I. NUMERICAL MODELLING

Chairmen: S.V. Kulkarni, Ž. Štih

Thursday, 16 October, 9.00 a.m.

1. **(Invited) A. P. S. Baghel** (Electrical Engineering Department, Indian Institute of Technology Bombay), **S. V. Kulkarni** (Electrical Engineering Department, Indian Institute of Technology Bombay)

MODELING OF MAGNETIC CHARACTERISTICS INCLUDING HYSTERESIS EFFECTS FOR TRANSFORMERS

The paper describes modeling of hysteresis for core materials of transformers. Grain-oriented (GO) materials, due to their excellent crystallographic features, are extensively used in cores of transformers. This work uses the Jiles-Atherton (JA) description in modeling of core materials. JA model based methods for accurate representation of anisotropic and dynamic hysteresis loops are discussed. Minor loop representation is also described in the paper. Using a standard nonlinear iterative method, numerical implementation of the model in 2D finite element method is demonstrated. Another technique for hysteresis modeling, based on complex permeability representation, is also elaborated.

2. **Seyed Ali Mousavi** (Royal Institute of Technology (KTH)), **Göran Endgahl** (Royal Institute of Technology (KTH)), **Dietrich Bonmann** (ABB AG, Germany)

STRAY FLUX LOSSES IN POWER TRANSFORMERS DUE TO DC MAGNETIZATIONS

This paper presents results of a study regarding the effect of DC magnetization due geomagnetically induced currents, GICs, on stray eddy current losses in structural parts of power transformers. 2D and 3D FEM models have been employed for simulations in this work. The aim of the study is to understand how a GIC event can cause an increase of the losses in the tank and other metal parts of the transformer.

The obtained results reveal that magnetization current wave shape has strong influence on the stray losses during a GIC event. It acts in two ways; adding higher harmonic to the stray flux and also disordering the stray flux distribution by creating unbalanced magnetomotive forces, MMFs, in the windings. The saturation of the core and magnetic shunts can affect the losses only during very strong saturation. This study can help to find a method to take into account the effect of GICs on stray losses by conventional design tools.

3. **Dario Šegović** (Končar Power Transformers Ltd.), **Franjo Kelemen** (Končar Power Transformers Ltd.)

ESTIMATION OF ZERO SEQUENCE IMPEDANCE IN POWER TRANSFORMERS USING 2D AND 3D FEM

This paper describes calculation of zero sequence impedance in three phase, three leg core type power transformers using 2D and 3D finite element method (FEM) calculation on example of 100 MVA power transformer. Paper also describes how winding connection and arrangement affects the size and calculation of zero sequence impedance.

4. **Oszkár Bíró** (Graz University of Technology), **Zarko Janic** (Koncar Power Transformers Ltd.), **Gerald Leber** (Siemens Transformers Weiz), **Kurt Preis** (Graz University of Technology), **Bernhard Wagner** (Siemens Transformers Weiz)

FINITE ELEMENT TECHNIQUES IN THE DESIGN OF POWER TRANSFORMERS

Various finite element techniques applied to the analysis of large power transformers are summarized. Two- and three-dimensional nonlinear, static and eddy current models to predict the losses in the windings, the laminated iron parts as well as in the conducting structural parts are developed. The computation of forces on the windings is also discussed.

5. **Saravanan Selvaraj** (Crompton Greaves Ltd. India), **Dr.Ronny Mertens** (Crompton Greaves Ltd. Belgium), **Geert Caluwaerts** (Crompton Greaves Ltd. Belgium), **Mahesh B Varrier** (Crompton Greaves Ltd. India), **Rafiq Mathersa** (Crompton Greaves Ltd. India)

INVESTIGATION OF IMPACT OF MAGNETIC SHUNT PARAMETERS ON TEMPERATURE DISTRIBUTION IN TRANFORMER TANKS

A set of reduced order models are developed to validate finite element based calculation of temperature distribution in solid and laminated magnetic structures in transformers with high current carrying conductors. Model details, measured and calculated losses and temperature of the models are presented. Effect of magnetic shunt type and its alignment with respect to stray flux direction on temperature distribution in the reduced order model are analyzed.

The magneto-thermal coupled field analysis methodology is applied to estimate the temperature distribution in Multi-Utility transformer, showed temperature higher than expected. Different cases of tank cover plate with electromagnetic shield , thicker magnetic shunts, and with non magnetic cover plate are analyzed to reduce the temperature.

With the modified shunt arrangement, the transformer passed the test as temperature were reduced by 100˚C.

6. **Andre de Souza Melo** (ABB Ltda), **Wilerson Venceslau Calil** (ABB Ltda)

HOT SPOT CONTROL OF STRUCTURAL PARTS DUE TO HIGH CURRENT LEADS IN POWER TRANSFORMERS BY MEANS OF THE 3D-FEM

The power transformers can be considered as one of the most expensive components at the power substation. For this reason, great efforts are applied in order to create power transformers designs as close to perfection as possible.

The aim of this article is to show the efficiency of the Finite Element Method (FEM) in calculating and controlling the hot spots generated by the stray flux, presenting a real case of a power transformer that was developing gases due to overheating while operating at rated load.

Added to the previous purpose, will be presented an analytic study performed with the main equations that rule the magnetic fields. The aim of this study is to check and create a quantitative feeling on how the materials and geometries influence the magnetic fields and the consequently losses and temperatures.

7. **Wílerson Venceslau Calil** (ABB Ltda), **Andre de Souza Melo** (ABB Ltda)

TEMPERATURE RISE ON METAL PARTS OF TRANSFORMER ON SIMULTANEOUS LOADING CASE CONDITION – REAL CASE

Power Transformers are one of the most expensive assets of the electric power system. For this reason, effort is get conceptual design as close possible to the technical perfection, aligning customers' needs and at the same time reducing costs. This paper presents a proposal for calculating magnetic tank shield and temperature rise on tank wall for certain types of loads imposed by customer on the technical specification.

8. **Ralf Wittmaack** (Siemens AG, Nürnberg, Germany)

CFD SIMULATION OF PRESSURE LOSS IN HVDC TRANSFORMER WINDING

At Siemens the in-house CFD code UniFlow is used to analyse fluid flow and heat transfer in oil-immersed and dry-type transformers, as well as transformer components like windings, cores, tank walls, and radiators. It can be employed to perform steady state as well as transient analyses. This paper describes its physical models and numerical solution methods.

Moreover, it presents an application to a valve winding of a HVDC transformer, cooled by mineral oil. This study is aimed at finding the flow induced pressure loss in the winding and the static ring assembly below and above the winding. The investigation includes isothermal runs with different inlet velocity and a conjugate heat transfer run with a conductor representation.

In the isothermal simulations a steady state is established and the pressure loss is an almost linear function of the inlet velocity. In the run involving heat transfer, the high buoyancy forces hamper the development of a steady state and the possibility to calculate a flow induced pressure loss.

