GENERAL REPORT FOR SC A2

(Transformers)

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SESSION OPENING

Claude Rajotte, SC A2 Chairman, opened the session at 08:45 with approximately 400 delegates attending. He welcomed attendees and explained the CIGRE Paris session organization with special reports, questions and contributions.

He also presented the SC A2 organization, activities and active working groups.

He ended his remarks by presenting the technical committee award to Mrs. Angelica Rocha from Brazil.

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PREFERENTIAL SUBJECT 1: BEST PRACTICES FOR TRANSFORMER ASSET MANAGEMENT

A total of 16 papers have been submitted, according the following sub-topics:

- 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).

PS1 - Keynote presentation by Mrs. Augusta Martins from Portugal

Mrs. Augusta presented a keynote on the best practices for asset management. She presented the main problems faces by asset managers and their needs, the definition of health index and its combination with the criticality index in the risk matrix. Post-mortem analysis and solid insulation ageing markers were presented as valuable inputs for an asset health review. Mitigation techniques to improve transformers useful life were also presented.

The Special Reporter Mr. Pawel Warczynski formulated the following questions to structure the contributions from delegates to the SC A2 Paris 2012 meeting.

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?

Question 1.1

A contribution from Australia reports the experience with the monitoring of 69 bushings rated 132 kV. All the bushings are 10 years old or less. On two occasions, the bushing monitoring system detected rapid and significant increase of capacitance and dissipation factor and the bushings were removed from service and stripped down for internal inspection. The inspections showed several insulation punctures between layers which could have led to a catastrophic failure of the transformer if the bushing would have been kept is service. The monitoring systems are not set to trip the transformer instead of sending an alarm.

A contribution from Switzerland presents the benefits of the off-line dynamic resistance measurement for OLTC condition assessment that can be used in combination with other methods or on-line approaches (e.g. acoustic). The method can be used to can be used to support strategic decisions about the maintenance or overhaul of the tap changer.

A contribution from USA reports that periodic oil sampling of OLTC has proved to be an efficient method to detect incipient faults and prevent transformer failures. The knowledge of the design and manufacture is required for a good interpretation of the dissolved gas in the oil. For bushing monitoring, experience over the last 15 years indicates a number of transformer saves but these must be balanced with the possibility of false positive. Monitoring solutions should be applied to targeted transformers and to the expected failure modes based on historic data.

A contribution from Japan reports that capacitance and power/dissipation factor monitoring has been widely used in the industry for the early detection of bushing failures. A different approach consists in using an acoustic sensor located close to the bushing for the detection of partial discharges in the bushing insulation. Noise suppression algorithm should be used to ensure a good detection.

A contribution from India reports case examples of bushing monitoring using capacitance/tan delta on-line measurements based on the phase to phase comparison. In one case, it has been demonstrated that the incipient fault could have been detected 3 days before the major failure occurred. In another case, a bushing was found with high level of dissolved gas in the oil and that was not correlated with a change of capacitance/tan delta.

Question 1.2

A contribution from Germany reports on the qualities of a modern software interface used for the interpretation of bushing monitoring data and the management of alarms.

A contribution from Germany reports recent findings on the interpretation of DGA data (using adapted Duval's triangle) for the detection of ongoing thermal, electrical or mechanical OLTC problems. The interpretation must be made taking into account the OLTC design features.

A contribution from Germany and Canada presented how root cause defect analysis and failure mode simulation can be used to test and validate algorithms of monitoring systems for bushings and OLTC.

A contribution from USA reports that several types of analytics can be obtained from bushing monitoring data (sum current, phase to phase, same phase) but there are always possibilities to get false positive. A good system will learn the local norm using statistical analysis in order to identify more clearly the abnormalities.

A contribution from Germany reports on novel algorithms for bushing and tap-changer monitoring. The bushing algorithm uses a voltage measurement to compensate the phase to phase unbalance and improve the detection accuracy. Acoustic tap-changer monitoring is increasingly being used by utilities and this contribution presents a novel method based on continuous wavelet transform for analysis, visualization and interpretation of the diverter switch vibro-acoustic signatures.

Question 1.3

A contribution from Australia reports the key parameters to ensure long term reliability (at least 15 years) of monitoring systems in terms of design, manufacturing and test: minimal cost and easily available, easy to fit or retro fit, reliable, compatible with oil and contaminants, no moisture ingress, leaks under tank cover pressure, quality material, simple testing/calibration, good manufacturer's endurance test.

A contribution from Poland reports on the hardware and system architecture requirements to improve the reliability and stability of monitoring systems. Detailed requirements are presented for specific applications.

A contribution from South Korea reports on the design, the sensitivity verification and the certification tests carried out in laboratory and on site to validate the performance of a UHF sensor used for partial discharge monitoring.

