STUDY COMMITTEE A3
(High Voltage Equipment)

GENERAL REPORT SESSION 2008

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The discussions of the 2008 Session of Study Committee A3, High Voltage Equipment, were managed by Mark Waldron, the Chairman of CIGRE SC A3. He was assisted by the Special Reporter, by the Meeting Secretary, André Giboulet, and the Secretary of SC A3, Edelhard Kynast.

The wide scope of SC A3 led to 31 interesting Reports, 69 prepared contributions and 10 spontaneous contributions during the Session. The origin of the contributions was from manufacturers (42%), consultants/testing organisations (11%), utilities (32%), CIGRE/IEC WGs (5%) and universities (10%). An average of about 300 experts during the morning and about half of them during the (Friday) afternoon attended the SC A3 Session. They contributed to the good quality of the discussions and the fruitful exchange of experiences and points of view.

For the SC A3 Session 2008 three Preferential Subjects were selected:
Preferential Subject 1: Managing an ageing high voltage asset population
- End of life assessment (age, capability, reliability, technical risks, expertise)
- Refurbishment and replacement strategies
- Application of monitoring and condition assessment techniques
- Operation of equipment beyond design life

Nine Reports dealt with Preferential Subject 1.

Preferential Subject 2: Developments in testing and verification of HV substation equipment
- Increasing test requirements (1000 kV transmission, large out-of-phase angles, changing network topologies) and decreasing margins between operation and design/test conditions
- Use of simulations for verification
- Interpolation and extrapolation of type tests for special system conditions
- Testing of hybrid switchgear assemblies

To facilitate the discussions, the twelve Reports for Preferential Subject 2 were divided into three groups (UHV, simulations and diagnostics).

Preferential Subject 3: Acceptance and experience of new substation equipment and techniques
- Stress alleviation techniques including controlled switching and novel applications of surge arresters (mid-line, non-line to ground)
- Non-conventional instrument transformers, IEC 61850 and monitoring and intelligence within equipment
- Mixed technology and composite insulated switchgear
- Fuseless capacitors

With ten Reports and four groups of questions (NCITs, composite housings, surge arresters and FCL), Preferential Subject 3 was addressed.

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Preferential Subject 1

Managing an ageing high voltage asset population

A considerable amount of information was presented in the Reports on ageing, addressing several topics of interest to, and presented by, users: methods to rank populations of equipments for replacement or refurbishment (**A3-101**), to choose between refurbishment and replacement (**A3-102**), to select the specimen for replacement based on diagnostics (**A3-107**), refinement of the measurement of the SF_6-gas leakage rate (**A3-105**), to determine which equipment will become overstressed (**A3-106**), to deal with the effects of corrosion, wear and ageing (**A3-108 and A3-103**), life cycle management in general (**A3-104**) and reliability figures from the recent worldwide survey by WG A3.06 (**A3-109**) were all presented.

In most Reports the importance of adequate data acquisition and data management was stressed: data on the assets and their role in the network, failure reports, maintenance reports, asset data, inspection and test reports, monitoring data and statistical data were all addressed. Failure rates were given in several Reports, mostly as cumulative failure probability distribution curves. Ageing can be directly linked to a significant increase in the failure rate over time and this relationship has been captured in IEC Standard 60505 (2004) “Guide for the evaluation of insulating systems of electrical equipment”, which defines ageing as the irreversible deleterious change to the serviceability of the equipment. Thus a distinction has to be made between Major Failures (MF), that influence the serviceability, and minor failures (mf), which may lead to MF, but do not (yet) interfere with the serviceability.

The authors of Report **A3-101** have clearly faced problems with the definitions of MF and mf, as given by CIGRE WG A3.06, since utilities see MF as failures that hamper the key functions of the network or even the business, and not as hampering the key functions of the equipment itself. This problem of definitions has also been addressed at former Sessions of SC A3, but a totally satisfactory solution has yet to be found. The experts of WG A3.06 (**A3-109**) have attempted to apply criteria that balance different perspectives (maintenance perspective, asset perspective, system perspective, company’s perspective) but problems of interpretation remain, the true impact of which requires clarification and deeper understanding. The concept of different levels to qualify a failure of equipment was recognised by the audience. The higher levels (system, business) play an important role at the stage of selecting the items for refurbishment and/or replacement, but the lower level (equipment’s key functions) is required for statistical analysis on failure rates, hazard curves, operational costs, capital costs, etc. in order to take decisions on refurbishment/replacement in general. It is at this last level where CIGRE WG A3.06 has given its definitions, so that the statistical information becomes available for the asset managers to take their decisions.

