

**A3 - 00****SPECIAL REPORT FOR SC A3  
(High Voltage Equipment)**

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**Special Reporter**

For the SC A3 Session 2010 three Preferential Subjects have been selected and the total amount of submitted Reports is 25.

**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.

Six Reports deal with Preferential Subject 1, as Report A3-103 has been withdrawn.

**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.

Nine Reports have been accepted for Preferential Subject 2.

**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.

Ten Reports will be discussed.

The Special Report has been accomplished by contributions from the convenors of the Working Groups of SC A3.

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## **Preferential Subject 1**

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

Three out of six Reports are related to UHV (**A3-104**, **A3-105** and **A3-107**), one Report refers to long Overhead lines (**A3-101**) and one Report deals with increased short-circuit current levels and its effect on TRV requirements (**A3-106**). In Report **A3-102** UHV, long lines and TRV requirements are 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 are 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.

**Q.1-1 Can experts from China, Japan and India inform the audience about the progress and experience with their UHVAC pilot projects and what further system developments they expect? For example is the configuration of the overhead lines mainly single circuit or double circuit, what is the power rating and what will be the configuration of the towers and the way of transposition of the double circuit UHV lines?**

The authors of Report **A3-105** pay 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. 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. 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 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 draw attention to the fact that for lightning impulse requirements users rely on a specification for UHV arresters of 20 kA only. This approach takes 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.

**Q.1-2 The specified margin between the nominal and the maximum system voltage in Report A3-105 is only 4% whereas other users give values in the range 5 to 10 %. How can operators in the future deal with such small margins? Are the high TOV requirements for surge arresters not contradictory to such small margins on one hand and to the high energy absorption requirements for surge arresters on the other hand? In Report A3-104 a lack of experience on lightning discharges on UHV conductors (back flash-over or direct stroke) is mentioned. Can experts add experience and/or information on UHV lightning discharge currents, which for the moment have been specified to be 20 kA for UHV surge arresters; how do utilities determine the SIPL/LIPL and the discharge currents? Are Participants willing to share thoughts about energy absorption capability of surge arresters: multiple cage design versus a single hollow insulator design, new testing requirements and possibilities, necessity to apply multiple UHV surge arresters, reliability assessment for an apparatus with hundreds of metal oxide blocks and available evidence to convert TOV AC stress into impulse currents?**

**Q.1-3 A more general question is about terms which are used by some authors but which may be confusing to other experts. In particular the terms high performance MOSA, high efficient arresters, high grade MOSA are not defined in the Standards or elsewhere and a technical or scientific meaning is not well defined. Can Participants give their view whether a new definition should be introduced in the Standards and why? Would it be better to simply make a clear distinction between the ratings and design requirements for system voltage above, say 550 kV, and below 550 kV?**

Switching overvoltages or SFO (slow front overvoltage) 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.

**Q.1-4 Report A3-207 describes fast transients caused by an air insulated disconnecter. These transients seem to be a factor 10 slower than the VFTO in GIS. Moreover, GIS may be more vulnerable to VFTO than air insulated busbars. Can the authors of Report A3-107 or other experts explain the differences in appearance and severity of VFTO in GIS, in MTS and in AIS? Which substation or bay configurations give the most onerous VFTO? Are there other causes of VFTO? What is the experience and policy of utilities with respect to VFTO?**

#### **Long overhead lines**

Report **A3-101** deals with long lines and controlled switching of shunt compensated long lines is a topic which is often discussed at the SC A3 Sessions. The authors present 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 are presented as proof the concept, although transformer energization needs further optimization.

**Q.1-5 Shunt reactors are usually switched by a controlled switching device, but what about other switching cases such as transformers, overhead lines, compensated lines, shunt capacitor banks? What are the experiences so far and what is the general policy of users? Is controlled switching mature enough to take into account for insulation coordination purposes? Can participants inform us about aspects such as the application of NCITs, long idle times and remnant flux measurements?**

#### **Increased TRV stresses**

Reports **A3-102** and **A3-106** both deal with TRV specifications. The authors of Report **A3-102** give a review of travelling waves phenomena, related to switching conditions and they have been active 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. 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 subject to an ITRV at both terminals, thus a double side ITRV.

