A3-00

SPECIAL REPORT FOR GROUP A3
(High Voltage Equipment)

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(Special Reporters)

The CIGRE 2004 General Session will be the first one where the newly established Study Committees will have the possibility to present themselves. In comparison to the scope of the former SC13 (Switchgear), SC A3 deals with all HV equipment - except power transformers, reactors and power electronic devices (HVDC, FACTS) - in the substations and in OH-line and cable connections.

For the Session 2004, SC A3 has selected three Preferential Subjects and 25 Reports have been submitted. The Preferential Subjects have been clarified by means of a list of topics, which almost all have been addressed in the Reports. Due to the wide scope of SC A3, the Special Reporters have clustered the Reports in 7 groups, spread over the Preferential Subjects, as follows:

- Pref. Subject 1: Development in HV devices and application of advanced IT tools (16 Reports):
    - Developments in circuit-breaker technology (A3-101, -106)
    - Composite insulators and surge arresters (A3-103, -104, -105, -110, -307)
    - Advanced instrument transformers (A3-102, -108, -109, -111, -113 and B2-101)
    - Controlled switching (A3-107, -114, -115)
- Pref. Subject 2: Combined HV devices and integrated functions (2 Reports):
    - Combined functions (A3-201, -301)
- Pref. Subject 3: Application problems with HV apparatus (7 Reports):
    - Reliability and maintenance (A3-305, -306, -112)
    - Abnormal stresses (A3-302, -303, -304, -308)

PREF. SUBJECT 1: development of HV devices and application of advanced IT tools

- Alternative breaker technologies
- New drive concepts
- Sustainability with regard to the environment, reduction of SF6 loss-rates
- Use of composite insulators and cast designs
- Low power instrument transformers
- Optical instrument transformers
- Implication on maintenance procedures (see Pref.Subj.3)
- Integrated monitoring and diagnosis (see also Pref.Subj.3)
- Improvement of performance by smart control of the device
- SF6 leakage

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Developments in circuit-breaker technology

During the last decade, the improvements in circuit-breaker designs are mainly those of a further development of existing technologies. Simplifications of designs, reductions of the number of arcing chambers, reduced mechanical energies, higher rated voltages for VCB's have been discussed at the CIGRE SC13 Sessions. Although the limits of these trends have not yet been reached, the authors of Report A3-101 did a step beyond the development of each individual technology and investigated the possibility to combine the SF_6 self-blast technology with vacuum technology in order to exploit the advantages of both. A (low content) SF_6 arcing chamber has been put in series with a vacuum bottle, driven by the same operating mechanism, albeit with a certain time delay for the vacuum interrupter.

Q.1-1 At the breaking of currents, especially in case of steep RRRV's, the vacuum interrupter is taking care of the initial part of the recovery voltage stresses (the so-called thermal part), as expected and as proven by the post-arc current measurement, shown in the Report. The post-arc current lasts for a few µs. After several tens of µs the dielectric stresses are almost completely borne by the SF_6-interrupter, roughly to a ratio 145/(145+24). Is this interpretation correct and does it mean that, generally speaking, 85% the dielectric part of the TRV can be covered by SF_6-designs with a much lower filling pressure or arcing chambers with a lower rated voltage? What happens to the SF_6 interrupter in terms of dielectric stresses in case of partial restrike of the vacuum interrupter ? What clue can be learnt form the post-arc current at L60?

Q.1-2 Did the authors already investigate or do they have an opinion about the behaviour of the hybrid design under stresses with long arcing times: large DC-time constants, major extended loop, super-asymmetrical currents, delayed current zero's? How is the behaviour of the hybrid design after a re-ignition or re-strike? Did other experts investigate similar hybrid solutions? Are there other experiences of innovative technologies devoted to the reduction of the environmental impact, by means of the reduction of the quantity of SF_6 gas or the replacement of this gas with other gases?

As stated above, there seems to be no limit to the trend to further optimise for instance the operating mechanisms. Two years ago a servo-motor drive has been presented and now the authors of Report A3-106 describe the advantages and disadvantages of a combined spring/servo-motor system.

