



**A3 - 00**

**GENERAL REPORT FOR SC A3  
(High Voltage Equipment)**

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The discussions of the 2010 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, Anton Janssen, by the Meeting Secretary, André Giboulet, and the Secretary of SC A3, Edelhard Kynast.

The wide scope of SC A3 led to 25 Reports, 66 prepared contributions and 13 spontaneous contributions during the Session. The origin of the contributions was from manufacturers (35%), consultants/testing organisations (11%), utilities (36%), CIGRE/IEC WGs (6%) and universities (14%). An average of about 300 experts attended the SC A3 Session. They contributed to the interesting exchange of experiences and points of view with respect to the three Preferential Subjects.

#### **Preferential Subject 1: Development in HV equipment to cater for increasing system demands**

- Increased transmission voltage (UHV).
- Increasing load current requirements for equipment e.g. facilitation of renewable and large generation site connections.
- Increasing fault current requirements for equipment.
- Limitations and developments in test techniques.
- Increased use of reactive compensation.

#### **Preferential Subject 2: Lifetime management of HV equipment**

- Effective assessment of end of useful life – analysis, testing & monitoring.
- Reliability assessment as a tool for lifetime management and as a driver for improved specification and design.
- Management of potentially over-stressed equipment pending replacement.
- Impact of environmental aspects.

#### **Preferential Subject 3: Prospects for introduction of new HV technologies**

- Fault current limitation.
- Vacuum for switching and/or isolation.
- Non-conventional instrument transformers.
- Prospects for application of new materials.

Six, nine and ten Reports were submitted for the three Preferential Subjects respectively (Report A3-103 has been withdrawn).

## **Preferential Subject 1**

### **Development in HV equipment to cater for increasing system demands**

Three out of six Reports were related to UHV (A3-104, A3-105 and A3-107), one Report referred to long Overhead lines (A3-101) and one Report dealt with increased short-circuit current levels and its

effect on TRV requirements (**A3-106**). In Report **A3-102** UHV, long lines and TRV requirements were addressed.

### UHV

On January 6<sup>th</sup>, 2009, in China, the worldwide first 1100 kV AC system has successfully been put into service. In this respect, one has to remember the 1200 kV system that has been operated in the former USSR from the mid 1980s until the early 1990s. Since then, enormous progress has been made in the field of insulation coordination by the introduction of high performance surge arresters, by the application of, for instance, pre-insertion (closing) resistors and opening resistors, and by the use of sophisticated transient simulation tools that have led to reduced margins in safety factors. These technologies have been applied to a pilot plant in Japan, to the system in China and will also be applied in other countries such as India (Report **A3-105**). The requirements put forward for UHVAC surge arresters are addressed in Report **A3-104**. In China, the first project consists of roughly 650 km single circuit OH-line with three substations which were built in either GIS or MTS (mixed technology switchgear) technology (Report **A3-107**). Other projects, incorporating double circuit overhead lines, will follow soon and, in China, a large number of UHVDC projects are also in progress.

In India both UHVAC and UHVDC projects are being planned (Report **A3-105**). Long distance transmission of bulk power from the North-Eastern Region (hydropower) and Central/Eastern Regions (coal fired power plants) to the load centres in the North, Western and Southern part of India will be mainly based on UHVDC connections with implementation planned from 2013. Long distance transmission from Independent Power Producers in the Western Region to the load centres in the extreme Western part of India and the Northern part is foreseen to be based on 1200 kV AC overhead lines. Basic specifications for the 1200 kV equipment are given in the Report including configuration of single circuit towers, insulation levels, surge arrester characteristics, creepage distance, short-circuit currents, physical clearances, circuit-breaker parameters, transformer characteristics. Attention is given to test facilities for design and development purposes (corona cage) and to a new facility, erected at the 420 kV Bina substation, for field tests. The latter consists of a short 1200 kV line, two 1200 kV bays and two transformer groups and will be put into operation in the middle of 2010.

