

General Report of SC A3&B3 Colloquium, September 26 and 27, Tokyo

Present and Future of High-Voltage Equipment and Substation Technologies

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Introduction

For the last week of September 2005 the Japanese National Panels of CIGRE SC A3 and of SC B3 have carefully organised a very successful International Colloquium on recent developments in high-voltage equipment and substation technologies. One of the topics of the Colloquium was the advanced techniques of compact substations and, at the end of the two-day Colloquium, the organising committee has arranged a technical tour in TEPCO's amazing underground 550 kV substation. After the Colloquium experts from CIGRE SC A3 (High Voltage Equipment) and SC B3 (Substations) have presented a one-day joint tutorial with totally nine lectures, followed by two-day meetings of SC A3 in Tokyo and SC B3 in Nikko. On Saturday, the Japanese hosts offered an optional tour through either Kamakura (near Tokyo) or Kyoto, thus closing a fruitful and pleasant week.

There is an ever increasing demand for electricity in nearly all countries in the world. In the developing countries the political decision makers are aware of the fact that electricity brings about substantial improvements in the quality of life of their citizens as well as in their economics. In the industrial countries a steady shift towards electricity as transportation medium of energy can be seen, due to its wide flexibility in applications and the economic and ecological features of large scale primary to electric energy conversion. Furthermore, in the industrial countries the electrical infrastructure is composed of rather large and complex power systems with aging asset grids. There is a growing need for replacement and refurbishment of this equipment. To provide solutions for these trends, scientists and engineers have to come up with reliable, sustainable and cost optimized technologies. Some technological trends have been highlighted at the sessions of the 2005 joint Colloquium of CIGRE SC A3&B3.

Keynote speech

Prof. Hitochi Okubo of the Nagoya University in Japan introduced the Colloquium by a keynote speech devoted to Future Technical Perspectives for Electric Power Equipment in Substations. He pointed at hot issues such as compactness, environmental impact and the ambiguity of the application of SF6-gas technologies. Examples of compact SF6-gas solutions were given: compact substations, compact equipment, combined equipment and integrated functions. As developments in new materials were mentioned: high/low permittivity with suitable treatments allowing an enhancement of the specific electrical field strength; functionally graded materials

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for the control of the electrical field and for the relaxation of electric charges; nano-materials to be used as non-organic fillers with new functions as improved dielectrical, thermal, mechanical and/or environmental performances. Special attention was given to high temperature operation of power equipment and non-flammable or less-flammable insulating and cooling fluids.

Prof. Okubo discussed also SF₆-gas emission control, reduction of SF₆-gas content and substitutes for SF₆-gas, including methods to assess the efficiency of the corrective measures adapted, such as the environmental Life Cycle Analysis and the economical Life Cycle Costing. Furthermore he pointed at the fundamental research into the physics of material degradation in order to predict/prevent dielectric breakdowns by means of diagnostic and monitoring techniques. Shortly, Prof. Okubo highlighted the fact that the reliability of high voltage equipment in Japan showed a much higher reliability than elsewhere in the world and that it is worthwhile to study the technological, managerial and cultural reasons behind this superior performance, especially when future asset management is taken into account. Last but not least, low loss and low cost power electronic devices with many different applications have been addressed as well.

Preferential subjects

Thus Prof. Okubo put the subject of the joint Colloquium in a wider perspective, although some examples given in the keynote speech showed up during the parallel sessions on the three Preferential Subjects. The three Preferential Subjects chosen for the joint SC A3&B3 Colloquium were:

- PS 1 Advanced HV equipment and related emerging technologies and their influence on substation design and operation
- *New solutions for HV equipment*
 - *Monitoring and diagnostic techniques and their impacts on economical and reliability aspects*
 - *New maintenance practices, life management and asset management such as RCM, CBM, IT based programs*
 - *Development and current status of UHV equipment*
- PS2 Field experience of novel techniques applied to substation design and layout
- *AC and DC HV equipment*
 - *Controlled switching technologies and their impacts on economical and reliability aspects*
 - *Mitigation system for severe duties (e.g. capacitors, arresters and fault current limiters)*
 - *Mixed Technology Substation: hybrid GIS and compact AIS*
 - *Substation secondary equipment*
- PS3 Environmental issues
- *SF₆ handling and recycling practice*
 - *Environmental impacts in all stages of manufacture, operation, maintenance and disposal of HV equipment*
 - *Development and evaluation method of environmentally friendly HV equipment and substations.*

Preferential Subject 1

For PS1 25 reports and a spontaneous contribution have been submitted, covering the topics mentioned above.

In three reports large substations adapted to the environment of a metropolitan area have been described. The authors give lay-out and design details of the very compact, mainly indoor and underground, substations, where in Sydney (Report 109) gas-filled transformers have been applied (for design aspects like transportation, cooling and noise emission of the transformers see Report 110) and in Tokyo oil-filled transformers (Report 118). In Report 109 special attention has been given to the overall monitoring system, including the SF₆-gas leakage supervision in the building and the SF₆-gas recovery methods figured out. The user stated that the environmental impact of the SF₆-gas emission to the atmosphere is less than the impact of the energy losses (and the related amount of CO₂) that would appear when the substation was a conventional one located far from the city centre, with a metropolitan distribution network at a lower voltage level connected. PD-sensors have been applied to the GIS, but no continuous monitoring system for PD has been installed. In Report 118 TEPCO's advanced substation of the technical tour has been highlighted, besides an outdoor compact 550 kV-GIS substation with modern high grade arresters, modern circuit-breaker design, 3-phase busbars and compact bays for the OH-lines. The authors explained to the audience that in the underground substation the LIWL level of the 550 kV GIS (1425 kV) is much higher than that of the transformers (1050 kV), as the components of the GIS have to be exchangeable with those of other substations, that may be located outdoors.

