TECHNICAL BROCHURES

B4 - HVDC and Power Electronics

REF. 000 1994 ***SC 14 WG 14.02*** ***A summary of the report on survey of controls and control performance in HVDC schemes.*** A survey questionnaire on HVDC controls and control performance was formulated and copies submitted for completion to DC schemes. This report serves as a data collection and summary of general control arrangements, strategies and parameters used in the schemes for which questionnaires were returned. For some schemes having significant and relevant operational experience, control performance was reported on and a summary analysis is contained.

REF. 003 1987 ***SC 14 WG 14.04*** ***Compendium of HVDC schemes throughout the world.*** The Compendium wants to give a survey of the HVDC systems all over the world in detailed fashion. Many datas are required for these descriptions and they have not been obtained from many systems. Those systems, for which not all data is available are described as far as possible. The compendium can only be updated if all receipients support the work and send information on latest available data.

REF. 025 1986 ***SC 38 TF 38.01.02*** ***Static var compensators.*** The rapid development of semiconductor devices and control techniques within the last two decades have enabled the development of controllable shunt reactive compensation devices with rapid response for electric power system applications. In recognition of the potential applications and the impact of such a flexible system design tool on future electric power systems CIGRE decided to form an Ad-Hoc Group to review the progress on the subject.

REF. 034 1989 ***SC 33/14 JWG 33/14.05*** ***Guidelines for the applications of metal oxide arresters without gaps for HVDC converter stations.*** This guide for metal oxide arresters without gaps for HVDC converter stations is a supplement to the application guide for insulation coordination and arrester protection of HVDC converter stations published in Electra No.96 (Oct. 1984). It gives basic information about metal oxide material and basic arrester characteristics which will be of value when designing and specifying an arrester protective scheme and specifying the arresters.

REF. 051 1996 ***SC 38 WG 38.01.06*** ***Load flow control in high voltage systems using FACTS controllers.*** The brochure gives an overview on the impact of different FACTS controllers on the system and presents examples of the use of such equipment in the system. It is written for engineers to understand the basic interactions between the FACTS equipment and the system when solving system problems.

REF. 065 1992 ***SC 14 WG 14.03*** ***AC harmonic filters and reactive compensation for HVDC with particular reference to non-characteristic harmonics.*** This paper summarises a report prepared by WG14-03 (Filtering and reactive compensation for HVDC) and is a complement to the paper published in Electra No. 63 (1979). The brochure included details on : Importance of non-characteristic harmonics, Generation of non-characteristic harmonics, Impact on AC and DC networks, Disturbance criteria, Transient operating modes, Solutions selected for recent links etc.

REF. 068 1992 ***SC 14 WG 14.07*** ***Guide for planning DC links terminating at AC locations having low short-circuit capacities. Part 1. AC/DC interaction phenomena.*** Part I of the Guide

AC/DC system interaction phenomena, discusses the effects of various aspects of interactions between AC and DC systems on the design and performance of DC schemes connected at locations where the AC system appears as high impedance. Part II : Planning guidelines, considers the impact of the interactions and their mitigation on economics and overall system performance.

REF. 077 1993 ***SC 38 WG 38.05.04*** ***Analysis and optimisation of SVC use in transmission systems.*** The thyristor controlled static var compensator is in widespread use in power transmission systems, although it is a relatively new shunt reactive power compensation device. With the aim to enlighten the possibilities and limitations of employing SVC's for voltage control and stability improvement a study has been performed on the subject.

REF. 078 1994 ***SC 14 WG 14.01.02*** ***Voltage and current stresses on thyristor valves for static var compensators.*** The application of SVC employing thyristor valves in power transmission systems has been rapidly increasing in the past decade. Nevertheless there is no International Standard for testing of the valves. As an essential step in developing a guideline the TF undertook a thorough review of the electric stresses experienced by the thyristor valves in operation.

REF. 082 1994 ***SC 38 WG 38.01.05*** ***Use of DC converters for VAR control.*** This brochure is intended as an application guide for system planners and operators as well as equipment engineers who want to evaluate control strategies for DC converters. It starts with an explanation of DC converter capabilities and how this can be evaluated for var control.

