12-00

GENERAL REPORT FOR GROUP 12
(Transformer)

by

P. Boss *
(Special Reporter)

Introduction

The discussion meeting was attended by about 300 delegates and included

- Opening remarks by Chairman Philippe Guuinic (F) about SC 12 (A2 in the future) activities.
- Objectives of WG 12-23 in the field of transformer data management by N. Fantana (DE).
- Introduction to the workshop on "Electrical Transient" conducted by M. Glinkowski (USA). The contributions presented during this workshop will be taken into consideration by the WG team.
- Introduction to the workshop on "Future of Tap Changers" conducted by J. Corbett presented under question 15. All contributions are analysed by the A2 Customer Advisory Committee with the intention to prepare an Electra Paper.
- Introduction to the general discussion on preferential subject "Transformer Decision Making" under the leadership of P. Boss (CH).
- An announcement of future activities in the field of reliability by J. Lapworth (UK).

The Chairman summarized the past SC12 activities, which led to the selection of the 2002 Preferential Subject. Closing activities were listed with reference to new Brochures : Short-Circuit performance (N°209) and Design Review (N°204). To comment on the CIGRE reorganisation a few slides were presented to explain the small change concerning the Transformer Committee now called A2. The most significant change is the instrument transformer activities, which are now reassigned to A3. This is because the new relevant technical challenges do not concern paper-oil insulation anymore. Then, the new A2 environment was described and future liaisons with A3, B3, C1, C4, D1 highlighted. Reinforced by the reorganization, the two main A2 strategic directions are confirmed : services to CIGRE customers (Reliability, Life management, Economics, Tutorials, ...) and technology issues (Safety, New technologies and New concepts, Electrical environment, Pre-standardisation work, ...). The Chairman invited the audience to utilize the Transformer Web site, on which the details about future events (new WG's, A2 Colloquium in Mexico June 2003, Tutorials in Poland, China, ...) can be found.

Preferential subject – Transformer Decision Making

The preferential subject is related directly to the work in progress of Working Group 12.20 "Economics of Transformer Management." The WG was directed to produce a guide to help the users of transformers to quantify the economical aspects (costs, benefit) in relation to the management of the apparatus. This guide will include (1) a list of key parameters relative to economic issues and (2) a list of references on some economic models related to these various key parameters or on some global model related to the complete subject.

Sixteen reports from 16 countries have been accepted as contributions for the SC 12 session. The present General report refers to questions, the background of which is detailed in the special report.

(*) ABB Sécheron SA, PO Box 2095, CH-1211 Geneva 21, Switzerland

Question 1:

Does the methods used make it possible to quantify really the ageing of the solid insulation? Are there examples of defects in service where measurements of dielectric response of type PDC, FDS or RVM where carried out during their life? If so, what level of equivalent moisture has been reached? Are other techniques available to deliver such a diagnostic? If so, which?

It is reported from S. Gubanski (SE), head of TF 15-01-09 that the influences of ageing in the solid insulation on the dielectric response have yet to be determined conclusively. Indications from the dielectric measurements on increased moisture content and increased oil conductivity should be treated as warning signals - more investigations are needed for explaining reasons. A summary of the final report is available on the WEB site from SC 12 under the reference: www.cigre-sc12.org/SC_12/news.htm.

Similar experiences in Australia have been reported by T. Saha.

According to the authors of report 12-101, the moisture content of new transformers is between 0.2 % and 0.7 %. According to investigations, transformers with an age of 25 years and more show moisture contents above 2.5 %. There was a clear difference in moisture content between generator and system transformers. The correlation between aging (DP) and temperature on units in service is difficult to establish due to the large variation of the temperature distribution within operating transformers.

Question 2:

Can the manufacturers or the users give criteria for moisture content which shall not be exceeded for equipment in service? Can experts quantify currently the probability of failures in function of the moisture content, if we take in consideration the increasing of the power factor (risk of thermal breakdown) or acceleration of ageing?

It is reported from S. Gubanski (SE) that there is a particular need to verify the estimates of water content determined by the dielectric response by comparing them with basic chemical measurements when estimating the risk for failure.

According to the authors of report 12-101, for safety reasons moisture content beyond 3 % has to be regarded as critical. Therefore it is recommended to dry the active part, if the relative moisture content in the solid insulation exceeds 2.5 to 3.0 %.

