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SPECIAL REPORT FOR SC A3
(High Voltage Equipment)

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Special Reporters

For the SC A3 Session 2014 three Preferential Subjects have been selected and a total of 27 Reports were submitted.

Preferential Subject 1: Equipment to cater for changing network conditions

- AC and DC substation equipment to meet new demands
- Equipment for future distribution systems
- New requirements for design, testing and equipment modeling.

Fifteen Reports will be discussed for Preferential Subject 1.

Preferential Subject 2: Lifetime management and ageing of T&D equipment

- Maintenance, monitoring and equipment diagnosis
- Influence of asset management practices, operating duty and stresses on reliability.

Six Reports will be discussed for Preferential Subject 2.

Preferential Subject 3: Impact of extreme operating conditions on T&D equipment

- Environmental stresses e.g. temperature, humidity, earthquake, wind, heavy rain, altitude
- System stresses and over-stressing e.g. short-circuit current, temporary overvoltage, transient recovery voltage, uprating or higher operating voltages
- Operational regime.

Six Reports will be discussed for Preferential Subject 3.

Preferential Subject 1

EQUIPMENT TO CATER FOR CHANGING NETWORK CONDITIONS

Changing network conditions lead to developments in the duties or technology of transmission & distribution substation equipment. These are addressed in a large number of Reports: developments in shunt reactor and shunt reactor switching (A3-101, 113), HVDC circuit breakers (A3-114), instrument transformers (A3-106, 107, 109, 111, 112, including an HVDC voltage divider), UHV circuit breakers (A3-104, 115), disconnectors (A3-102, 103, 110, including UHV), and current limiting (A3-105, 108, dealing with fault current and load current limiting).

Shunt reactors and shunt reactor switching

In Report **A3-101** a new design of an EHV shunt reactor, being a set of air core reactors, is presented. The assembly is in operation up to 345 kV and under development for 500 kV. Between phase and earth a number of modules are electrically put in series and physically mounted on top of each other and/or side by side, when necessary. To a picture and a drawing in the Report, the connections to phase and to earth are the upmost points of the reactor assembly. In this way the capacitance to earth can be influenced and consequently the transient voltage distribution along the modules. Further the transient voltage distribution can be controlled by surge arresters and/or capacitors per module. The inherent capacitance of the air-core reactors is much lower than that of oil-filled reactors and therefore the already high frequency of the load-side transient recovery voltage (TRV) becomes even higher. As the inductive current flowing through the shunt reactor is some hundreds of A, at switching off the current will be chopped. Current chopping generates high TRV peak values. With possibly small arcing times (small contact gaps) the high TRV results into a re-ignition and severe dielectric stresses to both shunt reactor and circuit breaker. Selection of a suitable circuit breaker deserves special attention. By means of additional capacitors or RC-damping circuits the TRV stress can be reduced as well as the risk of voltage escalation due to multiple re-ignitions.

A switch especially designed for its low chopping number (i.e. chopping current) and large minimum arcing time (contact gap), as described in Report **A3-113**, is most suited for shunt reactors switching. Multiple interrupters will be required at higher system voltages and the authors apply metal oxide varistors in parallel to each interrupter to share the TRV equally and to protect each interrupter for recovery voltages beyond its capability, especially at re-ignition of one of the interrupting chambers.

Q. 1-1 The switch presented in Report **A3-113** is not designed to clear fault currents. Is a separate circuit breaker required or is a fault in the shunt reactors to be switched off by the protection of the OH-line, cable system, transformer or busbar to which the shunt reactor is connected? In both Reports, the extra high TRV frequency caused by air core shunt reactors has been mentioned. What is the service experience with air core shunt reactors, with the voltage stresses to the switchgear, with switching overvoltages and with the mitigations (note that controlled switching will be addressed under PS 2)? To what voltage levels and which ratings air core shunt reactors and switches are applied nowadays?

HVDC circuit breakers

The authors of Report **A3-114** draw attention to DC current interruption, especially at high voltage (HVDC). They give an overview of different switching technologies, that may be capable to interrupt a DC fault current within a far shorter time than known from AC fault current clearing. Depending on the HVDC system requirements, a fault has to be cleared within some ms, up to ten ms, or may be cleared in a more conventional way. Most research nowadays is spent to fast fault clearing, that comes from the steep rising discharge current of the HVDC cables and the large capacitors in the voltage source converters. Tens of kA may be reached within the timeframe of ms. A new CIGRE JWG A3/B4.34 will study the technical requirements and capability of state-of-the-art DC switching equipment.

