ELECTRIC POWER RESEARCH INSTITUTE

EPRI HVDC Program Update

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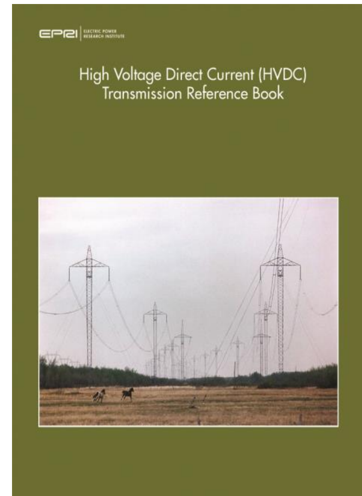
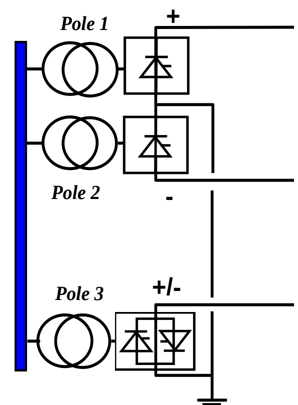
IEEE HVDC & FACTS Subcommittee Meeting
Atlanta, GA
August 7, 2019

EPRI HVDC Program Objectives

- Technology awareness to plan and deploy HVDC
- Data and information for the selection and replacement of a HVDC system and its components
- HVDC concepts to improve system reliability, to increase capacities and to interconnect renewable power sources

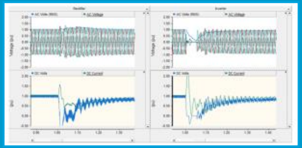




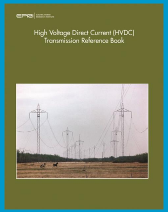
Research Strategy

Short Term

System Life Extension



Planning Guide

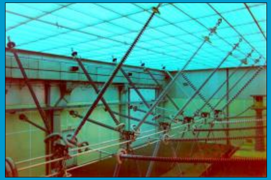


HVDC Reference Guide

Medium Term

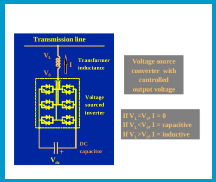
Electrical Effects

Live Work

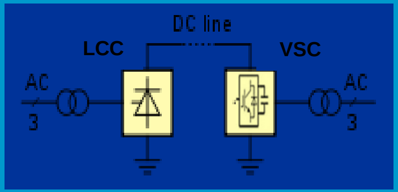


HVDC
Insulators

Long Term



Voltage Source Converter
DC Grid



LCC-VSC Hybrid Systems

DC Circuit Breaker

HVDC Program Team Members

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2019 Activities

Task Force: HVDC Program

Chair: Mike Staats, BPA

Task Force meetings:
- 1st meeting - Task Force Week in Charlotte (March 14)
- 2nd meeting – Along with HVDC & FACTS Conference in Palo Alto (September 24)

