Cigre SC A2 and D1
Joint Colloquium on Power Transformers
October 7-12, 2007, Bruges

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Following an invitation from the Belgium National Committee of Cigre, a joint colloquium between SC D1 ‘Material and Emerging Technologies’ and SC A2 ‘Transformers’ was held in Bruges, Belgium on October 7-12, 2007 and included a Tutorial session, a meeting of Study Committee A2 and several Working Groups. The colloquium was held in the St. Jans Hospital, a restored hospital created in 1855, in the centre of the historic town. 198 experts, from 35 countries, gathered to discuss new developments in the field of insulating materials, reliability of transformers and shunt reactors. More than 50 papers were presented. The colloquium got a support from some sponsors, which took part in the technical exhibition.

The Colloquium was open by Jan Declercq on behalf of the Belgium National Committee. A warm welcome was extended to all participants together with expressions of sincere gratitude to the sponsors who made this meeting possible.

The city of Bruges is a typical medieval looking city, founded in the 15th century and having many small streets, period buildings and monuments. Bruges is known today as the "Venice of the North" because when it was founded, it was then a major port situated on the North Sea coast possessing many canals that are still a notable and attractive feature of the city today.

Pierre Boss/Switzerland, Chairman of SC A2, reviewed the overall mission and current activities within SC A2, and the specific objective of this Colloquium. Three subjects were selected in coordination with SC D1. The first subject sought to deepen our knowledge of insulating materials; the second one addressed the issue of transformer reliability, risk assessment and oil corrosivity while the third one discussed the shunt reactors in terms of specification, loading and reliability.

Prof. Ernst Gockenbach/Germany, Chairman of SC D1, presented the mission of this SC and the need of liaison with SC A2. The work of the Study Committee is principally scientific in nature and its main aim is to provide timely information on new developments and trends to other CIGRE Study Committees. The link with transformers is especially obvious for WG D1.01 ‘Liquid Impregnated Systems for Transformers’.

Performance of conventional and new insulating materials for transformers

Lars Lundgaard/NO chaired this session and 19 papers were presented and discussed.

This interest on this topic clearly shows the close connection of the activities between SC D1 and SC A2 and was subdivided into 3 major subtopics:

- Thermal and dielectric performance, corrosivity, fire safety and environmental performance
- New materials, liquids and solids, material compatibility
- Experiences accumulated in view of maintenance of existing standards (hybrid systems, SF_6 etc).

A very important topic of this session turned to be the topic of insulating fluids in its different facets – dielectric or physico-chemical.

The first keynote was given by Dr. O. Lesaint/FR on breakdown and pre-breakdown phenomena in transformer insulation liquids. He showed that for mineral oil several propagation modes for the pre-breakdown phenomena (streamers) exist. The propagation modes result in large variation for time to breakdown, important for insulation coordination. Effects from contamination and scaling effects from experiment to transformer dimensions were discussed. The behaviour of mineral oil is well documented, but up to now no predictive model on streamers exist, because the streamer propagation largely dependent on the conditions like liquid nature, voltage shapes, distances). Dielectric performance in carefully selected experiments under defined conditions can provide useful data. This will have relevance both for mineral oils and for the new insulating liquids.

The second keynote from Dr. I. Atanasova-Höhlein/DE discussed the performance of insulating fluids in transformers and especially the properties which are to be regarded, starting from electrical properties on short or long distance gaps, physico-chemical properties like viscosity which are important for the thermal behaviour, as well as properties like oxidation stability and its relation to corrosivity, fire safety and biodegradability.

The need of liquids with a high fire safety for HV applications leads to a necessity of better knowledge of such liquids and their properties. This was the background for studies on partial discharge behaviour and dissolved gas analysis of biodegradable transformer fluid discussed in a paper from Australia. A paper from USA compared thermal performance between a natural ester and a mineral oil.

A report from UK compared physico-chemical, dielectric properties, and gassing properties under laboratory conditions of a natural ester, a synthetic ester and a mineral oil. It was found, that AC breakdown voltages are similar for all three kinds of fluids. The breakdown withstand strength of insulating paper impregnated with a synthetic ester fluid was found to be somewhat lower than for mineral oil and natural ester. Special attention was paid to the differences in the viscosities of the liquids and their significance for the impregnation process.