One of the two main topics of the Report is the elaboration of different test circuits to assess an HVDC circuit breaker's fault current interruption capability. Apart from the facilities to test power electronic modules of converters, the authors propose three different methods to simulate a DC current in their High-Power Laboratory. They elaborate a testing scheme based on an quasi DC current, being the crest values of a low frequency (e.g. 16⅔ Hz) half sine wave. Different short-circuit generators may contribute each after another to enlarge the duration of the quasi DC current. A second testing scheme makes use of the sequentially discharge of the magnetic energy stored in three large shunt reactors in a three-phase system. At the proper moments each reactor is disconnected from the source and discharged through the test object. The third method uses the DC component of a three-phase short-circuit current, when each pole is making the current at voltage zero in a four conductor scheme. The current though the neutral is a slowly decaying DC current (with a time constant of e.g. 120 ms).

The other main topic is modelling of the DC fault current interruption. The authors built a DC arc model to predict the success of fault current interruption and simulated the interruption of 1 kA DC. They performed a real test as well, applying the first test method to a quasi HVDC circuit breaker. A conventional AC circuit breaker was used with parallel a charged LC-circuit that superimposes a high frequency discharge current on the DC fault current, to force a current zero. With the arc characteristics obtained from the real test, good simulation results could be achieved.

Q. 1-2 Discharging of cables, OH-lines and capacitor banks into a fault is already known from AC networks. What makes the discharge current (voltage level, length of cables, size of capacitor banks, others) and the fault current so special in HVDC networks? Can experts explain the technical background on the HVDC circuit breaker requirements (fault current, clearing time) for different HVDC applications? Usually a steady increasing DC fault current is reported from HVDC fault simulations, but in the test circuits described in Report **A3-114** inherent DC fault currents with more or less constant amplitude are shown. Are the test circuits mentioned in the Report representative enough to verify the much faster HVDC circuit breakers? And can the DC source voltage and the TRV conditions be adapted to those of HVDC networks? What about the amount of energy to be absorbed by the HVDC breaker? Can experts compare hybrid technology HVDC circuit breakers (power electronics and mechanical switchgear) with fast mechanical HVDC circuit breakers, such as with an active resonance scheme? Can they provide recent developments?

Instrument transformers

Five Reports deal with instrument transformers. Report **A3-106** gives the results of an EU-project to develop a transportable reference HVDC voltage transducer for energy metering, based on a divider with high precision wire-wound resistors surrounded by a resistive-capacitive shield divider. A high accuracy is also discussed in Report **A3-107**, that addresses a diagnostic test techniques for capacitive voltage dividers, based on wireless bridge measurements, and in Report **A3-111**, that deals with the design parameters for RC-dividers used for power quality measurements. In Report **A3-109** quality checks and environmental requirements are described for current transformers with composite bushings, SF_6-gas insulation and pressure release valves. Rogowski coils made from printed-circuit boards are treated in Report **A3-112**. It has to mentioned that CIGRE WG A3.31 deals with non-conventional instrument transformers (NCIT) with digital output.

Q. 1-3 In Report **A3-107** and in Report **A3-109** service experience with failing and/or exploding instrument transformers is mentioned. In CIGRE Technical Brochure 512 (2012) a fire and explosion rate of 0.01 to 0.02 per 100 CT-years has been presented. Are such figures acceptable to utilities or is this dependent on the size of the population? Are explosion rates, failure rates, hazard rates, consequences experienced in service different from these figures? Are fatalities experienced and/or explosions after switching off? What is the risk to perform more and more diagnostic tests? In the Reports **A3-106**, **A3-109** and **A3-111** verification of the accuracy of voltage transformers is addressed. What is the failure rate with respect to the required accuracy? Are, opposite to the conclusions in TB 512, failure rates increasing over time, can a bath tub curve be seen? When not, is replacement the correct policy? What about the amplifiers and electronics used with low power instrument transformers (also for **A3-112**): DC-shift, bandwidth, saturation effects? Has the market share of NCIT improved since the 2008 Session? Also for regular applications? What is the success rate of the diagnostic test as highlighted in Report **A3-107**?

Q. 1-4 The authors of Report **A3-109** pay attention to multiple stress tests on composite insulators, especially to the orientation of the salt spray nozzles in case of large diameter insulators. They recommend an adaptation of the IEC TR 62730 and IEC Std 60507 in this respect. What is the opinion of other experts? Is the policy to replace paper/oil/porcelain insulated instrument transformers by SF_6-gas/composite insulators adapted by other utilities as well? Are such instrument transformers really more safe, or is it the pressure release device that improves the safety?