The authors of Report **A3-105** paid special attention to TOV (temporary over-voltage) during an unsuccessful SPAR (single pole auto-reclosing) operation which is followed by a three-pole line tripping (see Figure 3 of the Report). The amplitude and duration of TOVS and the available short-circuit power are dominant parameters for the specification of arresters, especially the energy absorption capability in relation to the protection level. TOVs are caused by the occurrence of single or multi-phase faults, by the Ferranti-effect on long lines and by (ferro)resonance phenomena. As (ferro)resonance has to be avoided as much as possible, one would expect a correlation between system voltage variation, short-circuit power level and TOV amplitude. For example a high short circuit power leads to less voltage variation and lower TOV amplitudes and vice versa: higher TOVs occur at locations with a lower short-circuit power. The specified margin between the nominal and the maximum system voltage in Report **A3-105** (UHV) is only 4% whereas other users gave values in the range 5 to 10 %, and even 10% showed to be too small under certain EHV network conditions. The high TOV requirements for surge arresters seem to be contradictory to such small UHV margins on one hand and to the high energy absorption requirements for surge arresters on the other hand.

In Report **A3-104** the severe requirements for UHV surge arresters are described, as utilities rely on low protection levels of the surge arresters in order to limit the insulation levels and thus the dimensions and costs of UHV equipment. The impulse energy handling capability of surge arresters, however, is specified for the condition of high TOVs and a high short-circuit power. This inconsistency has not been addressed by the authors of Report **A3-104**, but they drew attention to the fact that for lightning impulse requirements users rely on a specification for UHV arresters of 20 kA only. This approach took into consideration the fact that there are at least two surge arresters to absorb the lightning impulse energy. In Report **A3-104** a lance is broken for a design with multiple metal oxide columns in a single polymeric housing. Operating duty tests for UHV arresters are very important but

are still under discussion within IEC TC 37 MT 4 with support from the work of CIGRÉ WG A3.17, that will publish its Technical Brochure soon, and with the new WG A3.25.

An expert warned for thermal instability during the operating duty test at higher ambient temperatures, especially for multiple columns in a single enclosure, and showed also how with multiple housings in parallel the voltage grading can be controlled by external grading capacitors. The authors of Report A3-104 drew attention to the experimental energy handling research program of CIGRÉ WG A3.17 and WG A3.25, where the main conclusion is that the higher the current density in the MO blocks, the higher the energy handling capability of the blocks. Extrapolation of test results on individual blocks to the reliability of whole arrester, consisting of about 1000 blocks (UHV), is basically impossible, but proposals to improve the long duration current impulse test to a test to verify the repetitive charge transfer rating will lead to a higher confidence in the arrester's capability to handle the impulse energy.

The authors also informed the audience that within IEC TC 37 MT 4 and MT 10, one had decided, not unanimously, not to introduce a term as "high performance" or "high grade" into the Standards, as the IEC Standards do not refer to the quality of the design and the production technology of individual blocks and/or other internal parts, but to the performance of the whole arrester, whatever technology (sophisticated or not) is applied. Two IEC documents on energy handling are now under discussion.

Switching overvoltages or SFO (slow front overvoltages) for UHV can be limited to about 1.7 p.u. as reported in Report **A3-104** and in the publications of WG A3.22 on UHV Equipment. The switching overvoltages and TRV (transient recovery voltage) are to a certain extent the result of reflection and refraction of travelling waves, as described in Report **A3-102**. A particular group of switching overvoltages relates to disconnecter switching, especially in GIS and MTS, where very fast transient overvoltages (VFTOs) occur (Report **A3-107**) due to the charging of very short pieces of busbar which generates very fast oscillating travelling waves. The amplitude of the VFTO is influenced by the trapped charge on the busbar and can reach values higher than the BIL. The trapped charge, a stochastic variable, depends on the dielectric design (including the SF<sub>6</sub>-gas pressure) and speed of the disconnecter. The effect is that for certain designs measures to reduce the VFTO level have to be introduced and for other designs no measures have to be taken.