REF. 086 1994 ***SC 33 /21/14 JWG 33/21/14.16*** ***Overvoltages on HVDC cables. Final Report.*** The number of HVDC projects using long DC cables is increasing, mostly for submarine power transmission. A larger number of such HVDC schemes are already in operation or in planning stage. The economic design of DC cables is very important, because the cost of DC cables is high in proportion to the total cost of HVDC submarine cable transmission.

REF. 092 1995 ***SC 14 WG 14.03.02*** ***DC side harmonics and filtering in HVDC transmission systems*** The report deals with the harmonic voltages and currents of concern on the DC side of HVDC transmission systems. Its aim is to provide some guidance to both users and suppliers of HVDC links in such a way that a common understanding could be established in the area of DC side harmonics and filtering.

REF. 093 1995 ***SC 14 WG 14.01.02*** ***Guidelines for testing of thyristor valves for static var compensators.*** The application of static var compensators using thyristor valves in power transmission systems has been rapidly increasing in the past decade. Nevertheless there is no international standard for testing of thyristor valves for SVC. The scope of the work was limited to SVCs for power transmission systems. SVC for industrial applications (e.g. flicker control, control of voltage fluctuations caused by motor starting) are not in the scope.

REF. 097 1995 ***SC 14 WG 14.12*** ***System tests for HVDC installations.*** This guide is structured in eight parts and should give potential users guidance, regarding which course of action should be taken in planning commissioning activities. Structure of the tests and a brief statement of the purpose of the individual group of tests is presented. Commissioning an HVDC system is a very complex task which may affect more than the actual contract parties.

REF. 103 1996 ***SC 14 WG 14.05*** ***Commutation failures. Causes and consequences.*** Many aspects of the impact and role of the HVDC system on the rest of the power system can be studied and analysed without a detailed knowledge of the actual design and behaviour of the conversion process taking place in the HVDC convertors, but a more detailed scrutiny of a number of

phenomena requires a more detailed knowledge and modelling of the HVDC system and of the DC conversion process.

REF. 112 1997 ***SC 14 WG 14.17*** ***Semiconductor power devices for use in HVDC and FACTS controllers.*** During the recent years there has been a growing need for better utilisation of high voltage transmission systems. Power electronic equipment, having an inherent fast controllability, offers solutions to transmission system problems such as load flow and stability. Therefore, engineers are increasingly studying the potential of such equipment to make transmission systems more flexible and adaptive to changing requirements.

REF. 113 1997 ***SC 14 WG 14.01.03*** ***Test circuits for HVDC thyristor valves.*** In conformity with the usual classification of the specified tests into two major categories, dielectric tests and operational tests, the report is in two parts : Part 1 - Dielectric tests which deals principally with test circuits for verifying the high voltage characteristics of the valve, and Part 2 - Operational tests, which deals principally with test circuits for verifying the turn-on, turn-off and current related characteristics of the valve.

REF. 114 1997 ***SC 13/14 WG 13/14.08*** ***Circuit-breakers for meshed multiterminal HVDC system. Final Report.*** HVDC multiterminal (MTDC) Systems permit the exchange of energy between a number of HVDC substations. The particular advantage of the meshed system is that this exchange can continue even when one of the interconnecting lines is out of service. Investigations have shown that the performance of MTDC systems can be improved by installing HVDC circuit-breakers at appropriate locations.

REF. 115 1997 ***SC 14 WG 14.07*** ***Guide for planning DC links terminating at AC system locations having low short-circuit capacities. Part II : Planning guidelines.*** Guidance on planning and design of DC links terminating at AC system locations having low short-circuit capacities relative to the DC power infeed. The Guide is limited to those aspects of interactions between AC and DC systems which result from the fact that the AC system is 'weak' compared to the power of the DC link (i.e. AC system appears as a high impedance at the AC/DC interface bus). Some more general aspects of the design and planning of HVDC transmission schemes are described only when this adds to the understanding of the interaction phenomena and for the sake of completeness of the guidelines.

