For the SC A3 Session 2012 three Preferential Subjects have been selected and a total of 22 Reports were submitted.

**Preferential Subject 1: Equipment design to facilitate network developments**
- Design and testing of equipment for HVDC networks
- Role of intelligence within equipment
- UHV
- Impact of changes in AC network design and operation.

Ten Reports have been discussed for Preferential Subject 1, (Report A3-105 has been withdrawn).

**Preferential Subject 2: Reliability and lifetime of HV equipment**
- Experience and trends in reliability of HV equipment
- Prediction and management of end of life due to age and/or potential overstressing
- Role of condition monitoring and assessment.

Six Reports have been discussed for Preferential Subject 2.

**Preferential Subject 3: Environmental suitability of HV equipment**
- Design to minimise environmental impact
- Design and testing for extreme ambient conditions (temperature, seismic levels, pollution, …)
- Design for offshore/marine environments.

Six Reports have been discussed for Preferential Subject 3.

The Chairman, Mark Waldron, opened the Session with a presentation of the present state of the Study Committee and an introduction of the Special Reporters, the SC A3 Secretary and the Session Secretary André Giboulet, who also coordinated the next day’s Poster Session.

During the Session experts delivered 67 prepared contributions and 35 spontaneous contributions (including both questions and answers). The figure shows the origin of the prepared contributions.
The discussions around the topics of the Preferential Subject 1 and 3 have been guided by Anton Janssen, while Ankur Maheshwari conducted the discussion for Preferential Subject 2.

**Preferential Subject 1**

**Equipment design to facilitate network developments**

Equipment design for Ultra High Voltage (UHV) applications is addressed in four Reports, two for UHV DC applications (A3-104 and A3-111), two for UHV AC applications (A3-106 and A3-110). Further reference to UHV is made in A3-303, composite hollow insulators, and in A3-203, a simulation tool to design arcing chambers. In A3-109 the design of a tool to investigate the arc model parameters required to simulate current interruption by HVDC circuit-breakers is explained. Transformer limited faults (TLF) are the topic of the Reports A3-107 and A3-108.

In Report A3-101, the design of a vacuum circuit-breaker (VCB) for HV networks is described: VCB’s applied for shunt capacitor bank switching are discussed in Report A3-201, whereas another alternative for HV SF$_6$-gas technology is elaborated in A3-302. The environmental aspects were covered under Preferential Subject 3.

In the remaining Reports for Preferential Subject 1 a new method to test oil insulated equipment for explosion safety (A3-102) and the development of short-circuit currents in the Netherlands (A3-103) are given.

**UHV**

In China the developments in UHV AC and DC networks are considerable. The authors of Report A3-104 paid attention to the investigations of switching impulse flashover voltages across long air gaps at high altitudes. They applied their findings to phase to earth clearances in ± 800 kV DC OH-lines. Test results from test stations at an altitude of 4,300 m, of 2,254 m and of 50 m were compared. The 50% flashover voltages across the gaps in a typical tower head with clearances ranging from 4 m to 11 m were collected. The results were plotted against 50% flashover voltages calculated to several standards, including IEC 60071-2. They concluded that the approach detailed in IEC 60071-2 gives a too conservative outcome.

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The results may give a contribution to the discussions on the IEC procedures of altitude and atmospheric correction but no exact conclusions for any further standardizing work can be figured out from the description of the results and the proposed approach. Test results with more details should be given to the relevant IEC or CIGRE committees for an in-depth discussion. For such details and procedures the authors referred to Chinese references and standards which unfortunately are not very accessible to the interested readers from abroad. Experts pointed at the application boundaries of IEC 60060 with respect to gap length, gap factor and altitude; boundaries which are not explicitly stated in the Standard, unfortunately. The test results as presented in Report A3-104 for long gaps and high altitudes, though, match quite well with the results of similar tests performed some decades ago. Another aspect, not to be overlooked, is that with IEC 60060 a generally applicable formula has been introduced, that inherently involves relatively large margins, as that is the only way to catch the physical reality with many complicate factors (e.g. gap condition, insulators, air density).

On the question about the difference in insulation co-ordination between HVAC and HVDC, experts answered that despite the fact that the towers of DC-lines are differing from those of AC-lines, lightning impulse levels are similar. Switching impulse levels are different, whereas the time to crest is especially relevant for HVAC-applications. The standardized time to crest is specified as 250 μs, while for UHV times of 1000 to 3000 μs were mentioned. Experts stated that there is not much difference in the stress-level for higher times to crest for many applications. The bias voltage can be neglected for HVDC; in fact, the positive space charge due to the positive HVDC bias voltage has a positive rather than a negative effect on 50% flashover voltages.

