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SPECIAL REPORT FOR GROUP A2
(Transformer)

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Special Reporters

1. General

The scope of SC A2 covers all kinds of power transformers, including industrial, DC converter transformers, reactors and transformer components. All activities related to design, manufacturing, application of materials, utilisation, safety/environmental aspects, economic/commercial aspects, quality assurance and testing are covered. The two key strategic directions for SC A2 are to provide services to customers in terms of guidance on reliability, life management, economics, etc. and to work on technology issues such as safety, new technologies and concepts, electrical environment, pre-standardisation work, etc.

2. Group Discussion Meeting in Paris Session 2014

The three Preferential Subjects selected for 2014 are:

PS1 > Best Practices for Transformer Asset Management
PS2 > Transformers for Specialized Applications
PS3 > Field Experience with the use of Non-Conventional Materials and Technologies

57 contributions from 30 countries were offered with an unbalance between the three preferential subjects (27 reports on PS1, 17 reports on PS2, 13 reports on PS3). In total, 34 contributions were accepted.

The subjects discussed during the 2014 session will be useful for bringing new information to working groups that are currently running inside SC A2 and also to bring new ideas for possible new work.

Important information for the delegates interested in presenting a contribution:

- *The timing of the A2 session usually allows a maximum of 50 contributions; the priority will be given by time of submission, taking into account, of course, the pertinence in regards of the questions. Contributions received at least two weeks before the session will be automatically accepted - contributions received less than two weeks before the session will be accepted only if the maximum number of contributions is not reached.*
- *The day before the session day o(Wednesday August 27th), all delegates who want to make a contribution should come to the SC A2 chairman room before noon as the room will be close in the afternoon.*
- *The SC A2 session held on Thursday August 28th will start at 8h45 and the lunch time will be from 12h00 to 13h30.*
- *All the details concerning contributions (templates, rules, etc.) will be posted on the CIGRE website http://www.cigre.org/Events/Session.*

3. PS1 – Best Practices for Transformer Asset Management

3.1 Papers for Preferential Subject No 1

A total of 16 papers were accepted for this year's plenary session of CIGRE within the scope of PS1 that may be divided into two main thematic groups:

- Tools supporting transformer operation management, creating algorithms for assessment of the current technical condition of transformers (Health Index);
- On-line monitoring of the basic elements of power transformer equipment (bushings, on-load tap changers).

Paper A2-101 (Canada)
The article presents modified/innovative approach to supported management of transformer population, mainly undertaking technically and economically justified decisions on replacement of units. A population of more than 2000 transformers and shunt reactors were used to create this model and method. The key indicators have been singled out to be taken into account in creation of the Health Index, as well as in undertaking a decision on withdrawing a unit from operation.

Paper A2-102 (Canada)
The article presents results of the insulating paper tests conducted on a group of transformers selected for scrapping. The results of DP distribution as a function of the paper sampling location has been compared with selected paper insulation ageing indexes obtained with indirect testing methods (furans, alcohol). A series of factors which influence the results have been taken into account (temperature, transformer structure, electrical insulating oil condition, DGA results).

Paper A2-103 (Hungary)
The paper describes current experience in using the system used for transformer management and technical condition assessment in Hungary. Using information from an on-line monitoring system, an expert system has been developed for three groups of devices: transformers, circuit breakers and instrument transformers. The developed system gives an output signal as a resultant technical condition of each device. The purpose of this solution is to support the operation personnel in managing operation within the CBM program.

Paper A2-104 (Argentina)
This paper presents a multi-level tool intended to support transformer population operation management, including replacement of the devices. The conclusion-creating process is based on such information as: paper insulation ageing, probability of failure within a particular time period, analysis of economically

optimum solution (replacement, delivery of a lower-power unit for parallel operation). At paper insulation ageing assessment, the main parameters of the transformer construction and operation have been taken into account: Ageing Accelerator Factor, Hot Spot Temperature, load conditions and ambient temperature.

