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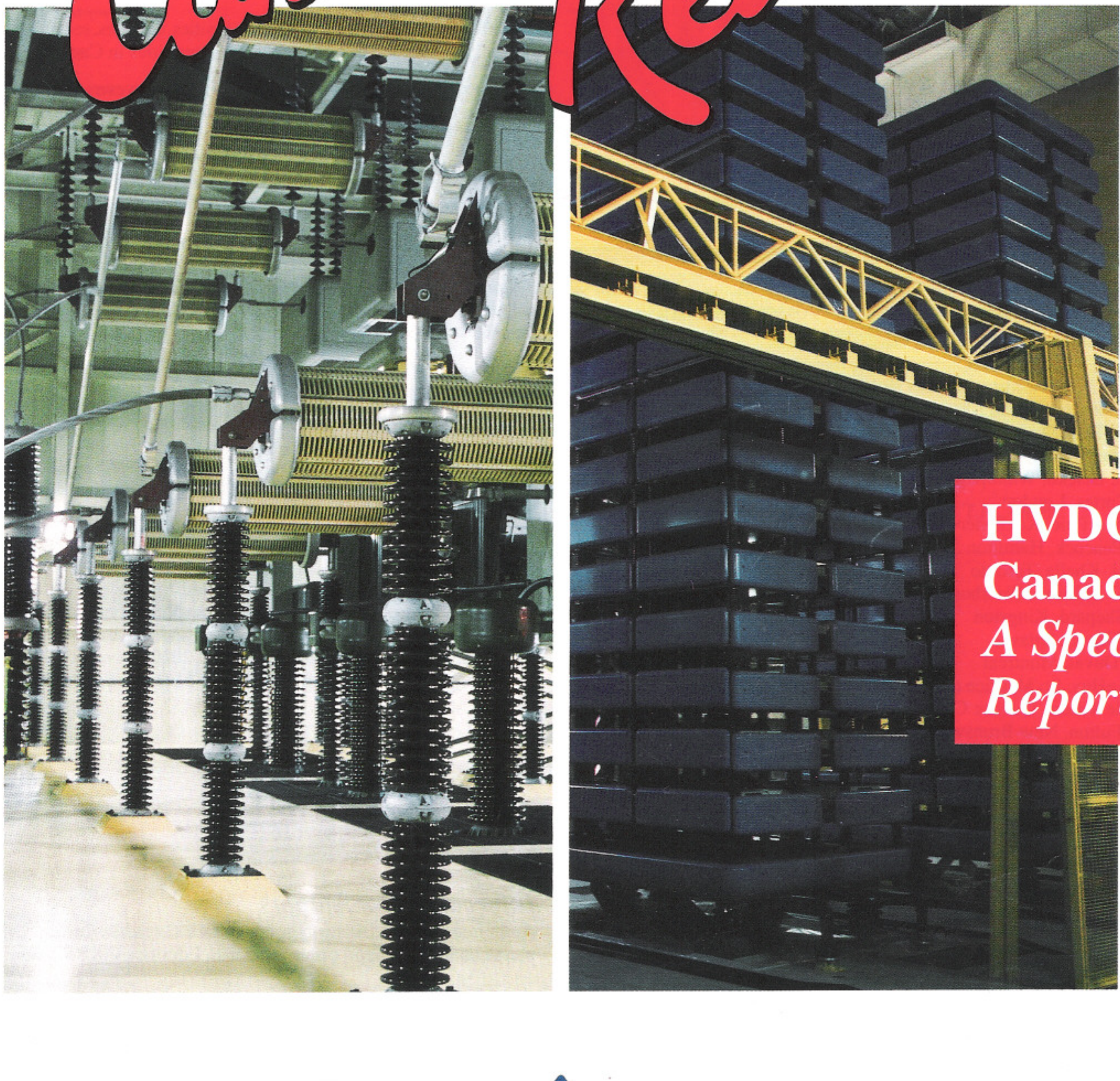

HVDC in Canada: *A Special Report*

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IEEE Canada

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IEEE Canadian Review General Information

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(i) Canadian members of IEEE;

(ii) Canadian members of the profession and community who are non-members of IEEE;

(iii) the associated academic (i.e. universities, colleges, secondary schools, etc.), government and business communities in Canada.

In this context, the *IEEE Canadian Review* also serves as a forum to express views on issues of broad interest to its targeted audience. These issues, while not necessarily being technologically-oriented, are chosen on the basis of their anticipated impact on engineers or their profession and the augmented academic, business and industrial community, or even the community at large.

To ensure that the *IEEE Canadian Review* have the desired breadth of issues and that the required depth of analysis be achieved, five Associate Editors are responsible for identifying issues and screening articles submitted to the *IEEE Canadian Review* according to the following general themes:

1- National affairs
2- International affairs
3- Technology
4- Industry scene
5- Education

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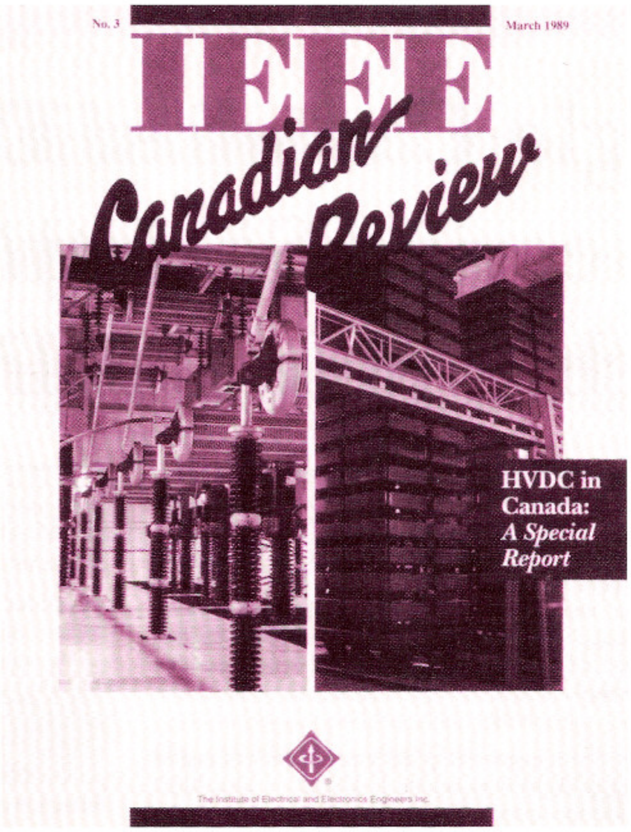

Mercury arc valves and solid-state thyristor valves from Manitoba Hydro's Dorsey Converter Station, 26 km northeast of Winnipeg. The valves convert high voltage DC coming from Manitoba Hydro's northern generating stations to AC. From Dorsey, the AC is distributed to the rest of the province via the 230 kV transmission system.

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A Single Canadian Electrical Engineering Society: An Achievable Goal?

by Dr. Robert T.H. Alden
Director, IEEE Canada

In Canada, we have two electrical engineering technical societies: IEEE Canada and the Canadian Society for Electrical Engineering (CSEE). The CSEE is the electrical arm of the Engineering Institute of Canada (EIC). The operation of two competing societies is expensive. The cost shows up in two ways: total membership fee, and duplication of volunteer time and effort. It results in loyalty splits and divisions that damage our profession. Are two technical societies needed in Canada? I ask you to join with me in positive action to achieve the goal of a single strong technical society that meets Canadian electrical engineering needs.

In terms of numbers, the CSEE membership is a small fraction of that of IEEE Canada, and most of those who belong to CSEE are also IEEE members. I therefore have the opportunity to utilize the medium of the *IEEE Canadian Review* to discuss this important issue with both memberships. Please respond. Let me know your point of view. It's your membership fees and the services you receive that are at issue. Are we maximizing the return on our investment? How can we satisfy our mutual interests and goals?

All volunteer societies need loyalty, coupled with a sense of real value received, to survive. Loyalties must be respected and encouraged in positive ways. There is a strong loyalty to IEEE within Canada in the many volunteers that serve on your active Section, Chapter, Branch, and Region committees (both past and present). However, the creation of CSEE in the late 60's was founded on the belief that Canadians needed a national society.

In the early 60's, when IEEE was formed by the merger of AIEE and IRE, the organization of Region 7 was largely run from the headquarters in New York. In this context, the concern over the lack of a uniquely Canadian Society was understandable. However, Bill Thompson, the Region 7 Director in the late 60's, was setting in motion the creation of our Canadian office and the special assessment to finance activities tailored to the needs of Canadian members. This paralleled the decentralization of IEEE and the evolution of national/regional activities to meet the specific needs of IEEE members in various parts of the world. The result is the transnational IEEE we know today.

IEEE Canada is a name, legally defined in our Bylaws, that is a short form for the Canadian (or seventh) Region of IEEE. We presently act, in many situations, as the national society in Canada. This is consistent with IEEE activities in the United States where a similar situation exists in Regions one through six. Together with the three Regions outside of North America, we form IEEE transnational with 10 IEEE Regions worldwide. Collectively we also share in the unparalled technical strength of the 35 IEEE technical societies.

The IEEE acts in the United States as a national society. In many countries outside North America, IEEE Sections act as the interface between strong national societies and the transnational IEEE. If there were a strong national Canadian society (apart from IEEE), then the role of our Sections in Canada would be similar. The passage of time has shown the difficulty in building strength in CSEE, and the prime reason is the very existence of a strong IEEE.

Our Canadian industries are reshaping for worldwide competition. Whether we like the particular terms of our new Canada - U.S. trade agreement or not, the concept of coping with global trade and the removal of barriers which lead to inefficient processes is one which is being adopted out of nessessity. In our chosen areas of competence - electrical, electronics, and computer engineering, we have been at the forefront of international standardization and practices. The transnational structure of IEEE is a reflection of this facet of our industry, and is thus one of the strengths of the Institute. Viewed from this point of view, the kind of relationship we have with our U.S. colleagues, and others around the world, not only predates the trade agreement but goes far beyond it. The Canadian IEEE membership has always valued these international goals; however, this does not imply a lack of interest or committment to Canadian matters.

The strength of IEEE in Canada is evident. Canadians have voted with their fee payments to endorse and enable the continued expansion of our strong technical programs. Members take advantage of the opportunity, in large numbers, to participate actively in the IEEE technical Society conferences, publications etc. Many of these truly international and world-class conferences are held in Canada. In governmental and educational spheres, Canadian IEEE entities and individual members are invariably present because of the reputation IEEE has earned. In 1987, at the Canadian Engineering Centennial, it was IEEE, not CSEE, that provided the electrical part of the program. This is a prime example of the EIC need for a strong electrical component. IEEE Canada is the society that has the resources to support and revitalize EIC.

Canada needs a credible national electrical engineering society with a Canadian perspective, Canadian priorities, and a Canadian agenda. I submit that the IEEE Region 7 of the 60's is evolving into that society in the form of IEEE Canada. Let's look at the record of development of uniquely Canadian accomplishments. Some of the highlights are: our national level McNaughton Gold Medal and extensive awards program at the local Section and Student Branch levels; training programs for Section and Student Branch officers; McNaughton centres in many of our educational institutions; our IEEE Canada office; our national and local publications. This is a record of solid Canadian contribution. I believe it demonstrates that the goals of both societies are so similar that a rationalization should be reached.

The crunch is this. Many people recognized that Region 7 of IEEE in the 60's could not meet the need for a Canadian society. IEEE Canada has evolved considerably since then. What further changes in policies or practices of IEEE Canada do you think should be pursued? What is required to combine our loyalties and energies?

