STUDY COMMITTEE B4

HVDC AND POWER ELECTRONICS

2008 SESSION

SPECIAL REPORT

SESSION SUMMARY REPORT

SESSION GENERAL REPORT

B4 - 00

SPECIAL REPORT FOR GROUP B4
(HVDC and Power Electronics)

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Special Reporters

INTRODUCTION

The work of CIGRE Study Committee B4 covers all aspects of HVDC and Power Electronics. The work includes monitoring the performance of existing transmission systems, planning, design, testing and operational issues of the new projects. The scope of B4 addresses all the relevant target groups in the power industry interested in power electronics. Economic and environmental subjects of this technology are also covered.

A total of 30 papers, including one invited paper, have been selected in accordance with the three preferential subjects for the 2008 session. The subjects of the papers vary from operational experiences, planned future projects and the challenges of the +/- 800 kV system.

The contents of some of the papers are not confined to one preferential subject only. Where relevant, some aspects of these papers are discussed under other preferential subjects as appropriate.

The preferential subjects decided by the Study Committee for the B4 2008 Sessions are:

1. Preferential Subject No. 1 - HVDC transmission projects including UHV applications

- 1.1 Operational Performance of existing HVDC projects, Upgrading/replacement of older project and application of Reliability Centred Maintenance in HVDC system design;
- 1.2 Feasibility studies of new HVDC projects;
- 1.3 Planning, Design and Reliability criteria and characteristics of new HVDC projects, also including considerations on overload capabilities and market aspects;
- 1.4 Issues and experiences with ground return and ground electrodes;
- 1.5 New development such as +/- 800 kV and VSC based HVDC projects

2. Preferential Subject No. 2 - FACTS applications and new developments

- 2.1 Feasibility studies;
- 2.2 Operational Performance and system impact of existing projects;
- 2.3 New FACTS projects;

3. Preferential Subject No. 3 - New power electronic equipment development and applications

- 3.1 New development on power electronic devices;

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3.2 Applications in distribution systems.
3.3 Applications for wind power and renewable energy sources.
3.4 Applications in DC grids for urban applications

Preferential Subject No. 1 - HVDC transmission projects including UHV applications

1.1 Operational Performance of existing HVDC projects, Upgrading/replacement of older project and application of Reliability Centred Maintenance in HVDC system design.

A total of 6 papers and one invited paper were accepted for this subject.

B4-101 presents recent experience in Japanese HVDC systems. The experience includes the following;

- Shin Shinano: Strategic planning for a replacement of outdoor oil-insulated thyristor valves and control systems. The paper shows the predicted failure rate of thyristors.
- Higashi Shimizu: Commissioning with a limited dc power due to a delay of ac transmission line completion and schemes employed for stable operation. The control modifications implemented to prevent voltage drop during converter deblocking are also described.
- Hokkaido-Honshu: Replacement of an analogue control system and improvement of a frequency control (AFC) performance to cope with an increase of change in dc power order.

QUESTION 1.1-1:

There are number of thyristor project over 20 years old. Even though the failure rate of the thyristors is still low, the utilities are faced with the question, what is the life of a thyristor? Is high leakage current an indication of potential failure? Should the thyristors with high leakage current be replaced before they fail? Is lack of spare availability the only criterion for replacing thyristors? In summary, the key question is what criterion can be used or be dominant to predict the failure rate of the thyristors?

B4-102 describes the upgrading of analog control and protection system with modern micro processor based systems. The upgrade was required to improve the reliability of the existing systems, to control the additional equipment and to meet the system regulator requirements. The new control and protection systems now control all the equipment including the auxiliary systems. The fast responding control systems are triplicated to meet the network reliability standards and other control systems are duplicated. The new system also performs additional functions of on-line monitoring of the equipment condition.

B4-108 presents the challenges associated with replacement of 40 years old mercury arc valve technology with the modern valves. The paper describes the replacement is not straight forward as the operational modes and the system transmission requirements have changed since the system was originally installed. A complete set of new studies (reliability, harmonics, planning, environmental, cable routing, etc.) are required to optimize the system and prepare the specification.

QUESTION 1.1-2:

Many older projects are facing the dilemma of continuing with life extension techniques or replacement. The changeover from Mercury Arc Valves to thyristor valves could be justified due to lack of spare parts and outdated technology but replacing old thyristor valves with new technology is presenting a unique challenge to the owners. One hand, the equipment is over 30 years old and should be replaced in a few years. On the other hand, the cost of longer outage required for replacement vs. the cost of number of short planned outage for life extension works against the justification for replacement. Can the valve replacement be justified only on the

equipment end of life, even though the availability may still be acceptable? What are the experiences of other systems in the justification of converter replacement? Does the diminishing of the operator's knowledge, size of teams and experiences with the older technology play determining role as well?

B4- 107 describes the application of Reliability Centered Maintenance (RCM) techniques to HVDC converter station. Before application of RCM, maintenance was performed yearly, which resulted in low availability and high maintenance cost. Various in steps in determining maintenance frequency and tasks using RCM philosophy are described. The application of RCM resulted in maintenance frequency being changed from yearly to every four years. This resulted in average of 3% increase in system availability.

B4-110 provides an overview of number of operational problems with two HVDC links in southern China. There were two transformer failures due to overheating connection in AC windings. Some bipole outages were caused by problem with the LAN. Due to lack spare parts, it is planned to replace control and protection after only 7 years of operation. The electrodes in the valve had accumulation problem. The ground electrode current caused overheating in neighboring ac circuits. Some outages were caused by the loss of station service.

QUESTION 1.1-3

What are the experiences of other systems with application of RCM to HVDC system?
Are the new systems designed with RCM philosophy in mind? If so, is there any increase in equipment cost? Are there other relevant contributions from experiences in reducing O&M costs of HVDC systems? As the HVDC links play an important part in every system, proper training of the operating and maintenance personnel is very essential. What techniques are being used for training staff? The hands-on experience is very valuable but it takes time. Are the simulators being used like the nuclear industry? What are the experiences of other systems in training of operators with simulators, if any?

QUESTION 1.1-4

As per CIGRE B4-AG04 survey the control systems contribute only 9% of the forced energy unavailability, yet a few projects have replaced the controls. What is the justification for replacement?
The paper 110 describes that the digital control and protection systems are going to be replaced due to lack spare parts after only 7 years of operation. In the old HVDC schemes the analog controls have operated for more than 20 years. Is this going to be a trend in replacing digital controls? What are the experiences of other systems with digital controls? What is the realistic life of digital controls taking into account the availability of hardware and software?

QUESTION 1.1-5

Paper 110 describes the problem of deposits on the grading electrodes in the cooling system. Number of other projects are either having or have encountered similar problems. What are their experiences? Are the reasons for these deposits completely understood? Are the deposits on the electrodes, an indication that some other metallic part in the valve is being eroded? How is this problem being resolved in the new valve design? Are the stainless steel components the answer?

B4-112 presents the interaction between the Itaipu HVDC system and the ac network. The rectifier is fed from the ten 700 MW 50 Hz machines whereas the inverter is feeding into a very large 60 Hz system. The paper shows that the performance of the 50 HZ system at the rectifier end is very sensitive to HVDC disturbances especially the commutation failures at the inverter end. It demonstrates how HVDC system controls can be used to damp oscillations in the ac network. The paper describes the effective use of special protection systems designed for specific disturbances.

B4-119 is a summary of the reliability performance of HVDC systems in operation worldwide during 2005 and 2006. The paper presents a summary of the average Forced Energy Unavailability (FEU) of all reporting systems for 2005 and 2006 on the basis of the major equipment categories but excluding outages due to transmission/cables. Converter transformer failures continue to contribute a large proportion of FEU for ac equipment. Eliminating converter transformer failures reduced the average FEU from 3.04% to 0.58% and EOH from 266.3 to 50.8 hours. The Median FEU and Equivalent Outage Hours (EOH) values for all reporting systems are 0.29% and 25.3 hours. The results include the data from transformer failure survey (conducted by AG B4-04 in 2007) for the years 2005 and 2006.

QUESTION 1.1-6

Paper 119 shows that a number of important systems are not reporting. What steps are being taken to encourage all systems to report? Is the reporting protocol for VSC systems being feasible to also be incorporated in the report?
Converter transformer failures continue to contribute a large proportion of FEU, the efforts made on design, manufacture and tests does not seem to show much improvement yet. Paper 110 also touches the critical issue of failures in converter transformers. The CIGRÉ JWG A2/B4 on Design Review and Test Procedures is to finalize its report by the end of this year. Are there measures to be taken by the user's side to improve the converter transformer caused FEU? Such as increasing spare units, building repair workshop near converter station for large projects, etc..Recent experiences with converter transformers failure events and predictive actions to avoid them are most welcome.

1.2 Feasibility Studies of New HVDC Projects

A total of 4 papers were accepted for this subject.

B4-103 describes the studies performed to transmit 6000 MW of power from the plant on the Madeira River in Brazil. The transmission distance is roughly 2500 km from the generation site. Power system studies included AC schemes of voltage levels ranging from 500 kV to 765 kV in and the DC schemes at ±500 to ±800 kV level. As a conclusion the DC solution was envisaged as the one with lower costs, less impact in the receiving power grid, better controllability and stability performance and less environmental impact. To transfer 6000 MW through a very long distance transmission system taking into account safety, reliability and economy it was proposed to design a HVDC transmission system with two ± 600 kV bipoles with 3000 MW each. The technical aspects regarding DC control to mitigate problems related with commutation failures on bulb power plant generators, the back-to-back device as a solution to operate in parallel with the 230 kV weak system, transmission staging scheme, economic voltage choice, and economic conductor bundle and tower configuration are also discussed in paper.

B4-109 presents the results of feasibility studies conducted to transmit 340MW of power from main land Mexico to Baja California south grid via submarine cable of about 200km. Two cable routes were studied using both line commutated converters and the voltage sourced converters. The VSC scheme was selected due to its low capital cost and its enhanced operating flexibility that includes black start, compact substations, less environmental impact with the use of polymeric cables, and inherent dynamic voltage support, so that no additional compensation is required. The system is planned to be in operation by 2010.

B4-111 discusses the studies performed to transmit the power in the South African region. The generation and the load are located far from each other thus requiring use of long distance HVDC transmission lines. The studies include monopolar, bipolar and tripole HVDC schemes including the VSC technology. A generic 1000 km, 2000MW system is used for studies.

