PSC

Specialist Consultants
to the Electricity Industry

Newfoundland and Labrador Board of Commissioners of Public Utilities (Board), Investigation and Hearing into Supply Issues and Power Outages on the Island Interconnected System

HVDC Engineer's Report to the Consumer Advocate

Prepared by Bradley D. Railing, P.E.

For ***Thomas Johnson,*** ***representing the Consumer Advocate of Newfoundland and Labrador***

Reference JC4834-MEMO-004b

Date 11-October-2016

IN THE MATTER OF
the *Electrical Power Control Act*, 1994,
SNL 1994, Chapter E-5.1 (the *"EPCA")*
and the *Public Utilities Act*, RSNL 1990,
Chapter P-47 (the "*Act*"*)*, as amended;

AND

IN THE MATTER OF
the Board's Investigation and Hearing
into Supply Issues and Power Outages
on the Island Interconnected System.

Ref: JC4834-MEMO-004b

Date: 11-October-2016

To: Thomas Johnson, representing the Consumer Advocate of Newfoundland and Labrador

From: Bradley D. Railing, P.E.
PSC North America

Memo Report – Newfoundland and Labrador Board of Commissioners of Public Utilities (Board), Investigation and Hearing into Supply Issues and Power Outages on the Island Interconnected System

1. Introduction

PSC North America (PSC) was retained in April 2014 via a consulting service agreement with the Consumer Advocate (CA) of Newfoundland and Labrador c/o attorney Thomas Johnson of the O'Dea-Earle law firm. PSC was retained to provide consulting services as requested to assist the CA with their intervention into the power supply issues and power outages associated with the Island Interconnected System, with focus on the HVDC transmission systems. Please note that PSC did not include a review of the HVAC or HVDC transmission lines, the CA retained another consultant recommended by PSC to review the transmission lines.

PSC has reviewed reports, drafted RFIs and reviewed RFIs per the request of the CA. This report will highlight the HVDC related issues that PSC feels will require follow up to avoid impacts on the reliability of the Island Interconnected System.

2. Overview of the Muskrat Falls and the Island Interconnected System

Figure1 shows the overview of the Muskrat Falls hydro project and the Island

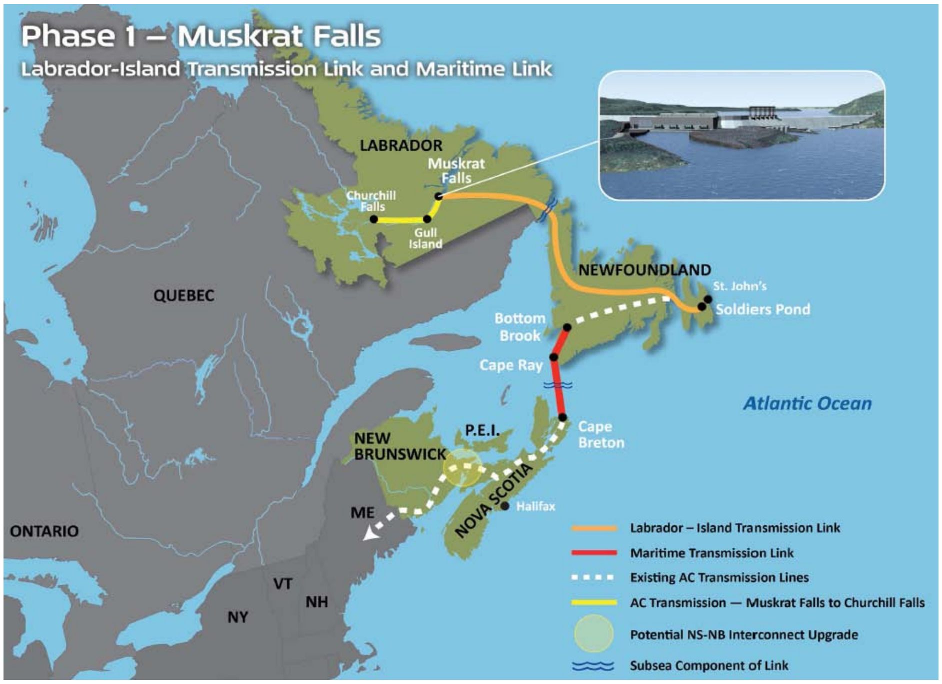

Figure 1 – Muskrat Falls and the Island Interconnected System [1, 2]

interconnected system. The key components and initial in-service dates for Muskrat Falls and the island interconnected system transmission are provided in Table 1.