VFTO due to disconnecter switching in GIS becomes a concern at the highest voltage levels, depending on moving contact speed, SF<sub>6</sub>-gas pressure and GIS configuration. Experts showed accurate simulations for several UHV substations, including MTS-installations. Apart from the peak value, that exceptionally may be higher than the BIL, attention was asked for the prevailing frequencies of VFTO that may resonate with transformer's Eigen frequencies (power and instrument transformers) and further high frequencies may cause EMC problems. Frequencies in GIS are about 10 MHz or more; while air insulated disconnectors provoke VFTOs with frequencies up to 1 MHz, which are not covered by a LI-test (Report **A3-207**). Based on a simulation of the interaction between system transients and power transformers, it is even questionable whether a chopped wave test covers these frequencies. Earlier studies (Report A3-301, 2004) indicated that the amplitude of such VFTO depends on the ratio of the load side capacitance and the source side capacitance.

#### **Long overhead lines**

Controlled switching of shunt compensated long OH-lines has been addressed in Report **A3-101**, a topic which is often discussed at the SC A3 Sessions. The authors presented a commercially available electronic device that can cope, in an advanced way, with a number of different conditions of shunt compensation, inter-phase coupling, mechanical scatter of the circuit-breaker, closing or re-closing, with/without fault, type of fault, type of voltage transformer, etc. By fitting Prony functions a series of voltage zeros are predicted and, by combining the prediction for the other poles, the optimum moments for a tripping command to each circuit-breaker pole is given. A back-up strategy in the case of failing algorithms is provided by the device as well. Numerous simulations and real field experience with both line and transformer energization were presented as proof the concept, although transformer energization needed further optimization.

Other experts pointed at the good experience with controlled switching also for shunt and filter banks switching and for transformer energization, an upcoming market. Controllers available now on the market, take into account the residual flux within the limbs of a transformer and adjust for parameters that influence the mechanical operation of the circuit-breaker such as temperature, hydraulic oil pressure, idle time, and auxiliary voltage. The benefits and good experience in service were stressed.

### **Increased TRV stresses**

Reports **A3-102** and **A3-106** both deal with TRV specifications. The authors of Report **A3-102** gave a review of travelling waves phenomena, related to switching conditions, based on their experience within CIGRÉ WG A3.13 “Changing Network Conditions and System Requirements” (Technical Brochures 335 and 336), WG A3.19 “Implications of three-phase line fault TRV to Standards” (Technical Brochure 408) and WG A3.22 “UHV Equipment” (Technical Brochure 362). Within WG A3.19 many discussions on fundamental issues around travelling waves took place and members found that a number of these issues have already been solved some decades ago. The value of studying older Reports and publications within CIGRÉ has been clearly demonstrated. In **A3-102** it is discussed which parameters have an influence on the surge impedances, what is the difference between the first and the last clearing pole, between single phase and three-phase faults, the impact of the mutual inductance from the other phases, etc. Clearing short and long line faults, out of phase switching, unloaded line switching and ITRV (inherent transient recovery voltages; i.e. travelling waves within a substation) are also treated. From the old literature it is known that the surge impedance experienced by the first clearing pole is smaller than that of the last clearing pole, but it is not widely recognized that the surge impedance “seen” by the single pole that clears a single phase fault current (SPAR) is identical to that of the first pole clearing a three-phase fault. The system conditions that lead to a TRV for the first pole to clear a 3-phase SLF that is more severe than the TRV of a standard single phase SLF, are very exceptional. LLF are in the meantime covered in the Standards by an adapted specification of the amplitude factor for T10 (in fact the old peak value of  $1.5 \cdot 1.53$  has been re-introduced by  $1.38 \cdot 1.76$ ). Another topic addressed is that of the discussion within WG A3.22: a circuit-breaker, when clearing a fault at a short distance, will be subjected to an ITRV at both terminals, thus a double side ITRV. Travelling waves at both sides of the circuit-breaker, as may show up in UHV AIS substations, will be covered by foreseen amendments to IEC Std 62271-100.