9. **Hugo M. R. Campelo** (EFACEC Energia, S.A.), **Rómulo T. Oliveira** (FEUP University of Porto), **Carlos M. Fonte** (FEUP University of Porto), **Madalena M. Dias** (FEUP University of Porto), **José Carlos B. Lopes** (FEUP University of Porto)

MODELLING THE HYDRODYNAMICS OF COOLING CHANNELS INSIDE SHELL-TYPE POWER TRANSFORMERS WITH CFD

The Shell-Type Power Transformers are designed and manufactured in order to guarantee the evacuation of internally dissipated energy while maintaining its operation within safe and reliable temperature limits. The energy evacuation is guaranteed by circulating a high heat capacity fluid through a set of well-defined interconnected cooling channels that guide it.

In this work the flow patterns in these cooling channels are comprehensively analyzed for different mineral oil flow rates and for two different heat densities using 3D CFD simulations in ANSYS Fluent. Different aspect ratios have been modelled using three geometries with different channel heights. The cross combination of these parameters is compliable with the most common Shell-Type designs used in practice. The three geometries used have been globally scaled down by a factor of 1:3 in order to be compared in the future with an existing experimental apparatus. The coil has been modelled as a hot wall with a constant heat flux.

From the CFD results it is possible to observe the oil being accelerated inside the cooling channels.

The results also reveal that the relative mass of oil distributed among the channels is almost independent of the flow rate which is a fundamental difference from typical Core-Type designs. Instead the oil velocity distribution inside each channel is influenced by increased oil flow rates wherein shifts from the typical parabolic shaped patterns are observed.

The increased oil flow rate promotes the appearance of recirculation patterns and corresponding low velocity areas wherein higher local oil temperatures can occur. At the end, a comparison of the coil surface temperature suggests that an optimum oil flow rate might exist for each design.

The work as a whole suggests the importance of computational techniques as CFD in order to pursue a progressive detailed knowledge about this particular power transformer technology. The herein obtained information is of paramount importance for the further development of reduced-order modelling approaches.

10. **Nebojša Gavrilov** (Končar Power Transformers Ltd.), **Ivica Roketinec** (Končar Power Transformers Ltd.)

ANALYSIS OF INFLUENCE OF RADIAL DUCT HEIGHT VARIATION TO BALANCING NATURAL AND FORCED OIL FLOW IN RADIAL DUCTS OF WINDING SEGMENT

The focus of this article is to find the way to equalize distribution of oil flow in a segment of winding with washers for natural and forced oil flow. Present studies show that for forced flow, the majority of oil flows through the last few ducts, whereas it is opposite in the case of natural flow. In this study, how gradual variation of radial ducts heights influence on distribution of oil flow in radial ducts will be analyzed. The analysis will be made for range of inlet velocities that corresponds from natural to forced flow.

11. **Bruno Bošnjak** (Siemens AG Power Transformers Nürnberg)**, Andreas Hauck** (SIMetris GmbH)**, Hermann Landes** (SIMetris GmbH)

COUPLED MAGNETO-MECHANICAL FINITE ELEMENT ANALYSIS OF A POWER TRANSFORMER IN SHORT CIRCUIT CONDITIONS

External short circuit is one of the most demanding load conditions a transformer can be subjected to. Short circuit withstand capability of power transformers is therefore quintessentially important in order to ensure the proper functioning of a power transformer during its lifetime. Accurate calculation of the forces and stresses a transformer is subjected to during a short circuit is a prerequisite for better, optimized design of the active part. Main focus of this paper is the investigation into dynamic electromagnetic and mechanical behaviour of a transformer winding subject to an external short circuit. For purposes of this simulation, a single-phase 100 MVA autotransformer active part was modelled using ANSYS and NACS software. Particular areas of the winding were modelled to a greater degree of detail in order to observe the effects of Lorentz forces during a short circuit on individual conductors. A transient coupled magneto-mechanical simulation of the transformer under short circuit conditions was carried out.

When subject to dynamic short circuit forces, the winding discs exhibited a profoundly resonant behaviour indicating a strong relationship between the natural frequency of the winding and the resulting stresses and displacements incurred during a short circuit. It has been shown that the position of the yoke changes the orientation and the distribution of the magnetic field vectors at the top and the bottom of the winding, causing a non-uniform distribution of forces along the top discs of the winding. This non-uniform distribution of forces along the circular shape of the winding conductor caused high stresses at the positions within the winding which were previously considered to be under lower stress when calculated using 3D static FEM and analytical methods.

12. **Kosjenka Capuder** (Končar - Power Transformers Ltd.), **Goran Plišić** (Končar - Power Transformers Ltd.), **Željko Štih** (University of Zagreb, Faculty of Electrical Engineering and Computing)

GENERIC APPROACH TO CALCULATION OF SHORT CIRCUIT CURRENTS IN POWER TRANSFORMERS

Power transformer in service is exposed to various voltage and current stresses. The ability to withstand short circuit is an essential requirement for power transformers.

There are different types of short circuit: single - phase to earth, double - phase with or without simultaneous earth fault and three - phase short circuit. These various short circuit conditions result in different stress conditions for the windings. Mesh analysis and symmetrical components are the two methods most commonly used for determining the magnitude of short circuit currents. In this paper, both methods will be presented with results compared on a real-case transformer. Also, a generic scheme using the symmetrical components approach is designed in order to standardize the short-circuit currents calculation for all power transformer types and to reduce the time required for obtaining results.

13. **Robert Platek** (ABB Sp. z o.o. Corporate Research, Poland), **Grzegorz Juszkiewicz** (ABB Sp. z o.o. Corporate Research, Poland)

SEISMIC ANALYSES FOR POWER TRANSFORMERS

Reliability and security of power systems, especially in areas prone to earthquakes, depends on the seismic withstand of its components and interaction of these components with other elements. All relevant power products and components should be designed and tested to guarantee high seismic performance. Option which is strongly recommended for seismic qualification is shake table test. This way is very expensive and in some cases like power transformers impossible due to its weight and size. Because of this the numerical analyses can be very helpful to determine the dynamic characteristic of the system. This way is more and more used during evaluation of seismic performance of power products, especially in the design phase.

In the paper a different numerical approaches for seismic analyses of the power transformers have been presented. In the first part of the article focus was put on typical simulation methods defined by IEEE and IEC standards. This approach is dedicated only for transformer's components. Due to fact that standards do not provide clear information about fluid influence on power equipment during seismic events, some investigations related with oil filled transformers were done and summarized. Three different numerical methods were investigated. First one is built based on the Fluid-Structure Interaction (FSI) methodology. In this approach combination of different software (CFD, structural, and coupling code) is used to cover phonemes related with fluid dynamics and structural analyses. FSI methodology gives a wide possibility but, it's very complex however, is very complex which can be a disadvantage for very complex objects. Next one uses acoustic elements, where the fluid is modeled as acoustic medium. This is method which allows to take into account fluid during seismic simulations in simplified way. The last one uses Lagrange and Euler element formulations (CEL) in which sloshing effect of the oil in power products can be considered. All this approaches can be very helpful to determine the dynamic characteristic of the transformers and its equipment including fluid.

14. **Mladen Marković** (Končar - Distribution & Special Transformers Inc.), **Ivanka Radić** (Končar - Distribution & Special Transformers Inc.), **Vlatka Matun** (Končar - Distribution & Special Transformers Inc.)