Can we conceive of an IEEE Canada which is viewed by IEEE as Region 7; and, for example, by the Engineering Institute of Canada and the Canadian Council of Professional Engineers as the Canadian Society of IEEE? *One technical society, with appropriate ties transnationally within IEEE, and nationally within Canada: I believe this to be an achievable goal. Let's make it a reality.*

The Chapter Dilemma: "Where's my Mom?"

This paper is prepared and presented in the spirit of encouraging a dialogue about the responsibilities of Sections (Mama RAB) and Societies (Mama TAB) for the IEEE offspring we call the Chapter.

Wallace S. Read
Treasurer, IEEE

All is not well in the Chapter camp. This may not be accurate for all Regions or in all Societies, but given the IEEE financial and technical resources, I believe we can do better, even in those areas where Chapters seem to thrive.

Essential to the examination of parental responsibilities is a knowledge of the needs of the child. Obviously, these include a requirement for identity, shelter, nurture, guidance, discipline and reward. It is in this broad context that I would like to review the way in which Mama RAB (Regional Activities Board) and Mama TAB (Technical Activities Board) behave towards the child Chapter and whether there is any need to strengthen the parental structure or relationship to make things better.

The IEEE Family Unit

No one would dispute the IEEE operational complexity. So varied are the interests of our members that the responsibility for special services such as education, standards, publications, etc. have been assigned to separate units. And the two units which arose from the amalgamation of IRE and AIEE as the initial member contact, both with transnational interest, are RAB and TAB. The former is a geographically-organized unit and the latter is a centralized technically-organized unit.

Immediately a dilemma surfaced. How do you service the technical interests of our members everywhere? Who should be the parent? What should be her reponsibility and how should the "other" parent support this member activity?

Well, those who had the responsibility for addressing this concern did make a decision. They felt that the closeness of a geographical parent (Mama RAB) rather than the remoteness of a centralized technical parent (Mama TAB) was more likely to ensure that the Chapter structure would survive and meet the challenge of delivering technical services. It is also possible that, at that time, they saw a larger and stronger member interface developing at the geographical level in RAB rather than at the technical level in TAB. On the other hand, I am sure that they recognized the importance of Mama TAB's close supportive role and trusted to RAB and TAB to ensure a close working relationship in the administration and delivery of this member service.

Whatever the reasons, so it was decreed and so it was written. The Bylaws clearly state there shall be two mothers:

- Mama TAB, the Society, who will conceive and give birth to a Chapter, not unlike the role of a surrogate mother, and
- Mama RAB, the Section, who, following birth, will legally nurture and raise the Chapter as it would one of its own Committees.

What the Bylaws are silent on is how this entity, the Chapter, is supposed to survive and prosper given it now needs all those things which I mentioned earlier: identity, shelter, nurture, guidance, discipline and reward.

Raising the Chapter Child

While the Bylaws clearly set out the roles of the two mothers, I believe there was an implication there. Just as Mama RAB was to seek the strength of Mama TAB for the birth, she was also to expect that the surrogate mother go beyond that role and act as wet nurse. Indeed, the drama and excitement of birth often triggered in Mama TAB a greater interest in the child and she has welcomed this expanded role.

We only have to read the guidance document written by the legal mother entitled "Chapter Operations - A Guide for Sections" to understand how Mama RAB expects her child to behave. But that same document clearly identifies the need for the continued interest and support of Mama TAB.

The Introduction States:

"Chapters are units within IEEE Sections formed to serve the specialized technical interest of Society members and to coordinate these with the local activities of the Sections and the broader activities of the parent Society."

and

"The Chapter, operating in concert with its parent Society and the Section, plays a major role in fulfilling the objectives of the IEEE."

As a result, I believe that when you boil it all down, there are in fact two mothering roles. One is to be a Conscience, a facilitator, an overseer, a disciplinarian which ensures the proper operation of the Chapter. The second role is one of support, both financial and technical, to ensure that adequate and quality programming occurs.

It seems to me that the first role requires a close geographical relationship. The child needs to be physically close to its mother so that the watchful eye can detect problems very early and take steps to correct them. Enter Mama RAB. The second role of nurturing the child is best accomplished close at hand as well. It is difficult to breast feed at a distance but, on the other hand, you can't breast feed if you have no milk. Enter Mama TAB.

If either of these roles break down, you have a difficult parent/child relationship and an undisciplined or undernourished child. Neither will be a good performer. Mama TAB will have to address whether she is prepared to support a child conceived by her but growing up under someone else's guardianship. Mama RAB will have to consider whether legal guardianship requires the parent to bear the cost of feeding the child as well. But either way, grandparents RAB and TAB had better more clearly define the roles of the mothers, shake hands and get on with supporting the Chapters in their important work.

It's tough trying to serve two parents unless the parents agree on how, when, where and why they will exercise their authority. Give Chapters a break. Don't abandon them. Just lay down the rules of the game so that they can understand them.

Identifying a problem is halfway towards solving it. I've given you my views. What are yours?

Direct Current Power Transmission in Canada

by Leonard A. Bateman
Associate Editor, International Affairs
IEEE Canadian Review

Since the first commercial transmission of Direct Current (DC) power in 1954, great strides have been made in the voltage levels and in the technology associated with this form of transmission. These developments have, in turn, helped to revolutionize the control of power systems.

Canada has been one of the most aggressive countries in using DC transmission, from the first installation in British Columbia between the mainland and Vancouver Island to the multi-terminal system now being installed in Quebec.

The unique features of the Canadian projects and the vast experience gained in the operation of DC systems has produced a wealth of knowledge on DC transmission which is well recognized internationally. Many engineers and scientists of the DC community in Canada are leading members of international technical organizations such as IEEE, CIGRE, and IEC. Electric power research institutes such as the Hydro-Quebec Research Institute (IREQ) and the Manitoba HVDC Research Centre are world renowned for their research contributions in the advancement of High Voltage DC (HVDC) technology. Canadian universities such as the University of Waterloo and the University of Manitoba are well known for their graduate and research programs in HVDC transmission. Canadian consulting companies have been invited and are involved in major DC projects in many countries including Brazil, China, India, New Zealand, the United States and Zaire. Capabilities to manufacture converter transformers, filter reactors, capacitors for filters and reactive power equipment have been long established in Canada. In the near future, there might be facilities to manufacture thyristor valves as well.

DC transmission is high-tech. It requires up-to-date and in-depth knowledge of the latest power electronic devices, the latest associated control techniques, the latest materials technology for external and internal insulation of high voltage high power equipment and systems, the latest techniques and devices for the control of power quality (i.e. control of system overvoltages and flow of harmonics into the system). It involves extensive research and development of computer models and programs for the design and operation of integrated power systems. And, of course, this Canadian expertise is based on the large, world-class DC projects required by Canadian utilities to respond to demanding Canadian conditions.

Of the many important DC links installed, the largest of these remains the Nelson River Transmission system in Manitoba. This system can deliver some 3200 MW from the Nelson River to the load areas of southern Manitoba. It was decided in 1966 to proceed with the development of the Nelson River and use ± 450 kV DC transmission. At the time, this was the highest operating voltage for a DC transmission system in the world and it required the reliable transmission of firm power over some 900 km.

This first phase (i.e. Bipole 1) of the total development used mercury arc valves because, at the time that the decision was made, there were no thyristor valves in service. The performance of this system, after the several years it took to reach the full bipole rating of 1610 MW in 1977, has been very satisfactory. In 1978, power began to be transmitted from the second phase (Bipole 2) of the project. This phase uses thyristor valves and reached full voltage operation (± 500 kV) in 1985. Full power rating will be achieved in 1990 when additional generation from the Nelson River is connected to the system.

Over the years, Hydro-Quebec has also been involved in DC interconnections to its system. In 1984, a 1000 MW back-to-back station was commissioned at Châteauguay, and is used as an asynchronous tie between the Hydro-Quebec network and that of the Power Authority of the State of New York. This was followed, in 1985, with a 350 MW connection to New Brunswick at Madawaska and a 200 MW connection to New England at Highgate. In 1986, the first step in a multiterminal line was placed in service between Des Cantons and Comerford, with a rating of 690 MW. As the reader will see in the first article of this Special Report, by Jacques Lemay of Hydro-Quebec, the latter system will be expanded to 2000 MW and will connect Radisson near James Bay to Sandy Pond near Boston.

The development of any new technology is not without its problems, and DC transmission is no exception. Much has been documented in the technical literature, but many scientists, engineers and technicians are still engaged in research which will, hopefully, solve the remaining problems.

In this respect, Dr. M.M. Rashwan and W. McDermid of Manitoba Hydro have contributed an excellent article discussing the flashover problems of 450 and 500 kV DC wall bushings. It is very timely as this problem is not limited to the Canadian scene. The development work on new types of construction for these wall bushings to ensure that oil fires will not develop, resulting in long outages, is very important.

Our last article, by D.A. Woodford and A.H. Young of the Manitoba HVDC Research Centre, points out the possibilities of increasing the power transfer over a given right-of-way by either converting the line to DC or adding a DC circuit to an existing line.This should be of interest not only to transmission engineers, but to all those who are interested in an overview of this problem.

We shall all see more use of DC technology, not only in long distance transmission and the interconnection of electrical systems separated by large bodies of water, but also for the interconnection between adjacent systems. There will undoubtedly be many challenges and opportunities for innovation and excellence. And Canadian expertise will continue to make substantial contributions to its advancement.

Current HVDC Activities in Quebec

Phase II of the Hydro-Quebec/New England HVDC interconnection will result in the first high-performance multiterminal DC (MTDC) system in the world.

by Jacques Lemay
Hydro-Quebec
Montreal, Quebec

In the past decade, significant amounts of surplus hydroelectric energy were made available by Hydro-Quebec to power utilities in the northeastern United States at lower costs than those of operating fossil fuel power plants. This led to interconnection agreements, energy banking agreements and, more recently, to firm energy and power contracts.

As the Hydro-Quebec transmission system is not designed for synchronous operation with the large interconnected eastern U.S. system many times its size, DC interconnections are required and provide the most economical solution for large-scale exports.

Energy Contracts with NEPOOL

The initial energy contract between Hydro-Quebec and the New England Power Pool (NEPOOL) covers the sale of up to 33 terawatt-hours (i.e. 1 TWh = 1 billion kilowatt-hours) of surplus energy over a period of 11 years. Consequently, a 690 MW point-to-point DC transmission system was placed in commercial operation on October 1, 1986. It consists of a 170 km, 450 kV bipolar DC line linking the Des Cantons converter station located near Sherbrooke, Quebec and the Comerford converter station located in the town of Monroe, New Hampshire.

Phase II of the energy contract calls for an additional 70 TWh over a ten-year period currently scheduled to begin in September of 1990. This is a firm energy contract as compared to the Phase I agreement which involved only surplus energy. The Phase I installations are consequently designed to accommodate the following Phase II: the capacity of the Des Cantons converter station is to be increased to 2000 MW by the addition of parallel converters and the DC line is to be extended south of Comerford to the new Sandy Pond 1310 MW converter station, located near the existing Sandy Pond 345 kv substation near Boston, Massachusetts. However, this doesn't explain the reasoning behind the necessity of a multiterminal system. To understand this, let's have a closer look at the Hydro-Quebec environment.