By applying now available formulae for ageing kinetic of cellulose, the ageing of a transformer may be estimated knowing its operating temperature and moisture content. It is reported by L. Lundgaard (NO) that the difficulty is to assess the condition of the transformer and the technical result of a revision. There are effects of acids and paper shrinking with possible loose windings as a consequence. CIGRE 15-01-10 has recently started a study on “Paper Ageing”.

Question 3:

What is the economical impact of a solid insulation rehabilitation (characterized by a low polymerisation degree) in term of life time extension? Can other experts bring similar experiences on this subject, in particular by using continuous processing techniques with the transformer in service? Report 12-102 indicates that the expenses of a major repair increase to a maximum 10 % of the transformer price, which is very low. What is included in such repair work?

According to the authors of report 12-103, certain oil reclaiming methods can prolong the technical life of the transformer by 10-15 years. K. Ryen (NO) reports that continuous degassing may postpone oil reclamation by eliminating moisture and oxygen. In the case of continuous degassing, the interpretation of dissolved gas analysis has to be adapted.

Question 4:

The deposit of pollutants on the surface of insulating parts may generate major defects. Are there criteria and admissible limits for this type of pollution? Are there statistical data on a possible correlation between the rate of this contamination and the probability of failure?

The authors of report 12-113 have developed a regeneration method for oil-paper systems representing 3-10 % of the transformer price. The oil circulation technique has the advantage of eliminating surface pollution.

N. Dhaliwal (CA) reports on positive experiences with continuous degassing in his country. L. Cheim (BR) indicates that oil reclamation will influence the furane content, but O. Berg (NO) confirms that the furane content will rise again after a certain time as degradation products from paper are continuously extracted during service life. V. Sokolov (UKR) reports on the non-homogeneous moisture distribution within the transformers. It is said that moisture content determined by electrical measurement can not fully reflect the real water content in certain critical parts. P. Austin (AUS) reports on experiments performed in Australia to determine the effectiveness of oil treatment depending on the material degradation.

Question 5:

Have statistical analyses been carried out in order to optimise the policy of maintenance or monitoring with respect to the failure costs? In particular, did one identify the potential of reduction of total costs (type LCC) if scenario of on-line monitoring or advanced diagnostic (partial discharges detection, frequency response analysis, dielectric response) is applied?

The authors of report 12-106 indicate a case where advanced diagnostic techniques have been used. This permitted much quicker decision-making in order to limit the loss of production and to improve the logistics and restoration of service after the disturbance. The relative cost/benefit related to this incident is 1 to 10.

C. Lajoie-Mazenc (F) indicates that on-line monitoring and advanced diagnostic techniques are not applicable to accessories causing the majority of defects. For this expert, a systematic inspection is still a valuable practice together with an optimised maintenance policy based on the RCM concept.

J. Lapworth (UK) indicates that on-line monitoring devices are used for OLTC, but no evidence of fault detection has been seen. It is difficult to find an economical justification in this situation.

Question 6:

In report 12-107, the theoretical loss of reliability according to status of the paper condition is clearly described. Do the authors or other experts have statistical data on defects in service to validate the criteria indicated in this report?

The authors of report 12-107 indicate that the number of failure due to thermal ageing represents 11% of accidents during the period 1992-97. In Japan, the replacement of coils after 30 years is in discussion. It permits taking benefit of new technology with reduction of losses and noise.

P. Boss (CH) and O. Berg (NO) reported on transformers in service in their countries where DP values for paper insulation of 100-150 can be found. There seems to be no agreement about limits for DP values around the world. In Japan a value of 450 is seen as critical, but in Germany a value of 350 is seen as normal. At this point a definition for limits of DP value should be considered (e.g. physical end of life of paper, 50% withstand reduction of mechanical withstand against new value, etc).

Question 7:

Report 12-115 raises the question of the validity and of the reliability of the solutions adopted during a refurbishment or a repair. Can some experts report on the economical potential of different solutions of revision (reclamping, drying of the windings, oil treatments) in terms of reliability or life time extension?