Experts from Japan illustrated, in Report **A3-106**, the high power requirements in the highly populated areas in Japan. These circumstances lead to shorter overhead lines, more cable connections, large power transmission substations and high short-circuit currents. Situations with high short-circuit currents and only a few overhead lines (thus a high RRRV: rate of rise of recovery voltage) are known from small substations at a short distance from large high power substations. Further, the longer the lines, the higher the TRV peak value that may be reached due to the longer travel time with steadily build up of TRV. The limited number of overhead lines in Japan is caused by the typically radial system structure rather than the meshed transmission networks known from other parts of the world. Radial systems tend to give positive reflections at the next substation, while meshed systems give no reflection or negative reflections.

In cable networks the TRV waveform will show a 1-cos shape, leading to higher values of the peak value, but with a larger time to peak. (Not addressed in **A3-106**, but because of the low initial RRRV the circuit-breaker will attempt to clear the current with a small arcing time/contact gap. Therefore the high TRV peak will appear across a relatively short contact gap.) The large power transformers applied in Japan give short circuit currents higher than 10% of the circuit-breaker rating, so that it was recommended to specify the severe TRV requirements of T10 (transformer limited faults) to a higher percentage as well (for instance for T30). A utility expert from Japan showed how by increasing the SF6-gas pressure the performance of a circuit-breaker can be slightly improved to cope with such conditions. Another interesting contribution was on the TRV amplitude reducing effect of the frequency dependence of the transformer inductance under secondary fault conditions.

## **Preferential Subject 2**

## **Lifetime management of HV equipment**

Two Reports gave failure statistics (**A3-205** and **A3-208**), two Reports used failure statistics to model future reliability (**A3-203** and **A3-206**), two Reports referred to life extension (**A3-201** and **A3-204**), two Reports addressed failures related to shunt reactor switching (**A3-202** and **A3-209**), and in one Report the effect of VFTO generated by air insulated disconnectors was dealt with (**A3-207**).

### **Failure statistics & modelling**

In the Reports **A3-205** and **A3-208** numerous failure data are given for 110 up to 750 kV equipment in Russia and 66 up to 500 kV equipment in Egypt, respectively. Information on failure cause, subcomponent responsible, effect of failure and different technologies was added too. In both Reports the number of failures is given, but no failure rates and hazard rates (failure rate over age of equipment: bath-tub curve). Also no distinction has been made between Major Failures (MF) and minor failures (mf). It is therefore difficult or even impossible to compare the figures with those of other countries. It is also difficult to make extrapolations to the future based on the bare figures given in the Reports. The additional information presented at the Session was still very scarce. Experts dealing with failure statistics are recommended to present results as MF and mf rates, with details per technology and preferably per age or group of ages. The international enquiries on the reliability of HV equipment, as conducted by WG 13.06/A3.06, form a good reference for the presentation of failure statistics.

Within WG A3.06 “Reliability of HV Equipment”, that conducted the 3<sup>rd</sup> international survey (the final results of which will be presented within one year) it has been discussed how to extrapolate results from a failure rate or hazard rate of the total population to another population. In a similar way, the authors of Report **A3-206** presented a method to transform the reliability results of a certain population of equipment to another population with limited reliability data. They applied the Bayesian Theorem to predict the failure rate of a new design of a circuit-breaker by using the available data from an older design and the limited data from development tests (reliability growth tests). In a further step they showed how limited early service experience with the new design can be used to better predict the general reliability in service. This second step, however, was only a simulated example, as the authors had to assume that a failure in service occurred.