B4-116 describes the adopted methodology for investigating the feasibility of interconnecting EU countries with the South Mediterranean Countries. The methodology is based on a two step-approach. At first, a screening phase is carried out having the aim of comparing the possible technical alternatives of the DC interconnector, location of the converter stations, sizing of the interconnector (converter stations, cable sections, overhead lines in the terrestrial legs) in relationship of the AC grid transfer capacities and the surplus/shortfall of power at both ends, preliminary configuration of the DC schemes and DC voltage. The second step of the methodology investigated technical, environmental and economic aspects of the interconnectors. The results of this methodology as applied to North-South interconnection between Italy, Algeria, Tunisia and Libya are described.

QUESTION 1.2-7

A dc transmission line running through a forest terrain is vulnerable to forest fires. If it is a bipolar line then both poles can be affected at the same time. What steps can be taken to minimize this risk? Is the answer to run each pole on a separate tower with sufficient distance between two poles? Are there any concerns about continuous earth return operation for a long time? This issue is of particular importance when considering the increasing number of long distance transmission schemes under consideration or under construction in China and India, respectively mentioned in Papers 110 and 117.
Is there any data available on the failure rate of bipolar HVDC transmission lines? What data is available on the types of dc transmission line faults? Should AGB4-04 be collecting this data?

QUESTION 1.2-8

The converter losses of HVDC VSC systems can be almost 3 times as that of HVDC Line Commutated Converters, as mentioned in Paper 109. How are the other HVDC VSC advantages capitalized against the higher converter losses? Is there more detailed comparative analysis between VSC and LCC technologies to be reported by authors of the above four papers, from Paper 104 or from other contributors? What are nowadays main reasons for choosing or not VSC transmission? In the application shown in Paper 116, were there any issues with ESCR requirements in Sicily, Sardinia and for power reversal to North Africa?

1.3 Planning, Design and Reliability criteria and characteristics of new HVDC projects, also including considerations on overload capabilities and market aspects

B4-104 describes the planning and design characteristics of the Storebaelt HVDC interconnection (400 kV, 600MW) between East and West Denmark. The interconnection provides economic benefits by allowing the sharing of the power generation between East and West Denmark. The interconnection is expected to reduce the market price of power by reducing the possibility of market dominance by power producers. Due to expected high utilization of the link the LCC converters were more economical than the VSC converters. With redundant cooling in operation, system is designed for continuous operation at 105% rated load and at 110% rated overload for 2 hours. In addition a 3 second overload capability of 135% is also available. There is a Cable Load Prediction System which continuously monitors the cable temperature and calculates the capacity of the cable on a real time basis. The monitoring system is triplicated was reliability reasons.

QUESTION 1.3-9

How does the Cable Load Prediction System, referred to in Paper 104 work? Are there any other cable systems using cable load prediction systems? What has been their experience?

B4-106 presents the results of an RTDS study of a multi-in-feed system in India. The multi-in-feed system consists of two bipoles at +/- 500 kV and one at +/-800 kV. The inverters are not located physically close to each other but electrically they are close. The study concludes that the overvoltages are within the specified limit for pole or bipole block of any of the systems. The commutation failure response of the systems is also acceptable for various faults near the inverters. It was shown that the inverter with the short circuit ratio of 18.8 was less susceptible to commutation failures as expected.

QUESTION 1.3-10

In India, China, Scandinavian countries and other systems a number of Multi Infeed systems are being planned. This is a subject of great importance and Working Group B4.41 is about to issue the final report in 2008. The response of HVDC inverter systems to an ac system fault presents a very challenging problem from system stability and overvoltage considerations. Can the commutation failure performance be improved by use of technologies, such as increased smoothing reactor or other than the series capacitor banks? Did authors of B4-106 calculate Multi Infeed Interaction Factors (MIIF) and how did they compare with the results of the study. In each way, the performance of multiple HVDC schemes loading the same electrical area may affect the characteristics and design of neighbour AC systems?

B4-113 describes the planning and design studies of the 1800MW HVDC interconnector in Saudi Arabia. The system connects the 60 Hz Saudi Arabian system to the 50 Hz systems of the neighbouring countries. The interconnector consists of three independently operating back-to-back poles of 600MW. The challenges of the location of the converter in a desert location are discussed.

B4-117 presents the studies conducted for +/-800 kV, 6000 MW system in India. The effect of commutation failures on the sending end system was investigated and measures to maintain the sending end system stability during commutation failures are described. The system consists of two parallel converters of 1500 MW each. Each converter is designed for 33% continuous overload. The studies show that filter switching is required to maintain the overvoltages within the design limits.

B4-118 presents the mean design features of 660MW, 500kV, 105km HVDC project between New Jersey and Long Island in USA. The 500kV undersea and underground cables are paper insulated mass-impregnated type. The project also uses an XLPE insulated-metallic return cable and a single fiber optic cable. Besides passive AC filters, active AC filters are also used.

QUESTION 1.3-11

A great details are given about how the undersea and underground cables are installed, what are the technical and economic background for choosing combination of one 500kV and one metallic return cable instead of combination of one +250kV and -250kV cables?
It should be interesting to know the criteria of determination and design of schemes with active AC filters, such as in Paper B4-118, in comparison with passive AC filters?

1.4 Issues and experiences with ground return and ground electrodes

B4-105 describes how the electrode sites were selected for the new +/- 800 kV link in India. Two geophysical studies were used to determine shallow resistivity (up to 150 meters depth) and deep resistivity structures (upto10 kms depth). Shallow resistivity measurements were carried out in an area of 600m x 600m using High-resolution multi-electrode DC resistivity imaging technique with 10m electrode spacing and a profile length of 790m (80 electrodes system). Data were acquired along many profiles for both Wenner and Schlumber configurations. Deep electrical resistivity structure up to the depth of 10kms around proposed Earth electrode station sites was delineated by using Magnetotelluric (MT) method. A location closer to the station was not found suitable. Acceptable sites were found about 40 km away from the stations.

QUESTION 1.4-12

With reference to Paper 105, it should be good to know what type of electrode is being planned, deep earth or ring type and why? Is there a plan to install blocking devices in the near by substations that might be affected especially when one converter is out of service and the remaining converters are loaded to 133%?
In terms of comparative experiences, what other methods of locating a suitable electrode site are available? What is the optimum area around the electrode site that should be investigated for low resistivity? Is 10 kms radius enough? Any comments from other contributors will be most welcome on this relevant aspect of HVDC schemes.

1.5 New development such as +/- 800 kV and VSC based HVDC projects

B4-114 describes the research and development requirements for +/-800 kV systems. The paper also identified the need for further research in the following areas:

- Bushings
- Transformers
- Overhead line and bus support insulators
- Earth electrodes
- Dynamic overvoltages

The paper concludes that transmission at +/- 800 kV is economically realizable.

B4-115 presents the design and testing requirements of the **+/-** 800 kV equipment. The components specifically addressed in the paper are converter transformer, transformer valve side bushings, wall bushings, smoothing reactors, dc bypass switches and disconnect switches. The design of the thyristor valve is not expected to present any problem. It is expected that the insulation at 800 kV will be the biggest challenge. The test facilities must also be developed to cater for the higher test voltage levels.

QUESTION 1.5-13

Paper B4-114 identified the immediate R&D needs on crucial equipment for +/-800 kV systems. For the long terms, what kind of different approaches should be considered in order to achieve more reliable and economical design? Are there other R&D experiences on this voltage level that could be reported?

B4-115 described excellent field experiences of composite insulators against pollution effects applied in existing HVDC systems. What is the opinion of authors regarding the necessity of pollution tests on composite insulators for 800kV HVDC applications?
Regarding the internal insulation design, the importance of time dependent field calculations is shown, how about the necessity of 3 dimensional field calculations? Are there efficient 3D field calculation software tools available?

2. Preferential Subject No. 2 - FACTS applications and new developments

2.1 Feasibility studies

B4-204 presents a new concept for improving the system stability by injecting real and reactive power into the system and as opposed to the traditional reactive power compensation only. It is proposed to connect a battery in parallel with the capacitor of a STATCOM. The battery will store the energy during normal operation by charging itself and supply the real power to the system when required.

2.2 Operational Performance and system impact of existing projects

B4-201 presents over 30 years of operational experience with SVC's in Australia. Some of the older SVC's have been refurbished. The main failure modes of the SVC's are;

- Failures within main plant items (transformers, reactors and capacitors)
- Fire in a TCR valve
- Flashovers in a TSC valve
- Cooling system failure leading to thyristor failures
- Failures due to disturbances on ac system causing misoperation of the auxiliary controls and protection.

This paper is of great importance to the Power Electronic field, since it provides a comprehensive report on many different causes and consequences of SVC equipment failures. Although being a relatively simple sub-system, according to Paper 201, an impressive record of failures on SVCs has been reported, this for sure will help other users in the world to manage their maintenance policies. This type of paper should always be encouraged to take part in CIGRÉ activities. The paper recommends a need to improve the specification and need to incorporate Reliability Centred Maintenance (RCM) at the design stage.

B4-202 describes the experience with two SVC's in France. The SVC's were installed to improve the low voltage in the area. The low voltages caused tap changer blocking and tripping of the wind farms. The capacitors alone were not found to be a suitable solution as the switching was slow and it resulted in amplification of existing harmonic voltages and caused disturbance to 175Hz signal used by the distributor.

QUESTION 2.2-14

What types of problems have been encountered with SVC's in other countries? What recommendations could be transmitted to the equipment producers so as to enhance the design? By employing STATCOM (based on VSC) as reported in Paper 204, which problems reported in Papers 201 and 202, could be avoided?
How can the experiences of SVC users around the world be shared? What are implications of incorporating RCM principles at the design stage? Will it increase the initial cost?

2.3 New FACTS projects

B4-203 presents a summary of proposed new facts projects in Power Grid of Russia. The proposed installations consists of traditional FACTS devices such as STATCOM, SVC and Controlled Series Compensation. In addition to the above it is proposed to install asynchronized rotating compensators. These compensators provide inertia for system stability in addition to the voltage controllability.

QUESTION 2.3-15

Many years ago, where utilities were concerned about high maintenance costs and low availability of rotating machines, such as synchronous condensers, the appearance of SVC was

somewhat considered as a maintenance-free device with "almost" the same characteristics of the older machines. After 30 years of experience with SVC, its own evolution to STACOM and the evolution on the rotating machines technology, perhaps the design of reactive compensation equipment should be revised as pointed out in Paper 203. It would be interesting to compare the standpoint of authors of Paper 203 with other countries and experiences.

