A3 - 00

SPECIAL REPORT FOR GROUP A3
(High Voltage Equipment)

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Special Reporter

For the SC A3 Session 2008 three Preferential Subjects have been selected and the total amount of submitted Reports is 31.

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 deal 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 are 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 will be addressed.

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Preferential Subject 1

Managing an ageing high voltage asset population

An considerable amount of information is 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**) are all presented.

In most Reports the importance of adequate data acquisition and data management is 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 are all addressed. Failure rates are 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.

In a similar vein there is clearly a difficult relationship between defects, mf and MF and particularly estimating the transition from one level to another. Deep and detailed investigations are required to study such relationships, as illustrated in Report **A3-108**, and referred to in Report **A3-102**. Even so it remains unclear whether it is possible to derive reliable time-wise relationships from the statistical data, such as that shown in the figures 2 and 8 of Report **A3-101**.

The first results from the third international survey on the reliability of HV equipment are presented in report **A3-109**. This very important work of WG A3.06 will lead to new figures on average failure rates for circuit-breakers, disconnectors and earthing switches, voltage and current transformers, and GIS. Failure rates are given for different apparatus, for different locations, for different enclosures, for different operating mechanisms and for different ages. Some trends can be seen with respect to ageing, but an important statement in the Report, not only applicable to the populations studied by WG A3.06, is that one has to be very careful in comparing failure rates of equipment of far different ages, as technologies have changed, maintenance policies may have been adapted, and only the fittest equipment has survived (see also **A3-104**). Other aspects, when dealing with failure curves in relation to ageing are: 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 several scenario 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. Further, experience with failure rates in the past can be used as a reference to assess future failure rates.

Q1-1 Adequate definitions (defect, mf, MF), frames of reference (asset vs system perspective) and proven, robust statistical techniques form the basis of any asset management strategy for HV equipment. Participants are asked to offer their perspectives on these aspects and particularly the open points mentioned above. Of particular interest are aspects such as the strengths & weaknesses (from a user perspective) of the various definitions, the most appropriate and efficient form(s) of data collection/presentation to inform asset management decisions, novel statistical techniques which may be employed to predict future performance and the technical and statistical validity of such techniques for the prediction of future failure curves from historic data. In which way is WG A3.06 dealing with the relationship between failure rate and age or usage?

Since 39% of MF and 63% of mf in GIS circuit-breakers in Japan is due 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 defect time-wise results into a mf is discussed although the precise derivation of the SF6-gas leakage rate (shown in fig.18) from the material deterioration (Arrhenius' law shown in fig.1) is unclear.

A similar approach is given in figure 8 of the report with grease deterioration due to oxidation (time, temperature) and metal powder (number of operating cycles) leading to a drastic increase in MF-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 this sharp increase. The knick-point is around 30,000 year-cycles, meaning that an average of 30 cycles per year leads to a limit age of 32 years; and 80 cycles per year to a limit less than 20 years.

Reports **A3-102, -103, -108** emphasise the role of small things such as corrosion, wear, ageing and leakage of O-rings and cork gaskets in the overall management of ageing assets. Such defects lead usually to mf and to costs for repair (maintenance, overhaul and refurbishment). However, in Report **A3-108** corrosion, wear and ageing lead to 39% of MF, data that is difficult to understand in relation to Report A3-206 (2006), where the MF-rate appeared to be stable over time.

As leakages are an important indication of defects and mf (maybe even MF), Report **A3-105** is on monitoring the SF_6-gas leakage, where the authors clarify 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. What remains to be addressed is the application of this technique in a practical context and an assessment of the potential for cost effective improvements over conventional diagnostic sampling and/or statistical trending techniques.

One of the apparatus in the survey of WG A3.06 is the voltage transformer for which, according to figure 9 the main insulation shows a clear ageing pattern. Voltage transformers for 420 kV form the main topic of Report **A3-107**. The authors introduce a pd-measurement at the operating voltage (life) to distinguish objects at the end of their life from still healthy objects. However, the rate of explosions per calendar year has not significantly decreased since the pd-measurements have been introduced, only the additional oil analysis seems to lead to a lower explosion rate. The number of destroyed voltage transformers is rather low, and information on the age at failure and the ages in the total population is important to draw conclusions about the residual life, but is not given in the Report.

Report **A3-104** re-evaluates 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 development such as those reported at the Session 2008, and the results of the studies of WG A3.06.