Paper A2-105 (Australia)
This paper presents computer techniques created to assess a transformer technical condition on the basis of a so-called electric insulation system defect pattern recognising procedure. The output signal is the Health Index determined mainly on the basis of oil tests (DGA, 2-FAL, BDV, DDF). The tool determines HI by interpretation of the test results available and by assessment of correlation between selected parameters. The created defect patterns were verified on an independent group of transformers. The results are presented in the paper.

Paper A2-106 (Germany)
This paper presents experiences collected on the basis of experiments conducted on a population of transformers identified for scrapping (both GSU and grid ones). Insulation paper was sampled methodically from these transformers and used in DP tests. DP distribution depending on the sampling place was tested. A formula for determining average DP of the whole transformer has been proposed, as well as its correlation with 2-FAL content. Additionally, comparative tests were conducted and the results of moisture concentration were compiled on the basis of direct measurement and indirect methods.

Paper A2-107 (Italy)
This paper presents an operational strategy of an Italian operator using Health Index as one of the parameters for assessing the transformer operational risk. Importance of an individual approach for each transformer in the population (CBM) has been emphasised. Factors which are taken into account in determining the HI value have been indicated. The HI values obtained have been attributed to the transformer four technical conditions enumerated in CIGRE publications.

Paper A2-108 (United Kingdom)
This article presents a comprehensive algorithm for assessing transformer technical condition using an Asset Health Index (AHI). Determination of the algorithm takes into account all the circumstances which may influence the current technical condition of the transformer, including the transformer's structure, diagnostic and oil tests results. Thanks to the system, the verifications of the transformer operation management effectiveness were made on the basis of the relative failure frequency value of the whole transformer population.

Paper A2-109 (United Kingdom)
This article presents a methodology used in Great Britain for post-mortem analysis. Advantages of the information gathered have been described, which is a support for the transformer operation management process. New procedures are presented with case studies on real transformers. Procedures have been implemented to get a more in-depth knowledge of the failure mechanism and reasons.

Paper A2-110 (United States)
This paper discusses issues of geomagnetic disturbance protection. Functionalities of widely used non-linear resistors are described. Certain modifications of the system are proposed in order to limit adverse GIC (Ground-Induced Currents) influence on a transformer.

Paper A2-111 (United States, Poland)
This paper discusses available methods for bushings on-line motoring system implementation. Their advantages and disadvantages are indicated. External factors which may disturb correct operation or cause incorrect interpretation of the results, as well as methods for their elimination are presented. Results recorded in a real system are also presented.

Paper A2-112 (Japan)
This paper discusses the effects of the 2011 earthquake in Japan on the electrical power system. Statistics concerning transformer damages are presented. The main causes of damages and suggestions of solutions are indicated in order to avoid them in the future. Methods and technical solutions of restoring the power system efficiency after such a disaster are presented.

Paper A2-113 (Sweden, Germany, United States, Switzerland, Canada)
Due to relatively large number of power transformer failures caused by bushings and on-load tap changers, the paper presents a modular solution for on-line monitoring of these devices. Vibro-acoustic and motor current measurements are used for the OLTC problems diagnosis. Sensitivity and purposefulness of this type of solutions are discussed.

Paper A2-114 (Norway, Sweden, Belgium)
This paper presents experiences in transformer operation management in Norway. Structures of the transformers used are discussed. Results of laboratory tests on paper insulation ageing process are presented. Information gathered on the basis of experiments conducted on transformers selected for scrapping is reported.

Paper A2-115 (Poland)
This paper discusses selected issues of moisture concentration in a transformer's electrical insulation system. A disquisition on their permissible loading depending on the moisture concentration and oil temperature in the top layer of a tank is made. Issues of the potential threats of starting-up wet units of the so-called cold reserve are discussed.

Paper A2-116 (The Netherland)
This paper describes the procedure for transformer operation management with the use of Health Index as the main support tool. The gradation algorithm used in the transformer technical condition assessment is described. Logical functions used to determine HI value (used in the case of e.g. some diagnosis data missing) is presented, as well as the algorithm for making decisions on possible further operation of a particular transformer within an particular period of time.