Item	Description	Planned In-Service Date (original)	Targeted In-Service Dates (latest)
1	Muskrat Falls Hydro Facility, 824 MW	Q4-2017 to Q1 2018	Q3-2019 to Q1-2021
2	Churchill Falls 315kV AC Switchyard and (2) 250 km, 315kV AC overhead lines between Churchill Falls and Muskrat Falls	Q4-2017	Q2-2018
3	Labrador Island Link 900 MW, ± 350kV, (2) converter stations, Muskrat Falls in Labrador and Soldiers Pond in Newfoundland (also includes 3 x 175 MVAr synchronous condensers)	Q4-2017	Q2-2018
4	Labrador Island Link 900 MW, ± 350kV, 1,100 km overhead transmission line,	Q4-2017	Q2-2018
5	Labrador Island Link, (2) overhead line to submarine cable transition stations, Forteau Point and Shoal Cove	Q4-2017	Q2-2018
6	Labrador Island Link Straight of Belle Isle Submarine Cable, (3) x ± 350kV, 30 km	Q4-2017	Q2-2018
7	Labrador Island Link, (2) sea electrodes and electrode lines, L' Anse au Diable in Labrador (400 km line) and Dowden's Point in Newfoundland (10 km line)	Q4-2017	Q2-2018

8	Newfoundland 230kV facilities, substations at Granite Canal and Bottom Brook, 230 kV transmission lines, 160km	Q4-2017	Q2-2018
9	Maritime Link 500 MW, ± 200kV, (2) converter stations, Bottom Brook in Newfoundland and Woodbine in Nova Scotia	Q4-2017	Q4-2017
10	Maritime Link, ± 200kV overhead transmission lines, 142 km in Newfoundland and 46 km in Nova Scotia	Q4-2017	Q4-2017
11	Maritime Link, (2) overhead line to submarine cable transition stations, Cape Ray in Newfoundland and Point Aconi in Nova Scotia.	Q4-2017	Q4-2017
12	Maritime Link Cabot Straight Submarine Cable, (2) x ± 200kV, 180 km	Q4-2017	Q4-2017
13	Maritime Link, (2) sea electrodes and electrode lines, Indian Head in Newfoundland (23 km line) and Big Lorraine in Nova Scotia (41 km line)	Q4-2017	Q4-2017

Table 1 – Muskrat Falls and Island Interconnected System Key Components [3 thru 9]

The Liberty report and Nalcor have recently reported a delay in the completion of the Muskrat Falls hydro generation plant from the originally scheduled winter of 2017-2018 to first power in Q3-2019 [7] and full in-service of Q4-2020 to Q1-2021 [6]. Nalcor [7] reported the Labrador Island Link and associated transmission facilities in Newfoundland and Labrador are now targeted for completion in Q2-2018. Emera [8] and ABB [9] have reported that the Maritime Link will be completed and ready for operation during Q4-2017.

Table 1 indicates that the Muskrat Falls, Labrador Island Link, various Newfoundland AC network upgrades and the Maritime Link are now out of synch for testing and commissioning. Maritime Link is targeted to be ready for commissioning during Q4-2017 which requires 500 MW of power transmission in both directions; Newfoundland to Nova Scotia and Nova Scotia to Newfoundland. The Labrador Island Link is targeted to be commissioned in Q2-2018 and 900 MW of power will be needed to transmit from Muskrat Falls to Newfoundland. The full power commissioning and operation of Muskrat Falls and the transmission projects may not be completed until Q1-2021.

3. HVDC Related Issues

The issues provided below were noted during PSC's review of Board's hearing record reports and RFIs. A summary of the issue is provided along with recommended actions for follow up.

3.1 HVDC Transmission Testing

The HVDC transmission systems are being built per contracts that have terms and conditions covering schedule, milestones for completion, performance guarantees, testing requirements and warranty periods. The Owners of the transmission systems typically have obligations in these contracts to provide high voltage supply for commissioning power by an agreed date. It appears that the Muskrat Falls supply will not be available to provide up to 900 MW of power for the HVDC commissioning tests. The impact [10] on the various HVDC contracts and operations has not been reviewed. It is unknown if the HVDC contractors will accept limited commercial operation if the equipment has not been fully tested and the contractors have not been fully paid. It is also unknown if HVDC operations and maintenance staff will be trained and available for testing and commercial operation.