UHV circuit breakers

CIGRE WG A3.28, Switching and Testing of EHV&UHV Equipment, has finalized its activities by the publication of Technical Brochure 570. The results are summarized in Report **A3-115** with sections devoted to the recommendation to IEC TC 17A, to recommendations to SC A3, to transformer limited faults and to specific findings from the modelling of a number of benchmark networks. A new CIGRE WG A3.33 will deal with the remaining questions for series and shunt compensation. In the meantime IEC SC 17A has introduced the recommendations of WG A3.22/28 in the Standards. The authors of Report **A3-104** describe the technical specification of a 1200 kV circuit breaker with a strong reference to the Technical Brochures 362 and 456 of WG A3.22, but no reference to the latest edition of IEC Std. 62271-100.

Q. 1-5 Can the authors of Reports **A3-104** provide additional information of the transformer limited fault TRV for 1200 kV rating (e.g. the capacitance of the connection between circuit-breaker and transformer; the TRV frequency)? WG A3.28 covered also transformer limited faults for voltages from 100 kV up to and including 800 kV. Most aspects are dealt with, but still not enough information is collected about the TRV frequency in case of a limited capacitance between circuit breaker and transformer. The main frequency can be deduced from FRA measurements on transformers, when specific information about the transformer characteristics and the precise connections for the FRA-measurement are known. Can experts provide information about EHV transformer's main frequency and/or results from FRA-measurements or contact the authors of paper **A3-115**?

Q. 1-6 One of the particular findings addressed in Report **A3-115** are the effects of homogeneity versus heterogeneity in network models and component models. In general, the more details are modelled, the less salient is the outcome of a simulation, unless all details are identical. For instance: more accurate transformer models tend to give lower peak values of the TRV when clearing transformer limited faults. Or the other way around: a simpler model gives higher peak values and leads to more severe specifications. The advantage, though, of simpler models are the transparency of the calculation results and the inherent margins, so useful to cover unexpected phenomena and ageing. What is the opinion of the audience with respect to complexity versus simplicity, taking into consideration the specification and standardization of HV equipment? Examples?

Disconnectors

The optional switching duties for disconnectors are (i) to charge and discharge sections (busbars) of gas insulated substations (i.e. capacitive current switching) and (ii) to transfer the power flow in a bay from one busbar to another busbar (i.e. bus transfer current switching) for both air and gas insulated substations. Bus transfer current switching (ii) is addressed in Report **A3-110** (and in **A3-115**). When changing the connection of a bay from one busbar to another busbar, the involved disconnectors will shortly form a loop together with both busbars (bus sections) and the coupling bay. The disconnectors have to be capable to close and open the loop. The loop current and the voltage drop along the loop depend mainly on the loop length and the total current flowing from one bus to the other, before and after changeover. Note that the bus transfer current may consist of a current contribution from other bays as well. Moreover, the voltage drop along the buses involves the currents from the other bays.
The test circuit usually applied to verify the bus transfer current switching capability consists of a voltage source, representing the loop voltage, and an impedance to limit the test current to the loop current; i.e. a rather simple configuration with limited degrees of freedom. The authors propose an

alternative test circuit that approaches real service conditions and gives more flexibility by independent tuning of loop voltage and loop current. Their test circuit consists of a current source that feeds two parallel branches with independent impedances, one of which is equipped with the disconnector under test. As current source they use a series LC-circuit with a charged capacitor; L and C tuned to the power frequency.

Q. 1-7 In service two disconnectors (A and B) are involved; A has to conduct the load current before the bus transfer, B afterwards; B has to make the bustransfer current and A to break the load minus transfer current. How can the authors tune their test circuit to fulfil these requirements? Is the rating of the bus selection disconnector determined by the rating of the busbar or the rating of the bay? Are there reasons to adapt the requirements for bus-transfer current switching in IEC 62271-102 (as done already for UHV)? In paper **A3-103** a bus length of 500 m at 420 kV has been reported, although not related to bus transfer current switching. Can utilities give examples of such large loops in their substations (location of coupling bay, length of each bus section, voltage level, AIS or GIS, rated current of bus selection disconnectors, maybe even actual bus transfer currents)?

