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VOLUME 2

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INSTITUTION OF ELECTRICAL AND ELECTRONICS ENGINEERS

North Italy Section

VOLUME 2

41 - IMPULSE VOLTAGE GENERATORS AND TESTING CIRCUIT COMPONENTS

Special Reporter : K. Feser (Switzerland)

41.00 K. Feser (Switzerland)
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41.02 A. Marinescu (Rumania)
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41.03 R. Peiser, H.J. Reinhardt, W. Strauss, J. Vogt, W. Wendt (Federal Republic of Germany)
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41.04 M. Cortesi, C. Mazzetti, A. Tomassi (Italy)
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41.05 K. Feser, M. Modrusan, H. Sutter (Switzerland)
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41.06 K. Feser, M. Modrusan, H. Sutter (Switzerland)
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41.07 R. Buccianti, F. Gallucci, A. Pigini, G. Sartorio (Italy)
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41.08 A. Marconcini, G. Picci, G. Villa (Italy)
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41.09 R. Buccianti, W. Mosca, D. Perinelli (Italy)
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42.00 L. Thione (Italy)
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42.02 K.H. Gonschorek (Federal Republic of Germany)
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42.03 K. Dharmalingam, B.I. Gururaj (India)
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42.04 R. Malewski, G. Dick (Canada)
Digital recording of HV impulses with correction of digitization errors by a microprocessor.

42.05 N. Hyltén-Cavallius (Brasil) - T. Parnell (Australia)
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42.06 N. Hyltén-Cavallius, J.R. Fonseca (Brasil)
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42.07 R. Peiser, W. Strauss (Federal Republic of Germany)
Impulse peak voltmeter with extended measuring possibilities.

42.08 H. Anis, M. Abo-El-Saad (Egypt)
Optimal up-and-down testing of external insulation.

42.09 G. Praxl (Austria)
Automated evaluation of high voltage tests.

42.10 A. Di Napoli, C. Mazzetti (Italy)
Time-analysis of HV resistive divider from the electromagnetic field computation.

42.11 M. Aro, Y. Rantanen (Finland)
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42.12 W. Breilmann (Federal Republic of Germany)
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42.13 A. Schwab, H. Bellm, D. Sautter (Fed.Rep.of Germany)
Peak-error correction for front-chopped impulse voltages.

42.14 T. Harada, Y. Aoshima, M. Harada, K. Hiwa (Japan)
Development of high-performance low voltage arms for capacitive voltage divider.

42.15 M. Darveniza, B.C. Holcombe (USA)
A fast Fourier transform technique for correcting impulse voltage divider measurements.

42.16 J. Wierzbicki, St. Kwiatkowski (Poland) - K. Feser (Switzerland)
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42.17 U. Wacker, H. Boecher (Federal Republic of Germany)
Recent measurements and computations of transient electromagnetic field propagation near high voltage arrangements.

42.18 R.E. Hebner, S. Annestrand (USA)
Evaluation of calibration techniques for multimegavolt impulse dividers.

42.19 K. Alstad, J. Huse, H.M. Paulsen, A. Schei, H. Wold, T. Henriksen, A. Rein (Norway)
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42.20 I.S. Grant, A.S. Paulson, R.E. Kennon, D.D. Wilson (USA)
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42.21 L. Thione, G. Villa (Italy)
Application of fibre optics to impulse voltage measurements.

43 - DC AND AC: GENERATORS, TESTING AND MEASURING CIRCUITS, PARTIAL DISCHARGES MEASUREMENTS

Special Reporter : A. J. Schwab (Federal Republic of Germany)

43.00 A.J. Schwab (Federal Republic of Germany)
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43.01 F. Hollinger, H. Schultz, H. Zimmer (F.R. of Germany)
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43.02 F. Bernasconi, W.S. Zaengl, K. Vonwiller (Switzerland)
A new HV-series resonant circuit for dielectric tests.

43.03 J.Berril, J.M. Christensen, G.C. Crichton, I.W. McAllister (Denmark)
A high precision 300 kV DC measuring system.

43.04 C. Mangiavacchi, G. Rabach (Italy)
Partial discharges amplitude spectra measurement and analysis in aging process evaluation.

43.05 H. House, F.W. Waterton, J. Chew (United Kingdom)
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43.06 K. Trümpy, G. Szaloky, J.J. Wavre (Switzerland)
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43.07 K. Umemoto, E. Koyanagi, T. Yamada, S. Kenjo (Japan)
Partial discharge measurement system using pulse-height analyzer.

43.08 D. Peier, V. Graetsch (Federal Republic of Germany)
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43.09 T. Kawamura, M. Ishii, M. Akbar, K. Nagai (Japan)
Stabilized DC source for testing of polluted insulators.

43.10 G. Karlsson (Sweden)
Loss tangent digital meter.

43.11 P. Seitz (Switzerland), P. Osvath (Hungary)
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43.12 W. Schulz (Federal Republic of Germany)
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43.13 E. Lemke (German Democratic Republic)
A new method for PD measurement on polyethylene insulated power cables.

43.14 G.A. Gertsch (Switzerland)
Measuring errors of instrument transformers in the frequency range of 1 to 10.000 Hz.

43.15 L. Battistelli, V. Mangoni (Italy) - G.A. Gertsch (Switzerland)
Influence of magnetic saturation and of the residual induction on the transient behaviour of capacitive voltage transformers.

43.16 U. Brand, H. Dietz, H. Eberlein (Fed. Rep. of Germany)
A metalclad testing set for voltage transformers for GIS.

43.17 R.E. James, F.E. Trick, P.J. McMullan (Australia)
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43.18 G. Liptak, R. Schuler (Switzerland)
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43.19 D. König, C. Neumann, H. Lipken (Fed. Rep. of Germany)
Partial discharge measurements of SF_6-insulated high-voltage metal-enclosed switchgear on site.

43.20 E. Bertani, E. Molteni, W. Mosca (Italy)
The measurement of partial discharges in shunt capacitors for power system.

44 - MEASURING METHODS·OPTOELECTRONICS

Special Reporter : C. Malaguti (Italy)

44.00 C. Malaguti (Italy)
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44.01 M. Aguet, M. Ianovici, Ph. Blech, B. Zürcher (Switzerland)
Measurement of impulse currents using optical fibers.

44.02 A. Braun, R. Zirpel (Federal Republic of Germany)
Opto-electronic transmission system for high-voltage measurements.

44.03 S. Rid, N. Trapp (Federal Republic of Germany)
Optoelectronic control equipment for high voltage test facilities.

44.04 T.H. Teich, J.A.G. Neale (United Kingdom)
Current measurement by means of the Faraday effect and the Pockels effect.

44.05 T. Horváth, G. Clement (Hungary)
Measurement of the distortionless electric field intensity of high voltage installations.

44.06 D. Armanini, C. Brambilla (Italy)
Electric field measurement devices used in the 1000 kV plant at Suvereto.

44.07 R.T. Waters, E.O. Selim (United Kingdom)
Field filters - New static probes for field measurement at electrodes.

44.08 W.B. Stark (United Kingdom)
A significant improvement in the performance of the rotating electrostatic fluxmeter.

44.09 M. Milkovic, R. Humphreys, R.D. Baertsch, N.C. Gittinger (USA)
A solid state lightning surge recorder.

44.10 C.M. Arturi, E. Carminati (Italy)
Industrial prototype of a frequency-modulated electro-optical current transformer.

44.11 L. Thione, G. Costa, E. Elli, A. Mantini, A. Centemeri (Italy)
Application of fibre optics to the measurements of corona losses in UHV experimental lines.