First of all, the Hydro-Quebec development plan calls for the completion of the La Grande power generation complex, in the James Bay area, before the end of the century. This will add some 4500 MW of generation and two additional 735 kV AC lines were originally planned to carry this power to the province's load centers. The first generating plant will be the additional capacity at the LG-2 site: six 330 MW units, identical to the original LG-2 units but located in a separate plant called LG-2A.

A second element of this environment is that the final planning studies for Phase II of the interconnection established operating restrictions based on security requirements for the northeastern U.S. transmission system because of the high power level involved. In practical terms, this means that when the total export power fed from all the interconnections connected to the Hydro-Quebec system exceeds a certain level, it becomes necessary to isolate from the Hydro-Quebec system the generation feeding Phase II. As a result, of the many scenarios studied to achieve isolation of generation in 1990, part of the LG-2 generating plant was chosen. However, this requires the extension of the DC line north from Des Cantons all the way to the James Bay area. The choice of LG-2 is a temporary solution while the LG-2A generating station is being built. Thereafter, the generation from LG-2A will be assigned to the MTDC system for either transmission to the load centers in Quebec or export to NEPOOL, or both. But, by the same token, this means that a change of strategy in Hydro-Quebec's original AC transmission plan is required.

Construction is under way...

Completion of a 1500 km, 450 kV DC line between the Radisson converter station, near the LG-2 generating station of the La Grande complex, and Sandy Pond, near Boston, will increase the capacity of the interconnection from 690 to 2000 MW. Commissioning will start in January 1990 and commercial in-service of Phase II is planned for September 1, 1990.

Shortly thereafter, the initial installations will be integrated into what will become the world's first truly multiterminal high-voltage DC system. Finally, the addition in 1992 of the 2000 MW Nicolet converter station near the load centers of Quebec will allow the multiterminal to fulfill its dual role of transmitting power within Quebec and exporting to New England.

Mise en service l'an prochain...

La construction de la ligne à courant continu à 450 kV et des nouveaux postes convertisseurs de Radisson, près de la centrale LG2 du complexe La Grande, et de Sandy Pond près de Boston, va bon train. Lors de leur mise en service commerciale en septembre 1990, les installations de la Phase II porteront la capacité de l'interconnexion avec la Nouvelle Angleterre de 690 à 2000 MW.

Quelques mois plus tard, les installations initiales y seront raccordées pour former le premier vrai réseau multiterminal au monde. Enfin, la mise en service en 1992 du poste convertisseur de Nicolet de 2000 MW, près des centres de charge du Québec, permettra au réseau multiterminal de remplir complètement son double rôle qui est de transporter de la puissance pour les besoins du réseau d'Hydro-Québec et d'exporter de l'énergie en Nouvelle Angleterre.

Mission of the Multiterminal System

In fact, Hydro-Quebec and NEPOOL have agreed to kill two birds with the same stone by building the Phase II MTDC system to meet two objectives:

1) increasing the capacity of the James Bay transmission system by approximately 2000 MW to supply the Hydro-Quebec system;
2) increasing to 2000 MW the capacity of the interconnection while allowing the possibility to isolate generation from the Hydro-Quebec system.

A Brief Survey of HVDC Projects in Canada

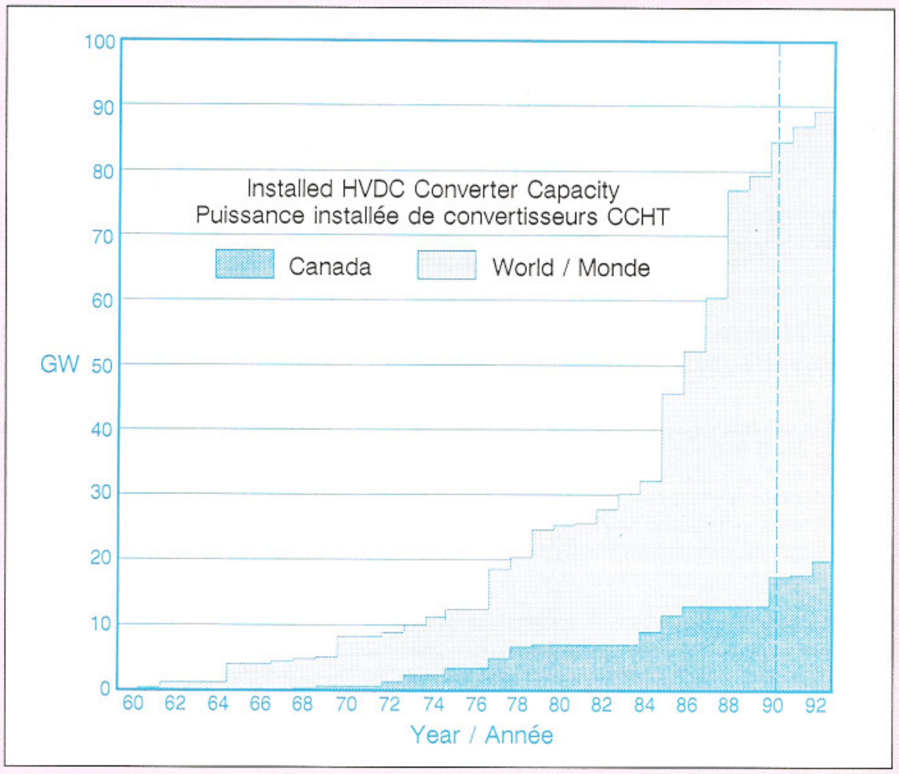


Figure 1: Growth of HVDC system installations

Since the emergence of High Voltage Direct Current (HVDC) transmission as a viable option, under certain circumstances, to AC transmission in the late fifties and early sixties, Canadian electric power companies have adopted it with the open-mind and enthusiasm tinged with caution of pioneers in spite of it being a new technology subject to rapid developments. In the past two decades, most of the power utilities in Canada have either installed DC links in their systems or have seriously studied the prospect of using it. Figure 1 shows the rapid growth of the use of DC transmission in the world and in Canada.

Table 1 identifies the DC schemes existing and under construction in Canada which can, in turn, be seen in Figure 2. Each of the Canadian DC projects has some unique features. In the Vancouver Island scheme in BC, one pole is at 260 kV with mercury-arc valves dating to 1968 and the other pole is at 280 kV with thyristor valves from 1977. As is usual with DC schemes, the build up of the project was staged, hence the difference in technology used for the two poles.

The Eel River back-to-back link in New Brunswick was commissioned in 1972 and was the first to use thyristor valves. The Nelson River DC transmission system is the largest operating DC link in North America with two bipoles (one 1610 MW at 450 kV with mercury-arc valves and the other of 1800 MW at 500 kV with thyristor valves). The above-mentioned 500 kV bipole was the first HVDC project to use water-cooled thyristor valves. The scheme is also the first designed to be able to operate with two bipoles in parallel.

The unique features of the Châteauguay link are that on the New York system side of the interconnection it has synchronous generators, thyristor controlled static var compensators, a very long ultra high voltage (765 kV) AC line, all connected to the AC bus of the converters of the link resulting in very interesting interactions between them.

Table 1: HVDC schemes in service in Canada. ***Réseaux CCHT en opération au Canada.***

No	HVDC System *Réseau CCHT*	Province *Province*	Transmission Distance km *Distance de transport km* Line *Ligne*	Cable *Câble*	Total *Total*	Rated voltage *Tension nominale* (kV)	Commissioning date *Mise en service*	Valve type *Type de valve*	Comments *Commentaires*
1	Vancouver Pole I	B.C.	41	33	74	+260	1968/69	Mercury arc *Au mercure*	Under sea cable *Câble sous-marin*
2	Eel River	N.B.			Back-to-back *dos-à-dos*	2x80	1972	Thyristor	Asynchronous tie with Quebec, *Lien assynchrone avec Québec*
3	Nelson River Bipole I	Manitoba	890		890	±450	1973/1977	Mercury arc *au mercure*	Long distance transmission *Transport de longue distance*
4	Vancouver Pole II	B.C.	41	33	74	-280	1977/1979	Thyristor	
5	Nelson River Bipole II	Manitoba	930		930	±500	1978/1985	Thyristor	
6	Châteauguay	Quebec			Back-to-back *dos-à-dos*	2x140	1984	Thyristor	Asynchronous tie with New York *Lien assynchrone*
7	Highgate	Vermont			Back-to-back *dos-à-dos*	56	1985	Thyristor	Asynchronous tie with Quebec *Lien assynchrone avec Quebec*
8	Madawaska	Quebec			Back-to-back *dos-à-dos*	130	1985	Thyristor	Asynchronous tie with N.B. *Lien assynchrone avec N.B.*
9	Des Cantons/ Comeford	Que/New Hanpshire	172		172	±450	1986	Thyristor	Asynchronous tie, phase I *Lien assynchrone, phase I*
10	Radisson/Sandy Pond	Que/Mass	1507	5.1 (1993)	1507	±500/ ±450	1990	Thyristor	Phase II of No.9, multiterminal in 1991 *Phase II, multiterminal en 1991*
11	McNeill	Alberta			Back-to-back *dos-à-dos*	91	1991	Thyristor	1st with no smoothing reactor *Aucune inductance de lissage*
12	Nicolet	Quebec			Tap *prise*	±475	1992	Thyristor	Final tap on multiterminal system, *Prise final sur réseau multiterminal*

The Madawaska DC link at the border of Quebec and New Brunswick is in parallel with the Eel River DC link and electrically close to it requiring close coordination in their operation.

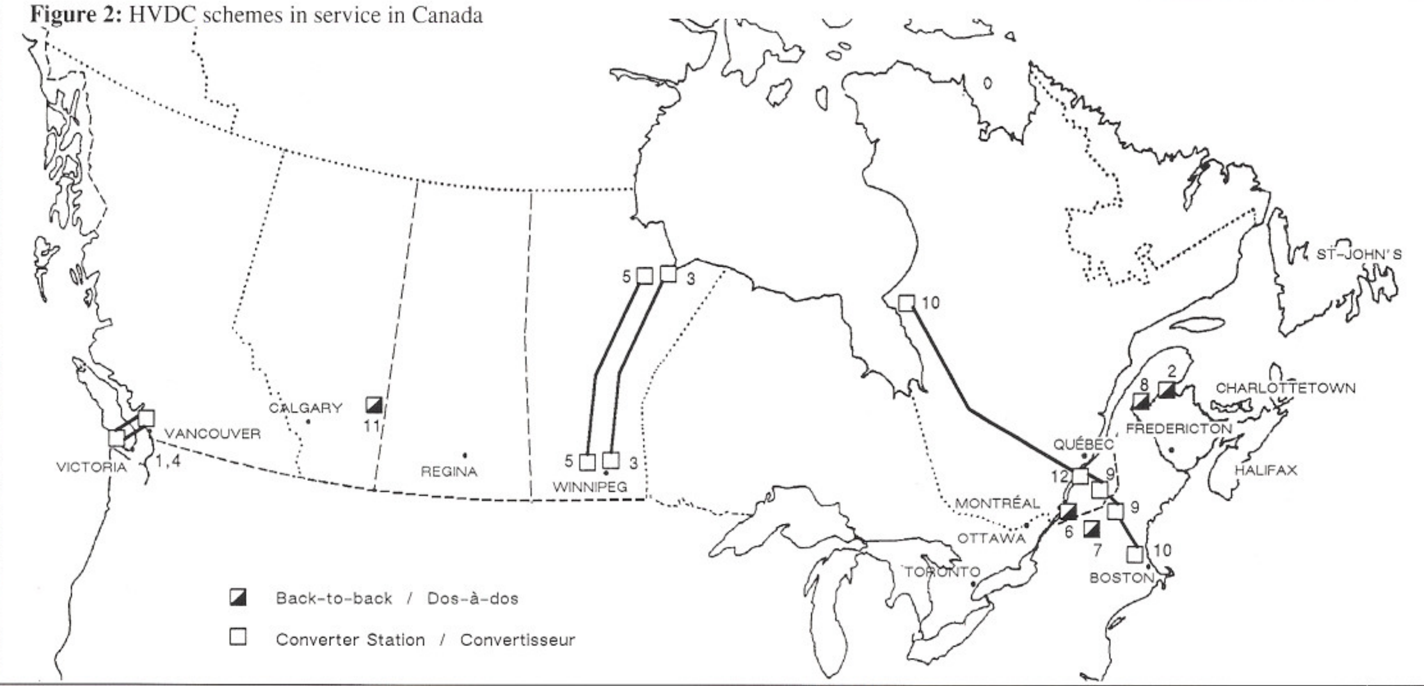
The Highgate DC link between Vermont Electric Power Company and Hydro-Quebec, located in Vermont State, is designed to operate even with AC system conditions weaker than hitherto acceptable for stable operation of DC links.

