Report.

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Acceptance testing of Genesis Isolated Digitizer 6600 for current zero measurements of high-voltage circuit breakers in high-power testing

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CONTENTS

1 GENERAL REQUIREMENTS FOR CURRENT ZERO MEASUREMENT

Measurement of current and voltage during the interruption ("current zero") of short-circuit current is the most demanding requirement of high-power testing equipment because of requirements regarding:

1. High vertical resolution. Extreme dynamic range for current and voltage measurement is required (currents in the order of 100 mA should be measured immediately after the interruption of many tens of kA of short-circuit current and few kV of arc voltage must be measured against high rising transient recovery voltage).
2. High time resolution and bandwidth (the relevant processes occur on a sub-microsecond scale).
3. Very severe electrical transients arise both in current as in voltage during the switching process.
4. Very high levels of power-frequency currents are involved.

Requirements 1, 2 are linked to the required performance of the measurement system, requirements 3, 4 are related to the required EM immunity of the system in the high-power/ high-voltage environment of test labs.

2 DEFINITION OF THE SYSTEM UNDER TEST

The current zero measurement system consists of transducers (here for current and voltage), digitizers (that have to operate in this specific application as close as possible to the test circuit breakers to keep the galvanic connections between transducer and transient recorder as short as possible, typically 2 m), transient recorders and signal processing software (for signal reconstruction).
Subject of the test was the combination of the following components:

Part	Type	S/N
Isolated digitizer 6600	845-082100	IEM 0700122
Isolated digitizer 6600	845-082100	IEM 0700113
Isolated digitizer 6600	845-082100	IEM 0700111
Isolated digitizer 6600	845-082100	IEM 0700107
Fibre optic cables 100m, 4x	069-913800	
Receiver card	845-79500	THD 0600301
Genesis transient recorder	986A0151	FIB25/100M800
Perception software	version 4	

3 HIGH-POWER TEST PROGRAM

Given the absence of standards and generally accepted calibration methods against which to test, KEMA decided to set up a dedicated test program, based on experience gained in ten years of current zero measurement. The intention is to provide the relevant EM stresses to which local digitizers are exposed during high-power testing, as well as to assess the performance during actual current zero measurement.

The tests consisted of 3 parts:

1. Measurement of current zero wavetraces of current and voltage in the current zero region of short-circuit interruption. Such a measurement was performed under "short line fault" test conditions, specified in IEC 62271-100 clause 4.105.
   This test is producing the most severe transient conditions for the circuit breaker in the current zero region. Commercially available test-breakers and a protoype breaker with rated voltage of 420, 245, 145 and 17 kV were used, with currents ranging from 50 - 80 kA.
   These test series were basically aimed at testing the suitability of the system under test for current zero measurements (cf. requirement 1, 2 from section 1).
   Additionally, in desktop experiments, for verification of the effective vertical resolution of the system, the number of effective bits of the system is determined (see annex A). This is a key parameter for current zero measurement.
2. Measurements of voltage wavetraces during high-voltage breakdown events in the immediate vicinity of the system under test ("re-ignition transients" test). Breakdowns at around 220 kV were created of a spark gap in air, that was subjected to the application of 276 kV d.c. voltage. Breakdown current was produced by the synthetic installation of the test lab (medium frequency current estimated at 770 Hz, 3 kApk) and was initially supplied by a capacitor of 15 nF, placed across the spark gap (high-frequency current estimated at approx. 300 kHz, 5 kApk).
   Four digitizers under-test were located at approx. 2 m from the spark gap (see photo section 7).
   These test series are aimed at verifying the integrity of the system, the undistorted and uninterrupted operation during re-ignition / restrike events (high-frequency electric and magnetic fields) of the circuit breaker under test (cf. requirement 3 of section 1).
3. Measurement of power frequency (50 Hz) current in the vicinity of high power-frequency current. Short-time current was generated (184 kA asymmetrical peak value, 70.9 kA RMS, 0.19 s duration).
   Digitizers of the system under tests were placed inside the loop (5 m diameter) that conducted the current.
   These tests are aimed at checking the immunity of the digitizers for high strength low-frequency magnetic fields (cf. requirement 4 of section 1).

