50 014 (380)
P	1.00003 (0.0001)	1202.4 (4)	50 223 (50)
Q	1.01 (0)	1248 (29)	—
R	1.001 (0.0015)	1186 (17)	—
S	0.9996 (0.0006)	1198 (26)	50 223 (750)
T	1.006 (0.005)	1267 (60)	49690 (250)
U	1.01 (0)	1244 (28)	—
V	0.9999 (0.0003)	1203 (7)	—
W	1.0078 (0)	1237 (30)	49 250 (230)
X	1.0004 (0.0013)	1209 (11)	50 414 (330)
Y	1 (0)	1202 (9)	50 533 (660)
Z	1 (0)	1216 (8)	50 521 (60)
Mean s	1.002[3] (0.003)[3]	1218 (25)	50 108 (450)
Error	+0.002[3]	+16	-112
Error (%)	0.2[3]	1.3	0.2
Range	0.0082[3]	81	1283

[1]Not all participants were able to process records which used two sampling rates.

[2]Experimental standard deviations (s) of the results from each laboratory are given in parenthesis below the value of the parameter.

[3]Values Q,U,Y and Z were excluded from the calculation because their quoted precision is less than that of the other values.

6. Evaluation of Full Impulses with Oscillations, Distortion and Overshoot

The analysis of records in Groups 3 to 6 is continuing. Some examples of results obtained to date are given in Tables 6 to 8. The experimental standard deviation and the range of each parameter are considerably larger than for Groups 1 and 2. Further work is needed to discover the reasons for these larger variations. In part, these larger variations are caused by differences in interpretation, e.g., for F1P five laboratories referenced the time to half-value to the peak voltage while three laboratories referenced it to the overshoot (see Table 8). Work is continuing and further results will be reported at the Conference.

Table 5. Results on measured smooth full impulses from Group 2 (B3P and CS2P).

Parameter	Mean Value (population)	Experimental Standard Deviation, s	Range
B3P Peak value	0.9986 (11)	0.0012	0.0026
Front time (ns)	835.5 (11)	60	219
Time to half-value (ns)	59 286 (7)	273	653
CS2P Peak value	1.0002 (12)	0.003	0.0092
Front time (ns)	1287 (12)	23	78
Time to half-value (ns)	51 025 (8)	339	897

Table 6. Examples of results on measured full impulses with oscillations from Group 3 (A1P and ES4P).

Parameter	Mean Value (population)	Experimental Standard Deviation, s	Range
A1P Peak value	0.9987 (12)	0.0026	0.0074
Front time (ns)	1376 (12)	209	733
Time to half-value (ns)	36 827 (8)	205	632
ES4P Peak value	-0.9851 (12)	0.021	0.0197
Front time (ns)	1034 (12)	192	278
Time to half-value (ns)	45 032 (8)	551	1670

Table 7. Examples of results on measured full impulses with some distortions from Group 4 (D1P).

Parameter	Mean Value (population)	Experimental Standard Deviation, s	Range
D1P Peak value	1.0044 (12)	0.0085	0.0258
Front time (ns)	1090 (12)	193	668
Time to half-value (ns)	51 092 (12)	388	1256

7. Conclusions

The initial work has shown that the user's software packages are satisfactory for the analysis of smooth full impulses in routine tests, and for comparison measurements against a Reference Measuring System. Results of evaluation of these waveforms show small experimental standard deviations. Larger experimental standard deviations have been found for impulses with oscillations and/or overshoot. Investigations are continuing to identify the causes of these variations and to propose suitable limits on uncertainties for such impulses.

Table 8. Examples of results on measured full impulses with large overshoot and oscillations from Group 5 (F1P).

Parameter	Mean Value (population)	Experimental Standard Deviation, s	Range
F1P Peak value	0.7282 (8)	0.0346	0.0993
Front time (ns)	299 (9)	69	186
Time to half-value (ns)	19 038 (5)	453	1124
	9881 (3)	113	226
Overshoot (%)	37.3	4.7	13.6

References

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/2/ *International Electrotechnical Commission Reference Publication*, "International vocabulary of basic and general terms in metrology", pp. 15–16, 1984.

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