Experts from Japan illustrate, 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 is recommended to specify the severe TRV requirements of T10 (transformer limited faults) to a higher percentage as well (for instance for T30).

**Q. 1-6 Surge impedances applicable for transient studies differ from those for power frequency phenomena, where the positive sequence low frequency components are used (as erroneously**

applied in A3-201). Are participants willing to inform the audience about the difference, if any, between the surge impedance used for lightning impulse studies (A3-104) and for switching transients (A3-102)? Can the authors of Report A3-102 or other experts clarify what exactly the problem is with short- and long line fault clearing, as the equivalent surge impedance given in IEC Std. 62271-100 is for most cases too high, certainly under SPAR-conditions? What can experts contribute about the so-called excursion factor “d” at the line-side? Do users or experts from standardization bodies have an opinion on double side ITRVs? How are standardization bodies dealing with such information gathered by CIGRÉ WGs?

**Q.1-7** Radial transmission systems are also known for long distance transmission, but for high density areas the question is whether other countries face the same network topology as described in Report A3-106, and face similar TRV problems? Are the authors with their cable networks aware of problems with short arcing times? Do other utilities recognize a trend to more EHV cables and mixed cable-line sections? Severe TRVs, caused by transformer limited faults are recently under discussion within IEC and IEEE: can experts elaborate upon the developments within standardization bodies?

**Q. 1-8** A question of another nature: are there any suggestions how the know-how collected by many CIGRÉ WGs and published in Reports, Brochures, Électra-articles can be made more widely available and better known?

## **Preferential Subject 2**

### **Lifetime management of HV equipment**

Two Reports give failure statistics (A3-205 and A3-208), two Reports use failure statistics to model future reliability (A3-203 and A3-206), two Reports refer to life extension (A3-201 and A3-204), two Reports address failures related to shunt reactor switching (A3-202 and A3-209), and in one Report the effect of VFTO generated by air insulated disconnectors is 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 is 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. 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 present a method to transform the reliability results of a certain population of equipment to another population with limited reliability data. They apply 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 show how limited early service experience with the new design can be used to better predict

the general reliability in service. This second step, however, is 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 is 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 describe 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 conclude 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 seems to be acceptable.

**Q.2-1 Can the authors of the Reports A3-205 and A3-208 can give additional information on failure rates, preferably MF and mf? Did they compare their results with the information published by WG A3.06 and the former WG 13.06 and would it be possible to show for some equipment the hazard rate (bath-tub curve)? Can experts in the field of reliability data collection give some recommendations?**

**Did the authors of Report A3-203 take into account teething failures due to erection and/or maintenance? What percentage of the failures show a random characteristic and what is the effect of random failures on the analysis? Maybe the authors can explain the transition from figure 1 to figure 5 and figure 6, especially for type D circuit-breakers? What are the dominant mf modes, to which MF-modes do they evolve and what is the propagation time? Are other experts dealing with statistical analyses to support maintenance decisions and can they provide examples?**

**Q.2-2 To apply Bayesian Theorem is not straightforward unless one relies on software packages. Can the authors of Report A3-206 or other experts comment to this statement? The 50% percentile of the survival function R(t) seems to have been used as a definition of the expected life, a value also known as the B-life: B-50. It is more usual to apply values such as B-10 or B-5 to decide about replacement of all assets so can Participants give their policy with respect to replacing an asset population with a certain percentage of completely failed equipment?**

### **Life extension**

Weibull curve fitting as a tool to find a hazard rate is also briefly mentioned in Report **A3-204**, where life extension of 50 kV oil-filled switchgear is illustrated. A user platform has been established to share spare parts, tools, know-how, skills, data, information and policies. FMECA is applied to find the most critical spare parts and failure causes. Diagnostic tools are 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”.

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 are 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 were 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.