A paper from Germany describes the most important advantages of insulating liquids other than mineral oil, e.g. silicone fluids or synthetic esters. A very big advantage of silicone fluids is their inflammability, which makes them desirable in case of demands for a low fire risk. Further characteristics, like viscosity vs. temperature and heat transfer should be considered in the transformer design.

A report from Japan dealt with a new low viscosity silicone fluid for transformers, as well as with SF_6 filled transformers as a prerequisite for fire safety.

Oil additives are being considered for retarding of paper ageing. First experiences on a laboratory scale have been reported by Norway.

An expert from Australia reported on the work of IEC TC42 and the changes and additions proposed to the next edition of IEC 60060-1, "High-voltage test techniques - General definitions and test requirements", that are relevant to testing of power transformers. A new procedure for the evaluation of impulse voltage waveforms, especially in the presence of overshoot is proposed. The new procedure is designed to enable a more accurate and consistent determination of the impulse test voltage and its time parameters in dielectric withstand testing of electrical insulation. The standard is not expected to change the performance of the test results but will lead to more consistency between testing laboratories.

The liquid insulation system is to be regarded in its integrity with the solid insulation. This is important not only for the performance of the whole system, but also for the diagnostics. New high-temperature insulation systems with conventional oil filling require different criteria for the evaluation of diagnostic markers, e.g. for DGA. Two reports – one from Belgium and one from USA were dedicated to the comparison of DGA between high temperature systems, as well as cellulosic systems and mineral oils.

A paper from Germany was discussed the importance of the evaluating content of atmospheric gases when analysing and interpretating of DGA.

Diagnostic procedures for the assessing ageing of solid insulation, like evaluation of water content and furanic compound analysis drew a lot of attention. Discrepancies between various known methods for assessing moisture were discussed in papers from UK and Germany. Moisture equilibrium and distribution between solid and liquid insulation is complex and dependant on the ageing state of the insulation system.

Using diagnostic procedures usually means considering all accessible data. This was clearly demonstrated in a paper on a fault investigation of a rectifier transformer. A paper from Slovenia reported on predicting paper ageing using a data pool of furanic compounds derived from own experience. In UK a similar approach has been developed and the authors reported on the difficulties to apply good relationships between furanic compounds and degree of polymerisation (DP) of paper. Furthermore, a DP-value of 200 has been proposed as an end of life criterion for paper.

Papers from Switzerland, Germany as well from Belgium were dedicated to post mortem investigations of the solid insulation and DP-values and the relation to other diagnostic parameters like DGA and furanic compounds. The relation between furanic compounds and DP-value seems to be strongly dependant on the type of transformer and its service conditions. Furthermore, service experience can be geographically different. This all shows that diagnostic models based on DP estimation from measured content of furans in oil cannot be generally. Further work is needed to verify such models from post mortem data.

<u>Transformer Reliability, Procurement, Monitoring & Maintenance, Corrosive sulfur</u>
Claude Rajotte/CA chaired the session and 26 papers were presented.

Reliability continues to be a major topic for users and manufacturers. The whole breadth of the subject was made available by SC A2 for submission of papers dealing with the subject. The first nine reported here addressed three areas of primary concern to the industry at this time. Six of the nine papers were devoted to corrosive sulfur, its causes, removal or mitigation, and the problems it presents to asset managers. The remaining three were concerned the effects on transformers of voltage transients caused by switching or other network electrical interactions, and the transient thermal behaviour of transformers filled with insulating fluids other than mineral oil i.e. silicone and ester fluids specifically.

