A3 - 00

SPECIAL REPORT FOR SC A3
(High Voltage Equipment)

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Special Reporters

For the SC A3 Session 2018, three Preferential Subjects have been selected and a total of 33 Reports (314 pages) were submitted.

Preferential Subject 1: Requirements for AC and DC Transmission & Distribution Equipment

- Requirements for DC equipment for multi-terminal HVDC grids.
- Mitigation measures to facilitate higher reliability.
- Developments in testing and verification for AC and DC equipment.

Fifteen Reports are numbered under Preferential Subject 1.

Preferential Subject 2: Lifetime management of Transmission & Distribution Equipment

- Diagnostics and prognostics of equipment.
- Influence of environmental and operational conditions on lifetime.
- Experience and countermeasures for over-stresses and overload

Seven Reports are numbered under Preferential Subject 2.

Preferential Subject 3: Novel Developments of Transmission & Distribution Equipment

- New switching devices and emerging equipment.
- Switching with SF_6 alternatives, equipment with new materials.
- Incorporation of intelligence into AC and DC equipment.

Eleven Reports are numbered under Preferential Subject 3.

The SC A3 Session covers a wide scope of technical equipment, while experts are usually dealing with only a few of the categories of equipment under discussion. To facilitate the audience, the Reports will be discussed per category of equipment (or specific topic): I Insulators, II Pressure rise in GIS, III Disconnectors (Disconnecting switches) and earthing switches, IV HVDC switchgear, V Controlled switching, VI High voltage circuit breaker performance, VII MOSA, VIII Instrument transformers, IX SF_6 alternatives, X Generator circuit breakers, XI MV switchgear developments and XII Capacitive current switching. A specific topic may cover Reports attributed to more than one Preferential Subject.

The discussion of some topics will start with the presentation of a representative Report or working group activity, followed by the prepared contributions and a discussion. To facilitate more spontaneous contributions by the audience only selected prepared contributions will be presented. All submitted and accepted prepared contributions will be published in the Session Proceedings as well as the spontaneous contributions. Further information is given at the end of this Special Report.

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Preferential Subject 1

REQUIREMENTS FOR AC AND DC T&D EQUIPMENT

Topics: I Insulators, II Pressure rise in GIS, III Disconnectors and earthing switches, IV HVDC switchgear, V Controlled switching, VI High voltage circuit breaker performance

I Insulators

Two Reports (A3-108 and A3-109) describe artificial as well as outdoor pollution tests on composite hollow insulators and (room temperature vulcanised silicone rubber coated) porcelain support insulators, respectively. Report A3-108 shows the results of laboratory tests with full scale samples under DC-voltage stresses, as well as those of the outdoor tests under AC-voltage stresses. While, Report A3-109 shows the results for both laboratory and outdoor tests AC-voltage stresses. In both Reports the solid layer method and the salt fog test are used to determine the specific creepage distance. In Report A3-108, a high deviation is reported between the measured values for the specific creepage distances and the expected values to IEC Technical Specification 60815-4; especially for salt fog tests. It is recommended to further investigate this deviation. Further in Report A3-108 the up & down test is described for the solid layer method and an adapted up & down test for the salt fog test, thus achieving a considerable reduction in test duration.

Report A3-109 starts with selection tests for the materials to be used for the coating: adhesion tests, hydrophobicity transfer test and hydrophobicity classification, all on sample plates. The authors have applied a long term (1000 and 2000 hours) salt fog test on two full samples each coated with a selected material. They ask for the consideration to cover silicone coatings in the standards as well as the material selection tests as described.

Q. 1-1.

An important aspect for the application of composite insulation materials is the proof of its long-term behaviour within a relatively short test period. Are salt fog test durations, such as 1000 or 2000 hours or even very short periods as with the up & down test, satisfying to the users? What about the 5000 hours multiple stress tests as formerly outlined in IEC TR 62730 (until 2012)? What service experience can be given?

Which aspects of pollution tests for composite insulators are adequately covered by the International Standards and which deserve more research? How do the long term outdoor tests correlate to the artificial pollution tests? Can the authors elaborate on the critical steam input rate used during the wetting phase of the solid layer test and on the statement that RTV-coated insulators collect more pollution than non-coated porcelain insulators, when exposed to the same solid layer suspension?

In their introduction the authors of Report A3-109 state that the utility nowadays applies composite insulators for their hollow core insulators, as at explosions less damage to the surroundings is expected to occur (explosions to be discussed under topic VIII, **Q. 2-4**). They further state that for mechanical reasons they do not use composite post insulators as busbar support or for earthing switches.

Q. 1-2

Can the authors elaborate on these mechanical and safety aspects? Is the same policy applicable to disconnectors? Do other utilities support this view and show service or testing experience?