STATISTICAL AND NUMERICAL ANALYSIS OF TRANSFORMER OIL AC BREAKDOWN

Transformer oil AC breakdown research is an important part of transformer insulation design. Research presented in this paper consists of statistical and numerical analysis of breakdown data measured in portable oil tester. Statistical analysis is done by modeling measured data as a random process with Gaussian and Weibull probability function. Numerical analysis uses statistical data for calculation of stressed oil volume, stressed electrode area and safety factors of “cumulative stress” method. Both statistical and numerical analysis showed how breakdown withstand depends on different variables and why they are important in measurement interpretation.

15. **Mladen Marković** (Končar Distribution & Special Transformers Inc.)

INSULATION OPTIMIZATION OF POWER TRANSFORMER LEADS

Power transformers reliability, amongst other things, depends on its insulation system. One of the part of the insulation system are high voltage leads, which should be properly insulated. This includes positioning an insulation barrier between the leads and a tank on a certain distance. This distance effects on safety factors (breakdown probability) for such system. The paper also presents optimization process with which both the breakdown probability and leads vs. tank distance could be minimized. It also proposes a method with which this optimization process could be confirmed.

16. **Jasmin Smajic** (University of Applied Sciences of Eastern Switzerland (HSR)), **Roman Obrist** (University of Applied Sciences of Eastern Switzerland (HSR)), **Martin Rüegg** (University of Applied Sciences of Eastern Switzerland (HSR)), **Bogdan Cranganu-Cretu** (ABB Switzerland Ltd.), **Carlos Roy** (ABB SA, Zaragoza, Spain), **Benjamin Weber** (ABB AG, Brilon, Germany), **Ebrahim Rahimpour** (ABB AG, Bad Honnef, Germany)

LIGHTNING IMPULSE MODELING AND SIMULATION OF DRY-TYPE AND OIL-IMMERSED POWER- AND DISTRIBUTION TRANSFORMERS

This paper presents in detail numerical methods and techniques for lightning impulse (LI) modeling and simulation of power and distribution transformers. The modeling methods are based on equivalent circuits of transformer winding entities resulting from the initial winding discretization determined by the required accuracy. The parameters of the equivalent circuit such as resistances and self- and mutual capacitances and inductances are obtained from field simulations (FEM). The circuit equations of the transformer’s equivalent circuit written in the state space form yield a large system of differential equations that is solved in time-domain by using the standard Runge-Kutta numerical integration technique. The obtained solution represents the voltage distribution over the winding in each moment of the LI-time (50μs). The results verification by comparison against measurements is presented in detail.

17. **Goran Plišić** (Končar - Power Transformers Ltd.), **Kosjenka Capuder** (Končar - Power Transformers Ltd.)

INFLUENCE OF WINDING CAPACITANCES TO GROUND MODELLING ON THE CALCULATION OF TRANSFERRED VOLTAGES IN POWER TRANSFORMER

During voltage transients, the windings of a transformer are coupled by electric and magnetic fields. To calculate the transients inside the transformer, a network model is typically used. The accuracy of calculation results obtained depends mainly on this model in which the windings are lumped into R, L and C circuit components. The windings are usually represented by discs, or groups of discs, with the corresponding resistances, inductances (self and mutual) and capacitances (series and to the ground) [1]. In case of impulse voltage, wave's steep front and consequently high frequency oscillations are the main reason why capacitances modelling is of major importance for the calculation of voltage distribution in winding and between windings.

18. **Vasily Larin** (All-Russian Electrotechnical Institute (VEI), Moscow, Russia), **Daniil Matveev** (Moscow Power Engineering Institute (MPEI), Moscow, Russia), **Alexey Volkov** (All-Russian Electrotechnical Institute (VEI), Moscow, Russia)

STUDY OF TRANSIENT INTERACTION IN A SYSTEM WITH TRANSFORMER SUPPLIED FROM NETWORK THROUGH A CABLE: ASSESSMENT OF INTERACTION FREQUENCIES AND RESONANCE EVOLVEMENT

Transformer together with its windings is a complex oscillatory system. The interaction between the transformer and an electric network during transients can cause the development of resonance phenomenon in the windings leading to overvoltages and the risk of transformer fault.

This report presents the results of studies of resonance phenomena in transformer windings, caused by interaction with an electric network containing the feeder cable. The approach to a simple assessment of dominant oscillation frequency of a voltage in the system "feeder cable – transformer" and estimation of the resonant frequencies of transformer winding is considered. The report also describes the technique for measurement of winding resonance voltages. The resonance phenomenon evolvement in transformer windings is considered and the impact of decaying oscillating applied voltage on maximum ratio of resonance overvoltages is estimated.

19. **Bruno Jurišić** (EDF R&D, France), **Ivo Uglešić** (University of Zagreb, Croatia), **Alain Xemard** (EDF R&D, France), **Françoise Paladian** (Université Blaise Pascal, France), **Philippe Guuinic** (EDF R&D, France)

CASE STUDY ON TRANSFORMER MODELS FOR CALCULATION OF HIGH FREQUENCY TRANSMITTED OVERVOLTAGES

Events such as lightning, switching of vacuum circuit breaker or switching operations in gas insulated substation (GIS) generate high frequency overvoltages. An equipment in a transmission or a distribution system has to be protected against such phenomena.

In the design stage of insulation coordination, which is usually based on electromagnetic transient simulations, the overvoltages, which are transmitted through transformers, should be accurately calculated in order to design an adequate protection of the system components. Since those overvoltages include high frequency components, the traditional, low frequency transformer models cannot be used for accurate calculation of transmitted overvoltages. Therefore, it is particularly important to have a proper transformer model, accurate also for representing the high frequency transformer behavior.

Two different transformer models for high frequency, are developed in an EMTP-type software program. The first model named "Black box" derives solely from the values measured on the

transformer terminals and does not require any knowledge of the transformer inner geometry. The second model named “Grey box”, is based on a lumped RLC parameters network, whose values are derived from the simple geometry of the transformer window and from the nameplate data.

In this paper, we propose to analyze the capabilities of a “black box” model and a “grey box” model to characterize a transformer at high frequencies. The case study is done on a distribution transformer which is to be located inside a power plant. The transmitted overvoltages calculated with the models in the EMTP-type software program are compared with measurements.

II. TRANSFORMER LIFE MANAGEMENT

Chairmen: I. Atanasova-Hoehlein, A. Mikulecky

Thursday, 16 October, 3:30 p.m.

1. **(Invited) Ivanka Atanasova-Höhlein** (Siemens E T TR)

INSULATING FLUIDS – DEVELOPMENTS, TRENDS AND INFLUENCE ON DIAGNOSTICS

Ideal insulating fluid can not exist, but a good knowledge on advantages and disadvantages of properties can give good rules for the choice of an insulating fluid for a certain application. The more stringent laws concerning environmental needs and fire protection open a niche for ester and silicone fluids. By modification of structure, further improvements in the physico-chemical properies can be achieved and drawbacks avoided.