**Q.2-3 The classification to find the most critical components (A3-204) looks rather arbitrary: the parameters (for the probability) as well as the method of numbering/adding/multiplying. Did the authors use a sensitivity check? Can experts show how they validated the methodology used for ranking purposes or is the general opinion that a hands-on approach is to be preferred above a more academic approach? What, in general, are the requirements for the application of diagnostic techniques: success-rate, economics, interval of measurements, safety? Are participants willing to share experience with life extension and life management? What policy is recommended by the participants with respect to the assessment of the performance of old HV equipment and/or how stressing beyond the former Standards can be judged?**

#### **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 is reported, while in Report **A3-209** external flashovers are 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) is mentioned as the cause of the flashovers across open units. The authors use simulations to show the effect of the discrepancy but they don't simulate current chopping and re-ignition phenomena, usually the cause of high amplitude transient voltages.

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, 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.

**Q.2-4 Can the authors of Report A3-209 or other experts involved explain why current chopping and re-ignitions are not considered? Controlled switching (Report A3-202) seems to be essential for shunt reactor switching (see also Q.1-5), 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? What is the experience with opening resistors in this respect? What diagnostic test techniques or monitoring techniques are applied to detect re-ignitions? What is the experience with type tests?**

#### **VFTO in AIS**

As mentioned under Q.1-3, VFTO due to air insulated disconnector switching are blamed in Report **A3-207** for the dielectric failure of a current transformer. The VFTO frequency of about 1 MHz seems to match the natural frequency of the current transformer which that is of a primary bar live tank type.

**Q.2-5 The configuration described is quite normal in air insulated substations. From a statistical point of view, dielectric failures of current transformers due to disconnector switching are not widely recognised. Can participants give their view? Are experts of the opinion that current transformers should be designed and type tested for VFTO in addition to the lightning impulse test or, conversely, is the concept of VFTO used to explain more fundamental weaknesses in the design or production of current transformers?**

## **Preferential Subject 3**

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

In three Reports the developments around HV vacuum circuit-breakers (VCBs) are described: **A3-303**, **A3-308** and **A3-309**. Fault current limiters are addressed in three other Reports: **A3-305**, **A3-306** and **A3-307** (FCLs). The four remaining Reports are 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 driver for these developments seems to be 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, require virtually no maintenance, are constructed from 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 extra-ordinary 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** point 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 is quoted to be challenging and may be a reason to opt for a double break design.

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 have 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 up to the moment of the dielectric breakdown. Further the authors point 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 explain some unique measurements, useful at the design stage of VCBs.

**Q.3-1 Can the authors or other specialists explain the arcing window of HV VCBs (e.g. why is arc prolongation required) and the criticality of SLF tests for VCBs (e.g.why is time delay required)? What hampers the possibility of single phase direct tests on HV VCBs and what about the sensitivity of HV VCBs for three-phase testing in comparison to single phase testing? Are the NSDDs, when they occur, correctly reproduced by the test circuits described? What do the authors of Report A3-309, despite the increased complexity of the test circuit, see as the main advantages of producing the correct recovery profile?**

**What can the authors of the Reports A3-303 and A3-308, or other participants, contribute regarding the design and performance of HV VCBs with respect to capacitive current switching? Is there any information available on the experience with a relatively large number of shunt capacitor bank vacuum switches, especially HV switches, widely used, for instance, in the USA?**

**Is the concern of users with respect to current chopping and associated over-voltage generation, NSDDs and long term reliability justified? Are VCBs more reliable mechanically than their SF<sub>6</sub> technology counterparts?**

**Why is SF<sub>6</sub>-gas free switchgear predominantly developed in East Asia and not in Europe or in the USA?**

### **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 operate 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 are simulated in detail by means of an RTDS (real time digital simulator), that represents a simple MV network with a FCL, based on positive temperature coefficient resistors. Real protection devices are connected to the RTDS in order to get a realistic behaviour. Differential protection acts quite well and no extra time delay is caused by the simulated FCL, but the inverse time protection shows considerable extra time delay, depending on the actual short-circuit case. The authors recommend, by the way, to apply a combination of a FCL with a circuit-breaker to act as back-up for the FCL (and protect also 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**. 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 are 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.

