TECHNOLOGIE ET IREQ

Institut
de recherche
d'Hydro-Québec

Report of activities
1993

Hydro-Québec
50 Years of Energy

Cover

Martin Boyer performs tests related to the robotization of some of the maintenance tasks on the distribution system.

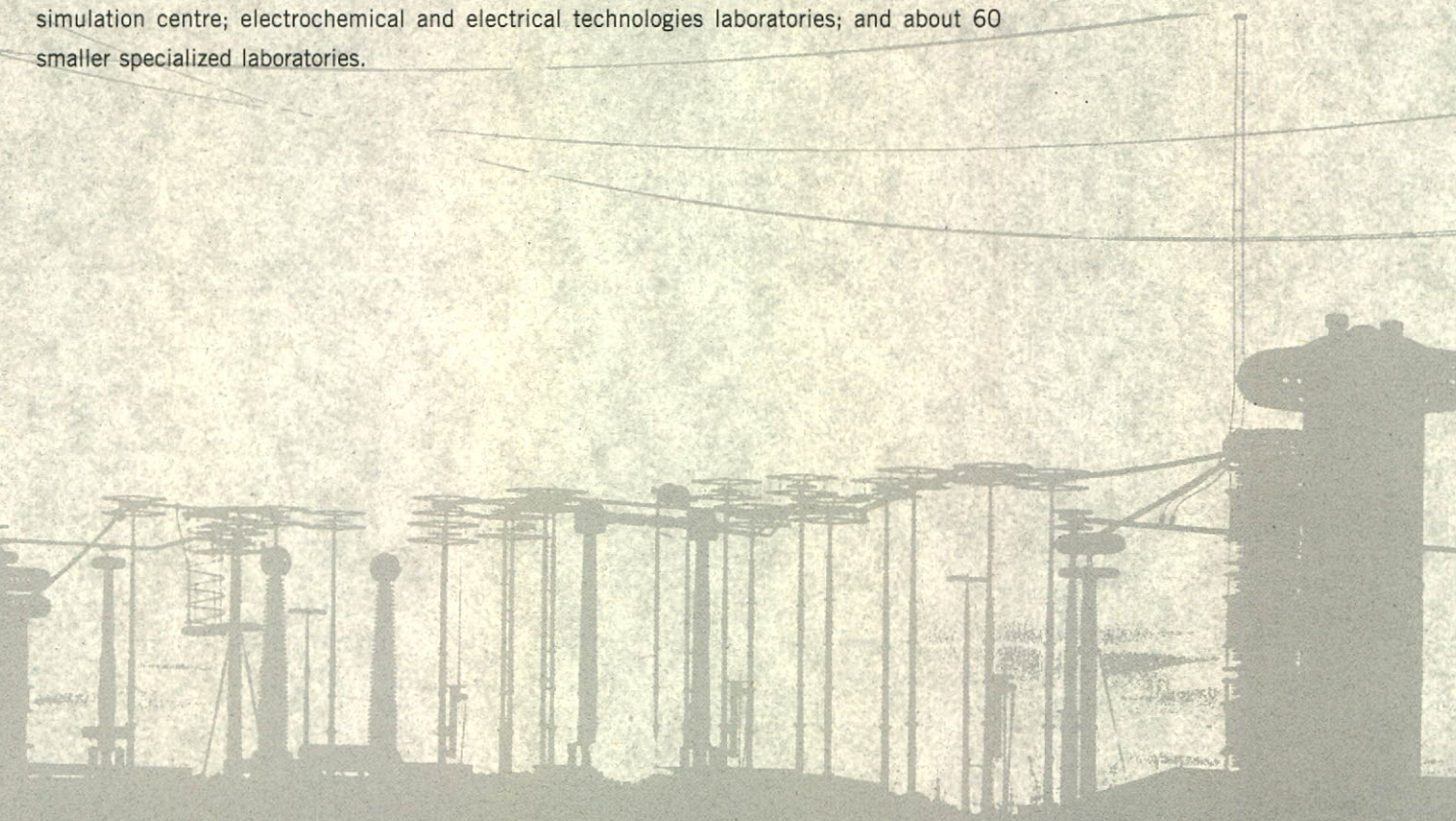
Hydro-Québec's Vice-présidence Technologie et IREQ (Technology and IREQ) conducts research, testing, development and demonstration projects in the areas of electric power generation, transmission, distribution and utilization.