A contributor stated that at high altitudes the flashover voltage of polluted insulators will decrease due to lower temperatures, but this effect is compensated by the air pressure at higher altitudes, which is not clear from his presentation where the pollution flashover voltages decreases with lower pressure. Therefore, another expert immediately pointed at old test results from, for instance, Russia and China, that showed no cancellation effect at all.

EHV and UHV applications of composite insulators used as busbar supports or as insulators of disconnectors are described in Report A3-111. The emphasis is on a hollow type support insulator designed for UHV DC in China. The specifications for the mechanical and dielectric behaviour of the UHVDC disconnectors and their dimensions are given. The insulators are filled with N₂/SF₆-gas, at the higher voltage classes, or with foam, at lower voltages to limit the water vapour accumulation inside the hollow space. Tests have been performed to study the dielectric effect of inadequate adhesion of the foam to the interior of the composite tube, the effect of defective sealing between flange and tube and the effect of long term water vapour permeation. Flashovers only occurred at the outside of the insulators, none at the inside.

At the SC A3 Session in 2010 in Report A3-304 an extensive study on composite hollow insulators has been presented. One of the remaining questions was on cyclic mechanical stresses, as a high number of mechanical cycles could harm the strength and tightness of the composite insulators, especially at the junction between insulator and flange. The authors of Report A3-111 were aware of this CIGRÉ Report and showed the endurance stresses applied to the post and disconnector insulators, especially with respect to the torsional (rotating) movement of the contacts. The endurance levels, given in the 2010 Report are, by the way, extremely high.

In Report A3-106 the authors from India showed the design, manufacturing and type testing of a 1,200 kV AC capacitive voltage transformer (CVT). The CVT has been installed at the national 1,200 kV test station. The specification is for an air insulated 1,200 kV substation. The authors paid special attention to ferro-resonance stability, temperature stability of the internal insulation as required for the measurement accuracy, the dielectric stresses due to SI and LI, and the electrostatic field distribution along the impressively tall structure. They referred to dry SI (1,800 kV), dry LI (2,400 kV) and chopped LI. They obviously applied porcelain type insulators.

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In Report A3-106 the authors did not refer to very fast phenomena, such as VFTO (very fast transient overvoltages), despite the fact that at the SC A3 Session 2010 attention has been asked for VFTO in air insulated substations (AIS). At the 2012 Session they explained that the capacitance of the CVT, 2000 pF, prevents electrical overstress due to switching operations of disconnectors. Another expert brought forward that VFTO are not an issue in air insulated substations, but publications about disconnector switching in old Russian air insulated substations (787 and 1150 kV) showed severe problems.

VFTO are a potentially serious problem for UHV GIS, where frequencies a factor ten or more higher than 1 MHz as generated in AIS may be present. A number of CIGRÉ WG’s are dealing with VFTO and the authors of A3-110 are involved in these investigations. They presented various methods to reduce the amplitude of VFTO, among which are the adaptation of the GIS configuration, of the disconnector design including its speed and of the substation technology (AIS, GIS, Hybrid). A possible solution to damp VFTO amplitudes is formed by a high frequency electromagnetic cavity resonator, arranged around a GIS conductor. Potentially by adding an external resistor VFTO’s can be damped, but further investigations are needed to optimize the resonator and to see its overall effects and applicability. Another solution to damp VFTO is installing ferrite rings around the GIS conductors. Several types and configurations have been implemented in an experimental test set-up, but the effectiveness is shown to be limited due to the fast saturation of the ferrite material. Within SC D1 a WG is proposing an insulation co-ordination procedure with a co-ordination factor $K_c$, a safety factor $K_f$ and a test conversion factor $K_{tc}$, which together will give a total factor of 1.15.

One expert showed that with three-phase enclosed GIS, the residual charge on a bus section, that has been switched off, could be larger than 1.0 pu, due to inter-phase coupling. More severe VFTO may be expected, but the application of three-phase enclosed GIS is not foreseen at the highest voltage levels were VFTO play an important role.

Arc model parameters

Report A3-109 addressed the development of HVDC circuit-breakers as a combination of very fast acting power-electronic devices and low loss mechanical devices. DC current interruption by the mechanical circuit-breaker requires a forced current zero, for instance by a resonant circuit. As the current amplitude and current gradient will be completely different from that with AC circuit-breakers, and to a certain extent can be freely chosen, the parameters for the arc models show different interrelationships. The authors’ aim was to determine arc parameters that enable modelling of arcs in DC breakers. A novel unipolar arbitrary current source has been proposed, consisting of a three-level inverter with special controllers to shape arbitrary current waveforms. The proposed system has been simulated, showing good results, and a proto-type of such a current source has been designed. The authors should be complemented for the design (though not yet proven) of this innovative solution.

