

HVDC Systems - Program 162

Program Overview

Program Description

Electric utilities are looking for cost-effective ways to increase and manage the transmission capacity to meet the growing load demand. Application of high voltage direct current (HVDC) technology within the existing AC system is one of the options to increase the transmission capacity. This program offers a comprehensive portfolio on HVDC research for application to existing systems and to better understand HVDC options when evaluating future transmission expansions.

For owners and operators of existing HVDC systems, the program offers the operation and maintenance strategies to extend life spans and enhance performance and reliability of individual equipment components.

For those that do not have HVDC systems, the program offers information and research about the most up-to-date HVDC technologies that can be adopted on their power system, either for bulk power transfer or for system performance improvement by managing transmission system flows and lowering the risk of cascading outages. For companies that wish to increase and manage the transmission capacity on the existing AC corridor, the projects on AC to DC Line Conversion and hybrid (AC & DC) rights-of-way offer attractive alternatives to achieve such a goal.

Research Value

- To provide technology awareness through technology watch newsletters, conferences, and workshops.
- To provide experience of recent HVDC technologies and electrical effects of HVDC to companies who are considering adopting HVDC technologies for either bulk power transfer, power system performance improvement, or transmission system flow management.
- To increase the capability of existing transmission corridors by providing methods to increase power flow, enhance flow management, convert HVAC lines to HVDC lines, and construct hybrid AC & DC lines.

Approach

EPRI research in HVDC may yield a variety of data and information that may be beneficial to program members. This information will come in a number of forms and is expected to include the following:

- Provide HVDC technology awareness by publishing reports and organizing industry-wide conferences and workshops
- Publish the HVDC Reference Guide for the design and operation of HVDC systems
- Resolve operational concerns of owners and operators of existing HVDC systems and those considering the addition of HVDC to their systems
- Evaluate Voltage Source Converter (VSC)-based DC transmission and advanced power electronic devices for adoption, and identify research and development (R&D) needs to further enhance the use of these technologies at higher voltages
- Perform evaluation testing of HVDC components and system performance
- Study HVDC electrical effects such as corona, audible noise, electromagnetic interference, in both radio and TV frequencies, as well as electric fields and ions so that companies can better understand how DC lines may effect their environment
- Develop strategies and guidelines for conversion of AC lines to DC lines, to increase and manage transfer capability on existing transmission corridors
- Provide leadership in theoretical and experimental fronts in HVDC, AC to DC line conversion, hybrid AC and DC, and operation of HVDC systems
- Demonstrate HVDC technology options at utility sites

Accomplishments

In the past, the HVDC Systems program has delivered valuable information that has helped its members and the industry in numerous ways. Some examples include the following:

- Life Extension Guidelines of HVDC Converter Stations and Transmission Lines: Extend life spans of individual equipment components, thus improving individual equipment reliability through best-practice operation and maintenance strategies. Enable members to extend life spans of existing HVDC systems. Avoid substantial costs as a result of improved and predictable network performance through an optimized maintenance program.
- Assessment and Evaluation of developing HVDC Technologies: Evaluation of Voltage Source Converter (VSC)-based DC transmission and advanced power electronics and identification of technical barriers that need to be resolved to push the technologies to higher voltages.
- HVDC Reference Book: Provide the state-of-the-art information for planners, designers, and operators.
- AC to DC Line Conversion: Assessment of the reliability impact when introducing HVDC links in existing transmission systems by converting selected AC lines to DC. Such conversions may increase power transfers on corridors by as much as 50% to 70%.
- Testing: Provide credible information by testing the equipment for HVDC operation at the EPRI Lenox laboratory.

