

# Study Committee A3 (High Voltage Equipment) - Current Activities and Prospects.

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## INVITED PAPERS

*ELECTRA is the journal of CIGRE Members. Nevertheless, a number of columns under the section 'Invited Papers' are now open to all contributors. This we hope will enhance exchanges between all players in the area of electrical power.*

*If in your country you have information about significant events or innovation in the area of electricity, please share this with us. Your contribution (2 500 words maximum) should be sent directly to the Central Office or to your National Committee. It will then be forwarded to the Editing Committee.*

*We rely on your collaboration, for which we thank you in advance.*

## Preface

Study Committee A3 was installed in context with CIGRE's recent restructuring in 2002. Any kind of substation equipment (except power transformers) such as switching devices, surge arresters, capacitors, bushings, instrument transformers, insulators are within the responsibility of A3. According to the mission statement the SC reacts to emerging problems but is also proactive to deal with future technologies and their possible impact on standards and power systems.

As the variety of topics in the SC is widespread, the remits for the working groups are carefully selected and focussed in order to pick only the most topical / important issues, thus matching the number of tasks to be done with the limited number of available experts in the field. It is the philosophy of the SC that having too many working groups might lead to a loss of focus, therefore, currently only ten WG's are active in the various fields.

The current work of the SC can be roughly subdivided into four major fields:

- Reliability of equipment
- Interaction between network changes and equipment development
- Support for standardisation
- Apparatus technology

## Reliability related topics

### *Survey on reliability of high voltage equipment*

Up to now, CIGRÉ has considered it important to collect, analyze and publish reliability data. Deregulation and new technologies, among other developments, have caused service and maintenance practices to change significantly, and as the last survey goes back to 1991, WG A3.06 has launched a new worldwide enquiry into service experience on high voltage equipment. The survey includes high voltage components such as: circuit breakers, disconnectors and earthing switches, instrument transformers and gas insulated substations (GIS). The work is in close cooperation with SC B3 (Substations). The survey runs for four consecutive years, 2004-2007. As in the previous surveys, definitions of "Major failure" and "Minor failure" are chosen for classification with a focus on failure mechanisms, properties of the equipment, etc. The volume of contributions is similar to that in the previous surveys. However, due to deregulation and reorganisation of industry a significant number of utilities in countries with strong traditional links to CIGRÉ have so far hesitated to contribute - this problem needs to be solved yet.

The survey was sent out worldwide in April 2004, and a network of contact persons has been established. Responses are stored in a database and due to be analyzed by the WG. It is still too early to present any trends or results. However, the build-up of the network can be considered already as a success in itself. The compiled information will be subjected to extensive statistical analyses with the purpose of obtaining trustworthy information on reliability and failures for the component types considered.

#### ***Voltage grading capacitors across circuit breakers***

During recent years failures of grading capacitors have been frequently reported. Therefore, WG A3.18 collected information about their reliability and failure history by interviewing utility representatives around the world. Mainly oil leaking from grading capacitors of AIS circuit breakers with more than 20 years service has been reported. But also some cases in gas insulated substations occurred. Disruptive dielectric failures of grading capacitors have also been reported with low inductive current switching by circuit breakers which had been for less than 15 years in service.

The cause of the disruptive failures has not been fully understood. Simulations show that the worst-case voltages across the capacitors can possibly be a few times the source voltage; however, this is not likely to cause problems. Of significantly greater concern are the high oscillating discharge currents that may occur during re-ignition. In a calculation example the current reaches almost 19 kA at 6 MHz. Stresses by high local transient voltages across capacitor elements, mechanical forces and hot spots at points with higher resistance may occur.

Measurement of mechanical stresses/shocks/vibrations directly on the

capacitors during switching operations with circuit breakers of different technologies, vintages and types of operating mechanism showed up to several tens of g's. As these represent only very high frequency stresses, they are assumed to be far less harmful than vibrations at frequencies closer to the mechanical resonance frequencies of the grading capacitors.