Most of its activities are designed to meet Hydro-Québec's short-term or medium-term needs that are directly related to customer satisfaction. Some of its resources are also set aside for prospecting and longer-term research. Technologie et IREQ is also responsible for charting the course of the utility's technological development and promoting the products and technologies resulting from its research. To maximize the success of its projects, it works in partnership with many organizations both in Canada and abroad, including research centres, universities and private-sector companies.

In addition to the work it does for Hydro-Québec, Technologie et IREQ conducts research and testing for outside clients.

Its human resources represent about 825 person-years and the number of permanent positions now totals 587. In 1993, its operating budget was $123 million.

Technologie et IREQ has impressive research and testing facilities at its disposal: a large high-voltage laboratory and an equally impressive high-power laboratory for the development and testing of transmission and distribution systems and equipment, a power system study and simulation centre; electrochemical and electrical technologies laboratories; and about 60 smaller specialized laboratories.



Armand Couture

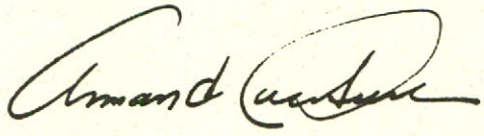
Once again, it gives me great pleasure to present the annual report of activities of the Vice-présidence Technologie et IREQ. Last year at this time, I had only been responsible for this group for a few months. Now, at the end of a full 12 months in office, I am witness once more to the many achievements of its personnel, the depth of their commitment and their unswerving dedication. I take advantage of this occasion, therefore, to congratulate and thank the entire staff, one of the major driving forces of our company.

In 1994, Hydro-Québec will be celebrating its fiftieth anniversary. In half a century, it has taken up challenges on many fronts: in the energy, technological and financial sectors as well as in economic development and service quality.

The Vice-présidence Technologie et IREQ has been a major player in tackling these challenges ever since the research institute was first founded in 1970, followed by LTEE in 1987. Its research and testing activities in the areas of power generation, transmission, distribution and utilization have always been motivated by the same determination to resolve the immediate operating problems of a power system that is unlike any other in the world, while never losing sight of the future needs of a utility which is constantly adapting to satisfy its customers.

I would like, here, to pay tribute to Vice President Alain Brosseau, who left us in December after seven years working with the Vice-présidence Technologie et IREQ. He devoted his time and energy to total quality, introducing improvement teams, strengthening the links between clients and suppliers, and networking with different partners in research and development.

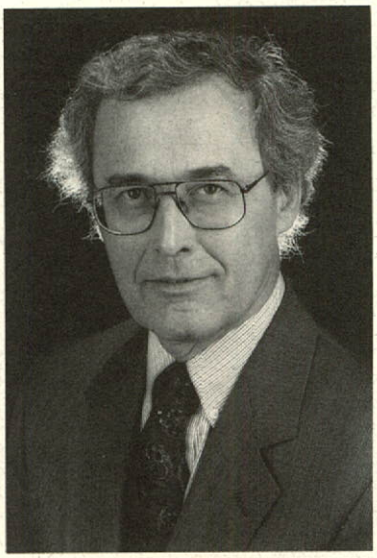
I would also like to welcome Louis Masson, who has taken over as Vice President. This appointment marks a return to old haunts in a way, for Mr. Masson was formerly researcher, program leader, department manager and Vice President, Laboratories, here before he was nominated Vice President, Power System Planning at Hydro-Québec in 1990. I am convinced that with Louis Masson at the helm, Technologie et IREQ will continue to contribute to making Hydro-Québec the foremost electrical utility in Canada by the year 2000.