2. **Josias Matos de Araújo** (Eletrobras Eletronorte), **Lílian Ferreira Queiroz** (Eletrobras Eletronorte), **Paulo Veloso Almeida** (Eletrobras Eletronorte), **Cleusomir Carvalho dos Santos** (Eletrobras Eletronorte), **Roberto Jander Costa Padilha** (Eletrobras Eletronorte)

MONITORING STRATEGY AND INTEGRATION FOR ASSET MANAGEMENT

Growth of Electric Power Systems to meet the increased electricity demand implies the need to improve the processes maintenance, asset management and diagnostics of the actual state of the equipment. The evolution of maintenance occurs both in order to improve the procedures used, and in order to make better use of resource management. The current scenario of the electricity markets in Brazil and around the world has led companies in the industry to operate in a context of high competitiveness, inducing a constant search for greater efficiency, better quality and lower supply costs. The advent of computer monitoring systems enabled the acquisition of data by electronic systems, providing deployment of predictive maintenance based on monitoring equipment. There was migration of preventive maintenance to predictive maintenance, which was only possible through monitoring systems online.

The monitoring systems allow remotely or locally and in real time, providing consistent information to maintenance personnel on equipment status.

This article shows the practice adopted by Eletronorte using the system using the System Diagnostics and Analysis Equipment - Diane, which uses data from testing of equipment, types of diagnoses, goals, types of faults and online monitoring line, resulting in preventing defects and failures.

In this regard, the use of the monitor can detect and act preventively pre-existing problems by reducing equipment downtime and maintenance costs. The system has been widely adopted in the process of predictive maintenance of Eletronorte, and in the supervision of monitoring condition of equipment.

3. **Fleischmann Werner** (Maschinenfabrik Reinhausen GmbH), **Krüger Thorsten** (Maschinenfabrik Reinhausen GmbH), **Ilgevicius Audrius** (Maschinenfabrik Reinhausen GmbH)

TRENDS IN TRANSFORMER LIFECYCLE AND ASSET MANAGEMENT

Various transformer brands and sizes, diverse tap-changer types, many transformer accessories and operational concepts, load behavior, ambient influences and increase of energy drives the vital importance to identify trends in transformer lifecycle and to develop asset management

strategies in order to keep operation reliability and to integrate obsolete systems into modern substation concepts.

The approach based on the health index allows a risk based maintenance and replacement prioritization and show how the asset manager may prioritize replacement decisions and improve maintenance programs.

Using CIM-based data communication, the information of different systems can be converted into a common information format.

4. **Michael Krueger** (OMICRON, Klaus, Austria), **Stefan Hoek** (OMICRON, Klaus, Austria)

NEW TOOLS FOR DIAGNOSTIC MEASUREMENTS AND MONTORING ON POWER TRANSFORMERS

With advancing age of power transformers, a regular check of the operative condition becomes more and more important. The Dissolved Gas Analysis (DGA) is a proven and meaningful method such that if increased proportions of H2 and hydrocarbon gases are found in the oil, the fault must be located as soon as possible. In order to find out the reason for high gas rates, further tests have to be performed. Common methods are: winding resistance measurement (static), On-Load Tap Changer (OLTC) test (dynamic resistance test), turns ratio and excitation current measurement, measurement of the leakage reactance and the measurement of capacitances and dielectric losses.

Innovative new tools like the Dielectric Response Analysis with Polarisation-Depolarisation Current (PDC) and Frequency Response Spectroscopy (FDS), the measurement of the transfer function with the Frequency Response Analysis (FRA), capacitance and dissipation factor measurement at different frequencies and the Partial Discharge (PD) measurement with modern synchronous multi-channel and multi-frequency PD systems enable more detailed diagnostic measurements on transformers. For the assessment of the danger potential of PD in transformers the knowledge of the location of the PD faults is essential. A powerful tool for PD location is the acoustical measurement with ultrasonic microphones and if possible together with triggering by corresponding electrical or UHF signals. Simultaneous PD measurements in the conventional frequency range according to IEC 60270, in the UHF range and of corresponding ultrasonic signals enable a better information about PD sources and their location.

The paper describes all these new methods and illustrates them with practical case studies for the diagnosis and fault finding.

5. **Ivan Kajapi** (HEP-PROIZVODNJA d.o.o.), **Luka Miškulin** (HEP-PROIZVODNJA d.o.o.), **Anton Mataija** (HEP-PROIZVODNJA d.o.o.)

DIAGNOSTICS OF INSTRUMENT TRANSFORMERS ON TS RIJEKA

This paper presents experience from over 30 year long period of diagnostics methods used to determine the condition of high-voltage instrument transformers installed on transformer station 110/35 kV Rijeka (TS Rijeka). The advantages/disadvantages of particular diagnostic method are overviewed and also how new methods are being implemented is described. The result of frequent measurements is planned replacement of instrument transformers that are at the end of their lifetime. Result of these actions is continuous availability and normal function of important 110 kV switchyard.

6. **Goran Skelo** (Electricity Transmission Company of Bosnia and Herzegovina), **Fikret Velagić** (Electricity Transmission Company of Bosnia and Herzegovina), **Amgijada Karišik** (Electricity Transmission Company of Bosnia and Herzegovina)

INSTRUMENT TRANSFORMERS TESTING USING ACOUSTIC PARTIAL DISCHARGES MEASUREMENTS

Suitability of acoustic partial discharge measurement method for detection of partial discharge activity in oil filled instrument transformer is analysed.

Results of acoustic partial discharge, insulation resistance and dielectric dissipation factor measurements on oil filled current transformers, which were removed from service due to poor measurement results , are presented. Also, DGA oil analyses confirmed bed insulation condition.

It was shown that, using acoustic partial discharge measurement, it is possible to detect instrument transformers with insulation in bad condition.

7. **Danijel Brezak** (Končar - Electrical Engineering Institute Inc.), **Dalibor Filipović-Grčić** (Končar - Electrical Engineering Institute Inc.)

ULTRASONIC METHOD FOR TESTING OF POWER TRANSFORMERS

Ultrasonic method of detecting PD is based on the fact that the electrical energy of the PD transforms in a mechanical energy, an ultrasonic acoustic wave that spreads through the transformer to the tank wall. From time difference of wave detection on different sensors, a possible location of the source can be estimated. Ultrasonic method can detect other transformer deficiencies such as loose contacts and local overheating of oil (T>200°C).

Three case studies are given in this paper. The first case was where DGA indicates the thermal problem in the oil and the result of ultrasonic testing points at OLTC contacts. In the second case an ultrasonic method was performed after electrical method detected high levels of PD at voltages much lower than the nominal. Ultrasonic method detected non-grounded parts of the returning limb electrostatic screen. In the third case, a failure of transformer, namely a breakdown from the HV bushing end shield, initiated a series of tests on similar transformers installed at the same substation. The assumption was that PD occurred in the shied epoxy insulation and eventually caused the breakdown.

8. **Bálint Németh** (Budapest University of Technology and Economics), **Gusztáv Csépes** (Diagnostics Ltd.), **István Kispál** (Diagnostics Ltd.), **Zsolt Laczkó** (MVM OVIT Ltd.)