Q1-2. A number of contributions have drawn out the complexities of lifetime management and the importance of material degradation, particularly regarding aspects such as lubrication and sealing, when analysing equipment condition, performance and remnant life. Since degradation tends to be sensitive to material type, equipment design and application/usage and operating environment, participants are invited to comment upon the practical use of material analysis methods and forensic examinations for asset life management. Furthermore, contributions are encouraged regarding the practical effectiveness of material analysis and monitoring systems for detection and/or prediction of failures and defects. In particular can participants offer views on whether reliable models be developed to use measurements and analyses to predict the rate of development of future defects and failures and hence optimise end of life decisions, taking in mind the effects of mf versus MF and a possible sharp increase in failure rates. Finally, views on future activities of CIGRE SCA3 in this area are welcome.

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 show 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** show 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** goes 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. Whilst these factors will vary from user to user it would be interesting to be able to estimate what minimum population level might support in-house refurbishment.

For the example given in Report **A3-102** a life extension of 10 years is mentioned, meaning that replacement of early units will start immediately after the refurbishment of the last circuit-breaker in the population. Whilst this lifetime extension is relatively modest 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.

Q1-3. Asset end of life decisions are influenced by a wide array of factors from technical performance through to the financial environment (favouring capital or operational spend) and the regulatory regime of the user. Participants are invited to provide examples of successful and not so successful end of life decision making. In particular aspects such as how is remnant life assessed, what are the lifetime expectations of HV equipment (considering operating environment), what role does major overhaul/refurbishment play and what is a reasonable time horizon for asset managers in order to maintain a sustainable network are of interest. From a less technical viewpoint information on topics such as the balance between operational and capital costs, the influence of short/long term regulatory regimes and the role of equipment renewal to facilitate network development and improved functionality (Report A3-104) will be welcome.

In Report **A3-106** for instance overloading is brought forward as a criterion to replace HV equipment. Year by year a systematic verification of network developments lead 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. In this particular case further information on which type of overload (rated current, short-circuit current, DC time constant or TRV-values) is dominant for their replacement program and the reason why there is, with respect to the DC-time constant, a quadratic relationship between short-circuit current and stress (equation 1) would be welcome.

The decision for refurbishment is accompanied by intensive studies: maintenance, operational and inspection reports, material investigations, forensic investigations, statistical evaluations, and even repeating some type tests. Regarding this latter aspect it is clear that the purpose of the testing and the reference specification must be clearly defined and that the interpretation of the results (Report **A3-102, -104**) and the overall evaluation of the tests must take account of the state of the test object (worn, re-conditioned etc) and its intended ongoing use.

The authors of Report **A3-103** give rather simple to measure parameters that can be used as a check of the equipment's condition. Even for rather old equipment the variation with respect to the original parameters is small or can be reset to be small. If suitable parameters can be identified which truly represent the performance of the equipment and which can be correlated with type test results, such techniques may permit much improved performance assessment without the need for repeat type testing as per Report **A3-102.**

Q1-4. The replacement of equipment due to inadequate rating, its management in service until replacement and the verification of capability of ageing and/or refurbished assets is an asset management challenge with significant safety implications in the event of equipment becoming overstressed. Participants are invited to contribute on the relationship between electrical stresses and equipment ageing/end of life, on the management of potentially overstressed equipment, on the methods used to ensure that ageing equipment retains its rated capabilities up until the point of replacement, on de-rating procedures for ageing assets and on the role, if any, of repeating selected type tests and the complexities of interpreting the results thereof.

Preferential Subject 2

Developments in testing and verification of HV substation equipment

PS2 is made up 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** will be dealt with under simulation and calculation techniques, as it is more general than only UHV applications. The diagnostic parameter considered in Report **A3-201** is the pd-level at operating voltage, as is used in Report **A3-107** on Instrument Transformers. Question 2-1 therefore addresses Report **A3-107** as well.

Diagnostics for MTS equipment

To start with the diagnostic topic, experts most probably remember the discussions during former Sessions about the necessity, or not, to perform an on-site test for MTS. (MTS: mixed technology switchgear, also called hybrid switchgear or hybrid GIS, HGIS.) The experience shown in Report **A3-201** gives a rather high dielectric failure rate: about 1% per bay-year (210 bays, estimated average service life 3 years, 4 or more failures). Hopefully these failures are teething failures, but especially teething failures require careful verifications of the conditions after erection!

Based on their experience, the authors recommend the application of diagnostic tests on a regular basis. They presently use add-on sensors, but would probably prefer to specify build-in sensors for new MTS-equipment (i.e. monitoring pd development) or even give preference to appropriate commissioning tests instead of the application of diagnostic tools.