3.2 Discussion for Preferential Subject No 1

Correct management of transformers maintenance has its clear-cut influence on their reliability and failure-free operation of the power system, as well as on the associated economic aspects. Currently, available expert system tools for supporting this process are being developed dynamically. This is mainly due to the significant increase of the calculation (computing) power, as well as to the new diagnostic tools intended for transformer technical condition assessment. Thanks to these factors, it is possible to "teach" the software to draw conclusions concerning the transformer itself and the conditions of its operation on the basis of a series of information made available in sufficient amount.

One of the elements which provide the input signal of such a system is on-line monitoring systems. Further developments should be expected regarding the quality of diagnostic information obtained as well as the broader use of advanced diagnostic methods aiming to the detection of major transformer failure modes.

In the whole process of decision-making, the transformers of older and of modern constructions should be analyzed separately because in each of the two cases, different problems will condition their correct operation. Undoubtedly, in the case of older units, the main problem will be ageing and moisture in the insulation system (divided into solid and oil insulation), as well as reduction of the transformer components reliability (bushings or on-load tap changers). In the case of new transformers, their economically designed construction might pose a risk for certain threats, e.g. connected with the presence of potentially corrosive sulphur in oil.

To sum up, it should be emphasised that the installation of on-line monitoring devices and the use of expert systems supporting the decision making process seem to be a natural strategy for the smart power transformer operation and maintenance management process.

3.3 Questions for Preferential Subject No 1

Question 1-1 Transformer bushings and on-load tap-changers are the components which have in many cases, throughout the recent years, contributed to serious transformer failures. Have on-line diagnostic systems already contributed to improve this situation significantly?

Question 1-2 Results of the on-line systems' measurements are still sometimes wrongly interpreted by their users. Are there any recent developments in the interpretation of the data coming from the monitoring systems, in particular for the monitoring of bushings and on-load tap-changers?

Question 1-3 What are the key parameters for design, test and manufacturing of sensors and related hardware to ensure long term reliability of monitoring systems ?

Question 1-4 There are several formulas or scoring system for Health Index determination. Is there an interest for benchmarking the various health index formulation used in the industry? What are the purposes of using health indexes (reinvestment, maintenance, etc.)?

Question 1-5 Which test results and condition information about transformers need to be included in the Health Index? How information available only for a small proportion of the transformer fleet can be integrated in the scoring system?

Question 1-6 Despite the importance of diagnostic information drawn from experiments on the transformers selected for scrapping, high post-mortem costs might limit the number of units investigated. Are there any guidelines, based on the previous experience, indicating what should be included in post-mortem investigations and how to evaluate the costs and benefits of such task?

4. PS2 - Transformers for Specialized Applications

4.1 Papers for Preferential Subject No 2

A total of 11 papers related to this subject have been submitted that may be classified into the following subjects:

- 4 Papers about Phase Shifting Transformers (PST)
- 2 Papers about HVDC transformers
- 2 Papers about Shunt Reactors
- 3 Papers about Testing / Design requirements

Phase shifting transformers

Paper A2-202 (Brazil)
Furnas of Brazil installed a 400 MVA 500 kV/ 138 kV autotransformer in series with a 400 MVA, 138 kV, +/-21.6° dual core, single tank PST in order to allow an additional in-feed from the 500 kV system into a 138 kV system without overloading the system and without exceeding its short circuit withstand. The total in-feed into Rio de Janeiro could be increased by 120 MW by proper balancing of the load flows on the 500 kV, 345 kV and 138 kV transmission lines while the losses could be reduced by 10 MW. As the system loading increased over 12 years of operation the secured in-feed via the new 138 kV connection could be increased from 270 MW to 310 MW by upgrading the protection scheme.