Tests were performed at KEMA High-Power Laboratory, Arnhem the Netherlands between March and July 2007.
Tests were supervised by prof. dr. R.P.P. Smeets (partly) and mr. S. Kuivenhoven M.Sc. (KEMA) and were partly wittnessed by mr. S. Roeloffzen and mr. H. Rijswijk (LDS Nicolet, Dongen, the Netherlands).

4 CRITERIA FOR ACCEPTANCE

Criteria were the following:

1. Intercomparison of the performance of the system in terms of vertical, time resolution (cf. 1, 2 of section 1), and bandwidth with the existing KEMA current zero transient recorder system in full-power interruption tests. This system, designed, constructed and tested at KEMA with over 1000 current zero tests is KEMA's standard method to record current zero information.
   For technical specifications, see annex B.
   To this aim, the output of the relevant transducers (rogowski coil, voltage dividers) were input to both systems at the same time and in an identical way.
2. Withstand, undistorted and uninterrupted performance under severe transient and steady state EMI conditions, prevailing during circuit breaker testing (cf. 3, 4 of section 1).

5 PERFORMANCE

Performance of the system under test with respect to each of the test-program items is as follows:

1. Current zero measurement test: In those tests in which the digitizers under test and the existing KEMA digitizers were coupled in an identical way to the same transducers (voltage divider, rogowski coil) the difference of the data signals was within the noise level of each of the systems.
   The vertical resolution, in the measuring ranges relevant to current zero measurement, expressed in the "effective number of bits" was established to be 10.6.
2. Re-ignition transients test: the system under tests showed no sign of disturbance from the nearby breakdown and its associated transients in current, voltage and its derivatives.
3. Power frequency tests: the system under tests was not affected by the close passage (1 m) of high amplitude 50 Hz current.

6 GENERAL CONCLUSION

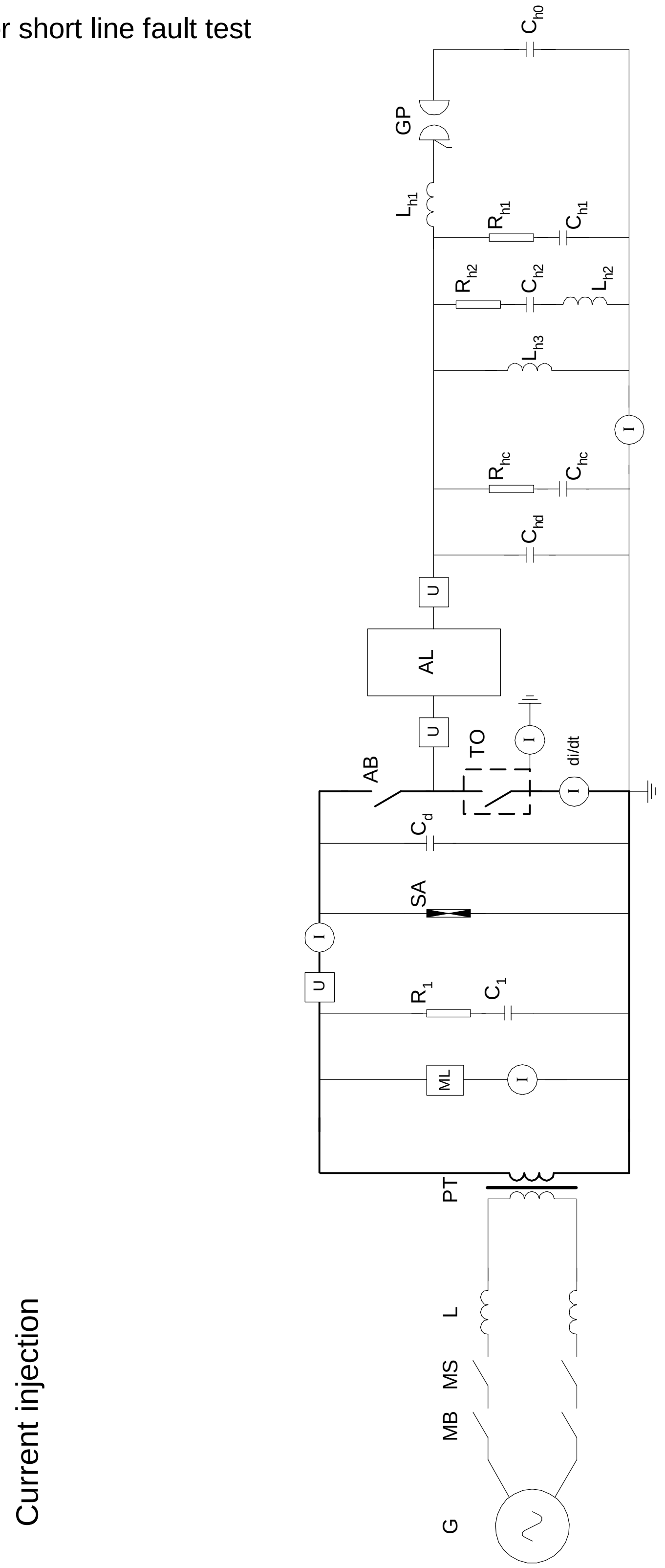
Based on the listed tests, and within the limits of its test-parameters, the Genesis 6600 isolated digitizer passed all test duties which are representative of high-power testing of circuit breakers.