The authors of report 12-115 indicate that no common views in UK exist regarding refurbishment. A significant amount of expenditure on mid-life refurbishment can be justified if this will result in a significant extension of remanent life, even if the transformer would otherwise last for another 10 years. The biggest uncertainty in such a situation probably lies not with cost or failure rate assumptions, but whether the remedial action proposed will in fact achieve the required life extension. For some situations, generalised statements can be made with some confidence about the economic justification for a particular course of action. In others there is too much uncertainty in assumptions to make a clear cut judgement. In any case, a clear economic model will help to identify what clarification is required to resolve the situation.

P. Austin (AUS) reports that economic evaluations by one utility has indicated that the cost of on-site refurbishment for 8 to 10 year life extension without any major component (e.g. bushing) replacement, but including improvement to oil preservation system, needs to be less than 15% – 18% of the transformer replacement value to be economically worthwhile.

J. Mendes (BR) reports that average time for on-site refurbishment has been reduced to below 60 days, compared to the traditional 90-120 days for factory refurbishment. In addition, the average transformer useful life extension is estimated to be approximately 12 years based on evaluation of the insulation paper Degree of Depolymerization. Finally, the average price of the refurbished unit is below 45% of the local market new unit price.

L. Cheim (BR) indicates that all types of on-line monitoring should be considered, not only gas detection. It is also indicated that on-line monitoring allows getting data from the equipment day by day, which is important in case of incidents.

Question 8:

Besides the cost reductions of operation due to lower losses, can we correlate the content of the technical specification with the reliability of the equipment in service as well as with the maintenance costs? Can the process of design reviews influence these two last parameters?

The authors of reports 12-105 and 12-109 confirm that modern optimisation tools may give higher reliability figures related to stray flux penetration in the tank wall and better cooling. Better performance will also have a positive impact on the safety margin and on maintenance.

P. Austin (AUS) reports that minor items may have a significant effect on reliability and safety (gasket, bushings, welded cover joint, etc).

E. Colombo (IT) says that precise information (e.g. hot spot capability of transformer) should be given to the operating people in order to overload the unit in a correct way.

Question 9 :

Can the authors of report 12-108 or other experts report on any feedback of field experiences, describing the economical advantages of an evaluation of a population of transformers, in relation with the reliability and maintenance costs? In particular, does anyone have a field experience to quantify the economical benefit to work on a TBM basis as mentioned in report 12-111 or on a CBM basis as applied today in many cases?

The authors of report 12-108 indicate that the evaluation of a transformer population allows lowering the peak of the investments and distributing them over a longer period, identifying the units with highest risk and finally identifying weaknesses in previous specifications.

According to the authors of report 12-111, CBM based on on-line monitoring can only be justified if high economic consequences induced by the unavailability of the equipment exist. Due to redundancy in the substation, it has not found any economical interest, but this policy may change in the future depending on evolution in operating the network.

P. Lorin (CH) indicates that on-line monitoring is an important feature to reduce repair costs.

Question 10:

On-line monitoring equipment has been in service for nearly 10 years in various forms. Do we have feedback from field experiences showing the impact on the reliability and on the repair and maintenance costs for transformers fitted out with a monitoring system, other than what was indicated in report 12-202 of the CIGRE SC 12 session 2000?

The authors of report 12-110 indicate that, due to the small number of on-line monitoring systems installed in field compared with the total number of power transformers, it is still unlikely to detect a major failure which occurs with a rate less than 2 %. On-line monitoring may help to fix problems more rapidly. Two cases are reported regarding cooling devices and gas generation of modern oils caused by chemical reactions.

The authors of report 12-111 indicate that dedicated on-line monitoring might be used in the case of abnormal behaviour of units. In these cases, the interpretation of signals delivered by on-line monitoring needs, in a specific situation, a rather complex comprehension of the different parameters delivered by the measuring equipment to evaluate the cause of the abnormal behaviour.

N. Dhaliwal (CA) reports that hydrogen-in-oil monitoring was not able to detect turn-to-turn faults. This monitoring has been useful in detecting problems related to the core and its support.

Question 11:

Which technologies must still be developed to offer a sufficient covering of 70-80 % of failures possibilities in order to guarantee a better reliability of the transformers ?

J. P. Patelli (FR), based on report 12-111, indicates that off-line diagnostics applied on a regular basis can be considered equivalent to on-line monitoring supervision, as specific symptoms can be traced in an efficient way.