The Des Cantons - Comerford interconnection is Phase I of a five terminal DC system under construction which links the Hydro-Quebec system to the New Hampshire and Massachusetts systems of the New England Power Pool. The power transmission equipment of Phase I of this project is from one manufacturer and that for Phase II is from a different manufacturer. The multiterminal system is being designed to operate under various arduous system conditions and configurations notwithstanding equipment from different suppliers.

The latest addition to the DC projects in Canada is the 150 MW back-to-back link between Saskatchewan Power and Alberta Power at Empress (i.e. McNeill converter station) located in Alberta, five miles from the Saskatchewan border. This will be the world's first DC link without a smoothing reactor.

- Chandra Krishnay and Lewis Vaughan
Hydro-Quebec Research Institute (IREQ)
Varennes, Québec

Figure 2: HVDC schemes in service in Canada



Since the Phase II contract is not a firm power but a guaranteed energy contract, exports can be curtailed during high demand conditions on the Hydro-Quebec system. The MTDC system will then make it possible to maintain some exports while supplying internal loads, by controlling the division of power between the two loads.

As was noted earlier, when the decision to extend the Phase I DC line to James Bay was made, the Hydro-Quebec development plan called for a new 735 kV AC line in the fall of 1992 to carry the power from the first units at LG-2A. As the system security requirements predicate the construction of a DC line all the way to the LG-2 complex anyway, the following changes were subsequently proposed:

1. the 2000 MW line is built for 450 kV DC instead of 735 kV AC,
2. the construction of the line is advanced two years.

This eventually proved to be a one-year change when it became necessary to advance the commissioning of the first LG-2A units in order to provide peak load power for the 1991-92 winter.

Description and Schedule

The Phase II installations will be implemented in three steps and when completed in 1992, will become the first high-performance multiterminal DC system in the world. The scheduled in-service dates for the three steps are:

1. September 1, 1990:
   a) A 1125 km extension of the DC line north from Des Cantons to a new converter station called Radisson and located 16 km south of the LG-2 generating station,
   b) A 300 km extension of the DC line south to the new Sandy Pond converter station whose rating has been increased to 1800 MW (compared to the 1310 MW initially planned).
2. June 1, 1991:
   Integration of the Phase I converters into the multiterminal system.
3. October 1, 1992:
   Addition of the 2000 MW Nicolet converter station, near the major load centers of Quebec city and Montreal.

Figure 3 shows the routing of the 1500 km line and the relative location of the five converter stations along the line. Figure 4 is an overall schematic of the multiterminal system, with converter station ratings, electrode configurations, line lengths and in-service dates.

The Phase I converters will be integrated into the multiterminal system only after successfull commissioning of the Radisson to Sandy Pond point-to-point system, in 1990. However, Comerford will only be operated in a point-to-point configuration with Des Cantons; therefore a maximum of four converter stations will operate in a multiterminal configuration at any given time.

Operation of the first multiterminal configuration, in the summer of 1991, will involve the Radisson, Des Cantons and Sandy Pond converters. During the 1991-92 winter period, the operation of Des Cantons as an inverter fed from Radisson will be essential for Hydro-Quebec. Indeed, during peak load conditions, the DC line will be the only transmission facility to accommodate the power from the new LG-2A generators. Outside of peak load periods, the three-terminal DC system will allow energy sales to NEPOOL while supplying part of the Quebec loads.

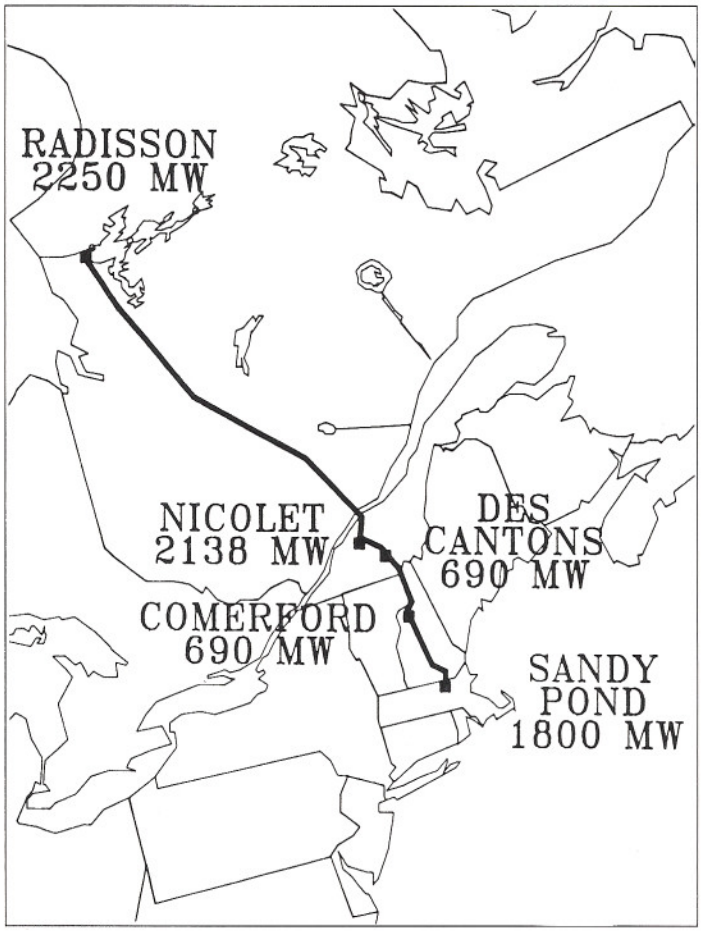


Figure 3: HQ-NEPOOL Phase II interconnection 450 kV multiterminal system, routing and location of converter stations.

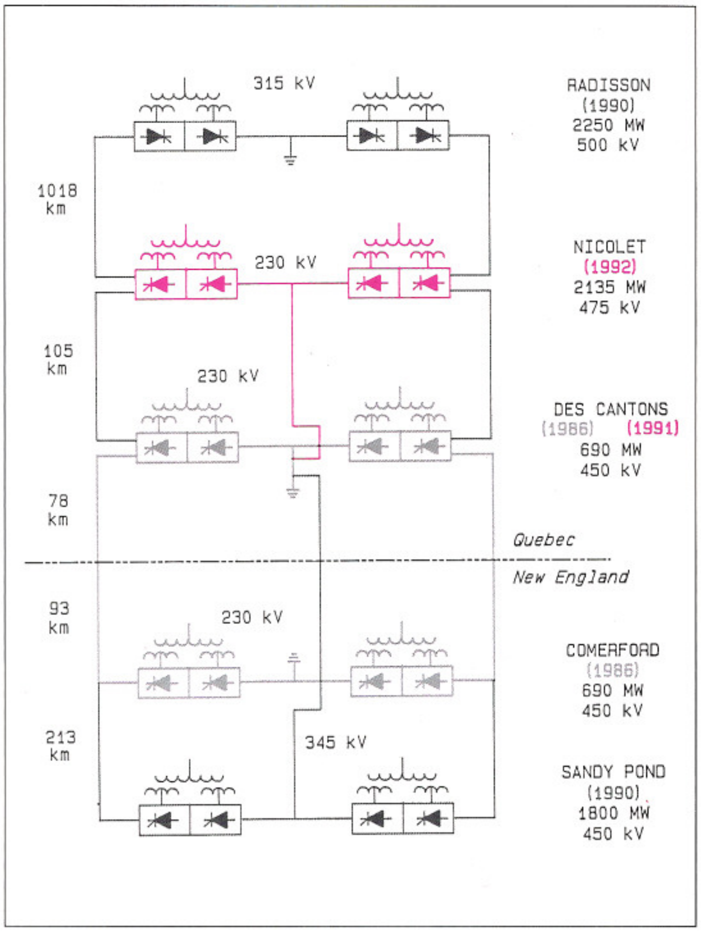


Figure 4: Overall schematic of HQ-NEPOOL Phase II system.

The addition of the Nicolet converter station, in the fall of 1992, will finalize the Phase II installations and give to the 1000 km northern section of the DC line its full 2000 MW transmission capability. The prefered multiterminal configuration from then on will be Radisson - Nicolet - Sandy Pond.

When transmitting power to the load centers of Quebec, the northern section of the DC line will actually be operated in parallel with the 735 kV AC lines of the James Bay transmission system. Large amplitude modulation of the power transfer on the DC line under these conditions will enhance the transmission capability of the mixed AC/DC transmission system.

Salient Features of the MTDC System

Without dwelling on the technical details, the following features of the MTDC system can be mentioned in order to fully appreciate its high-performance aspects:

1. The total length of the DC line from Radisson to Sandy Pond is 1500 km. The only longer DC line ever put in service is the Inga Shaba project in Zaire, and it is 1700 km long. Comparatively also, the Caborra Bassa line in Mozambique is 1414 km long and the Pacific Intertie on the west coast of the U.S. measures 1360 km.
2. The nominal power level of the Radisson converter station is 2250 MW at 500 kV. This is second only to the Itaipu project in Brazil, which has two 3150 MW bipolar lines at 600 kV, and to the Pacific Intertie which was upgraded from 1440 MW at 400 kV to 1840 MW at 500 kV by the addition of series-connected converters. The latter is presently being expanded to 3100 MW by the addition of parallel converters.
3. The first multiterminal configuration that will be possible (Radisson - Des Cantons - Sandy Pond) is a textbook application. Indeed the smaller converter has a rating of about one third of each of the other two (690 vs 2000 MW).
4. Performance requirements, such as recovery time following AC or DC faults, will be comparable to those of recent point-to- point systems. In multiterminal configurations, the proper coordination of the current orders to all stations relies on fully redundant microwave telecommunications in order to achieve the fast recovery times. However, should there be a complete loss of telecommunications, the MTDC system can still be operated safely, although with slower responses.
5. No DC breakers are used despite the expectations of experts (see: "HVDC: wheeling lots of power", IEEE Spectrum, June 1985, pp 30-36). This is due principally to the fact that if a DC breaker is used to isolate a faulty converter, coordinated reallocation of current orders is required in any case, to prevent commutation failures and the resulting disruption of the entire network. The small gain in isolation time provided by the DC breaker is offset by the control coordination delay (due mainly to telecommunications delays). Therefore, all main DC circuit switching actions are performed after currents have been forced to zero by coordinated control action.
6. Two types of large amplitude power modulation are used:
   a) when Radisson is operated isolated from the Hydro-Quebec system, a slow power modulation of up to 550 MW is used for the frequency regulation of the isolated generators,
   b) when the DC line is operated in parallel with the Hydro-Quebec system, fast power modulation derived from a frequency deviation signal is used to enhance the stability of the Hydro-Quebec system; this modulation makes use of the available short-term overload capability of the valves which was specified at 65% for 10 seconds at rated voltage.