Based on collected information about the stresses, recommendations for test procedures will be prepared within the next year. These will include electrical, mechanical and environmental tests giving valuable input for the currently ongoing IEC work.

#### ***Implications of solid state controls in the secondary circuits of HVAC circuit breakers***

The discussion on the benefits of solid state elements for the control circuits of HV AC circuit breakers is a long story. Therefore, the SC decided to aim for clarification and installed WG A3.12. In a first step, the reliability of conventional electromagnetic circuits has been investigated in a worldwide enquiry. For failure analysis, a very detailed breakdown of the secondary control system of a breaker into its subsystems and components was generated. The key conclusions are summarized below:

No single component was dominant, six (6) different components accounted for the majority (88%) of the failures.

Major and minor failures were approximately equal in number

There was a trend observed for more failures to occur in the 1-2 years following a maintenance operation. This was interpreted as an indication of the potential for human error during maintenance work.

The number of failures does not increase significantly with the number of operations. ● ● ●

The survey results provided little experience on modern electronic control systems. Future efforts will concentrate on the potential for such electronic control systems to provide alternatives to conventional technologies for improving control system reliability. This will include current state-of-the-art experience and industry needs. As almost all new installed facilities are based on SF<sub>6</sub> technologies, the focus will be on these.

## Interaction between network changes and equipment technology

### *Implications of network changes on the high voltage equipment*

In order to keep track of how changes and developments in the electric network will impact on requirements/developments of the primary HV AC substation equipment and vice versa, WG A3.13 was installed. Developments such as dispersed generation, long distance transmission of power, reactive power compensation/voltage control, power quality issues, power electronics are studied in order to recognise both their degree of expected penetration and the severity of their influence and as a consequence the necessity for future adaptations of the standards.

The considerations have to include a background of increased utilisation of equipment (in terms of age, loading and voltage stresses), reduction of size and complexity, incorporation of more intelligence and the application of more over-voltage protection and smart devices.

Increase of distributed generation (DG) has the following consequences:

- Load current and short-circuit current profiles in networks with DG

change with respect to flow, amplitude and variability.

- Immediate disconnection of DG will limit the special requirements for HV-equipment only with regard to the withstand capability for short-circuit peak values.
- Fault ride-through requirements will have an impact on the specifications of circuit-breakers that have to be able to withstand and switch under out-of-phase conditions, synchronisation, and islanding. IEEE C37.13 or IEC 62271-100, class S, are recommended; however, the dielectric withstand capability should be adapted and more guidance to users is needed.
- The impact of transients is larger on the DG units than on the network and its HV-components. Clever advanced protection schemes, adapted to the particular circumstances and DG-technologies, are therefore deemed to be necessary.
- The latest DG-technologies like DFIG (double fed induction generators) will relax the contribution to the short-circuit currents and to temporary and transient (recovery) voltages.

For long distance AC transmission the consequences for the HV equipment are:

- Multiple power transfers along long and very long distances lead to an increase of the application of long shunt and series compensated OHLs and long compensated cable sections which will influence the HV equipment.
- More prevalent and more severe TOVs temporary overvoltages and TRVs will be produced. Overvoltage limitation and adequate specification of the involved HV equipment is required.
- High performance metal oxide surge arresters, switched SAs, tele-tripping, controlled switching, advanced protection systems, shunt reactors with neutral reactor where applicable, metal-oxide varistors across CB units, specification of very

low probability of restrike CBs, (closing/opening resistors), by-passing series capacitor banks will/may be necessary.

#### **Implications of fault current limiters (FCL) on protection schemes**

Fault current limiters are a topic which has been widely discussed for several years. From many utilities they have been requested for various reasons, but an economical technology is not yet available. Nevertheless, SC A3 has been dealing with the topic for a number of years as a kind of support and in order to be ready in case of a technological breakthrough. TB 239 (WG A3.10) gives an overview on the state of the art. WG A3.16, established in 2003, continues the work, focusing in a first step on the impact and interaction of different limiting technologies on protection concepts in MV or HV systems, respectively.