51 - AIR INSULATION - PHYSICAL APPROACH

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51.00 R.T. Waters (United Kingdom)
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51.01 Y. Murooka (Japan)
Jutting electrode effects on breakdown voltage of 3 m rod-plate gap with positive switching impulses.

51.02 L.E. Kline, L.J. Denes (USA)
Prediction of the limiting breakdown strength in air from basic data

51.03 M. Chiba, T. Kouno, H. Fujita (Japan)
Stepwise propagation of surface discharge.

51.04 G.E. Maier (Switzerland)
Switching surge breakdown of rod(sphere) - plane gaps. Voltage drop and charge injection during the final jump.

51.05 J. Mrázek (Czechoslovakia)
Some results of czech research of long air sparks.

51.06 H. Isa, M. Hayashi (Japan)
Breakdown phenomena in non-uniform short air gap under impulse voltage.

51.07 H.D. Sprang (Federal Republic of Germany)
Analysis of breakdown mechanisms of long-air gaps under switching-impulse voltages with the help of a surface discharge analogy model.

51.08 F. Rühling (Federal Republic of Germany)
Calibration method for quantitative analysis of discharge channel diameter.

51.09 E.M. Bazelyan, V.I. Levitov, A.Z. Ponizovsky (USSR)
Electric field strength in the leader channel of a long positive spark in air.

51.10 I. Miyachi, K. Horii, S. Muto, G. Ikeda, S. Aiba (Japan)
Experiment of long gap discharge by artificially triggered lightning with rocket.

51.11 M. Darveniza, B.C. Holcombe (USA)
A two-electron population hypothesis for the leader channel in the breakdown of long air gaps.

51.12 G. Baldo, G. Pesavento (Italy) - B. Hutzler, J.P. Riu (France) - A. Fischer. P. Zacke (Federal Republic of Germany)
Phase to phase insulation : space charge effect on discharge development.

51.13 G. Pesavento (Italy)
Leader development under non standard lightning impulses.

51.14 M. M. Kekez, P. Savic (Canada)
Derivation of the breakdown characteristics of a positive rod-plane gap over a three-decade range.

52 - AIR INSULATION-ENGINEERING APPROACH

Special Reporter : B. Hutzler (France)

52.00 B. Hutzler (France)
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52.01 W. Mosch, H. Böhme, H. Löbl (German Dem. Rep.)
Breakdown of air-gaps heated by operating current.

52.02 T.E. Allibone, J.C. Saunderson (United Kingdom)
Sparkover of rod-plane, sphere-plane and rod-rod gaps stressed with DC voltages; effects of conditioning.

52.03 T.E. Allibone, D. Dring, N.L. Allen (United Kingdom)
The influence of electrode shape and condition on the humidity correction factor for negative polarity sparkover of rod-plane gaps.

52.04 W. Mosch, E. Lemke, E. Engelmann, M. Dietrich (German Democratic Republic)
Dimensioning of screening electrodes for UHV test equipments based on a critical streamer intensity.

52.05 W. Schulz (Federal Republic of Germany)
Erratic breakdown in air due to impurities in the presence of direct and alternating voltages.

52.06 T. Harada, Y. Aoshima, Y. Aihara (Japan)
V-T characteristics of air gaps for steep front impulse voltages.

52.07 P.V. Volkova, A.R. Koriavin (USSR)
Electrical strength of phase-to-phase air insulation in the light of discharge physics.

52.08 A. Fischer (Federal Republic of Germany)
Humidity and breakdown of 20 cm rod-plane gaps with negative impulse voltages.

52.09 J. Lalot, G. Gallet (France)
Breakdown phenomena at power frequency.

52.10 I.P. Kuzhekin, R.K. Borisov, V.L. Budowitch (USSR)
Investigation of dielectric recovery of gaps after pulse current passage.

52.11 C.W. Powell, H.M. Ryan (United Kingdom)
Switching impulse strength of a 765 kV simulated tower window with V-string insulators under artificial rain.

52.12 I.L. Krómer (Hungary)
Switching surge breakdown parameters of conductor-tower.

52.13 R.T. Waters, N. Farrag (United Kingdom)
Interdependence of impulse breakdown parameters and electric field.

52.14 M. Kleimaier (France)
Influence of the time to half-value on the impulse breakdown of large air gaps.

52.15 A. Pigini, G. Rizzi, R. Brambilla, E. Garbagnati (Italy)
Switching impulse strength of very large air gaps.

52.16 G.N. Alexandrov, Ju.A. Gerasimov, V.V. Korotkov (USSR)
The modelling of flashover in long air gaps.

52.17 G.N. Alexandrov, V.L. Ivanov, A.M. Sokolov (USSR)
Flashover characteristics of long air gaps for high voltage apparatus.

52.18 G. Baldo, G. Pesavento (Italy) - B. Hutzler, J.P. Riu (France) - A. Fischer, P. Zacke (Federal Republic of Germany)
Phase to phase insulation : effect of time shift between the two components of the applied voltage.

52.19 G. Baldo, G. Marchesi (Italy) - J. Lalot (France)
Breakdown of sphere-plane gaps under positive switching surges.

53 - CORONA IN AIR

Special Reporter : G. Baldo (Italy)

53.00 G. Baldo (Italy)
Special Report of Group 53.

53.01 M.S. Abou-Seada, A.R.M. Zaghloul, R.Y. Amer (Egypt)
A physical model for formative time lag calculation under space-charge-stabilized nonuniform fields.

53.02 I.C. Somerville, D.J. Tedford (United Kingdom)
The spatial and temporal variation of ion densities in non-uniform-field gaps subjected to steady state or transient voltages.

53.03 E.O. Selim, R.T. Waters (United Kingdom)
Current density distribution in negative coronas in air and nitrogen in the pressure range 0.1---760 torr.

53.04 D. Graf (Federal Republic of Germany)
Calculation of corona discharges in point to plane gaps.

53.05 M. Khalifa (Egypt)
On the controversial subject of glow corona.

53.06 H. Isa, M. Hayashi (Japan)
Observation of streamer corona under AC voltage by mean of streak photograph.

53.07 K. Arai, Y. Tsunoda (Japan)
Electric field by the space charge with temporal variation of mobility around a wire under corona discharge.

53.08 G. Berger, R. Hahn (France)
Statistical time-lag distribution of an electrical discharge in air.

53.09 Y. Murooka, S. Koyama (Japan)
A nanosecond surface discharge study in low pressures.

53.10 S.J. Dale (United Kingdom)
Primary corona characteristics and the dark period in long rod-plane gap discharges in air.

53.11 M.V. Sokolova (USSR)
The frequency influence on the discharge characteristics of an ozonizer.

53.12 A. Goldman (France)
Analysis of the energy losses on the plane of a point-plane negative corona for short gaps.

54 - SURFACE INSULATION

Special Reporter : P.J. Lambeth (United Kingdom)

54.00 P.J. Lambeth (United Kingdom)
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54.01 A.El-Arabaty, A. Nosseir, S.El-Debeiky, E. Nasser, A.El-Sarky (Egypt)
Measurement and analysis of dynamic discharge propagation on HV polluted insulators.

54.02 A.El-Arabaty, A. Nosseir, S.El-Debeiky, E. Nasser, E.El-Sharkawi, A.El-Sarky (Egypt)
Measurements of temperature of high-voltage polluted insulators using infra-red techniques.

54.03 L. Higginbottom, S. Zoledziowski, J.H. Calderwood (United Kingdom)
The dynamic model of flashover along a conductive surface.

54.04 R.M. Radwan (Saudi Arabia) - G.M. Abd El Salam (Egypt)
Effect of silicon grease on the DC electrical characteristic of polluted insulators.