Armand Couture
President and Chief Operating Officer
Hydro-Québec

MESSAGE FROM THE VICE PRESIDENT

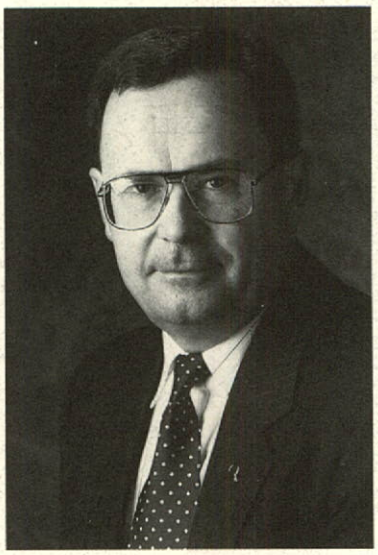
When I was appointed to the position of Vice President, Technologie et IREQ at the beginning of the year, I was immediately filled with confidence. I was honored by the confidence that Hydro-Québec was showing me in this appointment but I felt sure too, as I accepted this mandate, that I could count on the group's capabilities. After almost 20 years' experience at various levels within this group, I was fully aware that I could count on a staff as competent and dedicated today as they have been over the years.



Louis Masson

Moreover, their recent achievements merit congratulations and heartfelt thanks. Although all are worthy of mention here, it would be inexcusable not to single out the borehole inspection system with its gyroscopic camera, the continuous condition-monitoring system for HV circuit-breakers, telerobotized distribution maintenance activities, the faulty composite-insulator detector, tests on grounding sets, the new measuring system implemented at the high-power laboratory, shape-memory alloys, the signing of an R&D agreement with the 3M company for the development of batteries to power electric vehicles, the 800-kV underground-cable demonstration project, the study of high-performance thermostats, or the development and marketing of new manufacturing processes for aromatic products based on electrosynthesis.

Most of this work was performed under the leadership of Alain Brosseau, whose outstanding contribution must be acknowledged. Mr. Brosseau steadfastly pursued our objective to implement total quality management both in our internal activities and in our relations with internal and external clients. This objective will remain a priority, since I espouse it just as firmly as my predecessor did.



Alain Brosseau

In the years ahead, the Vice-présidence Technologie et IREQ will be called upon to exercise its technological leadership role even more. While it continues to meet the needs formulated by the utility, it will be increasingly involved, jointly with its clients, in putting forward suggestions, influencing technological choices and enhancing the strategic planning process.

It will also strengthen its links with outside partners in the development of advanced products and high-performance technologies and increase its marketing endeavors in order to contribute to the sustainable economic development of Québec.

In all its undertakings, the Vice-présidence Technologie et IREQ will pursue Hydro-Québec's current primary objective, to become the foremost electrical utility in Canada through customer satisfaction, efficiency and cost control.

Louis Masson

Louis Masson
Vice President
Technologie et IREQ

Hydro-Québec's *1993-1995 Strategic Plan for Technological R&D*, published at the end of 1992, was distributed to various client groups, both within the utility as well as among its industrial partners. The plan's objectives were thus used to update the 1994-1998 sector-based plans during the course of the year.

In 1993, Hydro-Québec allocated 1.73% of the revenue of its electricity sales for projects in technological R&D, representing a net total of $121 million. It should be noted that in 1992, the utility ranked sixth among Canadian companies in terms of R&D expenditure.

Members of the generation discussion group meet to consult on technology planning activities.

The R&D objectives for Hydro-Québec's *Performance Commitment* plan submitted last year were twofold. The first objective consisted in earmarking 1.8% of the revenue of the utility's electricity sales for 1993 for technological R&D, with the intent of increasing this proportion to 2% by the year 2000. R&D expenditure for the current year was 1.73% of the revenue of total electricity sales, mainly due to the delivery of several products described in this Report of Activities. The second objective involved the ratio for external funding for long-term projects, which was set at 50%. In 1993, this ratio was 53%, thanks to the funding obtained through the Centre canadien de fusion magnétique (CCFM) for projects in magnetic fusion. In order to monitor these two objectives, we developed a computer-based tool allowing us perform monthly follow-ups of R&D budgets and expenditures, in addition to meeting requirements on an ad hoc basis.