3. Preferential Subject No. 3 - New power electronic equipment development and applications

3.1 New development on power electronic devices

B4-301 describes the development of a compensated voltage divider for UHV application. The paper compares the performance of high ohmic voltage dividers with the RC compensated divider. The effect of stray capacitances and inductances, leakage currents on the insulator surface, the voltage and temperature linearity and stability and design of the resistors used and the temperature behaviour of the completed divider are presented.

B4-304 presents a new Multilevel Voltage Sourced Converter Topology for HVDC application. The technology is called MMC (Modular Multilevel Converter) which consists of a series connection of sub-modules. The output voltage of each sub-module can be switched either to zero or to the voltage of the integrated storage capacitor. A very smooth and nearly ideal sinus waveform can thus be generated with MMC converters, because each individual sub-module is switched individually. Based on this, the requirements for filter circuits are therefore drastically reduced. Additionally, the sub-modules can be switched at a significantly reduced frequency which in turn results in lower operational losses of the converter.

QUESTION 3.1-16

Can +/- 500kV level be achieved with the MMC topology with a single converter or will series converter be required? If used with overhead transmission line, how fast can the power be restored in case of a DC line fault in comparison with other techniques which employ one full voltage DC capacitor? Are there economic advantages of the MMC topology?

3.2 Applications in distribution systems

B4-306 describes an active grounding system for a distribution network using a multi frequency converter. The active grounding system has the following features;

- Earth-fault detection
- Transient earth-fault extinction and permanent fault current cancellation
- Location of both transient and permanent faults (being extinguished or not)
- Predictive maintenance of the network isolation

The fault extinction is carried out by cancelling the voltage of the faulted phase. The fault location is done by injecting neutral currents of specific frequencies.

QUESTION 3.2-17

The system injects full voltage between neutral and earth to extinguish the fault. Therefore the neutral connection of the transformer must be able to withstand full phase voltage. What type of design changes to the standard transformer, are required to add insulation for the neutral point? What are the advantages and disadvantages?

Are there any other examples of applications of the power electronics in the distribution system? Can the VSC transmission be economically justified to replace overloaded sub transmission systems, especially in the metropolitan areas?

3.3 Applications for wind power and renewable energy sources

B4-302 presents an application LCC HVDC for connecting wind farm to the network. The power is transmitted over 190km of off-shore cable and 50 km of on-shore cable. The comparison between VSC, LCC and hybrid alternatives is presented. The simulation results show that chosen LCC HVDC alternative meets the dynamic fault ride through and other Grid code requirements.

B4-303 describes various alternatives for integrating wind farms into the network. The paper provides case studies for large and small wind farms. For small wind farms an AC connection with SVC/STATCOM is proposed. For large wind farms LCC HVDC is proposed. Despite operational flexibility of the VSC technology its application for very large wind farms is not considered feasible due to high losses and converter capacity limitations.

B4-305 describes a feasibility of application of D-STATCOM for connecting a wind farm with fixed speed induction motor. The simulations show that without the D-STATCOM the wind farm connection does not meet the Grid code requirement. The study shows that the Fault Ride through Capability is dependent on the network data, the wind turbine data and generator data. As such, each case must be studied separately.

B4-307 presents two controls schemes for connecting a wind farm to the grid using a SVC and a switched capacitor bank. In the first control scheme the SVC current is maintained at a fixed value for specified range of bus voltage. When a fault occurs the SVC will respond to maintain the voltage. If the bus voltage falls outside a specified range the capacitor bank controls will switch the capacitors. In the second control scheme the SVC responds to maintain the bus voltage to a reference point and the capacitor bank controls maintain the current in the SVC.

QUESTION 3.3-18

With reference to Papers 302 and 303, it would be interesting to know the technical and economical impacts of 400MW offshore converter station upon overall grid performance? Could these influence the choice for LCC HVDC alternative? Are there other contributors to share their experience on this relevant topic?
The solution of a 10.5Mvar D-STATCOM needed in Paper 305 to meet fault ride through grid code requirement for a 9MW wind farm seems an oversized solution. Has the author or any other contributor considered the solution using a combination of capacitor banks and a small D-STATCOM?
Paper 307 shows good field test results of both solutions for steady state voltage fluctuation control, is there also transient fault voltage control (fault ride through) field test result available?

3.4 Applications in DC grids for urban applications

No paper received.

Appendix 1: Summary by the Special Reporter

DISCUSSION MEETING

for

SC B4, Cigre 2008 session

SUMMARY

GROUP B4
HVDC AND POWER ELECTRONICS

29th August 2008

Chairman : **Marcio Szechtmann** Secretary : **Bill Long**
Special Reporters: **Dr. Yanny Fu** and **Narinder Dhaliwal**

The chairman opened the meeting with introduction of the Working Group B4 structure.

The Guest speaker Mr. Stig Nilsson reviewed the history of FACTS technology.

The session was attended by about 250 delegates. 30 papers were covered by Study Committee B4. The discussion included 64 prepared contributions and 23 spontaneous contributions, thus reflecting the actuality of the preferential subjects and the large interest for the area of HVDC and Power Electronics.

The Mission of SC B4 is "To facilitate and promote the progress of engineering and the international exchange of information and knowledge in the field of HVDC and power electronics. To add value to this information and knowledge by synthesising state-of-the-art practices and developing recommendations". The scope of B4 addresses all the relevant target groups in the power industry interested in power electronics. Economic and environmental subjects of this technology are also covered.

Three preferential subjects were covered in the Technical Session:

1 HVDC transmission projects including applications at 800 kV

- Operational Performance of existing HVDC projects, Upgrading/replacement of older projects and application of Reliability Centred Maintenance in HVDC system design;
- Feasibility studies of new HVDC projects;
- Planning, Design and Reliability criteria and characteristics of new HVDC projects, also including considerations on overload capabilities and market aspects ;
- Issues and experiences with ground return and ground electrodes;
- New development such +/- 800 kV HVDC and VSC based HVDC projects;

2 **FACTS applications and new developments**

- Feasibility studies;
- Operational Performance and system impact of existing projects;
- New FACTS projects;

3 **New power electronic equipment development and applications**

- New development on power electronic devices;
- Applications in distribution systems;
- Applications in wind power;
- Applications in DC Grids for Urban applications.

PS 1: HVDC transmission projects including applications at 800 kV

There were 19 regular papers submitted under this subject. The breakdown of the papers was as following;

• Performance/upgrading of old projects	6
• Feasibility studies of new projects	3
• Planning design of new projects	4
• Ground electrodes	1
• 800 kV systems	4

In addition to the above, one invited paper on HVDC Performance from AG B4-04 was also submitted.

There were 13 special report questions discussed by 53 prepared contributions and 12 spontaneous contributions. As a result the following can be concluded:

Numbers of older HVDC projects are approaching the end of their life and the utilities are investigating various methods of replacing the old equipment and in some cases upgrading the capacity at the same time. Loss of knowledge due to retirement of experienced staff is also a concern for some of these projects. The analogue controls are being replaced with digital controls to improve reliability. The digital controls provide greater flexibility for changes and provide additional functions of on-line monitoring.

The thyristor failure rate is very low in general however some projects are replacing thyristor valves and controls to improve the reliability. It relation to digital controls, it is recommended that user's must train their staff to be able to manage the software. In addition it was recommended that users should by enough spares to last for the expected life time of the controls (25 years), at the beginning of the project.

Results of feasibility studies for interconnecting EU with North Africa, potential HVDC links in South African Power Pool and for developing hydro electrical potential of Madiera River in Brazil, were presented. Two bipoles rated at 3000MW at +/-600 kV were selected to transmit 6000MW of power from Madiera River to loads centres 2500 km away for reliability reasons.

One paper described the application of Reliability Centered Maintenance (RCM) techniques to the HVDC converter stations resulting in 3% increase in availability. The HVDC performance survey continues to show that converter transformer failures are major contributor to the system unavailability. However the new projects are minimizing the outage time by having available spares at site and designing the switchyard for quick change of the transformers. JWG A2/B4-28 has prepared a design review guide specifically applicable to the converter transformers. The application of on-line condition monitoring system is becoming a routine on converter transformers. The transformer failure survey conducted for years 2005 and 2006 has shown the condition monitoring systems have helped prevent number of potential transformer failures. Some projects have built transformer repair shops on site in order to reduce the outage time.

There has been a substantial reduction in the VSC converter losses, the losses are now only about 15% higher than the LCC converter. The foot print for a comparable size VSC converter is only 50%. The application of VSC technology to transmission of power is increasing. An overhead VSC based project has been planned in Africa. With the latest technological developments, VSC is likely to become the technology of choice up to 1000MW in near future.

The design of earth electrodes and finding a suitable location for the electrode continues to be a challenge. Some cable projects have chosen to operate with metallic return in order to minimize the environmental concerns related to earth return.

The cable systems are now using real time cable load prediction systems to take advantage of the ambient conditions. The load calculation is performed using the dc current, the ambient temperature at the surface and the cable temperature. The loading limit is fed into the controls and the limit is applied automatically.

UHVDC systems at +/-800kV are scheduled to be in service in next 2-3 years both in India and China. The R&D needs for the +/-800kV equipment have been identified and testing facilities are now available. Outdoor insulation coordination and the design of valve winding bushing at the +/- 800kV level appears to be the biggest challenge. The level of pollution, the altitude of the station and the transportation limits are the influencing factors on the transformer design.

At present there are no standards for testing the composite insulators. The software for calculating field distribution is available in 2D or 3D dimensions. For some cases (like bushing) it is not necessary to use 3D calculations as the object is symmetrical in one dimension.

It was demonstrated that the Multi Infeed Interaction Factor (MIIF) as suggested by WGB4-41 gives a good indication of the interaction between the various inverter stations. The studies should include the detailed representation of the controls and the controls should be coordinated to help the recovery of the converters.

PS 2: Facts applications and new developments

There were four papers submitted under this subject. Two papers were related to the performance of Static Var Compensators. One paper described application of asynchronized rotating compensator. Another paper described the application of STATCOM as dynamic energy storage device.

There were 5 prepared contributions and 2 spontaneous contributions at this session.

One paper described operational experience of 30 years with SVC's in Australia.
This paper is of great importance to the Power Electronic field, since it provides a comprehensive report on many different causes and consequences of SVC equipment failures. Although being a relatively simple sub-system, according to Paper 201, an impressive record of failures on SVCs has been reported, this for sure will help other users in the world to manage their maintenance policies.