II Pressure rise in GIS

Safety is an important design parameter for high voltage equipment. In Report A3-110 the simulation and testing of internal arcs in GIS is discussed. Under Preferential Subject 2, arcs in instrument transformers (topic VIII) will be addressed. The authors of Report A3-110 performed single and three-phase internal arcing tests on test models which are representative for a 145 kV GIS. The test results are compared with the pressure rise calculated by simulations based on CIGRE Technical Brochure 602 (WG A3-24, 2014). The authors included the effects of opening of the burst disc, the volume of the external exhaust compartment (during testing), the evaporation of conductor material and the exothermal reaction of conductor materials. Further they enhanced the gas model described in TB 602, to be

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applicable up to 10000 K (instead of 2000 K). As in TB 602 they concluded that the pressure and temperature rise due to aluminium evaporation and exothermal reaction is much higher than with cupper conductors. But, they also concluded that the contribution of conductor material evaporation is more severe than stated in TB 602. On the other hand a higher temperature of the gas results into a higher specific heat capacity and this compensating effect on the pressure rise has been covered by the authors' model.

Q. 1-3

As the results in TB 602, the authors point at the more severe effects of internal arcing when aluminium conductors are applied. In that case, the pressure rise after rupture of the burst disc is also astonishing. Can the authors or other experts highlight their experience with internal arc phenomena in relation to the rupture of discs, the rupture of GIS-enclosures and aluminium versus cupper conductors? Note that to CIGRE Technical Brochure 513 (WG A3.06, 2012), a few percent of major failures in GIS result in explosions. Do experts of the former WG A3.24 confirm the need for further fine-tuning their models?

III Disconnectors and earthing switches

The Reports A3-112, A3-113, A3-201 and A3-205 deal with induced current switching by earthing switches, bus transfer current switching by GIS disconnectors, and digitalization of disconnectors respectively. Bus charging current switching, bus transfer and induced currents switching are also shortly addressed in Report A3-307. Electromagnetically and electrostatically induced currents and voltages are under investigation for a couple of years, as well as bus transfer currents and recovery voltages (WG A3.28). For heavy loaded overhead lines, especially for long lines and rather compact and non-transposed lines, the specified values for induced current switching in the International Standards may not be sufficient. As there is a general trend to increase the loading of overhead lines, to erect more compact designs and vertical configurations without transposition, the statistical investigations in Japan (Report A3-112) may be or may become applicable to many utilities across the world. The authors advise to conduct an international survey to collect data. A similar situation occurs with respect to bus transfer current switching and bus charging currents, as substation buses become larger and the load currents higher. Here experts have reported that it is possible to reduce the currents by adapting the order of the bays, the configuration of the bus couplers, the procedure for bus transfer and/or a modification of the bus selection disconnectors. Attention should be given to bus transfer switching in large GIS and, especially, to large MTS, where requirements for AIS disconnectors should be applied to GIS-technology (Report A3-113).

Q. 1-4

Can experts highlight the need for an international survey with respect to induced current switching, bus transfer current switching and/or bus-charging current switching? Are there some requests for deeper investigations from standardization bodies? Are there maybe aspects not yet covered by the standards? What is the experience in service? And can manufacturers fulfil the requirements put forward by utilities? Are such requirements realistic? What is the experience with the endurance requirements as put forward in the standards (Report A3-113)?

In France, based on service experience, a large investigation program to improve the reliability of disconnectors is running (Reports A3-201 and A3-205). Disconnectors show a negative impact on the overall system reliability due to incorrect position information (faults in secondary and auxiliary system, wrong functioning of the kinematic chain, hot spots in primary contacts, blocked or broken parts). Under research are mitigations as advanced monitoring techniques (torque measurements), a digital drive with monitoring functions (Report A3-201) and pressure sensors near the primary contacts for monitoring and position indication.

Q. 1-5

Such improvements are partly applicable to existing (old) disconnectors as a retrofit and partly for new disconnectors. What is the relative cost increase compared to conventional solutions? Is for both cases a positive business case possible and how? What is the experience and policy of other utilities or

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manufacturers? Are the long-term reliability and availability of the new drive and monitoring techniques, including the electronic parts, indeed higher? Are earthing switches to be included as well?

IV HVDC switchgear

The Reports A3-104 and A3-105 deal with hybrid HVDC circuit breakers. Hybrid means that the load carrying branch of the circuit breaker is through metallic contacts with inherently low losses, but that DC current interruption is performed by a separate power electronics based branch. The mechanical load carrying branch shows a rather slow transition from "closed" to "open", compared to the power electronic branch. The Reports A3-111 and A3-115 deal with mechanical HVDC circuit breakers. Mechanical means that the load carrying function and the current interruption function are performed by the same mechanical switchgear. Typically a separate branch is required to inject a current of opposite polarity to force a current zero, thus enabling DC current interruption. Both hybrid and mechanical HVDC circuit breakers require a third parallel branch to absorb the magnetic energy released in the HVDC system inductance. JWG A3/B4.34 published CIGRE Technical Brochure 683 (2017) on the technical requirements and specification of the state-of-the-art HVDC switchgear.