CHECKING OF THE CONDITION OF TRANSFORMERS AND THE EFFICENCY OF OIL REGENERATION WITH RVM (RETURN VOLTAGE MEASUREMENT)

Up to now the insulation in HV power transformers has been made from oil/paper therefore the diagnosis of this kind of insulation will be also important in the next forty-fifty years. The lifetime of this equipment strongly depends on the condition of the insulation system. The ageing process of oil/paper insulating systems is a very complex and complicated phenomenon. In order to get a well-supported decision on the further operation of aged transformers, relevant information would be necessary on the condition of the oil-paper insulation. We also know that the oil-paper insulation has almost always inhomogeneous condition considering the temperature, moistening and ageing processes. The classical methods (insulation resistance, loss tangent, etc.) characterise the insulation by single measured value. This single value is not sufficient for relevant characterisation and diagnosis of such a complex system with lots of tons of insulation and with almost always inhomogeneous distribution of temperature, moisture and ageing

product. If we measure the polarization spectra in three states (new insulation in equilibrium and uniform polarization spectrum, new insulation with not uniform distribution of polarization spectrum, later reaching again the uniform distributions) the shape of three polarization spectra will be different. Comparing the polarization and classical methods of this three case we can realize that sometimes the “classical single values” are almost the same but the polarization spectra are different.

The three response methods provide very practical information about the insulation system (e.g. moisture, ageing). The moistening and accumulation of ageing by-products change the distribution of interfacial polarisation in the range of long time-constants. These promising response methods measure the polarisation distribution in the range of long time-constant (with other words, in the low frequency range). The three test methods were: Return Voltage measurement (RVM), the C and tgδ measurement in range of some tens of mHz to 50 Hz (FDS=Frequency Domain Spectroscopy), and the measurement of DC charging and discharging currents (PDC=polarisation and depolarization currents) up to some thousands of sec. These equivalent methods (RVM, FDS and PDC) are able to follow the changing of condition of insulation contrary to classical methods. Therefore a little bit surprising that until now the convenient standards is missing considering the polarization methods. In an earlier Hungarian research work (Budapest University of Technology) almost all the necessary measurements have been realized, consequently we are in possession of fundamental data considering the polarization methods. This paper would like to show a short review about the RVM technique, the correct interpretation of RVM data and a case study for the checking of the efficiency of the oil reclamation with RVM technique.

9. **Veronika Haramija** (Končar - Electrical Engineering Institute Inc.), **Dijana Vrsaljko** (Končar - Electrical Engineering Institute Inc.), **Vedran Đurina** (Končar - Electrical Engineering Institute Inc.), **Domagoj Vrsaljko** (University of Zagreb, Faculty Of Chemical Engineering And Technology)

THERMAL STABILITY CHANGE OF SYNTHETIC ESTER-BASED TRANSFORMER OIL

For good transformer condition assessment it is necessary to determine the condition of insulating materials, both liquid and solid. Transformer is reliable for as long as its insulation system resists deterioration. Therefore, thermal and oxidation stability are important characteristics of transformer oil. It is a measure of oil resistance for decomposition by the influence of oxygen and temperature. Oils with good thermal and oxidation stability retain their characteristics regardless the thermal stress.

Because of environmental and safety issues, the use of synthetic ester-based transformer oils is increasing. Although they have been in use in smaller transformers (distributive, traction, …) for decades, limit values for chemical and physical characteristics are still discussed. New methods for thermal stability evaluation can be useful for insulation condition assessment.

10. **David Bidwell** (Qualitrol Corporation), **Donal Skelly** (Qualitrol Corporation)

NEW TOOLS FOR ENHANCED DIAGNOSTICS OF DGA DATA

In the last decade there has been a significant change in the way transformers are viewed. Their importance together with their obvious value to the network has been enhanced and recognized, especially in light of the ageing fleet worldwide. At the other end of the spectrum, new transformers are now being designed and built to tighter tolerances as a result of competitive market conditions, with the knock-on effect that these “modern” devices do not appear to provide the same stability and longevity as those that were entering service in the 1970s and 1980s.

Against this backdrop, the advent of transformer monitoring has emerged and continues to develop at a rapid pace. Although still considered an emerging component of asset management practice, online DGA is rapidly gaining acceptance and recognition as one of the most powerful tools in protection against asset failures. While other transformer monitoring technologies abound, many of them now online, such as partial discharge, these products collectively combine to enable the move to condition based monitoring of transformer assets.

As online DGA monitors have evolved new products and technologies are reaching the market at an ever increasing rate. However, the quiet revolution is in the analysis of the data. As more and more monitors are installed, so the burden of data analysis becomes increasingly large. New ways of extracting value from this data required. One important approach is the use of Artificial Neural Networks (ANN) for DGA data analysis. Additionally, with the recognition that data from monitors must be easily transferred into meaningful information for the end-user, diagnostic tools, such as the Duval Triangle, have evolved where the addition of Triangles 4 and 5 brings significantly more value to previously mined data.

The mute question in this paper relates to whether or not existing online monitoring hardware has sufficient accuracy and repeatability of measurement to be of use with these more advanced diagnostic tools.

11. **Ivan Šulc** (Končar - Electrical Engineering Institute Inc.), **Robert Sitar** (Končar - Electrical Engineering Institute Inc.), **Antun Mikulecky** (Končar - Electrical Engineering Institute Inc.)

AN ASPECT OF TRANSFORMER INRUSH CURRENT

Paper analyzes a sparking phenomena that were observed on power transformers during their first few energizing. Sparks occurred on the flange between tank cover and tank side, in spite of the fact that a jumper (copper link) was used. The phenomenon was observed on transformers from different manufacturers, with various transformer ratings, three or five limb core.

Paper proposes a simple electromagnetic model for analyzing the phenomena. Three-phase power transformer is modeled in finite element method (FEM) magnetic software. Simplified 3D transformer model is used in order to simulate well known core saturation during the inrush current event. Voltages between tank cover and tank side are calculated for simulated conditions. The same model is used for calculation of possible currents flowing between tank cover and tank side, showing that a value of several kA can be reached.

In spite of the fact that the observed phenomenon is harmless mitigation measures are proposed. However, by doing nothing, sparking would disappear very soon.

12. **Zoran Andjelic** (Polopt Technologies GmbH, Switzerland), **Ramsis. Girgis** (ABB, USA), **Asim Fazlagic** (ABB, USA), **Andreas Seidel** (Woelfel GmbH, Germany), **Marcus Ries** (Woelfel GmbH, Germany)

STRUCTURAL-MECHANICS ANALYSIS OF 10G TRANSFORMER IMPACT

During transportation of large power transformers from the site of manufacturing to the user's site, the transformer is typically subjected to a variety of mechanical impacts either during transportation or during on / off loading. Transformers are commonly designed to sustain certain standard levels of transportation acceleration in all three directions, x, y, and z. Also, transformers are usually equipped with impact recorders to register the accelerations the transformer is subjected to during transportation. Described in this paper is a rigorous structural-mechanics analysis performed by the authors of this paper to study the impact of a 10 g vertical acceleration registered during the railway transportation of a large power transformer.