Q.1-3 Opposite to the hybrid hydraulic/spring operating mechanism that has been launched in the eighties, the hybrid solution in Report 106 seems to be a redundant drive, where the spring is applied as a back-up for the electric servo-motor drive. Such a redundancy in the operating mechanism is quite extraordinary. Is this approach a step forward to improve the reliability of operating mechanisms, despite its costs and complexity? Or is the redundancy in the proposed design solution in fact a questioning of the reliability of servo-motor drives in general: electronics, high-energy capacitors, servo-motor, self-monitoring? Do other experts support this vision and are other measures to improve the reliability foreseen? Can experts from CIGRE WG A3.12 ("Circuit-breaker controls") contribute to the discussion about the reliability of electric/electronic/digital control systems?

Composite insulators and surge arresters

Composite materials have been used as an alternative to porcelain and glass for the constitution of the insulation of overhead lines since many years now. The application of composite materials to the housing of HV devices is much more recent and its performance is still under study. Three Reports in this Session deal with the application of polymeric insulation to HV equipment (A3-103, -104, -110). Paper A3-103 reports the results of very long tests (up to 20 years !) carried out in natural pollution conditions on material samples and on real line and post insulators made of different composite materials. Statistical analysis is carried out on the test results to derive the time to breakdown under the hypothesis of a quasi-uniform electrical field. Report A3-104 deals with the application of HV composite insulators to HV equipment under different types of natural environments characterised by levels of pollution, ranging from the marine type of environment to the semi-desert situation. The behaviour of the samples is analysed in terms of surface ageing characteristics and pollution performances; the implications for the standardisation of laboratory tests are also put forward. The superior behaviour of modern polymeric materials is very strongly put forward and an important reduction of the specific creepage distances can be allowed. A discussion about the behaviour under natural and artificial environments of polymer housed surge arresters is reported in paper A3-110. Retrofitting of existing porcelain types insulators with RTV coatings is also considered.

Q.1-4 All the papers of this group claim a superior field performance of polymeric insulators for HV equipment with respect to ceramic type and with respect to polymeric line insulators, both in terms of pollution withstand and of ageing. Is the experience reported in the papers shared by other users? What is the effect of the type of environment on the performances? What is the effect of the type of design? Is there any experience in the reduction of creepage distances of polymeric equipment insulators? Also taking into consideration the better protection performances of modern metal-oxide surge arresters? Are there economical advantages in this change of insulation coordination practice?

Q.1-5 One of the aspects which is considered in this group of papers is the relationship between the results of standardised laboratory tests versus the observations of real field behaviour. The data reported shows the existence of a gap between these two approaches which calls for a discussion. Several type of short and long duration tests have been set up and standardised, deriving the experience from that of line insulators. What is the representativity of long term laboratory ageing tests presently standardised on equipment polymeric insulators and equipment? Is there any equivalence between the different cycles that are present in the standards and in the literature? It can be demonstrated that for a given type of material or design it is always possible to establish a test procedure that will make the samples fail; is it therefore correct to use different types of environmental stresses for the different types of insulating materials? Wouldn’t it be more rational to try to represent the environment in which the component is going to operate? Similar types of HV equipment insulators are used for the insulation of different types of components: how can this be taken into consideration in the standardisation? What is the influence of the active part inside the insulator on the pollution and long term behaviour of the insulator? Is it rational to carry out tests on materials or mock-ups instead of complete HV components? How can we combine functional tests on equipment with the performance tests on the insulation?

In Report A3-105 the overload behaviour and short-circuit testing (pressure relieve test) of metal-oxide surge arresters in polymeric housings are discussed, while Report A3-307 addresses high gradient (HG) surge arresters. The scope of the short-circuit tests is to verify that in case of fatal overload, the surge arrester fails in a safe way: without any explosion of the envelope or harmful projections of materials or sustained burning. Where the short-circuit tests for designs with venting systems (porcelain and polymer type A, tubular) seems to be established, the short-circuit test for the completely sealed designs is still under discussion within IEC TC37/MT04, especially the most onerous or most probable location of the failure inside the ZnO blocks, the fault initiation by a fuse wire, the pre-stressing method, the applied short-circuit peak current and the applied source voltage.
The lack of international consensus on several points had the consequence of a de-rating of the proposed test to an “informative annex” in the IEC-Standard 60099-4.