In Reports A3-105 and A3-115 the technology of different designs of HVDC circuit breakers and their (type) test results are discussed. Here the focus is on a very fast clearing of the DC fault current in a meshed HVDC-grid. To maintain the stability in an HVDC-grid the voltage dip, which is rapidly widespread compared to an AC-grid, should last shorter than some tens of ms. In the Reports A3-104 and A3-111, the authors promote protection policies which allow a much slower fault clearing. In Report A3-104 the fault current is limited by the PE-part of upstream hybrid HVDC circuit breakers. In this way the voltage dip is also limited and less critical for system stability, so that the particular circuit breakers may eliminate the faulty part within a more suitable time period. In Report A3-111 the focus is not on the stability of the HVDC-grid, but on the stability of the AC-grids. In fact a 100 ms interruption of the HVDC-interconnection is considered to be acceptable for each connected AC-grid (even with a high penetration of low inertia generators) and this time period is used to shut down the HVDC-grid, meanwhile eliminating the faulty section and restart the energization of the HVDC-grid. The proposed protection strategy also includes a back-up protection and leads to greatly reduced energy absorption ratings.

The technological developments in China are very fast. In Report A3-105 the development of the Zhangbei 500 kV HVDC grid in the neighbourhood of Beijing is described. It has to be in operation before the 2022 Winter Olympics. The hybrid 500 kV circuit breaker exists of three branches: (1) a load carrying branch with in series ten very fast VCB's (2 ms, 3300 A. 60 kV) and an H-bridge of water cooled IGBTs to transfer the current to (2) the switching branch with many bi-directional IGBT modules for fast clearing of the (fault) current and (3) the energy absorption branch consisting of MOVs. No details of the energy absorption rating are provided. As overhead-lines are applied, the circuit breaker is capable to perform an auto-reclosing sequence.

The requirements to absorb energy during the fault current interruption process poses a challenge on testing of HVDC circuit breakers. Reports A3-105 and A3-115 present test circuits to verify the DC current interruption capability of HVDC circuit breaker modules, based on pre-charged capacitors and on low frequency AC short-circuit generators respectively. Report A3-115 pays attention to test facilities which protect the HVDC circuit breaker as well as the test circuits in case the test object fails to interrupt the fault current. Moreover, the dielectric stress after current suppression is addressed.

Q. 1-6

In the concept elaborated in Report A3-105 the VCBs are switched very fast by means of Thomson-coils and under no-load conditions; in Report A3-115 DC current is interrupted by means of active current injection. What are the differences and impact between AC current interruption and DC no-load or load interruption (contact bouncing, lost particles, imperfect contact surfaces in relation to the dielectric stresses imposed by the energy absorption branch)? What is the impact of ten VCBs in series on the HVDC circuit breaker reliability? How fast are the HVDC circuit breakers of the Reports A3-105 and A3-115: time from trip-signal to complete transfer to the energy dissipation branch (internal current commutation time) and time from transfer until current zero (fault current suppression time)? Can the authors or other experts explain whether and why these times depend on the interrupted current? What is the influence of the auto-reclosing sequence on the required energy dissipation capability of the MOV-branch and should auto-reclosing be considered as a standard procedure?

Q. 1-7

Is the HVDC meshed grid protection policy as proposed in Report A3-104 or A3-111 acceptable from the point of view of power system stability? And is such a policy still acceptable when the power production in such a grid reached values of five or more GW? What are the limits of the proposed policies? And what are the achievements? Is auto-reclosing possible with such policies?

V Controlled switching

WG A3.35, “Commissioning practice of controlled switching” is finalizing its studies and a Technical Brochure will be published in 2018. Controlled switching is the topic of the Reports A3-103 and A3-203. It is also mentioned in Reports A3-304 and A3-308, but not in the Reports A3-202 and A3-306 (Report A3-202 deals with shunt and back-to-back capacitor bank switching, and Report A3-306 deals with UHV filter-bank switching, respectively) although for such applications controlled switching is beneficial. Capacitive current switching is discussed under PS 3 (topic XII).

The authors of Report A3-103 give service experience with controlled switching applied to energizing shunt capacitor banks (even back-to-back) with unearthed neutrals (Canada). They highlight the complexity of tuning the controller to the mechanical and dielectric (pre-arcing) characteristics of the circuit breaker and the drift and scattering of the operating times. By measurements and simulations the sensitivity of the inrush-currents to deviations in the precise prestrike moment are illustrated. Such measurements and simulations are required to set the proper alarm levels of the controller. Commissioning needs field measurements, such as those recorded in the controller: voltage and current waveforms. But the authors use also recordings of a special diagnostic system that provides line and coil currents as well as the exact moment of prestrike by transient electromagnetic emission (TEE). By such advanced tools the commissioning time can be reduced.

