1. INTRODUCTION

With the increasing demand of electrical energy and the growth of grid systems it turned out that also the transformer technology faced new problems to be solved.

Whereas in the past the activities of Study Committee A2 (former 12) Transformers were concentrating on design problems related to the rapid increase of rated voltage and power and the application of new materials, service conditions and their impact on the transformer performance have governed the discussions of the last two decades.

The two strategic directions of SC A2 have not been changed and are:

- To continue on transformer technology issues and to consider new information technologies (data, communication, web services).

- To provide services to CIGRE customers (reliability and availability including impact of accessories, life management, economical issues, tutorials, etc).

Recent activities are related to the problem of oil corrosivity, data management, condition assessment, reliability issues and support to CIGRE management for the preparation of the 2007 Symposium in China about UHV. For that purpose a new AG "UHV AC & DC Transformers" has been created. SC A2 will have to support other SC's like A3 (HV Equipment) by a liaison to cover some specific aspects in relation with the development of 1000 kV equipments. Eventually SC A2 will have to work also in the field of 1000 kV technology for transformers.

With the new organisation of CIGRE in 2002, the instrument transformers have been transferred to SC A3.

2. OVERVIEW ABOUT RECENT TECHNICAL ACTIVITIES WITHIN SC A2

2.1 VOLTAGE RELATED PROBLEMS

Until the mid of the century the highest system voltage had been increased step by step to a level of roughly 300 kV. But from then within no more than 15 years rated voltage climbed up to a level of 800 kV and more. The development of transformers and reactors for extra and ultra high rated voltage and design and test problems of this new generation of transformers was a main topic of the SC A2 activities in the late 60th and early 70th.

Intensive and extended work was dedicated to the aspects of impulse stress phenomena in HV-windings and to the development of appropriate impulse test procedures. In those days the risk of failure in service caused by lightning stroke or under impulse test was high. Research and development work was concentrated on the design of windings which were able to withstand impulse stress and on related test procedures.

Another field of activity was to develop non-destructive test methods in order to confirm reliable dielectric performance of large HV transformers. Ionisation problems and Partial Discharge measurement became an important item in the work of the Study Committee. The results of these activities were of major influence on the elaboration of the related IEC standards for dielectric tests including PD measurement and on the development of adequate measuring device.

2.2 CURRENT RELATED PROBLEMS

The increase of rated voltage was accompanied by a steep increase of the power rating of transformers. It culminated in 1 300 MVA rating of a GSU transformer in 1972 and 2 000 MVA bank rating of single phase autotransformers in 1980. As a consequence of the rapid increase in power manufacturers and users were faced with a couple of new

problems [1] concerning losses, short circuit strength and thermal performance which all entered the discussion platform of Study Committee A2.

Though the efficiency of large transformers is extremely high (99.5 % or more) the amount of load loss exceeded the hallmark of 1 000kW with considerable impact on the performance of the internal cooling. The development and application of OD (oil directed) cooling was only one consequence. Methods for loss measurement and heat-run tests had to be revised and adapted to the new demands. Stray flux problems and the application of proper protection against local hot-spots became more essential and initiated the development of calculation tools based on the application of advanced computer programs.

Another main concern was the short-circuit withstand capability of very large transformers reflecting that the short circuit forces were increasing dramatically by the increase of rated current and additionally by the increase of the short circuit power of the systems. These problems were extensively discussed in a Working Group and several times addressed as preferential subjects at the Paris Sessions. Looking into the list of preferential subjects since 1972, and reviewing the relevant publications and Working Group reports, it can be stated that Study Committee A2 played an active part in the related discussions and in the development of standards.

2.3 NEW CHALLENGES TO THE TRANSFORMER INSULATION SYSTEM

In the late 70th unexplained failures in large power transformers under transient voltage conditions initiated extensive studies of resonance phenomena in windings. The fast investigations covered the frequency range up to several hundreds of kHz typical for conventional transmission systems and stations. As a result of Working Group 12.07, "Fast Transients" recommendations for adequate design and testing were issued [2].

When gas insulated systems (GIS) for EHV application with direct SF6-connection to the transformer was introduced, a new kind of overvoltage impact on the transformer appeared: very fast transients (VFT), which are raised by switching operations in the GIS. It is the rise time of nano seconds and the high frequencies in the MHz range, which impose a new kind of stress on the transformer windings [2]. SC A2 is still involved in these matters in corporation with other Study Committees. About 20 years ago Japanese experts for the first time reported on phenomena of static electrification in HV-transformers with only, low response by other experts. But in the early 80th an increasing number of faults were reported, which were clearly related to static charging in large oil filled transformers. In collaboration with EPRI and other scientific institutions SC A2 started a Joint Working Group with SC D1 (former 15) to investigate into the basic physics of the phenomenon and to determine the influencing parameters and counter-measures. The results were presented in the CIGRE Technical Brochure N° 170 - 2000 but there are still some open questions remaining. The effects of geomagnetically induced currents in power transformers have been also investigated [3].