REF. 116 1997 ***SC 11/14 JWG 11/14.09*** ***Guide for preliminary design and specification of hydro stations with HVDC unit connected generators.*** Several technical and economical reasons strongly suggest that in certain HVDC applications it is of great advantage to simplify the rectifier station via a direct connection of hydro generating sets to 12 pulse converter groups. The proposed arrangement is referred to in HVDC literature as "Unit Connection".

REF. 119 1997 ***SC 14 WG 14.05*** ***Interaction between HVDC convertors and nearby synchronous machines.Final report.*** It is not uncommon that HVDC convertor stations and generators are situated electrically and geographically close to each other. This follows from the fact that HVDC links are often built to transmit power from a generating station to a load centre or another part of the power system. Examples of this are the Itaipu and IPP schemes. In these cases the HVDC and generator stations are designed more or less in parallel which means that overall good design can be achieved by appropriate coordination.

REF. 123 1997 ***SC 14 WG 14.18*** ***Thyristor controlled series***

compensation. The application of power electronic thyristor valves in HVDC and SVC technologies has enabled the development of controllable series devices with rapid response for use in electric power transmission systems. With growing environmental, regulatory and financial constraints facing the electric utility industry, technical advancements and economic solutions which allow increased utilization and relaible operation of transmission systems have potential benefits for utilities and their customers.

REF. 127 1998 ***SC 14 WG 14.11*** ***Guide for upgrading transmission systems with HVDC transmission*** Following the installation of the first HVDC transmission scheme between Sweden and the Island of Gotland in 1954, over 60 HVDC schemes throughout the world have been installed. Since their initial installation many of the HVDC schemes have been upgraded in various ways. By reviewing both what has been achieved in terms of upgrading and what potentially is possible to accomplish in an upgrade, this guide provides direction and the latest information on the subject.

REF. 130 1998 ***SC 14 WG 14.23*** ***Operational guidelines and monitoring of HVDC systems*** Major advances in technology for controlling HVDC systems has led to greater efficiency in operation and maintenance, as well as providing a reduction in staff. The quality and reliability of an HVDC system is directly dependent on the type of monitoring implemented. Recent developments now allow implementation of computer based information systems with significant improvements in the delivery and presentation of data necessary for supporting the operation.

REF. 136 1999 ***SC 14 TF 14.01.04*** ***Fire aspects of HVDC thyristor valves and valve halls.*** Survey of the possible causes of fires in valves and valve halls; assistance to users in the areas of specification, engineering and construction; comparative information on fire detection and protection systems; fire alarm and fire control sustems; guidance with fire-fighting, operation and maintenance; guidance to actions after a fire. This is also a reference document for discussion with insurance companies.

REF. 139 1999 ***SC 14 WG 14.30*** ***Guide to the specification and design evaluation of AC filters for HVDC systems.*** The principal purpose of the document is to give guidance to those responsible for : preparing the a.c. filtering aspects of Technical Specifications for HVDC projects ; evaluating the proposed designs, and monitoring the subsequent project. The main objective is to enable informed judgements to be made and future Technical Specifications to be written, such that the resulting a.c. filters are effective yet economical and are non under or over designed.

REF. 143 1999 ***SC 14 WG 14.25*** ***Cross-modulation of harmonics in HVDC schemes*** Harmonic cross-modulation is a term used to describe the variety of frequency interactions around the two converters that comprise and HVDC link and the effect on and interactions with the DC system and both AC systems. Because there are two converters involved, as well as two AC systems and any number of coupled frequencies, the number of interactions to be considered is infinite. Questions to be answered are : which interactions are the strongest, and whether they are likely to cause steady state or transient problems, and how to determine these interactions.

REF. 144 1999 ***SC 14 WG 14.19*** ***Static synchronous compensator (STATCOM)*** Rapid developments of solid state power electronic devices in the last three decades have led to the development and widespread application of static var compensators (SVCs). These shunt connected reactive compensation equipment provided an important means for enhancing electric power transmission system performance. Continued rapid developments in power electronic devices and control techniques let to utilisation of gate turn-off thyristor (GTO) devices to form new power electronic shunt compensation equipment which offered more robust output.