In Report A3-203 the application of controlled switching for transformer energization and shunt reactor (de)energization is summarized (India). The intention is to avoid large inrush currents, overvoltages, damage, false tripping and reignitions. The authors compare the energization of huge transformers (1500 MVA, 765/400 kV) without controlled switching and with two different methods of controlled switching. One method is closing the first pole at the peak line voltage and the other poles simultaneously after multiples of a half cycle. The other method is based on residual flux measurements to find the proper moment of closing of the first pole and of the last two poles simultaneously. Examples are given.

Q. 1-8

Can the authors explain why the controlled switching of the large capacity transformers without or with adaptation to the measured residual flux gives similar small inrush currents? This seems not to be quite in line with the conclusions from the former WG A3.07 as published in CIGRE Technical Brochure 263 (2005). What are the difficulties of residual flux measurements (offset, micro hysteris loops, measurement errors, controlled de-energization, etc.)? How complicated and time consuming was the commissioning process? Can other experts highlight the problems they face with commissioning, maintenance and modification of controlled switching or replacing circuit breakers?

VI High voltage circuit breaker performance

The authors of three Reports pay attention to improving the TRV withstand capability by MOV installed in parallel to the arcing chambers (Report A3-101), to the severity of the different type tests (Report A3-102) and to the auto-reclosing performance (Report A3-107). The latter is in fact not the performance of the circuit breaker but of the system, as the Report deals with the optimal tuning of the neutral reactor of shunt reactors to improve secondary arc extinguishing and therefore the reclosing performance.

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A well-known method to reduce the peak value of the TRV in special cases such as fault clearing in series compensated overhead lines is to apply MOVs across the arcing chambers. In Report A3-101 this method to reduce the TRV-stresses is simulated for three cases in the Brazilian network. As the authors state, the application has to be tuned to the specific network situation and cannot be generally applied. Nevertheless the simulations show that considerable TRV peak reduction can be achieved in the three cases described, but no reduction of the Rate of Rise of the Recovery Voltage (RRRV). See further Topic VII, related to MOSA.

A statistical evaluation of the success-rate of type testing of modern circuit breakers is presented in Report A3-102. The evaluation is per test duty and covers almost 1000 tests of circuit breakers rated 72.5 kV to 800 kV. As may be expected because of its high RRRV the short-line test duty L90 shows to be the most onerous test with a success-rate of only 43%. Followed by the 100% fault current interruption test duties T100s and T100a, each with 60%, and surprisingly the out-of-phase test duty with 58%. The out-of-phase test duty shows the highest peak value of the TRV of all test duties, but the test current is only 25%. Other test duties with lower currents (75%, 60%, 30%, 10% of the rated short-circuit current) show a much better success-rate. In addition the authors point at new measurements and tools for arc modelling, so that the performance margins can be better understood: pre-zero arc conductivity and transient pressure.

Q. 1-9
Can the authors or other experts highlight why out-of-phase is such a difficult test duty? Can manufacturers or users confirm the difficulty to pass this dielectrically stressful test duty? What about medium voltage? Often the out-of-phase test duty is combined with T30 in order to save testing time. What conclusion can be drawn from the statistics with respect to this combination? Are the out-of-phase results understood from the new measurements and simulation tools? Or are these tools more directed to the thermal interruption rather than the dielectric interruption phase that plays a role at out-of-phase tests and the interruption cases of Report A3-101? Are other tools required and/or available?

Preferential Subject 2

LIFETIME MANAGEMENT OF TRANSMISSION & DISTRIBUTION EQUIPMENT

Topics: VII MOSA, VIII Instrument transformers

VII MOSA

MOSA are addressed in Report A3-101, to reduce the peak value of the TRV as discussed under PS 1, in Report A3-106 to reduce switching overvoltages (China: UHV) and in Report A3-206 on MOSA reliability and service experience (Japan). To keep the dimensions and costs of the UHV infrastructure under control, the transient overvoltages (especially the switching overvoltages) have to be reduced as much as possible. The authors of Report A3-106 put forward the concept of a controllable MOSA. By this concept at the moment of a switching operation a part of the MOSA is by-passed by a switch (called “K-switch”), thus adapting the MOSA characteristics (in the example by 15% reduction). In this way a reduction of the switching impulse protection level can be achieved while maintaining the original lightning impulse protection level and the MOSA capability for temporary overvoltages.

Q. 2-1
The concept does not reduce the slow front overvoltages caused by a fault that occurs. Is, in this concept, the worst transient overvoltage to be considered in the power system the overvoltage due to the occurrence of a single phase to earth fault? Before switching a circuit breaker, how fast is the “K-switch” opened and closed? What is the time delay introduced in circuit breaker operations at fault clearing and reclosing; and how is the temporary overvoltage introduced by single phase faults handled? What type of switchgear is used for the “K-switch” and are there special dielectric or mechanical characteristics? Do other utilities apply comparable solutions to reduce overvoltages?