54.05 D.A. Swift (United Kingdom)
Flashover across the surface of an electrolyte : some methods of arresting arc propagation.

54.06 L. Egiziano, G. Lupo', B. Macchiaroli, P. G. Orsini (Italy)
Chemical and electrical investigations on insulators covered with semiconducting layers.

54.07 R. Kosztaluk, J. Mikulski (Poland)
Electric withstand strength of insulator strings under various atmospheric conditions.

54.08 H. Anis, O. Gouda (Egypt)
Behaviour of desert-polluted insulators under transient voltages.

54.09 A. Leschanz, E. Steinort (Austria)
Examination of the influence of silicon grease on epoxy resin outdoor insulations.

54.10 K. Lloyd (USA) - G. Marrone (Italy)
ENEL-EPRI joint research comparison results of pollution tests performed on some given insulator strings at two different UHV laboratories.

54.11 J. Danis, I.L. Krómer (Hungary)
Switching surge performance of transmission line insulation in ambient conditions.

54.12 J. Danis, J. Schnörch (Hungary)
The correlation between the parameters in the different pollution test methods.

THIRD
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IMPULSE VOLTAGE GENERATORS AND TESTING CIRCUIT COMPONENTS

Special Report of Group 41

by

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Basel, Switzerland

Nine reports were assigned to group 41. The topic can be splitted up in following groups :

- impulse voltage generators with controls,
- impulse current generators
- switching impulse test on transformers
- bushings and terminations
- compressed gas capacitors.

1. Impulse voltage generators with controls

For testing purpose the lightning impulse voltage and the exponential switching impulse voltages are standardized in specifications. Therefore most of the efforts in the development of impulse generators were in the past related to the generation of these standardized impulse shapes. With the better knowledge of the overvoltages occuring in practical power systems more complex waveshapes are often needed to be generated in laboratories to simulate actual stresses. Especially for fundamental studies leading to improved testing methods with technical or economical background the different non-standard waveshapes are of interest.

In this wide range of possible waveshapes there is a special trend in the last years to investigate the behaviour of insulation systems or components to two waveshapes :

- the steep front impulse voltages and
- the oscillating switching impulse voltages.

Both waveshapes are not recommended in specifications, but demonstrate their actual interest in three papers, presented to this conference. Paper 41-01 describes a new impulse generator circuit for the generation of symmetrical and asymmetrical oscillating switching impulse voltages as well as all exponential waveshapes, whereas papers 41-04 and 41-06 are related to impulse circuit for the generation of steep front impulses.

At the moment the oscillating switching impulse voltage is discussed as possible waveshape for On-Site testing of SF_6-substations. The main point of applying oscillating switching impulse voltage to capacitive test objects is the resonance behaviour of the circuit, resulting in reduced costs for a given test voltage for the impulse generator. A further discussed application of oscillating switching impulse voltages is in the field of switching surge tests on transformers by applying discharges to the low voltage side of a transformer. This technique is also used to produce oscillating switching impulse voltages with test transformers. The paper 41-01 describes a circuit generating the oscillating switching impulse voltage with additional elements in a normal Marx generator circuit. The construction of the generator uses an indoor design and put it in a tower enclosure. This solution for outdoor impulse generators is nowadays adapted to practical all commercial available outdoor impulse generators.

Question 1 :

Where are the practical test applications of the oscillating switching impulse voltages besides of research work in insulation design for EHV and UHV transmission lines ? Should the oscillating switching impulse voltage be discussed as alternative to the exponential switching impulse voltages because the overvoltage in power lines are oscillatory and for certain test objects it is more economical to generate oscillating impulse voltages ?

Paper 41-04 and paper 41-06 bring the steep front impulses to our attention. In both papers the steep front impulses are generated with peaking circuits in connection with normal Marx generators. The main problems involved are the behaviour of the gap and the practical problems to build the components including the gap with a low inductance. Rise times of less than 10 ns at voltages of 500 kV are demonstrated in paper 41-06.

One practical application of these steep front impulses seems to be in testing of modern electronics in substations, electronics in high voltage laboratories or electronics in telecommunications systems, avionics or military systems. In all these cases, the electromagnetic field generated by high voltage breakdowns, lightnings or atomic explosions can destroy the electronic components or lead to malfunction of electronic measuring or control systems. Paper 41-03 shows one possible solution for the interference problems in high voltage laboratories for the control of impulse generators. Similar solution used in the past have the optical link applied between µ-prozessor or minicomputer and control system, but also solution without any optical link are working (see paper 41-01).

Question 2 :

What is the experience of users or manufacturers of modern electronics in substations ? Is it necessary to introduce a high voltage interference test in substation to test the wiring and the compatibility of all electronics against transients ? What waveshapes should be used for testing purpose ?

2. Impulse current generators

For testing of power apparatus 4/10 µs or 8/20 µs-current impulses with specified peak amplitude of 100 kA resp. 20 kA are standardized. Measurements of natural lightning and statistical evaluation of the results show that the four parameters representing a lightning stroke can be simulated by an idealized current test waveform. Paper 41-05 describes a test circuit for the simulation of this current waveform.

Question 3 :

Is this new idealized current test waveform for the evaluation of the direct effects proposed by military specifications also relevant to the testing of high voltage arrestors or material for lightning protection.

3. Switching impulse test on transformers

A possible solution for the problem involved in the switching impulse test of transformers is shown in paper 41-02. As it is reported the main problem of transformer testing with switching impulses seems to be the different waveshapes resulting of the saturation of the core and therefore 4 to 5 impulses of opposite polarity and about 50% amplitude are applied before the test voltage. Then it is possible to get reproduceable waveforms at a certain test voltage. But changing the test voltage results in another waveform, therefore the reference-voltage and the test-voltage are different. With an adjustable d.c. current supplied permanently to the not tested low voltage terminal the saturation can be compensated and the zero passage of the voltage can be adapted to be the same for the reference voltage and the test voltage. This helps by the interpretation of the test results.

Question 4 :

What is the most often used practice of switching impulse tests with transformers ? What is the experience in evaluation of measured results of switching impulse tests with different time to zero ? Have other people applied the d.c. current for compensation and what are the practical experiences with both methods ? Are there any other problems related to the fact that the low voltage terminal of the transformer is connected to a certain impedance ?

4. Bushings and terminations

The last three papers are all dealing with the design of bushings or terminations for a.c. applications. Two papers 41-07 and 41-09 are describing a bushing or termination for laboratory use at very high voltage levels. The main purpose is to get an economical solution which can be built by laboratory people. The design characteristics described in paper 41-07 for air to air bushing and in paper 41-09 for terminations for testing of plastic cables are in this respect very useful.

Question 5 :

Can an air to air bushing be used to replace a wall bushing ? What is the long time behaviour and the outdoor performance of such a bushing ?

5. Compressed gas capacitors

Paper 41-08 describes a new design of a bushing used in a compressed gas capacitor, resulting in a reduced height but increased diameter of the apparatus. It is also stated that the electrical parameters can be kept with lower tolerances in respect to temperature and voltage variations than the older design.

Question 6 :

What is the maximum change in capacitance of different constructions of compressed gas capacitor ? Is it economical visible to use for the design of indoor compressed gas capacitors a bushing ?

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IMPULSE GENERATOR FOR TESTING THE INSULATION OF EHV - UHV TRANSMISSION LINES AND EQUIPMENT

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Abstract - It is of major importance for selecting adequate insulation for EHV and UHV transmission lines to use in tests such waveshapes that would simulate as closely as possible anticipated overvoltages in such lines. Presentday factory-made impulse generators fail to satisfy the researchers completely in this respect. The 5 MV universal impulse generator developed and manufactured by VEB TuR "Hermann Matern" (GDR) to order of DC Research Institute (USSR) meets the challenge most successfully.