Recommended Actions – Confirm (1) Hydro and Emera both have plans to deal with the delay in HVDC test power up to 900 MW and (2) the HVDC contractors will allow commercial operation of the HVDC equipment at limited power levels and (3) HVDC operations and maintenance staff will be trained and available for testing and commercial operation.

3.2 Dynamic Performance Modeling and Testing of Muskrat Falls, HVDC systems, synchronous condensers and AC transmission system

The addition of the Muskrat Falls hydro generation, the 315 kV transmission lines to Churchill Falls, the Labrador Island Link, the synchronous condensers in Newfoundland, the various 230 kV transmission upgrades in Newfoundland and the Maritime Link is an ambitious and challenging project. It is common practice to perform both steady state and dynamic performance modeling and testing, on power systems simulators such as PSS/e and PSCAD, to verify the stability of the complete system. There are multiple equipment suppliers involved that will each be responsible for providing models [11], and these studies may continue until Q2-2016 [12]. Hydro noted that PSS/e and PSCAD models will be validated [13] after the installation, testing and commissioning is complete.

It is not clear if Hydro is performing simulation studies, in advance of the HVDC transmission testing, using all of the manufacturer's models to study response to typical network disturbances, generator trips, HVDC line faults, etc. As noted above [12], these models may not be available until Q2-2016 and then work needs to be completed to load the various models and run simulation cases. The simulations will show if additional control or protection adjustments are needed prior to high voltage testing with the AC networks.

Recommended Actions – Confirm (1) Hydro and Emera have produced a common simulation model that includes their AC networks, the synchronous condensers, the Labrador Island HVDC Link, the Maritime Link, Muskrat Falls hydro units and AC networks that are interconnected to Nalcor and Emera, (2) Hydro, Emera and parties interconnected with their networks agree that dynamic simulations have been satisfactorily completed before high voltage testing and (3) Nalcor and Emera update their dynamic models after the commissioning is completed.

3.3 Compliance with NERC

Hydro has noted that they will be compliant with NERC reliability standards [14, 15] for their role in commissioning of the Maritime Link, and for the entire system for commercial operation. The resources and schedule [16] to determine required NERC compliance items has not been clear. Failure to complete NERC related action items could cause operating restrictions until these items are completed.

Recommended Actions – Confirm (1) Hydro and Emera have a NERC compliance plan, for commissioning and for commercial operation, in place that has been reviewed by an independent party.

3.4 Risk of Sea Electrode Stray Current

The Labrador Island Link and the Maritime Link will both use sea electrodes for the return conductor for the approximately 1% steady state imbalance current and for steady state operation in monopolar sea return. Monopolar sea return may be required if a converter station or one of the HVDC pole conductors is not available.

Sea electrodes can be carefully designed and installed, but testing is required to confirm that stray current is not impacting existing metallic infrastructure near the electrodes. If there are stray current impacts, the impacts may require rework to the electrodes or local protections on the impacted infrastructure. Failure to identify stray current impacts could result in operating restrictions.

Recommended Action – Consider a test of the electrodes after they are installed, but before the HVDC transmission testing, using mobile test equipment. Any stray current impacts could be detected and mitigated before the HVDC transmission testing and commercial operation.

3.5 Electrode Line Protections

Associated with the sea electrodes are the overhead lines that connect the converter station to the electrode. The lines need protections to detect open and short circuits. The details of the electrode line protections [17] were not provided. PSC's experience with electrode line protections has been mixed when using impedance or pulse echo methods in weather conditions that include snow and ice.

Recommended Action – Confirm that Hydro and Emera have electrode line protection schemes that have reliable operation in all weather conditions.

3.6 HVDC Asset Management Plans

Hydro indicated [18, 19] that development of asset management plans and related service agreements, for items such as submarine cable repair, would be considered in 12-18 months. The asset management plans need to include personnel, spare parts and services that are in agreement with the HVDC manufacturer's RAM (reliability-availability-maintenance) assumptions for the availability design targets. Failure to have a completed asset management plan could result in extended outages due to delays to access resources needed to repair the asset.

Recommended Action – Confirm that both Hydro and Emera have developed an HVDC asset management plans.

3.7 Project OPEX and CAPEX Budgets

Related to the HVDC Asset Management plan are approved OPEX (operating expenses) and CAPEX (major scheduled or forced maintenance items, planned replacements, future upgrades). The financial plans and budgets for the life of the project should include a forecast of the OPEX and ongoing CAPEX. There needs to be funds available to complete these items. For example, a submarine cable fault could cost in excess of $10M USD to repair and these funds would need to be available rapidly. Another example is the HVDC control system will likely need to be replaced after 15-20 years of operation. It is important that asset managers have plans for the financial management of OPEX and ongoing CAPEX. If these funds are not available when needed, the repairs or replacements could be delayed.