In comparison to some decades ago, the need for HVDC circuit-breakers seems to be more urgent. At the same time the requirements for such devices have become very stringent with respect to the fault clearing time. Conventional circuit-breakers alone cannot fulfil these requirements and very expensive solutions come in place. It is difficult to understand all these developments that influence each other: Less expensive converter technologies force more expensive circuit-breakers in meshed HVDC networks; the design of a meshed HVDC network depends on the type of converter and breaker; HVDC circuit-breaker requirements depend on type of converter and the design of the HVDC network.

Experts showed that in future HVDC-networks HVDC circuit-breakers have to clear fault currents within a few ms, depending on network topology and location of the fault. Very steep raising fault currents are expected as well as stability problems in the network, when faults are not cleared fast enough. Examples of technological solutions for breakers with a clearing time of some tens of ms have been presented, but these do not fulfil the fore-mentioned (most onerous) requirements. In order to come to a technical-economical more optimal implementation of HVDC grids, a co-ordinated design

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of all involved equipment is required. To achieve such a design the responsibilities of all parties have to be shared and netcodes have to be adapted. One expert brought forward that it could be wise not to apply meshed HVDC networks in order to simplify the requirements.

Other switchgear of a special nature has been presented: MRTB (commutates return current from earth electrodes to metallic conductors) and GRTS (commutates return current from conductors to earth).

**TLF**

With respect to transient overvoltages, transformer experts are mainly interested in the high frequency voltage distribution across the coils and windings inside the transformer, whereas circuit-breaker specialists have a main focus on the transformer response at its terminals. Usually the transformer experts, as those of WG A2/C4.39, consider transformer models for the highest frequencies, as excited by lightning impulses or VFTO (some up to tens of MHz). Circuit-breaker experts, though, look for transformer models to simulate switching over-voltages with frequencies from some tens of kHz up to hundreds of kHz. Beside the much simpler transformer model they have to include the electrical environment as well: Connections between circuit-breaker and transformer, attached equipment as CTs, MOSAs, post insulators, maybe CVTs or PTs.

Transformer limited faults (TLF) occur when a transformer feeds a short-circuit current to a fault behind the circuit-breaker, that has to clear the fault current, or when a circuit-breaker has to clear a fault current for a fault behind a transformer (at the other side of the transformer). In both cases, the transformer impedance will be the dominant factor in determining the short-circuit current’s amplitude and the TRV (transient recovery voltage across the breaker terminals) will be determined by the transformer’s characteristics. The authors of the Reports **A3-107** and **A3-108** use several methods to extract the dominant parameters that represent the transformer transient response. Among others they use an FRA-measurement of the transformer under investigation.

By means of representative RLC-circuits as well as by a pure mathematical approach, called vector fitting, the authors of Report **A3-107** demonstrated that it is possible to get a reasonable good fit for the multiple resonance responses measured by FRA (in the frequency band of interest). The TRV calculated with a simplified single or double frequency model however deviates considerable from that calculated by inverse Fourier transform from the FRA-measurement. With these transformer models the authors simulated the clearing of faults at several locations in an actual substation and showed that for the three models the TRVs calculated in the time domain differ more than expected. As their contribution to the Session they stressed the difference in TRV waveshape, depending on the windings involved in the fault. They used as an example a three winding transformer as applied to connect power plants, with a fault at the terminals of one winding, of the other winding or of both windings.

The authors of Report **A3-108** took several very large three winding transformers of different designs and makes: 525/275/63 kV, 1500 MVA. 3-Phase faults at each side have been simulated, based on FRA-measurements performed at each side and also on a manufacturer model of one of the transformers. Reasonably good agreement has been found between rather simple single and double frequency response models and the FRA-measurements and TRV-measurements (by the capacitor current injection method), although the amplitude factor for the double frequency response is less accurate. The authors explained how the interaction between the two frequencies has a large influence on the amplitude factor. Similar effects can be seen with the manufacturer’s multi mesh model versus the lumped transformer model. Without considering any physical losses, with a double frequency model or multi-mesh model the amplitude factor is reduced to about 1.7 (instead of 2.0).