The sector-based plans for 1994-1998 were updated at the *Technology Forum*, which saw the participation of several hundred people from various departments throughout the utility. These plans are in conformity with the 1993-1995 Strategic Plan, widely disseminated within the utility as well as among manufacturers of electrical equipment and other firms, such as those forming part of industrial clusters. For the first time this year, R&D project data sheets were produced describing the project contents and objectives, thus facilitating consensus and decompartmentalizing each person's work.

Substantial efforts were undertaken to integrate technological R&D planning with the utility's five performance areas. Close to 70 Forum members took part in a conference on the theme of R&D as a performance asset, with the purpose of demonstrating the role played by R&D in customer satisfaction. A few highly successful projects presented jointly with client groups included a sophisticated borehole inspection system consisting of a color camera coupled with a gyroscope, a detection system for perforated insulators, and research in electrosynthesis. These various activities reflect the dynamic nature of the Technology Forum. The Technology Steering Committee, for its part, has agreed to review the way the Forum operates so that an optimal structure can be devised using the experience culled from the past five years.

In order to improve technology management, a method was developed to *prioritize R&D projects* in generation using a multicriteria decision-support approach. We also launched the Van-tech project, a decision-support system which applies the discounted cash flow method to R&D activities. These two projects meet the utility's *Performance Challenge* objectives since they favor a fact-based analysis and enable initial problems to be quantified.

A new management concept was also tested for the Technology Steering Committee in order to devise an *optimal method of allocating financial resources.* Under the prevailing climate of budgetary constraints, it was necessary to find a way of ensuring that the best choices were made, that changes that benefit the utility could be implemented, and that available funds could be reallocated. For the 1994 budget forecast, a 5% operating margin was retained from the original R&D budget. After analyzing internal and external requirements, this amount was reallocated to high-priority areas, with an emphasis on client-oriented activities and safety-related R&D projects.

The utility's *subcontracting system*, which covers agreements made between clients and suppliers, was also revised. The major element in the revision consisted of a practical implementation of technology promotion into the R&D process while taking into account, from early on in the project, all of the phases involved in product implementation. Potential end users, those in charge of product promotion, and possibly industrial partners could thus become involved at a very early stage in carrying out projects. This new method would lead to a faster development of end products that meet users' needs, while at the same time reducing R&D costs. Along similar lines, a new *method of allocating royalties* resulting from commercialized products was developed. The royalties will be used to first pay off charges related to industrial property, with the remainder being added to the technology budget to constitute an operating margin.

Products resulting from R&D projects will benefit from special protection through the filing of *patents*. In 1993, we managed more than 1500 patents and patent requests in various countries. Patents were obtained for 13 new products and filed for 31 others. Those with the greatest strategic interest for the utility are related to ground transportation (ACEP, etc.), measurement equipment and techniques used in the operation of electric power systems, and power system equipment.

Lastly, our planning methods have been shown to be progressive and easily adaptable to organizational changes. We were able to adjust R&D planning using a market approach, when the energy efficiency activities carried out within our Commercialization and International Affairs Group were reorganized with a view to meeting the needs of residential, commercial, institutional and industrial markets.

During the Parliamentary Commission sessions held in 1993, one of the major topics discussed was R&D. In fact, 25 out of the 81 presentations dealt with this theme. The main expectations stated in these presentations included:

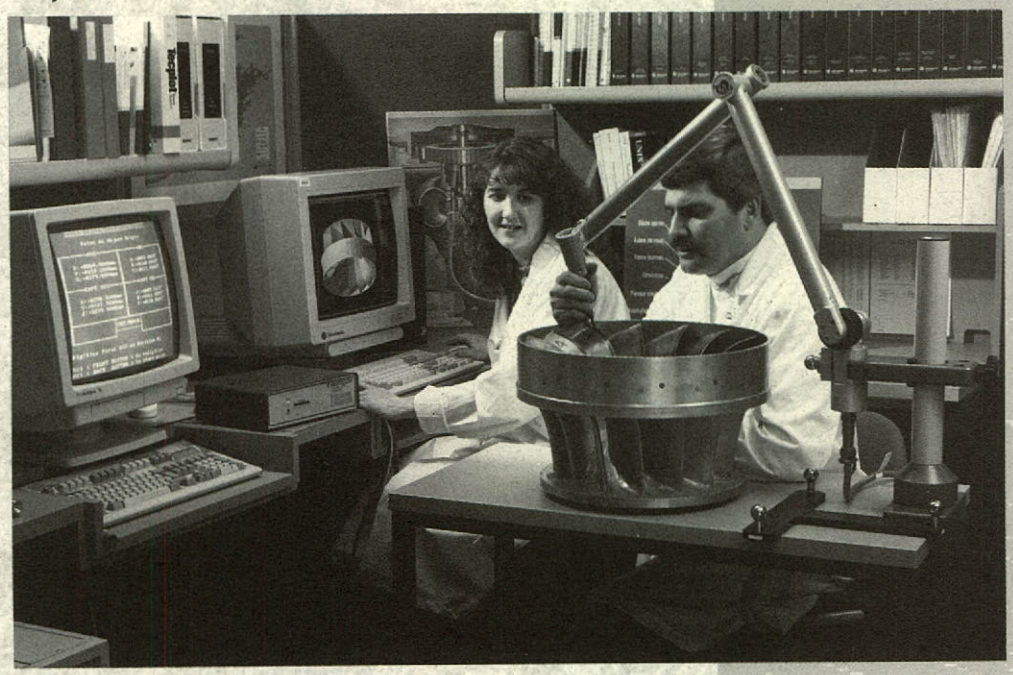
- increased expenditures in energy efficiency;
- greater investments in new energy sources;
- development of R&D partnerships between Hydro-Québec and outside organizations.

One of Hydro-Québec's ongoing concerns in R&D is setting up *networking* and *partnership* ventures with industry. In 1993, we took stock of the projects that had at least one outside firm collaborating on the technical aspects. For example, in 1992, Hydro-Québec's R&D investments of $20 million resulted in investments of $42 million on the part of its partners. The results of this review will be used to ensure more integrated management of R&D joint ventures.

The chair in the management of technology, which was created at Université du Québec à Montréal and is funded by the federal government, continues to promote many interesting activities. Renowned researchers from Europe and the U.S. have given lectures on innovation strategies implemented in industry. The chair also published a study on the evolving nature of R&D which covered the following three aspects: mechanisms to integrate prospecting into the decision-making process, R&D indicators used by other firms, and R&D and Hydro-Québec partners within the industrial clusters. A study conducted in 1993 revealed that Hydro-Québec supported the greatest number of university chairs in Québec.

A *new global planning process* was implemented within the utility in 1993, with the aim of integrating strategic and operational planning, budgets, and resources. The decision was made to wait until 1994 to include technology planning in the process.

Among the many projects performed in 1993 in the area of electric power generation, we have developed and performed field tests on a sophisticated borehole inspection system which allows us to detect cracks that could never be traced before, for lack of suitable instrumentation. In the numerical simulation sector, phase 2 of the MATH project continued with the three-dimensional modeling of turbulent flow in hydraulic turbines and the calculation of stresses and vibrations. The diagnostic module of SUPER, the continuous monitoring system for turbine-generators, underwent various stages of development in 1993 and a new device has been designed, the PD-Scope, which is used to measure and analyze partial discharges in generators. The Scompi robot, for its part, which was designed to carry out welding operations in turbines, found several applications at different turbine manufacturers' plants during the year.



In a study of hydraulic turbine modeling, Anne-Marie Giroux and Yvon Vigneau measure a typical runner of a Francis turbine using an articulated arm.