In 2005 the WG A2-32 was set up to deal with the problem of formation of copper sulphide in transformer insulation [4] [5]. The phenomenon has caused numerous failures in transformers and reactors. Some progress has now been made, especially in the field of test methods. A prerequisite for the formation of copper sulphide is the presence of corrosive or potentially corrosive sulphur species in the oil. The oil needs not necessarily be corrosive in conventional metal strip tests such as DIN 51353 or ASTM D 1275, or even in “extended” versions of these tests. Both naphthenic and paraffinic or intermediate oils may be affected. The phenomenon is not related to the absence or presence of phenolic antioxidant. Regardless of the nature of the oil, the occurrence of oils showing corrosive properties has increased in the last decade. Temperature is obviously a strong influential factor, since all chemical reaction rates are temperature dependent. However, temperature is not the only factor to determine the occurrence, nor the location of sulphide formation. In laboratory experiments copper sulphide formation was demonstrated in the range 80ºC to 150ºC.

A vast majority of failures known so far are within the groups shunt reactors, HVDC transformers and generator step-up transformers. A common factor of these types is relatively high loads; otherwise the connection is less evident. There are so far very few reports of failures in open breathing equipment, possibly partly due to less than optimal

oxygen content, and partly due to lesser occurrence of high voltage and highly stressed equipment among open breathers. Changes and long-term trends in equipment design and dimensioning may also have had some influence. These aspects deserve more study and consideration. As a consequence of the temperature dependence, factors such as load, ambient temperature and cooling settings will have an influence. Any extraordinary electrical stresses would also increase the risks of failures due to sulphide deposits. In particular, the occurrence of large and/or very frequent transients seems to have had a large influence.

2.4 SERVICEABILITY OF POWER TRANSFORMERS

In 1973 the ‘’oil crisis" terminated the trend towards steady increase of energy consumption and further increase of power and voltage ratings of the related equipment. Serviceability, safe operation and environmental and economical aspects became predominant.

As a key issue of loadability all aspects of the thermal performance including determination and direct measurement of tolerable hot-spot temperature, heat run test procedure, the application of Dissolved Gas Analysis to evaluate the test results, overload practice and its impact on remanent life expectation have been investigated by a very effective Working Group on thermal aspects [6]. A CIGRE Brochure titled “Thermal Aspects of Transformers” has been issued in 1995 (Ref N° 96).

Regarding the environment impact of transformers noise reduction is of increasing importance. WG 12.12 has elaborated the new IEC-standard on noise intensity measurement based on extensive measurements performed by the members of the group [7].

Provisions against fire hazard and pollution by oil spill in case of catastrophic faults on large transformers and new concepts with non-flammable insulation systems and rupture proof tank design have been discussed [8].
In recent years and in the near future life management and reliability are the main domains of activity in Study Committee A2 [9]. The principal reasons are that in the industrialised countries the bulk of power transformers have come to age and that deregulation of the energy supply market has forced economical considerations on the user side. Both aspects raise the question of more precise assessment of the remanent life and improved reliability of the transformer in service.

Study Committee A2 contributes to these considerations by intensive work in one Working Group on Life management (see CIGRE Brochure N° 227 - 2003). The scope covers general knowledge and theoretical issues, diagnostics and monitoring techniques and operations to be used after a problem has been diagnosed. In 2000, a WG was created to prepare a guide related to the Economics of Transformer Management. The final report as been published in 2004 in a CIGRE Brochure titled “Guide on Economics of Transformer Management” under the reference N° 248.

Finally, in 2006, WG A2-23 published a brochure titled “Guide on Transformer Lifetime Data Management” under the reference N° 298.

2.5 HVDC CONVERTER TRANSFORMERS AND REACTORS

The development and introduction of HVDC transmission systems was a new challenge for both transformer users and suppliers. Traditionally the transformer technology has to deal with AC phenomena and the design principles are related only to AC conditions. The designers had to learn how to match different dielectric requirements under transient and steady state DC conditions and to design adequate insulation structures which are able to withstand DC voltage and superimposed AC voltage stresses under test and service conditions. Furthermore they had to take into consideration harmonics in the load current and DC excitation of the core and their impact on noise and losses. Pollution of bushings and airside insulators required much more attention than under AC conditions. To respond to the particular service conditions extensive development work had to be performed. New and adequate test procedures had to be introduced in the standards. A Joint Working Group of SC A2 and SC B4 (former 14) worked very hard to

prepare standards for the specification and testing of HVDC transformers and reactors. The results have been published in Electra [10]. A joint activity between SC A2 and SC B4 has been reactivated in 2004.

2.6 NEW TECHNOLOGIES

The use of superconducting materials related to the transformer technology based on a practical application was shown [11]. Significant improvements can only be expected from new materials for conductors, magnetic circuit or electrical insulation.

3 - TUTORIAL

A serie of tutorials has been prepared on various topics (short-circuit, thermal performance, economics, etc). They are regularly presented in conjunction with local CIGRE activities, CIGRE Colloquium of SC A2, conferences, etc). Tutorials on other domains are in preparation.

4 - ON-GOING AND FUTURE DOMAINS OF ACTIVITIES

The main directions in the future will be:
- Phase shifter & HVDC Converter Transformers
- UHV AC & DC Transformers
- Life management & Reliability including accessories
- Service conditions and interactions in the electrical environment of transformers
- Environmental and economical impacts
- New / Non - conventional design concepts
- Tutorial

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