THE PAPER

Test waveshapes - In the last decade impulse generators have been used in different countries and helped obtain a wealth of experimental data on overhead line insulation which have proved the time to crest T_{cr} to be an inadequate criterion for assessing the impulse waveshape. This is evidenced by a "minimum" of the volt-time characteristic for air gaps several meters long, by the absence of a "minimum" and by a uniform reduction of the flashover level with T_{cr} increasing for air gaps over 10 m /1,2/, by the incompatibility of the volt-time characteristics (with T_{cr} = 1000 μs) obtained with impulse generators and those obtained with transformers /2,4/. Therefore a new criterion has been suggested and confirmed by coordinated tests /2/ for positive polarity impulses, which is based on an experimentally substantiated fact of flashovers occuring only at the "active part" $T_{0.7}$ of the wave front, i.e. during the time interval between 0.7 $\bar{U}$ and 1.0 $\bar{U}$, $\bar{U}$ being the impulse crest voltage corresponding to a 50 % flashover probability. This approach has permitted to bring in alignment test data obtained from impulse generators and from transformer cascades and to suggest a conversion technique for results obtained by the two methods. However, aperiodic impulses used in negative polarity tests or in moist contamination and wet tests of line and external equipment insulation result in distorted measurements of the

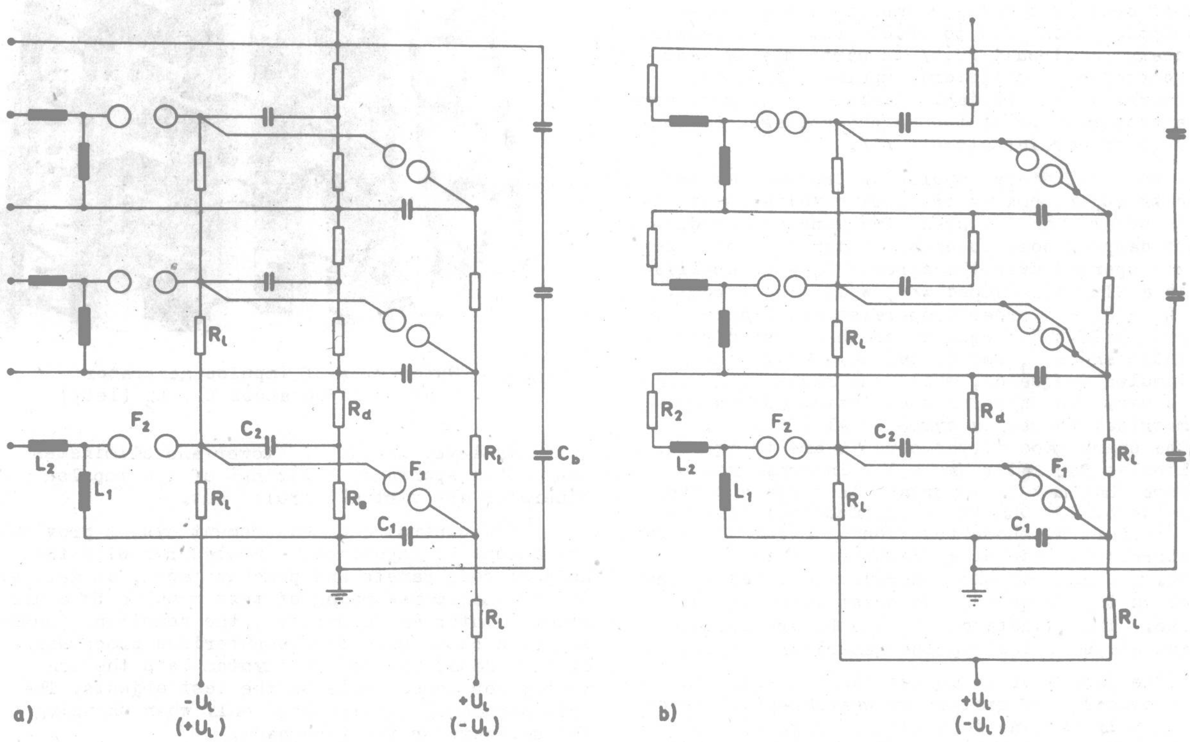

Fig. 1 Circuit diagrams of impulse generator (3 stages)
a) aperiodic impulse circuit b) oscillatory impulse circuit
C_1, C_2 - basic capacitances, C_b - load capacitance, R_d - damping resistor,
R_e - discharge resistor, R_2 - oscillatory impulse damping resistor, R_L - charging resistor,
L_1, L_2 - inductances, F_1, F_2 - spark gaps, U_L - load voltage

volt-time characteristics due to a profound difference in the shape between these impulses and the actual switching overvoltages after crest.
To avoid such distortions the impulse generator must be capable of producing both aperiodic and oscillatory impulses thereby permitting to obtain compatible volt-time characteristics with the help of a single installation. At present oscillatory impulses with T_{cr} = 2000 μs can be obtained only by using cascades of test transformers /3/.

<u>Design of the new impulse generator</u> - The TuR-designed impulse generator has taken account of the above requirements and has a number of features making it substantially different from earlier factory-made models of impulse generators. This 5 MV 20-stage impulse generator with the total charging energy of 800 kJ is of the conventional multiplier type and is capable of producing both aperiodic impulses with times to crest from 1.2 to 5000 μs and times to half value from 40 to 200,000 μs, and damped oscillatory impulses with frequencies of 500, 1000 and 2000 Hz. The generator can be charged through charging resistors or through pneumatically operated charging switches. The latter assure a high efficiency factor of the installation and a short charging time even with the longest impulses. Connected to the output of the impulse generator is a 450 pF slightly damped capacitive voltage divider which acts as the load as well. As T_{cr} rises the internal resistance of the generator gets increased. To avoid dips in the voltage curve because of leaders on the test object during tests with longer times to crest, an additional loading capacitance of 8 nF can be connected to the generator. Reliability of firing at any values of T_{cr} is assured by using triggered spark gaps of all the stages of the impulse generator. Twenty series-connected chopping spark gaps provide for chopping of aperiodic voltage impulses, with times to chopping from 1.4 to 10.000 μs. The symmetrical charging circuit /5,6/ is particularly adapted for generating oscillatory impulses (Fig. 1). It assures a more reliable firing of the generator and a better shape of the output voltage, as compared to an earlier circuit /7/.

An oscillatory impulse is produced at each stage by superimposing two cosine voltages of opposite polarities different frequencies and different damping coefficients. After the spark gap F_2 gets sparked over the circuit $C_1 - L_1$ oscillates in a slightly damped way, while the circuit $C_2 - L_2 - R_2 - R_d$ nearly operates aperiodically, but with half the frequency of the first circuit. The inductances L_1 and L_2 can be used to change the impulse frequency, while the resistor R_2 serves to vary the shape of oscillation curves from asymmetrical to nearly symmetrical (Fig. 2). All the spark gaps of the circuit are triggered. The impulse generator has a low internal resistance that may be important in certain tests. Its value of 180 Ohm is determined basically by the resistors R_d whose function is merely to limit the current in case of a flashover on the test object. A change of the generator load has a minor effect on the frequency and crest value of the impulse. The inductances L_1 and L_2 are arranged at each stage of the impulse generator (Fig. 3).