Both Reports are important for WG A3.28, Switching and Testing of UHV & EHV equipment, that is studying the TRV requirements for TLF between 100 and 1200 kV. Experts showed the accuracy of the different methods to estimate the TRV characteristics and also the difference in TRV between the first, second and last fault clearing pole. The developments in the Standards have been highlighted.
VCB technology
During former SC A3 Sessions the development and application of VCBs (vacuum circuit-breakers) for sub-transmission voltages have been discussed. Based on such publications, SC A3 has established WG A3.27, Vacuum Switchgear, to study the impact of HV VCB applications on the network and circuit-breaker specifications. The authors of Report A3-101 described the development of a live tank 3-phase operated VCB with a rated voltage of 72.5 kV. It is equipped with a common drive system and a single break per phase. In closed position, the operating mechanism has to give enough contact pressure in order to prevent overheating. As the dielectric strength outside the vacuum unit is less than the inner strength, due to the relatively small dimensions, the outer insulation along the vacuum unit (mostly porcelain) contains nitrogen. For many users, as it is clear from an enquiry of WG A3.27, the (claimed) very high electrical and mechanical endurance of vacuum breakers is seen as a clear driver for application of vacuum for sub-transmission voltages in frequent switching applications, such as for shunt capacitor-bank and/or shunt reactor switching.

The dielectric strength at clearing currents and in the open position are critical design limitations of VCB technology, as can be seen with capacitive current interruption; see also Report A3-201. For that reason in some designs multiple breaks are applied. Experts draw attention to out-of-phase conditions and capacitive current switching, especially under back-to-back conditions, which are most onerous for VCBs. This topic has been addressed under Preferential Subject 2.

The type of VCBs described in Report A3-101 has been installed at several substations in France, but not for applications with shunt capacitor banks. To the question from the audience whether special monitoring equipment has been installed to evaluate the performance of the VCBs, the authors answered denying. To the question whether X-rays are a problem when applying VCBs at 72.5 kV, the convenor of CIGRÉ WG A3.27 answered that such aspects are covered by standards and that the according measurements are under investigation.

Explosion safety
In Report A3-102 Russian experts explained an alternative method to test the explosion safety of oil filled equipment, in this case CTs. Instead of destructive tests in a high power laboratory, they have developed a type test technique by using explosives. The problem was to find a method to control the chemical reaction in such a way that the relatively slow pressure build-up coming from an electrical arc will be followed. The authors applied an impulse jet of powder gas (JPG) as an arcless source of the pulse pressure. In order to prove the behaviour of the paper/oil containment and its relief device during the pressure rise, sometimes water instead of oil has been used. In the Report the explosion safety test on several types of CTs (110 to 330 kV) is described. Prototypes of protection devices to prevent explosions are discussed as well.

In the past, experience with arcless tests were less successful in France, where a nitrogen driven pulse in water has been used. In the same contribution experience with explosions of instrument transformers was given. CIGRÉ WG A3.24 compared the proposed technology with the possibility to apply it for other equipment, not insulated with oil.

Short-circuit currents
At earlier CIGRE Sessions publications and contributions dealing with an increase of the short-circuit current levels and DC-time constants have been presented. There is a wide interest in fault current limiters (The Technical Brochure of WG A3.23 will be published soon), although the application at higher voltages is still very premature. In Report A3-103 the development of short-circuit currents in the Netherlands was addressed. The authors paid attention to the developments in the transmission network (420 kV), in sub-transmission systems (170 kV) and in distribution systems (12 kV). Also, the trend of increasing short-circuit current amplitudes during type testing at KEMA’s laboratories
was shown. The new WG A3.30 will pay attention to overstressing of existing equipment, including overstressing due to higher short-circuit currents, higher DC-time constants and more severe TRV requirements.

Sustainable energy and integrated markets lead to more electricity, more power generation capacity, more interconnections and more transformers. In Report A3-103 the development of the statistical distribution of prospective short-circuit currents over the years (420 kV) has been given, as well as the development of the number of interconnecting transformers. As a larger part of the short-circuit current will be fed through interconnecting and/or step-up transformers, the trend in DC time constants is also upwards. Countermeasures were discussed: Split networks, split busbars, operate transformers in hot stand-by mode. The authors described a special case being the modification of circuit-breakers to withstand the higher DC-time constants, proven by limited type tests. At the distribution level the impact of larger transformers, the (over)loading of transformers and the influence of dispersed generation have been highlighted. The fault current contribution by power-electronic devices (HVDC converters, DFIG and windmill generators with full converters) is usually limited as has been illustrated by some examples.