Paper A2-205 (India)
India reports about their first PST installation. It is a 315 MVA, 400 kV/220 kV autotransformer with an additional 105 MVA series transformer producing +/- 15° phase shift. The series transformer is excited from an extra regulating winding on the autotransformer. Again the purpose is to avoid underutilization of a new 400 kV line intended to reinforce the existing parallel 220 kV system. Results of load flow studies considering various generation and transmission topology scenarios led to the functional specification of the PST. The impact of tap change operations of the PST on the system was studied with EMTP. Short circuit currents were also simulated for the coupled units in order to be able to design for the proper short circuit forces.

Paper A2-207 (Italy)
One 450 MVA, 230 kV, +/- 54.9° and four 1800 MVA, 400 kV, +/-17.5° PSTs were installed in the Italian transmission network, all of dual core, two tank design. The 400 kV PSTs are installed two in series in order to allow operating the overhead lines at their thermal limits even in case of outage of one unit. Extensive electromagnetic simulations of the magnetic core and its structure with regard to saturation and local loss densities were performed at different loading conditions. Transient voltage distributions for two coupled active parts were performed.

Paper A2-210 (United States)
The design tools for optimization and verification of transformers developed by most manufacturers are applicable to one active part at a time. One of the more common PST concepts consists of two coupled active parts. Paper A2-210 presents a circuit analysis method to determine the internal voltages and currents at all windings during rated and overload conditions and during external faults. This information can then be used as input in the design and verification of short circuit forces, flux density variation under load, voltage drops of the individual active parts.

HVDC Transformers

Paper A2-204 (Germany)
The article presents mainly measurement results from dielectric studies of fiber optics under AC- and DC-stress. It presents a study of basic withstand strength and flash over statistics for simple oil gaps in which fiber optics have been inserted. Furthermore it presents PD measurements under DC withstand and DC

polarity reversal tests on dielectric models relevant to a winding end insulation. The articles concludes that the presence of fiber optics somewhat influences the dielectric withstand strength of a simple oil gap. It also concludes that the presence of fiber optics could increase the background PD level during DC-testing, even though not leading to PD high enough to trigger pulse counting according to IEC 61378-2.

Paper A2-208 (United Kingdom)
The article presents results from measurements of space charge in pressboard using pulsed electro-acoustic methods. It compares measurements from pressboard impregnated with modern, fresh mineral oil to measurements of pressboard impregnated with aged oil from an AC-transformer. The conclusion is that the more conducting aged oil also impacts the charge build-up process in the pressboard and that the estimations of trap energy distribution and apparent mobility can be used to verify the dielectric properties of different aging samples, although the calculations still need to be improved.

Shunt Reactors

Paper A2-206 (Russia)
The article describes the design and application of Controlled Shunt Reactors (CSR) in Russia. A new design concept providing new solutions and with lower losses than previous designs is presented. An operating installation in Western Siberia (Russia) of a 180 MVA, 500 kV CSR based on these principles is described. The CSR unit consists of three single phase reactors wye-wye connected into a three phase group. Delta connected compensation windings are used to suppress current harmonics. The power of the CSR is controlled by a DC magnetizing current which is fed directly to reactor main winding from the split neutral side. The CSR is installed to provide voltage stability and to compensate reactive power under varying load conditions on high voltage lines. It is also intended to provide arc extinction in case of single-phase short circuit during single-phase auto-reclosing. It can also function as a saturable reactor to suppress switching over-voltages in the transmission line.

Paper A2-211 (Sweden)
The article describes the applications, benefits and system aspects of Variable Shunt Reactor (VSR). Examples of different system aspects calling for dynamic compensation of reactive power resulting in the use of VSRs are discussed. In particular, the experiences from the Norwegian Transmission System operator (TSO) Statnett where VSRs are extensively used are described and discussed. The main benefits are shown to be improved power quality (reduced voltage steps from switching fixed reactors), to enable an optimal VSC operation and automated voltage regulation, to secure reactive reserves by "tuning" the reactor to give optimal headroom in SVC's and synchronous compensators, and finally, by reduce losses by “tuning the reactor” and allowing SVC's to operate in "minimum losses" position. In general, VSRs are considered to be efficient tools to provide flexibility and controllability in reactive power compensation and to meet the uncertainties that lie in the rapid changes in load- and generation patterns.