The generator is an outdoor installation but is housed in a stationary weather-proof envelope of polyurathane foam blocks (Fig. 4), 9,5 m in diameter and 22 m high provided with a 1 m diameter toroidal top-electrode. To increase the creepage distance, the envelope tower has a ribbed outside surface assuring rated parameters of the generator's operation in rain. An air conditioning plant maintains a uniform temperature and

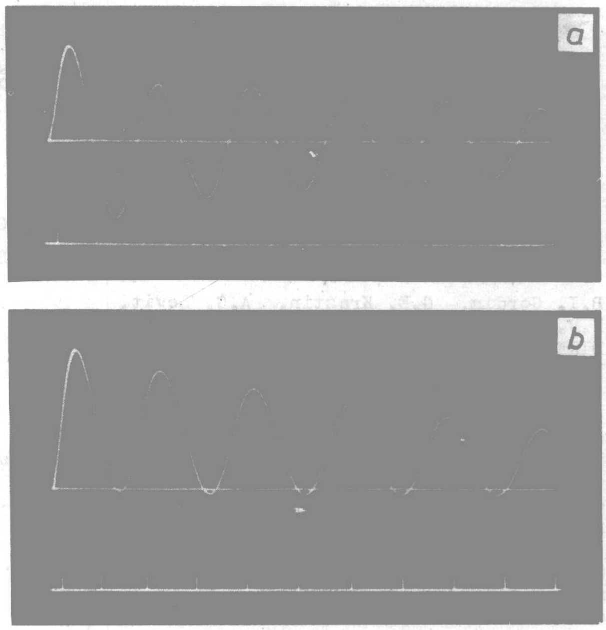

Fig. 2 1000 Hz Oscillatory impulses, timebase 500 μs per unit
a) symmetrical, crest value 1670 kV, R_2 = 100 ohms
b) asymmetrical, crest value 2480 kV, R_2 = 1920 ohms
$C_1 = C_2$ = 2560 nF, R_d = 16 ohms, L_1 = 8 mH, L_2 = 32 mH

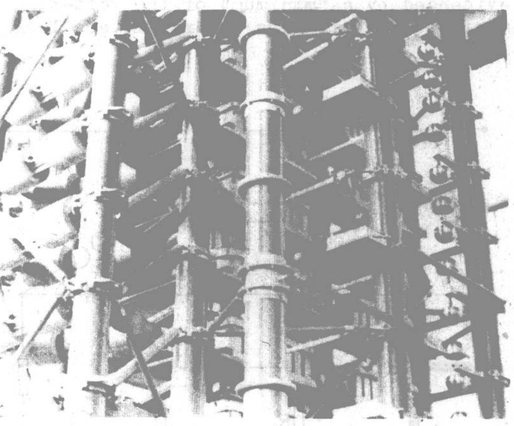

Fig. 3 Outer view of impulse generator showing inductances L_1, L_2 (left)

humidity level inside the tower and eliminates dust. Thus spontaneous firings of the impulse generator are virtually ruled out.

The control and measurement system provides for automatic experiment procedures with the help of code panels and punched tapes, as well as for automatic recording of test results by a numerical printer and a puncher, the resulting punched tapes being used for computerized processing of test data. The control system lets the investigator concentrate on the test objects. The test personnel get involved only when changing the software or the waveshape.

<u>Test results</u> - The impulse generator was commissioned in Leningrad, USSR, in September - December 1978. During the commissioning tests the generator was used to obtain 1.2 / 50 μs lightning impulses with 4 MV crest value,

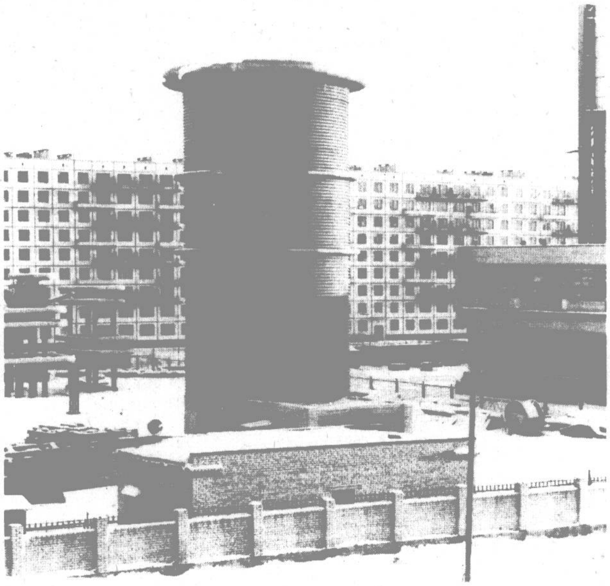

Fig. 4 General view of 5 MV impulse generator in in its tower (DC Research Institute, Leningrad)

250 / 2500 us, 500 / 10.000 us and 5000 / 200.000 us aperiodic switching impulses with 2.5 MV crest values, and oscillatory switching impulses with frequencies from 500 to 2000 Hz and crest values from 2 to 2,75 MV.
Aperiodic impulses were successfully and reproducible chopped. These and further tests took place under a variety of weather conditions (fair weather, light rain, shower, storm, snowfall, frost down to -30° C) which did not affect operation of the impulse generator. Normal indoor conditions were always maintained inside the envelope. There were a few cases of spontaneous spark gap extinction on the tail of 5000 / 200.000 us impulses. This appears to be the result of attaining a natural physiacal limit of superlong aperiodic impulses obtained with the help of spark gaps. The impulse generator was tested using the control and measurement system which functioned quite successfully. At present the impulse generator is used for a research project dealing with UHV transmission line insulation.

CONCLUSION

The 5 MV, 800 kJ universal impulse generator makes it possible to carry out various tests and research on EHV and UHV insulation under conditions very closely simulating those of actual operation. The wide range of impulse wave shapes and the automatic test procedures result in a higher confidence level of test results, a shorter test time, and a lower cost of experiments.

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THIRD
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POWER TRANSFORMER SWITCHING IMPULSE TEST METHOD USING DIRECT CURRENT SIMULTANEOUS DEMAGNETIZATION OF MAGNETIC CORE

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Abstract - An operative method for a switching impulse test (SI test) of transformer using direct current simultaneous demagnetization of magnetic core with which it can be obtained a controlled or even constant duration as far as to zero passage of SI, indifferent of the test voltage value is suggested.

It is analysed theoretically and experimentally the behaviour of the demagnetization circuit in transients caused by SI application and with a view to routine tests it is established the method of the two parameters for determination by calculation of the demagnetization current and of the time to the first zero passage for different test voltages.

1. INTRODUCTION

In the last years within of IEC and CIGRE has been discussed the amendment of the insulation tests available for some decades. One found necessary to introduce new tests and to abandon the tests useless strength the insulation and generally give a little indications about real behaviour in transformer service.

Materialisation of these proposals it is stated in [1] which introduce inter alia the switching impulse test (SI test) of the high voltage equipment with $U_m \geqslant 300$ kV, in the same time reducing the power frequency test voltage.

At power transformer SI test two significant problems arise, namely [2]:

- the decrease of the impulse duration due to saturation of magnetic core, generally obtaining a reduction of the time to first zero passage (t_0) proportional to overvoltage factor $K_s=\sqrt{3}/2(U_m/U_T)$ where U_T is the test voltage;
- difficult compare of the voltage and current oscillograms through winding under test at different test voltages with the view to insulation failure detecting.

In the papers so far published concerning this subject, the reduction of t_0 at voltage increase is compensated by change of the remanence flux from the magnetic core either by application of SI of opposite polarity in the interval between the useful impulses [3,4,5,6,7,8] or by a temporary application of a dc in the same time [2].