13. **Leonid A. Darian** (CJSC “Technical inspection UES”, Russia), **Vladimir P. Polistchook** (JIHT of RAS, Russia), **Alexey V. Shurupov** (JIHT of RAS, Russia)

TESTING OF MODELS OF EXPLOSION PROTECTION SYSTEM FOR HIGH-VOLTAGE OIL-FILLED ELECTRICAL EQUIPMENT

Explosions of high voltage oil-filled electrical equipment (OFEE) lead to a significant material damage. These explosions occur under action of an arc discharge (AD) which arises after internal short circuit. Modernization of OFEE design and protection systems is the possible way to achieve significant reduction of potential explosion and substantial reduction of material losses. Examination of perspective explosion-proof OFEE designs and new explosion protection systems demands the effective test methods. In present work results of development and application of an arcless source of pulse pressure (ASPP) are described. In ASPP the testing impulse is produced by the jet of powder gases (JPG) which arises at the combustion of explosive materials.

In this work results of experimental researches of AD in transformer oil (TO) at conditions typical for AD initial stage have been presented: current rise time was 3-5 ms, the maximum arc current was up to 30 kA, AD burning time was 3-20 ms. The energy released in AD amounted to 0.1 MJ. It was established, that electric field strength in AD column was about 0.2 kV/cm, gas producing factor in AD was 110 l/MJ, growth rate of pressure in TO was about 0.3 MPa/ms. These results allowed to create an ASPP with demanded parameters. Experiments proved that TO flow under action of AD and JPG are similar given that the same influence duration of the energy released in AD is equalled enthalpy of JPG at liquid inlet.

In this work the transformer fracturing behavior after explosion has been analyzed; and the requirements for protection systems have been formulated. By means of ASPP the breadboard model tests of two well-known OFEE explosion protection methods were carried out. In the first method it is assumed that the protection is reached due to fast dump of pressure inside of OFEE case when special membranes are opened. In the second protection method it is offered to establish porous coverings on internal surfaces of OFEE cases. Experiments were carried out on OFEE model with the characteristic size of 1 m at action energy up to 1.5 MJ. It was shown, that these systems cannot protect the transformer body from significant damages.

The dynamic protection system of transformer (DPS) has been described. The efficiency of this new system using ASPP has been verified in experiments with autotransformer of 25 MW. It was shown that DPS protects the transformer from considerable damages at least at dynamic impulse of about 3 MJ.

III. MATERIALS, COMPONENTS AND NEW TECHNOLOGIES

Chairmen: M. Hrkac, I. Sitar

Friday, 17 October, 8:30 a.m.

1. **(Invited) Miljenko Hrkac** (ABB SpA, Italy), **Angelo Baggini** (Università degli Studi di Bergamo, Italy), **Flavio Mauri** (ENEL Distribuzione SpA, Italy), **Roberto Zannol** (ABB SpA, Italy)

BEYOND OF ECODESIGN AND FUTURE OF TRANSFORMERS

Transformers are strategic assets in the electrical networks, playing an important role in achieving the ambitious energy efficiency targets set by the most industrialized countries. Considering Europe only, hundred terawatt hours (corresponding to several megatons of CO2) are wasted every year through no load and load losses. Although transformers are among the most efficient electrical devices, even slight improvements in their efficiency shall be highly valued, considering the amount of installed units and the fact that they are designed to operate for decades before being replaced. In this context, energy efficiency can be regarded as a crucial accelerator for the penetration of new ideas and innovative solutions in the transformers business.

In this paper, the present energy efficiency programs running in different countries are reviewed, paying particular attention to the European market. In addition, possible future scenarios and development directions are presented together with their implications on transformers technology

2. **Belgrand Thierry** (ThyssenKrupp Electrical Steel UGO), **Lemaître Régis** (ThyssenKrupp Electrical Steel GmbH), **Lahn Ludger** (ThyssenKrupp Electrical Steel GmbH)

HOW GRAIN ORIENTED ELECTRICAL STEEL MAY LOWER TRANSFORMER NOISE

When noise issues arise in transformers, magnetostriction of GO electrical steel is the first driver to be complained about. No one to one correlation between noise and magnetostriction figures has been found so far, therefore core model characterisation is needed to assess noise influence from GO electrical steel. In its development of new products to answer the growing environmental demand of the market, TKES has developed its own knowledge. Links between GO electrical steel process parameters and measured core noise are presented through experimental results.

3. **Radosław Szewczyk** (DuPont), **Giorgio Vercesi** (DuPont), **Serge Rebouillat** (DuPont), **Byoung Sam Kang** (DuPont)

INNOVATIVE MATERIAL SOLUTIONS TOWARDS OPTIMIZED PERFORMANCE OF TRANSFORMER INSULATION SYSTEMS

The article introduces new developments in the area of insulating papers and liquids for liquid-immersed power transformers. Based on identified gaps in performance characteristics of currently available range of insulating materials, new material solutions are proposed.

A new insulating paper, aramid enhanced cellulose, is described which combines two well known insulating materials: cellulose and aramid. The thermal performance of the new paper is better than that of thermally upgraded cellulose by at least 10°C. This improvement can be used in optimization of transformer design with regard to operating temperature or extension of insulation system life.

A new fluid, ester based fluid, is presented. The new fluid is based on a blend of natural and

modified natural esters, maintaining the majority of performance characteristics typical for ester liquids, but with greatly improved (reduced) viscosity. This could help accelerating the adoption of environmental friendly fluids in transformers without necessitating significant re-designing work for compensation of high viscosity impact; more typical for traditional natural or synthetic esters.

4. **Anđela Hadži-Skerlev** (Končar - Electrical Engineering Institute Inc.), **Božena Musulin** (Končar - Electrical Engineering Institute Inc.)

BIODEGRADABLE INSULATING LIQUID BASED ON VEGETABLE OILS

Natural ester liquids (fluids based on vegetable oils) as non-toxic and fully biodegradable material are alternatives to mineral oils which are environmentaly non-friendly insulating liquids.

Natural ester liquids have only recently been used as a dielectric in power transformers so there is not enough experience with this new insulating liquid in service.

Oxidation stability laboratory tests enable evaluation of insulation liquid quality and lifetime prediction. In this article the oxidation stability of various natural esters is investigated.

The gassing properties of insulating liquids are significant because DGA (dissolved gas analysis) is a diagnostic tool for detecting and evaluating faults in transformer.

The gassing behaviour of natural ester and mineral oil under termal stresses is investigated.

5. **Baburao Keshawatkar** (Raj Petro Specialities Pvt Ltd Chennai, TN, India), **Nalin Nanavati** (Raj Petro Specialities Pvt Ltd. Chennai, TN, India), **P.N. Narayanan** (Raj Petro Specialities Pvt Ltd. Chennai, TN, India)

CRITICAL ROLE OF DIELECTRIC FLUIDS IN POWER EQUIPMENTS

The technological revolution sweeping the world has added several dimensions to the nature of demand for power. An infinite host of high-tech manufacturing activities, medical science research, IT enabled products and services and explosive growth in transportation all require uninterrupted source of quality power. Further the world is witnessing the emergence of mega cities with large concentration of population. The delivery systems for power to effectively service this scenario pose immense challenges to the power engineer. In this background the power sector is also undergoing vast transformations in the transmission and delivery system. Apart from the rapid expansion in generation, transmission & distribution networks the advent of smart grid is seeing path breaking changes in improving the entire system to the common benefit of consumers, power producers and transmission & distribution agencies.