The importance of the collection of data, of the shaping of the raw data and of the statistical analysis, including the confidence limits, has been stressed by several experts. A need for further studies and support of utilities has been expressed. In this respect the work of CIGRÉ WG A3.06 was regarded as very important and the first results from its third international survey on the reliability of HV equipment were presented in report **A3-109**. Failure rates were given for circuit-breakers, disconnectors and earthing switches, voltage and current transformers, and GIS. Some trends could be seen with respect to ageing, but an important statement in the Report, not only applicable to the populations studied by WG A3.06, was that one has to be very careful in comparing failure rates of equipment of far different ages, as technologies might have changed, maintenance policies might have been adapted, and only the fittest equipment might have survived (see also **A3-104**). Other aspects, when dealing with failure curves in relation to ageing were mentioned: the size of the population, the homogeneity of the population, proper and clear definitions in relation to the domain of application, and an adequate time scale (for instance the so-called “event-free period”).

As shown in several Reports and stressed in Report **A3-104**, an important criterion for ageing is an increasing MF-rate. One of the most popular techniques to estimate the bath-tub curve is by Weibull curve fitting. By means of such techniques it can be seen whether ageing is already a problem, when it may become a problem and various scenarios for maintenance and/or replacement may be judged, etc. Adequate statistical modelling with its confidence limits is required to extrapolate results into the future, so that users can adapt their decisions to the situation within 10 to 20 years. Experience with historic failure rates can be used as a reference to assess future failure rates but further investigations are required to see whether such a theoretical approach holds true in real life. For instance, the available data on failures may be too limited or too undefined to develop useful bath-tub curves, or a sudden increase in failure rate may occur, that could not be predicted from the available data. Examples of such a sharp increase, albeit with minor failures, were given in Report **A3-108**. The sharp increases in the examples were caused by the combination of two different ageing mechanisms.

Since 39% of MF and 63% of mf in GIS circuit-breakers in Japan could be contributed to corrosion/wear/ageing the authors of Report **A3-108** have studied specific ageing processes such as O-ring deformation, flange corrosion, grease deterioration, mechanical deterioration of bellows, mechanical/electrical deterioration of spacers, wear-out of sliding contacts and shaft seals. Detailed information is given in the Report, together with diagnostic and maintenance techniques. For instance the plastic deformation of O-rings over time and how this leads to a mf is discussed. Another example is given in figure 8 of the Report with grease deterioration due to oxidation (time, temperature) and SF_6 decomposition powder (number of operating cycles) leading to a drastic increase in defect-rate over time (figure 7). In fact as shown in these figures, as the number of operating cycles is an average per year, the important parameter is proportional to age^2 and that leads to the observed sharp increase in defect rate.

As leakages are an important indication of defects and mf (maybe even MF), Report **A3-105** addressed monitoring the SF_6-gas leakage. The authors clarified that the measurement of small leakage rates is not trivial, as the density of the gas is varying with the time and is not uniform distributed within the enclosure. The authors used thermal network simulation and computational fluid dynamics in order to find the best location and conditions for the density measurement and evaluation. The authors explained that the technique is still in a stage of development, so that practical issues like costs and service experience cannot yet be addressed, but they expected that most costs will be with the digital models, which are supposed to be already available with manufacturers.

In a number of Reports (**A3-101, -102, -103, -104, 107, -108**) equipment lives longer than 25 years (i.e. longer than the original design life) have been addressed and several Reports clearly showed that "design life" is, at best, only a rough guide to actual service life. Performance and costs are major drivers for replacement and Reports **A3-101 and -102** showed that corrective and preventive maintenance, including large overhaul, are the main components of the costs. In fact, it can be concluded that there is a direct relationship between mf-rate and costs and possible that mf's are a more important component in the costs than MF. Report **A3-102** went on to conclude that a programme of in-house refurbishment is reliant upon a certain minimum population size. This population size must be influenced by factors such as setup costs, the treatment of the expenditure (capital vs operational), the expected lifetime improvement and hence the depreciation period.

For the example given in Report **A3-102** a life extension of 10 years was mentioned, but the authors explained that a life extension of 20 years is more realistic. Retaining older assets can be a very useful tool for deferring and/or smoothing the so-called re-investment wall. Of course, to manage long-life assets in a heavily utilised network without any significant deterioration in supply performance is a particularly challenging asset management problem. The authors illustrated at the session the detailed material investigations performed to establish the remnant life of equipment. Interesting information was also presented on expected useful life of new parts and reconditioned parts, so that anticipated total asset life can be determined.