The main disadvantages of these solutions are [9]:

- significant stress of the outside insulation; demagnetization impulses have positive polarity and relative high amplitude (60 ÷ 80% from full test voltage) and it is necessary to apply 3-4 impulses to obtain the saturation opposite to useful impulse;
- lower promptness of the tests; the number of the demagnetization impulses is bigger than the number of useful impulses and the fail of the oscillographic recording of one of the useful impulses leads to reccurence of demagnetization impulse series. Demagnetization under temporary applied dc requires the safe mechanic separation of the dc circuit to avoid HV penetration yielded by test impulse in dc source.
- the impossibility of the accurated control and adjustment of the demagnetization obtained by the help of the impulses or of the temporary applied dc due to unknown demagnetization coefficient of the magnetic core.

Therefore the change of the SI transformer test into a routine test need a safe and efficient test method and it is the purpose of the present paper to suggest a solution of this problem.

2. PRINCIPLE OF SUGGESTED METHOD

In Fig.1 it is given SI test circuit of a three-phase transformer completed on the low voltage side with the dc demagnetization circuit (thick lines) remaining permanently coupled.

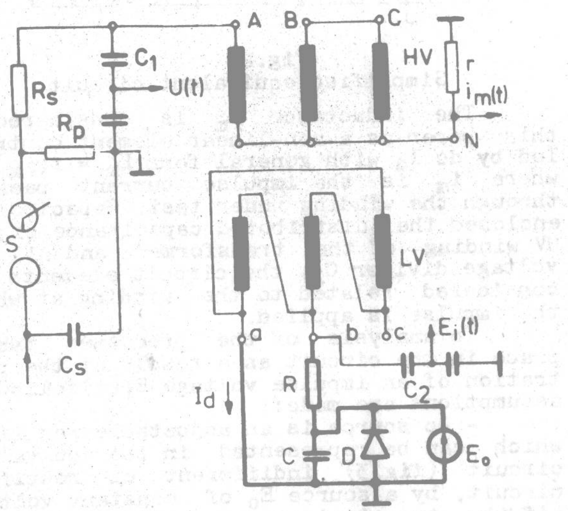

Fig.1
Suggested test circuit

The essential element of the circuit is RCD group having the following functions:

- transmission of the demagnetization dc I_d yielded by a controllable direct current source E_o;
- attenuation of the induced impulse voltage $E_i(t)$ at secure values for E_o source and its aferent circuits;
- additional protection of the low-voltage side at the accidentally breaking of the connection of the capacitor C by diode D which is "on" only when the impulse voltage amplitude at the terminals of the source exceeds E_o value.

SI test technique with the new proceeding is the following:

(a) - one or more reference impulses are applied to a voltage between 50 and 70% from U_T with $I_d=0$ and it is determined t_0 (at this voltage usually the magnetic circuit is already saturated);

(b) - a demagnetization current $I_{d\ max} = (0.05 + 0.15)\sqrt{2}\ I_{on}$ is established where I_{on} is the effective value of the no-load rated current at 50 Hz; in Section 4 it will be shown how to choose the accurate value of the demagnetization current;

(c) - the impulses are applied to the full test voltage which must have the same duration t_0 as the reference voltage now;

(d) - one or more reference impulses for $I_d = 0$ or $I_d < I_{d\ max}$ are applied if exceptionally the same duration of the impulses from (a) and (c) is not obtained;

(e) - the oscillograms at the reference voltage are compared with those at the test voltage after the classic rules of the insulation defectoscopy [2].

3. ANALYSIS OF DEMAGNETIZATION CIRCUIT PERFORMANCE AT SWITCHING IMPULSE APPLICATION

In Fig.2 it is presented the simplified equivalent circuit of the test circuit from Fig.1 in which one take into account the fact as the SI is generally applied on a winding and the demagnetization dc on another winding.

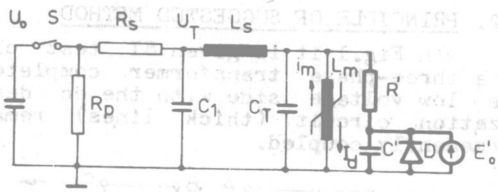

Fig.2
Simplified equivalent circuit

The inductance L_m is considered in this paper as a non-linear element controlled by dc I_d with general form $L_m = f(i_m, I_d)$ where i_m is the impulse current passing through the winding under test. Capacitor C_T enclosed the distributed capacitance of the HV winding of the transformer and of the voltage divider C_2; the circuit elements are considered related to the winding at which the impulse is applied.

To analysis of the processes taking place in the circuit as a result of the penetration of an impulse voltage $E_i(t)$ following assumptions are made:

- Dc source is an adjustable rectifier which can be represented in the equivalent circuit (fig.3) indifferent of rectifier circuit, by a source E_o of constant voltage (if the transient process time is lower in regard to conduction period of the rectifier diodes) in series with a diode d and with the equivalent leakage inductance L_{sr} of the rectifier transformer windings;

- SI has a single zero passage as a result of L_m saturation; the induced voltage $E_i(t)$ keeps a similar shape and according to theorem of equality of areas, the A_1 and A_2 areas must be equal (Fig.4).

Idealized impulse for calculation has the expression:

$$E_i(t)=E_i[\gamma(t)-(1+a)\gamma(t-t_1)+a\gamma(t-t_2)]$$

where $\gamma(t)$ is the unit step function; $\gamma(t-t_1)$, $\gamma(t-t_2)$ are retarded unit step functions and $a = E^2_{inv}/E_i$ represents the backswing.

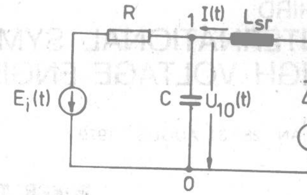

Fig.3
Circuit for calculation of $E_i(t)$ impulse penetration into the power source.

From Fig.4 one notice as the idealised impulse area A'_1 is larger than the real impulse area A_1 if $t_1=t_0$; one can so obtain the covered results.

The calculation conducted as in [10] leads to the following expressions for the change in time of the voltage at the rectifier terminals:

$$U_{10}(t)=E_o-(E_i(t)/R)\sqrt{L_{sr}/C}\ \exp(-\beta t)\sin\omega_o t \quad (1)$$

and for impulse current supplied by rectifier:

$$I(t)=(E_i(t)/R)\left[1-\exp(-\beta t)\cos\omega_o t\right] \quad (2)$$

where $2\beta=1/RC$ is the attenuation of circuit RC and ω_o is natural frequency of the $L_{sr}C$ circuit.

From the plotting of these amounts given in Fig.5 results that in the moment when $U_{10}(t)$ becomes equal to E_o the current has a maximum value and continues to flow until the whole magnetic energy stored in L_{sr} inductance is returned to the circuit. In the moment $t = t_3$ the current becomes zero and remains zero due to diode d "off". From this moment the validity of the relation (1) and (2) ceasses and further on voltage variation is given by the integration of the opposite oscillation of the voltage $E_i(t)$ due to RC circuit with the maximum value

$$(U_C)_{max} = -(A'_1/RC)\left[(t_2-t_3)/(t_2-t_1)\right] \quad (3)$$

To calculate the maximum voltage drop at the rectifier terminals they observe this takes place for $t=\pi/2\omega_o$ and therefore:

$$\Delta U_{max} = -(E_i/R)\sqrt{L_{sr}/C}\ \exp(-\pi\beta/2\omega_o) \quad (4)$$

Then the capacitance of C must be so chosen in the case of a given rectifier that to minimize ΔU_{max} i.e.:

$$\sqrt{L_{sr}/C} \ll R \quad (5)$$

Maximum voltage appearing at the rectifier terminals is:

$$(U_{10})_{max}=U_{10}(t_3)+(U_C)_{max}+E_o \quad (6)$$

After the fading of the $E_i(t)$ impulse the capacitor C charged at the voltage $(U_{10})_{max}$ given by (6) is discharged by R in the secondary winding of the transformer. The discharge has taken place by the time that the voltage at capacitor terminals decrease to E_o value, moment when the rectifier sets in conduction getting finally the constant dc $I_d = E_o/R$.