In a questionnaire, sent out in 2003, 53 answers from 14 countries show an increase of the need for short circuit current limitation especially at the HV level of 110 kV to 145 kV. Only 26 % of the answers indicate no need in general for fault current limitation. A need without restrictions was indicated by 47 % of the answers for MV and from 21 % for the HV level. A need with restrictions or comments like costs, reliability, references stated 10 % for MV and 6 % for the HV level.

The major goal of the WG A3.16 is to obtain an answer how the use of fault-current limiters has an impact on the protection schemes and functions in electric power systems. A relationship between fault-current limiters and protection schemes should be established by taking into account both protection and network specific issues, such as the impact of different FCL technologies, existing and new protection concepts, selectivity and innovative network configurations.

Therefore, as a start the WG focuses on the main protection principles such as over current, distance- and differential protection. In this first step for simplification the various techniques of fault current limitation are represented as black boxes representing the principal characteristics. The results will be ready in a TB by mid-2006.

A further task of WG A3.16 will be to analyze the main difficulties in the application of FCLs regarding protection issues in terms of location, degree of reliability and the coordination of clearing time.

#### **Non-conventional instrument transformers (NCITs)**

The use of digital communication in control and protection systems and increasingly compact substations favour electronic current and voltage transformers (ECT/EVT) with digital interfaces. Working Group A3.15 discusses (a) sensing technology, (b) practical application aspects as calibration, maintainability and reliability and (c) the integration of NCITs in control and protection communication architectures.

NCIT's use a variety of technology options ranging from optical sensing technology, Rogowski coils and capacitive voltage sensors to low-power transformers. Each option offers advantages for integration in specific primary apparatus; e.g. AIS applications benefit from the inherent electrical insulation of optical sensors, metal clad switchgear take advantage of cost-effective capacitive voltage sensors. The group compiles a technology survey and discusses past and present field applications.

The use of electronics and digital interfaces impacts maintenance, calibration and test procedures. Whereas the sensing heads usually increase the reliability of the primary apparatus ●●●

significantly, the electronic secondary converters on ground potential or in the control cubicle have a shorter service life than the primary equipment.

What might appear as a disadvantage in maintenance cost at first glance, increases the substation's overall reliability and reduces devastating faults on the high voltage side. To exploit this advantage, a proper design for maintenance, test and calibration, the group collects the appropriate design criteria and discusses specific applications and service experience.

NCITs and their interfaces are standardized in IEC 60044-7, IEC 60044-8, IEC 61850-9-x. They provide interoperability with present and future control and protection equipment and the ability to interchange NCITs from different vendors using even different sensing technologies. Currently, the standards offer four different digital and a variety of analogue interfaces which emerged during 2000...2003. The group discusses the impact of the different interface standards on the communication architecture, the engineering and commissioning procedure and plots possible future harmonization paths.

Accordingly publications and a TB which provide the user with guidance on the application of NCITs are expected by end 2006.

### Activities directly related to standardization

#### *The implications of enhanced TRV's with long line faults on IEC and ANSI circuit breaker standards*

Staged three-phase fault field tests, performed by Bonneville Power Administration in the Northwestern USA, verified EMTP models and the analytical theory that the first pole to clear a three-phase line fault may

result in a higher first peak than presently specified by circuit breaker standards. Consequently, SC A3 installed WG A3.19 to answer the following questions:

- Do standards need to be revised to cover the three-phase line fault TRV?
- Is the number of cases where the actual TRV could exceed the tested single line to ground TRV (as this is common practice) so small as to be considered a special case?
- If these are special cases do users need to be alerted to watch out for them and be given guidance as to which circuit breaker to apply in such cases?

Fundamental assumptions in the CIGRE work of 42 years ago led to the line fault TRV requirements currently embodied in IEC and IEEE Circuit Breaker Standards. The original assumption of very remote probability of a three-phase short line fault does not apply to line faults of any length. 40 years history of line faults in North America has shown that the proportion of three-phase line faults to all line faults is about 2% for voltages 345kV and higher and about 6% for 245kV and below. These are small numbers, but too large to be ignored.