In Report **A3-106** overloading was brought forward as a criterion to replace HV equipment. Year by year a systematic verification of network developments leads to a three year ahead program for replacement. This time span seems to be rather short, but the criteria to determine overloading conditions seem to be rather severe. However, the authors explained that the de-rating based on the

DC time-constant is not too conservative, at least not for circuit-breakers (maybe for CTs, but this was not clear at the Session). They showed the audience that in about one third of the decisions to replace equipment this is based on criteria such as DC time-constant or TRV values, rather than load current or short-circuit current.

Report **A3-104** re-evaluated the outcome of a CIGRÉ study on life management, (Technical Brochure 165, published in 2000) with a view to updating this major topic to reflect recent developments such as those reported at the Session 2008, and the results of the studies of WG A3.06. In this respect for SC A3 it was interesting to know what suggestions the audience brought forward for new investigations in the field of life management. Several experts stressed the need for sharing data, a better understanding of statistical techniques, sharing know-how on material degradation processes, sharing the information from forensic investigations, sharing the criteria for replacement,/refurbishment, sharing criteria for de-rating and the experience with high stresses at high ages, intervals for large overhaul, the impact of flexible solutions and new technologies on the end-of-life decisions for old equipment. Based on this kind of suggestions SC A3 will compile the terms-of-reference for a new WG.

Preferential Subject 2

Developments in testing and verification of HV substation equipment

Preferential Subject 2 consisted of two main topics: UHV equipment (**A3-202, -204, -205, -206, -211**) and simulation methods (**A3-203, -205, -207, -208, -209, -210, -212**) plus a third topic: **A3-201** (diagnostics for MTS). Report **A3-205** was dealt with under simulation and calculation techniques, as it is more general than only UHV applications. The diagnostic parameter considered in Report **A3-107** on Instrument Transformers was the pd-level at operating voltage, similar to the Report **A3-201** on MTS, so that pd-measurements was discussed under Preferential Subject 2.

Diagnostics for MTS equipment

At former Sessions of SC A3 the necessity for on-site tests for MTS (MTS: mixed technology switchgear, also called hybrid switchgear or hybrid GIS, HGIS.) was discussed. The experience shown in Report **A3-201** gives a rather high dielectric failure rate (estimated by the Special Reporter: 210 bays, average service life 5 years, 4 or more failures gives a dielectric failure rate of roughly 0.5 % per year). Hopefully these failures are teething failures, but especially teething failures require careful verifications of the conditions after erection. A manufacturer explained that the components of a MTS are identical to the components applied in GIS-technology and should be tested in the factory and at site in a similar way. Originally the components for the MTS-equipment under discussion were not subjected to routine tests with pd-detection at 1.5 or more pu, opposite to today’s practice. Since the introduction of exactly the same testing procedures the failure rates of MTS equipment is identical to that of GIS-equipment and very low. The on-site tests required are rather simple, as the benefits of, for instance, pd-tests on site are questionable.

However, in Report **A3-201**, the authors recommended the application of pd- tests on a regular basis. They presently use add-on sensors, based on UHF technology, and regard continuous monitoring as not cost-effective. Extended commissioning tests were also not recommended as these would hamper the flexibility and possibility of a fast erection of MTS-equipment. To the authors, the installation of temporary sensors to verify under operating voltage conditions the dielectric performance of the suspected HV equipment does not create problems of safety to the personnel involved (distances to HV-parts, especially with the compact designs of MTS).

Voltage transformers for 420 kV formed the main topic of Report **A3-107**. The authors introduced a pd-measurement at the operating voltage to distinguish units at the end of their life (with a risk of explosion) from healthy units. Safety clearly is problem here, especially when staff have to apply pd-sensors to the voltage transformers. The authors explained that in their substations an alarm is generated when the pd-measurement indicates an upcoming risk of explosion.

The measurement and evaluation of pd's in a substation, using the operating voltage, is always difficult, because of two problems: background noise and the non-variable level of the applied voltage. Signal-to-noise ratio is therefore an important parameter and by certain techniques the ratio can be improved and/or the background noise masked.