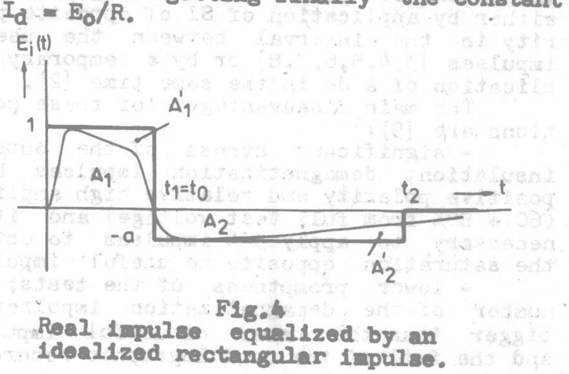

Fig.4
Real impulse equalized by an idealized rectangular impulse.

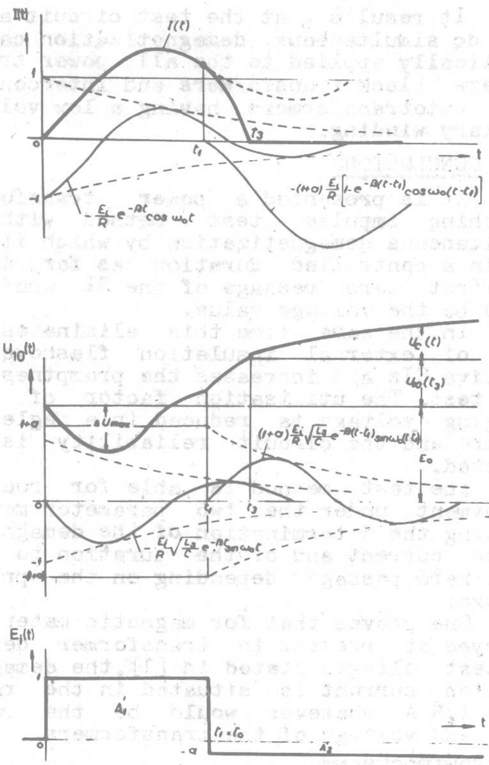

Fig.5
Current and voltage at the rectifier terminals calculated in the case of the idealized SI application

In Fig.6 it is presented the oscillogram of the induced voltage $E_1(t)$ and of the voltage at the rectifier terminals $U_{10}(t)$ getting by an 190 MVA 242/15.75 kV Y_od-5 block transformer test under the above circuit. Besides the similitude with the calculated curves from Fig.5 they notice the moment of blocking of the rectifier and further on the slow rising of the voltage due to RC circuit. It is also established a very good correlation for ω_o (1500 as to 1530 1/s calculated) on the other hand as it was to be expected the calculated value for ΔU_{max} is higher than that measured (150 as to 100 V) due to simplification inserted into the calculation (neglected of the ohmic resistance of the rectifier circuit and the adoption of the idealised rectangular impulse).
Repeatibility of t_o duration for succesive impulses is very good but for routine application of the suggested circuit must by found a method for predetermination by calculation of t_o and I_d at different test voltages.

4. TWO PARAMETER METHOD FOR DIRECT CURRENT AND DURATION TO THE FIRST ZERO PASSAGE DETERMINATION

Under conditions of the set forth method it can be considered that t_o is depending on two variable: test voltage U_T and the demagnetization current I_d i.e.:

$$t_o = F(U_T, I_d) \quad (7)$$

Then, the t_o variation regarding a presetted value, for a given U_T and I_d results from total differential:

$$dt_o = \left[\frac{\partial F}{\partial U}\right]_{I_d=ct} dU_T + \left[\frac{\partial F}{\partial I}\right]_{U_T=ct} dI_d \quad (7)$$

or

$$\Delta t_o = A\Delta U_T + B\Delta I_d$$

relation representing the searched dependence A and B are constants experimentally resulting from two reduced voltage tests, one at I_d=ct and another at U_T=ct on the following assumptions: test voltage should be not lower than the minimum voltage yielding magnetic circuit saturation and magnetic field yield by I_d on magnetic circuit should be $0<H_d<2H_c$ where H_c is the coercive field of employed magnetic material [10].
Thus, for instance at the 400 kV winding SI test of a 400 MVA 400/231 kV autotransformer at which demagnetization was made through the tertiary winding of 22 kV they obtained:

$$\Delta t_o = -1.75\cdot 10^{-3}\Delta U_T + 0.67\Delta I_d \qquad \text{ms,kV,A}$$

Oscillograms from Fig.7 demonstrate the appliance of the above method to the test of this autotransformer. The oscillograms rendered the voltage at the test winding terminals, current by winding respectively. Oscillograms 7c and 7d at reference voltage and test voltage have virtually the same duration t_o=1.8 ms and the difference regarding the calculated values does not exceed ±5%.

Common variation limits of the constants A and B for high power transformers in 400kV insulation class are:

$$A = -(1.2 \div 3.0)10^{-3}\text{ms/kV}$$
$$B = (0.4 \div 0.8)\text{ms/A}$$

Otherwise, if it is known the impulse magnetisation characteristic of the material and the magnetic circuit structure, A and B can be determined without other experiments [10].

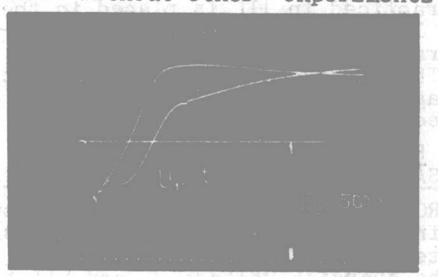

Fig.6
190 MVA 242/15.75 kV block transformer test. Time marking 0.3 ms; U_T=650 kV (K_s=2.72); t_o=2ms; I_d=1A

Relation (8) allows easily solve of two cases frequent encountered in practice, i.e:
- it is given t_o at reference voltage U_{ref} and I_d=0; it is asked t_o at given U_T and $I_d \neq 0$;
- it is given t_o at U_T and $I_d \neq 0$ given; it is asked $I_{d\ ref}$ at U_{ref} in order that $(t_o)_T = (t_o)_{ref}$.

5. OPTIMUM VALUE OF DIRECT CURRENT

The researches undertaken on the basis of the simultaneous magnetization characteristics with dc and impulse of the power transformer magnetic circuits [10] have shown as the dc demagnetization is the most effective for a demagnetizing magnetic field H_d in the magnetic circuit column on which there is fitted the test winding, which does not exceed $2H_c$ (H_c is here the coercive magnetic field measured in dc for a flux density of 1.5 to 1.7 T).

Thus, for instance for M3H transformer steel:

$$H_d/H_c = 1 \div 1.5$$

The main dimensions of the magnetic circuit and the number of turns of the low voltage winding being known it results the necessary value of the current I_d value immediately.

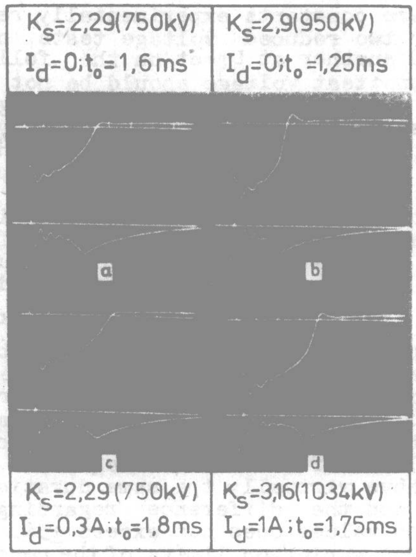

Fig.7
400 kV winding SI test of the 400 MVA 400/231 kV autotransformer;dc demagnetization by 22 kV tertiary winding. Time marking 0.5 ms.