REF. 149 1999 ***SC 14 WG 14.29*** ***Coordination of controls of multiple FACTS/HVDC links in the same system.*** Power electronics applications in high-voltage electric power systems date from the early 1970s when converters for HVDC systems bagan using thyristors to replace mercury arc valves. Since the mid-1970s all new HVDC systems have employed thyristor valves. Advances in power electronics have extended the application of fast switching currents to AC systems as well, resulting in the technology commonly known as FACTS, Flexible AC Transmission Systems. This document is intended to provide guideliens into the kinds of interactions that can occur and the means of analysis and design that are available to assure that a coordinated response is achieved and adverse interactions are avoided.

REF. 160 2000 ***SC 14 WG 14.27*** ***Unified power flow controller (UPFC)*** The result of a dialogue between utilities and manufacturers concerning the application of the unified power flow controller (UPFC). its purpose is to provide comprehensive information on the physical nature of such devices, the functions they can provide, the value of these functions for utilities, the way to implement them in the network, the problems to anticipate and the obstacles that may exist regarding cost-effective implementation.

REF. 183 2001 ***SC 14/37/38/39 JWG 14/37/38/39.24*** ***FACTS technology for open access*** Summary of the present state of the art on the key technological developments in the FACTS area, addressing in particular the open access aspects of networks and the scope for the application of FACTS devices therein. Contains the approved terms of reference. Definition of FACTS includes conventional devices such as phase shifting transformers, series capacitors and HVDC links for completeness and the possibility of combining them with FACTS devices to improve HVAC transmission system flexibility and control.

REF. 186 2001 ***SC 14 WG 14.20*** ***Economic assessment of HVDC links*** HVDC has been a viable technique since the 60's and has played a vital part in both long distance transmission and in the interconnection of systems. Its relative economic position has been much discussed over 30 years and this report is both an update of those considerations and a review of the present position. It reviews many aspects of transmission development common to both AC and DC transmission with a concentration on the specific aspects of DC as they give advantage or extra dimension to the long distance transmission of electrical power.

REF. 202 2002 ***SC 14 WG 14.26*** ***HVDC stations audible noise*** The principle purpose of this guide is to give specific recommendations to those responsible for preparing the audible noise aspects of technical specifications for HVDC projects, evaluating the proposed designs and monitoring the subsequent project. The main objective is to enable future technical specifications to be written and informed judgements made, such that the resulting outdoor audible noise levels fulfil applicable regulations and standards.

REF. 205 2002 ***SC 14 WG 14.31*** ***Custom power - State of the art.*** Custom power is a concept, based on the use of static controllers in the distribution system or in some instances, rotating machines, for the electric utilities to supply value-added power with the reliability and power quality requested by the customers. It includes consideration of all aspects of power supply that impact individual customers, including harmonics, inter-harmonics, voltage dips, overvoltages, range of steady state voltage and frequency variations and phase unbalance, in addition to the abover consideration fo reliability.

REF. 215 2002 ***SC 14 WG 14.32*** ***HVDC converter stations for voltages above +/- 600 kV*** The scope of the work is to review the current state of HVDC converter stations up to 600 kV and the problems associated with it and to investigate in detail what needs to be done to expand the technology to voltages above 600 kV and specifically to 800 kV. Parallel operation of converters is not considered in this document.

REF. 222 2003 ***SC B4 WG B4.05*** ***On voltage and power stability in AC/DC systems*** Significant new results concerning the definitions of voltage and power stability on AC/DC systems.

REF. 223 2003 ***SC B4 WG B4.28*** ***Active filters in HVDC applications*** This report presents both DC and AC active filters including the existing installations. The items of the report are nearly arranged in two consecutive parts, the first treating the DC application, while the second covers the AC filters. As active DC and AC filters share many concepts subjects may be dealt with in both parts.

REF. 237 2003 ***SC B4 WG B4.19*** ***Static synchronous compensator (STATCOM) for arc furnace and flicker compensation*** The brochure describes the application of STATCOM for arc furnace and flicker compensation. Starting from the measured flicker of an actual arc furnace, performances of the actual SVC compensation and the calculated STATCOM are compared. An utility application is presented which demonstrates the accuracy of the calculation method.