Another example of the use of failure rate data was the investigation of the effect of a changed maintenance policy on the hazard rate (bathtub curve) of HV circuit-breakers, as presented in Report **A3-203**. By maintenance (including inspection, diagnostic testing and servicing) the staff will detect mf before they have developed into MF. Larger maintenance intervals may lead to more MF, as during the interval some mf have evolved into MF. To investigate the effect of larger maintenance intervals, the authors described two possibilities to estimate the propagation speed and the increase in MF rate: by the real mf hazard rate plus heuristic know-how on failure propagation or by fitting a generic stochastic function that predicts the real MF hazard rate from the real mf hazard rate. By either model it is possible to find the effect of increased maintenance intervals on the MF rate. The authors concluded that an increase of maintenance interval will always lead to a higher MF rate, but for the reliable lower voltage class circuit-breakers with spring operating mechanism the increase in MF rate seemed to be acceptable. At the Session, service experience was given, confirming the conclusion from the model, but warning to be careful when extending the maintenance intervals. Another conclusion was that inspection and monitoring methods have to be as simple and reliable as possible.

The theory behind both models is rather complicated and the authors just highlighted some aspects of their models. An important statement was that an accurate data handling and proper statistical model is essential for the confidence in the output.

### **Life extension**

Weibull curve fitting as a tool to find a hazard rate was also briefly mentioned in Report **A3-204**, where life extension of 50 kV oil-filled switchgear has been illustrated. A user platform has been established to share spare parts, tools, know-how, skills, data, information and policies. FMECA was applied to find the most critical spare parts and failure causes. Diagnostic tools were under development to detect and trace partial discharges in the bushings between the different compartments. Such policies and diagnostic techniques seem to fit well into the scope of a new SC A3 WG on “Deterioration of ageing substation equipment and possible mitigation techniques”. An example from Japan illustrated how by analysing deterioration phenomena of disassembled old equipment, the important components and their remaining lifetime can be assessed.

Another new WG, closely related with the ageing topic, is on “Impact of overstressing of substation equipment”. The adequacy of the short-circuit current clearing capability of old circuit-breakers (Report **A3-201**) is one of the examples to be considered. In Report **A3-201** the assessment of the short circuit current interruption ability of old air-blast breakers is given. However, the considerations are far from clear and certainly not widely accepted, although some formulas have been based on Technical Brochure 135. In order to assess the performance of old equipment, one has to verify whether the design has been type tested in accordance with the contemporary Standard, whether the actual circuit-breakers are identical to that design, whether the relevant parameters of the old breakers are still within the margins defined for new breakers, whether the requirements of the old Standard are still acceptable for the present location and application and, in case of overstressing, what evidence is available to prove that the old design can handle the overstress. Re-testing may be an option to verify the performance, examples of which have been given by experts from France and from Japan (on hollow insulators).

### **Shunt reactor switching**

Requirements for shunt reactor switching are nowadays given in, for example, IEC Std. 62271-110, where re-ignition is only allowed at the first current zero after contact parting and re-ignitions, if any, should take place between arcing contacts only. In Report **A3-202** re-ignitions through the nozzle and to a main contact was reported, while in Report **A3-209** external flashovers were described. In the latter case too large discrepancy in the opening times between poles (which should be less than 1/6 of a cycle) and between interrupting units of a pole (which should be less than 1/8 of a cycle) was mentioned as the cause of the flashovers across open units. The authors used simulations to show the effect of the discrepancy but they did not simulate current chopping and re-ignition phenomena, usually the cause of high amplitude transient voltages, as they were looking for the lowest amplitude of the voltage to explain the flashovers.