The above mentioned analysis leads to the interesting result that the optimum demagnetization current value for the SI test practiced in [1] is placed in the range (0.5 ÷ 1.5)A for the majority of the common type transformers.

This reasonable value of the current encourages the practical application of the proposed test method.

6. RC CIRCUIT INFLUENCE UPON THE UTILISATION FACTOR OF THE CHARGING VOLTAGE

RC circuit used for direct current input into the LV winding of the transformer under test can affect both utilisation factor k of the charging voltage U_o and SI shape (the voltage drop is changed from cosine in exponential form at too little values for R).

To maintain the utilisation factor on the level considered reasonable at SI test in aperiodic regime $k=U_T/U_o \geqslant 0.7$ and in the same time to preserve the simultaneous demagnetization procedure efficiency, the expression of k is deduced from equivalent diagram given in Fig.2 where for small times (impulse front time) they can consider:

- voltage drop on capacitor C is neglected due to time constant $RC \sim 0.5s \gg t_o$
- current passing through inductance L_m is neglected in comparison with the current through capacitance C_T;
- resistance R_s high enough to be kept the aperiodic condition of the circuit at high frequencies and therefore can be neglected the leakage inductance effect.

Thus can be obtain a simplified circuit with only two energy accumulators C_s and C_T (enclosses C_1) for which 10 :

$$k = 1/\sqrt{[1+(R_s/R')+(C_T/C_s)][1+(R_s/R_p)]}$$

where $R'=n^2R$, n being the ratio of transformation on phase of the transformer under test.

Analysis shows for $n \geqslant 10$ that one can find $k \geqslant 0.7$ even for R = 500 ohms, which for $I_{d\ max}$ = 1.5A leads to a maximum voltage of the source E_o = 750 V.

If higher voltages of the source E_o are accepted, for instance 3 kV there is no limitation for the application of the method.

It results that the test circuit at SI with dc simultaneous demagnetization can be practically applied to the all power transformers, block transformers and interconnection autotransformers having a low voltage tertiary winding.

7. CONCLUSIONS

It is presented a power transformer switching impulse test method with dc simultaneous demagnetization by which it can obtain a controlled duration as far as to the first zero passage of the SI whatever would be the voltage value.

In the same time this eliminates the risk of external insulation flashover to positive SIs and increases the promptness of the test. The utilisation factor of the charging voltage is reduced in a neglected measure and the circuit reliability is not affected.

The test method is able for routine employment under the two parameter method allowing the determination of the demagnetization current and of the duration to the first zero passage depending on the applied voltage.

One proves that for magnetic materials employed at present in transformer design and test voltages stated in [1],the demagnetization current is situated in the range 0,5 ÷ 1.5 A whatever would be the rated power and voltage of the transformers.

ACKNOWLEDGEMENTS

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AUTOMATIC ON-LINE CONTROL BY MICROPROCESSOR OF IMPULSE VOLTAGE GENERATORS WITH POTENTIAL FREE TRIGGERING

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Abstract - A realised control system is described, in which a 8 bit microcomputer sets and regulates automatically the charging voltage and the firing gap length and releases a potential free trigger system. Because of generation of firing impulse at any desired potential, wide trigger range, short firing time lag and better triggering characteristic of multiple chopping gaps are possible.

The use of light guide transmission lines eliminate many problems of electromagnetic interferences. Hereby and through suitable shielding and earthing measures it is possible to run the measuring and control system in the high voltage laboratory without Faraday cage.

1. INTRODUCTION

In the high voltage impulse testing technique the following advantages can be achieved through automation of the testing procedure:

1. Reduction of personnel
2. Time-saving in testing procedure evalution of test results
3. Better set accuracy of the parameters of the test arrangement and in this connection reduction of faults of test procedure
4. Measuring and storing of a higher number of test dates
5. More speedy and accurate evalution of test results.

For a purposeful range of automation one has to take into account its advantages and costs. The following tasks of the test procedure e.g. can be automatized:

1. Setting and release of the impulse generator in accordance with the desired testing procedure
2. Measuring and recording of test results
3. Evaluation of test results according to given specifications and protocolling.

Recently several automatic test equipments for impulse voltage tests have already been developed. The automatic setting and release of an impulse generator using standard electronics is said in [1]. The automatic measurement, storage and evaluation of test results with help of an minicomputer in a well shielded testing cabine have been described in [2]. A model has been described in [3], in which the setting of the impulse generator is done with analog electronics, measurement and storage with a microcomputer and off-line evaluation with a processing computer IBM 1800. The favourable cost development on the field of microcomputer electronics with standardized cards offers new possibilities. A microcomputer on a single europe card with 1 k Byte RAM, 4 k Byte ROM and 20 parallel as also 2 serial 10 lines costs less than DM 1000,-.

With a high storage capacity of 16 k Byte EPROM or dynamic RAM on a single europe card very powerful microcomputer systems can be designed economically today with a few cards.

If time shortage occurs, different tasks can be assigned to several microcomputers. In such a multiprocessor-system data transfer between individual computers is possible with a priorised interrupt control.

The free programming of such systems make complex programming for test and evaluation as software possible and large numbers of them can be stored in the system PROM. Change or extension of programs is possible through transfer of corresponding PROM storing elements. A single and cheap adaption to new problems of automation is possible.

2. PRINCIPLE OF OPERATION OF THE CONTROL SYSTEM

In the present system the automatic setting and release of an impulse generator as well as measuring and storage of test results have been done by means of a 8 bit microcomputer. Fig. 1 shows the block diagram. The microcomputer sets automatically gap length S of the firing gap dependent on the desired relative gap voltage k and relative air density d as a function of the desired charging voltage U. The relative gap voltage k is the ratio of the actual voltage of the gap to the static breakdown voltage.

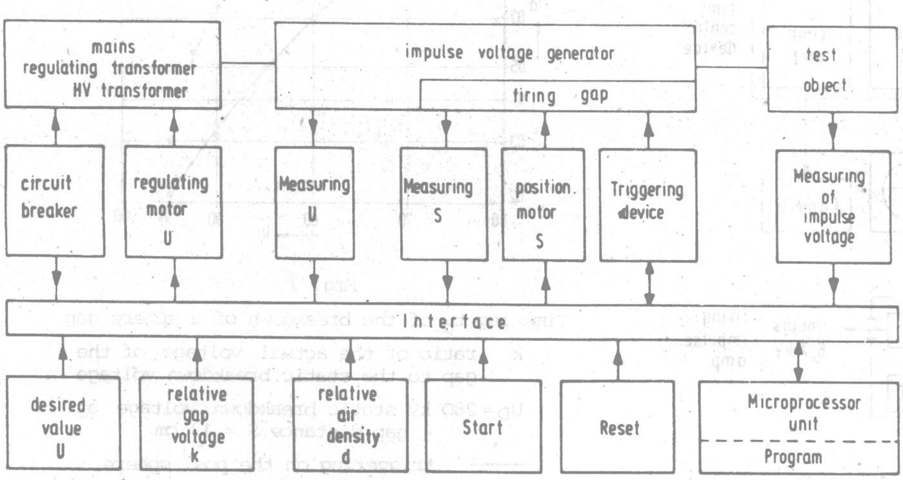

Fig. 1
Block diagram