Like many other experts in this field the authors of **A3-201** and **A3-107** see the pd-levels and patterns at operating voltage as relevant and relatively easy to measure parameters in order to determine critical deterioration of a dielectric medium. However, it can be questioned whether the pd-inception and/or -extinction voltage as function of a variable applied (over)voltage does not give more suitable information on the condition and residual life of the dielectric medium notwithstanding the extra complications. Unfortunately, at the Session experts did not address this question.

UHV technology

UHV technology has recently gained in international interest as several countries have plans to operate UHV-systems in the near future. Some decades ago pilot projects were undertaken in Italy, USA and Russia (where even 2000 km 1200 kV-lines have been built, half of it for a couple of years operated at 1200 kV) and for more than ten years a pilot 1100 kV project is in operation in Japan. This year a large 1100 kV project in China will be put into operation and during the following decade operational UHV systems are foreseen in India, Japan and Brazil. These developments have caused IEC and CIGRÉ (for instance WG A3.22 "Technical requirements for substation equipment exceeding 800 kV", Report **A3-211**) to pay greater attention to the specification of equipment above 800 kV.

The investigations of WG A3.22 in 2007 (Report **A3-211**) revealed a number of phenomena which are different for UHV systems in comparison to transmission networks at EHV-levels.
UHV networks show, for instance:

- a rather simple topology (radial rather than meshed): less refraction of travelling waves
- heavy conductors (6- and 8- sub conductor bundles): less damping, lower surge impedance
- large contribution to short-circuit power through UHV transformers (low X0/X1 ratio, low R/X ratio): low first-pole-to-clear factor, high DC-component, higher amplitude factor
- longer line lengths: higher TOV, higher SFO, larger secondary arc current
- need for advanced insulation coordination by adequate simulation techniques and smart application of MOSA
- more severe VFTO when GIS-disconnectors are not adapted to this phenomenon.

WG A3.22 has published a Technical Brochure with detailed information on service experience with 735 to 800 kV equipment and pilot experience with 1050 to 1200 kV equipment. On request of IEC SC 17A another Technical Brochure will be published with lessons learnt from 800 kV systems, the effect of long line length on TOV/SFO/FFO/TRV, knowledge extrapolated from the UHV pilots, the effects of several mitigations to limit overvoltages and to suppress secondary arcs, and specific recommendations for other important parameters.

By making full use of the possibilities to reduce UHV overvoltages, SFOs (slow front over-voltages) due to switching become relatively low (< 1.6 pu), and the uncontrollable SFOs due to the occurrence of an earth fault become dominant. In the opinion of the members of WG A3.22 this effect is more important, as the travelling waves excited by an earth fault will show less damping and less refractions with the rather simple UHV network topology than for meshed EHV systems. Such SFO are reported to become larger than 1.6 pu.

Some of the mitigations to reduce transient overvoltages and TRVs at UHV-level are part of the circuit-breaker and offer a problem for type testing, as to the International Standards a circuit-breaker has to be type tested independent from its design. Therefore, the TRV waveshape for each test duty is defined as the so-called inherent TRV; i.e. the TRV waveshape without any influence from the circuit-breaker or switchgear assembly. For obvious reasons the arc-circuit interaction has to be excluded, when defining the TRV waveshape, but also the influence of, for instance, opening resistors, grading capacitors, additional capacitors, parasitic capacitance of the switchgear assembly, varistors across the arcing chambers, etc. have to be excluded. Under special service conditions, this approach may prevent users and manufacturers to take full advantage of the possibilities to control TRV peak values and RRRVs. Such conditions occur not only with UHV-applications, but also with long line switching (Ferranti-effect) and series compensated lines.

In a number of contributions the advantages of the application of modern MOSAs were mentioned in order to achieve a more optimised insulation coordination. Such reductions of insulation levels and of margins between protection levels (LIPL, SIPL) and withstand levels (LIWL, SIWL) are based on the excellent service experience with MOSAs, certainly at transmission voltages. Moreover the service experience with MOSAs in the 1100 kV pilot plant in Japan showed UHV MOSAs to be stable and reliable components over more than 12 years. Examples have been given of discharge currents during lightning and switching incidents at the 500 kV-side of the transformer (energization of the UHV transformer; see also a CIGRÉ Report 13-209 of the SC 13 Session in 2000). In response to a prepared contribution highlighting the issue of switching surges due the energization of UHV transformers, a spontaneous contribution recommended to energize UHV transformers always from the EHV-side. The impact of MOSAs on the TRV waveshapes will be further investigated within WG A3.22.