Recommended Action – Confirm that both Hydro and Emera have developed OPEX and CAPEX plans and budgets.

Yours sincerely,

Bradley D. Railing, P.E.
Principal HVDC Consultant
PSC North America

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3. Teshmont Report, May 27, 2016.

4. Liberty Report, August 19, 2016.

5. CA-NLH-122, Independent Engineers Report for Maritime Link, Feb 8, 2014.

6. Maritime Link Environmental Assessment Report, Jan 10, 2013.

7. Nalcor June 24, 2016 press release, Muskrat Falls update.

8. Emera, The Link, Issue 09, Q3-2016

9. ABB press release, Maritime Link update, Sept 29, 2016.

10. CA-PUB-035, low power commissioning

11. CA-NLH-110, PSS/e and PSCAD models

12. CA-PUB-041, PSCAD studies Q2-2016

13. CA-NLH-109, detailed PSCAD studies after commissioning

14. CA-NLH-142, Hydro and NERC compliance

15. CA-PUB-044, Hydro and NERC compliance

16. IC-PUB-033, Hydro and NERC compliance

17. CA-PUB-037, electrode line protection.

18. CA-NLH-103, asset management

19. CA-PUB-038, HVDC O&M and service agreements

Bradley D. Railing

Principal HVDC Consultant

HELPING OUR CLIENTS POWER THE WORLD

PSC

Specialist Consultants to the Electricity Industry

Fields of Special Competence:

- Over 32 years' experience in the electricity industry
- HVDC transmission systems expertise
- Technical feasibility studies, conceptual design and technical specifications
- Field commissioning, project management, operations and maintenance
- Commercial and contract management experience

Qualifications and Affiliations:

Associate of Arts degree in Electrical Engineering Technology from Hagerstown Junior College, 1978

Bachelor of Science degree in Electrical Engineering Technology from Rochester Institute of Technology, 1984

Master of Engineering degree in Electric Power Engineering from Rensselaer Polytechnic Institute, 1986

Registered Professional Engineer, The Commonwealth of Massachusetts

Member of the IEEE Power Engineering Society and CIGRÉ

Career History:

2013 – Present	Principal HVDC Consultant, PSC North America
2006 – 2013	Chief Operating Officer Cross Sound Cable Company LLC
1998 – 2006	Project Manager and Vice President of Projects TransÉnergie US Ltd
1986 – 1998	Project Development / Project & Commissioning Engineer New England Electric System, NEES Global Transmission
1981 – 1986	Research Assistant Rochester Institute of Technology and Rensselaer Polytechnic Institute
1978 – 1981	Substation O&M Technician Allegheny Energy

Introduction

Bradley Railing is an experienced Principal HVDC Consultant based with PSC on the east coast of the USA, responsible for all HVDC activities for PSC North America. He holds a Bachelor of Science in Electrical Engineering and a Master of Engineering degree in Electric Power Engineering, and has over 32 years of electricity utility experience which includes direct involvement with regulated and merchant transmission projects around the world. His extensive experience encompasses technical feasibility studies, conceptual design, technical specifications, field commissioning, fault tracing, root cause analysis, project management, operations and maintenance with a specialization in HVDC transmission systems.

Mr. Railing also has expertise in the commercial aspects and management of transmission assets. He was previously the Chief Operating Officer for Cross Sound Cable project where he was responsible for the day to day operation of business.

Principal HVDC Consultant, PSC North America

Mr. Railing opened the PSC North America east coast office in Westborough, MA in April 2013. Assignments in the past year included technical support to transmission developers in the U.S., develop O&M plans and budgets for transmission developers, on-site HVDC commissioning support, root cause analysis of procedure and equipment failures at HVDC facilities in the U.S. and Australia, and technical lead for major control and main circuit replacement at two HVDC projects.

Chief Operating Officer, Cross Sound Cable

Mr. Railing was appointed the Chief Operating Officer of Cross Sound Cable following the acquisition by Babcock & Brown Infrastructure (BBI) in February 2006. He was responsible for the general management and day to day operation of the company. Mr. Railing also provided commercial and technical support to other BBI affiliates regarding HVDC and other T&D issues. Mr. Railing provided technical, commercial and operations support to the Trans Bay Cable project (US, 2010, 400MW). The Trans Bay Cable operations group was established by and managed by Cross Sound Cable.