One of the factors that play a role in the increasing level of prospective short-circuit currents is the increased uncertainty around power generation developments. Transmission System Operators and Distribution System Operators apply extra margins to cover future developments, and in addition they apply mutually margins as well. The uncertainty influences the RMS-value as well as the DC time-constant. Other utilities face similar problems, especially close to power plants. Attention has been asked for large DC-time constants near power plants in combination with missing current zero’s. A structural way to evaluate on a regular base such and other foreseen stresses on HV equipment has been presented by the convenor of WG A3.30.

It has been announced that soon IEC Technical Report 62271-306 will be published, the application guide for IEC Standard 62271-1 and 62271-100. In this application guide guidelines how to deal with large DC time-constants are given.
Preferential Subject 2

Reliability and lifetime of HV equipment

Reliability and life time management of HV Equipment has been covered in six Reports.

- One Report (A3-203) discussed computer simulation tool for the design and optimisation for UHV SF$_6$ circuit breakers.
- Three Reports discussed life time management including impact of stresses, reliability and maintenance optimisation techniques. Report A3-201 discussed stresses on circuit breakers due to switching capacitor banks with very high in-rush current, Report A3-202 discussed techniques for end of life estimation and optimisation of maintenance of HV switchgear and Gas Insulated Substations (GIS) and the Report A3-206 discussed reliability analysis of generator circuit breakers (GCB’s).

Computer simulation tools and methods for design and optimisation of UHV circuit breakers

Report A3-203 detailed the development of a very effective computer simulation method for predicting of arc interruption performance although the details of the model or the evidence of accurate prediction of arc interruption characteristics were not explicitly presented.

On the question with regards to the impact of computer simulation tools on circuit breaker development, contributions emphasised that the development time is reduced by combining tests and simulations. Beside a faster development, an increased understanding of the breaker’s functionality and ability to improve performance of the circuit breaker to cover increasing demands is also seen to be provided.

The simulation tools have assisted in reducing the development time, specifically by application for arc simulation. The learning’s from simulation process have also seen to provide valuable input for the improvement of future developments. Application of simulation tools and comparison with actual results can assist in continual improvement of the tools and their accuracy through ongoing calibration.

CIGRE WG A3.20 evaluated existing simulation technologies to determine the extent to which they can be used as a verification tools. This work describes the limit of simulation performance by the discrepancy between stress simulation and withstand prediction.

In summary, utilization of computer simulation tools is playing a dominant role in product development. It is an excellent and instructive tool in the development process. This has assisted in reduction of the number of tests performed to design the circuit breaker and the time taken to develop the circuit breaker. It is well established that simulation cannot reflect the reality with an accuracy of 100% and cannot replace tests. Whilst the simulation of stresses has been seen to be accurate for the prediction of performance to withstand stresses where performance has been proven by tests of similar design, it is not so true for new designs. Output from CIGRE working group A3.24 should provide further insight on this.

Note: CIGRE has undertaken research through WG A3.20 (see publication Simulations and Calculations as verification tools for design and performance of high voltage equipment – Cigré 2008) and more recently by WG A3.24 to further evaluate simulation techniques in specific areas where significant benefits can be foreseen, namely, for internal arc testing of SF$_6$ filled equipment.

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Condition assessment of circuit breakers

Report A3-205 discussed application of “Dynamic Contact Resistance Measurement” (DCRM) as a condition monitoring technique (in addition to other condition assessment tests), to assess healthiness of contact assemblies including arcing contacts and other components of the circuit breaker from 132kV to 765kV. The method has been applied by this Indian utility since 1998 and the authors report that they have successfully avoided the failure of at least 80 circuit breakers (CB’s) through these tests. The utility undertakes the time based CB overhaul (detailed internal inspection) based on the evaluation of the DCRM signature and the DCRM signature is required from their suppliers for all circuit breakers procured by the utility. They further utilise this technique to identify manufacturing defects.

The Report A3-204 discussed application of protection relays for the purpose of condition monitoring and their integration in the maintenance program of a utility in USA as a means to defer maintenance. The Report also brought out the benefits of monitoring circuit breaker performance in-service as it identifies the issues that are picked up by slow first trips that would otherwise not be evident during controlled testing. The Report also elaborates the benefits of utilising the information from these intelligent devices as a move towards a condition based maintenance and replacement program.

The authors confirm that the proposed strategy is equally applicable to both newer and older circuit breakers. The proposed setup is used to identify breakers that need maintenance intervention, monitor performance trends and effectively manage the maintenance cycles whilst mitigating the risks associated with long maintenance intervals. Any latest generation microprocessor based communicable relays can be applied for this function.