To capacitive current switching (i) the Standard has defined three optional test duties for disconnectors in GIS: (1) switching of short bus sections, (2) switching of long sections and (3) switching of grading capacitors of circuit breakers under full out-of-phase conditions. Test duty (1) is meant to cover the very fast switching phenomena, generated by travelling waves and reaching frequencies up to tens of MHz. Such very fast transient overvoltages (VFTO) are addressed in Report **A3-102** for UHV GIS disconnectors. The authors investigated by measurements and simulations the influence of the mechanical speed of the disconnector, the influence of the polarity of the short bus section's capacitive charge and the influence of the length of a busbar branch at the AC source side. The longer the length of the busbar branch the higher the peak value of the VFTO. The faster the speed of the disconnector the higher the peak value, but the charge polarity showed no influence on the peak value of the VFTO.

Complements have to be given to the authors of Report **A3-103** with the capacitive current switching tests in air insulated substations in service. They used a 420 kV pantograph disconnector and reported that in real life the charging current of long 420 kV bus sections can reach values as high as 0.5 to 1 A. For such service conditions guidelines for laboratory tests are given in IEC TR 62271-305. For GIS, this corresponds to the above mentioned optional test duty (2). The authors conclude from laboratory tests and from special tests in substations that the particular disconnector is capable to switch capacitive currents up to at least 1.0 A. Arc duration, arc behaviour and arc length are strongly influenced by the ratio of source side and load side capacitance to earth. Under laboratory circumstances this ratio is worse in comparison to service conditions, especially in very large substations, so that laboratory tests are at the safe side. This conclusion is in line with the statements in IEC TR 62271-305, and other publications.

Q. 1-8 Although the frequency bandwidths of the VFTO (GIS, short bus sections) and the restrikes of pantograph disconnectors (air, long bus sections) are completely different, the main concern is the same: no flashover to earth or other life parts, either by the arc or by overvoltages. What criteria are established or applied to consider the design of disconnectors as acceptable in this respect? What mitigations are possible to prevent flashovers and unacceptable transient overvoltages? How realistic is the assumption of the worst condition with a small source side capacitance? Should capacitive current switching be made mandatory for disconnectors? Are long bus sections to be switched by circuit breakers?

Current limiting

Two Reports are presented on current limiting. In Report **A3-105** the feasibility of the application of a superconducting 110 kV fault current limiter (FCL) in the Helsinki meshed grid is discussed. The authors paid attention to the impact of such an FCL on the fault current levels, on the system reliability, on power quality, on capital costs, operational costs and stochastic costs, and on customer interruption costs. By simulations the optimal location(s) and the optimal main characteristics of the

FCL have been determined. However, the optimal location and impedance showed to be inferior to a mitigation by changing the connection of a power plant from the 110 kV grid to the 400 kV network.

The authors of Report **A3-108** describe the application of a series reactor to prohibit overloading of an overhead line in one of the main 220 kV corridors in Spain. This corridor is especially loaded due to power generation by wind turbines. Per phase, the reactor is composed of four air core reactors in series and each reactor can be by-passed by a circuit breaker. A controller is used to keep the power flow within a predefined operating band, so that a "FACTS Series Compensation" is achieved.

Q. 1-9 Is the reliability of the current limiters, as proposed in both papers, taken into consideration? For instance due to failing cooling, due to the switchgear, due to switching overvoltages? Which mitigations are in place? Both the fault current level (**A3-105**) and the ampacity of the overhead line (**A3-108**) are weather dependent. Are weather conditions been taken into account for the design of the FCL and the setting of the controller, respectively? Can other experts give examples of current limiting business cases? Can they provide field experience and benefits of FCL at transmission levels?

Preferential Subject 2

LIFETIME MANAGEMENT AND AGEING OF T&D EQUIPMENT

Since decades lifetime management and ageing of substation equipment is a topic of major interest for the study committee A3 community. WG A3.29 deals with deterioration and ageing of HV equipment and WG A3.30 investigates overstressing of substation equipment. The most recent CIGRE events addressing this subject were the Paris Sessions 2010 and 2012, SC A3 Technical Colloquiums in Rio de Janeiro – 2007, Vienna – 2011 and Auckland - 2013. Again it has been elected as a preferential subject for CIGRE Session 2014 and will be covered by six Reports. Report **A3-206** deals with lifetime management of transmission equipment in general, but presents an example on how to apply the described process on a circuit breaker. Three other Reports also deal with circuit breakers, **A3-201**, **A3-202** and **A3-205**, addressing different aspects of dielectric performance, life extension of air-blast circuit breakers and impact of mechanic operations on the reliability of minimum-oil circuit breakers. Controlled switching is addressed in Reports **A3-203** and **A3-204**, where the service experience of the last decades is addressed as well as the requirements for getting a reliable point on wave (POW) system. Report **A3-113** deals primarily with shunt reactor switching and therefore is incorporated under PS 1. However, it also discusses the application of controlled switching and therefore it will be addressed as well in PS2. In Report **A3-303** controlled switching is compared with the application of pre-insertion resistors and will be discussed under PS 3.