A major keynote presented by a G. M. Bastos/BR provided a substantial and comprehensive overview of the prevailing reliability issues needing to be understood and applied by users in their specifications, choice of supplier, source of manufacture and maintenance practices if transformers are to operate successfully in service. It was emphasised users and manufacturers need to co-operate to attain these goals. It was recommended the immediate availability of alternative spare plant is the preferred way to achieve this in situations where electricity supply interruptions have to be avoided or kept to a minimum. The presentation offered several strategies for making use of transformer condition and risk assessments, many based on data derived from on-line and off-line monitoring devices, in particular those based on oil condition monitoring procedures such as DGA and 2-FFA. It was recognised wholesale measures cannot be applied in isolation. Examples were provided of historic data collections and analyses to provide the best overall economic and technical strategy to cope with forwarding planning tasks faced by asset managers, for example. The presentation included recommended task lists for implementation when failures occur. It was strongly recommended medium to large power transformer failures should be investigated; especially those that involve strategic plant or are part of a significant family of transformers. References to the causes of failure included corrosive sulfur. It was stated 17 shunt reactor, 2 step-up transformer and 3 converter transformer failures occurred because of corrosive sulfur in Brazil in 2006. In-service units identified having a corrosive sulfur risk had a passivator added and in some cases the oil also was replaced. Overall, this Brazilian presentation was an excellent preface to the remainder of this subject.

The effect of transient overvoltages on transformers is has been a recurring subject for SC A2 and previously SC12. Several Working Groups have studied the subject. Two other papers presented information on this subject in addition to transient overvoltage references in the above keynote presentation.

A report on the work done to date by the Cigre-Brazil JWG A2/C4-03 relating to the oscillatory phenomena that can occur between transformers and a network after a transient voltage event. The work has identified the need to revise specifications and to improve design reviews, system planning and system operational procedures. Digital simulation studies of the interaction between transformers and network operations, particularly switching, are recommended to quantify the magnitude and frequency range of the transient voltages at transformer terminals. Transient voltage frequencies in the range 10 kHz to 3 MHz have been simulated and high frequencies below 200 kHz are the most onerous. The greatest risk to transformers is from resulting internal winding resonant voltages.

On the same topic a joint paper by France and Germany drew attention to the consequences when pole-by-pole circuit breaker switching times are unequal and excessive. Studies of circuit breaker switching of an 110/20 kV system transformer were reported. Good correlation was found between the transient overvoltages obtained by simulation using EMTP programmes and site measured data. The studies showed discrepancies in circuit-breaker closing times could result in overvoltages up to 4.6 p.u. depending on the core saturation level and the magnetising in-rush current characteristic, in particular its non-linear characteristic.

The thermal characteristics of silicone and ester fluid filled transformers are an emerging topic for transformer test design engineers and operators. The physical properties of these fluids differ from mineral oil especially viscosity and thermal capacity as an Austrian paper emphasised. Special reference was made to transformer operation under ON conditions and at low ambient temperatures. The authors advocate the use of dynamic thermo-hydraulic computer programmes to calculate temperatures throughout the windings and cooler thermal network, a concept that has been much sought after for application to oil immersed transformers yet still not universally available. It needs to be highlighted; these recommendations apply solely to transformers designed electrically and thermally for silicone or ester insulating fluids.

The remaining six papers comprising the beginning of this Preferential Subject, all concerned the corrosive sulfur epidemic being experienced by the transformer industry.

A Belgium paper drew attention to the impact of the corrosive sulfur problem on transformer maintenance strategies and asset management. Corrosive sulfur degrades the intrinsic dielectric integrity of paper insulated winding conductors sometimes to the point of failure. The principal concern is for those transformers where oil tests indicate a corrosive sulfur constituent contaminates the oil. The problem in these cases is to prevent further degradation and failure and ensure transformer remaining life expectancy as far as possible. Belgium screened all its existing transformers and oils presently available on the European oil market for presence of corrosive sulfur and DBDS. The Cigre TF A2.32.01 test method was used i.e. a prepared sample of paper insulated copper conductor is immersed in the selected oil and maintained at 150 °C for 72 hours then examined for signs of copper sulfide deposition. The European mineral insulating oils were also tested for BTA and an other specific passivator content. Corrosive sulfur tests were also made on oil samples in storage since 1980. These revealed corrosive sulfur present in oil as early as 1989. Sixty-five transformers were found contaminated out of 120 tested for corrosive sulfur content. The paper provides results from treatments used to mitigate corrosive sulfur problem in some transformers. Side effects were noted, principally the reduction in passivator content with time and the tendency for sludge content and Tan-δ to increase.