World-First Aspects

The Phase II MTDC system will be the first high-performance multiterminal DC system in the world. There are two aspects to that statement, in comparison with other DC projects:

a) **Multiterminal:** in the Itaipu and in the Nelson River systems, two bipolar lines can be operated in parallel. Similarly, in the Pacific Intertie, two converters can be operated in parallel at both ends of the single bipolar line. In comparison, the Phase II system has converter stations in separate locations, and although the other systems are considered as multiterminal systems, the multi-location of the Phase II converter terminals certainly adds another dimension.

b) **High-performance:** the first multi-location MTDC system to be put in service was the Sardinia - Corsica - Italy system, when the 50 MW parallel tap on the island of Corsica was added to the existing 200 kV, 200 MW monopolar line in 1987-88. On this system, there is no centralized coordination of converter controls; the tapping station simply reacts to changes in the main link or is deliberately switched off before other switching actions can be performed. In comparison, the Phase II MTDC system will have high speed control and protection performances comparable to modern point-to-point systems.

Another world-first aspect of the project is the St. Lawrence river crossing. The planned overhead crossing located approximately 75 km north of the Nicolet station met strong opposition on account of its environmental impact. An agreement was reached to allow the aerial crossing, on a temporary basis, so as not to delay the interconnection project. However Hydro-Quebec must support or perform all the necessary development effort to build a 500 kV-class DC cable crossing in a tunnel as soon as possible. When the cable crossing will have been proven reliable, the aerial crossing will be dismantled. Design of the cables calls for a substantial amount of technological development since the highest voltage DC cables in service are at 280 kV, although a 400 kV DC underwater interconnection between Sweden and Finland is presently under construction.

On the technical side, the integration of a short section of about 5 km of cable into the long (1500 km) multiterminal line required particular attention to the evaluation of overvoltages imposed on the cables because of the variability of system configurations. It was found that lightning strokes on the DC line can cause high frequency overvoltage transients with polarity reversals. The presence of AC voltages superimposed on the DC voltage during some transients will also require special tests to verify the insulation of these cables. For that purpose, Hydro-Quebec is building a 13 million dollar cable test facility at its high-voltage laboratory. The same facility will also be used for the study of AC cables up to 750 kV.

Simulator Facilities

Because of the many novelty aspects of the Phase II project, Hydro-Quebec is purchasing a full replica of the actual controls of the MTDC system and connecting them to AC and DC simulator facilities that will be dedicated to the project until well after the commissioning of Nicolet in 1992. This will be housed-in and become part of the new Power System Study and Simulation Center presently under construction and slated to go into service in 1989. The simulator will maintain a permanent representation of the Hydro-Quebec transmission system that will be used to study all possible interactions between the AC and the DC systems as well as to simulate the commissioning tests for the multiterminal system.

DC Wall Bushings on the Nelson River HVDC System

Canadians continue to contribute to the evolution of HVDC technology.

by M. M. Rashwan & W. McDermid
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The flashover of wall bushings in wet weather, and in light and heavily polluted areas, has been reported for a number of High-Voltage Direct Current (HVDC) systems operating at voltages of up to ±600 kV. In addition, it has been reported that the flashovers occur more frequently on negative polarity bushings than on positive polarity bushings. Only recently, it has been demonstrated by laboratory tests that the mechanism of flashovers of horizontally-mounted bushings is related to the non-uniform wetting along the insulator surface.

This non-uniform wetting can occur due to the partial shielding of the bushing by the wall of the converter building. This shielding leaves a dry zone near the grounded end of the bushing. Even under conditions of very low pollution, non-uniform wetting can lead to flashovers.

Nelson River Bipole 1

Bipole 1 first achieved rated voltage as follows:

Pole 1	*Pole 2*
-450 kV	+450 kV
1975	1977

The dimensions and ratings of the wall bushings are:

Nominal voltage [kV]	450
Basic Insulation Level (BIL) [kV]	1550
Outdoor Creepage [mm]	14783
Outdoor strike [mm]	3500
Specific Creepage [mm/kV]	32.9

Following the commencement of Bipole 1 operation at -450 kV in 1975, flashovers began to occur; most of these involved wall bushings. Following the completion of Bipole 1 in 1977 (± 450 kV operation), some flashovers were also experienced on the positive polarity bushings, although the majority continued to occur on the negative polarity.

The flashovers were experienced primarily during light and heavy rain conditions, and also occurred under fog and wet snow. The worst conditions seemed to involve the first rain after a long dry spell. As a first attempt to solve the problem, the bushings were cleaned and greased with Castrol WT185 petroleum grease. However, after service experience of 5 years, it was realized that the grease would have to be reapplied every 2 to 3 years in order to achieve significant improvement in the flashover performance. The process of cleaning old grease and recoating bushings proved to be time-consuming and costly.

As an alternative to greasing, supplementary sheds (booster sheds) were installed on all Bipole 1, 450 kV bushings. Six booster sheds were installed per bushing, as is shown in Figure 1. The sheds were constructed from NEMA Grade GPO-3 resin bonded fiberglass sheets, 3 mm thick.

Booster sheds on vertical Alternating Current (AC) bushings eliminate water cascading effects. Although the function of booster sheds on horizontal DC wall bushings is not fully understood, it has been suggested that they act to: (a) improve the uniformity of the wetting, or (b) serve as barriers to restrict the travel of surface scintillations.

Technological Supply and Demand...

In October 1987, the catastrophic failure of a 500 kV wall bushing occurred at the southern terminal (Dorsey) of the Nelson River HVDC system. This was followed in 1988 by forced outages involving major defects in other 500 kV wall bushings.

This problem is typical of how power companies, when operating beyond the limits of their technology, must invariably contribute to its evolution....

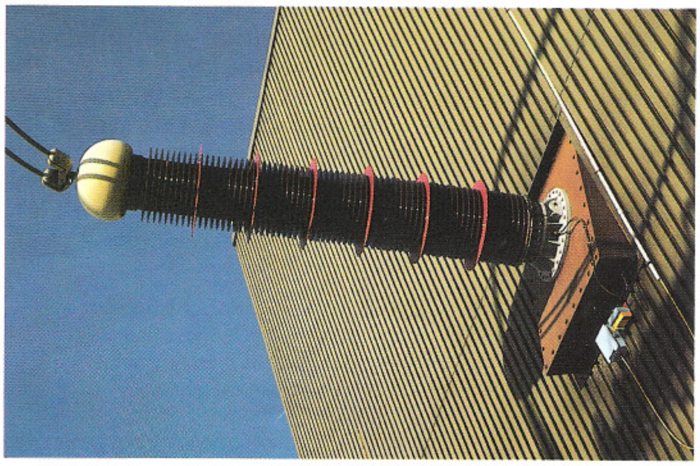
L'offre et la demande technologiques...

En octobre 1987, une traversée murale à 500 kV du système à CCHT de Nelson River, au poste Dorsey, a subi une défaillance explosive. En 1988, celle-ci a été suivie de nombre d'arrêts imprévus, dûs à des défectuosités majeures de plusieurs autres traversées murales à 500 kV.

Ce problème est typique du contexte des compagnies d'électricité, lesquelles n'ayant d'autre choix que de fonctionner parfois au-delà des limites de leur technologie, se retrouvent obligées de contribuer à son évolution...

Booster shed installation on the 450 kV wall bushings began in 1984 and was completed in 1986. To date, there has not been a flashover at this voltage on a Manitoba Hydro bushing that is equipped with booster sheds. As part of an on-going research project, one 450 kV wall bushing was left without booster sheds during 1987, and one flashover was experienced during strong wind and heavy rain.

Figure 1: A Bipole 1 wall bushing with booster sheds.



Nelson River Bipole 2

Based on the flashover experience of Bipole 1 wall bushings, the 500 kV wall bushings on Bipole 2 were specified with a larger outdoor specific creepage distance (43.6 mm/kV compared to 32.9 mm/kV).

The commercial operation of the Bipole 2 poles commenced in 1978 at ±250 kV. The poles achieved operation at rated voltage as follows:

Pole 3	*Pole 4*
-500 kV	+500 kV
1985	1984

The following represents the dimensions and the ratings of Bipole 2 wall bushings:

Nominal voltage [kV]	500
Basic Insulation Voltage (BIL) [kV]	1550
Outdoor creepage [mm]	21800
Outdoor strike [mm]	5450
Specific creepage [mm]	43.6

Between 1985 when Bipole 2 achieved full voltage operation (±500 kV) and October 1987, there was one flashover on the negative polarity bushing on the DC side of the inverter valve group at Dorsey Station. The flashover occurred during light rain and gusting winds. The bushing had not been washed since 1984. Booster sheds were not then in use on Bipole 2 wall bushings.

In October 1987, the Dorsey Station inverter valve group S-phase negative polarity valve winding bushing exploded and then caught fire both outside and inside the valve hall. The fault oscillograms showed two flashovers on that bushing, separated by a period of 47 ms. Prior to the flashovers, there had been high winds for several hours while rain had started approximately 30 minutes before the flashovers. The direction of the wind suggests that the porcelain near the wall would have been shielded from wetting.

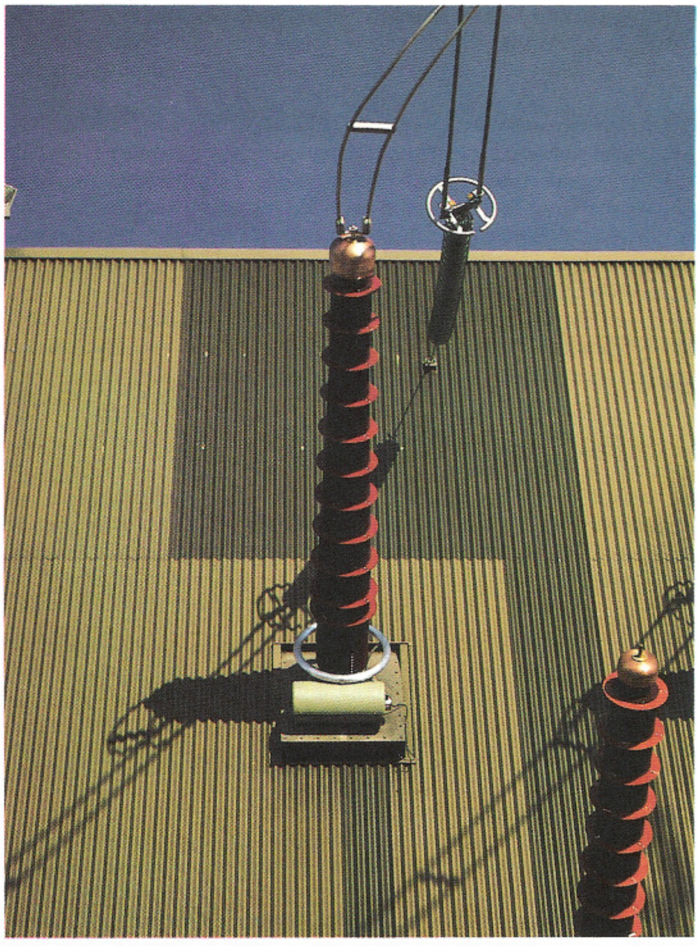
A period of five weeks was required to clean the smoke and fire damage to the valve hall equipement, both indoors and outdoors.