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Q. 2-2
As stated in both Reports A3-106 and A3-101 the described solutions to reduce the peak value of a switching overvoltage and the transient recovery voltage, respectively, offer the advantage to omit the pre-insertion resistors (PIRs). Are these really omitted and what are the technical and economic advantages of the solutions proposed compared to the PIRs?

The reliability of MOSA as summarized in Report A3-206, is very high. Most of the limited number of Major Failures (categories A and B in the Report) are caused by external causes like earth quakes and an excessive energy dissipation as shown by some examples. One of the 48 Major Failures resulted into damage to other high voltage equipment. Maintenance consists of visual inspection, insulation resistance measurement and leakage current measurement on a regular basis (every 2 to 12 years), but utilities in Japan are considering to reduce the frequency of maintenance. Some utilities monitor the discharge current and the number of discharges. The leakage current measurement includes measuring the waveform of the leakage current and good experience with this diagnostic technique is illustrated. The new CIGRE WG A3.39 “Application and field experience with Metal Oxide Surge Arresters” will collect and investigate service experience of MOSA.

Q. 2-3
Can utilities (users) share important service experience especially considering the consequential damage when a MOSA fails? What is the experience and policy with sacrificing MOSA to protect other equipment? What is service experience with specific diagnostic techniques?

VIII Instrument transformers (ITs)

The risk of violent failures (explosions) of ITs in AIS is mentioned in the Reports A3-204, A3-207 and A3-311. New technology ITs are introduced in the Reports A3-310 and A3-311.

In both Reports A3-204 and A3-311 a pressure relief device is implemented in an oil/paper insulated and a clean-air insulated IT respectively for AIS. The author of Report A3-204 pays attention to the type test procedure for internal arc tests on ITs: the location of the short-circuit wire, the difference between the IEC and the IEEE Standards and the interpretation of the test results. A new CIGRE WG A3.42 “Failure analysis of recent incidents of AIS instrument transformers” will investigate the service experience with violent failures and the possibilities to mitigate or reduce their impact. One of the mitigations for capacitive voltage transformers (CVTs), as given in Report A3-207, is monitoring the condition of the capacitors. The authors use the centrally collected information from energy metering by CVTs to detect sudden deviations as an indication of failing capacitors. By this monitoring system also other measurement problems have been detected. In the very short Report A3-310 a combined digital (optical) current transformer and capacitive voltage divider is highlighted. High precision measurements with integrated frequency, power, power factor, power quality and basic protection functions are possible.

Q. 2-4
In his conclusion the author of Report A3-204 states that for internal arc specification and type testing the single phase-to-earth fault current should be taken and not the three-phase fault current. Is neglecting cross-country faults and other multi-phase faults statistically a correct assumption or is this to be investigated by the new WG A3.42? Do experts of WG A3.42 or other experts support the author’s view that the type test as defined in the international standards should be better defined? Are other monitoring techniques than the CVT-measurement known to prevent violent failures; for instance TEE (topic V) or UHF PD-detection by multiple antennas? What is the explosion risk of the technical solution presented in Report A3-310? Some users believe that ITs with composite insulation are more safe than ITs with porcelain insulation. What is the service or test experience and which precautions for internal arcing have to be taken for composite insulators; for both for ITs and other hollow insulators (topic I)?

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Preferential Subject 3

NOVEL DEVELOPMENTS OF TRANSMISSION & DISTRIBUTION EQUIPMENT

Topics: IX SF_6 alternative, X Generator circuit breakers, XI MV switchgear developments, XII Capacitive current switching