HVDC and FACTS Conference:
- EPRI Palo Alto Office, September 25-26

Webcast:
- November 14
- 8:00 am Pacific Time

HVDC & FACTS Conference
September 25-26, 2019
EPRI Palo Alto Office

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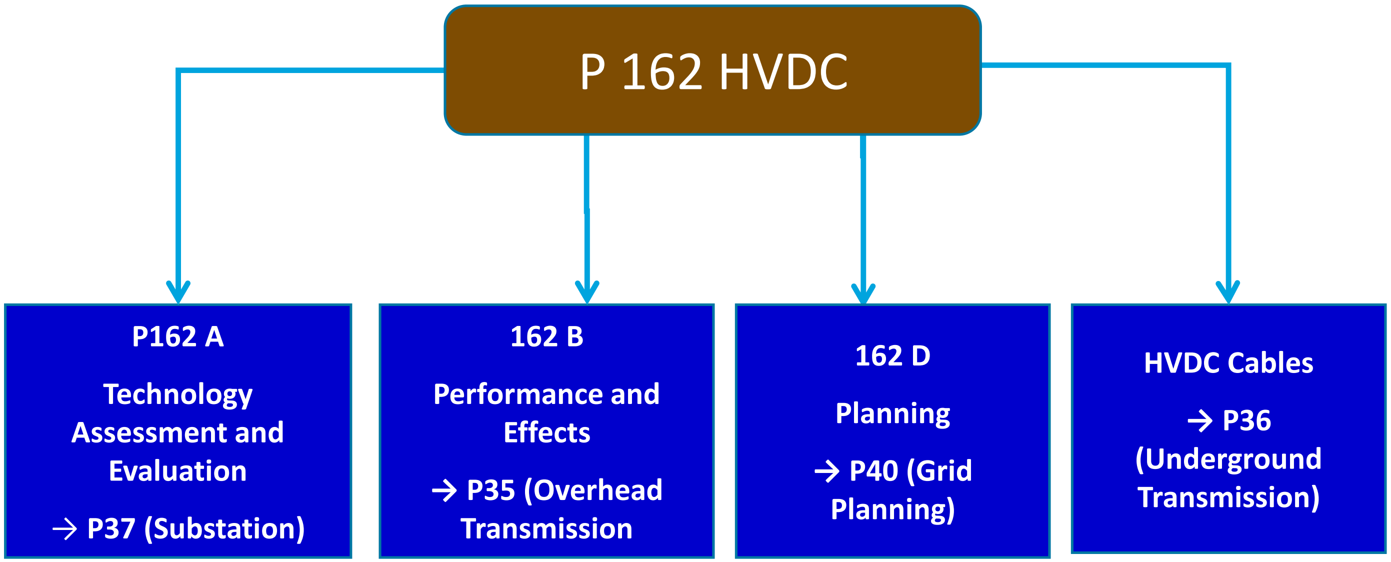
2018 HVDC Structure

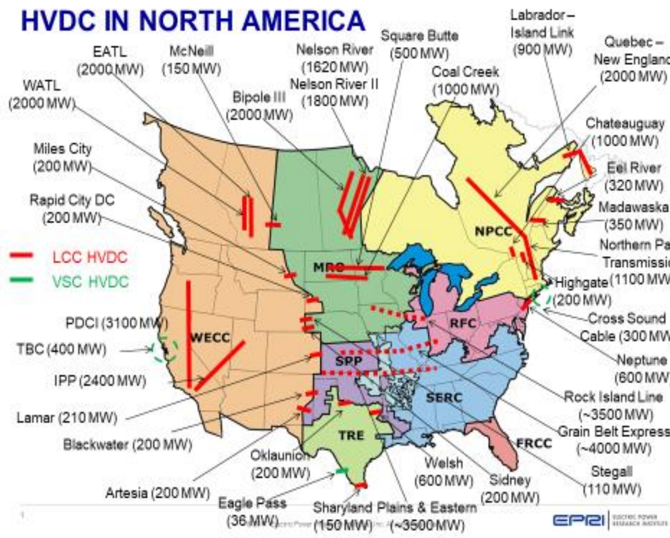


HVDC Converter Stations and FACTS Technologies (P37.116): *Research Tasks*

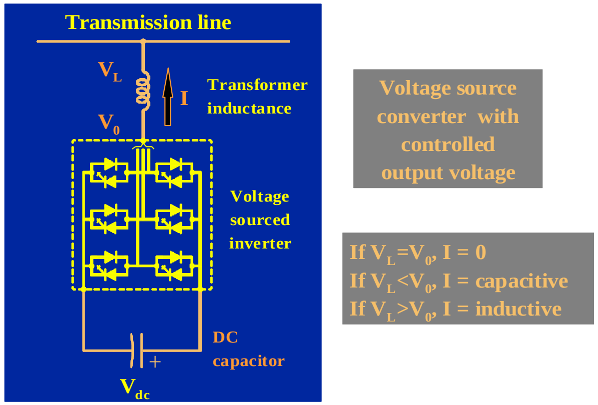
1. Assessment and evaluation of HVDC & FACTS technologies
2. Provide State-of-the-art information on HVDC & FACTS
3. Assist members selecting options for renewable integration and increased transmission capacity
4. Develop Operation, Maintenance, and Replacement Strategies
5. Update the HVDC Reference Book (Olive Book)
6. Innovate and Demonstrate New Concepts
7. Identify opportunities to reduce costs of HVDC & FACTS
8. Technology Transfer – Newsletter, workshop, and conference

Value:

- Keeping utilities abreast of HVDC & FACTS technologies
- Additional revenue to utilities by increasing transmission capacity using HVDC & FACTS
- Assisting utilities with best practices for operation & maintenance
- Providing a technical forum to interact & share with other utilities



STATCOM – Shunt FACTS Device



HVDC Reference Book – 30 Chapters

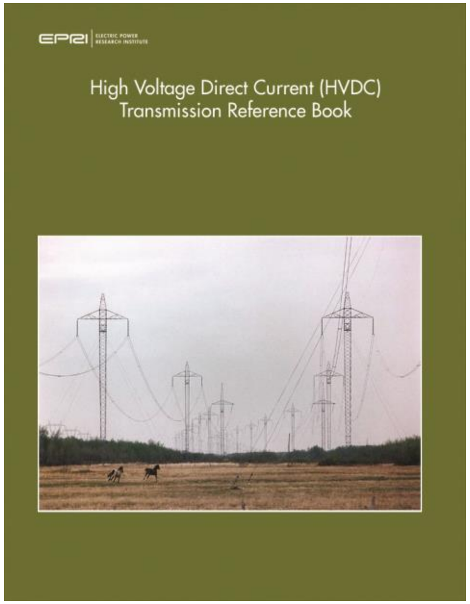
1 Introduction
2. Overview of HVDC Transmission
3. Analysis of Converter Operation
4. Configurations of HVDC Transmission Systems
5. Components of an HVDC Transmission System
6. Planning and System Design
7. Control and Protection
8. Reactive Power
9. AC-DC Interactions
10. Interference Effects from Converter Operation
11. Insulation Coordination
12. Converter Station Equipment
13. DC Transmission with Voltage Source Converters –(2018 update)
14. DC Trans with Series Cap Compensated Converters

HVDC Reference Book – 30 Chapters

15. Overhead Lines for HVDC Transmission
16. HVDC Cables – (2018 Update)
17. Simulation of HVDC Systems
18. Reliability and Availability
19. System Efficiency
20. HVDC System Cost Estimates
21. System Studies
22. Commissioning of HVDC Systems
23. HVDC Project Implementation
24. Operation and Maintenance
25. Life Extension of HVDC Systems
26. AC to DC Line Conversion
27. HVDC Ground Electrodes
28. Integrating HVDC into AC Grid
29. DC Grids
30. *HVDC Live Line Work Practices (will be added in 2019)*

Proposed 2019 Deliverables

1. Updated HVDC Reference Book – Olive Book
2. HVDC & FACTS Tech Watch Newsletter
3. HVDC & FACTS Conference
4. Single Arm Modular Multilevel Voltage Sourced Converter Concepts - Prototype Development
5. Best Practices for Operation, Maintenance, and Refurbishment for Life Extension of FACTS Controllers
   - FACTS Valve Cooling System Life Assessment Study
   - Novel STATCOM Control Strategies to Operate as Active Filter



Transmission and Substations Research and Development News

May 2010 — Research, Development, Demonstration, and Application Highlights

Dear Transmission and Substations Advisor,

Thank you for reading the first Transmission and Substations (T&S) Bulletin. This new publication was conceived at the February 2010 T&S Area Advisory Meeting, where the need was identified to update you on some of the latest research results, emerging industry issues, field deployments, and member-specific experiences. In this first edition, we have addressed some (but not all) of these objectives. I would like to encourage you to submit ideas that you would like to see in the bulletin—especially in areas of industry issues and utility experiences—to the Electric Power Research Institute (EPRI) team.

I would also like to encourage you to review the quarterly highlights that are provided on a regular basis for both the Annual Research Portfolio (base) and collaborative Supplemental Projects.

The EPRI team looks forward to our continued collaboration.

Andrew Phillips
T&S Area Director

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Facing the Challenges of Underground Transmission: Electromagnetic Field Mitigation and Worker Safety

The electric utility industry as a whole is facing existing and new challenges:
- Increasing cost of construction and materials
- Demanding requirements of less environmental impact
- Strengthening safety requirements for workers and public
- Aging transmission line and substation infrastructures
- Growing renewable energy initiatives
- Enhancing intelligent grid

The following are two typical examples of Electric Power Research Institute (EPRI) research that are undertaken in the field of underground transmission: environmental stewardship and safety.