One contribution also described failures of SVC's in detail. The failures seem to include all parts of the SVC's. The recommendations are a need to improve the specification and need to incorporate Reliability Centred Maintenance (RCM) at the design stage. Improved communication between the suppliers and the owners is also recommended.

The paper from Russia described proposal to install asynchronized rotating compensators. The added advantage of these devices is that they provide inertia to the system as well as the ability to control voltage.

The SVC's are still the preferred solution for power systems as they have lower power losses, high speed response and require less maintenance.

A new concept for providing system stability by injecting real and reactive power using a STATCOM was presented. However more research is required for developing a suitable energy storage device.

PS 3: New developments in power electronics devices

There were total of seven papers submitted under this subject. Four papers were related to the integration of wind farms into the grid. One paper described the development of voltage divider for 800 kV systems. One paper described application of power electronic devices in the distribution system. Another paper described new Multilevel Voltage Sourced Converter Topology for HVDC application.

There were 6 prepared contributions and 2 spontaneous contributions at this session.

The new Multilevel Voltage Sourced Converter Topology is very promising development for long distance overhead transmission and for +/- 500 kV level. To restore the power in case of a DC line fault, the AC circuit breakers have to be opened in order to clear the fault on the overhead line. There is nearly no discharge of the submodule capacitors during such an event, because the IGBTs can be turned off within microseconds and the fault current rise is limited by the converter reactors. After a re-closure of the AC circuit breaker, the converter can be immediately deblocked in order to ramp up the voltage and the DC power.

Four papers described the integration of wind farms to the grid. In each case different technology was selected. For large wind farms LCC HVDC system still appears to be a competitive alternative. The size of the wind farm and the configuration plays an important part in the selection of the technology used for integration.

It was pointed out that in evaluation of the cost of losses the utilization factor must be taken into account.

Session Closing Remarks by SC B4 Chairman

The Chairman of SC B4 summarized the discussion into 13 main topics and thanked all contributors and attendants for valuable contributions and their interest in the session.

Dr. Bjarne Andersen is the new Chariman of the study committee B4 and Mr. M. Zavahir is the new secretary of the study committee B4.

Conclusions

Overall the sessions were well attended and the discussions were timely.
The prepared contributions generated a lot of spontaneous contributions, leading to a healthy technical session.
There is an increasing scope for HVDC applications with the demand for high power long distance transmission from fast developing countries.

The challenges facing the HVDC community are both from equipment and system performance issues. The community is learning to cope with the increasing demands placed on it due to resolving transformer failures and the need to implement UHVDC solutions. Cigre is playing an important role in all these aspects and is helping the HVDC and Power Electronics applications to improve overall power system performance from environmental, technical and economical aspects.

Appendix 2 General Report by the Special Reporter

DISCUSSION MEETING

for SC B4, Cigre 2008 session

GENERAL REPORT

GROUP B4
HVDC AND POWER ELECTRONICS

29th August 2008

Chairman : **Marcio Szechtmann** Secretary : **Bill Long**
Special Reporters: **Narinder Dhaliwal** and **Dr. Yanny Fu**

The chairman opened the meeting with introduction of the Working Group B4 structure.

The Guest speaker Mr. Stig Nilsson reviewed the history of FACTS technology.

The session was attended by about 250 delegates. 30 papers were covered by Study Committee B4. The discussion included 64 prepared contributions and 23 spontaneous contributions, thus reflecting the actuality of the preferential subjects and the large interest for the area of HVDC and Power Electronics.

The Mission of SC B4 is "To facilitate and promote the progress of engineering and the international exchange of information and knowledge in the field of HVDC and power electronics. To add value to this information and knowledge by synthesising state-of-the-art practices and developing recommendations". The scope of B4 addresses all the relevant target groups in the power industry interested in power electronics. Economic and environmental subjects of this technology are also covered.

Three preferential subjects were covered in the Technical Session:

1 HVDC transmission projects including applications at 800 kV

- Operational Performance of existing HVDC projects, Upgrading/replacement of older projects and application of Reliability Centred Maintenance in HVDC system design;
- Feasibility studies of new HVDC projects;
- Planning, Design and Reliability criteria and characteristics of new HVDC projects, also including considerations on overload capabilities and market aspects ;
- Issues and experiences with ground return and ground electrodes;
- New development such +/- 800 kV HVDC and VSC based HVDC projects;

2 **FACTS applications and new developments**

- Feasibility studies;
- Operational Performance and system impact of existing projects;

- New FACTS projects;

3 **New power electronic equipment development and applications**

- New development on power electronic devices;
- Applications in distribution systems;
- Applications in wind power;
- Applications in DC Grids for Urban applications.

PS 1: HVDC transmission projects including applications at 800 kV

QUESTION 1.1-1:

There are number of thyristor project over 20 years old. Even though the failure rate of the thyristors is still low, the utilities are faced with the question, what is the life of a thyristor? Is high leakage current an indication of potential failure? Should the thyristors with high leakage current be replaced before they fail? Is lack of spare availability the only criterion for replacing thyristors? In summary, the key question is what criterion can be used or be dominant to predict the failure rate of the thyristors?

The thyristor failure rate as per AGB4-04 biennial performance report on HVDC systems continues to be well below 0.5%. The consensus in the industry has been that the “thyristors do not age”. However some HVDC schemes have had increased failure rate of the thyristors. Quite often the failure is caused by failure of another component at the thyristor level such as snubber circuit, grading capacitors, etc.

The performance of the thyristors can also be affected by degradation and “wear-out” mechanisms. There are two main categories of such degradation:

Mechanical wear-out - This type of degradation can be caused by thermal cycling which can affect the brazed joint and flange on the capsule. Degradation can lead to loss of hermeticity of the capsule, which can allow the thyristors to “breathe” and hence allow the moisture to enter the capsule. Thermal cycling may also cause scrubbing of the pressure-contacted interfaces or weakening of the spring that applies contact force from the gate lead to silicon.

Electrical degradation - Cosmic Rays have been known to be a cause of sudden spontaneous failures of semiconductor devices, with GTOs being particularly vulnerable. Theoretically, cumulative exposure to damage by cosmic rays could lead to an increase of on-state voltage drop and decrease of Qrr. However the practical evidence of this phenomenon is scarce.

There has been lot of interest in relationship between the increase in the leakage current and the thyristor failure rate. High leakage current itself does not indicate that the thyristor is about to fail. However, a progressively increasing leakage current could be an evidence of aging thyristors in a scheme that is experiencing high failure rate. There is no known mechanism which could lead to an increase of leakage current in thyristor that has not been subjected to any mechanical wear out.

Every thyristor has a weak point at the edge of the silicon slice. This point of silicon has to be beveled in order to reduce the surface electrical field and to prevent localized electrical breakdown of the air, this edge bevel is covered with a protective layer of silicone rubber.

Analysis of the location of the failure site of the thyristor can also be very informative. However, the failed thyristor must be removed from valve as soon as possible after the failure before the failure site is destroyed. Since even a few hours of operation can destroy the failure site, removal of the thyristor immediately after failure is not always possible due to commercial requirements to operate the scheme.

In summary, the progressive increase of leakage current indicates that some property of the thyristor is being degraded. However, unless accompanied by increased thyristor failure rate should not be a reason to initiate complete thyristor replacement. If thyristor failure rate is increasing, the failure rate of other valve components must also be investigated.

In case a large scale replacement of thyristors is warranted and the original source of supply is not available care must be taken to properly interface the thyristor with other valve components.

QUESTION 1.1-2:

Many older projects are facing the dilemma of continuing with life extension techniques or replacement. The changeover from Mercury Arc Valves to thyristor valves could be justified due to lack of spare parts and outdated technology but replacing old thyristor valves with new technology is presenting a unique challenge to the owners. One hand, the equipment is over 30 years old and should be replaced in a few years. On the other hand, the cost of longer outage required for replacement vs. the cost of number of short planned outage for life extension works against the justification for replacement. Can the valve replacement be justified only on the equipment end of life, even though the availability may still be acceptable? What are the experiences of other systems in the justification of converter replacement? Does the diminishing of the operator's knowledge, size of teams and experiences with the older technology play determining role as well?

Depending on the condition of the various components of the HVDC scheme and the system requirements, it can either be a partial replacement where only some parts are replaced (e.g. control, valves, etc.) or complete replacement in which case capacity can also be increased.

Number of factors has to be taken into account to justify replacement.

Equipment Age -

Normally the equipment life is about 30 years but in practice it can be extended to 35-40 years by implementing various life extension measures. Assuming the equipment is still in operation after 25 years an economic analysis should be performed on the replacement of the equipment at some future date (5 -10 years). The preplanning will allow the equipment to be replaced at an opportune time without affecting the transmission adversely

Cost of forced outages -

In the open market environment severe penalties may be levied if a forced outage occurs and the contracted power can not be delivered. Not only it affects the power delivery at the time but if the forced outages are too frequent, the reputation as a reliable power provider will also be affected which in future may mean less business.

Maintenance cost -

As the equipment approaches the end of life, more frequent outages may be required to maintain the equipment in addition to the scheduled maintenance. These outages are required to make repairs to prevent forced outages and often scheduled during low loading period.

Availability of spare parts -

The repairs to various components can be made only if spare parts are available. As the time goes by, the supply of parts may become scarce due to change in technology or the original supplier may have either discontinued or planning to discontinue the original components.

Need for system upgrade -

In some cases, the replacement may be required simply because the requirements of the system have changed and an upgrade is required either to add more capacity or to implement additional control functions even though the original equipment may not reached end of its life.

Schedule for replacement -

The replacement of old HVDC systems presents a unique challenge. In majority of the cases there is no alternative transmission available for transferring power during the time when the system is being replaced. The replacement schedule should be established well ahead of time so that it has minimum affect on the day to day business. Depending on the configuration of the system the replacement may be carried out at the same time a generator is taken out for overhaul.

Team work -

For systems, where only parts of the system are replaced (e.g. only valves or only controls) it is essential that the experts from the utility (who understand the old equipment) and the supplier must work together as a team. The interfaces and the functions must be clearly defined. More emphasis should be placed on factory testing and minimizing the actual system tests in the field. It is often necessary to replace equipment in stages (e.g. one converter in fall and the other in the spring, etc).

Environmental concerns -

In some cases concerns about environmental issues may dictate replacement of the equipment regardless of the availability figures. One utility replaced all the oil filled filter reactors with air core reactors. The problem was created when the number of reactor porcelains failed resulting in oil spill. It was economical to install air cored reactors than implementing counter measures to contain the oil spill and/or fire.