Compact substations are also addressed in a number of other publications on mixed technology solutions and apparatus with combined functions. In the Reports 120 and 121 utility's problems with scarce space are solved by compact, flexible and even mobile solutions from different manufacturers. The pre-fabricated and modular bays are completely shipped and erection at site is fast and easy. A problem with mixed technology or hybrid solutions is the dielectric routine test at site: dead-tank circuit-breakers are normally not routine tested but GIS-installations are subjected to a dielectric test, including a PD-measurement. With respect to reliability and routine testing the manufacturers tend to give an ambiguous answer to the question whether the hybrids are to be regarded as small GIS-installations or as enlarged dead-tanks. The authors of the Reports 116 and 117 mention combined function apparatus, leading to more compact and reliable substation lay-outs: a 5-position disconnecter inside a hybrid technology bay and an air-insulated disconnecter/circuit-breaker with the feature to design substations without disconnecters. The new IEC Standard for disconnecter/circuit-breakers IEC 62271-108 is offered for voting in October 2005 and voting will have consequences for the disconnecter-standard as well (IEC 62271-102). An expert summarized the discussion on this apparatus as a smart solution for countries where the application is allowed.

The refurbishment of outdoor air-insulated substations with double deck busbars, erected in the fifties, has been addressed by Japanese experts. Consideration has been given to the required extension of capabilities, the need to improve the installation for safety reasons, the very limited area available and the necessity to keep the substation in operation during the refurbishment. TEPCO has chosen for a mixed technology solution, as shown in Report 115. Aging as such has been addressed in Report 114 and a survey among utilities for criteria to determine the end-of-life of circuit-breakers is presented. The answers from utilities from Australia and New Zealand do not differ too much from the results from worldwide enquiries, as performed by CIGRE WG

13.08 and show for instance that utilities' priorities are with safety, reliability, maintenance costs and rating while the most frequently used criteria are reliability, maintenance costs, age and spare parts. From further detailed questions the author discovered that obsolescence belongs also to the criteria quite often applied. The authors explain the difference between priority and application of criteria by the fact that age and obsolescence are easy to use criteria. A participant from Japan stated that he sees the work of CIGRE WG A3.06 as very important with respect to benchmarking, while the work of the old WG 13.08 (CIGRE TB 165) is still useful.

The failure curve with age has been discussed in Report 113. To be more precise: the failure curve with confidence limits as a function of the event-free time (i.e. after the last maintenance) has been presented and conclusions about maintenance intervals have been drawn. Possibilities to detect incipient failures are discussed as well. The main advantage of the investigations was the possibility to enlarge the interval between maintenance actions. The authors face problems with the definition of Major Failures as will be discussed further at Report 101. Diagnostic techniques and monitoring are treated in several reports and the Reports 124 and 122 address especially the necessity and the (dis)advantage of the application of monitoring systems from a point of view of overall reliability and economics. Some experts from the audience stressed that monitoring systems are advantageous when considering substations at a long distance and/or the fact that due to monitoring maintenance staff will leave the GIS alone. In the Reports 119, 123 and 122 monitoring systems are discussed for respectively 800 kV GIS (PD-measurements), EHV-GIS (remote monitoring of PD, gas leakage and gas decomposition) and circuit-breakers (standard device).

In Report 112 a good overview is given of the relation between the wide set of information needed by asset managers on one hand and the asset management environment on the other hand. Information from operational and/or maintenance experts, as mentioned in the former papers, is only a part of the whole set of information needs required to take decisions about long lasting infrastructures. A clever link between the operational information and the business values (of importance to the stakeholders) is the key of success for asset management.

Anyway, from the reports mentioned before, it is clear that reliability/availability/maintainability data based on a representative population of equipment and service experience form essential information for experts dealing with the development of HV equipment, substation layout, maintenance strategies and diagnostic/monitoring techniques. At this very moment the third international survey on the reliability of HV equipment is running, taking into consideration circuit-breakers, disconnectors, earthing switches, instrument transformers and GIS-installations: Report 101. Fortunately the response worldwide is quite good and the population seems to be larger than for instance the population of circuit-breaker-years used in former enquiries. As the discussions showed, CIGRE WG A3.06, conducting the third worldwide survey, is facing some problems with the interpretation of the meaning of Major Failures. Some participants do not see a Major Failure as the components malfunction with respect to its principal functions (i.e. the definition used in former enquiries), but as depending on the impact of the failure on the network's functions. Such differences in the definition of Major Failures make it difficult to transfer utility's own enquiry results into the CIGRE formats.

Another international survey, conducted 8 years ago, dealt with electrical endurance of circuit-breakers; i.e. the number and amplitude of short-circuit currents interrupted by a circuit-breaker

during 25 years. Recently, CIGRE TF A3.01 published the results of a Monte-Carlo analysis of the original data and concluded that the electrical stress level of 90% of the circuit-breakers is less severe than the type test duties for short-circuit testing as defined in the IEC and IEEE Standards. In Report 102 the authors show that a similar analysis on recent detailed data from three Japanese utilities proves the correctness of the Monte-Carlo approach. The investigations are based on the famous formula of Sabot on the wear of SF₆-gas circuit-breakers as a function of the interrupted short-circuit current.

A topic also related to short-circuit currents has been described in Report 104, where, based on UK experience, the DC-component of a short-circuit current as calculated according IEC 60909 has been discussed. More accurate frequency scaling factors, as used in the IEC-Standard, lead to a better prediction of the current peak value at the moment of interruption. In case of large DC-time constants a practical guidance for de-rating circuit-breakers seems to be very beneficial. A spontaneous contribution from Finland dealt with missing current zero's at the interruption of asymmetrical short-circuit currents in the 420 kV-grid very close to large power plants. In the discussions the effect of three phase clearing of asymmetrical short-circuit currents has been mentioned, especially the last poles in case of a first interruption in the phase without DC-offset. Furthermore, attention has been asked for the large DC-components that may appear in industrial installations and on oil-platforms. Experts from the audience pointed at the very simple application rules for large X/R ratio's, as today given in the appendix of IEC 62271-100, but users feel not comfortable with these rules. WG A3.20 (Simulation Tools) offered to have a closer look into circuit-breaker's capabilities with large X/R ratios. Anyway, short-circuit currents still form a topic that not yet has been clarified completely.