Regarding current zero measurement capability, the Genesis 6600 isolated digitizer meets the internal KEMA requirements for current zero measurement.

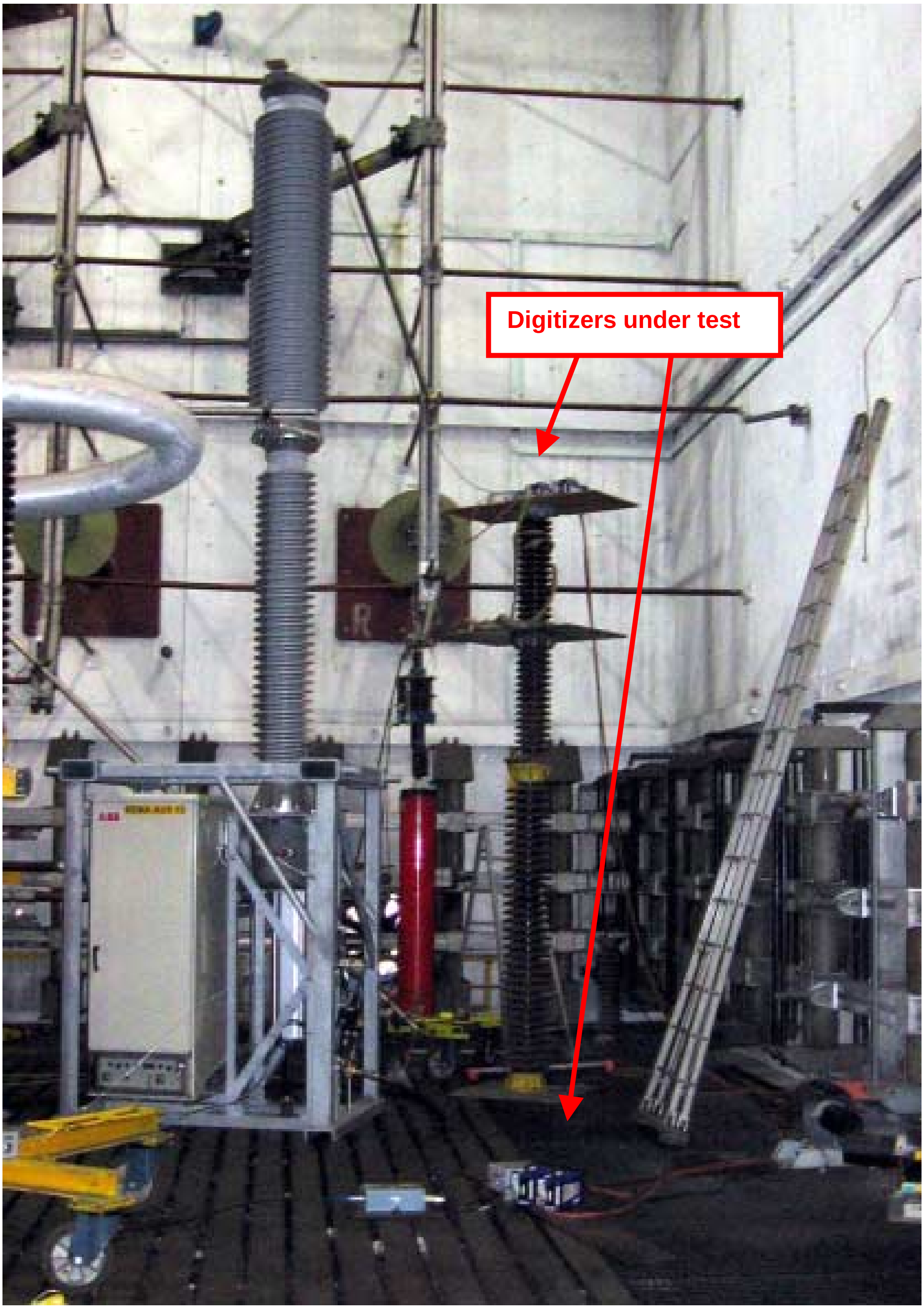
7 CIRCUIT DIAGRAMS, TEST SETUP PHOTOS AND REPRESENTATIVE WAVETRACES

7.1 Test 1: Short line fault current zero test

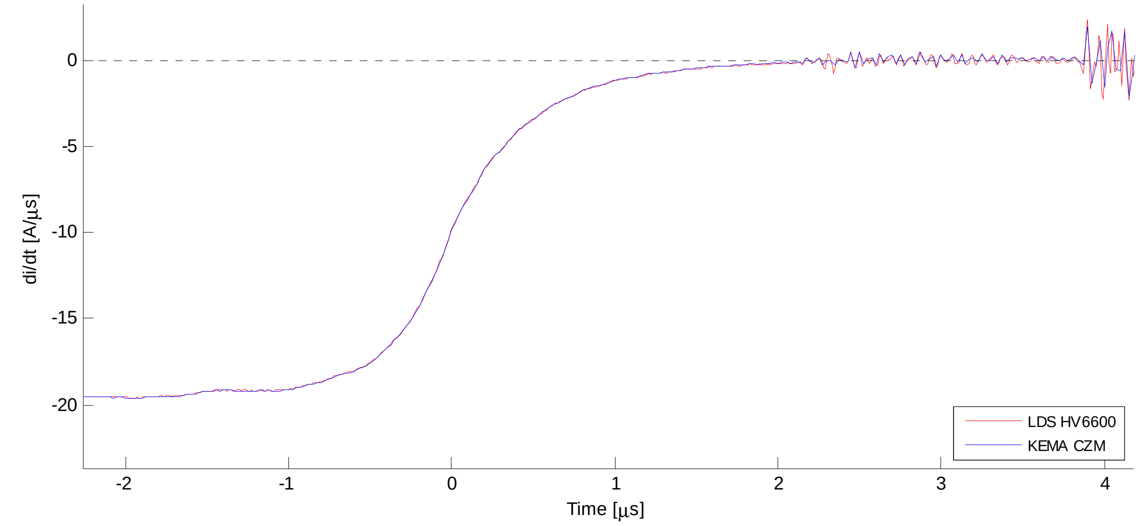
Test-circuit for short line fault test



G	= Generator	L	= Reactor	U	= Voltage Measurement to earth
MB	= Master Breaker	TO	= Test Object		= Current Measurement
MS	= Make Switch	R	= Resistor	AL	= Artificial line
PT	= Power Transformer	C	= Capacitor	ML	= Multi-loop device
SA	= Surge Arrester	AB	= Auxiliary Breaker	GP	= Gap
VS	= Voltage Source				