A large contributor to the impact of the three phase line fault TRV magnitude is the ratio of actual source side short circuit strength to the circuit breakers interrupting rating. When this ratio exceeds about 80%, the three phase line fault TRV tends to exceed the conventionally required single phase test values. For ratios equal or lower than 80%, simulations done so far suggest that TRV's are covered by present or slightly modified type tests.

Along with the studies on three-phase versus single phase short-line faults (L 90, L75, L60), CIGRE WG A3.19 is also considering the severity

of the TRV wave-shapes due to clearing faults at a longer (L 50, L40, L30) and a very long distance (L10) from the circuit-breaker, results expected in 2007.

#### **Application guide for IEC 62271-100 and IEC 60694**

One of the prominent tasks of CIGRE is to provide the scientific background for the standardisation work carried out in the IEC.

However, over the years much of the valuable background information and the scientific results have tended to get lost due to the natural changes in the membership of the CIGRE and IEC Committees. As a result, questions arise due to the lack of understanding of the IEC requirements. Proposals are made for investigations and standardisation on subjects, which had been clarified years, sometimes decades, ago. Therefore, for quite some time, it has been felt necessary to provide an application guide for the users of the IEC standards for high voltage alternating current circuit breakers. Thus in 1997 CIGRE SC A3 (then SC 13) took the initiative to form a Working Group A3.11 with the task to write an application guide for IEC 60056 (now IEC 62272-100) and IEC 60694.

Addressed are utility, consultant and industrial engineers who specify and apply high-voltage circuit breakers and circuit breaker development engineers, engineers in testing stations, and engineers who participate in standardisation. It is intended to provide background information concerning the facts and figures in the standards and provide a more comprehensive basis for specifications for high voltage circuit breakers. The scope covers the explanation, interpretation and application of IEC 62271-100 and IEC 60694 (in future: IEC 62271-1) as well as relat-

ed standards and technical reports with respect to high-voltage circuit breakers. However, it is not intended to be used as an electrotechnical training course or to replace textbooks.

As the installation of standard equipment is in general more economical than the use of special designs, the Application Guide will help the utility and industrial engineers in the selection of the appropriate ratings to conform to their requirements and specifications. This should take into account that in future high-voltage networks will be worked harder and closer to their limits and that high-voltage circuit breakers of present-day technology have been designed and procured for a lifetime of several decades. It is recognised that certain conditions may necessitate requirements which are outside the circuit breaker standards. In such cases, the Application Guide will help the user to specify the various ratings or possible additional testing to achieve the most economical solution. Publication is planned by the end of 2006 in form of two TB's.

## **Apparatus technology**

### **Modelling of equipment**

Computer modelling of various phenomena and functions becomes an increasing part to support development, design, testing and interaction with system phenomena of the equipment. In order to survey current modelling methods and to evaluate their usefulness and validity, WG A3.20 was installed in 2005.

Main topics are to evaluate those fields:

- Where computational simulation can support, simplify or even replace verification tests.
- Where simulations can expand the understanding of the apparatus ●●●

- Where simulations demonstrate real life conditions and/or non standard applications
- To figure out which type of software can be used for which application.
- To find methods to verify the accuracy of simulations
- To establish a framework for quality rules
- To make proposals on how simulations could be implemented in standards

Basically two categories of simulations have been identified:

- Calculations predicting the exact equipment performance, which can replace verification tests.
- Simulations extrapolating performances to different conditions by using the results of particular well known conditions, which can reduce the number of verification tests.

In a first exchange of information amongst manufacturers, test institutes and universities it turns out that all manufacturers use the same CAD system, in 70% of all cases commercially available software and in several cases even identical software. Benchmarks of other industries (e.g. the airline industry) showed that there is a tendency to trust more and more calculations, but nevertheless tests still play an important role.