Report **A3-206** presents how life management of transmission substation equipment is handled in Romania and gives a practical application example of a 420 kV circuit breaker. The Report explains the technical and regulatory definitions for the end of life, which are on the basis of the life extension process of T&D equipment. Once the regulatory life is achieved (*useful life* in the Report) the equipment may still be kept in operation, depending on its state and performance. Regulatory rules allow the transmission utilities to extent equipment's life up to the physical end of life is reached. The decision point within this process is the residual life assessment, that has to be carried out and is based on on-line monitoring data collected since equipment commissioning and on off-line measurements and tests. The life extension analysis example presented in the Report is the basis for the decision process of the transmission utility and makes use of an expert system to help predicting the residual life. The economical decision path of the process is to decide whether it is worth to extend the equipment's life at a higher maintenance cost or to schedule for replacement. According to Report **A3-206**, the costs incurred with the life extension analysis shall not be more than 3% of replacement costs of circuit breaker, otherwise it is not worth to carry it out. To the author's experience it is not worth to perform expensive and time consuming analysis with disconnectors and surge arresters, due to their market prices.

Q. 2-1 How are the practices in other countries concerning the definition of end of life of transmission equipment? Is the regulatory end of life defined? Is the physical end of life related to an unacceptable risk to perform not according to systems requirements? If not, please explain the criteria. How is the time period necessary to replace a whole sub-population taken into account?

Q. 2-2 After a long period of development of lifetime management techniques, based on expert systems, monitoring, maintenance and reliability databases, are utilities actually applying them in practice as a decision making process? Do this practice lead to the improvement of installation total costs? Considering todays transmission equipment market, is it worth to apply sophisticated lifetime processes for all kinds of equipment? What kind of equipment has been the main target for life extension analysis?

Controlled switching

Reports **A3-203** and **A3-204** deal specifically with controlled switching (CS) reliability and circuit breaker qualification for CS applications. Report **A3-113** primarily dealing with shunt reactor switching also covers CS aspects for this kind of application.

Since 1995 several CIGRE publications in ELECTRA and as Technical Brochures have been issued covering different aspects of CS technology and application, specially by WG A3.07: TB 262, 263 and 264. The long experience with CS systems, nowadays more than 20 years, offers good material for the analysis of the long term performance and reliability of this kind of solution. CS is not anymore an emerging technology, but it is a widely used solution for the reduction of transients due to reactive load switching like shunt reactors, shunt capacitor banks, unloaded transformers, whereas it is still timidly applied for unloaded transmission line switching. In general CS is recognized as a rather efficient means for reducing switching transients. However, the intrinsic sophistication of this kind of solution calls special attention for the circuit breaker specification as well as maintenance practices, which can impact the total costs of the installation, as pointed out in Report **A3-113**.

A quite relevant point for the success of CS applications is the performance of specific parameters of the circuit-breaker, like the necessary low scatter of operating times and the steepness of the rate-of-rise and rate-of-decrease of the dielectric strength of the circuit breaker contact gap during a switching operation. In the meantime a new IEC Technical Report was issued, IEC/TR 62271-302 – Alternating current circuit breakers with intentionally non-simultaneous pole operation, which covers the requirements and test procedures for circuit breakers intended to CS applications. Other relevant point addressed by this standard is the influence of external parameter variations on the circuit breaker performance, like ambient temperature, control voltage, gas pressure, idle time, etc. However, there is still a standardization gap for controlled switching applications, that is the CS device itself, what makes some utilities to prescribe their own testing requirements.

As for any high voltage equipment or system, commissioning of controlled switching is also a key factor for the successful operation of the circuit breaker-controller system, as well as the adequate maintenance of the circuit-breaker and eventually necessary corrections of controller parameterization in the field. The newly created WG A3.35 “Guide lines and best practices for the commissioning of controlled switching projects” will make available in the next future the best practices of worldwide utilities on and manufacturers for CS commissioning and maintenance.