Other contributions drew attention to the possibilities of using MOSAs to optimize insulation coordination at 420 kV-level as well. Now that the reliability of MOSAs is widely accepted by users, there may be increasing acceptance of MOSA’s being integrated into a GIS and of their application as a means to reduce margins between protection and withstand levels which is common practice for system voltages of 800 kV and above. It was brought forward that advanced insulation coordination has also be studied within SC B3, WG B3.01.03, for compact substations. Attention has to be given to the reduction of the rated voltage in comparison to the TOVs that may occur. Another suggestion was not to rely on a single MOSA.

Four of the five Reports related to UHV equipment dealt with type testing of switchgear (MTS in Report **A3-202**, AIS in **A3-204**, test circuits in **A3-206** and general test requirements in **A3-211**). One of the items of testing, especially short-circuit current making and breaking tests on circuit-breakers, is the suitability of unit tests and multi-part testing. This topic has also been addressed in Report **A3-210** and in Report **A3-206** reference is made to the equivalence of mechanical, dielectric, electro-dynamic and gas-thermal stresses, when performing unit tests.

A special problem for test stations is how to deal with the high TRV requirements at full pole testing (**A3-206**) such as for the T10 to the new edition of IEC 62271-100, with a first-pole-to-clear factor of 1.5. Test laboratories make use of double synthetic schemes to produce the required TRV-waveshapes, with the test equipment either placed on an insulated platform (XIHARI) or at earth potential (KEMA). The contributors did not explain whether or how the required recovery voltage is sustained by the new testing schemes. Another problem, not addressed, comes from the short-circuit current distortion or voltage/power level at the power frequency current source during synthetic tests, taking into consideration the large number of interrupters (test object plus auxiliary breakers).

The short-circuit current make test has to be performed in many cases as a full pole test, thus requiring a synthetic test circuit (**A3-202**). When test stations are not capable to test UHV circuit-breakers under full pole conditions, half-pole tests have to be considered or tricks like fuse wires and reduced SF_6-gas pressure. It was explained that such methods may be applied for high-speed earthing switches, but cannot be applied to circuit-breakers due to the dynamic behaviour of the SF6-gas which is essential for their performance.

At the Session a method for testing UHV circuit-breakers equipped with opening resistors has been presented (multi-part tests). Also a method to perform dielectric tests by the use of two voltage sources that have a minimum mutual influence was given. For dielectric tests, in Report **A3-202** the advantages of an encapsulated power frequency UHV transformer to test UHV equipment was mentioned. One of the contributions explained the problem of the overshoot of the applied test voltage and a new task force within SC D1 will study this problem, especially for UHV applications.

A manufacturer mentioned the excellent performance of optical voltage and current measurements for application during UHV tests and to UHV substations. To the spontaneous question whether distances in a UHV substation are not far too large for optical fibres used in optical devices, the manufacturer answered that distances up to at least 10 km can be handled without any problem.

Simulation and calculation techniques

WG A3.20 "Simulations and Calculations as Verification Tools" presented Report **A3-210**, where a distinction was made between simulations/calculations used for the interpolation of test results, for the extrapolation of test results, for the verification of test results and to replace type tests. Examples for each of these four categories have been given.

Two interesting topics raised in Report **A3-210** are: the dielectric benchmark and the verification of the dielectric coordination between main and arcing contacts. The dielectric benchmark, as performed by WG A3.20, showed the very good similarity between various simulation techniques for dielectric stresses. But, at the same time, these models did not converge to a single conclusion on the dielectric performance of the sample used, as here the manufacturers' experience with respect to necessary margins plays a very important role. Another example of the power of simulation techniques is the verification that, throughout the interruption process of a single pressure SF_6 gas circuit-breaker, the point of weakest dielectric withstand strength is between arc contacts (as it should be) rather than between arc and main contact.

A well-known example of simulation/calculation techniques, which is used to replace testing, is the verification of the seismic withstand capability of HV equipment, such as for AIS circuit-breakers. Simulations/calculations of seismic stresses were mentioned in the Reports **A3-204, -209 (-302, -307)**, and elaborated in Report **A3-212**. Exactly ten years ago experts from India presented Report 13-201 (1998), showing relatively simple and therefore understandable and practical calculations for the seismic stresses on circuit-breakers.