Whilst integrating the monitoring function in protection devices may be beneficial in applications where intelligent controllers are not deployed for control function, such integration as limited advantages for applications where intelligent controllers (e.g. controlled switching devices) are deployed. In such cases, retaining control and monitoring functions within the controller is a better solution as opposed to integrating control and monitoring functions within protection devices.

In summary, successful application of protection and control devices for condition monitoring is observed and specific examples have been provided for monitoring performance during first trip. Controlled switching devices are more successfully being applied for circuit breaker condition monitoring and benefits for life time management can be realized through this. Application of specialized circuit breaker monitoring devices requires careful design and application of proven technology.

Lifetime management – stresses, reliability and maintenance optimisation

Report A3-202 discussed the utilisation of in-service experience for the end of life estimation and optimisation of maintenance of HV switchgear and GIS substations. It mentions the need to modulate the maintenance practices based on the generation of GIS deployed and the authors’ experience with respect to the reliability of the first and second generation GIS switchgear and how they have been overcome by the latest generation of GIS equipment. The authors mention that the results from their studies align with the findings of CIGRE working group A3.06. The paper discusses use of probabilistic data analysis to determine optimal maintenance.

Detailed analysis on impact of change in maintenance intervals on reliability of a particular circuit breaker were presented and whilst the analysis shows reduction in reliability with increased maintenance intervals, it is proposed that the impact of reduced maintenance
intervals on planned outages is greater than an optimised maintenance strategy applied on an integrated bay level basis. Whilst the reliability of some of the individual equipment “may” be reduced, the overall system availability is expected to be better in an optimised maintenance strategy situation.

Some of the factors that impact on difference in reliability of equipment at various voltage levels include:

• For lower voltages the ratio between lightning impulse voltage (dimensioning voltage) and nominal voltage are typically higher
• The number of components are more in circuit breakers at higher voltage levels, having a consequent increase in the failure probability
• Improvements in technology over time have seen improvements in reliability performance for all voltages.

When considering reduction in size of the equipment, consideration should be given to the probable impact on the reliability of equipment due to reduced margins.

A Transmission System Operator (utility) in France presented the change in approach to renewal and replacement strategy from merely by major failure rates to managing circuit breakers based on gas leaks as well as targeted management based on known generic failures. Utilisation of spare parts stock, ability to undertake partial replacement and replacement of every gas compartment are also considered by this utility.

Using equipment definition as a multi stage unit based on the results of CIGRE WG C1.1, a methodology has been presented to assess maintenance necessity of equipment. The model is based on the idea to store expert knowledge of experienced service personnel in an artificial neural network. This ensures that expensive equipment can be kept online even though the expert knowledge has retired. A big advantage is of course the “storage” of expert knowledge in a simulation tool to keep expensive equipment online. First results from the application of the model show that a better prioritization of maintenance measures leads to a reduction of failures. The model and proposed application are particularly useful in the context of depleting expert knowledge and provides a benefit of a longer “useable” life to the equipment through retention of equipment knowledge and appropriate management intervention.

In summary, increase in servicing interval has been shown to increase the failure rates of circuit breakers. Observation is that whilst maintenance optimization may lead to increase in failure rate for particular equipment it has seen to have a positive influence on the overall availability of the network. It is acknowledged that the GIS technology has improved over the time due to new design and return of experience. Dielectric failures reported in GIS have been mainly due to surface abrasion of operating rods in the disconnector and earth switches. A multistage equipment model that utilizes maintenance data and human knowledge has been presented. Whilst not reported as being used by the utility right now it is a logical model that can be extended to predict condition and modulate future maintenance requirements.

Report A3-206 discussed lifetime experience in reliability of generator circuit breakers (GCB’s) and that of HVCB’s and proposes utilisation of the reliability information to modulate maintenance resulting in higher cost efficiencies and greater availability of GCB’s. The Report detailed the root cause of failures of the analysed GCB population. Whilst the analysis utilises information on GCB’s of a particular manufacturer, the conclusions are useful and aligned with the outcomes from reliability surveys conducted by CIGRE working group A3.06. The operating mechanisms are the main cause for most failures of circuit breakers. Performance statistics presented by various experts confirm that the reliability of full spring operating mechanisms is much higher compared to hydraulic, hydro-mechanical spring and pneumatic operating mechanisms. Comparison of statistics by CIGRE
working group A3.06 concludes that the modern SF₆ HVCB’s and SF₆ GenCB’s show nearly the same reliability behaviour regarding failure frequencies and their dependency on age. It also concludes that the main failure characteristics and components responsible for major failure show nearly the same tendencies.