Three papers relating to corrosive sulfur issues were presented by Sweden. The first addressed the effect of mercaptans and disulfides in transformer oil. Both were shown to be potentially corrosive to metals and the latter, in the form of DBDS, was detected in many transformer oils showing a corrosive behaviour. The paper introduced the concept of determining the disulfide content of oil by treating it with zinc and acetic acid to determine the total mercaptan content by titration. It was suggested this test might provide a useful means of determining if an oil is corrosive or not.

The second Swedish paper suggests the way to reduce DBDS and other potentially corrosive species in transformer oil is by on-site oil treatment. Two transformers were treated, each containing around 200 ppm of DBDS. In the first case the total oil volume was passed through the on-site oil treatment plant, from the transformer to an oil storage vessel and back, twice. In the second case, the oil was circulated several times between the transformer and the storage vessels via the same oil treatment plant. In both cases the total disulfide and mercaptan contents were reduced to non-detectable levels. It is suggested these experiments show the corrosive content of transformer oil can be reduced by conventional on-site oil treatment equipment. Some regard has also to be paid to checking and probably restoring the oxidation stability of the treated oil.

The third Swedish paper, by a leading mineral oil producer and supplier, reported on the effectiveness of a specific passivator, as a means of avoiding copper sulfide deposition. The authors believe measurement of oil copper content is a more significant indicator of the degree of copper corrosion activity in a transformer. It was contended the Cigre A2.32 test method is suitable for batch testing new oils. The action of the passivator is described and reference is made to alternative passivators such as benzotriazole (BTA) and tolytriazole (TTA). The researchers recognise some measurable loss of the original concentration of passivator occurs in practice but claim results show that once passivator covers the copper surfaces, further copper corrosion is hindered. One of the findings mentioned in the report concerns significant passivator retention in the cellulose paper surrounding a conductor. Several important conclusions are drawn from these studies including a claim that in practice passivator concentration does need to be restored when it is detected the original concentration has dropped.

The final paper on the subject of corrosive sulfur, by Japan, added to the above Swedish paper. It stated the copper sulfide deposition affected the paper. Various parameters were examined including sulfur species, temperature, local environment, test configuration, passivator type and content. Sulfide, disulfide and sulfoxides were said to influence copper sulfide generation. An extensive series of tests were made in the course of these studies and reference to the detailed conclusions is recommended.

Further progress in partial discharge detection in the Ultra High Frequency range (UHF) was reported from Netherlands. Two 90 MVA 150 kV transformers were equipped with four UHF sensors mounted on dielectric windows. Sensitivity of propagation and detection could be validated in a realistic transformer environment. UHV sensor can also be inserted through a drain valve if no dielectric windows are available and the performance of these sensors was compared with the dielectric window set-up. Both UHF sensor-techniques were compared during an induced voltage test on a 75 MVA, 50 kV shunt reactor, as well as during the PD acceptance tests in the factory. These practical experiences provide further insight into the application of UHF PD monitoring techniques to power transformers.

Bushing failures are responsible for a large number of transformer major failures and with ageing transformer population, the situation is not likely to improve. Application of power factor and DGA techniques is limited because they require a transformer outage. A report from Canada describes a large-scale experiment, run by a large utility, to identify a method that would be sensitive enough for early warning and convenient for periodic measurements. Field test indicates that a "relative measurement" method of bushings on the same electrical phase is more sensitive than the sum-current method. Stability of the parameters derived would allow for periodic measurement and on-line monitoring could be limited to the more suspicious bushings.

Reduction of winding clamping pressure can lead to a reduction of strength under short circuit stresses. A report from Germany proposes a novel method for clamping evaluation. The method uses a record of the inrush current upon energisation and the resulting transient in oil pressure. Due to statistical behaviour, several successive energisations are recommended. Oil pressure is recorded either at the Buchholz relay or in the main tank drain valve. Assessment of data is made in time and frequency domains. Relation between measurements and clamping pressure has been demonstrated in laboratory and in high power test station for different type of windings.