Examples of the high degree of complexity of the physical/chemical processes during short-circuit current interruption were given in Report **A3-203** and areas where computer models cannot be verified or the physical phenomena are not yet well understood are highlighted (material ablation, thermal radiation, gas turbulence and the disequilibrium of the SF_6-gas). Despite the short-comings of the simulations, the authors regarded such tools as very helpful in understanding the gas behaviour and in making relative comparisons. Experts brought forward that the engineer's experience is usually related to the global performance of equipment, while advanced simulation techniques offer the possibility to acquaint knowledge of local phenomena. It is in the combination of both approaches that the real advantages can be achieved.

Another position was taken in Report **A3-208**, where the authors tried to get around the time consuming design optimization that is based on FEM (finite element method) and iteratively has to lead to a result. Instead, the authors applied a sequential approximation technique, based on simplified simulation codes. The so-called Kriging model has been employed, The authors presented a comparison between predicted performance and test results. A close match was observed, proving the value of the tool during development. Although the engineer's experience is still crucial to estimate the circuit-breaker performance during physically complicated processes, for the future the authors expected the tool also to be capable to predict the performance at these more difficult to simulate stresses.

Examples of verifications by means of simulations/calculations (seismic withstand strength and thermal expansion withstand strength) and of extrapolations of test results (equivalent capacitance of busbar, temperature rise of a long GIS enclosure, temperature rise at a high ambient temperature and contact erosion due to high frequency currents) were given in Report **A3-209**.

Report **A3-205** described newly developed procedures for three dimensional (3D) calculations of surge arresters for EHV and UHV systems and first results of the calculation of the temperature distribution in the arrester have been reported. The capacitive voltage distribution has been compared with the voltage distribution when the non-linear characteristic of the metal oxide (MO) material is considered, leading to more realistic results, because of the self grading effect. (Purely capacitive calculations may lead to too conservative results.)

Also the influence of intermediate grading rings on the voltage distribution was investigated, and it was stated that the influence of such measures needs to be studied very carefully because they may even deteriorate the voltage distribution. Further the voltage withstand test was discussed, and it was stated that, especially for UHV arresters, the complete arrester housing including grading rings needs to be tested. Tests on individual housing units were considered to be not acceptable. For the tests the MO material should be replaced by adequate grading components. Figure 10 of Report **A3-205** showed an external grading system (grading rings) reaching down to the first intermediate flange. The distance between the ring and the flange could be critical and might lead to a flashover between the grading system and the flange. Big diameters of the external grading system might require large distances between the phases in a UHV system. One could imagine that a combination of external (e.g. rings) and internal grading measures (e.g. capacitors parallel to the MO column) leads to a further optimized voltage grading.

MO surge arresters for UHV application in an AIS (air insulated substation) can be designed principally in two different ways, some separate housings in parallel or some (e.g. four) MO columns in parallel in the same housing. In case four MO columns (or more) are in parallel in the same housing, polymer tube or porcelain hollow insulator, the temperature in the housing will be quite high and questions can be put forward with respect to the thermal stability of such a design and the need for extra cooling measures, like metal between the MO resistors in the columns. In such cases the use of simulation and calculation tools give a tremendous reduction in development time in comparison to real tests. From a design point of view a manufacturer stressed that for UHV AIS it is recommendable to apply multi-column arresters (multi-housings) with direct moulded silicon rubber, giving superior thermal characteristics.

Report **A3-207** as well as **A3-210** dealt with the simulation of internal arc performance. This is important as for environmental reasons test labs are more and more restricted in performing destructive tests on SF_6 gas filled equipment. According to Report **A3-207,** for internal arc testing the SF_6-gas may be replaced by air, to verify the mechanical strength of the enclosure. WG A3-20 mentioned the difficulty of simulation of the exothermal reaction of aluminium particles with SF_6 and SF_6 decomposition products. Internal arcing tests with MV switchgear proved that the exhaust phenomena behave differently for SF_6-gas in comparison to air, as illustrated by some figures in Report **A3-207**. The heat content of the exhausting SF_6-gas is higher than that of air, and the cooling down process is slower. To solve this problem the topic of simulation of internal arc tests on SF_6-gas filled switchgear will be investigated by the new WG A3.24.

Preferential Subject 3

Acceptance and experience of new substation equipment and techniques

Four groups of papers: instrument transformers (ITs, NCITs, merging units) with 5 Reports, insulators (composite housings, spacers in GIS) with 3 Reports, surge arresters and FCL with each 1 Report.