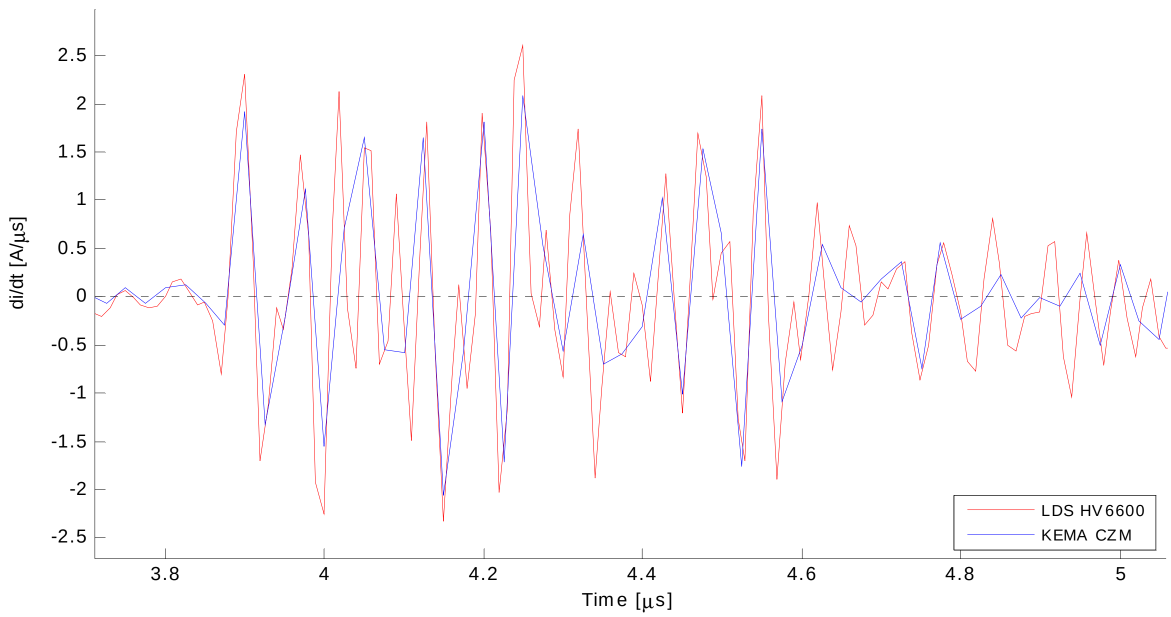
Short line fault test set-up



Current zero wavetraves (rogowski coil output) from system under test (LDS, red) and existing system (KEMA, blue) in the current zero (t = 0) region

Input range LDS HV6600: +29.0 A/µs to -29.0 A/µs

Input range KEMA system: +26.1 A/µs to -26.1 A/µs



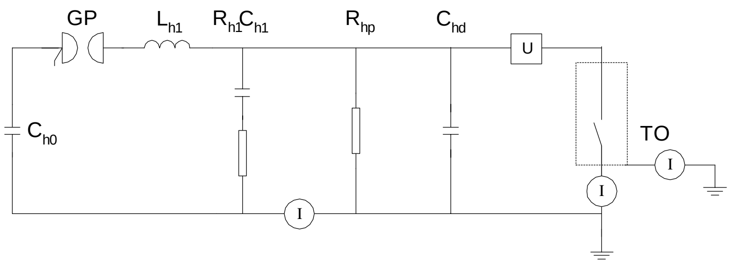
Current zero wavetraves (rogowski coil output) from system under test (LDS, red) and existing system (KEMA, blue) during electrical discharge after interruption (detail)