A contribution from United States reports that monitors should be designed for safety and for long life. The life of the monitor should exceed the transformer life and if it is not possible, the supplier should explain the symptoms of degradation. Clear installation procedure and validation of the installation by end-to-end test are key factors for long term reliability.

Question 1.4

A contribution from China describes a deterioration index used for replacement prioritization. Transformer deterioration index is based on condition of deterioration, risk of internal faults, life cycle cost, and maintainability. Each item is weighted for the calculation of the index.

A contribution from France reports the implementation in a commercially available system of an asset health Index AHI that targets the replacement decision (long term perspective) and an asset maintenance index AMI that targets the short term urgencies for maintenance. Several analytics are implemented to calculate the probability of failure and the remaining life of the asset.

A contribution from Spain reports that a decision tree (AI) is the more promising technique for the estimation of the probability of failure related to individual health indicator. All the necessary data is not always available so sharing experiences and information within the industry with common methodologies would be very useful.

A contribution from South Africa describes a health index formulation classified in 5 different conditions depending on the score. The weighing factors given to the selected indicators, i.e. the solid and liquid insulation, DGA/electrical tests and visual inspections, are presented and explained.

A contribution from Great Britain describes the use of Asset Health review for a number of years (since 1989) and its application for replacement and refurbishment planning. The concept of current and mitigated health index (after corrective actions are taken to improve the condition) is discussed and the difference between the two indices is used for the refurbishment planning.

A contribution from Australia reviews the different approaches that have been use for creating health index scoring and weighting system. Benchmarking between users from different utilities can bring several benefits for assessing local practices but is also very challenging. It is concluded that further research and development need to be done to determine the required framework.

A contribution from Italy reports the health index developed and used as an input for the determination of the risk for failure. This risk of failure is also influenced by the number of events (stress) and the probability of the event to cause damage.

A contribution from Netherlands discusses the background for the creation of a health index and indicates that several approaches are used in the industry. The benchmarking would increase the learning curve of the industry in general and therefore increase reliability and reducing risks.

Question 1.5

A contribution from France describes the condition parameters (66 data) used in the formulation of a health index implemented in a commercial software system. Out of the 66 data condition parameters included, 20 data are contributing to 66% of the overall health information. The level of confidence is

deducted from a completeness index which gives an indication of the % of missing data that could be due to lack of measurements or measurements that are past due.

A contribution from South Africa introduces the concept of abbreviated asset health review to manage situations when not all the input data is available to produce the health index. This approach makes it possible to make a summary assessment but it is still required to obtain the full set of data to estimate the risk of failure.

A contribution from Hungary presents the input parameters of a status indicator developed for fleet condition assessment. The evaluation is made using all the available data.

A contribution from Great Britain reports that the asset health indices cannot be calculated if some minimal information is not available, i.e. recent DGA result and basic nameplate data to identify possible weaknesses in design or construction. When more data is available, the heath index is refined in several stages.

A contribution from Australia reports that there are various AI algorithms that can be applied to the creation of a health index and they could be well suited to solve the problem of incomplete data set for the whole condition assessment of a fleet of transformers. Researches in universities are encouraged.

A contribution from Netherlands reports a method based on transfer functions to map the existing data points to the required format for the assessment functions. The transfer functions can also estimate the data points in case of missing data. This estimation is based upon deduction using physical models or statistical inference.

Question 1.6

A contribution from Spain reports some proposals to optimize the costs of post-mortem investigations: invest in a powerful information system and an exhaustive inventory, make an agreement with the scrapping company and reduce the number of paper samples to test.

A contribution from Japan reports the results of bushing investigation when removed from service after transformer overhaul. I was found that air and water ingress are possible due to ageing of the various oil sealing and in the case of the investigated bushings, it was not possible to diagnose the condition with electrical tests (capacitance, power factor, partial discharge). However, the oil tests were conclusive.

A contribution from Great Britain explains that the cost of a post-mortem investigation is less than 1% of the direct cost of a new transformer and the largest operator of transmission voltage transformers in Great Britain finds that the value of the information obtained to the Asset Health Review process is more than sufficient to justify the direct cost of the forensic examination. Post-mortem investigations are being performed on all scrapped transformers by this operator.

Discussion

Several spontaneous contributions were raised from the floor regarding the following topics:

- Issues related to the used of subjective weighting factors or non-related parameters for the creation of a health index.
- The data required to create a health index depends on what is the intended purpose (replacement program of maintenance). The quality of the data and the confidence level are key elements.
- Benchmarking of health index practices would be a good thing but a framework is needed.

- There are concerns related to the non-expert use of health index results that could lead to wrong interpretation.

- Importance of using a good tap adapter design for bushing monitoring application to make sure it does not affect the reliability of the bushing itself even if the cable is not connected to the measuring instrument.