Instrument transformers

A "non-conventional" instrument transformer, based on the technology of a conventional inductive voltage transformer, but adapted to prevent/reduce ferro-resonance, was described in Report **A3-303**. The authors distinguished two operational conditions that lead to ferro-resonance (see also WG A3.13's Technical Brochure 336):

- an un-loaded busbar (busbar, busbar section or bus section between open circuit-breaker and open line disconnector) through the grading capacitors of the circuit-breaker and the non-linear inductance of a voltage transformer
- open-phase modes (for instance during SPAR of a shunt compensated OH-line, single pole operation of a feeding OH-line terminated with a transformer) through the capacitive coupling between phases and the non-linear inductance of shunt reactor or transformer.

The authors presented mitigation by replacing a part of the magnetic core by structural steel in order to increase the resistive load of the voltage transformer, so that ferro-resonance is immediately damped. Other well-known solutions, such as the application of capacitive voltage transformers (CVTs) to busbars or loading the open delta winding to damp ferro-resonance and the application of NCITs, are not discussed in the Report. In a contribution from a utility it was explained that ferro-resonance belongs to the most important causes of voltage transformer failures in service. The remedial action applied by this utility is to specify an iron core with a small air gap to force a more linear magnetization characteristic. This solution is very effective at low costs.

Optical CTs and VTs, Rogowski coils and capacitive dividers were dealt with in the Reports **A3-301, -304 and -308**. Despite the apparent advantages of such technologies (wide bandwidth, large dynamic range, compact and light, easy to handle electrically), all authors only addressed special projects, special applications and pilot projects. Such applications are PMUs (phasor measurement units, to observe system dynamics), revenue metering, HVDC and SVC applications, PQ measurements, laboratory and field test measurements, calibration purposes, split-core and special shape applications, arc furnace transformer protection, travelling wave protection, etc.

A number of reasons why the market share of NCITs for normal applications is still limited were given at the Session including: a lack of service experience, poorly suited for use in combination with older protection relays, reliability and service life of the associated electronic equipment, the difficult process of establishing Standards for the communication. Manufacturers regarded the problems with stability, calibration and/or re-calibration as having already been overcome. The recent implementation guideline to the IEC Standard 61850-9-2 together with the Standard itself formed a real improvement for the communication platform. There is still room for improvement, especially with respect to a time synchronization network, but soon a CDV hopefully solving these problems will be issued by IEC.

A SAMU (stand-alone merging unit) has been discussed in the Reports **A3-301, -304 and -306**. In contrast to the conventional technique, transmission of information is nowadays separated from the supply of power to the protection and metering equipment, thus allowing low voltage/energy levels to transmit the signals, and in order to cope with EMI the signals are protected in a digital or optical way. A SAMU thus converts the signal from an IT or NCIT to a certain standardized output signal, mostly a signal at an Ethernet platform, in conformance with IEC 61850-9-2. Modern secondary equipment used for protection, control and monitoring is able to handle such digital signals that are offered in parallel to the serial input ports of all applications. From the SAMU to the secondary equipment the signal may be passed on by coax/triax cables or by optical fibres.

In Report **A3-306** a universal SAMU was presented, suited to connect conventional instrument transformers as well as devices with low voltage analogous output signals and devices with digital output signals. These output signals (input to the universal SAMU) seem to have to follow a standardized format, so that customized signals cannot be dealt with. The SAMU seems also not to be capable to deal directly with optical signals. Oppositely, for instance in Report **B5-205**, a dedicated SAMU facilitates a customized interface to, on one hand, the robust sensor techniques and to, on the other hand, a general platform, based on IEC 61850-9-2. A spontaneous question was how the system described in Report B5-205 can be connected to conventional protection relays. As the sensors are attached to the secondary side of conventional instrument transformers, the answer was evident: conventional relays are still connected to the conventional instrument transformers, but modern relays will be connected to the Ethernet bus.

The authors of Report **A3-304** illustrated the development of sensors and interface equipment, as applied to an outdoor 170 kV GIS. As this was a recent pilot project, the authors could not give much information about service experience.

Two spontaneous questions addressed interesting topics: can different NCIT technologies give a different transient behaviour, and whether by means of NCITs applied to bushings pd's can be picked up? From the audience no answer to both questions was given.

Insulators

In Report **A3-305** the optimization of spacers in GIS was treated by authors who have published also a paper at the SC A3 Session in 2006 (A3-104). This time the application of ANN (artificial neural network) to optimize the design of a spacer with respect to the electric field distribution was illustrated. In addition the authors described how by the application of FGM (functionally graded material) similar results for an optimal field distribution could be achieved.