Numerous electromagnetic field (EMF) management methods for reducing magnetic fields produced by underground transmission lines have been developed and studied during the past two decades. The mitigation methods are application specific, depending on line designs and locations. Some methods are effective in reducing the aboveground magnetic fields but are difficult or expensive to construct, and some methods can result in a reduction of cable system power transfer ratings or have other practical implementation difficulties. In 2008, EPRI performed research to assist utility personnel in selecting the most suitable magnetic field management techniques to achieve their specific objectives based on overall design requirements and economic considerations.

The research results (see EPRI report *EMF Management User's Guide for Underground Transmission Systems* [1015925]) provide guidance in understanding and quantifying the ampacity derating effects of applying various magnetic field management techniques. Using these results, the EPRI Underground Transmission Workstation software was upgraded in 2009

continued on page 2

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P36 Underground Transmission Structure – 2018

EPRI's R&D - P36.008 HVDC Cable Systems

Key Research Question:

- Significant growth in HVDC Cable Systems for grid integration & interconnections including renewables (e.g. offshore wind) integration
- HVDC Land and Submarine Cable Systems – lengths increasing
- Advances in HVDC Cable and Converter Technologies
- Additional manufacturing capacity – more HVDC manufacturers [e.g. Prysmian, Nexans, Sumitomo (J-Power Systems), NKT, LS Cable, Furukawa Electric, Zhongtian Technology Submarine Co (ZTT)]

- **Objective:**
- Develop tools and methods for utility engineers to effectively apply HVDC cables

P36.008 HVDC Cable Systems

Approach:

- Investigate & Evaluate design tools to prepare feasibility studies
- Evaluate cable insulation materials and aging characteristics for optimal designs
- Develop methods to extend the life of HVDC cables
- Evaluate operational practices in application of HVDC cables based on technical and economic benefits
- Evaluate condition assessment, maintenance, inspection, and fault location methodologies.

Research Value:

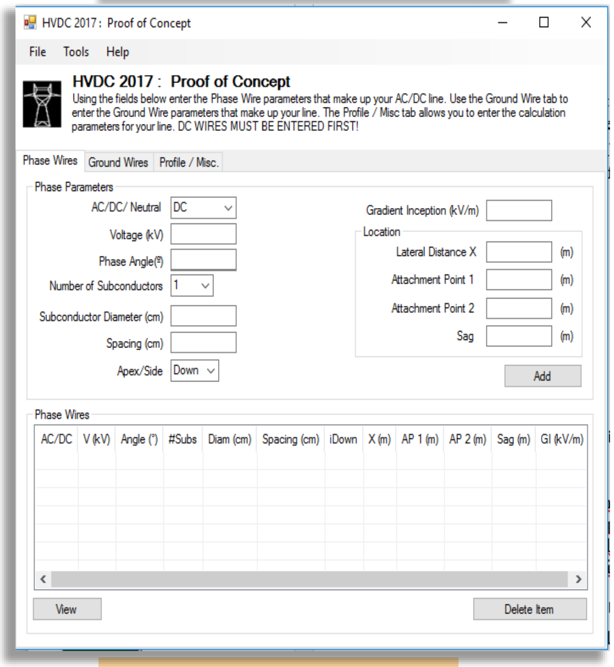
- Research produces new understanding, methods, and tools for utility engineers and designers for HVDC cable applications, operation, and maintenance.
- Use of reference books and design tools may result in more effective designs
- Effective inspection and monitoring of assets may lead to increased asset utility and improved reliability.
- Better understanding of failure mechanisms and prevention procedures may extend asset life and prevent unexpected outages

2019 Deliverables

TITLE
EPRI High Voltage Direct Current (HVDC) Transmission Reference Book (Olive Book) – 2019 Update (Report) (3002015538)
Methods and Case Studies for HVDC Cable Ampacity and Cable Insulation Electric Stress Calculations for Utility Users - Procedures for Underground Transmission Workstation Implementation (Report) (3002015539)
Feasibility of Applying HVDC Underground Cable Systems for Power Transmission – Case Study (Report) (3002015541)

HVDC Performance and Effects (P35.019)