At the interruption of the shunt reactor current, current chopping can cause a high TRV peak at a frequency of some kHz or more. As the inductive current is small, SF<sub>6</sub>-gas circuit-breakers are capable of interrupting at small arcing times, thus stressing the small contact gap with the high TRV peak value. A re-ignition is probable and the shunt reactor will face a very steep overvoltage with an amplitude larger than the TRV at the moment of re-ignition (see also Report **A3-301**). Due to the travelling waves, high frequency resonance may occur inside the reactor windings, especially around the peak value of the TRV where the highest overvoltages are expected and may exacerbate risk of re-ignition taking place between other electrodes than the arcing contacts. Controlled switching (Report **A3-202**) is essential for shunt reactor switching, but how is the optimal arcing time determined, as too short arcing times will lead to a higher probability of re-ignitions, while long arcing times will give higher chopping numbers and a higher re-ignition overvoltage? Attention has to be given to a proper setting of the target arcing time, as a wrong setting will cause more harm than benefits. Depending on a number of parameters, typically an acceptable arcing window can be found, wider than the scattering of opening times. Otherwise, as an expert recommended it, the arcing time has to be set longer than a half cycle. A manufacturer stated that his controller automatically adapts the target arcing time when re-ignitions would prevail. Of course, it stays important to verify the mechanical operation time, including the pole and unit discrepancy.

For some designs of circuit breaker up to 145kV, no controller is needed; nevertheless even in that case, controlled switching may have some advantages for the endurance point of view (extended number of operation). The experience in service with controlled shunt reactor switching seems to be positive. IEC standard 62271-110 is under revision, to include the lower voltage classes. Moreover, there is a proposal to adapt the criteria to allow more re-ignitions.

## **Preferential Subject 3**

### **Prospects for introduction of new HV technologies**

In three Reports the developments around HV vacuum circuit-breakers (VCBs) were described: **A3-303**, **A3-308** and **A3-309**. Fault current limiters were addressed in three other Reports: **A3-305**, **A3-306** and **A3-307** (FCLs). The four remaining Reports were devoted to non-conventional instrument transformers (NCITs), **A3-301** and **A3-310**, to new grading capacitors, **A3-302**, and to composite hollow insulators, **A3-304**.

#### **HV VCBs**

In Japan numerous VCBs have already been applied at rated voltages of 72 kV and above: 3350 for transmission networks of utilities and about 5000 at industrial plants as reported in Report **A3-303**. As it has been reported that also in China many HV VCBs are in operation, SC A3 has established a new WG on “The impact of the application of vacuum switchgear at transmission voltages”: WG A3.27. The drivers for these developments seem to be the need for maintenance free equipment and to avoid the use of SF<sub>6</sub>-gas, known for its high global warming potential. However VCBs appear to have more advantages, as they are well suited for very frequent switching operations, are reliable, are constructed with non-flammable materials and produce less noise, due to the limited mechanical energy impulse. There are disadvantages as well, some of which can be reduced or mitigated as explained in Report **A3-303**: rated currents larger than 2.5 kA and short-circuit currents larger than 25 kA require extraordinary provisions, current chopping may cause high over-voltages, the long term reliability of the vacuum bottle is questioned and the phenomenon of NSDDs (non-sustained dielectric discharges) with its consequences is not yet completely understood.

The authors of Report **A3-308** pointed at the development, again in East Asia, of SF<sub>6</sub>-gas free switchgear installations for distribution and transmission voltages, including VCBs. Dry air under a pressure of several MPa in combination with 3-dimensionally optimized spacers allows for space requirements as small as achievable with SF<sub>6</sub>-gas technology (MV). A single break VCB for 170 kV with a strong axial magnetic field and multiple shields is still under development, but the first test results look promising. Similar technological achievements have been mentioned in Report **A3-303**. Capacitive current and out-of-phase switching still was quoted to be challenging and might be a reason to opt for a double break design. Re-strikes might also be prevented by improved travel characteristics and/or by the design and conditioning the contacts.