Extensive tests were performed in France to assess the remaining life of 28 years old, 100 MVA, 225 kV transformer that had to be relocated. The high level of Furan (8.5ppm) was not consistent with loading history and it was decided to perform short-circuit withstand test as part of the condition assessment program. Visual inspection had revealed traces of overheating on active parts but no significant reduction of clamping forces. The short-circuits tests were carried out without any displacement and sampling of paper on a low voltage winding revealed a degree of polymerisation above 400, corresponding to about mid-life of a transformer. This surprising result raised many questions and comment among participants leading to a conclusion that furan content is still only indicative.

Winding displacement following a short circuit is often detected using the Frequency Response Analysis (FRA) method. One problem with this method is that there is no objective procedure to compare the data and expert judgment has to be involved to establish whether the winding displacement is significant. As a result of joint effort between Germany and Austria, different algorithms are proposed to quantify the difference between two curves using several mathematical methods. It appears not possible yet to cover all cases of winding displacement using a single classification number.

Assessing the conditions of winding insulation from oil sampling entails several difficulties. An interesting proposal arising from Norway involves the immersion of a paper sample in the oil of the transformer. Measuring contamination from moisture and acidity on a paper sample rather than an oil sample is advantageous due to higher concentration of the contaminants in paper and the fact that uncertainties in partitioning is avoided. The sampling rig described can also be applied on service-aged transformers.

Assessment of transformer conditions has relied for several decades on the analysis of dissolved gas (DGA). Field experience from South Africa and USA for on-line monitoring of these gasses was reported and the benefit of monitoring individual gasses promoted.

Although determination of moisture content in solid insulation is a difficult endeavour, it remains a concern for several aging transformers. A paper from Canada and USA described a novel approach based on a continuous monitoring of moisture in oil and a calculation involving oil-paper interface temperature, oil-paper partition curve at equilibrium, insulation thickness and water migration time constant. The method proposed allows for separate assessment of water content in winding insulation and pressboard barriers. The report also emphasised the misleading results that can be derived from a single measurement of moisture in oil.

Some 20-30 years ago, static electrification use to be a serious problem on some transformers. This problem was resolved at the time by reducing oil velocity and improving oil flow pattern. However, a report from Japan indicates that the problem might be coming back as the transformers ages. Cases of static electrification have recently been observed in both shell-form and core-form transformers. The aged oil is not showing any increase in electrostatic charging tendency and the investigation is pointing toward aged pressboard. Results of investigation suggest that degradation by-products are absorbed by the pressboard leading to an increase the charging tendency.

It is well recognized that transformer reliability in the longer term can be heavily influenced by the decisions made in the pre-life stages, i.e. specification and procurement. Today the transformer market is buoyant for the first time in many years. Capacity is now constrained and prices have risen sharply with leads times stretching significantly. This situation entail for the de-regulated industry significant rising costs they have not seen before. The pressure on costs caused by these changes is where problems can arise. A paper from UK addresses these issues in an effort to raise the profile of the criticality of the design review and factory quality control and test processes as the key steps to ensuring high reliability and long life of the unit being manufactured.

The expected replacement wave in the current power grid faces asset managers with challenging questions. Assessing the "remaining life" or the long-term reliability of an aged transformer is a common concern for most utilities. A report from The Netherlands advocates that for transformers, the future failure probability can be predicted based on the ongoing physical degradation processes and the future loading scenarios as input. It treats remaining life in terms of future failure probability and offers the asset manager means of selecting the optimum refurbishment or replacement scenario. On the same subject, a paper from USA, Sweden and Germany promotes the assessment of individual risk of failure for each unit of the transformer fleet. The parameters used in the assessment are grouped as risk factors that are linked to the different failure modes resulting from mechanical, thermal or electric stresses. The aim is to provide a precise risk of failure estimate by focusing on specific knowledge of transformer design, condition of the insulation, system historical failure patterns and statistical failure rates. A third paper, from USA, focused on the practical evaluation of winding insulation aging caused by temperature, moisture and oxygen. Based on the standard Arrhenius loading relationships, the history of loading and insulation condition is used to generate a hazard rate function.