Q.1-6 Can users illustrate pressure relieve experience with polymer metal-oxide surge arresters in service? Are they supporting the importance of a well defined short-circuit test? Can they or manufacturers/scientists give information about the probability and consequences of failures? Has CIGRE WG A3-17 (Surge Arresters) statistical material available or is the new WG A3-06 (Reliability of High-Voltage Equipment) collecting data? What about surge arresters in GIS?

Q.1-7 In terms of the failure mode of the MOV blocks, paper A3-105 points out that the better the homogeneity of the MOV blocks, the lower is the probability of puncture close to the rim under overload conditions. Are the findings reported in the paper representative? Report A3-307 deals with HG elements: has the probability of puncture through the centre of the HG blocks increased? The authors of Report A3-105 recommend, when applied, only a fuse wire in the centre of the ZnO blocks. Is their view supported by other testing authorities, by users and by manufacturers?

Q.1-8 The authors explained testing experience and testing problems when short-circuit laboratories lack enough voltage and enough power to test the designs under service conditions. Based upon problems in the laboratory, based upon some physical constraints caused by the arc voltage and because of a better representation of the service conditions, the authors also recommend to initiate the

full short-circuit current about 2 ms after voltage zero. Do other experts support this idea? Are the recommendations equally applicable to surge arresters with venting systems? Is a difference in approach for MV resp. HV/EHV arresters foreseen? Is the probability of a complete failure close to voltage minimum negligible? Do users know by chance the short-circuit current peak factors?
What precise advantages do the authors foresee: higher rated voltages to be tested, longer housings, more representative tests, lower costs of testing? Are the limitations given in the paper recognised by other laboratories (minimum applied voltage in relation to the arrester's height and the arc voltage)?

The increase in the varistor voltage of the HG-blocks per unit of thickness, as described in Report A3-307, allows a dramatic reduction in the surge arrester total height. The use of this technology allows a small improvement in the protective performances (5% reduction in the residual voltage) and a favourable environmental impact through simplifying and compacting the complete assembly.

Q.1-9 The reduction in the height may be jeopardised by the necessity to add internal spacers to guarantee the withstand capability of the housing to the residual voltage of the device itself. What is the experience and the need in the axial compaction of the device? What are the potential applications of such type of devices apart from the GIS and oil-immersed where the external medium helps in avoiding the surface flashover of the blocks under the residual voltage of the surge arrester? What is the experience in the development, test and use of HV equipment combining the functions of surge arresters with other functions in the same envelope?

Advanced instrument transformers

The application of non-conventional instrument transformers, using optical and/or electronic technology and digital signal processing can potentially simplify and compact the primary devices, increase the flexibility of the system and reduce the occurrence of problems specific to the conventional instrument transformers technology. However, although the initial developments of optical technology for instrument transformers are more than 15 years old, early applications suffered from instability due to temperature variations, mechanical problems and accuracy. Recent technical improvements allowed a dramatic increase in the reliability and stability of these devices and enabled their wider application virtually on all voltage levels. Several techniques and policies are available in terms of sensors, degree of integration and output characteristics and protocols. Papers A3-108 (electronic: capacitive and Rogowski), A3-109 (optical), A3-111 (optical) and B2-101 (passive all fibre technology with optical voltage signal derived from CVT) report the experience of the application of voltage and current transducers for metering and protection. All four reports summarize the development phase, tests (A3-108 includes conformity testing) and trial installations in service.

Q.1-10 The papers of this group reported the application of optical or electronic technology in general for the realisation of non conventional instrument transformers. What is the experience worldwide in the practical application of such technologies? How do the different possible techniques used for the sensors and the integration compare with one another? What are the criteria to select the proper technology as a function of the application? What are the possible accuracies and calibrations obtainable? In which primary signal range? What are the factors influencing the accuracy? What is the stability of present optical and electronic instrument transformers with the temperature? Is there any degradation of the performances with time? What is the influence of mechanical stresses? Can the members of the new WG A3-15 (Non-Conventional Instrument Transformers) give their view?