The installation of temporary sensors to verify the dielectric performance of the suspected HV equipment under operating voltage conditions may create issues of safety of the personal involved (distances to HV-parts, especially with the compact designs of MTS (Report **A3-201**) and risk of explosions, especially with the voltage transformers (Report **A3-107**)), but in both papers safety has not been addressed.

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, but this is not always clear from the descriptions. For instance figure 7 of Report **A3-201** suggests a much higher level of background noise (blue line) than the pd-signal from the internal excitations, although the authors in their main text give another view.

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.

Q.2-1 What is the opinion of the authors, of manufacturers and of other experts on the necessity to perform on-site tests to MTS equipment? Is there a preference to apply monitoring sensors or diagnostic tests or a combination of these and, when considering diagnostic test techniques, how is safety risk taken into consideration in comparison to the risk of a dielectric failure? When performing pd-measurements, what is the experts' experience with respect to the relevant parameters (pd level, pd pattern, inception voltage, extinction voltage, a combination, others)?

UHV technology

UHV technology has recently gained in international interest as several countries have serious 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 has been in operation in Japan. This year a large 1100 kV project in China will be put into operation and during the following decennium 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 attention to the specification of equipment above 800 kV.

There is a difference between IEC and some other Standards in the definition of what has to be called the rated voltage. To IEC it is the maximum operating voltage, at least for switchgear, while other Standards refer to the rated voltage as being the nominal operating voltage, that may be exceeded by 5% or 10%. In that case the system in China has a nominal voltage of 1000 kV and a rated voltage to IEC of 1100 kV but in Report **A3-202**, on the application of MTS in China, one refers to a rated voltage of 1000 kV, and such terms can lead to confusion and misunderstandings.

The investigations of WG A3.22 in 2007 (Report **A3-211**) reveal 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-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 (available through CIGRÉ CO) 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), but 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.

Four of the five Reports related to UHV equipment deal 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 equivalency 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. Another problem 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). Also 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. In the Reports no information is given on a suitable test (a separate test to prove that the operating mechanism is capable to deliver the required force and speed). No details have been given on the proof of the circuit-breaker's ability to make a symmetrical and, especially, an asymmetrical short-circuit current.

For dielectric tests, in Report **A3-202** the advantages of an encapsulated power frequency UHV transformer to test UHV equipment have been mentioned. The authors mention also problems with respect to bus transfer and bus charging tests.

Q.2-2 Can experts on insulation coordination (e.g. from IEC TC 28) inform the audience on the decision taking process with respect to the rated voltages, the related LIWL and SIWL levels and their views on SFO due to the occurrence of single earth faults in UHV-systems? Is information available on the standardization process for UHV switchgear and whether or not the advantages of (auxiliary) equipment like opening resistors, MOSA, etc. may be taken into account when defining the (inherent) TRV waveshape? The Participants are requested to give their experience with and thoughts about the type testing problems given above (unit testing, suitable tests, make test, TRV peak value, encapsulated transformer).

While Report **A3-202** deals with UHV MTS, it does not show any application of NCITs or built-in highly reliable MOSAs. Oppositely in Report **A3-204** an AIS-solution is described with NCIT-applications and a very special (double) semi-pantograph disconnector, although not very clearly shown in the figures 7 or 11.

Q.2-3 Are MOSAs nowadays reliable enough to be incorporated in GIS or MTS-equipment even for UHV? Conventional ITs seem to cause large technical design problems and high costs, when applied at UHV; can Participants reflect on the (dis)advantages of conventional versus non-conventional ITs? Similarly AIS disconnectors for UHV applications show very large dimensions; can manufacturers show how they reliable deal with these dimensions?

Simulation and calculation techniques

WG A3.20 "Simulations and Calculations as Verification Tools" presents Report **A3-210**, where a distinction is 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 are 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 shows the very good similarity between various simulation techniques for dielectric stresses. But, at the same time, these models do not converge to a single conclusion on the dielectric strength 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 checking whether at any moment, during the interruption process of a single pressure SF_6 gas circuit-breaker, the point of weakest dielectric withstand strength exists between arc contacts (as it should be) or between arc and main contact (to be disapproved). It would be interesting to know, for instance from test labs, whether such dielectric coordination problems occur less, since the introduction of more advanced simulation techniques.

A well-known example of simulation/calculation techniques, that are 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 are 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 are 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 regard such tools as very helpful in understanding the gas behaviour and in making relative comparisons. The tools are even useful to train young staff. Still, one may expect that the commercial available and/or homemade software packages are applied to assist and not to replace the well-experienced designer of the HV equipment.