Performance

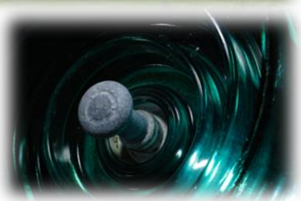


•Fields and Effects

•Space Charge

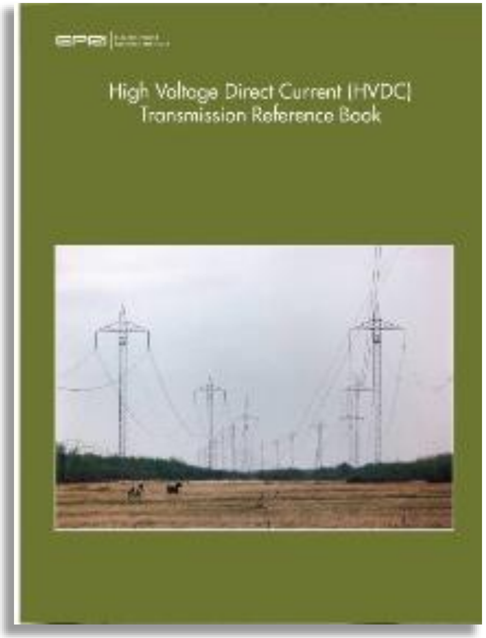
•Hybrid Lines

Application



- HVDC Line Design Guide
- Hardware Corona Specifications
- Insulators
- Electrode Lines

Reference



- HVDC Reference Book
- The Olive Book

Design Guide Contents – End of 2018

- Introduction
- Guide Outline
- Line Performance
- Ground Electrodes
- Conductor Selection
- HVDC Insulation
- Hardware Corona Testing
- **Live Line**
- Electrical Effects

Updated Chapter in 2019

Live Line Working

2019 Deliverables

Product ID	Deliverable Title	Schedule
3002015660	Pre-SW TLW Gen 2 – HVDC Electrical Effects Module (BETA)	12/31/2019
3002015661	TLW-Gen2 – HVDC Calculations	12/31/2019
3002015662	HVDC Overhead Line Design Guide	12/31/2019
3002015538	HVDC Reference Book: Olive Book	12/31/2019

HVDC Planning

PROGRAM	40
PROJECT	24B
TASK FORCE	

R&D Goal

TP

(1) Increase planner's knowledge on the potential benefits and challenges of the implementation of HVDC technology,

(2) Provide systematic approach and tools for planning transmission solutions with HVDC

R&D Approach

- **HVDC Planning Case Study**
  - Case study to illustrate procedure in HVDC Planning guide
- **Update HVDC Planning Guidelines**
  - Expand guidance on the use of HVDC technology for integration of off-shore wind generation
  - Update to HVDC planning guide developed in 2015/16

Deliverables

- [Tech Update] HVDC Planning Case Study
- [Tech Update] HVDC Planning Guide
- [Tech Brief] Integration of Offshore Windfarms with HVDC [published]

Integration of Offshore Windfarms with HVDC
Considerations for Utilities Planning

- Outlines considerations for planning integration of offshore wind farms with HVDC transmission via subsea cables.
- Describes the need for specific planning techniques, modeling and analysis tools
  - Feasibility analysis
  - Offshore planning issues
- Updated version delivered this year for P40.24


Considerations for Utilities Planning the Integration of Offshore Wind Farms with HVDC