Q.1-11 One of the major open points is linked with the selection of the type and protocol of output of the instrument transformer to the measuring or protection devices. The use of traditional analogous voltmetric and ammetric circuits for the measurement of electrical quantities and of electromechanical protections required a high level of output signal from the instrument transformer. This fact contributed to the inhibition in the use of optical technologies. The present availability of digital meters and protections opens the field to a wider application of such devices. Two facts need to be addressed: first of all the way in which to manage the transition between the full-analogous to the full-digital policies, and secondly the protocol to be used in the full-digital substation of the future. What is the experience in the transition between the conventional instrument transformers and the innovative technologies? What are the achievements and the challenges in the transition between the high energy analogous communication, the low energy analogous communication, the full digital communication? What is the experience in the application of the IEC 61850 communication protocols?

Report A3-102 presents the application of printed circuit board Rogowski coils for the construction of non conventional instrument transformers. Such devices measure the rate of current change and can be used, with an appropriate signal integration, to measure currents for protection or signalling purposes. The declared performances are striking, in terms of level of accuracy, measuring range, signal bandwidth and short-circuit performances. In Report A3-113 the authors illustrate the results of a wide in-service checking campaign to assess the stability of the metrological properties of conventional instrument transformers; capacitive voltage transformers have been found as the most prone to degradation but, surprisingly, also inductive voltage transformers were found degraded in their metrological properties; on the base of the experience reported in the paper, the authors also suggest the possibility, through what they call “the electronization of the secondary circuits”, to adapt corrective measures suitable for the continuation of the use of such devices inside their accuracy class.

Q.1-12 Can the authors of paper A3-102 elaborate on the declared levels of accuracy in terms of current range and frequency? What is the influence of the A/D converters and integrators to these performances (drift, offset, noise)? What is the experience in the practical application of such devices to high voltage systems? The possibility to use split-core designs open the potential application to retrofitting of existing systems and to the on-line calibration of conventional instrument transformers. What is the experience in the on-line check and calibration of instrument transformers? What are the testing protocols used? What is the experience in the retrofitting of instrument transformers through a conversion of secondary signals using electronic techniques? Can other utilities give examples of improving the performance of conventional instrument transformers by means of “electronization”?

<u>Controlled switching</u>

Where in some fields of application the usefulness of (micro)electronics is still an item of dispute (see Q.1-3), in other fields like protection, monitoring, control, but also metering, micro-electronics seems to be accepted fully. In the field of controlled switching the discussions are no longer about the problems with electronics, but about potential reductions in circuit-breakers stresses (A3-107), the optimal interaction between controller and circuit-breaker (A3-114) and the more complicated applications, as shown at the Session in 2002 (for example: transformer inrush currents) and now in Report A3-115 (three-phase shunt compensated line re-closing). CIGRE WG A3-07 “Controlled Switching” has finalised its activities by several publications in Électra, also recently. The three Reports support or elaborate the findings of the working group.

Q.1-13 In Report A3-107 the de-energisation of shunt capacitor-banks has been described. Due to the capacitive current through the system impedance the system voltage at the location of the capacitor-bank is a few percent larger in comparison to the voltage after switching off the capacitor-bank. This causes an initial voltage jump of the TRV, the effect of which is neglected by the authors. Does this mean that there is no influence of this jump on the arcing time? Other system conditions, leading to even larger jumps, are those under light load conditions, Ferranti-effects and load-rejection: high system voltages (possibly beyond the rated voltage) requiring switching off of capacitor-banks. Can the authors, users or other experts reflect on the probability, experience and effects of such system conditions? Do the authors support the view that controlled switching will be an advantage under these conditions?

Q.1-14 The authors of Report A3-107 studied several aspects related with the capacitive current switching tests as defined in IEC 62271-100 and claimed that the performance is not significantly influenced by the way how the TRV is shared among both circuit-breaker terminals or by pre-stressing with T60. Is this correctly understood and also supported by other experts, as usually pre-stressing is considered as quite severe for both capacitive tests and the verification of electrical endurance tests? Are the authors in favour of performing capacitive type tests and mechanical/electrical endurance type tests on the combination of circuit-breaker and controller?