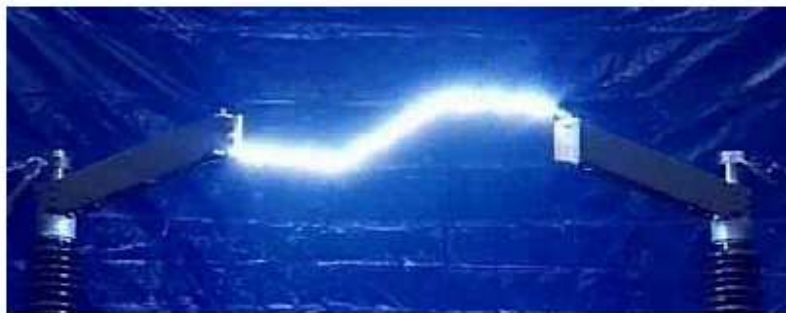
In Report 103 the complexity of short-circuit current flows in case of a high penetration of distributed generation has been addressed. Also to the topic of out-of-phase conditions (especially under fault ride through requirements), out-of-phase currents and out-of-phase switching attention has been given. The authors stated that the new amendment to IEC 62271-100 will provide utilities and users with TRV-classes (T30S) that can be required under such circumstances, but also dielectric withstand capability during islanding and synchronisation have been mentioned.

The authors of Report 106 showed the necessity to define proper testing conditions for air break disconnectors, that are requested to interrupt capacitive currents larger than, say, 0.5 A. They stress that current level, source side capacitance and permitted switching overvoltages have to be well-defined. But, as explained by a participant, utilities in the North-America are used to switch capacitive currents up to 5A at 138 kV without whip release, and up to 15 A with whip release. Where in Report 106 it is stated that Standards should be more strictly, on the contrary, in Report 108, dealing with polymeric insulation of metal-oxide arresters, it is promoted to relax the requirements put forward in the International Standards and user's specifications. The excellent behaviour of such devices under atmospheric pollution and seismic conditions give reason to reduce creepage distance and therefore height drastically, without impairing its behaviour and even with a further improvement of its seismic strength. As clarified during the discussions, the largest problem is the acceptance of more relaxed requirements by the users.

Novel technological developments have been given in the Reports 105, 119 and 111; the first two reports with respect to circuit-breaker techniques. In Report 119 a Korean manufacturer showed

the good service experience with recently delivered GIS-installations: 800 kV/50 kA/8000-2000 A. The PD-monitoring system has been mentioned above. To questions from the audience the authors answered that the 800 kV circuit-breaker has been half-pole tested to the new IEC 62271-100, but during the event in Tokyo it will be subjected to full pole voltage injection synthetic tests. The design has also been tested to a mechanical endurance test of 20,000 operating cycles. The authors of Report 105 highlighted the development of a new type of spring mechanism, based on a torsion bar. They also illustrated how the performance of a single break 145 kV to 362 kV circuit-breakers can be improved up to 80 kA by the application of coupling capacitors at both sides of the arcing chamber.

A Japanese 80 MVA statcom (power-electronic reactive power compensator), as a completely new substation device, is in operation since June 2004; Report 111. The proud authors demonstrated the excellent performance and the good service experience so far. Questions from the audience were related to the absence of harmonic filters, the technology used to measure the harmonic content and the consideration of alternative solutions like shunt capacitor/reactor banks or synchronous condensators.



Erratic and stiff arc of air-break disconnecter [106]

Preferential Subject 2

For PS2 thirteen reports have been submitted, covering the topics mentioned above.

Three reports addressed the integration of substation components. In fact the three contributions argue that increased reliability and advances of for example metal oxide arresters, polymer technology and gas insulated equipment enable the integration of components to the benefit of cost, reliability, space and safety. Report 201 discussed integrated surge arrester systems. This report underlined that the integration of surge arresters with other components currently used in electrical power systems, offer benefits including improved over-voltage protection, lower costs and space savings. However, it was also said that concerns centre round the mitigation of damage in case of arrester failure and the potential implications for test procedures. An important, but not yet fully answered, question is whether the basic insulation levels of electrical networks could be reduced with a wider deployment of integrated arresters.

Remarks from the audience focused on the increasing complexity of the equipment and the associated specification aspects, on the need to address interchangeability, need of additional standards, and on the protection principles in terms of first and second defense lines.

The perceived reliability and maturity of substation equipment also raised the more general question whether all current test procedures to verify the integrity of primary equipment under higher voltages are still necessary. This question needs further study also in the context of the activities of the B3 working group on compacting substations.

Report 202 describes the refurbishment of the 380 kV air insulated substation Soazza using hybrid HV technology and has been prepared by authors from the Nordostschweizerische Kraftwerke AG in Switzerland. The refurbishment of this substation is an illustrative example of how to improve the performance and reliability of an existing important node in the European transmission system. As appeared from the presentation, circuit breakers were replaced with integrated switching modules, a GIS transfer bus was installed and the control and protection equipment replaced.

Striking is the very short time needed for the realization: the installation was handed over to the user less than six months after the contract was signed. The time needed for on-site activities was even less. It was said that the service interruption time was only four weeks “as a result of good preparation of the site”.

Report 203 is about the refurbishment of another 380 kV substation (Laufenburg) in Switzerland using hybrid switching modules. Authors from the utility and manufacturer of the primary equipment have prepared this report. A comparison of various options revealed that the solution with Multifunctional Switching Modules, in which various devices including current and voltage transformers are integrated, was the best one. With the application of switching modules also a simplification of the substation layout, including the elimination of an auxiliary bus-bar, was possible. This was feasible because of the expectation that a bay could be replaced by a spare one within 24 hours. It was argued from the audience that with this technology commonly a bay is replaced by a spare one rather than making on site repair. On being asked, the author confirmed that this replacement could be done without affecting the availability of adjacent bays and/or bus-bars.

Multifunctional Switching Modules can offer benefits in terms of substation layout, space usage, costs and, in particular, short realisation time. As speakers said these modules combine the advantages of air insulated equipment and gas-insulated devices. Indeed, experience shows the high reliability of GIS while the comparative advantage of air insulated equipment is the short time to repair.

Contributions from the audience focused on the question whether monitoring equipment was integrated (which was not the case) and on the maintenance aspects of individual components such as selector switches and earthing devices. Also the ambient temperature conditions (more in particular low temperatures), the calculation of life cycle costs and actual space savings were addressed. One of the participants stressed that the compartments must satisfy certain minimum dimensions to avoid problems.