3002010074
Technical Update, October 2017

EPRI Project Manager
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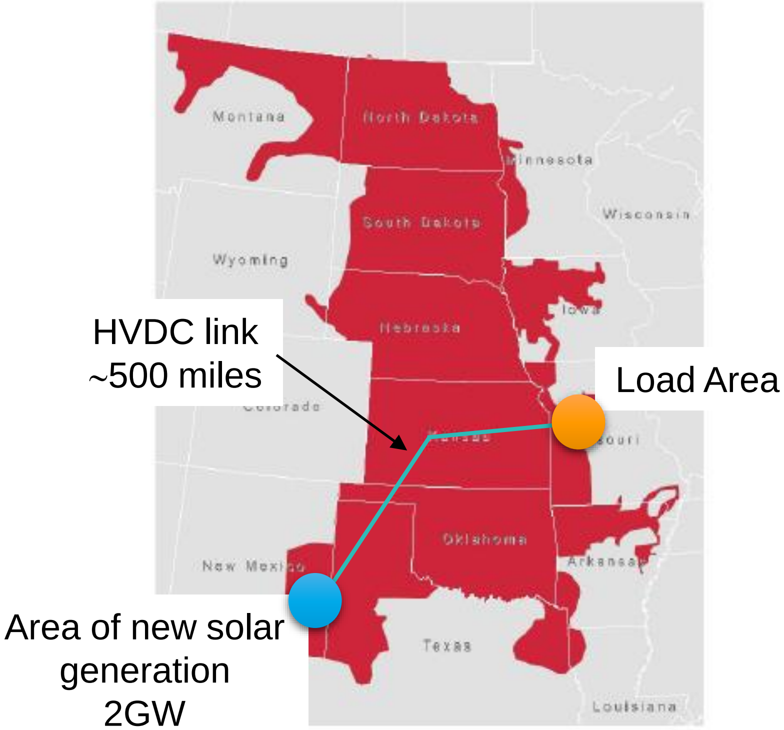
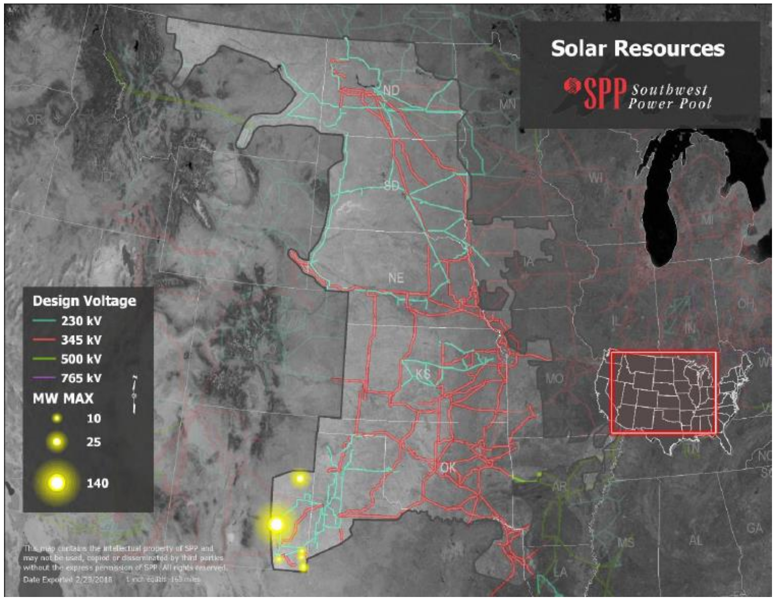
Guide to understand the issues surrounding interconnection offshore wind farms via HVDC in a planning context

Case Study – with thanks to SPP

Assumed future scenario of large integration of solar generation





Source: https://www.spp.org/documents

Key Supplemental Projects

Project	Description
	Applications of Research Results
Member Specific	Integration of HVDC into AC Grid – Application to Specific Utility Systems
Member Specific	Life Extension Guidelines Application to HVDC Converter Stations – Application to Specific Utility Converter Stations
	Industry Issues
105557	Minimum Approach Distances for HVDC Live Work Measurements of HVDC/Hybrid Electrical Effects (Scoping and evaluating Member interests)

Integration of HVDC into AC Grid – Application to Specific Utility Systems

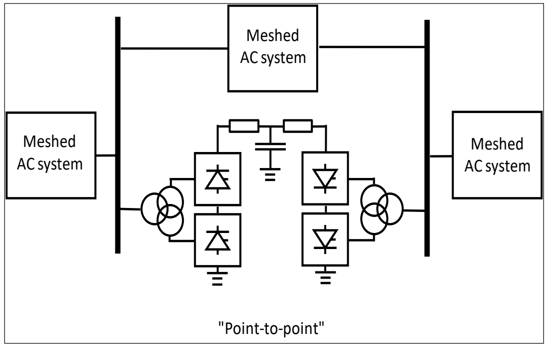
Objectives and Scope

- Build on the results from the base funded project.
- Perform utility specific system studies (load flow and stability) considering HVDC additions to the existing AC grid.