QUESTION 1.1-3

What are the experiences of other systems with application of RCM to HVDC system? Are the new systems designed with RCM philosophy in mind? If so, is there any increase in equipment cost? Are there other relevant contributions from experiences in reducing O&M costs of HVDC systems? As the HVDC links play an important part in every system, proper training of the operating and maintenance personnel is very essential. What techniques are being used for training staff? The hands-on experience is very valuable but it takes time. Are the simulators being used like the nuclear industry? What are the experiences of other systems in training of operators with simulators, if any?

Reliability Centered Maintenance (RCM)

Present market conditions demand that all power system components including the HVDC schemes must operate at high reliability and availability levels. Paper B4-107 described successful application of Reliability Centered Maintenance (RCM) techniques to an HVDC system which was already over 20 years old. The implementation of the RCM program had an immediate impact on the availability of the DC transmission system by reducing the frequency of outages required to perform the maintenance program, and by focusing more on non-intrusive "Predictive Tasks" (Condition Monitoring) versus intrusive time based Preventative Tasks.

Reliability Centred Maintenance eliminates the need to perform maintenance every year. This results in increased availability of the system as planned outages are reduced. In addition the maintenance costs are reduced as the amount maintenance done every year is reduced. The challenge however is to determine the appropriate maintenance interval. It is therefore essential to continuously monitor the effectiveness of the maintenance program and make adjustments over time if necessary.

In order to maintain and effective maintenance program it is very essential that detailed documentation of the all the maintenance and repairs is stored. The documentation should not only include the cost of repair but also include the loss of revenue. A detailed root cause analysis must be performed periodically on the costly failures

The maintenance program should be supplemented with a condition monitoring program. Developments in the software, storage technology and digital sensors allow the assets to be monitored on continuous basis. The data can be transmitted to a central location where it is stored and analysed. The condition of the asset determines when and what maintenance need to be performed.

Training-

To keep the operating and maintenance personnel trained basically two areas for training were proposed:

A) Operator Training Simulator to train the operators
B) Basic C&P Hardware and Software to train the operating and maintenance personnel

A) Operator Training Simulator
The objective is to provide a training facility for the realistic operation of the HVDC System with the same functionality as provided on the local Initiation and Monitoring System (Human Machine Interface). This simulator is a stand-alone equipment with the same "look and feel" as the original HMI System.

The Operator Training Simulator serves mainly for training the normal operation of HVDC Systems. The normal operation is defined as start-up and shut-down procedures with healthy main equipment, auxiliary sub-systems and operation control equipment.

Operators exercise operations on the local HMI. The HVDC System reacts correspondingly to the commands. The operator then can observe and must actively take the role of the opposite Converter station operators. This training results in a complete understanding of the HVDC System.

In addition to the above the simulator can be designed to simulate processes, control functions and operation without communication to the remote station.

B) Basic C&P Hardware Equipment and Software tools for Training

To provide hands-on training facilities for operating and maintenance personnel, identical Control & Protection Hardware and Software is required, A stand-alone hardware consisting of an HMI and C&P equipment, can be used to get a good hands-on training performance by the personnel at the station in case of emergency situations e.g. loss of redundancy or loss of power transmission. The training should cover the following:

- The replacement of defective modules during operation
- The correct use and handling of software tools
- Reading of diagnostic trace functions
- handling of computer programming units

It is recommended that regular training of all related operating and maintenance staff should be scheduled at regular intervals (e.g. every 2 months) and executed using the real hardware and software tools, not just the reading of manuals.

QUESTION 1.1-4

As per CIGRE B4-AG04 survey the control systems contribute only 9% of the forced energy unavailability, yet a few projects have replaced the controls. What is the justification for replacement?
The paper 110 describes that the digital control and protection systems are going to be replaced due to lack spare parts after only 7 years of operation. In the old HVDC schemes the analog controls have operated for more than 20 years. Is this going to be a trend in replacing digital controls? What are the experiences of other systems with digital controls? What is the realistic life of digital controls taking into account the availability of hardware and software?

With replacement of analog controls in various systems around the world, Nelson River BP1 and BP2 are the only large HVDC system left which still operates on analog controls. All other systems have some form of digital controls.

The consideration for replacement of the control systems was best explained by one of the contributors as following:

"*The ideal date to replace equipment is the day before the equipment stops working. However this date is not achievable in the real world, because it's just impossible to predict when the equipment will definitely stop. Besides, there is also the time required to do all necessary steps of a replacement, like preparing specification, buying, producing, installing and testing the new equipment. So, the decision of replacement has to be taken with safety margin of time in order to minimize the risks and avoid possible penalties caused by undesirable equipment unavailability.*

For HVDC control systems, we have also to consider that they are the brain of the HVDC transmission system. In case of a complete system failure, without any possibility of replacement or repair, part of the energy will not be transmitted by the HVDC link until new equipment is installed. So the responsibility to define the deadline for control system replacement is very high, no matter its current contribution to the forced energy unavailability".

The reasons for replacement of controls by various HVDC schemes are as following:

- The controls were over 20 years old and new features were required which could not be incorporated into the existing controls.

- The controls were replaced as part of life extension project where the controls were identified for replacement as the exact life span can not be predicted.
- The controls were over 25 years and advantage was taken of a window of opportunity presented by outage of large generator.
- Spare parts were not easily available and the experienced personnel had retired.

An important consideration in the maintenance of the controls is the training of the station staff. The engineering staff should participate in the factory testing and the commissioning of the equipment, including system tests. The station maintenance and operating staff should participate in the commissioning of all the components including sub-system and system tests. The supply of the equipment should include all the hardware and software tools necessary to make any future changes to digital control systems (in cases where the supplier also has the maintenance contract, this will not apply).

The following recommendations should be considered for new projects to avoid problems in the future:

- The appropriate number of pre-tested spare parts should be considered when setting up the project. To buy a higher number of spare part modules is strongly recommended.
- The spare part modules must be pre-tested in the original hardware and software system environment.
- Related tools e.g. programming units and the number of memory modules have to be available.
- The operators/engineers at site should be permanently trained to make sure that they are able to handle the technology.
- The overall life time of an Control and Protection System is about 25 to 30 years or longer if spare part recommendations are followed.

QUESTION 1.1-5

Paper 110 describes the problem of deposits on the grading electrodes in the cooling system. Number of other projects are either having or have encountered similar problems. What are their experiences? Are the reasons for these deposits completely understood? Are the deposits on the electrodes, an indication that some other metallic part in the valve is being eroded? How is this problem being resolved in the new valve design? Are the stainless steel components the answer?

The question of deposits described in paper B4-110 was addressed by the supplier as following:

- The grading electrodes collect all charged particles in cooling water.
- The deposits on grading electrodes was determined to be mainly aluminum hydroxide Al (OH)3 / Al O(OH).
- Heat sink is the only aluminum component in the cooling circuit. Stainless steel is not an adequate alternative due to thermal property.
  The aluminum alloy is protected by a very stable aluminum oxide layer, which has to be destroyed before the growing of scaling can be explained.
- Destruction of oxide layer is possible by acid or alkaline ambient conditions, which exist in cooling water circuit.

- Possible roots of impurities in water circuit: material of ion exchanger, water flow rate, water quality and filtering equipment.

More investigation is necessary to fully explain the reasons for these deposits. In the interim, the electrodes would need to be cleaned periodically.

Nelson River BP2 was the first HVDC project to use water cooled thyristor valves. The valve design used stainless steel heat sinks. It was reported that in 30 years of operation no significant deposits have been observed.

Itiapu project also reported that having corrosion problems in the coupling. The solution was to add platinum electrodes. However these electrodes do have to inspected and cleaned every 6-8 years in order to maintain their functional integrity.

Areva reported as following:

Ultra-pure de-ionized water can have a very low conductivity, less than 0.1 uS/cm. However, no matter how sophisticated the de-ionization equipment, it is not possible to reduce the conductivity completely to zero, because water always dissociates into H+ and OH- ions, to an extent governed mainly by temperature. As a consequence, any water pipe spanning two points at different electrical potentials will inevitably carry a small leakage current. When the applied voltage is only AC, the consequences of this are not particularly serious, but when the applied voltage has a DC component, certain electrochemical reactions inevitably take place at the anode and cathode electrodes.

Theoretically, with inert (noble) electrodes and ultra-pure water, the only electrochemical reactions should be the generation of gaseous oxygen and hydrogen at the anode and cathode respectively. In practice, however, the situation is always more complex and a proportion (usually very small) of the charge passing through the cell results in other electrochemical reactions. These can result in the erosion of material from one electrode and the deposition of material on the other. Both effects have the potential to cause coolant leaks and other harmful consequences. The potential of a coolant leak to occur as a result of erosion of material is a particular concern.

Aluminum, which is widely used as a heat sink material because of its excellent thermal conductivity, is very vulnerable to erosion in the event that leakage currents flowing in the water are allowed to impinge directly on the aluminum. In order to prevent damage to the aluminum it is necessary to ensure that the leakage currents flowing in the water do not flow directly from water to aluminum but instead pass via some inert electrode material. In this way the vulnerable aluminum is protected from damage.

Areva recommends:

- Only selected grades of aluminum and stainless steel, and a small number of polymeric compounds that include XLPE, PTFE and EPDM, to come into contact with the coolant.
- The leakage current density should be kept below a threshold level where the erosion or deposits are negligible.
- Install a stainless steel sleeve between the polymeric tube and the aluminum heat sink so that the current does not flow directly from coolant to the aluminum.

QUESTION 1.1-6

Paper 119 shows that a number of important systems are not reporting. What steps are being taken to encourage all systems to report? Is the reporting protocol for VSC systems being feasible to also be incorporated in the report?
Converter transformer failures continue to contribute a large proportion of FEU, the efforts made on design, manufacture and tests does not seem to show much improvement yet. Paper 110 also touches the critical issue of failures in converter transformers. The CIGRÉ JWG A2/B4 on Design Review and Test Procedures is to finalize its report by the end of this year. Are there measures to be taken by the user's side to improve the converter transformer caused FEU? Such as increasing spare units, building repair workshop near converter station for large projects, etc..Recent experiences with converter transformers failure events and predictive actions to avoid them are most welcome.