Input range LDS HV6600: +29.0 A/µs to -29.0 A/µs

Input range KEMA system: +26.1 A/µs to -26.1 A/µs

7.2 Test 2: Breakdown test

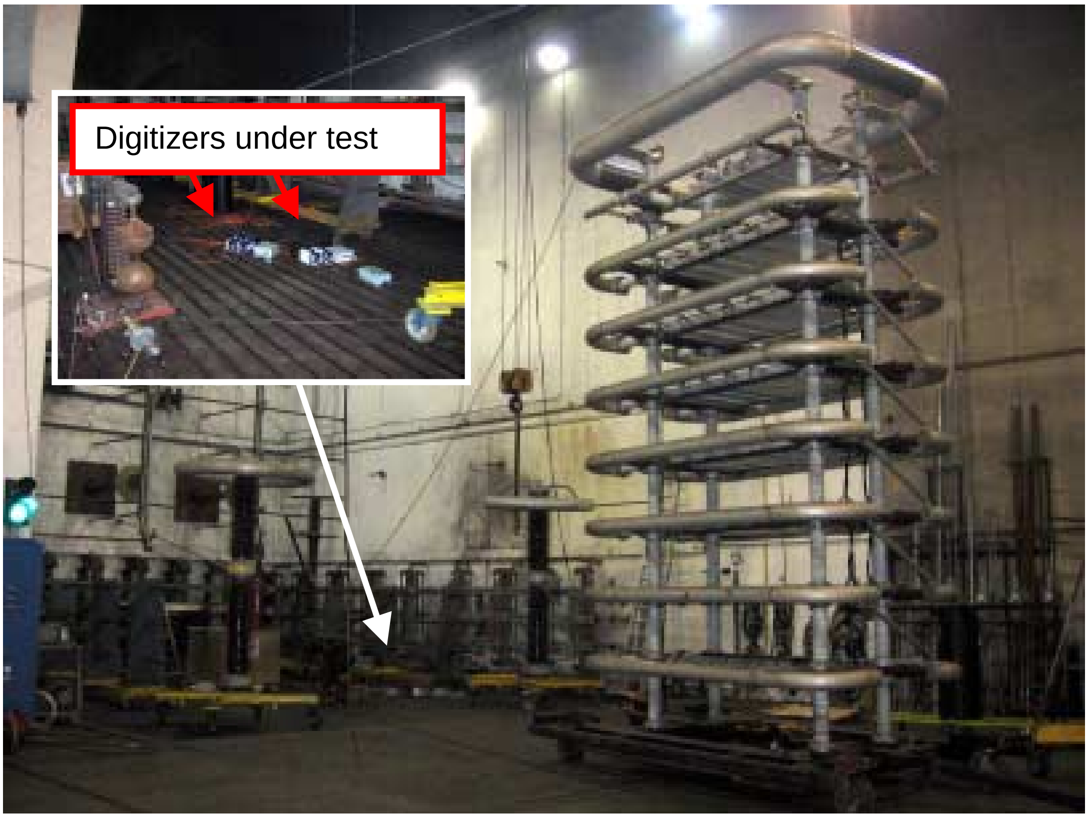
Test-circuit for breakdown test



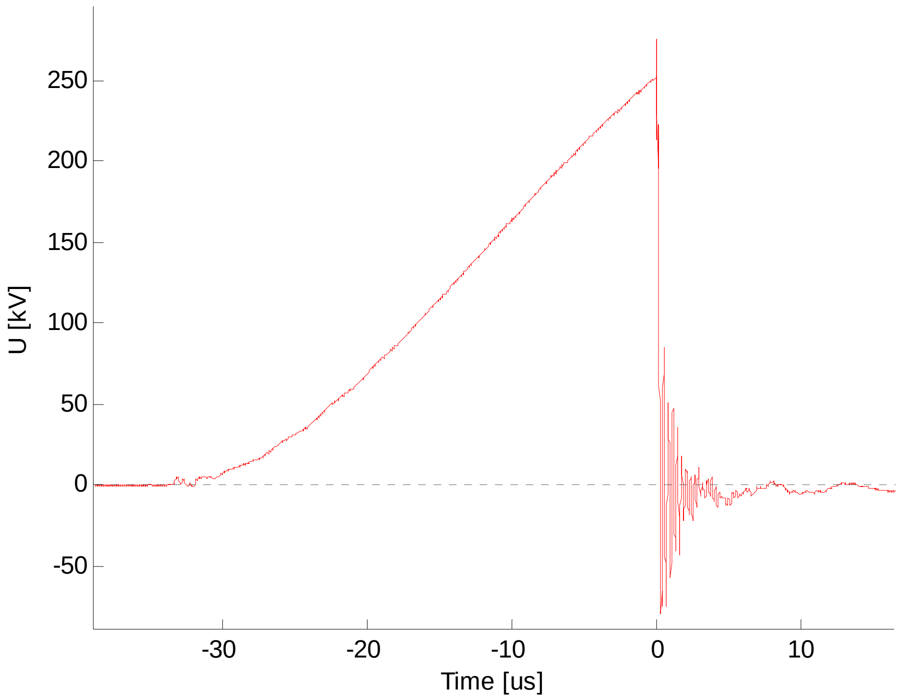
G	= Generator	TO	= Test Object	U	= Voltage Measurement to earth
MB	= Master Breaker	L	= Reactor	I	= Current Measurement
MS	= Make Switch	R	= Resistor		
PT	= Power Transformer	C	= Capacitor		