Q. 2-3 After more than 2 decades of operational experience with controlled switching application, how are utilities satisfied with this technology? How reliable are the existing applications? For CS applications, how do utilities check the conformity of the controller – circuit breaker system? Besides most used CS applications – shunt reactors and shunt capacitors – are utilities already applying CS to a large extent to reduce transformer inrush currents to switch unloaded lines? How is the operational experience (reliability) of this kind of application?

Q 2-4 Report **A3-203** raised up a quite interesting by-product of controller alarms: they can be used as part of the monitoring strategy for the circuit breaker condition. Are other utilities applying similar kind of indirect monitoring philosophy? Are external monitoring devices being applied to access controlled switching systems performance or diagnosis?

Circuit breakers

Report **A3-201** addresses the voltage distribution coordination between series connected breaking chambers of multi-chamber circuit breakers. It is investigated the occurrence of breakdown delays between the chambers in series during prestrikes for CB closing and re-ignitions or restrikes during opening operations, subject also covered in CIGRE TB 368, dealing with stresses on grading capacitors. The theory of the voltage distribution along the grading capacitors is explored. A non-intrusive technique based on transient electromagnetic emission captured by antennas is successfully applied to determine the breakdown instants on each of the CB breaking chambers. The described method is as an alternative for condition diagnostics of CB in service, gives valuable information on the mechanical chain of multi-chamber CB and the dielectric behaviour of the contacts gaps in a dynamic situation. JWG A3.32/CIRED deals with non-intrusive condition monitoring for HV/MV equipment.

Report **A3-202** applies the accelerated failure time (AFT) model to predict the time to end of life of old minimum-oil circuit breakers (MOCB) in service. The main parameter investigated was the number of mechanical operations. This kind of reliability modelling is not commonly used for HV equipment lifetime management, but showed to be quite promising when applied to MOCB. In principle, it could also be applied to other CB technologies or even other types of equipment. However, statistically based analysis of HV equipment is always dependent on appropriate asset management databases.

Report **A3-205** deals with life extension of air-blast CB. This kind of equipment is well-known due to its robustness and performance margins, a consequence of CB dimensioning techniques used about 40 years ago. Besides, the high arc voltage and relatively high post arc currents make air-blast quenching technology to be quite efficient to damp some kinds of switching transients. On the other hand, it produces much higher chopping currents than SF_6 CB. All these advantages together may be attractive for utilities to extend the life of well performing air-blast CB by means of refurbishment. However, this decision is heavily dependent on available skills, spare parts supply and costs, as well as the necessary time to carry out the work. Another decisive aspect is the costs of new CB, which have significantly dropped in the international market in the last decades. For the two examples presented in Report **A3-205** it was worth to extend the life of two different types of MV and HV air-blast circuit breakers, even when considering the costs for laboratory tests carried out to verify their performance and provide additional information for life extension decision.

Q. 2-5 Are utilities applying nonintrusive monitoring techniques to transmission & distribution equipment, like the one presented in Report **A3-201**, based on transient electromagnetic emission captured by antennas? If so, which subparts of the equipment have been monitored? What was the aim of the application and the corresponding benefit for the equipment life management?

Q. 2-6 Reports **A3-202** and **A3-205** relate successful experiences of life extension of circuit breakers having old technologies and long time in operation. How is the experience of other utilities with life extension of old equipment? Have life prediction models been successfully applied to predict end of life of transmission & distribution equipment? Does the local boundary conditions (cost structure, available personnel with necessary skills, manufacturer local support, etc.) influence the decision process to go for it? Are other utilities applying testing in old equipment as part of the life extension decision process? In this case, are the corresponding testing costs worthwhile? Could utilities comment on their experience with end of life criteria? According to utilities practice, what are the three most applied criteria for equipment replacement? Do regulation rules play a major role, or is equipment overrating or reliability the decisive topics? Or functional requirements, such as with respect to the risk with asbestos fibres or reactor limited fault clearing?

Preferential Subject 3

IMPACT OF EXTREME OPERATING CONDITIONS ON T&D EQUIPMENT

The six papers for Preferential Subject 3 cover different topics: electrical and dielectric stresses not covered by Standards (**A3-301**), recommendations to mitigate the risk of overvoltages due to (virtual) chopping of small inductive currents by VCBs (**A3-302**), pre-insertion resistors for shunt capacitor switching (**A3-303**), seismic design of substation equipment (**A3-304**), heavy snow and severe pollution (**A3-305**) and very large generator circuit breakers (**A3-306**).