To Report **A3-309**, type testing of VCBs with a high short-circuit current rating or a high voltage rating requires special test circuit considerations. As the requirements for the RRRV are very tough for generator circuit-breakers (IEEE C37.013) and testing with the correct power frequency recovery voltage (IEC 62271-100) is very critical to MV and HV VCBs, KEMA had developed synthetic test circuits that can fulfil both requirements. In the Report it is stated that, in case of re-ignitions, re-strikes or NSDDs, the test circuits simulate the correct system behaviour (i.e. voltage) up to the moment of the dielectric breakdown. Further the authors pointed out that the arc-circuit interaction is completely different between VCBs and SF<sub>6</sub> technologies: SF<sub>6</sub>-gas arcs give an extinction voltage peak before current zero and almost no post-arc current, while VCBs show no extinction peak but a relatively large post arc current. Especially with SLF tests, where the arc-circuit interaction determines the correct initial TRV wave-shape, the vacuum arc behaviour hampers the proper response of the test circuit. Another test problem at synthetic testing is the application of a trick to prolong the arc, in order

to test the correct arcing window. Again, the interaction between the re-ignition circuits used for this purpose and the vacuum arc is completely different for VCBs,. Finally, the authors explained some unique measurements, useful at the design stage of VCBs.

### FCLs

“Guidelines and Selection of FCL” is the domain of CIGRE WG A3.23 and the FCL described in Report **A3-305** is certainly of interest for this WG. The principle of the new design is rather simple: a transformer with a short-circuited secondary side gives a relatively low impedance, that can be increased instantaneously by opening a fast opening switch at the secondary side. The opening switch is of the explosion type with a fuse in parallel. It is for single use only, so that more sets are installed in parallel, each activated by a fast closing device, in order to recover the original state and operated during consequent short-circuit cases. The required ratio between normal and FCL impedance is higher for bus couplers than for feeders and therefore the FCL transformer applied for an HV overhead line has no limb, while that in the coupling bay gets a limb. Examples of specifications are given.

Report **A3-306** deals with the interaction between a FCL and a differential protection system, as well as an inverse time protection. The behaviour of the protection systems were simulated in detail by means of an RTDS (real time digital simulator), that represented a simple MV network with a FCL, based on positive temperature coefficient resistors. Real protection devices were connected to the RTDS in order to get a realistic behaviour. Differential protection acted quite well and no extra time delay was caused by the simulated FCL, but the inverse time protection showed considerable extra time delay, depending on the actual short-circuit case. The authors recommended, by the way, to apply a combination of a FCL with a circuit-breaker to act as back-up for the FCL (and to protect the FCL).

Type testing of FCLs is rather difficult, as high power test stations, even the largest, do not offer enough power to test FCLs adequately, according to the authors of Report **A3-307**. Experts from test laboratories did not agree with this statement, at least for the examples given. They stressed that it is important to consider acceptance criteria, such as applied at short-circuit withstand capability test for transformers. Other experts showed examples for the application of FCLs at EHV levels, where unbelievable high levels of the short-circuit currents are foreseen: for instance 120 to 140 kA at 110 kV in the neighbourhood of Moscow. It would be interesting to know the details of such network configurations. Also, it would be interesting to know how new devices, such as modern windmills, contribute to the short circuit levels at lower voltage levels. New pilot projects for current limiting as well as new technologies have been presented at the Session.

At the initiative of the USA Department of Energy a new IEEE Task Force has been established in January 2009 to draft a guide on testing of FCLs. The Task Force acts in close cooperation with WG A3.23. By means of two examples of real FCL technology, the wide ranging discussions between manufacturers and users about the requirements were illustrated, thus showing the need for some guidance in this field. The Task Force will identify requirements from the application, from the technology, from the existing Standards (where applicable) and from the existing testing capabilities.