- Post-mortem investigations are increasingly being used to explain replacement decisions to the regulator.

Contributors were invited to provide a written version of their comments for inclusion in the session proceeding.

PREFERENTIAL SUBJECT 2: TRANSFORMERS FOR SPECIALIZED APPLICATIONS

A total of 11 papers have been submitted, according the following sub-topics:

- Phase Shifting Transformers (PST)
- HVDC transformers
- Shunt Reactors
- Testing / Design requirements

PS2 - Keynote presentation by Mrs. Sheila Batey (UK)

Mrs. Batey presented a keynote on transformers for specialized applications. Design and testing challenges were presented for HVDC and phase-shifter transformers.

The Special Reporter Mr. Greve formulated the following questions to structure the contributions from delegates to the SC A2 Paris 2014 meeting.

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?

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?

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?

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?

Question 2.1

A contribution from Japan reports that special considerations for downsizing of PSTs are necessary to cope with several transportation limitations and the specially developed design are presented. A good communication between utility and supplier is necessary.

Question 2.2

A contribution from Australia reports that the specification of a PST should consider expected footprint and weight, the swing angle in both directions and the voltage tapping range. Before a project to install a PST is initiated, it is also recommended to check if other options are applicable.

A contribution from Korea discusses on the design characteristics of the core depending on the phase angle and the power factor of the load.

A contribution from Germany reports that the appropriate selection of on-load tap-changers (OLTC) is of great importance when designing phase-shifting transformers (PST). The contribution presents some special topics which should be considered very early in the design stage, because they may have an impact on the OLTC selection as well as on the design of the PST itself.

Question 2.3

A contribution from Korea reports that the connections between the tanks of dual core PST must be made for electrical insulation tests.

Question 2.4

A contribution from Korea explains the impact of the load on the phase angle of a PST. It is important that the purchasers specify those parameters correctly to ensure a better design.

Question 2.5

A contribution from Germany reports experience with the use of fiber optics in HVDC transformers and the analytical and practical investigations that were carried out to assess the effects of the sensors on the electrical DC field stress.

Question 2.6

A contribution from Ukraine reports experience with controllable reactive power device (CRPD) and presents the different possible applications.

A contribution from Norway reports experience with VSR and some applications which do not require a high regulation speed (ordinary OLTC is sufficient).

A contribution from Russia reports experience with a new design of controllable shunt reactor (CSR) rated 180 MVA, 500 kV.

Question 2.7

A contribution from Sweden reports that more than 40 VSRs have been installed since 1996. The units have voltage ratings between 110 kV and 420 kV with (maximum) power ratings between 16 Mvar and 200 Mvar. The number of installations in various markets around the world indicates a significant interest in this type of reactors.

A contribution from Norway reports that only one VSR major failure was reported for 174 unit-years of experience.

A contribution from Russia reports experience with controllable shunt reactor (CSR).

Question 2.8

A contribution from France reports on a short-circuit validation of a 600 MVA autotransformer using 2 mock-ups to test the radial and axial strength of the windings.

A contribution from France reports experience with short-circuit testing of transformer on 6 designs including 400 MVA auto and 240 MVA transformer. It has been shown that tests on a mock-up can represent correctly the real forces and therefore can be a valuable approach when a full-scale test is not technically or economically possible.

A contribution from France reports that short-circuit testing using a mock up can be representative of the harshest cases, whatever the complexity of the application. However, the feasibility can request the implementation of several mock-ups to cover all the possible mechanical failure modes.

Discussion

Several spontaneous contributions were raised from the floor regarding the following topics.

- Effect of configuration on testing of PST (separated or complete as in the final installation).
- The cost of short-circuit capability assessment using mock-up compared to full-scale tests.
- Applications of VST for fast and slow regulation.

Contributors were invited to provide a written version of their comments for inclusion in the session proceeding.

PREFERENTIAL SUBJECT 3: FIELD EXPERIENCE WITH THE USE OF NON-CONVENTIONAL MATERIAL AND TECHNOLOGIES

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.

PS3 - Keynote presentation by Naoki Hayakawa (JP)

Mr. Hayakawa presented the history of superconducting transformers, from the discovery of the superconductivity in 1911, to the first conceptual design in the 80's and to the different prototypes in the 90's and later on. Mr. Hayakawa presented the motivations to develop a superconducting transformer, in particular the lower losses, lighter weight, compactness, etc. The capability of fault current limitation is also considered as a novel motivation to improve system stability and was described in more details. The development of superconducting transformers made in different countries in Europe, Asia and North America was discussed with some details concerning the Nagoya University program in Japan and the Smart Grid demonstration in the US. Finally, the key technologies for future development were discussed, in particular the solid insulation development, the electrical insulation at such low temperature, the rating & testing, cooling system and system coordination.