An analysis of all requested tests and stresses in service on all products within the scope of WG A3.20 shows that for the time being simulations can only replace tests when an extrapolation of already proven performance can be made using well accepted calculation methods. The main reason for that is the lack of ability to predict exactly the limits of performance of a device as it comes off the industrial production line. Nevertheless, in future the WG sees such possibilities for some dielectric, heat run, short time current and mechanical tests and a very limited

number of power tests. There is no doubt that simulations will expand the understanding of all functionalities in our apparatus.

The next activities will be

- To categorize further the possible simulation methods and
- To perform such a simulation using different software from different manufacturers and to verify it via tests. That will be done via benchmarking dielectric calculations. A first publication is planned by end of 2006.

#### *Evaluation of stresses of surge arresters and appropriate test procedures*

In order to evaluate the possible risks with older gapped arrester designs, possibly reaching their end of life, and to give guidance for renewal programmes an overview on the actual world-wide population of arresters of the different types is aimed at. A questionnaire has therefore been developed and will be distributed world-wide by WG A3.17. Field experience with arresters, design, age and maintenance work are the main topics. The questionnaire covers distribution and transmission arresters, AIS and GIS designs.

Other major topics yet not well understood are the phenomena linked to energy dissipation of MO-surge arresters. Various tests exist to assess the energy capability of arresters, but when talking about the energy capability it is not clear what is really meant. Is it the thermal stability of the arrester (this is a question of the design), is it the cracking of the MO-block due to thermal shock or is it the change of the electrical characteristics of the block? And what is the influence of the impulse parameters as current steepness, magnitude, duration, repetition rate on the energy capability. The WG A3.17 launched a research project on energy

handling capability of MO arresters. The first test setup is ready and pre-tests have been performed, showing the reliability of the test installations. The test sequence has started in March 2006 with participation, technical and financial, of principal manufacturers and utilities.

In the current standard IEC 60099-4 some tests and procedures apply to the old gapped arrester design and have less meaning for modern gapless MO-arresters. Today almost all distribution arresters are polymeric-housed, and from the high voltage arresters approx. 40 % to 50 % have polymeric housings, with increasing tendency. Therefore a critical revision of the actual standard is necessary. Due to more and more field and testing experience some tests may be modified or skipped. A problem still unsolved is the pollution behaviour and related tests, especially for multi-unit polymeric-housed arresters. Four different aspects have to be considered: the external flashover, partial heating along the active parts, internal partial discharges due to radial field stress and the behaviour of the insulating material itself (ageing etc.). A first publication on the topics can be expected by the end of 2007.

#### ***Aspects for the application of non-ceramic insulators to HV and MV apparatus***

Polymeric materials are increasingly used for housings of high voltage apparatus, such as surge arresters, circuit breakers, instrument transformers, etc.. Design and selection criteria change drastically due to the superior pollution performance due to the non-shattering characteristics of these materials and to the possibility of moulding the housing very close to the active parts (e.g. resistors in surge arresters). The internal active parts of the equipment can interact with the housing in terms of grading,

heating, partial discharges, ageing, sealing etc. thus influencing the performance of the apparatus. Completely new questions arise in terms of design, testing and standardisation. Thus working group A3.21 was recently installed to analyse the technological solutions adopted in the field, their service performance and to arrive at possible consequences for testing and standardisation. Attention will be given to electrical, thermal, mechanical and environmental points of view.

#### **Future involvement of SC A3:**

As already pointed out, the selection of tasks of SC A3 comes either by way of actual emerging problems and/or by attempts to foresee the future and possible implications for the high voltage equipment. In context with the latter consideration a few topics and research areas are listed below, where involvement is expected and might be reflected by new WG's and subjects for conferences.

- 1000 kV equipment and testing
- hybrid solutions
- knowledge preservation
- ageing equipment/end of life decisions
- DC components - calculation and application
- line surge arresters (ref. controlled switching)
- intelligence in equipment

#### **Acknowledgement**

The author sincerely appreciates the contributions and inputs of the various working group members/ convenors, namely: C.Sölver, M.Runde, H.Wilson, A.Janssen, H.Schmitt, H.D. Schlemper, R.Alexander, H.Schramm, F.Heil, B.Richter, M. De Nigris ■