Design / Testing requirements

Paper A2-201 (Austria, France)
The paper describes the evaluation of the short circuit capability of a 570 MVA single-phase transformer by comparison to a similar reference mock up transformer designed manufactured and short-circuit tested for this purpose. The tests were performed in two steps. The first step was a successfully performed customer acceptance test where nominal short circuit currents were applied to demonstrate the short-circuit stresses in the real unit. The second test series was a “destructive test” consisting of increasing current shots until a noticeable change in the reactance was experienced. The article presents design evaluation and calculation approaches to verify the short circuit withstand capability of large power transformers unable to be tested in high power laboratories.

Paper A2-203 (China)
In this article the construction features of ultra high voltage winding exits are analyzed and the test scheme and the test items are determined. An insulation test instrument was designed and manufactured which allows the exit lead to be tested independent from the transformer or reactor which is different

from the traditional lead exit test approach. The long term insulation property under power frequency voltage for 10 hours was proposed as the main test item to evaluate the insulation reliability. The partial discharge level was taken as the characteristic parameter to study.

Paper A2-209 (United Kingdom, Germany)
The paper summarizes design recommendations arising from experience with offshore transformers. Whist the term "offshore transformers" is used throughout the paper the comments apply equally to any offshore oil filled plant. The harsh environment in combination with the difficult / costly access is a new challenge for the design of offshore installations. After describing different possible layouts of an offshore platform, experiences are summarized and recommendations are given concerning the following subjects: cooling, insulating fluids and fire, connections, transporting, installation & commissioning. The possible benefits achieved by the use of ester filled transformers and or online monitoring are discussed.

4.2 Discussion for Preferential Subject No 2

Four of the presented papers are related to Phase-shifting transformers (PSTs) that allow re-directing power flows in meshed networks. PSTs were installed mainly in North America in the 70s and 80s, their need being driven by meshed networks covering large geographical distances or by tightly meshed but severely loaded networks around large cities like New York or Chicago. When deregulation of utilities started in other parts of the world and more recently massive, fluctuating injection of power from renewable energy sources came into play there was a rise in the number of phase-shifting transformer projects all over the world. Experience with the "first wave" of PSTs revealed the need to develop a deeper understanding of the special loading conditions and transient conditions seen by this special type of transformers. This was also reflected in the 12 papers presented at the joint CIGRE A2&C4 colloquium held in Zurich in 2013.

Transformer related topics to be clarified are:

- Variation of the loading of the magnetic circuit(s) as a function of magnitude and direction of the through current and as a function of tap position. There is a tendency towards partial saturation of the core(s) when a PST is used to reduce or reverse the natural power flow.
- Currents in the different windings during external faults and resulting short circuit forces.
- Distribution of switching and lightning voltage surges along and between all windings.
- Proper coverage of operating conditions by factory testing.

System studies are necessary to:

- Determine the angle range of the PST based on current and on future scenarios for the network topology and loading conditions.
- Make the angle step size compatible with network stability.
- Upper and lower bounds for the short circuit impedance with regard to system short circuit withstand and acceptable voltage drop (regulation).
- Insulation coordination and protection.

Two of the presented papers are related to HVDC transformers, one paper describing dielectric studies when fibre optics are installed in the winding for temperature measurements and the other paper discussed experience with the measurement of space charge with electroacoustic methods. Two presented papers are related with shunt reactor, discussing in particular VSR (Variable Shunt Reactors) in terms of design, application and benefits.

Finally, three additional papers discusses Design and Testing requirements in general. One paper discusses the evaluation of short circuit capability of a large single-phase unit, another paper discusses the construction and testing of high voltage winding exits and the last paper summarizes the design recommendations arising from experience with offshore transformers.

4.3 Questions for Preferential Subject No 2

Phase shifting transformers

Question 2-1: What is the experience of utilities with the actual utilization of PSTs versus the scenarios applied during the specification phase?