Q.1-15 In Report A3-114 special attention has been given to the effect of idle times on circuit-breaker closing times. The authors show the necessity and success of an adaptive correction of the controlled switching time delays. Can the authors explain the effect of idle times on the opening characteristics? Are the authors in favour of monitoring switching overvoltages and transient currents to assess the performance of controlled switching? Is the experience of other experts confirming the statement that idle times show a stable and reproducable closing (opening) time deviation after 100 hours?

Shunt compensated lines, as discussed in Report A3-115 (or two years ago in Report 13-206), are normally long OH-lines with an important bulk transmission function. Usually for such OH-lines a single phase auto-reclosing scheme is applied and the application of three-phase auto-reclosing seems to be less probable. Special precautions against temporary overvoltages (caused by resonance between shunt reactor and line capacitance) may be necessary, such as applying a neutral reactor between the three-phase shunt reactor and earth, and attention should be given to secondary arcs and induced currents (Q.3-12).

Q.1-16 What is the utilities' opinion and experience with three-phase versus single phase auto-reclosing on shunt compensated lines? What is the service experience with controlled switching to reduce switching overvoltages?

For an auto-reclosing sequence, the authors of Report A3-115 distinguish between an algorithm based on calculating the envelope of the voltage beat pattern across the open poles and an algorithm to calculate the exact voltage waveform. As the envelope method is not accurate enough in all cases the authors prefer the second method, despite the fact that more computer power, calculation time and a higher signal to noise ratio are required. But the second method, based on Prony synthesis functions, offers also the possibility to accurately calculate the necessary (variable) extra time delay to prevent pre-arcing.

Q.1-17 Following the second method the authors elaborate along two ways how the optimum instant for closing of the second and third pole can be determined, but it is not clear why method A leads to such a late closing of the third pole and why method B leads to completely different switching instants in the voltage over time graphs (figure 6 versus figure 7). Do the methods include the prediction of the waveforms after reclosing of the first and second pole? Can the authors explain the principal differences and consequences of method B versus A? Maybe they can simulate figure 8 for method B to show the reduction in switching voltages? Is it to be foreseen that such complicated calculations can be performed in due time and with the required accuracy under service conditions?

PREF. SUBJECT 2: combined HV devices and integrated functions

- Emerging solutions
- New types of components
- Reliability in comparison to conventional arrangements
- Enhanced functionality
- Cost efficiency
- Maintenance procedures
- Service experience
- System interaction
- Testing procedures

Combined functions

Preferential Subject 2 has been selected as more and more users are looking for simpler and cost-effectiver substation lay-outs. By combining apparatus, or by combining functions, less equipment and less space (area, volume, expansion) is needed and environmental impact is reduced. Two Reports are related to this Preferential Subject, although only one Report has been submitted for Preferential

Subject 2: A3-201, dealing with disconnecting circuit-breakers. Report A3-301 addresses the use of air-insulated disconnectors to interrupt capacitive, magnetizing and load currents.

The authors of Report 201 claim that the high reliability and availability of circuit-breakers have lead to a situation that disconnectors, necessary to make safe maintenance possible, can be omitted. They underline that the air-insulated disconnectors need more maintenance than circuit-breakers. By means of circuit-breakers with inherently disconnector capabilities and some special measures, it is possible to design much simpler one-line schemes for the substations. IEC SC 17A is preparing a new Standard for such devices: IEC 62271-108. In the Report examples of a 400 kV double busbar/double breaker substation and a 130 kV single busbar scheme with one bus-sectionalizer have been elaborated.

Q.2-1 For the 400 kV substation the switching procedure for maintenance activities seems to be more or less comparable with that for conventional substations when maintenance has to be performed on busbars, busbar disconnectors, circuit-breakers or line/transformer disconnectors. Maybe the authors can illustrate in detail how the “manual disconnecting” is working and in which way they provide safety grounding of all HV-parts? Are other users applying similar one-line schemes and switching procedures?

Q.2-2 For the 130 kV substation no grounding switches are shown on the busbar sections and/or sectionalizer bay. For maintenance on a disconnector-circuit-breaker half the OH-lines/transformers/capacitor-banks have to be switched off, even the 400/130 kV transformer! Is that acceptable for such an important substation? How is the sectionalizer maintained? Why is the 400/130 kV transformer not connected to both busbar sections? What is the opinion of other utilities and what is the experience in Sweden so far?