Another position is taken in Report **A3-208**, where the authors try 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 is employed, and it seems to be a kind of "meta-tool" to manage parameter setting for sequential models in the process of optimization.

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) are given in Report **A3-209**. Contact erosion is determined for a situation of a shunt reactor circuit-breaker, experiencing re-ignitions. Re-ignition current and frequency are 4.1 kA and 560 kHz, respectively. In the Report the frequency of the re-ignition current has been mentioned, but the number of re-ignitions seems also to be important. It is not clear how the authors incorporated the number of re-ignitions in this or another model. It is also not evident how they extrapolate the endurance limit from these test results (figure 14).

Q.2-4 Can Participants reflect on the comparison/balance between the advanced, but complicated, simulation techniques available today (including the so-called "meta-tools") and the simpler, more straightforward methods based on long standing experience? For example, does an approach as described in Report A3-208 not lead so far from the intuitive understanding of engineers, that only the tools mentioned "comprehend" what is going on? This being the case, how are such processes overseen and verified by those responsible? Can the authors and other manufacturers explain to which degree nowadays such tools play a significant role (are advanced simulations, such as shown in the paper, dispensable, supportive or indispensable) and to what degree is knowledge/experience nowadays secured by such tools? What future development in this regard is foreseen?

Report **A3-205** describes 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 are reported. The capacitive voltage distribution is 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 is 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 is discussed, and it is stated that, especially for UHV arresters, the complete arrester housing including grading rings needs to be tested. Tests on individual housing units are not acceptable. For the tests the MO material should be replaced by adequate grading components. Figure 10 of Report **A3-205** shows that the external grading system (grading rings) reach down to the first intermediate flange. The distance between the ring and the flange could be critical and lead to flashover between the grading system and the flange. Further on big diameters of the external grading system may 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 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 4 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.

Q.2-5 Participants are asked to give their opinion on internal and external grading measures, on proper test procedures to simulate the natural grading by the MO-material, on the necessity of such tests and on the thermal stability issue with several MO columns within a single housing. How useful can simulation techniques be applied in these fields and are users willing to accept the simulation results?

Report **A3-207** as well as **A3-210** deal with the simulation of internal arcs. 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 prove that the exhaust phenomena behave differently for SF_6-gas in comparison to air, as illustrated by some figures in Report **A3-207** but the figures 7 and 10 show differences in the behaviour of the pressure relief, that is not straight forward understandable. Also the moment of pressure relief in the photographs of the figures 5 and 9 has not been clearly shown.

Q.2-6 Can experts from manufacturers side, users side and test stations bring forward how they evaluate the outcome from such simulations and simulated tests (like air for SF_6) and highlight examples of such evaluations? How do utilities see the importance of internal arc tests and how do they intra- and extrapolate the results from type tests to their particular situation? Can the authors explain some points that are not completely clear in their Reports?

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, is described in Report **A3-303**. The authors distinguish 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 present 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. The authors call their solution ARVT (anti ferro-resonant voltage transformer) and compare it with conventional inductive voltage transformers (by the authors called: “CVT”), especially in Table 1.

Optical CTs and VTs, Rogowski coils and capacitive dividers are dealt with in the Reports **A3-301, -304 and -308**. Despite the overwhelming advantages of such technologies (wide bandwidth, large dynamic range, compact and light, easy to handle electrically), all authors only address 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. The last application is based on high frequency current measurements, up to 100 MHz (**A3-308**) and for such applications a Rogowski coil is well adapted. The mechanism of the protection based on travelling waves is rather complicated; it is, for example, not clear why the first current wave after fault initiation is positive, where the reflection of a second wave from the fault location can be seen, how a wave reflected at busbar B can pass the fault location.

Q.3-1 The authors describe a number of niche applications, but what is the market penetration of NCITs for conventional applications (the normal installed base) and what is hampering an increasing share in the market? Are there significant technical performance issues (e.g. reliability, accuracy, dynamic range, drift, stability, EMI, weather impact, mechanical stresses) or are today’s issues more related to (lack of) service experience and aspects such as maintenance, modifications, replacement? Is there a need for frequent (on-site) re-calibration?

Q.3-2 Two special functions have been addressed in the Reports A3-303 and A3-308: mitigation of ferro-resonance and travelling wave protection, respectively. Participants are asked to give their opinion on and experience with mitigations of ferro-resonance and, when possible, with travelling wave protection.