It should be noted that in HVDC wall bushing applications to thyristor converter groups, there are two distinct differences between the fault current in the DC side wall bushing and the valve winding side wall bushing.

In the case of the side wall bushings, the current following a flashover is very limited in magnitude by the control action, as well as by the finite energy stored in the smoothing reactor and the DC line. However, in the case of the valve winding bushings, the flashover causes an overvoltage which in turn leads to the sparkover of the top valve arrestors. This translates into a short-circuit between two AC phases. The amount of current in this case is much larger than for the DC side flashover. Hence, the valve winding bushing is usually at a much higher risk following an external flashover.

An investigation of the failure and subsequent analysis of the performance of other similar bushings revealed that the problem is related to the unequal wetting of the procelain. This results in a much higher than normal voltage on the surface of the porcelain near the grounded flange. This condition, coupled with the internal design of the condenser core (the location of the grounded foil in particular) can lead to a high dielectric stress applied radially on the porcelain. The presence of this stress may lead to puncture of the porcelain and the catastrophic failure of the bushing. There is some evidence to suggest that the porcelain damage is cumulative, and that the bushing may operate for a relatively long time with this radial puncture until eventually there is an external pollution flashover which involves the puncture as part of the flashover path. Experience has shown that gas-in-oil analysis can be useful for detecting this sort of damage in advance of failure, with acetylene being the most prominent fault gas.

Figure 2: A Bipole 2 wall bushing with booster sheds.



Corrective Measures to Bipole 2 Wall Bushing Problems

In consultation with the manufacturer, it was decided to rebuild all 500 kV wall bushings associated with Bipole 2 (18 bushings). The rebuilt bushing cores have a different design in order to reduce the stress on the porcelain near the grounded end during conditions of unequal wetting. Furthermore, to protect the porcelain, an arc interceptor in the form of a grounded toroid has been positioned at an axial distance of 597 mm from the grounded flange (Figure 2). This distance was selected based on the internal design of the condenser core. The function of the toroid is to attract any arc due to an external flashover of the bushing. In order to reduce the chance of an external bushing flashover, eleven booster sheds similar to the ones used in Bipole 1 are mounted on the outdoor porcelain (Figure 2).

In addition to the standard routine and type tests carried out on the rebuilt wall bushings, it was decided to perform a series of clean fog and non-uniform rain tests to a maximum DC voltage of -600 kV, with and without booster sheds. For the clean fog and one of the non-uniform rain tests, a contamination layer of 0.02 mg/cm^2 Equivalent Salt Deposit Density (ESDD) was applied to the porcelain. This pollution level is almost twice the amount encountered in service at the inverter (which has the higher pollution condition). It is interesting to note that, at -600 kV and 0.02 mg/cm^2 ESDD with booster sheds installed, there was no flashover of the bushing during a clean-fog test of 3 hours duration. By comparison, for the same test conditions with no booster sheds, the minimum flashover was -311 kV after 2 hours. Gas-in-oil and other diagnostic tests indicated that the bushing had passed the test program without damage.

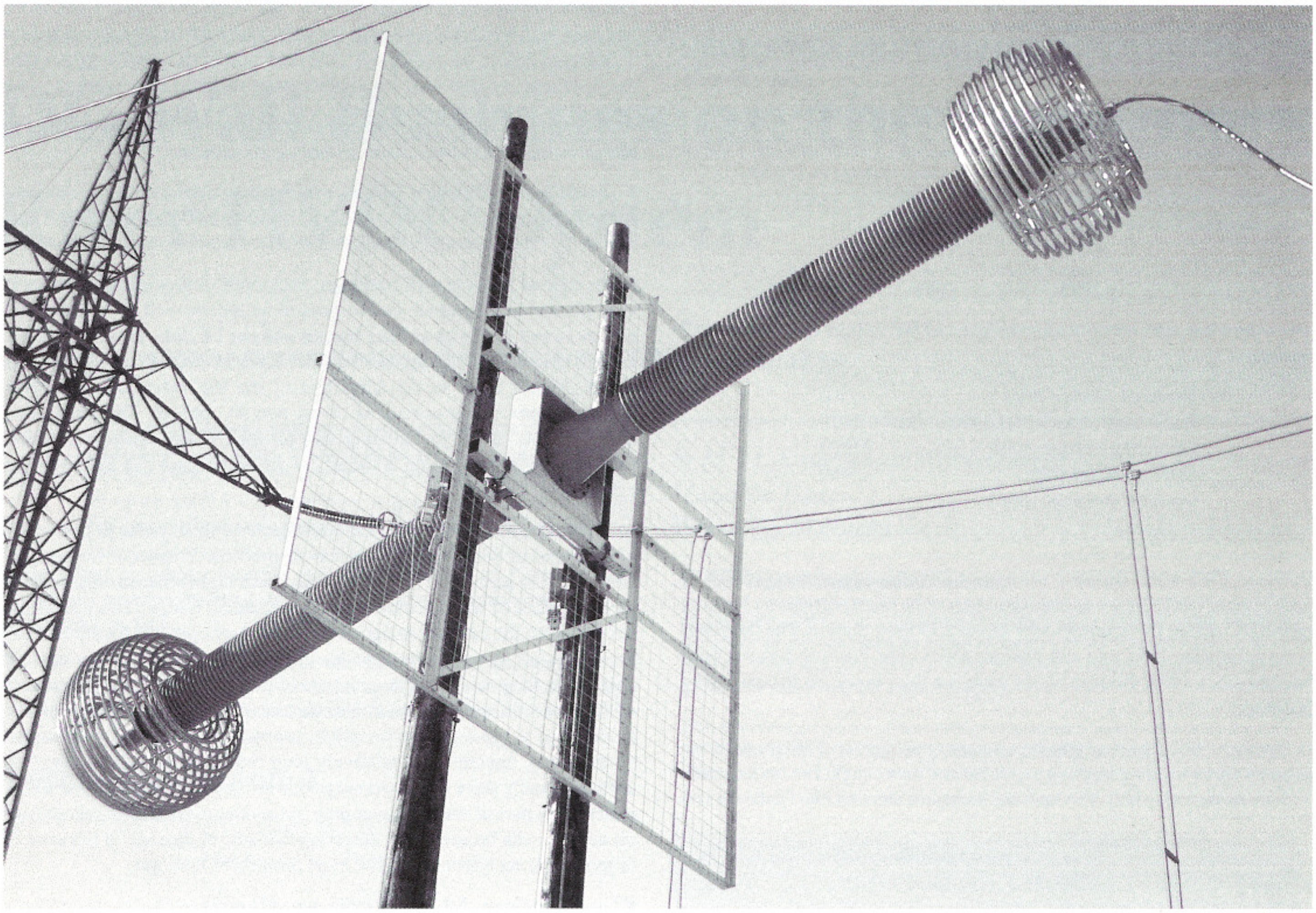


Figure 3: A 450 kV outdoor/outdoor composite dry bushing with silicone rubber sheds.

Looking into the Future

Manitoba Hydro is actively pursuing alternatives to oil-filled porcelain wall bushings for HVDC applications. These activites include the following:

1. Monitoring the leakage current on an outdoor/outdoor SF_6 filled dry condenser bushing with silicone rubber sheds. This project is supported by the Manitoba HVDC Research Centre and the bushing was contributed by F & G Hochspannungsgerate of the Federal Republic of Germany. The bushing is energized at -450 kV with no load current. The purpose of the project is to evaluate the insulation performance of dry type bushings under field service experience (Figure 3).

2. F & G Hochspannungsgerate is also supplying to Manitoba Hydro an outdoor/indoor wall bushing of similar design to the above but rated at 500 kV and 2000 A. This will be in a valve winding position in the -500 kV valve group Dorsey Station. The reason for installing it in this position is to evaluate it under the highest possible operating stress and the worst pollution conditions in the HVDC system.

3. Manitoba Hydro also supported the Canadian Electrical Association (CEA) Project 203-T-421 which included the evaluation of one of the above wall bushings with silicone rubber sheds under pollution conditions at the Hydro-Quebec Research Institute. We consider the results to date to be promising.

It is the opinion of the authors that SF_6 filled dry condenser bushings with silicone rubber sheds provide an attractive alternative to oil-filled porcelain wall bushings in HVDC valve hall applications. This eliminates the risk of fires in the valve hall. It should be noted that due to the hydrophobic properties of silicone rubber, these bushings appear to perform better than porcelain from a pollution flashover point of view, without the need to grease or employ booster sheds.

Acknowledgements

The authors would like to thank their colleagues in both the Production Division and in the HVDC Design Department of Manitoba Hydro for their help and support during the rebuilding program. As well, thanks are due to personnel at IREQ for carrying out the pollution tests on one of the rebuilt bushings. The authors would like to thank F & G Hochspannungsgerate and in particular Dr. F. Hammer for their cooperation and for the supply of the dry wall bushings.

Using DC to Increase Capacity of AC Transmission Circuits

Adding or converting existing lines to DC: a solution to limited rights-of-way?

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Electrical Power Transmission: Facing New Challenges...

Power system planners determine what power lines are needed to meet the ever-increasing demand for electricity. However, notwithstanding the strategic importance of electrical power transmission to our civilization, it is becoming very difficult, if not impossible in some cases, to license a new transmission line. Is there an alternative?

Le transport d'électricité: les nouveaux défis...

Les planificateurs de réseaux savent concevoir à l'avance les lignes de transport requises par la demande sans cesse croissante d'électricité. Nonobstant l'importance stratégique du transport d'électricité pour notre civilisation, il devient de plus en plus difficile - voire impossible, à certains moments - de faire approuver une nouvelle ligne. Comment sortir de cette impasse?

The demand for electric power is steadily increasing, and despite efforts in conservation of energy and load management, the reserve capacity of existing transmission systems is gradually being depleted. The utility engineer today is faced with mounting public concern over transmission lines being built in their community or across their property. Licensing procedures now involve a significant degree of public participation and proposals for new lines are often met with fierce opposition.

Concern has spread with reports that alternating current (AC) magnetic fields are a possible cause of biological effects on humans. In Texas for example, a situation where a school is located alongside a transmission right-of-way (ROW) raised the biological effects issue to such an extent that the public demanded that either the school or the lines be moved. Where public concern is so heightened, it is a *fatal flaw* to assume that economic necessity will permit new lines to be constructed and brought into service within a reasonable time frame.

Increasing Line Capacity

The utility transmission engineer is forced to seek innovative ways to get power to the load centres under circumstances where no new right-of-way for the transmission can be acquired. There are many techniques for increasing the power transfer capacity of a given right-of-way. These include:

1. Reconductoring the transmission line.

The current-carrying capacity of AC lines can be increased by replacing the existing conductors with larger ones. This solution, however, may require reinforcement of the line towers, and is feasible only for short line sections where thermal loading - and not impedance - is the dominant limit.

2. Increasing the voltage of the circuit.

Conversion to a higher voltage can be an effective way of increasing power transfer capability if there is enough margin in the original design to allow for the increase. Higher electric field gradients, resulting from the higher voltage, may necessitate raising the conductors by increasing the tower height (which may be expensive or even impractical). Corona effects, such as audible noise and radio interference, require consideration to ensure that standards are not exceeded.