Question 2-2: Which features should be considered in the specification of a PST in order to avoid a stranded investment?

Question 2-3: Is it possible to properly represent transient voltage stresses in operation occurring in PST designs with multiple active parts by performing factory tests on the individual units?

Question 2-4: In which way can a purchaser reassure that the PST will not experience saturation effects in service?

HVDC Transformers

Question 2-5: Is the customer side properly aware of the novelty risk when specifying monitoring solutions that possibly impacts the integrity of the transformer? Is there any widely available data judging the risks with use of fiber optics?

Shunt reactors

Question 2-6: Papers A2-206 and A2-211 describe two technologies for variable shunt reactors. The main difference in performance is in the regulations speed and in the regulation range. For what system applications is the higher performance of the Controlled Shunt Reactor necessary and for what applications are the lower speed and regulation range of a Variable Shunt Reactor sufficient?

Question 2-7: What field experiences in terms of installed units, voltage and rating, years in operation and markets can be reported for Controlled Shunt Reactors and Variable Shunt Reactors, respectively?

Testing / Design requirements

Question 2-8: To realize a mock-up for a GSU transformer it has been necessary to do some adaptations. Would it be possible to do the same in case of large power autotransformers with relevant regulating windings or in case of large phase shifting units that have a more complex structure compared to a GSU transformer?

5. PS3- Field Experience with the use of Non-Conventional Material and Technologies

5.1 Papers for Preferential Subject No 3

A total of 6 papers have been submitted, according the following sub-topics:

- Experience with new insulating liquids and solids (maintenance, performance, diagnostics, life cycle costs), improved winding and core material and technologies
- Experience with new technologies for components: bushings, tap changer and other transformer accessories
- High-Temperature Superconductor (HTS) transformer experience and applications

Paper A2-301 (Australia) discusses the factory and field experience with monitoring of core type transformer filled with Vegetable oil. A unique feature of on line monitoring of moisture in oil and temperature in oil in the field was used and the summary results of periodic change for DGA and moisture in oil values over a period of 8 years are presented. The paper describes the process of migration of moisture from insulation to Vegetable oil and back to insulation due to temperature variations. It also presents the advantages of having the second on line moisture monitoring at a location close to the bottom of tank. The on-line data suggests a 'two speed' moisture migration pattern in the transformer, where the water from the surface of insulation was migrating to the oil with the temperature increase and returning back to the surface with the temperature decrease daily, while in parallel to the first process the amount of water in the oil was gradually decreasing over the years. The paper also demonstrates the efficiency of the advanced oil preservation system.

Paper A2-302 (France, Serbia) discusses the degradation of cellulose based insulation due to ageing phenomenon in natural ester and mineral oil. It presents a study of moisture equilibrium in impregnated paper and pressboard and the oil in which they are immersed. Moisture equilibrium isotherms were created for temperatures from 40 to 120°C and for water content in paper and pressboard from 0.5 to 5%. A second objective of the research was to study the thermal ageing at 140°C up to 120 days in order to evaluate the long term stability of different oils and solids. It was found that oil pyrolysis was the dominant degradation mechanism, while oxidation and hydrolysis were minor processes. Stability and performance of natural ester were found to be very good, especially regarding the impact on solid insulation. Degradation of solid insulation was present at a reduced rate, in comparison with mineral oils, on the basis of highest degree of polymerization values at the end of ageing.

Paper A2-303 (Russia) presents the studies conducted on core type superconducting transformer prototypes (laboratory scale). In the windings of a high-temperature superconducting (HTSC) transformer with a dense arrangement of superconducting turns and layers, the magnetic induction is generated by the total ampere-turns of the windings. It describes the edge effect, and, as a result, excess increase in the current density on the edges of cylindrical windings. The effect of the external magnetic field generated by currents in the other turns of the windings of the transformer is minimal, and therefore superconducting windings are located in their self-magnetic field, which is equal to a magnetic field of one turn taken separately. The principle of designing multi-stranded superconducting wire with localized magnetic field with an optimal arrangement of current carrying elements has been demonstrated and substantiated with tests performed on prototype HTSC transformer.