Current Year Activities

- Provide technology watch with the latest developments in the HVDC technology
- Update the leading reference guide for the design and operation of HVDC systems
- Resolve operational concerns of owners and operators of existing HVDC systems and those considering the addition of HVDC to their systems
- Evaluate HVDC system performance and conduct component testing
- Evaluate electrical effects such as electromagnetic interference and fields and corona in laboratory field settings
- Develop conversion of AC lines to DC lines to increase transfer capability on existing transmission corridors, including hybrid solutions where AC and DC lines share corridors or structures
- Demonstrate HVDC technology options at utility sites

Estimated 2010 Program Funding

\$1.0M

Program Manager

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Summary of Projects

PS162A HVDC Technology Assessment and Evaluation (069266)

Project Set Description

This project set offers technical information to electric power utilities on HVDC systems. The information covers both new technologies and experience gained in the past fifty years from operating HVDC systems. The process of converting AC lines to DC operation to gain additional transmission capacity will be investigated and studied in detail in order to develop schemes ready for implementation. This project set is suitable for both owners and non-owners of HVDC systems to select proper HVDC technologies for their applications. The knowledge transfer will be in the form of technology watch newsletters, reference books, workshops, and conferences.

Project Number	Project Title	Description
P162.003	HVDC Technology Surveillance and Reference Guidelines	This project will publish periodically a newsletter with the latest information on current and new HVDC developments and installations as well as update the HVDC Reference Book.
P162.004	AC to DC Line Conversion and Hybrid (AC and DC) Rights-of-Way	This project will address technical and economical options of converting AC lines to DC. It also will explore issues when building and operating hybrid lines sharing AC and DC on the same right-of-way.

P162.003 HVDC Technology Surveillance and Reference Guidelines (062104)

Key Research Question

It is important that the power industry has access to the latest developments and advances in HVDC technology. EPRI continues to build a comprehensive library of information on HVDC technology for the benefit of the industry. EPRI has been developing reference materials that capture and consolidate related HVDC information and knowledge.

Approach

This project seeks to enhance the knowledge of HVDC technology in these ways: 1. Publish Technology Watch newsletter - To foster future developments in the HVDC area, as well as to disseminate technical developments in a timely manner, a technology watch newsletter will be published periodically with the latest information on the current and new HVDC installations taking place worldwide. The HVDC Technology Watch tracks developments in HVDC technologies such as:

- VSC DC transmission for both overhead and underground
- Application of DC for renewables and new power sources
- Segmentation of AC systems with DC ties
- New cable for DC operation

In addition, a biennial HVDC conference or workshop will be organized and it will be sponsored by EPRI and members. 2. Update the HVDC Reference Book – Information will be developed for the *HVDC Reference Book* (also known as the “Olive-colored” book). Research will help capture the latest information on HVDC technology and operational data for existing HVDC systems. A formal peer review of the existing EPRI HVDC handbooks and related reference books led to recommendations where reference book revisions are critical. The handbook will help to:

- Guide members in specifying an HVDC system by leading members through each step of the design process and confirming that the implications of tradeoffs are well understood. The book will cover the design of the line, converter, and associated converter substations.
- Guide members in considering environmental aspects of these systems, since they differ between HVDC systems and AC lines. This handbook will study these aspects and provide members with insights on the interactions between HVDC systems and the broader society.
- Guide members in assessing existing HVDC systems and the options available when addressing repair or replace decisions and life extension options.
- Provide tools to help optimize HVDC system design.

The outline of the HVDC Reference Book was developed in 2006, and two chapters—HVDC Lines and Simulation Tools—were developed in 2007. In addition, two more chapters—Commissioning of HVDC Systems and VSC DC Transmission—were completed in 2008. Remaining chapters are being developed or will be developed in the future and a final *HVDC Reference Book* (Olive Book) will be issued with all updated chapters. The tech watch, conference and reference book will provide valuable insight into HVDC technologies for companies presently operating HVDC systems and those contemplating HVDC as a possible transmission option.