If the conductor-to-tower clearances are insufficient at the higher voltage, the insulator strings may need to be lengthened or formed into "V" strings to reduce conductor swinging. Tower modifications may also be required to accommodate these changes.

If the right-of-way has sufficient width, the existing transmission line may be entirely replaced with a new higher voltage line or a line with an increased number of circuits. Conversion to a higher voltage also requires replacing switchgear and adding new transformers in the substations.

3. Rebuilding the line with six phases.

The rebuilding of an AC circuit with a six-phase line has been investigated in the United States. In comparison with a conventional double-circuit line, the six-phase line is characterized by lower electric and magnetic fields at the edge of the right-of-way. However, the six-phase line is not without its drawbacks: it requires the complete rebuilding of the transmission line circuit, and special phase-shifting equipment is needed at the line ends.

4. Conversion to Direct Current (DC) transmission.

Much has been written about converting AC transmission lines to DC. The economics of AC to DC conversion are more favourable on long circuits without taps since DC taps tend to be relatively expensive. When the AC circuit is judiciously designed to anticipate eventual conversion to a DC circuit, the cost of the changeover and upgrade can be kept to a minimum. This may be accomplished by designing the line with bundled conductors, and making provisions for future transfer of the centre phase conductors to the outer phases, thereby utilizing all conductors for DC operation.

5. Series and shunt compensation.

The power transfer capacity of an electric transmission system can be marginally increased with the addition of series and shunt compensation. Capacitor installation is the least costly way to compensate the power system. Static var systems and synchronous condensors are more costly alternatives, but these have the advantage of increased voltage control capability.

6. DC overbuild

Some configurations of AC transmission lines, such as the 230 kV Gulfport structure (Figure 1), lend themselves to the addition of a DC circuit carried above the AC circuit. Another option for overbuild is to build a new structure immediately adjacent and in line with the AC structure and to carry the DC circuit (at a higher level than the existing AC circuit) on the new structure.

The utility engineer can examine all the options listed above in his search for the most effective and least costly way to increase the power transfer capability of an existing electric power transmission corridor.

The Manitoba HVDC Research Centre has been studying the use of DC for this application, and proposes two practical options which are presented here for further consideration. A review of commonly used transmission tower types identified a wood pole 230 kV AC Gulfport structure as representative of the type most likely to be candidate for upgrading, due to the fairly extensive use of this structure throughout North America. Manitoba Hydro, for example, has seven interconnections to Saskatchewan, North Dakota, Minnesota and Ontario with 230 kV Gulfport transmission lines. Similarly, a double circuit 230 kV lattice tower was selected as the representative steel structure.

A prime consideration for the study was that significant amounts of additional power must be transmitted along the existing transmission lines. A second consideration was that the basic structure of the tower was to remain rather than envisage the complete replacement of towers and circuits.

230 kV Gulfport Structure

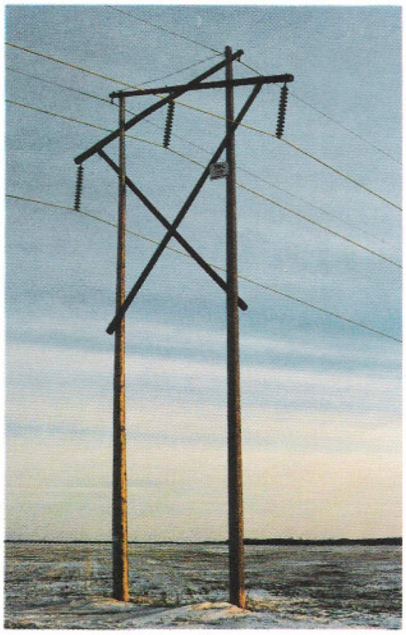


Figure 1: 230 kV Gulfport woodpole transmission line structure.

The Gulfport woodpole structure is shown in Figure 1. The tower is essentially a wood pole "H" frame carrying the conductors in flat formation with the centre phase raised slightly above the two outer phases and with lightning protection provided by two overhead shield wires.

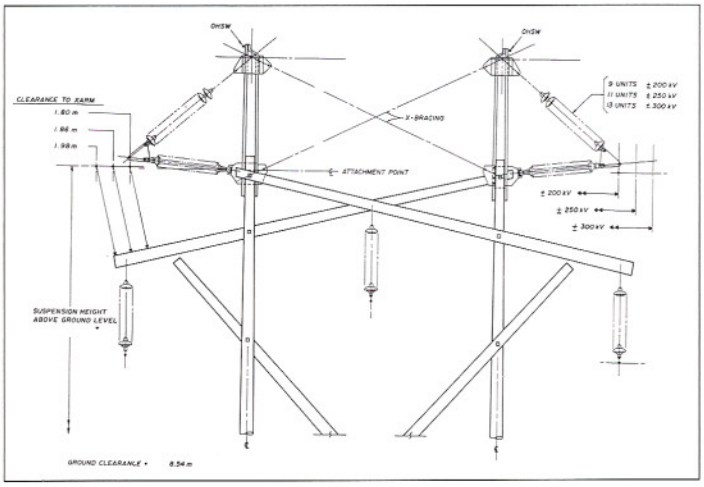
Figure 2 depicts the tower modifications required for the addition of a DC circuit above the existing AC circuit. A unique feature is the use of insulated cross arms to support the DC conductors. Increasing the pole spacing can accommodate increasing DC voltages from ±200 kV to ±300 kV, as shown in Figure 2.

The critical consideration is the ability of the tower to support the extra weight of the conductors. Using current CSA standards, calculations indicate that the Gulfport tower can support the proposed arrangement but with reduced loading factors on vertical, transverse and longitudinal loads. Although minimum CSA standards are achieved, load factors may be below utility requirements.

Improvements in the load factors appear to be possible by providing additional supports at the pole top level and by adding a second set of cross bracings. Additionally, with further appropriate structural modifications, it should be possible to install larger DC conductors of up to 3.8 cm diameter.

The 230 kV Gulfport line would normally be expected to carry approximately 300 MW. Having 2.96 cm diameter DC conductors operating at ±250 kV will provide an ampacity of 870 amps at 40°C which, in turn, translates into 435 MW in the DC circuit. This, of course, is in addition to the AC circuit capacity of approximately 300 MW. This represents an increase of 145% over the present level of the 230 kV line. If it is economical to strengthen the structures to carry the 3.81 cm diameter conductors, then under the same conditions of sun and wind, the normal ampacity would be increased to 1216 amps. At ±250 kV, this gives a power level of 608 MW, an increase of 200% over the original capacity of the AC line alone.

Figure 2: Modified tower top of the Gulfport structure accommodating the addition of a DC circuit.



The electrical effects from the hybrid AC/DC circuits on the Gulfport structure were assessed based on separate calculations for the AC and DC circuits respectively (i.e. the effects from the AC circuit were calculated ignoring the DC circuit and vice versa). The calculated values of maximum conductor surface gradient, maximum electric field, radio-interference (RI) and audible noise (AN) for the separate AC and DC circuits are shown in Table 1.

Based on work done by others, it can be predicted that the principal effect of the proposed hybrid arrangement will be to increase the maximum conductor surface gradient on the AC conductors, with a resultant increase in RI and AN. The AC circuit will provide a significant screening effect on the DC electric field, ion current and charge densities at ground level, and no problem is expected from the DC line electrical effects.

The proposed hybrid arrangement with DC voltage not exceeding ±250 kV is expected to have acceptable electrical effects. The voltage limit is ±200 kV for the smaller DC conductor.

Insulation for the DC line to be added to the Gulfport structure is in the form of an insulated crossarm with the strut portion composed of a solid post-type insulator and the tie portion composed of normal cap and pin type insulators. The porcelain insulator crossarm shown in Figure 2 has been proposed for an actual DC line, but is not yet in service and is expected to provide similar service life as porcelain insulators presently used on HVDC lines. The arrangements with non-ceramic insulators would be essentially the same. At this point in time, non-ceramic insulators have very little service history. Portions of two DC lines in the United States have non-ceramic insulators in place, and in time more confidence in their use will be gained. Since the arrangement with non-ceramic insulators would be essentially the same as that shown in Figure 2, no special consideration has been given at this feasibility stage to non-ceramic insulators.

Compact Design

Since the physical arrangement of the DC conductors are dictated by the configuration of the Gulfport structure, and since the DC conductors fit into the existing right-of-way, there is no requirement to study a compact arrangement for the added DC bipole.

With the Gulfport structure, the fact that the DC conductors are located almost directly above the outer conductors of the AC circuit makes it extremely difficult to install the DC conductors while the AC circuit is live.

No major difficulties are foreseen in being able to carry out maintenance on either the AC or DC circuits while the lines are live. Certain physical details would have to be investigated for an actual design but as a concept, the proposed arrangement presents no unsurmountable problems.

Lightning Performance

The conceptual arrangements for adding DC circuits to AC towers, as proposed herein, retains the use of overhead shield wires on the structures. For the Gulfport structure, the DC circuit is located above the existing 230 kV AC circuit and the overhead shield wires are raised about 2.4 metres. The AC circuit is shielded by both the DC circuit and the overhead shield wires, and hence the probability of direct lightning strokes to the AC conductors will be reduced. The probability of back-flashovers from the AC circuit to the ground lead on the structure may increase slightly due to the greater height of the overhead wires, but the increase is expected to be small or negligeable. On an overall basis, the lightning performance of the AC circuit should be improved.

The overhead shield wires will provide a shielding angle of about 41 degrees for the ±200 kV bipole, to about 52 degrees for the ±300 kV bipole. With the relatively large shielding angle, there would likely be a significant number of direct lightning strokes to the DC circuit. However, this should be acceptable,

TABLE 1

Electrical Effects of the Two Circuits on the AC/DC Hybrid Gulfport Line

a) 230 kV AC circuit only, one 2.96 cm conductor per phase.

	Calculated Value	Generally accepted Limits
Maximum conductor gradient (kV/cm)	16.5	-
Maximum electric field (kV/m)	5.3	-
RI at 1 MHz (15 m from outer phase) Fair-Maximum dB (uV/m)	42.3	48.0
AN (at edge of ROW, 15m from centre-line) Rain-150 dB (A)	46.5	52.0

b) DC circuit only.

Voltage kV	Pole Spacing m	Maximum Conductor Gradient kV/cm	Maximum Nominal Field kV/m	Maximum Total Field kV/m	RI at 1 MHz (15 m from pos. pole) Fair - 150 dB (uV/m)	AN (at edge of ROW, 15 m from centre Fair - 150 dB (A)
Conductor 1 x 954 MCM (2.96 cm), mid-span height 8.54 m.						
±200	10.8	21.3	4.5	13.4	44.3	28.9
±250	11.5	26.2	5.9	23.7	53.0	36.8
±300	12.2	31.2	7.2	31.3	56.5	43.5
Conductor 1 x 1590 MCM (3.81 cm), mid-span height 8.54 m.						
±200	10.8	17.04	4.82	11.1	35.7	23.8
±250	11.5	21.14	6.18	16.2	49.2	31.9
±300	12.2	25.20	7.69	23.4	56.6	38.6
±350	12.9	29.23	9.24	35.9	60.4	44.2
Generally Accepted Recommended Limits:				30.0	52.0	52.0

because of the relatively small disturbance to the AC system caused by the DC monopolar faults and the rapid restart capability of a DC system.