A SAMU (stand-alone merging unit) is discussed in the Reports **A3-301, -304 and -306**. Opposite 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, but 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 is 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.

The authors of Report **A3-304** illustrate the development of sensors and interface equipment, as applied to an outdoor 170 kV GIS. Although this is a pilot project, the audience will be interested in future applications and aspects like reliability and redundancy (sensors, electronics, SAMUs and Ethernet devices) and environmental influences (weather, moisture, temperature and EMI-problems).

Q.3-3 The idea of a standardized output of a SAMU is the interoperability of different secondary equipment from several manufacturers. Can the authors and other experts on digital interfaces present the minimum requirements needed to ensure this operability? What is the experience of utilities? How deal utilities and calibration authorities with the accuracy requirements for metering, when such SAMUs are applied? How is dealt with the inaccuracy introduced by digitalization? How are users and manufacturers dealing with the topics mentioned before (reliability, redundancy, environmental influences, stability)?

Insulators

In Report **A3-305** the optimization of spacers in GIS is 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 is illustrated. In addition the authors describe how by the application of FGM (functionally graded material) similar results for an optimal field distribution can be achieved.

Two Reports (**A3-302 and -307**) deal with composite housings and bushings, the working area of WG A3.21. The advantages of such insulators are evident: less vulnerable to shooting, explosion safe, easy to handle, more compact, more reliable, 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 mention adaptation of the Standards with respect to the requirements for seismic performance, testing of empty housings in relation to the dielectric stresses of bushing applications, HVDC and UHV applications.

Q.3-4 The duration of life cycle and endurance tests is relatively short in comparison to the required service life, say 40 to 50 years. Which considerations allow experts to extrapolate their test experience to the design life and can Participants give service experience that does not support the conclusion that the ageing performance of composite housings and bushings is very good? Are countermeasures or techniques to reduce biological growth and deter gnawing by birds or rodents necessary and available? Can the authors explain which studies at this moment are undertaken to propose improvements to the Standards (pollution, biological growth, seismic performance, empty housings, HVDC, UHV)? Can experts inform the audience about developments in insulating materials, for instance with respect to nano-materials, FGM, etc.?

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) are 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 ago, an increase of ten to twenty percent in the average specific energy absorption capability can be seen. The analysis of the results show 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 reveal 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 are very high compared to the normally guaranteed energy values for MO surge arresters in the data sheets of the manufacturers. The research work was limited, for the time being, to the single impulse energy handling capability. As long as different types of impulses have been used the question comes up whether it may be possible to replace the various standardized impulses today with only one impulse for better comparability of published data referring to "energy". In the present IEC standards (IEC 60099-4) only the line discharge class gives information about energy handling capability. The line discharge class is used to calculate the energy input for the line discharge test and the operating duty test as well.

Q.3-5 What can be concluded from the derived values for the MO resistors to the performance of MO surge arresters in the system, where thermal stability is the main issue? What are the consequences of the failures modes to the users? Is it possible to give, derived from the results of the research work, a new definition for "energy handling capability"? How will a newly defined test impulse influence the existing tests in the actual IEC standard? Can Participants highlight experience with and developments in so-called "high grade" MOSAs?

FCL

FCL (fault current limiters) are 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 will be 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** gives some examples. With respect to this coordination, FCLs can be divided in three groups:

(1) the conventional FCLs, 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** is on the last category.

Q.3-6 Can the author or other experts of WG A3.16 explain the optimal coordination between category (3) FCLs and protection systems? Why is the application of a FCL as bus-coupler not discussed or is this a category (1) or (2) FCL? Can Participants inform the audience about the service experience so far with pilot projects and what applications of FCLs are foreseen? How is the co-ordination with protection systems arranged for these pilots?

A few last remarks from the side of SC A3 on working groups, not mentioned before:

- At the beginning of 2007, WG A3-12 "Circuit-breaker Controls" has published its final document as Technical Brochure 319
- At the end of 2007, WG A3.13 "Changing Network Conditions and System Requirements" has finalized its studies by the publication of two Technical Brochures (335 and 336)
- WG A3.18 "Operating Environment of Voltage Grading Capacitors applied to HV Circuit-breakers" has finalized its studies and the Technical Brochure will be published in 2008
- WG A3.19 "Implications of three-phase line fault TRV to Standards" has finalized its studies as well and the Technical Brochure will appear in 2008.

A last announcement: next year August a joint colloquium of SC A3 and SC B3 will take place in Sterrenbosch, near Capetown (Kaapstad) in South-Africa.