REF. 240 2004 ***SC B4/A2 JTF B4.04/A2.01*** ***Analysis of HVDC thyristor converter transformer performance*** A presentation of performance summaries with failure areas described and classified as bushings, valve windings, AC windings, static shields, load tap changers, core and magnetic shields or internal connections and leads together with short descriptions of the failures. Present transformer test methods are also evaluated for adequacy. Comparisons with the previous report are included.

REF. 242 2004 ***SC B4 WG B4.35*** ***Thyristor controlled voltage regulators: Parts 1 and 2*** A two part report containing three non-conventional methods of voltage regulation by reactive power control : voltage controlled static var compensator, shunt capacitor bank series shorting and special delta star switching. The second part explores the feasibility of static on-load transformer tap changers.

REF. 269 2005 ***SC B4 WG B4.37*** ***VSC Transmission*** This Brochure describes VSC Transmission technology, i.e. HVDC transmission using Voltage Sourced Converters. A comparison with Line Commutated HVDC technology is provided. The WG found no technical reason why this technology could not be used at high voltage and power, and concluded that such development would depend solely on the perceived commercial return on the R&D investment.

REF. 280 2005 ***SC B4 WG B4.33*** ***HVDC and FACTS for distribution systems*** The development of new high power electronic switches has made it possible to implement Voltage Source Converters (VSCs) and other converters for usage in power systems. These converters offer now applications in distribution systems too, where they can resolve problems of environmental or planning restrictions and, as they are fast acting, they can either eliminate or mitigate frequently appearing power quality problems.

REF. 337 2007 ***JWG B4/A3/B3.43*** ***Increased System Efficiency by Use of New Generations of Power Semiconductors*** The TB presents the present developments of power semiconductors, with lower losses, higher switching frequency, converter modularization…, and their new application areas, in order to propose and evaluate new or enhance equipment for increased system efficiency.

REF. 352 2008 ***WG B4.34*** ***Capacitor Commutated Converted (CCC) HVDC Interconnections: Digital modeling and Benchmark***

Circuit Capacitor Commutated Converter -CCC- calls for developing models for digital studies. The TB discusses the state of the art in digital studies of HVDC connections with CCC converters and proposes a benchmark circuit. It will serve as a simplified guide for application/specification of this type converter stations.

REF. 364 2008 ***WG B4.41*** ***Systems with multiple DC Infeed*** The TB provides an analytical framework for the understanding of interactions amongst multiple HVDC line commutated inverter stations within a common ac system. The theoretical development is complemented by actual system examples of multi-infeed HVDC planning

REF. 370 2009 ***WG B4.39*** **Integration of large Scale Wind Generation using HVDC and Power Electronics** New large wind farms, both onshore and offshore, may face challenges such as, system stability issues, the need for the wind farm to provide system/ancillary services, and difficulties to build overhead lines. The TB shows how HVDC and other types of Power Electronics can help overcome these challenges, thereby helping to integrate large scale wind farms into power systems.

REF. 371 2009 WG ***B4.40*** **Static Synchronous Series Compensator (SSSC)** The TB provides the basic principles of the Static Synchronous Series Compensator (SSSC), its functional features, basic characteristics and applications, and gives information on topologies, harmonic generation issues and modeling. It describes existing worldwide SSSC installations and presents a future outlook of SSSC.

REF. 388 2009 JWG B2/B4/C1.17 Impacts of HVDC lines on the economics of HVDC projects The study considers the overall HVDC system economics, capital (lines and stations), losses, operation and maintenance. The most economically favorable voltages and conductor configurations are studied for several HVDC system alternatives. It is shown how the HVDC line and the converter stations selection impact each combination. Directives are presented on the 'best-solutions' for different sets of transmission parameters.

REF. 406 2010 JWG A2/B4-28 HVDC Converter Transformers - Design review, test procedures, ageing evaluation and reliability in service JWG A2/B4.28 monitored the reliability in service of HVDC Converter Transformers and the TB reports, over a period 1971-2009, an encouraging decrease in the failure rate. It also reviewed existing standard test specifications, with a view of representing the real service conditions. The importance of the Polarity Reversal (PR) test and the effect of the oil conductivity and the polarization time are stressed. The conclusion is that at this stage the existing test should not be modified.