It was recalled that during the CIGRE SC B3 Colloquium in Venezuela in 2001 so-called “Modular Switching Units” have been discussed. In the presented reports “Integrated Switching Modules” and “Multifunctional Switching Modules” are mentioned. These names appear to more or less cover the same type of equipment. Mixed technology would seem an appropriate name but it was said that in Study Committee B3 “Substations” the issue of definition is being addressed.

There is no doubt that upgrading and refurbishment of existing substations is an increasingly important and challenging task for utilities and manufacturers. Challenges include the construction of cost-effective new facilities under existing space constraints, adaptation to prevailing environmental and safety legislation, and maintaining or even improving reliability. The contributions and discussion revealed that for refurbishment projects various options including new configurations need to be taken into consideration. Similarly, an integration strategy between existing and new technology, with respect to the secondary systems, must be developed. This session made clear that within that context modules, in which various switching and other component are integrated, are an attractive option.

To deal with increased short circuit levels some of the following methods have traditionally been used:

- Upgrading of existing switchgear and other equipment
- Changes in network topology, e.g. splitting of grids or splitting of busbars
- Introduction of higher voltage levels
- Use of complex control strategies like sequential tripping

An alternative to these methods is the use of fault circuit limiters (FCL) or current limiting reactors (CLR). Report 205 discusses the use of fault current limiters and why they have become integrated into modern utility systems. Some questions that arise in the report include:

- Why have fault current limiters (FCL) recently become a necessity in utility systems?
- What is a fault current limiter and what types are available?
- How does a FCL affect protection devices in a power system?
- How does one analyze and classify what type of FCL is needed in a system?
- On an international level, who is using such devices?
- What successful applications has FLC been used in?

Originally most power systems encompassed both generation and transmission. Increased independent power producers have caused power systems to evolve and separate these two entities that once went together. This shift in separation has had great effects on power system stability. The addition of independent generation has in turn increased the interconnections of the network causing the fault current to rise. This could potentially harm equipment if the fault current exceeds their rating. One of the solutions to this posed problem is the use of fault current limiters.

FCL decreases fault current to allow equipment to remain in service during a fault.

Protection plays a huge role in maintaining the operation of any power system. To ensure that a fault current limiter is working effectively with other protection schemes, it is important to understand how a FLC affects the protection's performance. One must observe how the network is configured, what type of FLC is being used, and the present protection devices implemented. This area is still under development and is presently being studied by the WG A3.16.

To evaluate how essential fault current limiters are to a utility system, a questionnaire was sent out by WG A3.16 to various countries all over the world. The results were that most countries depend on this type of protection for their medium and high voltage systems. Only 26% were not in need of any sort of FLC. The paper describes two different countries (Japan and Germany) that have successfully implemented FLC protection in their utility systems.

In Germany, a superconducting FCL was installed and put into service on a 10kV substation located in Nephthen on April 1st, 2004. The FCL is used for bus coupling, which means that the FCL couples two secondary MV transmission lines tapped from the HV lines. The maximum short current calculation for the bus coupling system yields 14 kA. With the use of this FCL, the current can be reduced to 8kA.

In Japan, an arc type driven FCL has been tested on a 6.6 kV distribution feeder at Electric Power Co. in Tohoku for two years starting in December of 1998. Its main purpose is to protect sensitive loads from voltage drops or sags. The FLC is rated to limit current between 2.7 kA and 12.5 kArms to the half and is installed between loads and distribution systems with a cogeneration system. Before the installation of the FLC, many tests were carried out to ensure its effectiveness with current protection devices.

Although the use of CLR is not a novelty, authors of report 206 present case studies resulted from the experience of Brazilian utilities.

This report discusses how the deregulation of Brazil's utility system increased the number of independent power producers causing the need for fault current limitation. Brazil is currently implementing current limiting reactors to solve this problem. Although there are disadvantages to this method, it appears to be a more economical approach than substituting existing equipment.

This report also analyzes the disadvantages of CLR's.

A severe disadvantage of a CLR is the rapid increase in transient recovery voltage across the circuit breaker contacts during a fault. This is caused by a very large surge impedance from the reactor and can be rectified by connecting a capacitor across it.

Another disadvantage occurs when using CLR's for applications on a large scale. As reactors become bigger their associated reactance increases as well. As Figure 6 shows in the paper, when the reactance increases the current decreases to a certain point then remains constant. This means that the effectiveness of a reactor is limited to a small range. In the example of Tucurui, once the reactor reaches 27 ohms, transmission overload problems occur.

Controlled Switching – Technology was dealt with in three reports

Circuit breaker monitoring/diagnostic and Point-on-Wave switching (POW) applications are becoming more popular in high voltage networks. Diagnostic tools may produce:

- Cost reduction in terms of optimization of maintenance activity
- Extension of breakers lifetime
- Prevention of catastrophic failures

Controlled switching offers a lower cost solution compared to closing and/or opening resistors and can also be used to achieve a significant contact wear reduction. The report 207 investigates the hardware and software requirements for the implementation of a diagnostic system and a point on wave controller. It also analyzes the similarities between the two applications and the possible benefits of an integrated approach. The report addresses questions such as:

- What is the Software comparison between the Circuit breaker monitoring diagnostic and the Point on Wave methods?
- What is the Hardware comparison between the Circuit breaker monitoring diagnostic and the Point of Wave methods?
- What is the system architecture of the installed systems?
- What are the advantages of integrating the diagnostic function and POW switching function in a single hardware platform?

The comparison between the Circuit breaker monitoring/diagnostic and the Point on Wave showed a large overlap in identical functions. A good POW algorithm needs to make a very accurate forecast of the operating time of the circuit breaker. Sophisticated tools are required for the circuit breaker operating time monitor and their statistical description. The same need is required for the diagnostic controller.

There are many hardware level resources that overlap in functionality. An item that might not be evident at first glance is the manufacturer know-how. In order to achieve the best possible accuracy in operating times forecast it is important to know the relationship between the influencing variables and the circuit breaker behavior. The manufacturer can tailor to these parameters according to the specific breaker version, or check accuracy during routine tests. This would help the POW application or any accuracy of the diagnostic algorithm.