P. Austin (AUS) reports that better reliability has to be linked with the major causes of failures and their related costs. A survey performed in Australia shows that dielectric failures in windings and accessories have a high impact on failure costs. With regard to on-line monitoring equipment, partial discharges within the windings are one of the more difficult things to detect. It is said that on-line monitoring can increase the availability of the equipment, but can not improve its reliability.

Question 12:

Does anyone have feedback from field experiences concerning the reliability and possible failures on units affected by planned overloads? Are the current technical specifications sufficient for managing these cases well?

According P. Austin (AUS), the potential failure from ageing of insulation due to overload is low; more important is gas bubbles and thermal runaway in transformers with insulation having a high moisture content. Based on experience, however, other types of problems have been detected and consideration needs to be given to this aspect in technical specifications. Examples of in service problems at up to or at full load have been (1) heating of electrostatic shields in shell type autotransformers (old design deficiency), (2) overheating of tanks due to leakage flux (no tank flux shunts) and (3) overheating during in-service overload tests to 1.3 p.u. at some gasketed joints due to current flowing through the bolts – this was easily fixed by fitting copper bridges. For many years (as early as 1976) at least two Australian utilities have specified factory tests on all transformers to prove their loading capability and this has included tests up to 1.3 or 1.5 p.u. to prove that the transformers can be loaded in accordance with the loading guide within the thermal capacity of the transformer or as specified. Full thermal imaging scans are made of the transformer tank and bushings during the test. From these tests a number of potential failure producing defects have been detected during the overload test, which were not readily apparent during the normal temperature rise test.

According O. Verdun (F), more information from a condition assessment survey is needed to take full benefit of the loading guide according IEC 76. The maintenance quality is also an important parameter when an overloading has to be considered.

A. Fazlagic (USA) indicates that moisture content in paper shall be taken in consideration when overloading is a key issue (risk of bubbling).

Question 13:

The authors of the report 12-114 emphasize positive feedback of field experiences. Can other experts bring other information on their approach? Do the rules in preparation within IEC for on-site testing fit well the techniques used today? Are the drying techniques for on-site applications sufficient? If no, what should be improved?

Authors of report 12-114 indicate that the priority should be to establish guidelines for specification of large transformer on-site repairs. Results drawn from past experiences show that focus should be placed on methods and techniques for more efficient measurements like load loss based on the reduced current method and the long duration induced voltage test with partial discharge monitoring. Monitoring of the insulation moisture based on (1) the oil moisture and (2) direct measurement of pressboard block test pieces using the Karl Fisher method has shown the excellent quality of the applied on-site drying process. All transformers repaired following the on-site repair technology presented in the Cigré Report 12-114 were returned back to operation with insulation moisture well below 1% weight (in the range of 0.4% to 0.7%). Of course, the drying efficiency and required time depend on the quality, care and control of parameters of the whole repair on-site process. Any improvement for on-site drying like low-frequency heating is welcome. However it must be competitive in time and cost, including required initial investments.

W. Hauschild (DE) reports that a new IEC standard related to the HV test technique on-site is in preparation. This work is carried out by WG CIGRE 33-03 and IEC TC 42. The relevant document has the reference IEC 60060-3 "HV test technique – Part 3: Definition and requirements for on-site test".

In his contribution, Y. Ebisawa (JP) presents a drying concept applied for the site-assembly of large units as reported in previous CIGRE contributions during the 1994 and 2000 sessions. According to the author, it is possible to supply on site a high quality drying process.

P. Austin (AUS) reports that in Australia, some field repairs and refurbishments, including untanking of smaller size (66 kV and 132 kV) transformers, have been carried out as well as many dry outs at site. A number of techniques have been used in Australia. This includes circulation of hot air where the air is replaced by nitrogen to heat the transformer and then vacuum is applied. The transformer is appropriately lagged to reduce heat loss. After a number of cycles, the method reduced the moisture content from 2.8% to 0.8% on a 150 MVA transformer. Other methods use oil to transfer heat. The most common method is to use oil to heat the core and windings, then remove the oil and apply high vacuum. Another is to spray hot oil on the windings with the tank under vacuum. One service provider has used a temporary building of thermal insulation around the transformer with hot air at 90 °C circulated between the tank and enclosure to maintain heat during the vacuum cycle. This system effectively dried a 255 MVA GSU after replacement of all three windings.