Injection circuit		
C_{h0}	µF	2.7
U_{h0}	kVd.c.	276
L_{h1}	mH	16
f_h	Hz	
R_{h1}	Ω	3200
C_{h1}	µF	0.5
C_{hd}	nF	15
R_{hc}	Ω	
C_{hc}	nF	
R_{h2}	Ω	
C_{h2}	µF	
L_{h2}	mH	
R_{hp}	kΩ	12
L_{h3}	mH	
f_{RV}	Hz	

Prospective TRV of supply		
$u_{recovery}$		
u_1	kV	
u_C	kV	390
t_d	µs	6
t_1	µs	
t_2	µs	45
t_3	µs	
Rate of rise	kV/µs	



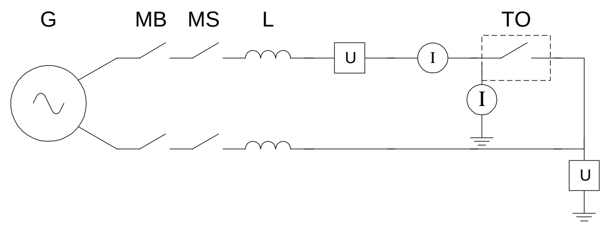
Test set-up for breakdown test



Voltage wavetrace of breakdown

7.3 Test 3: Short-time current test

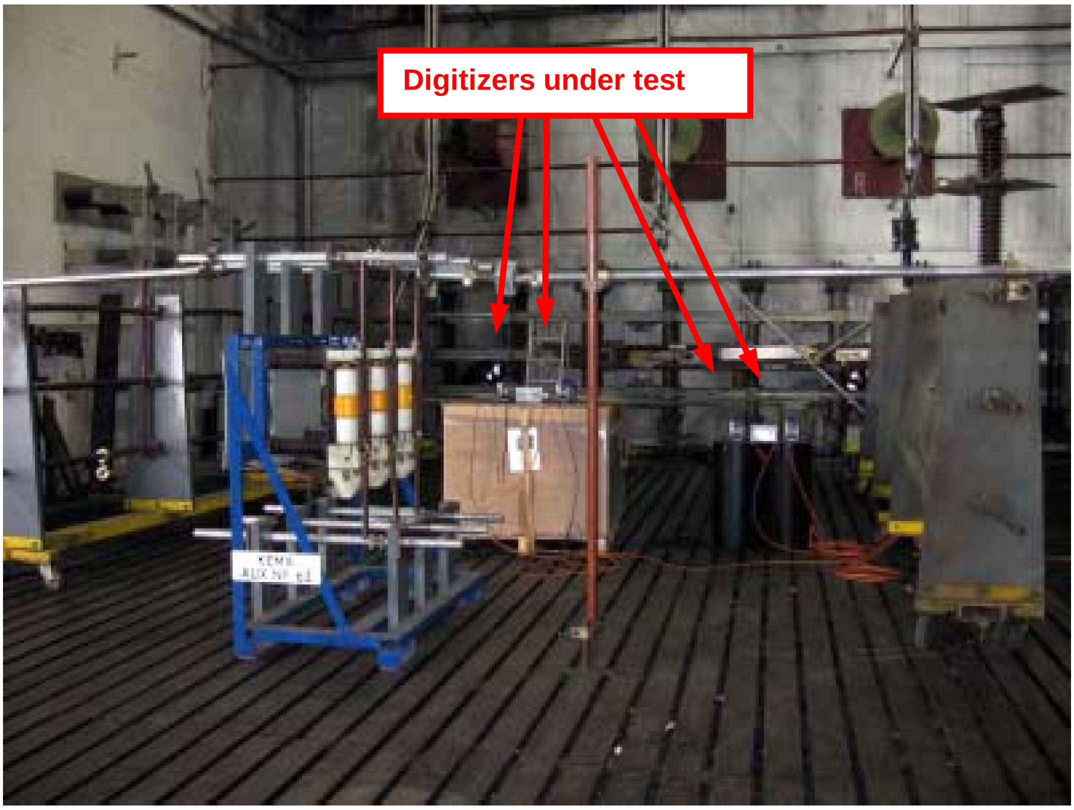
Test-circuit for short-time current test