Impact

This program strives to provide the following impact when companies apply the results:

- Increased understanding based on unbiased technical information about HVDC technology options
- Enhance DC power systems reliability and availability through performance and maintenance improvement strategies
- Mitigate safety concerns for personnel by providing guidelines for live line work on HVDC systems
- Enable companies to reduce transmission costs by fostering construction and maintenance of cost-effective HVDC infrastructures to increase power transfer levels
- Provide a comprehensive resource for members to remain abreast of HVDC technology and ensure that engineers have the most current information

How to Apply Results

State-of-the-art information about HVDC technology from the most current *EPRI HVDC Reference Book* will help management, planners, and engineers simplify cost-effective operation, maintenance, and planning decisions in the HVDC area. The tech watch newsletter and the biennial HVDC conference or workshop will help members facilitate technology transfer and the generation of future research ideas.

2010 Products

Product Title & Description	Planned Completion Date	Product Type
HVDC Tech Watch - Newsletter: This HVDC Tech Watch newsletter will document all the latest information on the existing and newly planned HVDC installations all around the world. In addition it will highlight the latest technology breakthroughs in this area.	12/31/10	Technical Resource
HVDC Reference Book (Olive Book): Some Chapters: Some chapters of the HVDC Reference Book will be published as a technical update. The chapters will be selected using member advisory input and will be based on their importance for immediate application.	12/31/10	Technical Update

Future Year Products

Product Title & Description	Planned Completion Date	Product Type
Biennial HVDC Conference/Workshop and Proceedings: EPRI will organize a biennial HVDC conference and will invite utilities, manufacturers, and consultants to exchange ideas. The conference proceedings will be distributed with the presentations.	12/31/11	Technical Update
HVDC Reference Book (Olive Book): Complete Draft: All the chapters written in the previous years will be integrated into one final HVDC Reference Book (Olive Book).	12/31/11	Technical Update
HVDC Tech Watch - Newsletter: This HVDC Tech Watch newsletter will document all the latest information on the existing and newly planned HVDC installations all around the world. In addition, it will highlight the latest technology breakthroughs in this area.	12/31/11	Technical Resource
Final HVDC Reference Book (Olive Book): All the chapters written in the previous years will be integrated into one final HVDC Reference Book (Olive Book).	12/31/12	Technical Report
HVDC Tech Watch - Newsletter: This HVDC Tech Watch newsletter will document all the latest information on the existing and newly planned HVDC installations all around the world. In addition, it will highlight the latest technology breakthroughs in this area.	12/31/12	Technical Resource

P162.004 AC to DC Line Conversion and Hybrid (AC and DC) Rights-of-Way (063311)

Key Research Question

Conversion of alternating current (AC) lines to direct current (DC) lines can increase the transmission capacity of long-distance lines by eliminating some AC system-imposed power flow limitations. Also, AC/DC conversion may extend the thermal limits by more efficient use of the existing insulation system. Advances in power electronic converters at higher voltage, current, and power ratings change the economics and make it economically attractive to convert AC lines to DC lines. Also, as siting and permitting of new transmission corridors becomes increasingly difficult due to environmental and societal constraints, converting existing AC transmission lines to DC may increase power transfer capabilities to satisfy increasing load growth. While AC/DC line conversion appears feasible, many issues need to be investigated. Hybrid (AC and DC) rights-of-way will maximize the use of the existing corridors; however, there are many design and operational issues that need to be addressed while operating the AC and DC on the same tower or in the same transmission corridor.

Approach

This project will address the following issues:

- AC line to DC line conversion
- AC and DC on the same tower
- AC and DC in the same corridor

This project will address many aspects of AC/DC line conversion, including the selection of DC voltage and DC current ratings, insulation coordination including transformers, filters, and economic analysis. This project will also provide a comprehensive analysis of various technological options for AC/DC line conversion and compare these options technically and economically. Field demonstration of these technologies will be conducted, working closely with participants so that they will gain firsthand experience. The operational experience of such converted DC lines will be documented.

This project will address design and operational issues of hybrid (AC and DC) lines sharing rights-of-way or towers. The issues include clearance requirements, live work issues, and managing electric field issues and ions close to hybrid lines.