In summary, findings from survey undertaken by CIGRE working group A3.06 shows reliability of Gen CB’s and HV CB’s is comparable. Selection of generator circuit breakers need to consider the difference in duty, in specific level of stresses imposed on them (e.g. high degree of asymmetry at contact separation, delayed current zero, rate of rise and time delay of TRV) as compared to general purpose circuit breakers. Type of operating mechanism has again been seen to be a major factor in difference in reliability of CB’s. Spring operating mechanisms are shown to be more reliable than others. As a result of reduced complexity of the operating mechanism and improvements in design, the latest generation circuit breakers are proving to be much more reliable than their predecessors.

The Report A3-201 again brings to fore the known challenges of switching capacitor banks and in specific the transient current whilst making the circuit. The Report specifically highlights the challenges of applying vacuum circuit breakers to capacitive switching duty. This topic was also a point of focus in the Special Report for CIGRE SC A3 Session 2010. The Report highlights that the late self-restoring breakdown events (NSDD) occur exclusively in vacuum circuit interrupters and very frequently during back to back switching at rated voltages > 30kV. Whilst highlighting the difference in behaviour of the vacuum and SF₆ circuit breakers capability for switching capacitor banks, the Report highlights the challenges of being able to perform three phase energization with full inrush currents in test set up. The Report presents a new measurement method to monitor the field electron emission (FEE) current in vacuum gaps. It describes the test circuit developed by KEMA to test performance of CBs for capacitor bank switching as close as practical to the standards.

In summary, experience from Japan on successful application of VCB’s for 72/84kV since 1980 has been presented. Various design considerations proposed include larger size vacuum interrupters (to reduce field strength between contacts), an axial magnetic field electrode (to reduce level of surface damage) and utilization of contact material with a higher melting point. Specific testing consideration should also be given to SF₆ or VCB technology installations where back to back switching resulting in high inrush current is possible. The work undertaken by Cigre working group A3.26 and A3.27 are relevant in this area. Two questions were raised, one on the need of a dedicated IEC standard for VCB and one regarding the level of x-ray emission for the highest voltages. Concerning the second question, answer provided by one expert has shown that the level will not exceed the requested values by the IEC standard.

The positive influence of adapted contact materials on performance of capacitive switching by vacuum circuit breakers was discussed.

The CIGRE working group A3.29 and A3.30 deal with the Deterioration of ageing high voltage equipment both due to in-service and over stresses, and possible mitigation techniques.

Note: Stresses imposed by capacitor switching have been studies by CIGRE WG 13.04 and more recently by CIGRE working group A3.26 (Capacitor bank switching and impact on equipment).

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Preferential Subject 3

Environmental suitability of HV equipment

The six papers for Preferential Subject 3 covered the effects of pollution on insulators (A3-301 and A3-303) and on substation connectors (A3-305), the effects of seismic perturbations on equipment (A3-306) and alternatives for SF₆-gas applications (A3-302 and A3-304).

Pollution

Salt and desert dust in combination with high humidity and fog caused flashovers across the insulators to earth of 500 kV CTs in Egypt. Investigations in both the dielectric performance of the CTs and the methods of cleaning and live line washing were addressed in A3-301. The authors concluded that for unknown reasons the best procedure showed to be to wash the CTs, which are equipped with special sheds and an extended arcing distance, from bottom to top, and, opposite to the other equipment, under dead condition only.

Whereas in Report A3-111 hollow composite insulators for supports were described in Report A3-303 advantages of hollow composite insulators for electrical equipment (houses) were denominated: Weight, strength, flexibility in production, extruded sheds, lining to protect against SF₆ by-products, etc. A prototype 1100 kV DC bushing is shown. The pollution performance of helical profile to IEC 60815 is claimed to be better than that of a deviating helical profile, such as Spirelec insulators. Good pollution withstand performance was reported from test stations in heavy marine and very industrially polluted areas, without any washing of the insulators. The authors repeated that for DC applications the insulation and creeping distance requirements are more demanding than for AC applications, certainly under circumstances with high pollution severity values.

The authors of A3-303 claimed a better explosion safety with composite insulators and this has been confirmed by the examples given by several experts, especially from high power test stations.

In Report A3-303, design optimizations of composite insulators for DC applications with a consideration of a partial loss of hydrophobicity has been described. The application of composite insulators to EHV voltage levels, AC, formed reason for a number of questions from users, especially in hot and harsh environments. Experts answered that one should carefully specify the environmental conditions for composite insulators in terms of NSDDs, birds, etc. Questions about delamination between inner tube and silicon cover, as experienced for instance in high power test stations provoked also various reactions from confirming similar experience to abnormal conditions that require special lining and production techniques.