**Q.3-2 There is quite a difference with respect to the capabilities of test laboratories when comparing three- versus single phase tests (usually a factor 0.57 instead of 0.33), or the inherent apparent power required (circuit-breaker testing) versus optimal power transfer (transformer), or required for power frequency phenomena versus transient phenomena (Report A3-309). Maybe testing authorities can reflect on their capabilities? Regarding the experience with testing the short-circuit withstand capability of transformers, the criteria to be fulfilled have proven to be very critical: does the Task Force take into account criteria to assess the performance of the**

**FCL? Are participants with experience in testing and/or applying FCLs willing to share their views?**

**Q.3-3** The authors of Report A3-306 refer to the increasing penetration rate of windmills that could considerably contribute to the short-circuit current. However, modern windmills, especially the large ones, are of the variable speed type in order to extract as much energy as possible from the wind: the double fed induction generators (DFIG) or synchronous generators with a full converter. Both types will reduce the short-circuit current to a little above the rated current. What is the opinion and experience of the audience with the contribution of wind mills and wind farms? What is the influence of such technologies on the behaviour of protection systems?

**In Report A3-305 the concept of FCL devices for HV networks is described. The authors refer to situations where the prospective short-circuit current is larger than 63 kA. Under which conditions in 110 kV networks do the authors foresee short-circuit current larger than 63 kA and to what level should it be reduced? What unacceptable short-circuit levels do other utilities foresee in their HV and EHV networks?**

### 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 is not measured directly, but the electric field somewhere in the neighbourhood is determined. The optical electric field sensor itself is calibrated by a voltage impulse at a lower amplitude, measured accurately with a capacitive divider.

The authors of Report **A3-310** describe 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.

**Q.3-4** Electric field measurements as substitute for direct voltage measurements can be made by optical technologies, as proposed in Report A3-301, or by more conventional technologies. Are testing experts applying the optical or conventional field measurements? What is their experience and range of applications (diagnostics as described in Report A3-309, research as described in Report A3-301, type testing)? The authors of Report A3-301 point at the critical length of the sensing fibre head, when measuring currents in the MHz-range (figure 5), but the shorter the length the lower the degree of polarization. Maybe the authors can explain the limits of optical fibre technology in this respect? WG A3.15 “Non-conventional Instrument Transformers” is about to publish its Technical Brochure and is asked to illustrate their view on the application possibilities of NCITs, and calibration issues. Can experts contribute to the state of the art with respect to the “round robin” calibration test for current transformers, as applied for high power laboratories?

### New grading capacitors

In Report **A3-302** a brand-new idea to achieve reliable and cost-effective grading capacitors is 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 can 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 elaborate the effect of the ratio between the capacitances. Research and development of this creative method of voltage grading is not yet fully completed and issues with a mechanical, dielectrical and/or gas-flow thermal nature still have to be solved or proven to be solved.

**Q.3-5 The capacitances will be much lower than those of conventional grading capacitors. Can the authors and other participants elucidate the effect of much lower grading capacitances and whether the capacitors, in that case, cannot be omitted? What will be the effect for other phenomena, such as SLF performance, ferro-resonance, disconnecter duties, VFTO, reliability of circuit-breaker?**

#### **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 are published in Report **A3-304**. The insulators are composed of glass fibre re-inforced epoxy resins with a silicone rubber cover, that show many advantages and, in fact, no known problems with respect to vapour permeation. But, as quantitative information is 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 cannot directly be translated into an increase in vapour penetration. So far, the study confirms the good service experience related to vapour permeation.

**Q.3-6 As the mechanical load is expected to be the most critical parameter, what is the opinion of experts to introducing a type test with cycling mechanical load into the Standards? Is there any further experience with cyclic load and/or leakage, that may contribute to establishing the level and the number of cycles, when necessary? What is the expected life duration of hollow composite insulators (WG A3.21) and how will that possible age influence the requirements for endurance type tests?**

Experts who wish to contribute to the SC A3 Session are kindly asked to send their prepared contribution to the Special Reporter before **August 10<sup>th</sup>, 2010**, in order to check whether and where the contributions fit into the program. It will be difficult to accommodate prepared contributions that are received after August 10<sup>th</sup>.

Contributors will need to contact the Chairman and Special Reporter of SC A3 on the day before the Session (i.e. on Monday, August 23<sup>rd</sup>) at a location in the Palais de Congres, to be announced by CIGRÉ Central Office.