One of the most important tasks in any risk management program is the hazard identification, because it is impossible to mitigate a hazard that cannot be identified, or is not well understood. A report from Brazil proposes a hazard identification method based on information technology to address the classical questions of risk perception within the company, what is actually at risk, what risk is acceptable, what is the mechanism or failure mode involved. One of the advantages of using these value networks is that they are flexible and provide a road map for logical thought. The main contribution of these diagrams is improving communication. Another risk management approach is presented in a paper from The Netherlands applied to a group of 450 high-voltage transformers. The overall goal of the maintenance strategy is to balance several business values, in particular, finance and service reliability. A tool has been developed to quantify “service reliability” into economic terms in the form of the utilization price. Using this utilization price it is fairly straightforward to make a cost/benefit analysis on possible maintenance strategies.

A paper from Russia and Switzerland, presented on behalf of Study committee SCA2, reviewed the means and tools that are still to be developed to maintain aged transformer population. It is recognised that due to low loading, many transformers do not suffer significant thermal aging but the process of degradation might be progressing by different means other than just thermal although diagnostic tools available are not effective to some aging mode defects. It is highlighted that transformer life may be determined by several components: thermal degradation of the winding insulation, reduction of dielectric strength of major and minor insulation, reduction of mechanical strength of windings under impact of through fault current and vibrations, degradation of accessories specially bushings and OLTC’s. Several recommendations are made for future revision of Cigre and IEC documents to provide the tools and means for ensuring reliable operation of aged transformers.

Shunt Reactors, Series Reactors and associated equipments

Claes Bengtsson/SE chaired this session and 8 papers were presented and discussed.

Shunt reactors ratings, in general, range upward from 20 MVAr at voltages between 11 kV and 765 kV or slightly higher. They embody design aspects, materials and construction methods that are common to power transformers. Service performance should conform closely to that of transformers but in reality there appears to be a higher incidence of outages and failure than experienced with transformers. The papers reported upon here identified several factors to account for this. Foremost is the fact that shunt reactors operate at varying loads around their designed rating depending on the variations in applied system voltage. Repeated switching and system harmonics are special considerations because they both affect losses and mechanical forces on windings and cores. Both the shielded and gapped-core shunt reactors types demand special attention be paid to magnetic field induced mechanical forces on cores and windings. These considerations together with those of thermal design and factory proving tests all tend to make reactors a subject of special consideration by purchasers and manufacturers.

The SC A2 remit for this subject concerned shunt and series reactor of all types, rating and voltage class in particular their related service application and including their design and construction, specification, reliability, condition assessment and service performance. Seven papers were presented. They included a keynote address and referred almost entirely to oil-immersed shunt reactors used to control system voltages when systems are lightly loaded or for reducing excessive voltages at remote ends of long transmission lines during energisation and switching.

A keynote address by R. Cormack/ZA referred to the long-term overheating effects on windings, core parts and flux shields. These were usually detected by on-line gas detection monitors or by diagnostic gas analysis of routinely taken oil samples to minimize unplanned outages. Reactor faults are not necessarily always catastrophic but instead can be persistent lower order faults that need to be monitored. Examples of this kind were shown of local core faults across areas of the core surface that were due to fusing across the cut edges of coreplate. Several countries reported a higher fault rate for reactors compared to transformers. South Africa reported that out of a population of thirty-eight 765kV reactors twenty had failed in service over 22years. The causes included core burrs, overheating due to trapped oil, high inter-disc voltage stresses, corrosive sulfur and damage during transport.

A comprehensive review of shunt reactor reliability, condition monitoring and end-of-life assessment was provided by an Australian paper. The ensuing conclusions and recommendations were based on some forty years service experience of shunt reactors of various ratings, designs and construction in the range 66 kV to 550 kV. For example, of sixty-two reactors purchased during this period, four failed due OIP bushing explosions and two due winding electrical failures. Five reactors were retired due to age and age related faults. The remaining fifty-two reactors have been in service for 1069 service years to date. The reactors were purchased from eight manufacturers. The authors consider the real lesson from this and other data presented in their paper is to buy from good manufacturers. Several other case studies were mentioned in the paper. Of note, the effect of alternative periods of energisation and de-energisation operation is believed to have jeopardized the dielectric integrity those reactors employing free-breathing oil conservation systems and located in humid climates, by increasing moisture concentrations on or in internal insulations.