Opposite to the Swedish solution, where the disconnector function is taken over by the circuit-breaker, in Report A3-301 it is described how disconnectors can fulfil to a certain extend the function of a circuit-breaker or switch. Normally disconnectors are used to de-energize small parts of the substation installations and to provide safety separations from the parts still energized. The authors state that air disconnectors are able to break magnetizing currents typically less than 1 to 2 A (no inrush currents) and capacitive currents up to a few amperes, but arc duration and switching overvoltages are strongly influenced by the source side capacitance (smaller source side capacitance leads to longer arcing times and higher overvoltages). Another duty of disconnectors is to commutate relative large load currents (hundreds to thousands A) from one busbar to another, from one OH-line to another and from a by-pass circuit to the series capacitor-bank. It is this loop current switching that gives the largest reach of the arc and therefore a risk of flashover to other phases or to earth.

Q.2-3 Can utilities illustrate their experience and policy with the interruption of capacitive, inductive and load currents by means of disconnectors? Under which conditions do they switch OH-lines and maybe cables or capacitor-banks with disconnectors (up to which currents, sizes or lengths)? For circuit-breakers the recovery voltage is expressed in p.u. multiplied by a voltage factor that depends on the neutral treatment of the system and the capacitive load and on the pole discrepancy. What is the effect of such parameters when switching capacitive currents with disconnectors? Do utilities transfer load from one transformer to another by means of disconnectors?

Q.2-4 Do the authors recommend certain limitations in the application of disconnector switching, or special measures or do they have in mind to adapt the Standards or the Application Guides for disconnectors? What do they regard as the best choice in case of, for instance, the transfer of load from one transformer to another or from one cable to another: that the disconnector is used for the load transfer function or just for the interruption of the magnetizing current and small capacitive currents?

PREF. SUBJECT 3: application problems with HV apparatus

- Impact of wave form and multiple strikes/lightning strokes on the energy capability of surge arresters (HG: see Pref.Subj.1)
- DC application of surge arresters (not covered)
- Impact of severe, non standard and special duty service on design, performance and life cycle

- Reliability and testing/specification of grading capacitors for HV circuit-breakers
- NSDD's of switching devices
- Interaction between switching equipment and other HV components (e.g. transformers)

Reliability and maintenance

Preferential Subject 3 is devoted to application problems with HV-apparatus. As such reliability and maintenance topics can be considered: the Reports A3-305, dealing with failure data and condition based maintenance, A3-306, discussing failures of voltage grading capacitors, and A3-112, presenting dynamic contact resistance measurements.

For failure frequencies of large populations of HV circuit-breakers the authors of Report A3-305 fitted standardised failure patterns, that are used to draw conclusions about the population's behaviour with respect to failures. In this way they can derive maintenance policies, such as run-to-failure or overhaul at fixed intervals of age or usage. They can also draw conclusions about the optimal interval.

Q.3-1 The authors are not referring to the age as such, but to the event-free interval, meaning that at replacing some parts, they reset the clock for the evaluation of failure frequencies and failure patterns. What precisely is to be regarded as an event (visual inspection, diagnostic test, greasing, replacing oil or SF6-gas?) and which failures should be correlated to which events? To the opinion of the authors both major failures (MF) and minor failures (mf) are events and therefore in the failure patterns there is no distinction between MF and mf; is this correct?

Q.3-2 In Report A3-305 a number of real failure patterns have been presented. What are the confidence limits of the graphs shown and what is the influence of one or two singularities? See for instance the sharp increase of the failure rate of hydraulic drives of SF_6 technology breakers (is such a sudden "end-of-life" realistic?) and the wear-out of the drives of minimum oil breakers (so close to a "random" failure pattern?). Can the authors highlight the advantages of such analyses, and would it be possible or not to use the technique to extrapolate trends to the future (or is such an extrapolation risky when figure 7 is compared with the figures 5 and 6)?