### NCITs

Since the SC A3 Session in 2004, the developments in the field of NCITs and their applications have been reported. The authors of Report **A3-301** have actively participated in the publications and contributions on optical instrument transformers: technological improvements to mature performance requirements (2004), benefits for calibration purposes (2006), advantages for special applications (2008) and suitability for high voltage testing (2010). In Report **A3-301** the good service experience since 2008 with portable live calibration sets for 550 kV CVTs in Canada is given, taking into consideration the high accuracy requirements on voltage measurements (amplitude and phasor angle) for the application in state estimators and PMU-measurements. Other examples of high voltage testing are the measurement of the very fast voltage and current patterns generated at re-ignitions during shunt reactor switching and voltage measurements at UHV levels. In both examples the voltage was not measured directly, but the electric field somewhere in the neighbourhood was determined. The optical

electric field sensor itself was calibrated by a voltage impulse at a lower amplitude, measured accurately with a capacitive divider. An author explained that such applications are common technology in the microwave and high speed telecommunication industry.

The authors of Report **A3-310** described the design, simulation and comparison of accurate current measurements for fast transients by means of a shunt and by means of a Rogowski coil. In the field of calibration of current measurements usually attention is given to standardized waveforms, like in Report **A3-310** and IEC 60060, but the calibration of high amplitude currents, that play an important role in high power testing (both power frequency and higher frequencies), gets less attention. From a high-power test laboratory the experience with the so-called round-robin test has been given. A new IEC Standard for such applications is under construction: IEC 62475 High Current Test Techniques.

### **New grading capacitors**

In Report **A3-302** a brand-new idea to achieve reliable and cost-effective grading capacitors was launched. Two concentric shields, each connected to one side of the interrupting unit of a circuit-breaker, form the capacitance across the contacts as well as the capacitance to the tank. By varying the dimensions of the shields, the ratio of these capacitances could be optimized. The most onerous situation for a proper voltage distribution between interrupting units is that with a short-circuit direct at one of the circuit-breaker terminals. For such a situation the authors elaborated the effect of the ratio between the capacitances. Research and development of this creative method of voltage grading was not yet fully completed and issues with a mechanical, dielectrical and/or gas-flow thermal nature still had to be solved or had to be proven to be solved.

To several experts the low capacity offered a better performance in case of Ferro-resonance and out-of-phase conditions (for the disconnecter annex to the circuit-breaker). As disadvantages they mentioned the lower RRRV performance (SLF) and the worse voltage gradient (in case of multiple units). According to the manufacturer these disadvantages could be mitigated by a proper design.

### **Composite hollow insulators**

The Technical Brochure of WG A3.21 “Aspects for the Application of Non-Ceramic Insulators to HV and MV apparatus” will become available in 2010. One of the physical properties addressed is the vapour permeability of composite hollow insulators. Extensive investigations in this field were published in Report **A3-304**. The insulators were composed of glass fibre re-inforced epoxy resins with a silicone rubber cover, that showed many advantages and, in fact, no known problems with respect to vapour permeation. But, as quantitative information was lacking, scientists in Germany have investigated the vapour permeation through the material in comparison to the vapour penetration along the metal flanges and along the metal-resin bounding. The mechanical stress on the insulator was expected to have a considerable impact on the vapour permeability, but remarkably no effect of any mechanical pre-stress on the samples could be found. Only at cycling load tests with extreme mechanical stress and high numbers of cycles some micro-cracking nearby the flanges could be detected, by means of helium tracers, but this could not directly be translated into an increase in vapour penetration. So far, the study confirmed the good service experience related to vapour permeation.

The overall good performance of composite insulators led for an expert to the conclusion that new tests should be adapted to the design and application (manufacturer’s design tests) rather than generally applicable type tests. Here, the Chairman of IECTC37MT4 made an exception for arrester applications. Another expert confirmed the conclusions of report A3-304 with respect to the low permeability that easily can be handled by an adequate amount of desiccant.

At the end of the Session the Chairman thanked the Authors, the Experts who contributed to the discussions, the audience and the Secretaries and Special Reporter for their input.