Two Reports (**A3-302 and -307**) dealt with composite housings and bushings, the working area of WG A3.21. The advantages of such insulators are evident: less vulnerable to vandalism (e.g. gunshots), explosion safe, easy to handle, more compact, better pollution performance, a good ice and snow performance. The ageing performance seems to be good (better than for composite line insulators) and biological growth seems not to form a problem. In Report **A3-307** the authors mentioned adaptation of the Standards with respect to the requirements for seismic performance and testing of empty housings in relation to the dielectric stresses of bushing applications, HVDC and UHV applications.

The duration of life cycle and endurance tests is relatively short in comparison to the required service life, say 40 to 50 years but experts explained that the experience with composite line insulators is much longer than with composite housings and bushings. Based on the excellent experience with line insulators, a service life of 40 to 50 years was considered as reasonable. The very good hydrophobic characteristics (hydrophobicity transfer and recovery) of composite line insulators as well as hollow insulators was illustrated.

A special contribution dealt with investigations to prevent bird picking on composite insulators, using the spicy taste of special peppers. From the audience the suggestion was made to investigate also whether the colour of the insulators could have an influence on the birds' appetite. In another contribution it was explained that within SC D1 it has been investigated and found that biogrowth has only a surface effect, resulting in a flashover voltage still much higher than with porcelain insulators.

WG A3.21 will issue a Technical Brochure in 2009 with service experience as well as recommendations to adapt the IEC Standards.

Surge arresters

WG A3.17 “Surge Arresters” has written Report **A3-309**, where the preliminary results of numerous tests to determine the energy handling capacity of metal-oxide resistors (varistors or blocks) have been presented. Several thousands of MO resistors from six manufacturers were tested to their actual energy limits under different kind of current stress. Compared to an earlier comparative study published by other authors about ten years earlier, an increase of ten to twenty percent in the average specific energy absorption capability could be seen. The analysis of the results showed the importance of a clear definition of failure criteria. Depending on different stresses the limits of an MO resistor may be given by the material itself, or by the coating system of the resistor. The results revealed that metal-oxide varistors failed mainly by showing cracks, by flashovers and mostly by a change of the characteristic voltage (measured at a peak current density of 0.12 mA/cm²). Mechanical failures and punctures occurred far less and a change in the residual voltage (measured at a 10 kA pulse 8/20 µs) happened very seldom.

The research was performed to find the limits of the MO resistors, which is a matter of the material and coating system of the MO resistors. The found energy capability values were very high compared to the normally guaranteed energy values for MO surge arresters in the data sheets of the manufacturers. The research work has been limited to the single impulse energy handling capability. The authors explained that the outcome of the studies are not directly relevant to the users, but help manufacturers to optimize the products and help standardization bodies to compile more effective specifications. The recommendation will appear in a Technical Brochure to be published in 2009.

FCL

FCLs (fault current limiters) were the study object of the former WG 13.10 and WG A3.16, that both have published a Technical Brochure (one in 2003: 239; and one to appear in 2008). In the meantime CIGRÉ SC A3 has established a third WG on FCL: WG A3.23 “Application and feasibility of fault current limiters in power systems”, and its first meeting was hold during the 2008 Sessions.

The new Technical Brochure offers the user a framework for the coordination between a FCL and the protection system, and Report **A3-310** gave some examples. With respect to this coordination, FCLs can be divided in three groups:

(1) the conventional FCLs, such as fuses and current limiting reactors, where users are well experienced with the coordination between FCL and protection scheme
(2) other technology FCLs that interrupt the short-circuit current, so that protection coordination is comparable with the policy applied with fuses, though fault location is still required
(3) FCLs that limit the short-circuit to a certain level (the follow current) and make coordination with protection systems necessary and complicated.

The focus of Report **A3-310** was on the last category.

The coordination of protection and FCLs is very complicated and leads to a solution that is to be regarded as a compromise rather than an optimal solution. WG A3.16 therefore did not give solutions but offered a tool to manage all different aspects, like the type of FCL, the protection functions involved, protection sub-items, the location of the fault and the location of the FCL. The guidance for application of FCLs to future users will be offered in the Technical Brochure, published soon.

The SC A3 Session concluded with a last announcement for the joint colloquium of SC A2, A3 and B3 to be held in August 2009 in Stellenbosch, near Capetown (Kaapstad) in South-Africa. The event will take place in close coordination with the Southern African Regional Conference .