Q.3-3 In Report A3-306 many problems with grading capacitors have been described. On a total of about than 1750 capacitors with roughly 33,000 years of service, five exploded and hundreds were found with oil and SF_6-gas leakages. Would a statistical analysis as meant in Report A3-305 have given early warnings or other conclusions than replacing all grading capacitors?

Q.3-4 The grading capacitors are applied to 300 kV and 420 kV GIS circuit-breakers and therefore difficult to replace. The phenomena described in the Report are oil leakage due to poor workmanship, fatigue damages of foil conductors and the explosions without clear evidence of the cause. Do other users experience similar problems? Are explosions of grading capacitors and severe oil/SF_6 leakages reported? Is there a reason why the problems are so evident in Norway? The authors are involved with the activities of CIGRE WG A3.18, a new working group that is investigating worldwide the problems with grading capacitors and is collecting information to be used to improve the Standards. What measures for improvement are suggested?

The authors of Report A3-112 refreshed the Dynamic Contact Resistance measurement applied at low operating speed, as described more then 20 years ago (for instance by S. Ikeda, IEEE PAS-100, 1981, pp. 4869-4875). The method of analysis of the resistance traces has been improved and relevant parameters have been defined.

Q.3-5 Electrical wear is expected to appear as erosion of the tip of the arcing contacts, both in a radial direction and in a axial direction, but also as erosion of the nozzle. Dynamic Contact Resistance measurement offers possibilities to assess the erosion of the arcing contacts, but not of the nozzle, which is regarded nowadays as at least as vulnerable to electrical endurance as the arcing contacts. What is the authors experience with these forms of erosion? Can other users contribute with their experience? What is the experience with electrical wear in general; which applications lead to severe electrical wear (see also Q.3-11)?

Q.3-6 The authors showed several examples of the Dynamic Contact Resistance measurement that are not related with electrical wear as such but with the detection of defects and failures. Two latent failures have been discovered by this diagnostic technique. Is the Dynamic Resistance measurement to be regarded as a quite usual diagnostic technique? Is it normally applied with the low operating speed? What is the experience with this technique? What about the vibration pattern technique that has been launched also about 15 years ago: is it still in use and useful ?

<u>Abnormal stresses</u>

Four Reports refer to abnormal stresses experienced or caused by HV-equipment. In Report A3-302 the dielectric stresses on step-up transformers in relation to the application of generator circuit-breakers are summarized. In Report A3-303 Non-Sustained Disruptive Discharges (NSDD) are evaluated. Report A3-304 is devoted to electrical stresses in service and Report A3-308 deals with high-speed earthing switches that have to divert induced currents from the arc at the fault location and then to break the induced currents.

The application of generator circuit-breakers between step-up transformer and generator offers a number of advantages, especially for the operation and design of the power plant. The authors of Report A3-302 paid attention to overvoltages, the impact of which may be more severe with a generator circuit-breaker than without. The authors pointed at voltage surges transferred from the HV-side to the LV-side in cases where due to an open generator circuit-breaker the generator capacitance is not available to reduce the overvoltages; they pointed at switching overvoltages generated by the generator circuit-breaker and they pointed at temporary overvoltages due to phenomena like stuck-pole and ferro-resonance. The last can be avoided by pole discrepancy detection resp. open delta damping devices.

Q.3-7 Transferred overvoltages and very steep TRV’s are avoided by the application of snubber circuits and/or surge arresters, that, at least for large generator circuit-breakers, are integrated in the design. Are the authors and other experts of the opinion that generator circuit-breakers always have to be equipped with such devices? These devices are usually applied at the “system side”- terminal, isn’t it? A similar question is to be put forward with respect to pole discrepancy detection and the open delta arrangements on the voltage transformers: should it not be a part of the total generator circuit-breaker package? Also for smaller units?

Q.3-8 Smaller power plants will face similar problems, but more and more VCB’s are applied as generator circuit-breakers. The authors warn for the switching overvoltages, generated by VCB’s, for instance at breaking load currents or magnetizing currents. In which way the ANSI-Standard C37.013 or manufacturers prevent such switching overvoltages? What is the experience of the users with generator circuit-breakers for smaller power plants (< 50 to 100 MW) and what is the experience with standard MV circuit-breakers applied as generator circuit-breakers? CIGRE WG A3-13 (Changing Network Conditions and System Requirements) is interested in such phenomena, as well as problems with out-of-phase conditions, breaking asymmetrical currents, large short-circuit current peak values, including problems for circuit-breakers in the vicinity of power plants. Is field experience available?