The Special Reporter Mr. Ahuja formulated the following questions to structure the contributions from delegates to the SC A2 Paris 2014 meeting.

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?

Question 3.1

A contribution from Germany reports that fast streamers build up at lower voltages in natural ester liquids than in mineral oil. Because of its higher viscosity, switching time of diverter switch is increased. There are prolonged switching arcs in natural ester liquid. Nitrile rubber mixtures may get brittle / weak. Natural ester liquids polymerize when in permanent contact with ambient air.

A contribution from Germany discusses moisture in natural ester liquid and the hysteresis characteristics. Even if natural ester can take much more moisture, the important aspect is to keep the solid insulation dry.

A contribution from Japan reports on the repasses oil (one of the natural ester fluid). In this liquid, the breakdown voltage does not decrease with high water content.

Question 3.2

A contribution from Republic of Serbia reports experiments that show that after having been exposed to same conditions of ageing with relatively low oxygen content, paper in natural esters showes higher

DP than in mineral oil. Nevertheless, natural esters are highly unstable in the presence of oxygen and may affect significantly the kinematic viscosity of the oil and so, the oil cooling performance. Moreover, according to the current state of knowledge, it is not known whether and how aged/polymerized natural ester oil can be reclaimed but the basic concept would be the same as in mineral oil reclamation.

A contribution from United States and Brazil indicates the large quantity of tests performed by several different institutes, companies and universities around the globe on this regard consistently stating there any effect on degree of polymerization of paper impregnated with natural ester fluid versus mineral oil. The author proposes that the improvement in the thermal aging characteristics of cellulose aged in the natural ester is the result of at least two modes of protection provided by the natural ester: dry-out process (also called water scavenging), and the transesterification (steric hindrance of the cellulose hydrolytic reaction).

Question 3.3

A contribution from Japan indicates that viscosity of natural ester increases significantly at low temperature and it is therefore not recommended to switch an OLTC below -10°C.

A contribution from France indicates the growing interest of using natural esters in transformers is driven by a better biodegradability and also higher fire safety. It is well known that higher pour point could be an issue for cooling and especially for transformer restart at low temperatures. It has been found that natural ester has almost the same performance as mineral oil in terms of breakdown voltage and behaviour in wet conditions.

The same contributor from France indicates that DG is used since several decades as a relevant tool to establish the diagnosis of oil-filled transformers and how it becomes important to know if it can be applied on natural esters. Laboratory tests have been made to see the nature of gasses created and the applicability of diagnostic techniques as Duval triangles to such type of oil. These laboratory tests confirm the applicability of Duval Triangles to detect both Electrical and Thermal faults. It can be also added that both extraction methods (vacuum degassing and stripping) are applicable with ester oils.

A contribution from United States indicates Natural Ester based fluids behave differently at low temperatures than mineral oil. Mineral oil may shrink, crack, and create voids as it cools beyond its pour point temperature. Additionally, mineral oil will tend to condense out water, especially since it has a low water solubility limit. In the event of prolonged outages or extended periods of time where equipment is exposed to temperatures that are continuously lower than –20°C, the viscosity of the fluid could increase, hampering fluid flow. However, full scale tests confirm that transformer losses quickly warm the fluid such that normal flow and cooling result, without undue aging of the insulation system.

Question 3.4

A contribution from United States reports that the mixture with mineral oil will not vary the fire point until about 8% of content. Flash point and some other physical properties will vary proportionally to the mixture.

Question 3.5

A contribution from Unites States reports that the correct calculation of the leakage flux distribution is essential to calculate the eddy losses along the height of the winding. To reduce the losses, efforts should be taken to reduce the radial leakage field entering the winding.

Question 3.6

A contribution from Switzerland reports that a short-circuit test will be performed by the end of 2014 on a 31,5 MVA 66/22 kV dry-type transformer. Despite this test is planned, the authors mention dry-type transformer short-circuit testing is not critical since the relatively small LV side current, the high mechanical robustness of casted coil and the relatively low expected temperature from 2s short-circuit current.

Discussion

Several spontaneous contributions were raised from the floor, in particular on the performance of natural ester at low ambient temperature.

Contributors were invited to provide a written version of their comments for inclusion in the session proceeding.

CLOSING REMARKS

In his closing address to A2, Chairman Claude Rajotte summarized the highlights of the contributions that were presented during the day.

He thanked the Special Reporters and the Secretary for the tremendous work in preparing and running the session. He also thanked the keynote speakers, authors of paper and contributions, and the attendants for their valuable contributions and for supporting A2.

Mr. Rajotte drew this A2 2014 Paris Session to an end by confirming that the next SC A2 Colloquium will be held in Shanghai, China, in September 2015. Detailed information will be available on the SC A2 web site.

The session was closed at 17h45.