Vice President of Projects, TransÉnergie US Ltd

As Vice President of Projects for TransÉnergie US Ltd, Mr. Railing was responsible for project implementation; EPC contract administration; commissioning, operations and maintenance for all TransÉnergie US projects; as well as support of project development. These were all ABB, HVDC Light, VSC based projects. He handled these duties for the following projects:

- Directlink Project (Australia, 2000, 3x60 MW)
- Cross Sound Cable (US, 2002, 330 MW)
- Murraylink (Australia, 2002, 220 MW)

Project Development, New England Electric System, NEES Global Transmission

Mr. Railing provided technical and commercial expertise on independent transmission project development in the U.S., South America, Australia, and New Zealand while at the New England Electric System. (NEES). These projects included:

- Long Island Cable Project - drafted the technical specification for the EPC contract.
- Block Island Cable Project - develop cable route and converter sites for an HVDC Light transmission system, preparation of technical specification of the AC network interface equipment and converter stations.
- South Morang 330 kV Series Capacitors, Victoria Power Exchange, Australia - member of the technical and commercial team for a RFP response.
- Trans Power New Zealand / Hybrid HVDC Link - consulting assignment to advise on project structure, site management and commissioning. Develop data acquisition system.
- South America - participated with ABB on the design and specification of a new modular type of HVDC converter station for back-back configurations.

Project & Commissioning Engineer, New England Electric System, NEES Global Transmission

Mr. Railing was the NEES project engineer and commissioning engineer for the Quebec / New England, Phase II, multi-terminal upgrade of the Comerford HVDC station and the construction of the Sandy Pond HVDC converter stations. Mr. Railing also coordinated an AC reinforcement project to relocate two 115 kV lines from single circuit towers to a double circuit tower.

IEEE, CIGRÉ and EPRI

Mr. Railing has authored numerous technical papers for IEEE, CIGRÉ and EPRI. Mr. Railing is a member of CIGRE B4-63, Commissioning of VSC HVDC Schemes.

Specific HVDC and T&D Projects

2013 to 2015 (PSC North America)

- Transmission Project Development, U.S. – Technical support to project development team to draft position paper on project benefits, drafted technical and O&M related sections of proposal documents, developed O&M organization and budget, assisted with selection of project sites and transmission routes, technical support for selection of transmission technology, drafted technical specification for EPC contract, provided capital and O&M cost inputs to project finance models, and assisted developer with proposal documents.
- HVDC fault tracing and root-cause analysis – Performed onsite investigation regarding switching and tagging procedures, assisted a team of onsite investigators regarding severe damage to main circuit equipment and transformer bushings, investigation of air – core reactor failure, investigation of IGBT power electronic failures in VSC converters, investigation of corona activity in a VSC valve structure, investigation of HVDC cable and cable joint failures, investigation of electrical shocks to personnel in high voltage switchyards, investigation of cooling system failure to thyristor valve and investigation of modifications to air-core reactor cooling.
- HVDC controls and main circuit equipment upgrades and replacements – Technical lead on the replacement and upgrade of portions of an HVDC control system to add new features. Technical lead on replacement of an HVDC converter station and integration with the existing system.
- HVDC Submarine Cable Repair, U.S. – Owner's Engineer providing commercial and technical support to assess the cable damage and develop the repair plans and agreement, on-site technical and commercial support during repair process.
- HVDC Asset Management, U.S. – Developed estimate for the asset retirement obligation to remove the HVDC submarine cable system and converter stations at the end of life.
- HVDC Asset Management, Australia – Reviewed and updated utility best practice documents for HVDC converter stations and cable systems.
- HVDC Asset Management, Australia – Technical study of faults and repair strategy on HVDC cable system.

2006 to 2013 (CSC Operations LLC)

- Trans Bay Cable Project - Project team member for EPC contract support, project implementation and O&M contract management.
- Cross Sound Cable Project – Chief Operating Officer responsible for management of the day to day operation and administration. Also participated in as a member of the field engineering teams in scheduled and forced outages, fault tracing and engineering of solutions.
- Transmission Acquisition - Participated on the Babcock & Brown acquisition evaluation team on several AC and HVDC transmission projects in the U.S. and Australia.
- Tejas Transmission – Participated as a member of the Babcock & Brown team on their proposal for the CREZ facilities.