Upgrading a Double Circuit Steel Tower

A typical double-circuit 230 kV steel tower used in North America is shown in Figure 3. As described below, significant corridor power level increases can only be achieved if both AC circuits are replaced by two DC bipoles. If only one circuit is replaced, and assuming that only two of the available conductors are used, the current and power capacities of the DC circuit at ± 250 kV and 40°C are 1216 amps and 608 MW respectively. This represents a power level increase of about 100% over the original AC circuit, but only 50% over the power level of the corridor. If the voltage is increased to ± 300 kV, the corresponding line and corridor power level increases would be 133% and 67%. Studies indicate that the cost of building the required converter stations would not be justified by the increase in power level.

If, however, the AC circuits are replaced by two DC bipoles, each bipole would carry 608 MW; the total transmission corridor capacity would be increased to 1200 MW. By undertaking modifications to the upper part of the structure to support two DC bipoles, each pole having two 3.3 cm diameter conductors, the power level at ±250 kV would increase to 998 MW per bipole giving a power level increase of 233% (from 600 MW to 2000 MW) for the transmission corridor.

A double-circuit 230 kV AC tower used with two DC circuits with no change in conductors is shown in Figure 4. The spare conductors could be assigned to one or both DC bipoles to reduce losses or increase the current capacity of one bipole. Modifying the upper structure with new insulated crossarms, as shown in Figure 5, will accommodate the 2000 MW power transfer capability.

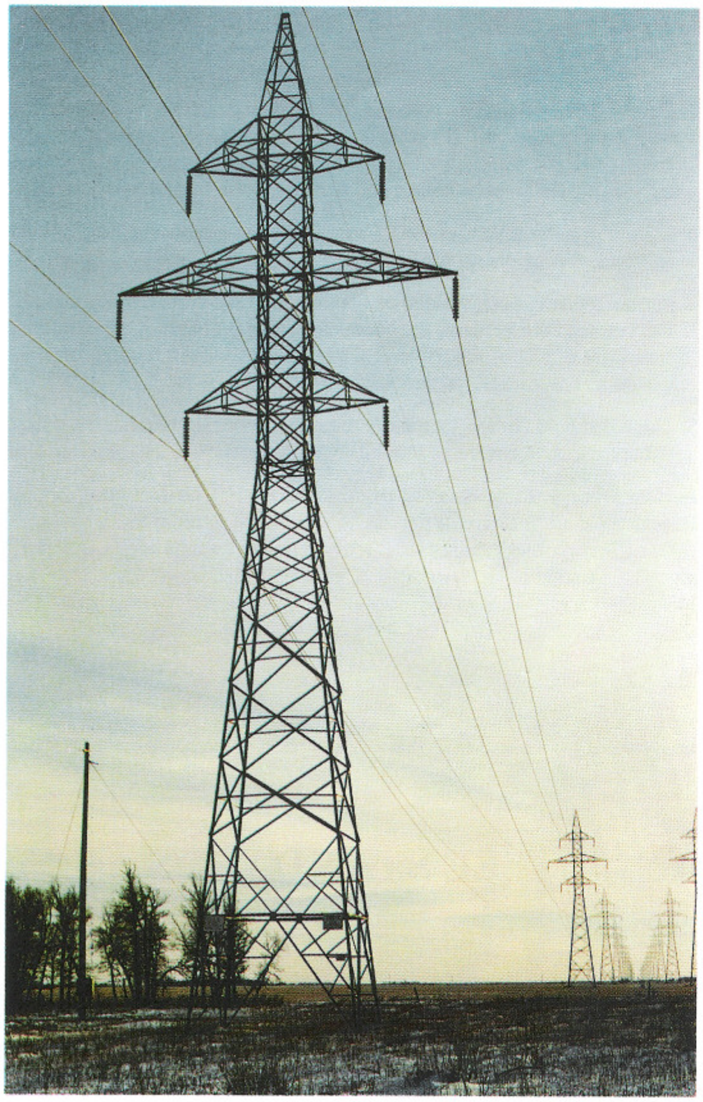
The double-circuit steel structure would present no difficulties in terms of hot line maintenance. Use of the insulated crossarm will probably be beneficial in terms of reducing the electric field effects at the edge of the right-of-way, and may be considered a form of "compacting" the lines. The overhead shield wire would remain in its original location and provide adequate shielding for the DC circuits.

Further Studies

The preliminary work examining AC/DC hybrid transmission is encouraging as it points the way to a realistic solution to the challenge of expanding transmission capacity when additional right-of-way is restricted. However, before the hybrid line concept can be incorporated, further work is needed. Some areas requiring more work include:

1. The effects of AC coupled voltages and currents on the DC circuit, and in particular how such voltages and currents affect the operation of the DC converter should be examined. It is known that fundamental (60 Hz) frequency currents flowing in the DC side of a converter will result in saturation of the converter transformer. Suitable controls or filters can be used to minimize this undesirable effect.

Figure 3: One form of double-circuit 230 kV AC lattice steel transmission line tower used by Manitoba Hydro.



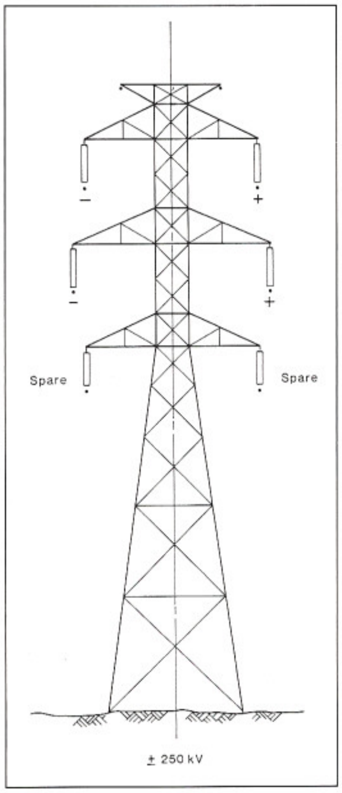


Figure 4: A double circuit 230 kV AC lattice steel transmission line tower converted to double-circuit AC transmission.

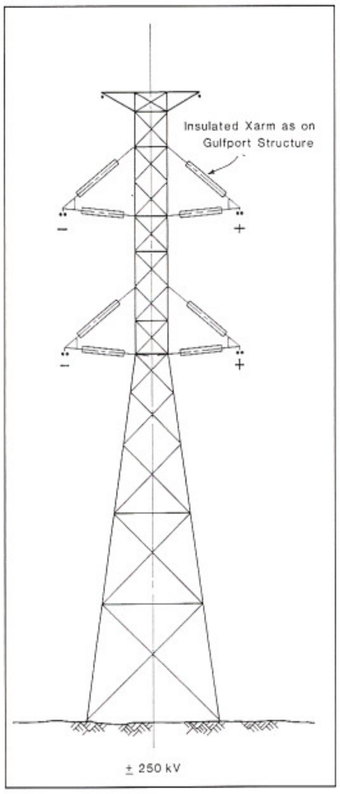


Figure 5: Replacing crossarms of a double-circuit 230 kV AC structure with insulated crossarms for double-circuit DC operation.

2. Corona effects from DC voltages not exceeding ±250 kV (using typical conductor sizes from 230 kV AC lines) are expected to produce acceptable levels of electric fields, but further studies should be carried out, particularly on the Radio Interference and Audible Noise from the AC circuit.

3. Lightning performance of the DC circuit covering both shielding failures and back-flashovers should be studied.

4. Further information is needed on the impact of AC system faults and AC/DC contact fault between the conductors. The problem of arc extinction following a DC line flashover is being examined under funding from the Canadian Electrical Association.

5. The wood pole Gulfport structure requires further structural analysis and structure tests to ensure its suitability for conversion to a hybrid line.

Further work in these areas is being carried out. The Manitoba HVDC Research Centre is active in finding an acceptable solution to the restricted right-of-way problem and use of DC transmission circuits seems to provide an attractive solution. It is anticipated this topic will become more important in the 1990's, as electric power demand increases while construction of new overhead transmission lines becomes more difficult to achieve.

Acknowledgement

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VISIT BEAUTIFUL VICTORIA THIS SPRING!

First MicroMouse competition in Canada

by Dr. Michel Fortier, Past Chairman, Montreal Section

In mid-October, from the 13th to the 19th, was held the first of the MicroMouse competitions in Canada: MicroMouse MONTREAL International. This event attracted teams from Montreal, Cambridge (Mass., USA), Portsmouth (UK), Irvine and Los Angeles (Calif., USA), and as far away as Australia.

The MicroMouse comptetition originated in the United Stated in 1979 following an announcement in Spectrum, pp.21-22 Jan. 1978). The goal then was to create a mobile robot with sensors that enabled it to find the exit of the maze. The robot would only know such things as wall dimensions, wall and floor colors and maximum dimensions. It would have to determine the maze configuration by exploration using its sensory devices. To do this, it would follow corridors, memorize intersections when encountered and return to these intersection points from dead ends; this, it would do until a path was found to the exit.

At that time, the challenge was to find the exit within a 15 minute period. Today, the challenge is not only finding it but how fast it can be done. Today's MicroMice try to chart more than one path to the center square (which replaces the exit of early competitions). This is followed by a "speed phase" in which the best path is used to go to the center in as little time as possible. Today's challenge is in data acquisition, driving the robot forward or into turns, tolerating imprecisions, handling error buildup, etc...

The MicroMice in the October 19 Competition were of varied design. Thumper (UK) was a 1980 design: a heavy duty platform on four wheels that had a voice synthesizer on board...with a British accent. It did its best, but its old belts had slackened-it could not finish. An enjoyable contender nontheless. Canadian entries were from Ecole Polytechnique (Mouse-Mobile) and McGill University (MicroMouse II). Both had three wheels and one of them used stepping motors.

The best maneuvering came from MITEE III (USA). It performed an exploration phase with clean control similar to others but the striking difference came in the speed runs. Then, unlike other mice, it would cut corners and move on diagonals.

Another MicroMouse competition will be held in Montreal on July 15-16, 1989. For more information, contact Dr. M. Fortier at (514) 765-7822.

The results of the competition were as follows:

1st Prize - $300: MITEE III (21.5 sec.) - MIT (USA)
2nd Prize - $200: MITEE II (23.3 sec.) - MIT (USA)
3rd Prize - $100: ENTERPRISE (34.3 sec.) - Portsmouth Poly. (UK)
Best Canadian: MicroMouse II (74.5 sec.) - McGill University.
MicroFinishing mice were awarded $250. Other Awards were given to:
Mouse-Mobile (Ecole Polytechnique) for MicroMechanics
MITEE III (MIT) for MicroIntelligence
ENTERPRISE (Portsmouth Polytechnic) for MicroDesign
MITEE III (MIT) for MicroInnovation

Student Paper Awards

Awards were presented to the authors of the winning papers in the 1988 Student Papers Competition on October 12, at the Programmable Control Conference.

Back row, (left to right): Wayne Zelmer, Technical University of Nova Scotia; Christopher Bachalo, University of Windsor; Anthony Oakley, Technical University of Nova Scotia; Pam Woodrow, Manager, Canadian Member Services; Joe Karnas, SAC Vice-Chairman, CCC; Bob Alden, Director, Region 7; Gerard Dunphy, Memorial University of Newfoundland; Les Tanne, University of Alberta.

Front row, (left to right): Ian Radziejewski, Simon Fraser University; Michael Kisel, Ryerson Polytechnical Inst.; Nathan Schachter, Chairman, Programmable Control Conference; Randy Marsden, University of Alberta; John Rampelt, Radio College of Canada.

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