In Report **A3-301** an overview is given of a number of special stresses, not covered by the Standards, but partially under investigation by several CIGRE WGs or treated as special cases by IEC. Examples of such stresses are the increased TRV-stress caused by series capacitor banks, fault current clearing in the vicinity of shunt capacitor banks, TRV peak value as a function of the first pole-to-clear factor and the amplitude factor, DC-time constants, transformer limited faults with a small capacitance between transformer and circuit breaker, high operating voltages and temporary operating voltages, induced currents and voltages to be switched by line earthing switches, dielectric withstand of polluted life tank circuit breakers applied in power plant bays and an internal switching overvoltage in a GIS at charging an unloaded busbar. In the past, many of the topics have been addressed and reported, but either for a limited scope (for instance 800 kV and UHV only) or are not well-known to the community. Nowadays CIGRE WG A3.30 deals with overstressing.

Q. 3-1 What is utilities' policy and experience with operating HV equipment at voltage levels above the rated voltage? For operation conditions where overstresses are expected, how do utilities take them into account when specifying equipment? What specific topics have to be further investigated, to the opinion of the authors or other experts? Are these topics not or not correctly addressed in the Standards or in CIGRE Technical Brochures? If not, which topics are not yet under consideration of present CIGRE WGs or IEC MTs? Or, is there a need for more education, tutorials or easily available publications?

The authors of Report **A3-302** paid attention to multiple re-ignitions at the interruption of small inductive currents by VCBs (vacuum circuit breakers) and the associated dielectric stresses on transformer windings. When switching unloaded transformers with modern VCBs, harmful over-voltages are not expected to occur, unless an inrush current is interrupted. Switching of inductive load currents, though, may result in damage, especially when virtual chopping occurs and/or the transformer insulation is in bad condition. Simulation results are confirmed by laboratory measurements of the dielectric stresses across transformer windings. Based on the investigations, the authors present an overview of practical cases and a score card for actual cases in service, showing whether simple mitigation measures have to be taken.

Q. 3-2 There is a tendency nowadays to regard multiple re-ignitions and virtual chopping by VCBs as phenomena that are under control. Under which conditions this holds true? What is the experience of users? Is a score card as mentioned by the authors useful in this respect? Not much information is given about the score card: can the authors present more details or give a reference? Is the score-card also applicable to VCBs for sub-transmission levels, the domain of CIGRE WG A3.27?

In Report **A3-303** a comparison has been made between the application of controlled switching and the application of pre-insertion resistors in case of closing capacitor banks. The authors point at the required accuracy of controller, circuit breaker's closing time and the RDDS (rate of decrease of dielectric strength). With respect to accuracy and reliability they refer to the results of the third worldwide enquiry on circuit breaker reliability. At the same time the authors claim that the reliability of pre-insertion resistors has greatly improved, since much simpler designs to by-pass the resistors have been introduced. By transient simulations, the effects of deviations from ideal closing moments are shown, both with controlled switching and with pre-insertion. Although controlled switching has been simulated with an additional inrush reactor and the pre-insertion resistor without inrush reactor, the switching overvoltages in the latter case are generally lower. A lance is broken for the application of simple modern pre-insertion resistors.

Q. 3-3 Simulations have been performed for capacitor banks with and without earthed neutral, and for back-to-back applications. Can the authors highlight the results from back-to-back simulations? What about other applications: underground cables, re-closing overhead lines, etc.? What is the service experience with closing and opening resistors applied to modern circuit breakers? What is the relationship between the failure rates quoted in Technical Report 510 and mechanical scattering, as mentioned by the authors?

Two Reports from Japan address severe environmental stresses: **A3-304** concerning earth quakes, especially the lessons learned from the Great East Japan Earthquake, and **A3-305** concerning heavy snow and severe pollution in relation to composite insulators. To the Japan Standard JEAG 5003 high voltage substation equipment has to withstand a seismic impulse of 0.3 G at the bottom of the equipment (resonant three cycles sine wave). But, in the past, TEPCO specified the requirement to withstand twice this acceleration, that happens to result into a centroid acceleration in the range that has been measured during the Great East Japan Earthquake. This is probably the reason why the percentage of damaged substation equipment has been reported to be less than 1%. Nevertheless detailed analysis of the damaged equipment revealed a few points for improvement, such as damage due to non-linear effects (plastic deformation and the collision of parts during the vibrations) as well as the higher than expected transfer of mechanical load through connecting conductors (between HV apparatus and for equipment directly connected to OH-lines).