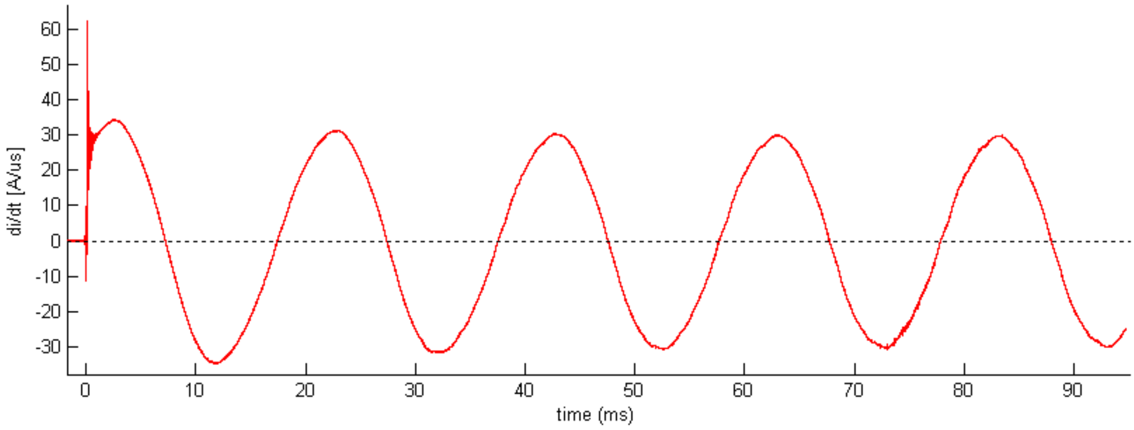
G	= Generator	TO	= Test Object	U	= Voltage Measurement to earth
MB	= Master Breaker	L	= Reactor	I	= Current Measurement
MS	= Make Switch				
PT	= Power Transformer				

Supply		
Power	MVA	512
Frequency	Hz	50
Phase(s)		1
Voltage	kV	7,3
Current	kA	70
Impedance	Ω	0.104
Power factor		< 0,1
Neutral		not earthed

Load	
Short-circuit point	earthed



Short-time current test set-up



Rogowski coil output during short-time current output

ANNEX A DEFINITION AND CALCULATION OF EFFECTIVE NUMBER OF BITS

The method of calculation of the Effective Number Of Bits (ENOB) is derived from Application note 728 “Defining and Testing Dynamic Parameters in High-Speed ADS, part 1” from Maxim Integrated Products, http://www.maxim-ic.com.

The ENOB value is calculated from the converter’s digital data record as

$$\text{ENOB} = \text{N-}\log_2 \frac{A_{MEASURED\_ERROR}}{A_{IDEAL\_ERROR}}$$

where N is the number of digitized bits, $A_{MEASURED\_ERROR}$ the rms value of the average noise and A_{IDEAL_ERROR} the rms value of the quantization noise error, expressed as

$$A_{IDEAL\_ERROR} = \frac{A_{FS}}{2^N \sqrt{12}}$$

AFS is the converter's full-scale input range. At zero input, with the input terminated with a 50 Ω terminator, recordings were made at various input span settings and sampling frequencies. The rms value of the average noise, equal to the standard deviation, was determined as

$$A_{MEASURED\_ERROR} = \sigma = \sqrt{\frac{1}{n-1}\sum_{i=1}^{n}\left(x_i - \overline{x}\right)^2}$$ where the sample mean is $\overline{x} = \frac{1}{n}\sum_{i=1}^{n} x_i$

ANNEX B TECHNICAL SPECIFICATIONS OF KEMA’S TRANSIENT RECORDER

Technical specifications of the recorder, used for comparison during current zero test series 1 are as follows:

- Maximum sampling frequency: 40 MS/s.
- Vertical resolution: 12 bit (effective number of bits 10.6 in relevant input range).
- Maximum input voltage span: 18Vpp.
- -3 dB bandwidth: > 20 MHz.
- SNR: 66 dB.
- Transient recorder memory: 256 kS per channel.
- Optical digital off-line data transmission.
- Battery operated.