Q.3-9 Another item of discussion with VCB’s is the topic of NSDD’s. In Report A3-303 a historical overview of the topic and a number of considerations have been given. The general idea is that NSDD’s is a common phenomenon, but generally speaking not harmful, opposite to restrikes that are to be regarded as harmful. In order to distinguish between NSDD’s and restrikes the authors propose to redefine the present IEC definition, but what is precisely meant by the “inrush” current of the main capacitive load and how can this be detected unambiguously (see also the appendix to Report 303)? What is the position of IEC SC 17A and what is the opinion of CIGRE WG A3.11 (Application Guide for IEC 62271-100)? Is a simple rule of thumb available under which conditions NSDD’s could develop to significant transient voltages, especially at capacitive current interruption?

Since a number of years electrical endurance for HV circuit-breakers has been under discussion, but now IEC SC 17A is about to publish IEC Technical Report 6271-310. As there is still confusion about the correct interpretation of the data collected by the former CIGRE WG 13.08, that conducted a worldwide survey on the fault currents interrupted by circuit-breakers, in Report A3-304 an overview has been given of the statistical treatment of the raw material. In the meantime SC A3 has established a task force (TF A3.01) to verify and assess the results as described in this Report.

Q.3-10 Two different statistical problems have been mentioned in the paper: 1) the statistical analysis of the raw material with sometimes only a few data points 2) the accumulated stress distribution from two independent statistical distributions. Can members of TF A3.01 or other experts contribute to the methodology applied in Report A3-304?

Q.3-11 The conclusion of Report A3-304 is that the number of tests to simulate 90% percentile of the electrical stresses during 25 years of service life (or maintenance interval) can be halved. A group of experts claim that the 90% percentile should be taken for a subpopulation, being the 10% most stressed breakers (as to their opinion the other circuit-breakers will not be subjected to the electrical endurance type test), but only scarce or none information is available about this subpopulation. What is the experts' vision? Can examples be given of service conditions that lead to a high number of short-circuit current interruptions at fault current amplitudes close to the circuit-breaker rated value? What is the expert's opinion about asymmetrical current interruptions having a far larger impact than symmetrical current interruptions?

In Report A3-308 the extra-ordinary stresses on a high-speed earthing switch for the Korean 800 kV-lines have been mentioned. The single pole operated GIS earthing switches are able to make a short-circuit current, but also to break electromagnetic induced currents (up to 8 kA) and electrostatic induced currents (up to 750 A). The switch is of a special design derived from a single break puffer circuit-breaker. Also the test circuit to verify the design is "tailor-made". The authors have to be congratulated with their success!

Q.3-12 The recovery voltage at breaking the electromagnetic induced current (the high-speed earthing switch at the other side of the OH-line is still closed) is unexpected high: 1 p.u. Although the recovery voltage due the capacitive coupling (the other switch clears also) is expected to be higher, even then 1 p.u. is considered to be very high. Can the authors explain the reason for these high RV's due to induced voltages? The details of the test circuit are not visible from the current- and TRV-traces, but can the authors explain the exact process of current injection, interruption by auxiliary breaker, interaction with rectifier and the stresses on the high-speed earthing switch? How often do they expect that the switch has to operate and has it been tested for mechanical and electrical endurance as well? Are the problems described with secondary arc faults and electromagnetic/electrostatic induced currents also recognised by other utilities?

Conclusions and outlook

By widening its scope from switchgear to most HV-components in substations, SC A3 has successfully collected a large number of interesting Reports. For the near future the developments point into a direction of a further integration of the HV-devices and functions, thus simplifying, compacting, improving the substation layout. Triggered by the Preferential Subjects, promising examples have been given in the Reports sent in for the present SC A3 Session. A next step will be the SC A3/B2 Joint Colloquium in Tokyo (September 26/27, 2005) concerning the impact of technological developments in HV-equipment on substation layout.