Testing in service for extreme stresses due to heavy snow, melting snow and severe pollution is the topic of Report **A3-305**. The authors report good results of the behaviour of composite insulators during field tests for 30 months (72 kV, heavy snow), for 16 months (550 kV, heavy snow) and for 7 years (84 kV, severe pollution). Hydrophobicity, ESDD, NSDD and leakage currents have been investigated as well as a laboratory test afterwards on the interface between core and housing (84 kV).

Q. 3-4 Extreme conditions require adequate design specifications and feedback from service. Utilities and manufacturers worldwide can learn from the colleagues who experienced the extreme conditions. What lessons have been learned from recent severe circumstances, like the earthquakes in Japan and China, floods all over the world, bushfires, extreme snow, ice, rain, pollution? Especially which specifications have been adapted in the International Standards for high voltage equipment? Or are certain extreme environmental conditions deliberately excluded from the scope of the Standards? Do utilities facing such extreme conditions consider a probabilistic approach to determine equipment requirements? Or are the requirements defined for a worst case scenario? What are the possibilities to simulate the performance of equipment, for instance with respect to seismic requirements? The severity of a field test is important, but also the considered duration of a field test. How can field tests, as described in Report **A3-305**, be extrapolated to an expected life of more than 30 to 40 years?

The application, specification, construction and testing of a generator circuit breaker package is described in Report **A3-306**. The focus is on fault current clearing, the system source fault and the generator source fault, with their typical requirements for the TRV. The hybrid synthetic-direct test method is revealed, but most important are the chapters on current zero phenomena, as measured with special high tech sensors, and on arc models suitable to predict the performance of the test object. Based on such arc-circuit interaction simulations, the influence of a test circuit parallel capacitance on the generator circuit breaker performance is shown.

Q. 3-5 The authors observe a different arc-circuit interaction of the generator circuit breaker (SF_6 technology, tens of kV, hundred or more kA) in comparison to regular high voltage SF_6 circuit breakers. Can they highlight the post-arc current and pre-zero conductivity particularities? And explain the influence on the TRV waveform? How useful are the high precision measurements of current zero phenomena for the designers? Can examples be given?

General information

Within SC A3, High voltage equipment, four Working Groups have published or will publish their Technical Brochures in 2014:

WG A3.24	Simulating internal arcs and current withstand tests
WG A3.25	MO varistors and surge arresters for emerging system conditions
WG A3.27	Vacuum switchgear
WG A3.28	Switching and testing of EHV&UHV equipment. (TB570)

Other working Groups are:

WG A3.26	Capacitor bank switching and impact on equipment
WG A3.29	Deterioration and ageing of HV substation equipment
WG A3.30	Overstressing of substation equipment
WG A3.31	NCIT with digital output
JWG A3.32	Non-intrusive condition monitoring for MV/HV switchgear
WG A3.33	Experience with equipment for series/shunt compensation
JWG A3/B5.34	Technical requirements and capability of state-of-the-art DC switching equipment
WG A3.35	Guidelines and best practices for commissioning and operation of controlled switching projects.

Important

Experts who wish to contribute to the SC A3 Session are required to send their draft prepared contribution to the Special Reporters before **August 1st, 2014**, in order to check whether and where the contributions fit into the program: anton.janssen@alliander.com. Prepared contributions in draft, which are received after **August 1st**, will not be accepted and considered. During the Session, for each prepared contribution a time slot of three-four minutes will be available, so that the number of slides essentially has to be less than four. After receiving the draft prepared contributions the Special Reporters will review the size and readability of the power point presentation. They will give recommendations to the experts and inform them whether the prepared contribution will be accepted by August 8th.

On the day before the Session (i.e. on Thursday, August 28th) Contributors need to contact the Chairman, the Secretary and Special Reporters of SC A3 at a location in the Palais de Congrès, to be announced by CIGRÉ Central Office. The SC A3 Group Discussion (Session) will be on Friday, August 29th, in Salle Bordeaux.

When the Chairman calls for spontaneous contributions, attendees are allowed to provide a spontaneous contribution, which is required to be forwarded within a maximum delay of 2 weeks after the Session to anton.janssen@alliander.com .

The authors of the SC A3 Session Reports may present the results of their studies during the Poster Session on Wednesday morning, August 27th, 2014. For each Report (and each SC A3 Working Group) space for a single A0 poster will be available. Before **August 1st**, draft posters have to be sent in digital format to André Giboulet, the Session and Poster Secretary: consulting38@gmail.com. After receiving the draft posters the Session and Poster Secretary will review the readability of the draft posters.