There is significant potential in the integration of diagnostic function and POW switching function in a single hardware platform. The advantages are:

Economic: the common HW and SW resources are not duplicated. Only one set of sensors (position, pressure, temperature etc.) is needed. Only one processor and relevant SW are in charge of operating times computing.

Efficiency: The integrated controller, with POW and diagnostic tasks is closer to the circuit breaker and, possibly embedded in it. This solution makes it easier to collect all the input

information required to achieve the best accuracy in the timing performance. In addition the integration in the CB makes it easier to embed all the manufacturers know how, which assures the best possible fidelity in the algorithm response.

These devices need to improve their communication capabilities to find a smooth integration over the utility communication infrastructure. Web server and Internet communication are keywords for the evolution of such communication capabilities.

Special attention is given nowadays to find available techniques to mitigate switching transients in power systems. Report 208 aims to present the Brazilian experience with classical means of mitigation, such as circuit breakers with pre-insertion resistors, etc. The main focus is on controlled switching systems (CSS), since it is becoming more appealing technically and economically to mitigate such switching transients and to improve power quality.

Using switching transients mitigation techniques in power systems help to improve power quality in general sense. Also can be stated that the controlled switching devices (CSS) are becoming more and more available to perform such role, besides allowing significant equipment cost reduction. It is also relevant to point out that analyses of this nature have always been a matter of concern in studies of equipment insulation coordination. However it is necessary nowadays to go ahead and take power quality issues also into account, since these power system-switching transients may affect sensitive load supply. It was seen that the application of CSS could afford a more wide use of compacted lines in power systems. In terms of capacitor banks the use of controlled switching permits to avoid equipment damage, voltage oscillation and sensitive load disturbance. Regarding power transformer energization, it is possible to avoid mainly, the occurrence of sympathetic interaction and its undesired consequences. To shunt reactor switching off, there are benefits in terms of avoiding equipment damage due to re-ignition elimination.

Inrush current is a problem that occurs when transformers are energized with no load. This high level of temporary current can cause wear and destruction to the transformer core and decrease its useful life. A solution to this problem is using a controlled switching system. This approach is not normally taken because of the difficulty in measuring the residual flux in a transformer core. However, Japan utilities have developed a controlled switching method that takes residual flux into account. This paper further discusses this technique in practice.

- How is the residual flux measured from a transformer core?
- How is the inrush current minimized using a controlled switching system?
- What tests were performed to ensure this method effectively reduces inrush current?

High voltage (HV) circuit breakers are used frequently in the power system for both switching operations and fault interruption. Recently, new technology has emerged to replace the current spring operating mechanism. Utilities, particularly in Sweden, are trying motor drive circuit breakers. The past experience with these breakers is discussed in the report 210. Some questions that arise from this report include:

- Where are motor drive circuit breakers being used and how long have they been in service for?
- What are the advantages to the motor drive method?

- How are these circuit breakers monitored in substations?
- What tests should be conducted upon installation of these circuit breakers?
- Are there any flaws in this technology? If so, what are they?

Motor drive circuit breakers are used on capacitor banks. Capacitor banks require frequent switching of the breakers. Therefore the high mechanical endurance of this type of breaker is suitable for the application. These devices have been in service since 2000, and initially started in Sweden and Italy. These circuit breakers are gaining in popularity as over 100 installations have been made since their debut in utilities.

The advantages of motor drive circuit breakers are that speed and timing have increased stability due to the motor being controlled electronically. Originally breakers stored energy in springs, which was transferred by compressed air, chains, and hydraulic fluid. This caused an abundance of instability. Also the overvoltage transients measured on the breakers with motor drive are much smaller than the original breakers.

Monitoring the status of motor drive breakers is important in substations. It does not require sensors, and provides an early warning prior to a fault. Monitoring can be accomplished using an RS232 port and LAN or remotely using a modem. Within monitoring there are many levels of supervision, they are constant monitoring, automated self check, and manual trend analysis. Constant monitoring runs continuously in real time and checks the capacitor voltage, the firmware status, and the position of the breaker. The automated self check, also known as “micro-motion”, runs at specified intervals or when initiated remotely. This checks all the primary and secondary functions of the motor drive. This is done by performing a sequence of controlled movements on the contacts of the circuit breaker.

Report 211 describes the fault protection used on a Kii channel HVDC link that transmits power generated on Shikoku Island to Honshu Island in the Kansai region. This transmission line spans 100 km between converter stations and is designed to transmit approximately 10TWh annually. Nearly half of this 500kV DC line is under ground and the other half is above ground. This system has two main lines and two return lines to ensure power can be transmitted if one side is down.

The advantage to continuous operation control is that it allows the DC converters to continue running during a fault. Most HVDC systems stop the DC converters during a system fault. This delays the converter between 200 to 500 ms after the fault has been removed to recover transmission ability. This continuous operation control minimizes the delay down to around 100 ms. Verification was also made that the remaining phases will compensate for the faulted phase, confirming the recovery functionality.

Field Experience with Secondary Systems was addressed by three reports. Report 212 summarizes the various drivers underlying the introduction of digital technology and the engineering and operational experience gained by a number of utilities in The Netherlands during almost two decades. This technology was used for both the refurbishment of existing substations and new substations.

Though the experiences of the various utilities with digital equipment are mixed, there is sufficient evidence that the performance of digital control systems can satisfy the requirements, in a single case after some teething problems are solved. This observation is in line with the finding of a CIGRE study in 2003 that most utilities are satisfied with digital control systems.

The Dutch experience also shows that a for digital control equipment a life span of 20 years and more can be achieved albeit certain components might no longer be available within the service life of the control system because of advances in technology, commercial limitations and other reasons. The use of alternative components is most likely to incur added costs and engineering efforts, and it is thus important to develop a strategy to tackle component obsolescence and unavailability of equipment. The authors also stress that users should face the possibility that manufacturers lack specific expertise of older generation systems. The report highlights the point that a proper EMC and EMI management and a consistent engineering practice is vital to achieve and maintain integrity of the digital control system.