The complex requirements of power place enormous stress on the efficient performance of the transmission distribution networks. This would be possible only with the equipments in the system functioning at highest degree of reliability. Hence all the components including insulating materials should have characteristics to withstand any type of load stress. In this the dielectric fluids have an extremely important role in the effective performance of the transformers, reactors, instrument transformers etc., forming part of the transmission system. The technological progress in the dielectric insulating materials today enables the power sector to customise solutions to meet all specific requirements.

In this paper we share our findings about the long term efficient performance of modern catalytic hydro-processed dielectric fluids in EHV transformers and reactors. Our observations are that the present day dielectric fluids enjoy exceptional quality of purity, stability ensuring unmatched performance lasting the whole lifespan of the transformers and reactors.

6. **Petar Gabrić** (Končar - Electrical Engineering Institute Inc.), **Antun Mikulecky** (Končar - Electrical Engineering Institute Inc.), **Damir Ilić** (Faculty of Electrical Engineering and Computing (FER), Zagreb), **Vladimir Podobnik** (Končar Power Transformers Ltd.)

INFLUENCING FACTORS IN INSULATION MODEL TESTING

The aim of this paper is to examine different factors that influence the quality of insulation models high voltage testing results. These factors are related to model geometry and model testing procedures. Model geometry is visually checked, several influencing factors are detected and their influence on el. field calculation results is evaluated using finite element method (FEM) and cumulative method for oil-barrier insulation design. The procedure for model geometry uncertainty estimation is performed using first-order Taylor series approximation. Also, the influence of previous voltage exposure history of a specimen, so-called “memo effect”, is estimated with a cumulative exposure method.

7. **Zdenko Godec** (Končar - Electrical Engineering Institute Inc.), **Vjenceslav Kuprešanin** (Končar - Electrical Engineering Institute Inc.)

TEMPERATURE RISE OF POWER TRANSFORMERS: COMMENTS AND PROPOSALS TO IEC 60076-2:2011

Two years ago, a new, third edition of IEC 60076-2 standard was published [1]. Over a period of two years, we have had the opportunity to evaluate this new standard in practice. In the paper, it is shown that the criterion for stagnation 1K/h + 3h is not entirely satisfying. Better criterion is 1K/3h, or extrapolation to stagnation - as given in second edition of the standard. A formula for hot-spot determination is not complete and it is suggested how to improve it. In the new standard, three formulas for winding average temperature determination are given. Based on experiments, we conclude that the best formula is the simplest one, and two additional formulas are without any benefit. According to [1], paragraph 7.11, measurement uncertainty estimates of results should be given in test reports - but only as information. No procedure for measurement uncertainty estimation is given, and measurement uncertainty is not used in decision-making. Therefore, the third edition of the standard is uncompleted and not motivating in terms of efforts to increase the quality of the measurement results. In the paper, the procedure for measurement uncertainty estimation is proposed and suggestion is given for appropriate decision making.

8. **Robert Sitar** (Končar - Electrical Engineering Institute Inc.), **Žarko Janić** (Siemens E T TR LPT GTC RES; Končar - Power Transformers Ltd.)

APPLICATION OF THE TEMPERATURE-TIME METHOD FOR MEASUREMENT OF LOCAL POWER LOSSES IN TRANSFORMER STEEL PARTS

Paper presents an application of temperature-time method for measurement of local losses in magnetic steel. Developed measurement system is described with focus on design of sensors and choice of instruments. Chosen equipment is tested on a DC circuit designed for measurement of losses in aluminum and copper conductors. Same measurement system is used for local loss measurement on magnetic steel rings. Measurement errors due to non-uniform loss distribution inside magnetic steel and heat dissipation to surrounding medium are analyzed and estimated.

9. **Mario Stuhne** (Končar - Power Transformers Ltd.)

RESEARCH OF DIFFERENCE BETWEEN SOUND PRESSURE AND SOUND INTENSITY MEASUREMENTS AS A FUNCTION OF DISTANCE FROM POWER TRANSFORMER

In noise measurements, two physical quantities can be directly measured, sound intensity and sound pressure. The focus of this paper is to give a mathematical relationship between those two values and the differences between them, as a function of distance from the measured source object (in this case that is a power transformer). In the end, a series of measurements of sound pressure and sound intensity at different distances from the power transformer is made, followed by the evaluation of a function that will describe the differences versus distance from the noise source.

10. **Ahmed Gamil** (SGB Regensburg, Germany), **Franz Schatzl** (SGB Regensburg, Germany)

NEW METHOD TO OPTIMIZE NO-LOAD NOISE OF POWER TRANSFORMERS BASED ON CORE DESIGN & TRANSFORMER OPERATING CONDITIONS

This paper introduces a new algorithm to calculate and optimize no-load noise (sound pressure) of power transformers, and to identify iron sheet parameters. The calculation consists of two steps: the 1st step consists in calculating an initial sound pressure level (A-Evaluation) which has approx. 70 % accuracy within a tolerance interval of ±2dB (A). The 2nd step consists in estimating the expected deviation from the initial calculation to reach 90 % accuracy in the final results. This deviation could be due to material handling, quality tolerance, core manufacturing, etc.

The optimization process consists of two parts: the 1st part takes place before choosing a certain iron sheet for calculation to identify the sheet parameters required for computational accuracy (“Sheet Optimization”). The 2nd part consists in considering a core design with an undesirable sound pressure level in order to reduce it to an acceptable limit. This part takes into account the other limitations such as no-load losses and transformer dimensions (“Design Optimization”).

For new iron sheets in the market, there is no measurement history to rely on. However, the algorithm is also capable of identifying the sheet parameters for calculation based on the available algorithm data base and the magnetostriction measurements of the iron sheet manufacturer.

11. **Emanuel Almeida** (EFACEC Power Transformers), **Pedro Pedro** (EFACEC Power Transformers), **Paulo Martins** (Instituto Superior Técnico), **Carlos Silva** (Instituto Superior Técnico)

EVALUATION OF DIFFERENT STEELS UNDER HIGH LOADING RATES FOR SHORT CIRCUIT APPLICATIONS

This paper draws from independent experimental results pertaining to the properties of steel loaded at high strain rates, similar to those found in power transformer short-circuits. The steels that were tested are common non-alloy structural steels and high strength structural steels. The experiments showed that the most common structural steels, when loaded at high rates, are capable of absorbing considerably more energy than in quasi-static conditions. On the other hand, the high strength structural steels that were tested showed no improvement in their energy absorbing characteristics at high strain rates. The paper provides some examples to show how the experimental results may be incorporated in the design of steel components for short circuit safety. The last part is focused on the permanent deformation of steel and assesses its influence on the impedance variation of the power transformer following a short circuit.

12. **Bruno Bošnjak** (Siemens AG Power Transformers Nürnberg), **Mario Stuhne** (Končar - Power Transformers Ltd.)