REF. 407 2010 JWG A2/B4-28 HVDC Converter Transformers - Guidelines for conducting design reviews for HVDC converter transformers A design review provides a common customer-manufacturer understanding of the applicable standards and specification requirements. It is an opportunity to scrutinize the design to ensure the requirements will be met, using the manufacturer's proven materials and methodology. This document prepared by A2/B4.28, is based on the existing guide (TB 204) while expanding to address specific aspects associated with the HVDC Converter Transformer, such as higher harmonic or transient waveforms.

REF. 417 2010 B4-45 Technological Assessment of 800kV HVDCApplications Studies carried out by the WG and work being carried out by manufacturers show that no major problem is anticipated with the implementation of 800kVdc HVDC technology,considered techno-economical where large amounts of power is to be transmitted over long distances. The test levels specified in this TB should be beneficial to utilities and manufacturers and should streamline the requirements of testing and test values.

REF. 447 2011 B4-48 Components Testing of VSC System for HVDC Applications. The brochure gives detailed description of component stresses under

steady-state condition and fault condition respectively, followed by the test philosophies. The useful test procedures are also presented.

REF. 492 2012 B4-46 Voltage Source Converter (VSC) HVDC for Power Transmission - Economic Aspects and Comparison with other AC and DC Technologies. The objective of the WG was to develop an assessment process to evaluate the beneficial impact of VSC-HVDC on power systems. The proposed methodology includes a straightforward analysis of important environmental facts that have to be taken into account for an appropriate assessment. Case studies have been provided in order to demonstrate the application of the proposed methodology. This WG gives a snapshot on the current technology, application areas and economic values. With ongoing developments it can be expected that VSC-HVDC will become even more attractive for bulk power transmission and might become an economic feasible alternative to other technologies.

REF. 508 2012 B4-44 HVDC Environmental Planning Guidelines. The guideline provides an overview of the environmental issues to be considered in the technical design and environmental approval processes associated with an HVDC system. It provides an overview of the different HVDC systems and their components, with a focus on possible environmental issues. The environmental impacts and possible mitigation measures of the components and sub-components of HVDC schemes are described.

REF. 533 2013 B4-52 HVDC Grid Feasibility Study. Until now most HVDC schemes have been point to point connections. A few multi-terminal schemes have been built with one extra terminal. But there have been many discussions of using HVDC for more advanced grids. The TB investigates the technical and economic feasibility to build such HVDC grids. The first question to answer is if HVDC grids offer any advantage over many point to point HVDC connections inside an AC grid. Another important question is if it will be possible to build HVDC breakers that are necessary to make the grid reliable. One more question is if one can make protections and control to the grid. These and many other challenging questions are studied in the Brochure.

REF. 536 2013 C4/B4/C1.604 Influence of Embedded HVDC Transmission on System Security and AC Network Performance. This brochure highlights the gain in flexibility provided by an embedded HVDC link (defined as a DC link with at least two ends connected to a single synchronous AC network) for an existing HVAC grid. It also points out the possible technical issues that may arise, along with the different capabilities and performances depending on the underlying DC technology. Illustrations through existing or planned projects are proposed, in addition to open models for a benchmark network and VSC converters.

REF. 553 2013 B4-47 Special Aspects of AC Filter Design for HVDC Systems. This new TB is intended as an Addendum to the 1999 Technical Brochure 139 "Guide to the Specification and Design Evaluation of AC Filters for HVDC Projects", which was subsequently converted into IEC/TR 62001. It addresses four areas which continue to be problematic and controversial: a.c. network harmonic impedance, pre-existing harmonics, a.c.-d.c. harmonic interaction, and current-based interference criteria. As well as making recommendations, it attempts to inform and explain, so that

project-specific decisions can be made with full knowledge of the technical background while balancing the risks and benefits appropriately.

REF. 554 2013 B4-49 Performance Evaluation and Applications Review of Existing Thyristor Control Series Capacitor Devices – TCSC. This TB is the result of a study performed by WG B4.49 on the use of TCSC systems in AC transmission lines. TCSC systems are used to increase the power transfer capacity of AC lines. AC lines can be readily tapped at a low cost along its corridor and therefore, are often the preferred transmission line technology. Fifteen TCSCs in commercial operation were evaluated. The technical justification for the systems and how well the systems have met the expectations is included in the TB.