Impact

High voltage direct current lines may have a large impact on reliability and economic performance. This project strives to provide the information, engineering methods, and decisionmaking support to help companies convert existing transmission lines to DC. DC lines may help an owner as follows:

- Defer construction of new transmission lines, avoiding major capital investment costs
- Increase overall system reliability
- Reduce costs of power transmission, potentially reducing electricity rates to end-use customers
- Increase power transfers as much as 50% to 70% over those of existing infrastructures

How to Apply Results

The project helps planners and engineers convert existing AC lines into DC lines and thus increase capacity throughput on existing corridors. The project provides multiple technological options to convert AC lines to DC lines, provides operational experience in AC/DC line conversion, and provides benefit cost comparisons for each type of AC/DC line conversion technology. In addition this project will provide ways of designing and operating hybrid (AC and DC) rights-of-way.

2010 Products

Product Title & Description	Planned Completion Date	Product Type
Hybrid (AC and DC) Rights-of-Way Issues: This report will document all the design and operational issues related to hybrid (AC and DC) rights-of-way.	12/31/10	Technical Update
Demonstrate AC/DC Line Conversion Technologies at Utility Sites: This project will demonstrate the AC line conversion to DC operation at a host utility site.	12/31/10	Technical Update

Future Year Products

Product Title & Description	Planned Completion Date	Product Type
Demonstrate AC/DC Line Conversion Technologies at Utility Sites: This project will demonstrate the AC line conversion to DC operation at a host utility site.	12/31/11	Technical Report
Hybrid (AC and DC) Rights-of-Way Issues: This report will document all the design and operational issues related to hybrid (AC and DC) rights-of-way.	12/31/11	Technical Report
Demonstrate Hybrid (AC and DC) Rights-of-Way at Utility Sites: This project will address the demonstration of hybrid (AC and DC) rights-of-way at utility sites.	12/31/12	Technical Update
Demonstrate Hybrid (AC and DC) Rights-of-Way at Utility Sites	12/31/12	Technical Report

PS162B HVDC Performance and Effects (062967)

Project Set Description

This project set investigates the performance of HVDC components as well as electrical effects from HVDC transmission lines. A benchmark performance index will be created for each component to identify problem areas that can be improved. Component testing will be performed. Electrical effects will be studied under laboratory environments. Through testing and research studies, guidelines will be established for acceptable levels of component performance and electrical effects.

Project Number	Project Title	Description
P162.005	HVDC System Performance and Component Testing	This project is a mix of systems performance analysis, theoretical studies, and practical tests, both in the field and in the laboratory.
P162.006	Electrical Effects of HVDC	The project will produce a state-of-the-science report on the topic of electrical effects based on worldwide experience with HVDC transmission. The report will address all the issues regarding electrical effects; it will describe the underlying physics, provide design guidelines, provide guidance as to where and where not mitigation strategies may be needed, and describe instrumentation for performing measurements. These activities will be followed by full-scale experiments for the refinement of measurements and calculations. Software that incorporates the results will ultimately be developed.

P162.005 HVDC System Performance and Component Testing (069268)

Key Research Question

HVDC technology has experienced enormous growth worldwide in the past 50 years, and close to 100 HVDC systems are currently in operation. Understanding HVDC system performance is critical to extending the life of an existing HVDC system or to build a new HVDC system. Many of the existing HVDC schemes operating in North America and the rest of the world are over 20 years old. As these systems age, benchmarking the HVDC system performance becomes important in order to propose remedial measures to optimize and improve system performance.

The testing of HVDC components is also important for understanding the overall system performance. Components used on existing lines will need to be tested from time to time to ensure their integrity and to perform investigations if a failure occurs. Components to be used on new lines or new components to be used on existing lines will need to be tested beforehand in order to confirm compatibility and performance levels.