1998 to 2006 (TransEnergie US)

- Harbor Cable Project – Technical and commercial support to develop the EPC contract and permit filings.

- New Jersey Cable Project - Technical and commercial support to develop the EPC contract and permit filings. EPC contract negotiation for the converter stations.
- Lake Erie Link - Technical and commercial support to develop the EPC contract and permit filings.
- Cross Sound Cable Project – Project Manager for the EPC contract, design and engineering review, QA/QC manager, commissioning manager and O&M plan.
- Murraylink - Project Manager for the EPC contract, design and engineering review, QA/QC manager, commissioning manager and O&M plan.
- Directlink - Project Manager for the EPC contract, design and engineering review, QA/QC manager, commissioning manager and O&M plan. Worked on site in Australia as the TEUS Project Manager from Jan – Dec 2000.
- US to Quebec Cross Border Projects - Technical and commercial support to develop the EPC contract and permit filings.

1986 to 1998 (New England Electric System, NEES Global Transmission)

- Long Island Cable Project – Drafted the technical specification for the EPC contract and participated on the project team to develop a proposal for LIPA.
- Block Island Cable Project – Developed a cable route and converter stations sites for an HVDC Light transmission system between RI and Block Island. Technical specification of the AC network interface equipment and the converter stations.
- South Morang 330 kV Series Capacitors, Victoria Power Exchange, Australia – Member of the technical and commercial team with NEES Global and ABB to develop a proposal for a response to an RFP.
- Trans Power New Zealand / Hybrid HVDC Link – Consulting assignment to advise on project structure for QA/QC, site management and commissioning. Develop a data acquisition system to measure and record AC and DC parameters. Write a training manual and operator competency review for the data acquisition system.
- Sandy Pond and Comerford HVDC Converter Station O&M Support – Managed several projects to upgrade and repair main circuit equipment including a converter transformer repair, repairs to 450 kV voltage dividers and retrofit of the valve cooling system components in the high voltage areas.
- South America – Participated with ABB on the design and specification of a new modular type of HVDC converter station for back-back configurations. Technical specification of the AC network interface equipment and the converter stations. A member of the project development team on several HVDC transmission and back-back proposals in Brazil, Argentina and Paraguay.
- Quebec / New England, Phase II, Multi-terminal HVDC Project – Project engineer assigned to support the EPC contract for the Sandy Pond HVDC Converter Station and the upgrades of the Comerford HVDC Converter Station. Project engineer assigned to coordinate several AC reinforcement projects including the relocation of two 115 kV lines onto a single double circuit tower. Senior project engineer assigned to manage the site construction, factory QA/QC, site commissioning and hand-over to O&M.
- NEES T&D System – Project engineer for several substation and power plant projects including substation expansions, steam turbine water induction protections, power plant low voltage supply stability enhancements and studies to retrofit variable speed drives on forced induction fan motors.

1981 – 1986 (Rochester Institute of Technology and Rensselaer Polytechnic Institute)

- Research assistant at Rensselaer to study impact of SF6 insulation withstand to fast and slow rise time transients.
- Cooperative education work assignments at Westinghouse Vacuum Interrupter plant, and Daverman Associates Inc., an architect and electric utility consulting firm.

1978 – 1981 (Allegheny Energy)

Substations and Controls Department (MD and VA) - O&M technician in the Potomac Edison, Substations and Controls Dept. Responsible for performing routine maintenance and fault tracing of substations main circuit equipment, relay & controls, SCADA and telecommunications. Write and implement switching and tagging procedures for 2.4 – 500 kV substations. Inspection and commissioning of repaired or newly installed equipment.

Technical Publications:

1. J.K. Nelson, J. Sollia DeMacedo, B.D. Railing, "Divergent Field Behavior of SF-6 Subjected to Steep Fronted Surges", Conference Record of the 1986 IEEE International Symposium on Electrical Insulation, Washington, DC, June 9-11, 1986, pp 151-154.
2. J.A. Donahue, D.A. Fisher, B.D. Railing, P.J. Tatro, "Performance Testing of the Sandy Pond HVDC Converter Terminal", (92 WM 216-2), IEEE Transactions on Power Delivery, January, 1993, pp 422-428.
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5. J. VanCoevering, J.P. Stovall, R.L. Hauth, P.J. Tatro, B.D. Railing, B.K. Johnson, "The Next Generation of HVDC - Needed R&D, Equipment Costs, and Cost Comparisons", EPRI Conference on the Future of Power Delivery, April 9-11, 1996, Washington, DC.
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