ANALYSIS AND EXPERIMENTAL VERIFICATION OF STATIC TILTING BEHAVIOUR OF CTC IN TRANSFORMER WINDINGS

This paper presents a numerical model and experimental verification of the critical tilting force calculation for transformer winding conductors under static axial pressure. For the purposes of this investigation a structural finite element method model of a non-epoxy bonded continuously transposed conductor used for the construction of transformer windings was developed.
The mechanical behaviour of two different transformer winding conductors under static axial pressure was simulated. The radial position of CTCs was varied according to manufacturer tolerances in order to closer correspond to the actual physical models. The displacements, stresses and strains obtained from the simulation are presented and analysed. This calculation is compared to existing analytical and empirical calculations in the IEC 60076-5:2006 and available literature. The results of these calculations were experimentally checked by pressing three physical winding models in a hydraulic press with the force corresponding to calculated critical tilting force and above. The resulting deformations of the winding conductors were photographed and compared to the results of the simulations.

13. **Leonardo Štrac** (Končar - Power Transformers Ltd.), **Franjo Kelemen** (Končar - Power Transformers Ltd.)

MAGNETISATION CURRENT OF A LARGE POWER TRANSFORMER AND ITS HARMONIC SPECTRUM IN NORMAL AND GIC CONDITIONS

A measurement of the harmonic spectrum of magnetisation current was performed. This paper analyze the results of the harmonic spectrum of magnetisation current in standard no-load test at various values of induction in the, magnetisation current harmonic spectrum during single-phase no-load test was considered and the impact of combined AC and DC magnetisation on core behavior and harmonic spectrum. A mathematical model of transformer core is introduced. The calculated results are presented.

14. **Helfried Passath** (Siemens AG, Transformers Weiz, Österreich), **Gerald Leber** (Siemens AG, Transformers Weiz, Österreich), **Peter Hamberger** (Siemens AG, Transformers Linz, Österreich), **Florian Bachinger** (Siemens AG, Transformers Linz, Österreich)

DIRECT CURRENT COMPENSATION – FIELD EXPERIENCE UNDER SERVICE CONDITIONS

Modern grain oriented core steel used in power transformers has a very high magnetic conductivity. This advanced material makes the transformer susceptible even for small direct current (DC) in the power grid. Already minor DC increases the no-load noise and no-load losses of the transformer considerably. This effect is known as half-cycle saturation. In order to overcome these parasitic DC an active compensation method called “DC compensation” (DCC) was recently developed by Siemens [1].

The question about the origin of the DC is not fully answered yet. However the following sources have been already identified: power electronics, renewable power generation (wind, solar), HVDC transmission lines and DC operated railroad or subway systems. The parasitic direct currents can flow over the power lines to ground or asymmetrically in the power line phases only.

In this paper field data, a four-month DC load profile, of single-phase core type transformers, equipped with active DC compensation, are shown. The discussed unit, a bank of three single-phase autotransformers, is in service mainly exposed to DC flowing from the overhead lines

through the windings to the common neutral. DC magnitude varies from 0.05 A to about 0.2 A DC per phase throughout the day. From factory tests we know that only 0.2 A DC causes a noise increase of 5.6 dB(A) compared to the noise level without any DC compensation. This might cause troubles at the substation when noise has to be below a guaranteed level.

Data analysis of the field data shows that the DC throughout the day follows a clear profile with its highest level during midnight and lunch time. This might indicate a correlation to the load and/or switching operations in the grid to adjust to the actual needed load.

However, the DC compensation equipment fully eliminates the direct flux in the core and thus the DC caused increase in noise.

15. **Igor Žiger** (Končar - Instrument transformers Inc.), **Danijel Krajtner** (Končar - Instrument transformers Inc.), **Zvonimir Ubrekić** (Končar - Instrument transformers Inc.)

PUSHING THE BOUNDARIES OF INDUCTIVE VOLTAGE TRANSFORMER DESIGN

Designing inductive voltage transformers for the highest voltage levels (550 kV and above) is a true challenge indeed. The main reason for this is their complex internal R-L-C structure, including an insulating system which needs to be resistant to all types of overvoltages and consequent dielectric stress it can encounter during its lifetime. This is why it is necessary to verify behavior of such transformers during the design process, and under four sets of standard test overvoltage types; the Power Frequency Withstand Voltage (PFWV), the Lightning Impulse Withstand Voltage (LIWV, i.e. BIL), Chopped Impulse Withstand Voltage (CIWV) and the Switching Impulse Withstand Voltage (SIWV).

The main idea of the paper is to demonstrate that by understanding the influence of crucial parameters of the appropriate equivalent diagram on the voltage distribution across the active part of the transformer, it is possible to define the overall design of inductive voltage transformers so that they can satisfy even the most rigorous insulation requirements, thus pushing the boundaries of design even further.

16. **Branimir Ćućić** (Končar - Distribution & Special Transformers Inc.), **Nina Meško** (Končar - Distribution & Special Transformers Inc.), **Martina Mikulić** (Končar - Distribution & Special Transformers Inc.), **Dominik Trstoglavec** (Končar - Distribution & Special Transformers Inc.)

DESIGN IMPROVEMENTS IN MODERN DISTRIBUTION TRANSFORMERS

In the paper design improvements of distribution transformers related to improved energy efficiency and environmental awareness are discussed. Eco design of transformers, amorphous transformers, voltage regulated transformers and transformers filled with ester liquids are analyzed.

As a consequence of growing energy efficiency importance, European Commission has adopted new regulation which defines maximum permissible levels of load and no-load losses of transformers with rated power ≤ 3150 kVA, and minimum peak efficiency index for transformers with rated power > 3150 kVA up to 40 MVA. The impact of new regulation on the design and economy of transformer is presented.

Amorphous transformers, with up to 70 % lower no-load losses in comparison to the conventional transformers, could be an alternative with respect to energy efficiency. Although their initial price is higher than the price of conventional transformers, some studies show that they might have economic advantages.

The increasing penetration of distributed energy sources can cause an increase in voltage variations in low voltage networks. To keep the voltage within limits defined by EN50160,

voltage regulated distribution transformers could be used.

Although mineral oil has been used as a dielectric fluid in transformers for many years, there are some environmentally friendlier alternatives – natural and synthetic ester-based fluids.

17. **Mario Jurković** (Končar - Distribution & Special Transformers Inc.), **Ivan Sitar** (Končar - Distribution & Special Transformers Inc.), **Damir Žarko** (University of Zagreb, Faculty of Electrical Engineering and Computing)

MODERN DESIGN OF ONBOARD TRACTION TRANSFORMERS

This paper describes modern design of an onboard traction transformer, i.e. design of the active part and cooling system depending on application and use of special materials.

The influence of power supply characteristics (AC or DC) on transformer design and differences between uni and multi-system transformer design have been presented.

Finally, it is described how the harmonics in the load current influence the transformer design, especially the design of the cooling system.

18. **Audrius Ilgevicius** (Maschinenfabrik Reinhausen Germany), **Erich Steindl** (Maschinenfabrik Reinhausen Germany)

IMPROVED GRID SYSTEM EFFICIENCY AND RELIABILITY

Traditional response to increased and fluctuating power demand is the extension of grid (increase of grid capacity). This paper informs about alternative strategies, which face the new conditions in the grid system by improving its efficiency and reliability. Key factors are regulation of power flow and advanced automatic regulation of grid voltage. These tasks are done by equipment as phase shifting transformer, variable shunt reactors, advanced automatic voltage regulators and power flow regulators.