REF. 563 2013 B4-38 Modelling and Simulation Studies to be performed during the lifecycle of HVDC Systems. The purpose of this CIGRE TB is to provide an overview of the simulation tools, models and study procedures typically required at different stages of the lifecycle of an HVDC system. The document classifies the lifecycle of HVDC into five main phases: studies for planning and preparation of technical specification of an HVDC project; studies performed during bid process; post award studies; studies performed for commissioning, studies over the operational life of the HVDC system. For each stage the brochure presents the objectives, required input data and results of the main simulation studies as well as discusses the study related responsibilities between the entities involved to the HVDC project. The brochure also presents examples how the main simulation tools presented in the brochure are applied for HVDC lifecycle related studies.

REF. 590 2014 B4-04 Protocol for reporting the operational performance of HVDC Transmission Systems. Recognizing that the experience gained on HVDC transmission systems could be of value throughout the industry, CIGRÉ Study Committee 14 established Working Group 04, This WG group is now renamed as Advisory Group 04 (AG B4-04). Performance of DC Schemes, with terms of reference which included an obligation to collect information on all systems in commercial service. It was considered that such information could be useful in the planning, design, construction and operation of new projects. It was also envisaged that the sharing of operational performance data could be of benefit to those concerned with the operation of existing HVDC links or those planning new HVDC links. It was clear that such reports were best prepared in accordance with a standardized procedure so that, with time, the accumulated data from several systems would establish a basis against which performance could be judged.

REF. 604 2014 B4-57 Guide for the Development of Models for HVDC Converters in a HVDC Grid. This TB documents the requirements of simulation models for modular multi-level voltage-sourced converters (MMC-VSC) that would form the basis of a DC Grid and provides a framework for model development that is consistent with known MMC-VSC technologies presently used. This framework can be adapted to changing power electronic topologies and control algorithms. In addition, a 9 bus DC Grid test system was developed and documented. Two and four bus test systems that are subsets of the 9 bus system are also presented.

REF. 609 2015 B4-51 Study of Converter Transients Imposed on the HVDC Converter Transformers. The LCC HVDC converter transformers are connected between the AC system and the HVDC converter. A converter transformer is subjected to voltage and current transients as a result of normal converter operation and the faults on the converter side. This document identifies the voltage and current transients imposed by the converter that must be taken into account by the transformer designer.

REF. 617 2015 AG B4.04 HVDC LCC converter transformers - converter transformer failure survey results from 2003 to 2012. Every year, the Advisory Group AG B4-04 collects information on the performance of HVDC systems around the world. Over the last 20 years this data has shown that converter transformers in Line Commutated Converter systems are the single largest contributors to the forced energy unavailability. In order to provide more detailed information on the transformer failures, AG B4-04 also conducts survey on transformer failures every two years. The results of the surveys conducted on failures from 2003 to 2012 are described in this brochure.

REF. 619 2015 B4.55 HVDC connection of offshore wind power plants. The first wave of HVDC connected offshore wind power plants (WPPs) has been commissioned and many more are planned in the North Sea, along with other sites around the world. VSC-based HVDC has become the preferred solution for large offshore WPPs, with cable distances typically above 100 km (including both offshore cable and on shore cable to the converter terminal) to the AC grid connection point. This is largely due to several technology advantages offered by VSCs, when compared to other HVAC or HVDC options, resulting in a more economically attractive transmission solution. In addition, a number of HVDC submarine cable connections for power exchange between countries are being planned and the possibility of connecting WPPs to these interconnections, and to future HVDC grids, are being seriously considered. The issues associated with expanding a WPP and HVDC connections with equipment from multiple vendors are subjects which need to be developed further, but are outside the scope of this brochure. Compliance with Grid Codes (GCs), which define the performance during normal and abnormal operating conditions, is another subject area in need of further development. Existing GCs are however written for AC connected WPPs, and for an offshore WPP these conditions typically apply only at the AC grid connection point. This raises the possibility of optimizing the overall WPP and the HVDC converter, with potential economic and maintenance benefits. However, if the HVDC connection and the WPP are provided by different vendors, such optimization cannot be done properly unless concerns about IP rights and operation benefits are clearly laid out and understood by all stakeholders involved. Guidelines and recommendation for point to point and multi terminal HVDC connection of offshore WPPs are therefore highly needed and of mutual interest for the HVDC and WTG industries in order to be able to provide the best possible solutions for all stakeholders.