During the last 10-15 years all involved parties concerning the advantages and disadvantages of applying substation automation systems have gained a growing experience and resulting awareness. A particular concern has always been the manageability of substation automation systems during its (by many perceived too short) lifecycle. Concerns in terms of changes made to the system, testing of changes, retention of the detailed technical knowledge of a particular system and finally the lack of awareness of the necessity of version control of the applied components and software modules within the utility have led to many fierce discussions regarding the change management of substation automation systems.

The report 213 describes why changes are applied to systems and what kind of testing is required to approve the change. Change management is divided into categories depending on the origin of the change and the impact to the rest of system. Testing of substation automation systems is described and what to test after different types of changes made to the system after commissioning. The impact of the skills level of personnel on the test quality and last some issues concerning the version control of hardware and software.

There have been many developments with Digital Control Panels and Electronic Instruments based microprocessor techniques for gas insulated switchgear (GIS) technology. Such advancements include:

- Upgrade of the digital control panel (DCP)
- Use of Rogowski coils and Capacitive voltage dividers
- Communication between SCADA and substation controller equipment using optical fibers through serial interfaces

Report 214 highlights some of the questions posed upon implementing of these advancements in GIS equipment. These questions are:

- What components are comprised the DCP?
- What functions are capable with the DCP?
- What are the advantages to communication through SCADA?

- How reliable is the new DCP prototype what measures have been taken to ensure this?
- What are the advantages of Rogowski coils and capacitive voltage dividers?

The DCP has many components associated with its design these include: microprocessor based digital controller, LCD screen, digital inputs and outputs (DI, DO), analogous inputs (AI), relays. One of the most useful tools provided by the DCP, is the LCD screen. Its function is to provide a user interface for an operator. The LCD screen works in conjunction with all the other components so an operator can verify control commands issued, observe GIS alarms, annunciation, and gas densities for each section. The operator also has the ability to control circuit breakers (CB) as well as auxiliary contacts and contacts from auxiliary relays (DS and ES). The communication through SCADA enables operators to maintain remote control access of functions within the GIS equipment. SCADA provides information about monitoring, measuring, and system conditions. These all contribute to Substation Automation Systems (SAS).

The Rogowski coils and capacitive voltage dividers are an adequate solution to the problem of operating safety in conventional CTs and VTs. Both devices have completed tests and have passed specifications concerning instrument transformers. Rogowski coils measures the current through the coil and integrates the result to obtain a nice linear output. Where as capacitive voltage dividers use two capacitors, a sensor, and a calibration box to measure voltage that also gives a linear output.

In conjunction with these technological developments the Reports 126 and 127 have been discussed. Report 126 shows the capability and possibility of IEC 61850-9 with non-conventional instrument transformers. It also showed field test results of interoperability of equipment which is a very important feature of IEC 61850. Paper 127 showed the high performance and capability of optical current and voltage sensors including the possibility of higher reliability and lower maintenance costs.



Modern Optical Current Transformer

[126]

Preferential Subject 3

For PS3 six reports have been submitted, covering the topics mentioned above.

Most of the attention is focused on the SF6 issue: this gas, widely used in the electrotechnical field, has unique dielectric and arc-quenching capabilities but, being chemically very stable and characterized by a molecule of big dimensions, has a very high Global Warming Potential: around 24000 times that of CO2. The reduction of emissions of SF6 to the atmosphere is among the priorities of the different Countries that have adopted the Kyoto protocol.

Four papers out of six presented for PS3 deal about this problem: papers 302 and 303 report national experiences of Norway and Japan respectively. The first approach imagined in Norway (302) was the proposal of a very high importation tax (850 Euro/kg) on SF6 to reflect its Global Warming Potential and motivate the utilities and the manufacturers to reduce its consumption or find alternatives. The national consciousness that the adoption of this measure would create important problems in terms of increase of capital and operation investments expenditures lead to the a change of position towards a binding and verifiable agreement between utilities and authorities to monitor the use and to reduce by 30% the emissions of SF6 in the atmosphere in a 10 years perspective. A GIS user group was established to keep track of the situation, report to the authorities, train utilities personnel on adequate gas handling procedures and disseminate the SF6 emission reduction awareness.

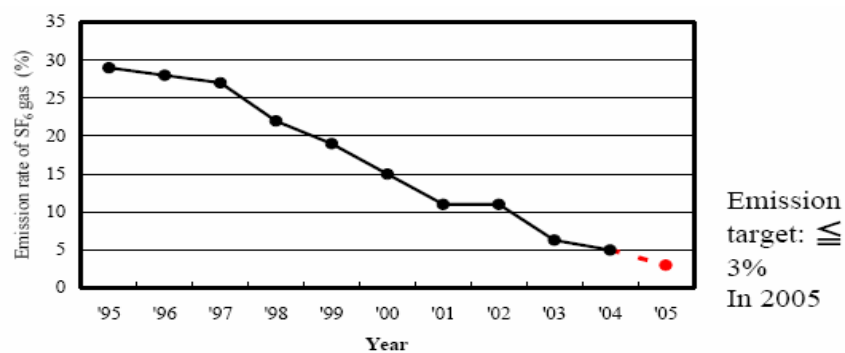
A similar approach was adopted in Japan (paper 303) where a voluntary action plan was proposed by the Organisation of Manufacturers and the Organisation of Utilities to the Environmental Authorities. The focus was made on gas handling and reclaiming. The goal of the plan is to reach, by 2005 a rate of recycling of SF6 of 99% (where in 1998 the recycling was not even considered) and a reduction of the SF6 emissions to the atmosphere to reach a rate of 3% against the 40% of 1998. This important goal, verified through the monitoring of the gas quantities among the different parties involved, is obtained also by means of the use of adequate (in terms of number and capacity) gas reclaiming plants both in the gaseous and in the liquid phase.