Paper A2-304 (Italy, Spain, Switzerland) presents an overview of the superiority of dry-type transformers with respect to safety for people, property and the environment. It demonstrates the use of new concepts for indoor substations without the need for costly protection means and without the residual risks related to liquid-filled transformers. This paper presents a number of different realized or planned dry-type transformers for indoor and outdoor installations, the related components, and the experience gathered while installing the transformers and taking them into operation. It describes that combining dry-type transformers with gas-insulated or hybrid gas-insulated switchgear allows for a very compact and safe indoor substation. Such installations can be placed in the basement of any building and conceptual outlines are presented in the paper.

Paper A2-306 (Mexico) presents the experience covering different aspects of design and testing of more than 20 high voltage transformers filled with natural-ester fluid. It describes that due to different dielectric permittivity constant and lower partial discharge inception/breakdown voltage level for natural ester fluid, it requires certain modification to the dielectric design and the insulation arrangement. Also the higher viscosity of the natural-ester mainly influences the need of different cooling solutions for the coils, as well as additional external cooling equipment. A comparative study for different characteristics of transformers filled with natural esters and mineral oil is presented, including power factor, capacitance, insulation resistance, temperature rise, dissolved gas analysis, and others. Acceptance levels/criteria are presented as a proposal to the industry, as well as recommendations from the user point of view are also given.

Paper A2-307 (Mexico) presents an overview of a research project developed between Mexican utility, IIE (Electrical Research Institute) and transformer manufacturer, in order to evaluate natural ester fluid performance of a 25/33.3, 230 kV shell type autotransformer installed on the Mexican grid. It describes the process followed for study of the dielectric and thermal performance of autotransformer operating with natural ester, condition assessment, re-design of oil preservation system and on-line monitoring equipment. It also presents the studies for dielectric strength using various electrode configurations with uniform and non-uniform electrical fields, moisture sensitivity, partial discharge, bacterial growth, thermal and infrared characteristics, oxidation stability, material compatibility and temperature performance of the vegetable oil.

5.2 Discussion for Preferential Subject No 3

Four of the presented papers are related with the first sub-topic on new insulating liquids and solids. Two of these papers compare the natural-ester fluid performances with mineral oil in terms of design and testing for the first one, and in terms on the cellulose degradation when expose to long-term operating condition for the second. One of the other papers emphasises field experience with natural ester, with more the 8 years period of DGA and moisture data in several different operation conditions and the last paper presents also a field experience of ester-fluid on a 230 kV shell type autotransformer.

There is no paper related specifically with the sub-topic of new component technologies, even if one paper discusses the safety and environment advantages of dry-type transformers for indoor or outdoor installations. Finally, the sub-topic on HTS transformer is covered in one paper, in which a study of a laboratory scale core-type transformer is described.

5.3 Questions for Preferential Subject No 3

Question 3-1: Does the higher moisture content in natural ester oils as compared with mineral oil have any negative effects on the dielectric properties of insulation system?

Question 3-2: Is there any effect on degree of polymerization of paper impregnated with natural ester fluid? What are the parameters required to assess the residual life for natural ester fluid and if natural ester fluid can be reclaimed like mineral oil?

Question 3-3: What are the risks associated with energizing a natural ester filled transformer at ambient temperatures of -20 °C and below? Is there any reference Standard or guide for evaluating the DGA results of transformers operating in service filled with Natural Ester or Vegetable oil?

Question 3-4: For retro-fill transformers, what is the maximum percentage of residual mineral oil permissible with natural ester fluid? What is the effect on flash point and other oil properties?

Question 3-5: What is the experience on verification of localized hot spot and loss in the HTSC wire due to the effect of leakage flux entering the windings?

Question 3-6: Is there any short circuit test performed on 69 kV Class and ≥ 25MVA dry type transformers? If so, how do the epoxy vacuum cast coils stand up to this type of short circuit test, particularly with respect to the sudden heat generation?