Approach

This project will involve a multi-faceted approach to dealing with the challenges facing the analysis and testing of DC performance levels and components. DC system performance statistics will be developed based on the existing DC schemes around the world. Documents already prepared by the International Council on Large Electric Systems (CIGRE) and IEEE on DC system performance will be used and further work will be conducted to generate more meaningful and practical approaches to improve the DC system performance. DC system performance of some specific DC schemes will be analyzed in detail. Problematic areas such as converter transformer failures will be identified and further work will be conducted to remedy these issues.

Different HVDC components such as insulators, conductors, towers, and earth electrodes will be tested in an effort to assist the utilities with making informed decisions such as repair versus replacement or even to specify a new HVDC scheme. HVDC live line working studies will be performed in various full-scale and

laboratory situations, to establish safe guidelines for companies who want to practice live line DC maintenance.

Accelerated aging tests for components such as insulators will be performed to better understand the effects of static electric fields on the performance of insulators in general and composite insulators specifically.

Research on the performance of converter stations and the corrosion effects of DC systems will be conducted as well. The issues related to current and voltage upgrade of DC systems will be documented. All of this is aimed at supplying valuable information and insight to members.

Impact

The research can affect the utility's operations in several ways, including the following:

- Extend the life of an HVDC system by improving the system performance.
- Insulator research can result in better line performance.
- System performance benchmarking can lead to a better understanding of what needs to be improved, which leads to better system performance.
- Live line studies can result in better live line maintenance practices, which leads to improved safety and better line performance.
- HVDC electrode studies lead to better ground electrode performance and therefore safer operation.

How to Apply Results

The research program will be structured in such a way that research results will be easy to implement into day-to-day operations using standard procedures. Training courses and seminars will be held to help disseminate the information into the companies so they can apply these results into their own HVDC system operation and maintenance.

2010 Products

Product Title & Description	Planned Completion Date	Product Type
HVDC System Performance - Benchmarking: This project will provide the benchmarking results of the HVDC system performance and identify problem areas that could be improved for better performance.	12/31/10	Technical Update
HVDC System Performance - Aging Tests and Live Work: This project will provide the results of accelerated aging of components (such as insulators) and HVDC live work procedures.	12/31/10	Technical Update

Future Year Products

Product Title & Description	Planned Completion Date	Product Type
HVDC System Performance - Benchmarking: This project will provide the benchmarking results of the HVDC system performance and identify problem areas that could be improved for better performance.	12/31/11	Technical Report
HVDC System Performance - Aging Tests and Live Work: This project will provide the results of accelerated aging of components (such as insulators) and HVDC live work procedures.	12/31/11	Technical Report

Product Title & Description	Planned Completion Date	Product Type
HVDC Electrode Design and Corrosion Effects: This project will provide better electrode design procedures and also document the corrosion effects of HVDC systems.	12/31/12	Technical Update
Current and Voltage Upgrade Issues of HVDC : This project will document the issues related to current upgrade and voltage upgrade of HVDC schemes.	12/31/12	Technical Update
HVDC Electrode Design and Corrosion Effects: This project will provide better electrode design procedures and also document the corrosion effects of HVDC systems	12/31/13	Technical Report
Current and Voltage Upgrade Issues of HVDC : This project will document the issues related to current upgrade and voltage upgrade of HVDC schemes.	12/31/13	Technical Report

P162.006 Electrical Effects of HVDC (062103)

Key Research Question

High Voltage Direct Current (HVDC) is an established technology for bulk power transmission that can be more efficient than High Voltage Alternating Current (HVAC) transmission. HVDC power transmission is being used worldwide, and more than 100 systems are in operation.

As power consumption increases and land for transmission corridors becomes more difficult to acquire, HVDC and AC-DC hybrid solutions may become cost effective. It is anticipated that more companies will use HVDC technology for transmission because they often can transmit more power than traditional HVAC lines. However, there are some issues to be investigated regarding HVDC electrical effects, which are different than those of AC lines.