Paper 301 reports of a cryogenic technique to recapture and recycle SF6. The working principle consists in chilling the gas to temperatures as low as -196 degrees inside a suitable cylinder, causing the condensation of the gas. The saturate vapour pressure of the SF6 at that temperature being in the range of 1 mbar, there is no need of any vacuum pump to extract the gas from the GIS equipment. The cryogenic technique and the consequent fractional distillation also allows to remove contaminate from the gas in an very efficient gas-recycling process, with particular reference to CF4, air, water and oil and to obtain a gas fulfilling the requirements of IEC 60480 or even 60376. This technique, together with an advanced design of the building basement (made as a labyrinth with sealed compartments) to ensure a safe and quick reclamation of any accidental spill of gas, allowed the conception of a very big underground substation where all components (comprising the transformers, reactors, and the switching equipment and busbars) are SF6 insulated, for a total amount of more than 20 tons of gas. In case of accidental leakage, the gas flows through chambers following a pre-determined path down to a chamber where it can be recaptured (even if mixed with air) by means of the described cryogenic technique. Another feature presented in the paper from Australia is a device and a procedure for topping up leaking circuit breakers under live conditions, thus avoiding the interruption of supply linked with this

maintenance operation. This practice was not shared by other utilities present in the audience because of the potential problems linked with the rupture of the gas pipe to the circuit breaker chamber that would have severe consequences and because of the risk (especially if this technique was adopted for GIS installations) of moving the particles inside the tank, causing potential dielectric breakdowns. Moreover the audience pointed out that circuit breakers can be considered as tight (leak rates lower than 0.1% per year have been reported in Germany also on very old equipment), especially since the adoption of modern aluminum castings.

To conclude the review of contributions dealing with SF6, paper 306 discusses the results of an extensive laboratory investigation on gas mixtures considered as an alternative to SF6; in particular the paper shows that the dielectric and arc-quenching capabilities of N2 and N2/CO2 mixtures up to 2 MPa cannot practically compete with that of SF6: as a matter of fact, the dielectric tests carried out on a GIS having the dimensions for a 245kV system isolated in SF6 did not pass the dielectric tests required for the 145kV, even at a pressure of 1.3 MPa. On the base of the results of the investigation presented, the equipment which could result from the application of the gases subjected to the tests would be much bigger or would work at much higher pressures than the present technologies; thus the potential environmental gain obtainable by the use of alternative gases vanishes. Moreover, the lively discussion pointed out that, the results of Life Cycle Assessment studies demonstrated that the use of modern HV GIS substations located close to the loads can have an environmental load by far lower than that of conventional AIS stations forcedly installed far away from the loads. The opinion expressed was that the effort shall be focused on the optimization of the available technologies to reduce SF6 leaks, more than in the search of alternative insulating media.

Paper 304 reports the experience of a circuit breaker manufacturer with the “design-for-environment” approach: a demonstration is given that, by means of the so called “EIME approach” an important reduction of the environmental burden of electrical equipment can be achieved, with particular reference to the reduction of material weight, avoidance of materials potentially harmful for the environment and a particular attention to components life-cycle Joule losses. The subject of lifecycle Joule losses is the focus of paper 305 in which an analysis is presented demonstrating that by changing the station configuration from the classical AIS with 1+1/2 circuit breaker to the hybrid configuration using modular NSR an important reduction of the Joule losses can be obtained, together with other important flexibility advantages. The environmental effect of the losses reduction is very important taking into account the duration of the life of the substation (40 years) and has a certain influence on the operation costs of the plant.



SF6-gas emission rate in Japan [303]

Conclusion

Apart from the more fundamental research issues raised by Prof. Okubo, the state of the art with respect to compact substations, combined functions, SF₆-gas handling/reduction/emission, monitoring, aging, end-of-life decisions, maintenance intervals, asset-information has been addressed in a number of papers, that contributed to the success of the Colloquium. A list of the presented papers with authors is attached. The authors together with the participants, session chairmen, reporters and supporting staff made the CIGRE SC A3&B3 Colloquium to an outstanding event.

CIGRE SC A3 and SC B3 are grateful to the Japanese National Panels for SC A3 and of SC B3, especially the chairmen Mr. Kiyoshi Goto (B3) and Mr. Hiroki Ito (A3) and their associated staff, for the excellent organisation of the whole week and for the warm atmosphere of Japanese hospitality.



550 kV Shin-Toyosu underground substation [118]

Attachment

Accepted Papers for 2005 CIGRE SC A3 & B3 Joint Colloquium in Tokyo

Present and Future of High Voltage Equipment and Substation Technologies

PS1: Advanced HV equipment and related emerging technologies and their influence on substation design and operation

New maintenance practices, life management and asset management such as RCM, CBM, IT based program

101 Sweden (WG A3.06)

First results from on-going CIGRE enquiry on reliability of high voltage equipment
C.-E. Sölver, on behalf of CIGRE WG A3.06

102 The Netherlands, Japan (TF A3.01)

Electrical Endurance of high-voltage circuit breakers in service
R. P. P. Smeets and H. Ito

Non-standard duties with changing network conditions

103 The Netherlands, United Kingdom, Switzerland (WG A3.13)

Changing network conditions and system requirements part 1: distributed generation,
A. L. J. Janssen, M. Waldron, J. Jäger, Q. Bui-Van, M. Glinkowski, M. Claessens, F. Gallon and H. Kawano

104 United Kingdom

Short-circuit currents with high DC component time constants: calculation methodology and impact on switchgear specification & rating
T. Fairey and M. Waldron

105 USA, Japan

Development of 245kVGCB with a spring operating mechanism and application of a grading capacitor as a mitigation system for severe SLF duties
H. Wilson, R. Yeckley, S. Billings, D. Yoshida, K. Kamei, H. Kohyama and H. Ito

106 Canada, the Netherlands

Capacitive current interruption in atmospheric air
D. F. Peelo, R. P. P. Smeets and J. G. Krone

New solutions for HV equipment, mixed technology substation: Hybrid GIS and compact AIS

108 Japan, Sweden

Design and testing of polymer-housed surge arresters with special emphasize on seismic stresses and selection of specific creepage in costal areas

S. Narita, A. Sawada, H. Watanabe, B. Johnnerfelt and L. Stenström

109 Germany, Japan, Australia

Sydney's Haymarket Substation – a major milestone in applied innovation in substation design,

D. Kunze, K. Toda and D. Paton

110 Japan

Gas insulated transformer for urban under-ground substation,

T. Kobayashi, K. Toda and H. Hashimoto

111 Japan

Operating performance of the STATCOM in the Kanzaki substation,

H. Yonezawa, D. Takayama, Y. Shinki, N. Morishima, S. Funahashi, T.Fujii, M. Azuma, H. Teramoto and N. Ito

New maintenance practices, life management and asset management such as RCM, CBM, IT based programs