IX SF_6 alternatives

As alternative technologies to SF_6, different gas mixtures are dealt with in four Reports of A3-301, A3-305, A3-307 and A3-309, also state-of-the-art vacuum interrupter technologies are dealt with in two Reports of A3-302 and A3-311. While all gas mixtures consist of CO_2 as main component, second and third gases are different among the four reports. Report A3-305 deals with arc interruption by a gas mixture of CO_2, O_2 and fluoroketones, while a gas mixture of CO_2, O_2 and fluoronitriles is used in Report A3-301, and a gas mixture of CO_2 and fluoronitrile (i.e. without O_2) is applied in Reports A3-307 and A3-309. Guided by the four reports, questions can arise for comprehensive understanding of methodologies for selection of optimal contents of gas mixtures and switching performances of gas mixtures. The benefits of additional O_2 must be one of major interest. The reports also suggest that deeper understanding and more careful consideration are necessary for application of the alternative gases compared to conventional SF_6 equipment. Some trends can be seen: the design of the arcing chamber has to be adapted slightly different from the SF_6-technology to the gas mixture technology, static gas pressure is required to be higher than with SF_6-gas as well as transient gas pressure behaves differently form SF_6-gas, the mechanical and electrical endurance has to be verified. In addition, critical switching duties are main concern for each gas mixture. Report A3-301 and A3-309 regard the duty of L75, which requires thermal interrupting capability, as one of the most difficult breaking tests for the fluoronitrile mixture. Report A3-309 also indicates a higher arc voltage of the fluoronitrile mixture than of SF_6 during L75 test. On the other hand, the authors of Report A3-305 show good thermal interrupting capability (L90) partially attributed to CF_4 formation and proven by the small post arc current magnitude and shorter time to peak. However, the test duty T10 interruption performance (dielectric interrupting performance) tends to decline at a lower rate of the fluoroketone content. When the mol percentage is reduced to 3% from the original 5% (which shows a performance equal to SF_6), a fifty percent higher gas pressure is required. As another alternative to SF_6, vacuum interrupters are dealt with in Report A3-302 for generator circuit breakers and in Report A3-311 for 145 kV circuit breakers. Capabilities for high current and high voltage are mentioned respectively.

Q. 3-1

Can the authors and other experts guide the audience through the relevant information they want to share: ketones versus nitriles, O_2 added or not, static gas pressures, mol percentages, performance limits, endurance limits and their dominant factors (I^2t or It?), low temperature application, etc.? Do the manufacturers increase the opening speed of the contacts as compared with that of circuit breakers with SF_6 to secure the capacitive current switching performance? Is there any impact of the decreasing content of fluoro-gasses (due to decomposition) on the capacitive current switching performance? For better understanding the criticality of the SLF duty with fluoronitrile gas mixtures, can authors or other experts provide details about the post arc behaviour? Can the authors of Report A3-305 highlight whether and why fluoroketon mixtures show a higher capability on thermal interruption? Does the higher arc voltage of the fluoronitrile mixture suggest a superior bus transfer performance for disconnectors? Can authors or other experts give proposals about the treatment of gas mixtures containing decomposition by-products generated by current interruption, and show how the partial densities can be monitored?

Q. 3-2

Alternative solutions to prevent the use of SF_6-gas, as given in Report A3-311, are still limited to the lower transmission voltages, but cover a large amount of applications. Can experts provide any suggestions about the possibility and technical/economic challenges of vacuum interrupter for higher ratings than 145 kV and differences between live tank and dead tank designs? What are the limits foreseen for single interrupter VCBs? Are the potential issues related to capacitive/inductive current switching as identified by CIGRE WG A3.27 solved? Can the authors of Report A3-302 provide the limit on rated current of present and future vacuum interrupters with single and multiple breaks? Can

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the authors or other experts show the potential market share compared to the total SF_6-gas business? Are other examples of alternatives than vacuum, fluoronitriles and fluoroketones to be mentioned?

X Generator circuit breakers

The Reports A3-114 and A3-302 deal with generator circuit breakers; in Report A3-303 attention is given to functions as specified for generator circuit breakers. To Report A3-114 many dielectric and mechanical failures in generators, power plant motors and other equipment were caused by the high voltage generator circuit breaker. This was partly caused by false synchronization (including flashover across open contacts) and partly by the transfer of the power plant house-load between the network transformer and the auxiliary transformer that is fed by the step-up transformer. By applying a medium voltage generator circuit breaker the transfer is no longer necessary. In Report A3-302 the design of a 24 kV/12500 A/100 kA generator circuit breaker based on vacuum circuit breakers (three parallel interrupters per phase) is summarized and further development up to 27 kV/14000 A/120 kA is mentioned. Attention is given to clearing fault currents with inherently delayed current zeroes; by simulations the authors defend that like with SF_6 technology vacuum technology may force current zeroes to occur within the arcing window that can be handled by the circuit breaker. A result of simulation is introduced which shows a successful interruption by clearing delayed current zeroes under the condition with an additional arc fault voltage of approximately 300 V. They also point out that current chopping and dangerous reignitions will not occur, since the generator load current is too large.

Q. 3-3

Usually generators are switched off by reducing the power output until the reverse power relay gives a trip signal. Isn't there not a risk of current chopping by vacuum circuit breakers at such low current levels? And what about clearing the step-up transformer excitation current as mentioned in the IEC/IEEE Standard? What is the risk of current chopping by generator circuit breakers of SF_6- or air-blast technology? How is adequate current sharing between the parallel bottles guaranteed?