Performance Reporting

Advisory Group AG4.04 has been carrying out an ongoing "marketing" process to encourage additional projects to report. There are projects that have made a decision not to participate for a variety of reasons - lack of knowledgeable personnel, cost and value added reasoning. Some existing projects have stopped reporting because of retirement of senior people who understood the process of reporting. Some new projects do not want to report because of supposed commercial implications of data. This is a continuous process and a number of different methods have been tried by the AG and are continuing.

We are seeing more Voltage Source Converter systems coming on stream. In general the existing reporting protocol is applicable to VSC systems and it is feasible to incorporate reported performance in the biennial paper. All that is missing are the performance reports from VSC systems.

Adding members to the Advisory Group from India and China could improve the chances of receiving more reports. There has been good success with the India projects and there has been increased interest in participation from China over the last several reporting periods, however, we still have not received reports that follow the protocol.

Overall, individual contacts by members of AG seem to produce the best results. Further encouragement by country members of B4 would be appreciated.

Transformer Failures

The JWG A2/B4-28 is in the final stages of issuing the Design Review Guide. This guide has been developed specifically for the HVDC converter transformers with input from users, supplier and consultants. The JWG has also prepared a tutorial on the reliability of converter transformers. Tutorial shall be posted on the website once it is completed.

The users have taken one or more of the following steps to mitigate the converter transformer failure problem:

- Installed on-line monitoring on the converter transformers.
- Use on-line degassing units for removing the gas while the transformer is still in service.
- Purchased spare transformers for each type.

- Ensure that the switchyard is built so that transformer can be changed in 2 days.
- Make changes to the transformer specification.
- Perform detailed design review.

QUESTION 1.2-7

A dc transmission line running through a forest terrain is vulnerable to forest fires. If it is a bipolar line then both poles can be affected at the same time. What steps can be taken to minimize this risk? Is the answer to run each pole on a separate tower with sufficient distance between two poles? Are there any concerns about continuous earth return operation for a long time? This issue is of particular importance when considering the increasing number of long distance transmission schemes under consideration or under construction in China and India, respectively mentioned in Papers 110 and 117.
Is there any data available on the failure rate of bipolar HVDC transmission lines? What data is available on the types of dc transmission line faults? Should AGB4-04 be collecting this data?

To minimize the effect of forest fires two approaches have been used.

<u>a) Use two monopolar dc lines</u>

For minimal risk, the poles can be separated by a suitable distance from each other. Two DC lines, CahoraBassa - Apollo and Inga Shaba, installed the pole conductors on two different structures which were separated by 1 km apart. Forest fires often cover wide areas and separating by short distances may not buy much for security for the higher cost of two right of ways and two towers.

The experience of CahoraBassa - Apollo link is summarized as following:

- The major causes of flashovers on both lines are POLLUTION and FIRES.
- It is likely that the large and vigorous grass fires would have caused near-simultaneous faults on a bipolar line
- Monopolar lines offer immunity against simultaneous fire-induced faults.
- In the case of pollution flashovers, the Eskom experience has been that common-cause factors, namely, mist and high humidity could lead to near-simultaneous flashovers on monopolar or bipolar lines.
- The choice of a monopolar line configuration has been vindicated – in terms of sabotage and floods – when one line was temporarily put out of service; ground return allowed the system to keep running.

<u>b) Two Bipoles of Smaller Rating</u>

The economic and system studies for the Madeira project in Brazil concluded that the optimum solution was to build two bipoles of 3150MW at +/- 600kV. The transmission lines will be bipolar and will be separated from each other by 10 km. In addition to the consideration about the line faults, the dynamic stability of the receiving system for loss of a bipole was also a major determining factor.

<u>DC transmission line faults</u>

There is data available on the effect of DC transmission line faults on converter performance in the biennial report by AG04. The report shows the number of forced outages of the converter systems and the corresponding equivalent outage hours associated with the outages due to transmission line faults. The type of faults - pole or bipole - is sometimes listed in the individual reports, but not reported in the biennial paper.

The cause of the line faults is not reported under the present protocol.

QUESTION 1.2-8

The converter losses of HVDC VSC systems can be almost 3 times as that of HVDC Line Commutated Converters, as mentioned in Paper 109. How are the other HVDC VSC advantages capitalized against the higher converter losses? Is there more detailed comparative analysis between VSC and LCC technologies to be reported by authors of the above four papers, from Paper 104 or from other contributors? What are nowadays main reasons for choosing or not VSC transmission? In the application shown in Paper 116, were there any issues with ESCR requirements in Sicily, Sardinia and for power reversal to North Africa?

The VSC technology has made considerable progress in last few years. The VSC converter losses have been reduced to a level where it can now compete with the LCC technology for power levels up to 500MW and will soon be economical for power level up to 1000MW. The VSC converter losses are now of the order of 115% of the LCC converter, according to one manufacturer, which seems to be an optimistic ratio for the present time, achievable in near future .

The VSC technology offers the following advantages over the LCC technology:

- Site area is reduced to almost 50% and ac filters are eliminated.
- The VSC offers black start capability thus eliminating the need to have local generation for starting. This is especially important if one terminal is located on a small island.
- Reduced construction time.
- Provides ability to regulate ac bus voltage without having to install additional ac filtering.

One contribution presented cost comparison for 750MW BTB system. The cost of VSC system was only 77% of the LCC system.

First long distance overhead VSC transmission project is scheduled to be in service in Nambia in 2009. The system is rated for 300 MW at 350 kV. The transmission line distance is 970 km.

QUESTION 1.3-9

How does the Cable Load Prediction System, referred to in Paper 104 work? Are there any other cable systems using cable load prediction systems? What has been their experience?

The Cable Load Prediction System (CLPS) uses the dc current, sea bed temperature and the cable sheath temperature as input parameters. Specially designed algorithm calculates steady state capability and short term capability for 15 and 60 minute durations. This information is sent to the SCADA system where it is applied to the converter controls.

The CLPS allows the utilisation of available temperature margins to increase the capacity of the cable through continuous control of the cable real-time temperature. Temperatures on cable surfaces and in the ground are measured with three redundant Pt100 elements. If the redundant Pt100 elements indicate different measured values, the measured values are invalid and an alarm is sent to the SCADA system.

No other cable load prediction systems were reported.

QUESTION 1.3-10

In India, China, Scandinavian countries and other systems a number of Multi Infeed systems are being planned. This is a subject of great importance and Working Group B4.41 is about to issue the final report in 2008. The response of HVDC inverter systems to an ac system fault presents a very challenging problem from system stability and overvoltage considerations. Can the commutation failure performance be improved by use of technologies, such as increased smoothing reactor or other than the series capacitor banks? Did authors of B4-106 calculate Multi Infeed Interaction Factors (MIIF) and how did they compare with the results of the study. In each way, the performance of multiple HVDC schemes loading the same electrical area may affect the characteristics and design of neighbour AC systems?

Multi Infeed Systems

Increasing power demand combined with long distances between the generation and the load has resulted in increased use of HVDC transmission. In China, India, Denmark and Brazil multiple HVDC inverters will be located in the same area. These types of system configurations are referred as Multi Infeed Systems. Working Group B4-41 was formed to study the technical challenges related to Multi Infeed systems and develop a guideline for the planners.

WG B4-41 developed an interaction factor called Multi Infeed Interaction Factor (MIIF) and developed a definition of Multiinfeed Interactive ESCR (MIESCR**).**

A brief description of these is included here for reference.

Multi Infeed Interaction Factor (MIIF)

To complete the basic knowledge of interaction potential, a new factor called the Multi Infeed Interaction Factor (MIIF) is introduced. The ac system parameter most reflective of the interaction of a particular inverter with the ac system is the inverter ac bus voltage. The MIIF relates interaction between any two inverter ac voltages.

At the new HVdc infeed ac bus and with the new link injecting rated power, induce an approximate 1% step voltage (deltaVn) through the artificial switched connection of a shunt reactive element. Observe the percent change in ac voltage at other inverter ac buses of concern. The ratio of these numbers is the MIIF between the two buses.

$$\mathrm{MIIF}\ e\,n = \frac{\Delta\, Ve}{\Delta Vn}$$

where ΔVe is the observed voltage change at another existing inverter ac bus.

Multiinfeed Interactive ESCR Definition (MIESCR)

The traditional definition of ESCR at a single infeed inverter bus is:

$$ESCRi = \frac{(SCCi - Qfi)}{Pdci}$$

where SCCi is the short circuit MVA available on the inverter bus i
Qfi is the bus filter and capacitor MVA
Pdci is the rated dc power of the link.

Critical Effective Short Circuit Ratio, CESCR is the critical value of ESCR for which the maximum available power on the HVdc link is its rated power.

If it can be considered that ESCR is a general indicator of performance, especially with respect to fault recovery and power voltage instability, then it would be logical to redefine the meaning of Pdci for a multiinfeed definition of ESCR. Therefore:

$$Pdc_i \quad \text{becomes} \quad Pdci + \sum j \; (MIIFj,I \times Pdcj)$$

where j represents all links in electrical proximity so that now

$$MIESCRj = \frac{(SCCi - Qfi)}{Pdci + \sum j \; (MIIFj,I \times Pdcj)}$$

WG B4-41 report provides detailed explanation of how MIIF and MIESCR can be used to determine the possible interaction between the inverter.

Paper B4-106 provided results of RTDS study of a multi-infeed system in India. The study concluded that the Dadri inverter was least affected by the faults at the other two inverters (Bhiwadi and Agra). The authors later calculated the MIIF for the same system. **Using the guidelines of B4-41 the same conclusions were drawn using the MIIF.**

Similar analysis was performed for the Madeira project in Brazil and the conclusions were as following;

- The performed studies for the future Brazilian HVDC Multi Infeed scheme confirmed the expected dynamic behavior based on MIIF and MIESCR indexes evaluation.

- In case of new planned HVDC Multi Infeed schemes, it is strongly advisable to calculate the values of MIIF and MIESCR indexes, in order to have preliminary information about possible difficulties to be experienced.

- Since the dynamic performance of each HVDC link may be dependent on the other, studies involving HVDC Multi Infeed configurations must be always carried out considering both links in operation, **avoiding simplifications,** when the pointed out indexes indicated possible interactions.

There was general consensus that increasing the size of the smoothing reactor is not only costly but may not substantially improve the commutation failure performance and recovery. However, a “close-in” machine voltage support with strong exciter performance (e.g. generators or synchronous compensators) can help both commutation failure susceptibility and recovery rate.