Value

Increase Understanding:

- Power flow optimization
- Power oscillation damping
- Transient stability improvements
- Sub-synchronous Resonance damping
- Special protection & control strategies
- Coordination of dc control with ac network controls including generator controls



Details and Contact

- Price: $100k to $200k (varies with size of system & tasks)
- Qualifies for TC & Self-Directed Funds

Ram Adapa

radapa@epri.com, (650) 855-8988

Life Extension Guidelines Application to HVDC Converter Stations

Objectives and Scope

- Assess service life of converter station components & provide recommendations including:
  - Converter transformers
  - Valves & Valve hall
  - Controls & Cooling system
  - Filters

Value

- Statistical life spans of components
- Converter Station on-site evaluation
- A technical report with recommendations whether to repair or replace

Details and Contact

•Price: $110k

• Qualifies for TC & Self-Directed Funds

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Minimum Approach Distances for HVDC Live Work

Objectives and Scope

- Develop safe distances for live-work
- Conduct flashover tests at EPRI Lenox lab to
- Investigate space charge effects
- Determine flashover of the air gaps

Value

- Avoid outage for maintenance
- Ensure worker safety
- Current minimum approach distances were estimated by extrapolating data on AC flashover values

Details and Contact

- Price: 50k per year for three years or $150k total
- Qualifies for TC & Self-Directed Funds

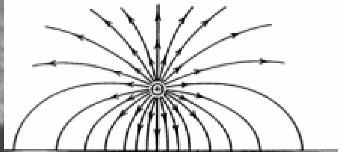
Gary Sibilant

gsibilant@epri.com, (704) 595-2598

Measurements of HVDC/Hybrid Electrical Effects

Objectives and Scope

- Better understanding and management of electrical effects
- Procurement/fabrication of instrumentation
- Measurements on operating lines: multiple lines, multiple times,
  various climatic conditions
- Algorithm updates and validation



Value

- Provide scientific evidence on the prediction of electrical effect values
- Provide technical support for applications of HVDC and hybrid lines as a viable technology
- Address permitting and public concerns
- Optimize the design and operation of lines

Details and Contact

•Price: 50k per year for three years or $150k total

• Qualifies for TC & Self-Directed Funds

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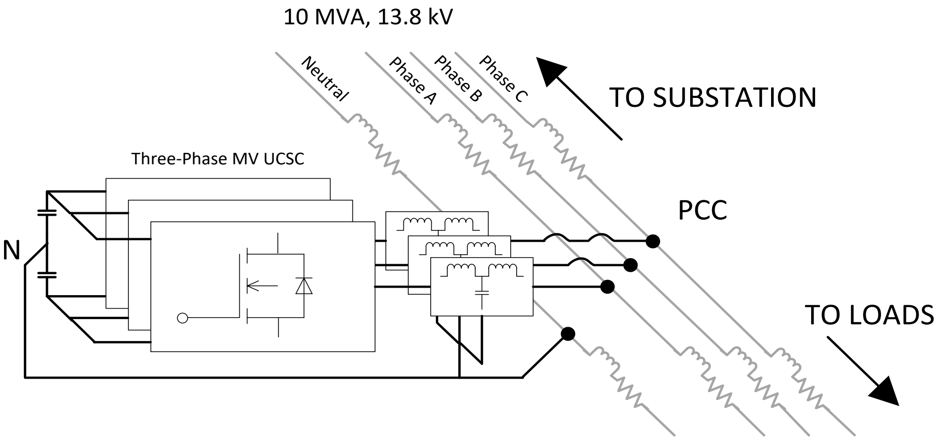
Unbalanced Current Static Compensator (UCSC)

Objectives and scope

- Current unbalances in the utility three phase distribution systems causing neutral currents
- Develop a prototype of Medium Voltage (MV) UCSC using SiC devices for direct connection to distribution systems without the use of transformers
- Cofunded by Southern Company & AECC (Arkansas Electric Cooperative Corp)

Value

- UCSC balances all three phases and eliminates neutral currents and the associated losses.
- Reduces the need for building additional feeders



Schematic of MV–UCSC for 3 Phase, 4 Wire Distribution System

Details and Contact

- Price: $150 k per utility ($75 k per year for 2 years)
- Qualifies for TC and SDF

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A new FACTS/Custom Power Device for balancing load on all 3 phases

Together…Shaping the Future of Electricity