Q. 3-4

The vacuum arc voltage at the interruption of large asymmetrical fault currents has been measured to be 100 V or more (Figure 3 in Report A3-302). As the arc is of a resistive nature, isn't the arc voltage depending on the momentary value and isn't the amplitude proportional to the current peak value? Did the authors simulate the vacuum arc as a current or time dependent resistance or as a fixed voltage source? Also at out-of-phase switching missing current zeroes can be encountered. As shortly mentioned in Report A3-303 and elaborated in CIGRE Technical Brochure 716 (JWG A3/B5/C4.37, 2018) "System conditions for and probability of Out-of-Phase", faulty synchronization gives a fast acceleration/deceleration of the generator rotor and therefore a fast decrease of the AC-component of the out-of-phase current. Did the authors of Report A3-302 include this phenomenon in their simulations? Which service experience can be given with clearing generator short-circuit and out-of-phase currents by vacuum circuit breakers? Can the authors of Report A3-302 show the waveforms of three-phase short-circuit and out-of-phase with the condition of the longest duration of delayed current zeros? Can the authors or other experts give examples of actual test results of clearing delayed current zeros defined in IEC/IEEE 62271-37-013?

Developments in distribution and sub-transmission grids lead to volatile, variable and bi-directional power flows, mainly caused by dispersed generation. Report A3-303 draws attention to MV switch-gear that has to switch generators or isolate and synchronize parts of networks. As long as conventional power plants are involved MV circuit breakers may have to fulfil requirements known from generator circuit breakers, including to withstand the dielectric stresses across open contacts between two separated networks or a generator and a network. Nowadays, most dispersed generators are non-synchronous power plants (i.e. generators connected by power electronic converters), which show a complete different behavior.

Q. 3-5

Can utilities or other experts report on the need for MV general purpose circuit breakers to separate generators or power systems, to support islanding and/or to synchronize generators or power systems?

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What service experience can be shared? Which requirements are applicable for MV grids with non-synchronous power plants? What about the dielectric strength across the contacts of relatively small circuit-breakers in relation to separated networks?

XI MV switchgear developments

As discussed for disconnectors under PS 1, digital information-, control- and drive-technology penetrates also into the area of MV circuit breakers, re-closers and fault interrupters: Reports A3-303 and A3-304. In Report A3-304 the technology supports the performance of the circuit breaker by precise control of the travel characteristics for each pole independently and supports its diagnostics. In Report A3-303 the technology is applied for added functions like tele-control, automatic system restoration, fault localization and islanding. Other developments are a trend to implement circuit breakers rather than fuses and switches, to install compact designs, to put installations in confined spaces, or at difficult to access locations and to specify switchgear that is to a large degree “plug and play”.

Q. 3-6

Some of these developments may be forced by circumstances such as a lack of space or the need for more advanced protection, but others are perhaps more questionable. What are the business cases behind the technological developments such as a digital drive, fault localization, compact and submersible designs, “plug and play”? What about tele-control and auto-restoration? Is this a wide trend or only for special cases? Can the experts categorize per application the requirements for MV switchgears and the field experiences and/or common failures? Can the experts give an image of the future self-supervising and diagnostic techniques for equipment using Internet of Things (IoT) and their influences on asset management strategies? Will the expected life of state-of-the-art MV switchgear be tending to decrease due to the more intensive use of electronic devices?

XII Capacitive current switching

Capacitive current switching is the topic of Report A3-202 (shunt and back-to-back capacitor bank switching in Egypt), Report A3-306 (UHV filter-bank switching in China), and Report A3-308 (long shunt-compensated cable switching in Spain). In Report A3-202 the problems with switching overvoltages, inrush currents (up to 10 kHz), large dI/dt especially for the secondary side of current transformers are mentioned; phenomena already discussed in CIGRE Technical Brochure 624 (WG A3.26, 2015) and its references.

In Report A3-306 an extended type test of an 1100 kV live tank breaker for back-to-back filter-bank switching is described. The test voltage was 1.3 p.u., the capacitive current 400 A, the inrush current 8 kA/4250 Hz, class C2 to IEC 62271-100 (120 making and 168 breaking operations) plus a margin test consisting of 4 sequences with each 120 making operations and 96 breaking operations (at minimum arcing times). In total 600 making and 552 breaking operations were performed with only one restrike. A very low probability of restrike can be deduced for the first 3000 operating cycles and a low probability for the next 2000 operations at site. With an extreme maximum of about 500 cycles per year in service (usually less than 250), an overhaul interval of at least ten years can be achieved.

Q. 3-7

Like back-to-back shunt capacitor banks, filter-banks are switched on and off quite frequently, thus making an endurance type test necessary. Due to the large numbers of operating cycles, at regular intervals the circuit breaker has to be overhauled. Is an interval of ten years acceptable to the users? Do utilities keep track of the number of single capacitor bank and back-to-back bank operations and do they consequently apply overhaul? What is most critical: the electrical or the mechanical endurance or the combination? What is the service experience with circuit breakers that are applied for frequently switched capacitor banks? Are the PIR-switches critical from the point of view of endurance? Can the authors or other experts give the service experience of controlled switching applied for capacitor banks, especially for UHV? Are there any differences of stresses among circuit breakers applied for cable-systems, capacitor-banks and filter-banks?