REF. 649 2016 B4.54 Guidelines for life extension of existing VDC Systems. HVDC systems have been in commercial use since 1954, and most of them are still in operation. Renovation, modernization and life extension of HVDC stations have to be considered by utilities and grid operators, as they are usually the most cost effective options for maintaining continuity and reliability of the power supply to the consumers. This BT provides guidelines for making the technical and economic decision on life extension of existing HVDC stations against replacement.

REF 663 2016 B4.53 Guidelines for the procurement and testing of STATCOMS. This document is expected to be used by System Planners, System Operators, System Users, Investors and all other stakeholders that will be involved in the various stages of a STATCOM project, from the project inception to the final date when placed in service. As the technology used in STATCOM's advance, this brochure attempts to give high level guidance to how to properly procure and test a STATCOM installation without defining how one should explicitly specify the equipment required. In saying this, a great deal of the content of this brochure is based upon the contributing member's experience in either integrating a STATCOM into their grid or supplying one. The technology associated with STATCOMs is developing very quickly, with many vendors able to supply quality equipment. In order not to interfere with what vendors may be able to supply and developing test standards produced by CIGRE and other international organizations (IEC, IEEE), reference are made to existing standards where applicable.

REF 671 2016 B4.62 Connection of wind farms to weak AC networks. Issues with connection of wind power plants (WPP) to weak AC systems and how to improve the performance of these systems have been addressed. The working group has also investigated the interactions between wind generator converter systems, power system, and other power electronic in the vicinity. Guidelines for screening of potential connection points, selection of WPP models, and possible avenues for mitigating these issues are provided.

REF 675 2017 B4.61 General guidelines for HVDC electrode design. HVDC electrodes have traditionally been installed on HVDC transmission systems to provide a low resistance current return path during both monopolar and bipolar operation using the earth and/or sea as the conductive medium. HVDC electrodes are in general less costly and have lower losses than dedicated metallic return conductors. Environmental concerns related to electrode operation have become more prominent in recent years due to greater public awareness of potential impacts, tighter environmental approval processes and increasing numbers of HVDC projects. While the environmental approval process can be challenging, the long-time successful operation of older electrodes indicates many of the potential environmental impacts from electrodes can be minimized or eliminated either by suitable selection of the electrode site for impacts remote from the electrode or by application of good design techniques if the impacts are near the electrode or on the electrode site. With the development of new geophysical and geological investigation techniques, and more powerful computer simulation tools for electrical field studies and infrastructure modelling, potentially more economical designs of ground electrodes can be achieved, and the impacts of the electrode operation on existing or potential future infrastructure can be more accurately quantified. This technical brochure is prepared to formalize methodology and guidelines for the analysis, design, construction and testing of new electrodes and refurbishment or extension of existing electrodes. It is a collection of most recent techniques, processes and descriptions of software and procedures available for site selection and electrode designs.

TB 683 2017 JWG A3/B4.34 Technical requirements and specifications of state-of-the-art HVDC switching equipment. The new applications projected for future DC grids and multi-terminal DC systems at different voltages suggest that various DC equipment may be required; in particular all sorts of switching devices. However, the requirements for DC switching capabilities are different from those for AC equipment. In the brochure, a review of the technical requirements of HVDC switching equipment and an overview on the technical capabilities and limitations of existing switching equipment is given. Included are all sorts of switchgear such as disconnecting switches, earthing switches, transfer switches, and especially circuit breakers.

TB 684 2017 JWG B4/C1.65 Recommended voltages for HVDC grids. This technical brochure provides guidance for system planners and designers to choose the optimal DC voltage for High Voltage Direct Current (HVDC) grids. This includes a clear technical definition for the “DC voltage” in line with current practices and standards, a list of recommended values based on technical considerations and drivers from system planning, and a flowchart to guide the selection of the optimal voltage for individual projects.