When HVDC lines go into corona, they can cause audible noise, electric magnetic interference, ozone production, spark discharges, and human sensations, as do HVAC lines. However, unique to HVDC lines is the ejection of electric charge into the space around the lines (called "space charge"). This charge results in the formation of charged ions and charged aerosol particles. These charged particles result in DC ion currents to ground and into other objects such as people, distribution lines, and other utility lines. These DC currents can cause problems and need to be quantified and possibly mitigated. In addition, the space charge results in a significantly increased DC electric field level, which can cause objectionable human sensations, and charged aerosol particles can be blown far downwind, causing similar problems far off the right-of-way. These effects need to be measured, studied, characterized, quantified, and possibly mitigated.

Approach

This project will review all the previous work done at EPRI and elsewhere on the subject of HVDC electrical effects associated with HVDC corridors. EPRI will issue a report that discusses the issues and presents possible mitigation options, as well as recommendations for full-scale testing. Ultimately, full-scale tests on an existing HVDC test line at the EPRI high-voltage laboratory in Lenox, Massachusetts, will be used for the studies. Mitigation techniques will be explored. The results will be documented in EPRI reports, and workshops will be held at the Lenox lab, which will allow participants to observe, measure, and immerse themselves in the HVDC environment in order to give them firsthand experience about the issues.

Impact

- Increase power transfer capacities on transmission corridors substantially through application of HVDC technology, with safety, reliability, and public acceptance.
- Address issues about electrical effects that are surely to be brought up in permitting and public forums.

How to Apply Results

Transmission operators, planners, designers, researchers, and engineers will use the results of this project to explore the electrical effects of HVDC lines in order to understand where, and where not, such effects may be an issue. This information will help in the optimum design and operation of HVDC lines from the point of view of electrical effects, and it will help gain public acceptance of HVDC and hybrid transmission. It will provide tech transfer activities to companies considering HVDC so that they understand the issue of the HVDC electrical environment, particularly that caused by the production of space charge, and will provide options for mitigation where needed.

2010 Products

Product Title & Description	Planned Completion Date	Product Type
<p>Electrical Effects of HVDC Transmission Lines: State-of-the-Science: This Technical Update will document the state-of-the-science of the electrical effects of HVDC transmission lines. Much work has been done in the past at the EPRI high-voltage laboratory in Lenox, Massachusetts, at BPA, at ESKOM, and elsewhere. The report will review all the results from these studies and put them into perspective. In some cases crude approximations or assumptions were necessarily made at the time, and the accuracy of measurements and calculations will be reviewed. The differences of the results between the various studies will be explored. Recommendations on what research needs to be performed to definitively establish methods for measurements and calculations will be provided. The topic of hybrid (HVAC and HVDC together) transmission will be reviewed.</p>	12/31/10	Technical Update

Future Year Products

Product Title & Description	Planned Completion Date	Product Type
<p>Electrical Effects of HVDC Transmission Lines: In late 2011 a workshop will be held to review the work performed in 2010 and 2011. The workshop will include hands-on measurements of HVDC electrical effects from a full-scale test line. Participants will experience firsthand the human sensations associated with HVDC space charge. HVDC software will be exercised.</p>	11/30/11	Workshop, Training, or Conference
<p>Electrical Effects of HVDC Transmission Lines: Full-Scale Tests: In 2011, full-scale tests will be made at the EPRI high-voltage laboratory and measurements and characterizations of the electrical effects will be developed or confirmed. Specialized instrumentation will be prototyped as needed. Tests will need to continue into 2012 to be sure they are made in all seasons, but the interim results will be documented here in a Technical Update.</p>	12/31/11	Technical Update
<p>Electrical Effects of HVDC Transmission Lines: The results of the work to date will be incorporated into EPRI software.</p>	12/31/12	Software
<p>Electrical Effects of HVDC Transmission Lines: A Technical Report will be issued documenting the results of all the work performed, and it will include studies made with the EPRI software.</p>	12/31/12	Technical Report
<p>Electrical Effects of HVDC Transmission Lines: A comprehensive workshop will be given.</p>	12/31/13	Workshop, Training, or Conference