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Report A3-308 deals with switching an 126 km long (mainly submarine) 132 kV AC XLPE cable, shunt compensated. The whole system exists of two parallel cable circuits, each with six three-phase switchable shunt reactors (3*17 Mvar at each side). Two switching conditions have to be met at energization of a cable: low switching overvoltages (achieved by all shunt reactors connected and by closing at voltage zero) and reduced occurrence of missing current zero phenomena (achieved by less connected shunt reactors and by closing at voltage maximum). An optimal energization procedure has been found by simulations and has been implemented by controlled switching. The other side is switched by a synchro-check relay. Similar phenomena have been reported in CIGRE Technical Brochure 336 (WG A3.13, 2007).

Q.3-8
Worldwide more and more long sections of shunt compensated AC-cable are expected to be installed. What is the service experience so far with circuit breakers and with switching overvoltages? What typical engineering phenomena have to be considered? Can the authors or other expert suggest the effect of the arc voltage across the circuit breaker contacts on missing current zero phenomena in long cable network? Is there a need for deeper investigations by CIGRE? The project described in Report A3-308 is a double cable circuit with at each end a substation with a breaker and a half scheme; in total eight circuit breakers equipped with controlled switching relays. Is there a mutual influence with respect to the switching phenomena? Are the problems confined to energization only (for instance: restrikes)?

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General information

Within SC A3, dealing with AC & DC Transmission & Distribution equipment, seven Working Groups have published or will publish their Technical Brochures in 2017/2018:

WG A3.25	MO varistors and surge arresters for emerging system conditions (TB 696)
WG A3.29	Deterioration of ageing substation equipment and possible mitigation techniques (TB to be published in 2018)
JWG A3.32/CIRED	Non-intrusive methods for condition assessment of distribution and transmission switch-gear (TB to be published in 2018)
WG A3.33	Experience with equipment for series/shunt compensation (TB 693)
JWG A3/B5.34	Technical requirements and capability of state-of-the-art DC switching equipment (TB 683)
WG A3.35	Guidelines and best practices for commissioning and operation of controlled switching projects (TB to be published in 2018)
JWG A3/B5/C4.37	System conditions for and probability of Out-of-Phase (TB 716)

Other working Groups are:

WG A3.30	Overstressing of HV substation equipment
WG A3.31	Instrument transformers with digital output
WG A3.36	Application and Benchmark of Multi Physic Simulations and Engineering Tools for Temperature Rise Calculation
WG A3.38	Capacitor switching in distribution and transmission systems
WG A3.39	Application and field experience with Metal Oxide Surge Arresters
WG A3.40	Technical requirements and testing recommendations for MV DC switching equipment at distribution levels
WG A3.41	Interrupting and switching performance with SF_6 free switching equipment
WG A3.42	Failure analysis of recent incidents of AIS instrument transformers

Important dates

Experts who wish to contribute to the SC A3 Session are required to send their draft **prepared contribution** to the Special Reporters before **July 15th, 2018**, in order to check whether and where the contributions fit into the program: anton.janssen@alliander.com. The draft presentations will also be checked on readability and technical/scientific content (no commercial information is allowed). Prepared contributions in draft, which are received after **July 15th**, will not be considered for presentation at the Session. During the Session, for each prepared contribution a time slot of three to 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 and whether it can be presented; before **August 15th**. Authors and WG-convenors who are invited to give a short (ten minutes) presentation of their Report will be informed before **August 15th, 2018**.

The **SC A3 Session** is scheduled for Wednesday, **August 29th**, in the Salle Bordeaux, at the 3rd level. On the day before the Session (i.e. on Tuesday, **August 28th**) **all experts with Prepared Contributions** 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 CIGRE Central Office.

During the Session the Chairman may call for spontaneous contributions. Attendees who provide a **spontaneous contribution**, are allowed to deliver a text for the Proceedings. This text is required to be forwarded within a maximum delay of two weeks after the SC A3 Session (thus by Wednesday **September 12th**, 2018) to anton.janssen@alliander.com.

The authors of the SC A3 Session Reports present the results of their studies during the **Poster Session** on Tuesday morning 9:00-12:00, **August 28th, 2018**. If the author(s) cannot attend the Poster Session the National Committee is requested to send a substitute. All SC A3 WGs will present the progress and results so far of their investigations. For each Report (and each SC A3 Working Group) a monitoring screen will be available to show the poster. Before **August 1st**, draft posters have to be sent in digital format to anton.janssen@alliander.com or wpepper@ausgrid.com.au. After receiving the draft posters, the Convenor of the A3 Poster session, Wayne Pepper (Australia) will review the readability of the draft posters and inform the authors.