QUESTION 1.3-11

A great details are given about how the undersea and underground cables are installed, what are the technical and economic background for choosing combination of one 500kV and one metallic return cable instead of combination of one +250kV and -250kV cables?
It should be interesting to know the criteria of determination and design of schemes with active AC filters, such as in Paper B4-118, in comparison with passive AC filters?

<u>DC Cable Aspects:</u>

From the cable side, the advantage of using one HVDC Mass Impregnated cable and one XLPE insulated MV cable compared of using two HVDC Mass Impregnated cables are the following:

- Shorter manufacturing schedule, as it could be possible to split the construction on two different production lines.
- Use of standard laying equipments, as it is easy to coil the XLPE cable on a second platform on board the vessel, and bundle it during laying to the HVDC cable.
- Shorter jointing assembly time in case of repair.
- Overall lower costs.

<u>Converter Station Aspects</u>

The selection of one high voltage cable and one low voltage cable represents the best technical and economical solution for this project. Such a solution has been widely utilised for DC converter voltages up to 500kV, 660MW. In terms of availability such a scheme can be considered as being equivalent to a single 3-phase circuit in that, the failure of any component within the DC circuit will result in the cessation of power transfer. However, with this arrangement it is possible at the time of construction or many years later to add a second converter connected to a new High voltage cable on one converter DC terminal but the other DC terminal can share the Medium voltage cable of the original converter. Such an arrangement allows the DC transmission losses to be reduced as the DC current through each converter can be balanced such that the DC current only flows in the High voltage cables and not in the Medium voltage cable. Also, in the event of any outage condition, e.g., a cable failure or a converter fault, then the remaining equipment will still be able to transmit some power. Hence, such an arrangement can be considered equivalent to a double 3-phase AC circuit.

Where a 12-pulse converter arrangement is utilised there will always be some DC voltage stress on the converter transformer insulation, irrespective of the DC cable arrangement. Whilst there are a few examples of relatively low power HVDC links operating as 6-pulse converters the majority operate as 12-pulse, principally in order to reduce the harmonics generated by the converter and hence reduce the duty on the harmonic filters. However, the introduction of VSC technology has seen the more wide use of 6-pulse bridge arrangements being utilised, at up to 350MW to date. Such an arrangement means that the converter transformer can be designed without taking into consideration the additional insulation requirements and hence testing imposed by DC voltage stresses and hence the cost of the transformer is reduced and the number of possible manufacturing and testing facilities of a transformer for this application increases.

With each DC converter terminal connected to a High voltage cable, in the manner now prevalent with VSC converter connections the converter connection has two DC voltages raised to a potential with respect to earth and hence the arrangement is “bipolar”. However, as the loss of any individual plant item, e.g., a cable or a converter will result in the loss of the complete interconnection this arrangement can be compared to a single 3-phase AC connection. As there is no Medium voltage cable to share with a second, future, converter, any future converter would require two additional cables, that is, the DC side of the two converters would, by necessity, be independent of each other.

Need for Active AC filters in addition to Passive AC Filters

Active AC filters have been installed at each converter station to substantially reduce the harmonic current injection and consequently the likelihood of telephone interference. The transmission rights-of-way on Long Island and in New Jersey are typically congested, and often have adjacent phone circuits. Accordingly, the harmonic current (IT-level) design target specified for the Neptune HVDC Project was very low, less than typically specified for HVDC schemes.

The active AC filters are designed to improve the effectiveness of the passive AC filters and to mitigate harmonic currents flowing in the AC network at frequencies not or insufficiently covered by the installed passive branches (Sayreville: 2 x TT 12/24/36 + TT 5/12/37 +TT 3/12/37 + DT 3/5; Duffy Avenue: 2 x TT 5/12/24 + 2 x TT 3/12/48 + ST3). Taking the specific harmonic AC system impedances into account (mix of cable systems and overhead lines), such low harmonic distortion / IT-levels, as recorded during commissioning of both converter stations, can only be achieved using active AC filters

QUESTION 1.4-12

With reference to Paper 105, it should be good to know what type of electrode is being planned, deep earth or ring type and why? Is there a plan to install blocking devices in the near by substations that might be affected especially when one converter is out of service and the remaining converters are loaded to 133%?
In terms of comparative experiences, what other methods of locating a suitable electrode site are available? What is the optimum area around the electrode site that should be investigated for low resistivity? Is 10 kms radius enough? Any comments from other contributors will be most welcome on this relevant aspect of HVDC schemes.

Area for Electrode Site

Industry experience is that there is no rule-of-thumb to identify an optimal area when investigating a suitable site for location of earth electrode. A very important subject is to investigate what you have underneath until you reach the magma representing the remote earth.

An example as demonstration: In one area under investigation there is a large area with sediments with low resistivity to a depth of about 200 m. Underneath, the sediment is a 10 km thick layer of crystalline rock. The material further deeper has a good conductivity.

We assume a ring electrode with a diameter of 1 km at a depth of about 2 m and a current of 2 kA. As the rock acts as an isolator, most current will flow in the surface layer. The voltage drop from the centre of the electrode area up to a radius of 10 km will be about 50 Volts.

However, the current has to reach the remote earth and the voltage drop across the 10 km of crystalline rock will be about 600 V although the area has a radius of 10 km. Based on this information only the complete area will have a voltage of about 600 V compared to remote earth, which is far too much.

Deep cracks in the crystalline rock will improve the situation.

The design of the electrode itself will be easy. No problem regarding step voltage etc.

The investigation must continue until it is assured that the voltage to remote earth will be low enough. The investigation must cover also the direction downwards.

QUESTION 1.5-13

Paper B4-114 identified the immediate R&D needs on crucial equipment for +/-800 kV systems. For the long terms, what kind of different approaches should be considered in order to achieve more reliable and economical design? Are there other R&D experiences on this voltage level that could be reported?

B4-115 described excellent field experiences of composite insulators against pollution effects applied in existing HVDC systems. What is the opinion of authors regarding the necessity of pollution tests on composite insulators for 800kV HVDC applications?
Regarding the internal insulation design, the importance of time dependent field calculations is shown, how about the necessity of 3 dimensional field calculations? Are there efficient 3D field calculation software tools available?

<u>+/- 800 kV R & D Needs</u>

Paper B4-114 identified following area for R & D.

- Converter technology
- Bushings
- Transformers
- Support insulators
- Overhead lines
- Earth electrodes

One contribution stated that the both suppliers and the utilities have already devoted significant resources into these areas.

<u>Pollution tests on Composite Insulators</u>

Extremely long insulator sets would be necessary in case of porcelain (up to 16 m for 800 kV at the highest pollution severities), while more reasonable values would be necessary in case of composites, if benefit is taken of their better performance. It is therefore importance to set up proper qualification methods for composite insulators especially DC. Unfortunately it is not an easy task.

Setting up of standardised pollution tests of composite is since long time in the agenda of IEC and CIGRE but an agreed solution is not yet available. Could the difficulty arise from the fact that the determination of a standard pollution test, at least at the level of type test, for composites is a false, unreachable and rather useless target? As a matter of fact when new composite insulators are tested according to the standardised methods applicable to ceramic insulators, their performance is much better than that of ceramic insulators because of their hydrophobicity. If the hydrophobicityy is fully artificially eliminated through specific treatments, which seems the hard target of some proposed procedures, then why to test the composites? It could be easier to test a ceramic mock up with similar characteristics, or anyway to derive the expected performance from that of ceramic insulators. If something intermediate is made, with an elaborate treating of the surface, the actual test conditions of the insulator tested could be difficult to assess and the tests could result hardly reproducible. Probably the actual problem is not to determine the performance at the beginning or at the end of the life, but to determine up to what life time the composite insulator maintains the required advantages, assumed in many cases as 25-30% over ceramic ones. It could be derived that, unless a representative accelerated ageing test is found and agreed, we will have to rely also in the future essentially on the knowledge acquired from the day-by-day increasing field experience, which will need however to be accurately collected and analysed.

<u>3D Field calculations</u>

The bushing is typically an axial-symmetrical geometry, and normally also the pressboard barrier system in the transformer turret looks as the same geometry; for this reason a standard 2D software with a rotational capability can be sufficient to carry out the analysis.

Different approach has to be followed for example for complex insulating structures like the HV connection coming from the transformer winding, normally with one or more curves. In this case an accurate analysis requires a software with 3D capabilities.

3D software being more complicated to be use (and consequently is more time consuming in hardware and software resources and requests skilled specialists for its use) and also more expensive than a 2D one, normally the 2D is employed for standard problems, and only when really necessary the 3D software is applied.

2. Preferential Subject No. 2 - FACTS applications and new developments

QUESTION 2.2-14

What types of problems have been encountered with SVC's in other countries? What recommendations could be transmitted to the equipment producers so as to enhance the design? By employing STATCOM (based on VSC) as reported in Paper 204, which problems reported in Papers 201 and 202, could be avoided?
How can the experiences of SVC users around the world be shared? What are implications of incorporating RCM principles at the design stage? Will it increase the initial cost?

<u>SVC Failures</u>

The failures of SVCs can be classified into following three categories:

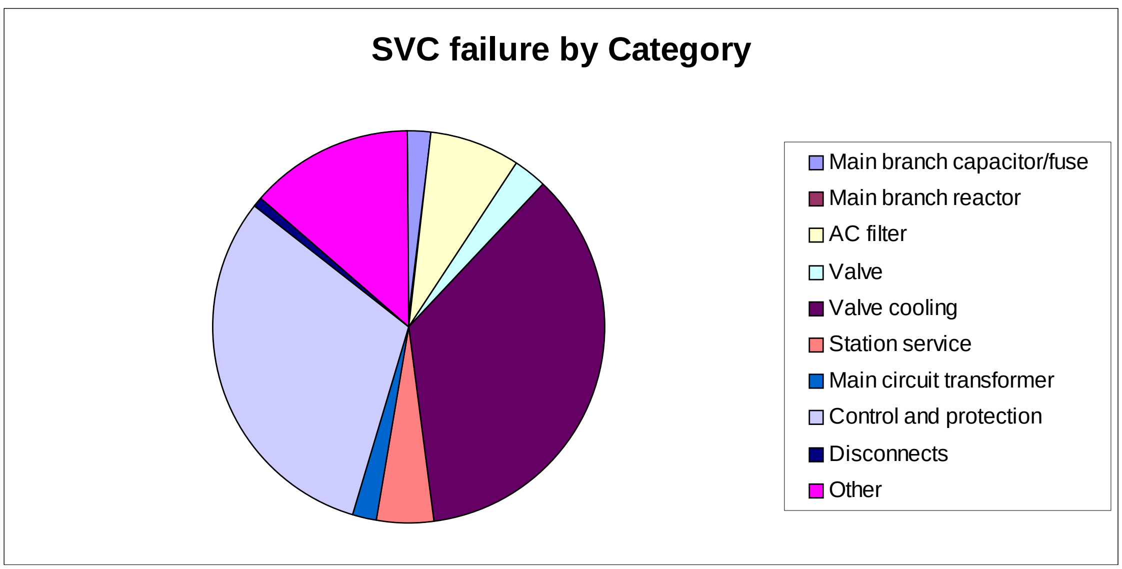
a. Equipment Problems which are related to the failures of various components of the SVC. This includes rapture of capacitor cans of TSCs and/or harmonic filters, thyristor valve damages and/or fires, failure of control printed circuit boards, failure of valve cooling systems and failure of auxiliary power supplies

b. Maintenance Problems which were attributed to lack of qualified or trained staff, lack of spare parts,(e.g. control card), limited supplier support or inadequate documentation and replacement of failed or destroyed power components without solving the inherent problems

c. Operational Problems relating to lack of expertise, use of SVC for other than its primary function (e.g. use SVC as a simple switched shut device) and attempts to use the SVC beyond its capabilities without proper investigations.