Question 14:

Which solutions are used to reduce the risk of failure due to these new type of transient effects? Which benefits in terms of cost or life time prolongation have been reached?

According the authors of report 12-116, the Fast Transient problem is well recognized in the case of motors and generators. The same protective devices may be applied in transformers (Surge arresters, Surge Capacitors, RC snubbers …). It is most important to be aware of a possible problem of interaction of the CB and the transformer. This depends on the network configuration, type of breaker, frequency of switching, economic importance of the installation and power outage consequences, etc. (as in the case of transformers in arc-furnaces, metal industry installations …).

A. Mercier (CA) indicates the importance to transformers of controlled switching of CBs. CIGRE WG 13-07 is dealing with that topic. Instead of high inrush current during conventional typical CBs closing, controlled switching may limit the current to the magnetisation current only.

Question 15:

Can experts, other than those mentioned in [2] report on the impact of preventive maintenance as described above in terms of global LCC costs and in terms of reliability or failure rate? Is there similar data *for a policy of risk management rather than a policy of well defined maintenance?*

J. Harley (USA) presented a contribution relative to OLTC monitoring practices in some US utilities. This contribution was partly dedicated to question 15 and partly to the workshop "Future of Tap Changers" during the 2002 session. It is well known that transformer on-load tap changers (OLTC) are expensive to maintain. For some United States users of this equipment, more than 50% of the transformer maintenance budget is consumed by their maintenance. OLTCs are also the single biggest contributor to catastrophic transformer failures. In order to reduce maintenance and capital costs a number of utilities have adopted some form of monitoring to supplement or replace maintenance based on calendar time and number of operations. Monitoring practices were discussed with four large US utilities: Commonwealth Edison, Consolidated Edison Company of New York, Potomac Electric Power Company and Public Service Electric and Gas Company. The purpose of monitoring, methods employed and use of data varies widely. In spite of this, there is a consensus that monitoring does significantly reduce maintenance costs and the number of failures. One utility continuously monitors 375 transformers with OLTC. It does not do periodic dissolved gas analysis (DGA) of the oil in the OLTC compartment. Two of the other utilities continuously monitor selected OLTC transformers in addition to annual DGA. For one, this is 150 of 695 transformers with OLTCs; the other continuously monitors 29 of 400 transformers with OLTCs. Finally, for the four utilities surveyed here, 20 % of the installed OLTC have on-line monitoring installed. The two utilities using continuous monitoring to detect both mechanical and electrical problems report extending operations before maintenance by 50-300%. They used the results of the monitoring and past performance instead of using time and number of operations. The other two utilities do not think their maintenance costs are high relative to the cost/benefit of continuous monitoring. Having maintenance directly responsible for both interpretation of monitoring and OLTC work management seemed to minimize anecdotal stories of problems. However, several utilities noted that even high level alarms could be ignored because of the frequency of alarms or operators too busy with switching or tracking alarms with higher priority.

The purpose of monitoring was consistent among the utilities: schedule maintenance, not prevent a failure. Repetitive maintenance alerts from continuous monitors on some OLTC were used by one utility to determine the incipient cause of failures. Designs were modified and interventions are now decreasing. Another utility has experienced high level alarms decreasing 66% between 2000 and 2001. The trend is continuing although the number of minor (low level) alarms is increasing. It thinks that the decrease in high level alarms is a result of a combination of (1) early problem detection from periodic and continuous monitoring and (2) a conscientious effort to address problems as they became identified. It uses monitoring as a threshold alarm and depends on an analyst to interpret information or request more data. A third utility has increased maintenance calls with more continuous monitors installed. However, many problems are being detected at an incipient stage.

A contribution during the workshop indicates that in Australia 28 % of OLTC failure are related to lack of or poor maintenance.

Session closure

At closure, J. Lapworth (UK) presented the A2 future activities in the field of Reliability. Three aspects were mentioned: "Check on manufacturers / Improve designs" for new transformers, "Manage network reliability" for midlife and "Manage risk" for units at the end of life. This will be discussed at the "III WORKSPOT" transformer event (November 2003) in Brazil.

The Chairman closed the Session with special thanks to the leaders of discussion and reminded the audience to visit the Transformer Web site (www.cigre-sc12.org), which is an effective and fast way to stay in touch.