A marine or an off-shore environment is very harsh from the point of view of corrosiveness and dielectric stress. As shown in Report A3-305 it is the surface roughness caused by corrosion and the thin conductive saline moisture layer that disturb the electric field at the perimeter of conductors and connectors. By 3D FEM analysis of the electric field around 765 kV AC connectors the weakest points have been detected and redesigned. Good agreement between simulation and corona onset tests has been found.

To the question whether the saline layer might smooth the surface and whether the conductive humidity layer might compensate for the surface roughness, the author answered that the opposite is true, as water molecules polarization will exacerbate the local electric fields. Further he explained that in the simulation it is impossible to represent surface roughness, as that would require a 3D simulation that has to cover magnitudes that are 10⁶ smaller than the test object.

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Seismic perturbations
Large and long structures, like several hundred metres of GIS-busbar, may face earthquake waves of different acceleration patterns. By simulations the authors of Report A3-306 showed that mechanical stresses are possible, that are much higher than 0.3 G, as applied during type tests. Similar calculations are used to determine the resonant frequencies of sections of a GIS. For example the circuit-breaker section, being a part that could be tested at a platform for seismic tests. The support structure of the breaker section under test has been adapted in such a way that the same resonance frequencies were obtained as with the complete GIS. So, an accurate and practical test method has been obtained. The authors showed another example of their simulation techniques, where the augmented response of equipment installed at a floor upstairs was predicted.

Upon request of the Special Reporter, the authors explained the damage to HV equipment at the Great East Japan Earthquake of March 11th, 2011. Despite the fact that the earthquake with a magnitude of 9 was more severe than the earthquake used to the Japanese guideline for seismic design, JEAG-5003, the Major Failure rate of electrical equipment was very small. The practice to apply safety factors of 2 or more showed to be beneficial. Much more damage was encountered at the earthquake in Sichuan, May 12th, 2008, with a magnitude of 8. An expert showed a lot of damage, especially with porcelain insulators, while the performance of composite insulators and GIS-equipment was rather good. The impact of this earthquake in China could be imagined by pictures of power transformers that were lifted from their basement.

Alternatives for SF$_6$
In Report A3-101 an HV VCB as an alternative for an SF$_6$-gas circuit-breaker has been presented; in A3-302 a gas circuit-breaker based on CO$_2$ has been described. CO$_2$ was applied at a higher pressure than SF$_6$, but as liquefaction is not an issue with CO$_2$, no application problems were foreseen. A live tank 145 kV, 31.5 kA, 3150 A CO$_2$ circuit-breaker, three-pole single drive has been designed, built and tested with good results. The only drawback mentioned in the Report is the higher temperature during the heat run test, as the heat dissipation of CO$_2$ is poor in comparison to SF$_6$-gas. A two-year pilot installation in a substation as capacitor bank breaker and as line breaker has been used as a proof of principle.

Arc models were addressed in the Reports A3-109, A3-203 and A3-304. The authors of Report A3-304 paid attention to the effect of local conditions of the arc, where no thermo-chemical equilibrium exists. They used a computer model of an arcing chamber with N$_2$ as quenching gas, as this gas is less complicated than SF$_6$. As a conclusion the authors postulated that for nitrogen thermo-chemical non-equilibrium does not occur between the two arcing contacts, and is therefore less important with respect to the thermal interruption capabilities of the design.

The authors of A3-302 stated that the design has been based on SF$_6$-gas technology, but optimized for CO$_2$-gas. In Report A3-304 nitrogen has been simulated. Several experts highlighted the advantages and disadvantages of CO$_2$ and N$_2$ in comparison to SF$_6$ and vacuum, especially the dielectric characteristics. But also arc by-products due to decomposition as well as due to the ablation of the nozzles have been addressed. Each arc extinguishing medium and insulation gas has its advantages and disadvantages, but modern design techniques, such as arc modelling, enable the developments of alternatives for SF$_6$-gas breakers, as required by society.
The next event will be in Auckland, September 14th to 20th, 2013, Skycity Convention Centre: 2013 New Zealand CIGRE Symposium with participation of SC A2, A3, B1, B2, B3 and C6.

For the last time as SC A3 Session Chairman, Mark Waldron thanked the Special Reporters, the SC Secretary and the Session Secretary; and also the authors, contributors and the audience. After the Sessions Hiroki Ito from Japan, the convenor of WG A3.22/28, took over as Chairman of SC A3.