IEEE Working Group 12 SVC Failure Survey

For a number of years, Working Group I4 (SVCs) of the Substations Committee of the IEEE Power and Energy Society has been collecting data relating to forced outages of SVCs throughout the world. A number of utilities have responded to the survey, including both the author's companies and the Working Group is grateful for the responses. The results of the survey show that cooling plant faults are the leading cause of failures. The results point out the necessity of providing a reliable cooling plant, with good quality equipment.



The survey contains one-year snapshots of SVC operation, so some of the failures reported in the paper may not appear in the survey responses. The preliminary results of the survey to date are shown in the pie chart.

The types of faults in descending order are:

Cooling plant	34%
Control and protection	31%
Other	14%
AC filter	8%
Station service	5%
Valves	3%
Main branch capacitor/fuse	2%
Main circuit transformer	2%
Disconnects	1%

Main branch reactor	0%

These results suggest that a similar pattern of failures might be seen on STATCOMs and other VSC based devices.

Following recommendations are made for improving the reliability of the SVCs:

a. Comprehensive system studies should be conducted for preparation of the specification. SVC dynamic range (or stages) should cater for present and future network requirements to fulfill its function with minimum use of mechanical devices and without using transformer on-load tap changer operations.

b. Feedback comments from pertinent suppliers should be solicited before issuing final specification including comments on the physical dimensions. This will ensure that suppliers have sufficient space to install the equipment.

c. Develop and maintain a qualified team for operating and maintaining the SVC installation beyond the initial supplier training program.

c. Share the SVC experience with respective consultants, suppliers and other SVC users.

2.3 New FACTS projects

QUESTION 2.3-15

Many years ago, where utilities were concerned about high maintenance costs and low availability of rotating machines, such as synchronous condensers, the appearance of SVC was somewhat considered as a maintenance-free device with “almost” the same characteristics of the older machines. After 30 years of experience with SVC, its own evolution to STACOM and the evolution on the rotating machines technology, perhaps the design of reactive compensation equipment should be revised as pointed out in Paper 203. It would be interesting to compare the standpoint of authors of Paper 203 with other countries and experiences.

There was only one contribution for this question.

The use of synchronous condensers can be advantageous at weak system points, where the inertia can help to improve dynamic stability in the system. Such a system may further benefit from a fast response time and an extended underexcited operating range.

In many power systems, however, the focus is on high speed of response and most importantly: low power losses. Static var compensators like SVC or state-of-the-art STATCOM are the preferred solution for such systems today. Functioning without rotating parts static devices are also less demanding with respect to civil engineering, e.g. foundations, and require less maintenance.

Superconducting excitation windings for synchronous condensers may contribute to reduce losses of the condenser. To evaluate the overall effectiveness of the compensator increased investment cost, additional losses of the cooling system and maintenance requirements should be considered.

3. Preferential Subject No. 3 - New power electronic equipment development and applications

3.1 New development on power electronic devices

QUESTION 3.1-16

Can +/- 500kV level be achieved with the MMC topology with a single converter or will series converter be required? If used with overhead transmission line, how fast can the power be restored in case of a DC line fault in comparison with other techniques which employ one full voltage DC capacitor? Are there economic advantages of the MMC topology?

Modular Multilevel Converter (MMC)

Paper B4-304 described a new type of multilevel converter technology referred to as MMC (Modular Multilevel Converter). It consists of a series connection of submodules. The output voltage of each submodule can be switched either to zero or to the voltage of the integrated storage capacitor. A very smooth and nearly ideal sinus waveform can thus be generated with MMC converters, for each submodule is switched individually. Owing to this, the requirements to filter circuits are much less severe. Additionally, the submodules can be switched at a significantly lower frequency which, in its turn, leads to lower operational losses of the converter. The MMC converter has a modular design resulting in its high flexibility. The converter also uses standard ac transformers.

Economical comparison to other topologies

- Equipment cost in the same range
- More industrial standard equipment
- Lower capitalized operational losses

DC voltage of +/- 500kV:

It was stated that the DC voltage is limited by the capability of the C&P and +/- 500kV is possible based on utilization of 4.5kV IGBTs.

Recovery from DC faults in case of Over head line (OHL)

When a dc line fault occurs the converter reactors substantially reduce the effect of the fault and limit the current rise rate to only a few tens of amperes per microsecond. These faults are swiftly detected, and, due to the low current rise rates, the IGBTs can be turned off at absolutely uncritical current levels. As a result there is virtually no discharge of the submodules. Ac breaker is then tripped to clear the fault. Dc breaker is not required. After a predetermined de-ionization time the Ac breaker is then re-closed and the transmission can be resumed if the fault was only temporary as it is mostly the case for overhead transmission lines.

Each case would have to be studied separately to determine actual time for restorage.

3.2 Applications in distribution systems

QUESTION 3.2-17

The system injects full voltage between neutral and earth to extinguish the fault. Therefore the neutral connection of the transformer must be able to withstand full phase voltage. What type of design changes to the standard transformer, are required to add insulation for the neutral point? What are the advantages and disadvantages?
Are there any other examples of applications of the power electronics in the distribution system? Can the VSC transmission be economically justified to replace overloaded sub transmission systems, especially in the metropolitan areas?

<u>Active Earthing System For Distribution Networks</u>

Paper B4-306 presented an active grousing system for a distribution network using a multifrequency converter. The novel earthing system presented allows network operation and maintenance (O&M) and continuity of supply of the MV distribution network in which it is installed by overcoming the limitations of the traditional earthing systems used currently in distribution network MV substations due to the capability of controlling the neutral current and voltage of the network. It is based on the combination of a multi-frequency power converter and a protection and control system.

The active earthing system has the following advantages over the conventional earthing systems:

- Transient earth-fault extinction: neutral current and voltage control, by the injection of a network frequency current in the neutral, permits reducing fault current to the minimum as in resonant earthing.
- Fault detection: earthing through the converter leads detecting the fault as easily as in a medium or solid earthing system.
- Faulted feeder identification and fault location: the injection of multi-frequency currents in the neutral of the network allows high impedance fault location.
- Network condition oriented maintenance: when required by the user, an undervoltage or an overvoltage is provoked in the selected phase voltage, while detection and location are accomplished.
- Active earthing system minimizes step and touch voltages as a result of the low values of the fault currents, ensuring an optimal protection for personnel and equipment.

It was stated that the utility purchases transformers with neutral point insulated for full voltage.

3.3 Applications for wind power and renewable energy sources

QUESTION 3.3-18

With reference to Papers 302 and 303, it would be interesting to know the technical and economical impacts of 400MW offshore converter station upon overall grid performance? Could these influence the choice for LCC HVDC alternative? Are there other contributors to share their experience on this relevant topic?
The solution of a 10.5Mvar D-STATCOM needed in Paper 305 to meet fault ride through grid code requirement for a 9MW wind farm seems an oversized solution. Has the author or any other contributor considered the solution using a combination of capacitor banks and a small D-STATCOM?
Paper 307 shows good field test results of both solutions for steady state voltage fluctuation control, is there also transient fault voltage control (fault ride through) field test result available?

Integration of Wind Farms

With increasing concern about the environment, more and more emphasis is place on development of renewable energy sources. Over the last decade the wind power has emerged as significant source of renewable energy. The wind farms can be off shore or on land. In some countries the wind farms represent a significant percentage of the total generation. The Grid codes are now in place, which require the wind farms to ride through faults without tripping-off.

The integration of the wind farms into an existing network is presenting the industry with new challenges. The LCC HVDC technology and other power electronics technologies are playing an important part in integrating the wind farms into the networks.

Papers 302, 303, 305 and 305 describe four different applications of integrating a wind farm into the network each one using a different technology or a combination of technologies. The important point to note is that to perform proper economic evaluation for particular system all available technologies and a combination thereof must considered as alternatives. As is demonstrated in these papers there is no universal solution for integrating wind farms.

The cartelistic of various technologies can be summarised as following

LCC HVDC Solution

- May require SVC/STATCOM support for off shore.
- Off-shore converter may require Synchronous Compensators
- Low converter losses
- Large site area
- Viable solution

VSC Solution

- Optimum technical solution
- Control of real and reactive power flow
- Minimum station area
- Higher converter station losses than LCC

SVC Solution

- Suitable for small land wind farms
- Control reactive power flow

Session Closing Remarks by SC B4 Chairman

The Chairman of SC B4 summarized the main discussion topics and thanked all contributors and attendants for valuable contributions and their interest in the session.

Dr. Bjarne Andersen is the new Chariman of the study committee B4 and Mr. M. Zavahir is the new secretary of the study committee B4.

Conclusions

Overall the sessions were well attended and the discussions were timely.
The prepared contributions generated a lot of spontaneous contributions, leading to a healthy technical session.

There is an increasing scope for HVDC applications with the demand for high power long distance transmission from fast developing countries.

The challenges facing the HVDC community are both from equipment and system performance issues. The community is learning to cope with the increasing demands placed on it due to resolving transformer failures and the need to implement UHVDC solutions. CIGRE is playing an important role in all these aspects and is helping the HVDC and Power Electronics applications to improve overall power system performance from environmental, technical and economical aspects. Integration of wind farms is being achieved using all aspects of HVDC and power electronics technologies.