An interesting but detrimental effect of repeated switching was also referred to in a joint paper from Sweden and Denmark with regard to large wind power installations. As an alternative to frequent reactor and capacitor switching operations, the authors suggested it would more appropriate to replace the conventional shunt reactor by a regulated type in which a separate tapping winding is used to regulate the power through the reactor. Several methods of accomplishing a satisfactory arrangement of tappings were suggested. The effect on both reactor losses and the available step-to-step tapping power would need to be carefully assessed for each regulating winding arrangement.

The concept regulated shunt reactors was taken further in a paper from The Netherlands which described an innovative development that has been in service now for some four years and involves a shunt reactor installed within the main tank of a conventional OLTC equipped transformer. The OLTC allows the reactance to be varied. The unit can operate either as a normal transmission transformer or as a three-phase shunt reactor depending on the connections within the unit and their accessibility with the unit de-energised.. The unit is seen as an alternative solution to a tertiary connected shunt reactor with the advantages of having fewer connections, tanks and oil volume. It was stated the unit exhibits a higher sound level in reactor mode compared that when operating solely as a transformer.

It is well known that major technical concern in shunt reactor design is to minimize potential noise and vibration effects. In a joint paper from Sweden and India studies indicate there is a risk of long-term material fatigue or mal-operation of accessories if vibrations are not kept low. It was emphasized stresses cannot be evaluated by noise measurement alone. Instead vibration measurements and analysis is recommended. Several examples were given providing evidence in support of this recommendation. Ultimately, the vibration level that can be tolerated depends upon the intrinsic strength of the tank structure and any anti-vibration measures incorporated in the design. The use of strain gauges to determine stresses due to vibration was not endorsed. Instead it was claimed measuring maximum tank vibrations and calculating vibration stresses was more practical. It was recommended vibration stresses should be limited to a range not exceeding 30 N/mm^2 to avoid tank resonances due to the double fundamental operating frequency (Hz).

The final paper of this subject, presented by jointly by Sweden and Brazil, follows closely on the paper referred to immediately above. It concerns a novel technique for reducing the sound level of shunt reactors and transformers that involves installing vibration isolators between the tank and the active part in combination with low acoustic impedance materials placed between the active part and the tank base and cover. It was said the success of this design was dependent on the core design and the dynamic properties of the material involved. The technique described has been applied already to transformers but this is the first application to a reactor. It is clear from the paper that successful application of this technique requires some substantial understanding of the structural dynamic behaviour and the consequent acoustic responses as with other methods having a similar purpose.

Other activities

As part of the transformer colloquium, a one-day tutorial was presented by four WG Convenor who were presenting their results for the first time:

- Ageing of cellulose insulation in transformers by Lars Lundgaard/NO
- Copper sulphide in power transformer insulation by Mats Dahlund/SE
- Transformer lifetime data management by Nicolaie Fantana/DE
- Recommendations for condition monitoring and condition assessment facilities for transformers by Paul Jarman/UK

About 70 participants attended the tutorial and displayed great interest throughout the day.

Study committee SC A2 held a one-day meeting to review the progress of each working group and to lay down terms of reference for futures activities. Among the decisions taken at the meeting was the initiation of new working groups: WG A2.36 will review procurement recommendations in view of the changing market conditions; WG A2.37 will review all existing national survey on transformer reliability with an effort to harmonize definitions and discuss best practices. It was also decided that the 2009 Colloquium would be held in Cape Town, South Africa and the 2011 Colloquium in Japan.

The Colloquium concluded with a well-attended technical visit to the offshore substation feeding the Shipping Assistance of Ostend. During the colloquium, delegates were also fortunate to enjoy benefit from several social events in Bruges including a tour by boat on the Monday evening along some of the canals referred to at the start of this report, an official reception hosted by the City at the resplendent gothic Town Hall and finally a medieval dinner at the Holy Hart Church where M. Pierre De Pauw, chairman of CIGRE NC of Belgium, welcomed the delegates. The accompanying persons were also able to take part in a well-planned programme of visits in Bruges, Brussels and Ghent.