112 The Netherlands (WG B3.06)

Implementation of information strategy to support utility asset management

WG B3.06

113 Germany, Switzerland

Selection of maintenance strategy by analysis of service experience

G. Balzer, D. Drescher, F. Heil, P. Kirchesch, R. Meister and C. Neumann

114 Australia

Circuit breaker end-of-life decisions in Australia and New Zealand

S. Jones

115 Japan

Summary of rehabilitation projects for EHV substations owned by EPDC

T. Sakai, K. Yokotsu

116 Italy

Assembly of high voltage devices

R. Cameroni, C. Granata and L. Calamari

Substation compaction

117 Sweden

Suitable single line configurations and corresponding availability and space requirements in applications of disconnecting circuit breakers for AIS S/S

H.-E. Olovsson and C.-E. Sölver

118 Japan

Advanced compaction design for 500kV substation

T. Kobayashi and Y. Ichikawa

119 Korea

Overview of 800kV gas insulated switchgear in real commercial operation

J. B. Kim, D. J. Yang, W. P. Song, H. S. Kho, M. H. Kim, J. C. Heo, J. H. Kim and B. H. Lee

120 France, Switzerland

Compact optimized GIS, modular hybrid substation bays, mobile GIS substations
M. Bues et and E. Mikes

121 Australia, Italy

Compact integrated bay modules for new 145kV substations
M. Blundell, D. Roby and C. Piazza

Monitoring and diagnostic techniques and their impacts on economical and reliability aspects

122 France, USA

Diagnostic and monitoring tools applied to asset management
J. P. Dupraz, A. Fanget, T. Jung and G. F. Montillet

123 Japan

Monitoring and diagnostic techniques for GIS / GCB
K. Yoshii, K. Shimizu, M. Kamei, T. Nakajima, T. Kato, Y. Matsuyama

124 United Kingdom

The development of a model to assess the economic viability of on-line condition monitoring and its affect on the reliability of an EHV SF₆ circuit breaker
G. D. Camps, T. A. Cumming, D. Gibson, S. Olson, G. W. Ault and J. R. McDonald

126 France

Interoperability field experiments in substations using IEC 61850-9.2 with Non Conventional Instruments Transformers and all secondary equipment
D. Chatrefou

127 Canada, Finland

Optical current and voltage sensors in EHV series capacitor banks application
F. Rahmatian, D. Peelo, G. Polovick, B. Sunga, and J. Lehtimaki

PS2: Field experience of novel techniques applied to substation design and layout

AC and DC HV equipment

201 China, Germany, Switzerland (WG A3.17)

Integrated surge arrester systems
R. S. Perkins, F. Greuter, V. Hinrichsten and B. Richter

202 Switzerland

Refurbishment of a 380 kV AIS-substation using hybrid HV technology
B. Sander, S. Läderach and R. Vogt

203 Switzerland

Refurbishment of the 380kV AIS-substation Laufenburg using hybrid switching modules
D. Fücksle and R. Vogt

206 Brazil

Brazilian successful experience in the usage of current limiting reactors for short-circuit limitation

J. Amon Filho, P. Fernandez, E. Rose, A. D'Ajuz and A. Castanheira

Controlled switching technologies and their impacts on economical and reliability aspects

207 France

Field experience in HV circuit breakers controlled switching and condition monitoring in Latin America

R. Boero and W. Finazzi

208 Italy, Brazil

Use of controlled switching systems in power system to mitigate switching transients. Trends and benefits - Brazilian experience

P. Fernandez, P. Esmeraldo, J. Amon Filho and C. Zani

209 Japan

Application of controlled switching for transformer energization taking into account a residual flux in transformer core

M. Hijimoto, K. Kamei, H. Kohyama, H. Ito

AC and DC HV equipment (GCB)

210 Sweden, Italy

Field experience with motor drive as an operating mechanism for HV circuit breakers

D. Windmar, T. Roininen, R. Cameroni and L. Nordin

211 Japan

Fault protection of metallic return transfer breakers - field experience of HVDC equipment of Kii channel HVDC link

Y. Oue, Y. Nakagoshi, M. Hatano, M. Takasaki, T. Yamagiwa, S. Nishiwaki, K. Kamei and H. Ito

Substation secondary equipment

212 The Netherlands

Field experience with digital control equipment in substations and lessons learned

A. N. Zomers

213 The Netherlands (WG B3.05)

Change management of substation automation systems

F. Baldinger, L. Hossenlopp, D. Holstein, M. Janssen, C. Twomey, S. Läderach, F. Engler, L. Andersson, J. Martens, P. Molski, H. Timmerman, E. Bockel, P. Lindbrad and B. Terkelsen

214 Korea

Development of intelligent gas insulated switchgear using electronic technology

J. B. Kim, M. S. Kim, J. R. Jung, W. P. Song and H. S. Kho

PS3: Environment issues

301 Australia, New Zealand

New techniques for recapturing and recycling SF₆ gas and topping-up energized equipment

A. Stokes, C. Jones, M. Blundell, S. Jones, D. Roby, J. Shann

302 Norway

Efficient measures for reducing emissions of SF₆ from high voltage equipment

M. Runde and A. Mjelve

303 Japan

Recent practice for huge reduction of SF₆ gas emission from GIS & GCB in Japan

K. Yokotsu, Y. Ichikawa, H. Yonezawa, T. Sakai, T. Yamagiwa and T. Yokota

304 France, Switzerland, USA

Full EcoDesign of a 72.5kV GIS substation

I. Huet, H. Aeschbach, C. Tschannen, K. Pohlink, J.-L. Bessedé, G. F. Montillet and J. M. Pérez de Andrés

305 Spain, Germany

Economical and environmental comparison based on electrical losses with regard to AIS and mixed technology substation lay-out

E. Pagan, C. Martinez, F. Salamanca, R. Salazar, P. Glaubitz, S. Poehler and T. Weström

306 Germany

Investigations concerning discussed alternative SF₆ in HV equipment for insulating and arc-extinguishing properties

E. Kynast

Spontaneous contribution to PS1:

Non-Zero Current Break (power-point-presentation)

J. Elovaara, Fingrid