Work related to the maintenance of hydraulic structures included a field evaluation of concrete surface repair mortars and the selection of six products on the basis of their superior performance. We also pursued the research undertaken jointly with external partners on methods of predicting erosion by cavitation and conducted a study of the metallurgical degradation of the main components of Tracy thermal generating station. As far as new generation technologies are concerned, we have made progress in the development of a wind turbine-diesel generator combination and carried out a technical and economic feasibility study with the federal laboratory CANMET on the potential of a photovoltaic system to produce electricity. Lastly, we completed the development of PERESE, software used for long-term generation planning, and developed a parallel algorithm for hydraulic simulation in environmental management.

MATH PROJECT

Phase 2 of the MATH project (development of models for hydraulic turbine analysis), undertaken in an aim to enhance our expertise in numerical simulation, generated many activities in the past 12 months. Noteworthy examples include three-dimensional modeling of turbulent flow and calculation of stresses and vibration. We also carried out a series of experimental tests to validate the software developed.

The work involved numerical simulations of fluid flow in the scroll cases, runners and draft tubes of hydraulic turbines and computation of the stresses, frequencies and modes of vibration on blades and runners; the results were then compared to experimental results. As we proceed to gradually digitize the geometry of the utility's major turbine-generator units, our attention has centered mainly on the design of software for modeling, mesh generation, computation and analysis.

Fluid flow is such an interesting and complex topic that Hydro-Québec, manufacturers and universities have formed a consortium under the auspices of the research program set up by CERCA (Centre de recherche en calcul appliqué) in Montréal. Our contribution to the experimental work under way on fluid flow has been to participate in the development of a velocity probe that has been calibrated at École polytechnique fédérale in Lausanne. The probe support is now under development, which means that it will soon be possible to take measurements of the flow velocity at the generating station. This project was undertaken for the Generating Station Installations Department.

MÉCANIQUE
(MECHANICAL ENGINEERING)

PD-SCOPE, A NEW MEASURING DEVICE FOR PARTIAL DISCHARGES

To improve preventive-maintenance practices for turbine-generators, we have undertaken a research project for Hydro-Québec's Generation Facilities Department in an aim to develop measurement systems and a technique for interpreting partial-discharge spectra in generators. This project has led to the development of PD-Scope, a measuring device which operates at a rate of 6 billion measurements per second and allows simultaneous monitoring of several partial-discharge sensors as well as recording of the impulse waveform from each sensor.

The latest version of PD-Scope comprises 12 channels connected to as many sensors placed at strategic locations in the three-phase windings on a machine. The smallest discharge triggers the device, which immediately starts to record the signals arriving from each probe at a rate of 500 million measurement points per second, in 12 segmented memories. The measurements are complete when the memories are full, i.e. after 1024 events.

To enable the user to analyze the real shape of the partial discharge, each channel of the PD-Scope is equipped with an integrator for regenerating the original signal. The analysis is performed by considering that the first time the scope is triggered corresponds to the start of a cycle of phase A of the generator; the times of occurrence of the subsequent triggering events are measured with an accuracy to the nearest nanosecond. By studying the signal shape, the polarity reversals, the propagation times and the phase affected, the user is able to locate each discharge site and determine the degree of degradation there.

CÂBLES ET ISOLANTS
(CABLES AND INSULATION)

SUPER: Continuous monitoring of turbine-generators

The SUPER project, initiated several years ago in an aim to develop computer-based continuous monitoring for turbine-generators that would reduce the downtime involved in inspecting these units and carrying out timely repairs. The first version of SUPER comprised 64 sensors, an acquisition module, and a computer for data processing and storage, and generating reports on the measurements performed. Positive results of tests on two turbine-generators led to a decision to install the system on other Hydro-Québec units this year.

Meanwhile, by the end of 1992, we had completed the development of a diagnostic module in answer to a request by the Generation Maintenance Department. Based on expert-systems technology, this module is designed to help station personnel accurately and rapidly interpret data collected by SUPER. Although this first version of the diagnostic covers the most serious problems affecting turbine-generators, it is still a preliminary one. Before installing it definitively in generating stations, we have therefore begun to refine it by enriching its database and validating the diagnostics with the data produced by SUPER. Our focus over the past year was consequently on studying the anomalies that SUPER identified in the behavior of the two units under observation.

MÉCANIQUE
(MECHANICAL ENGINEERING)

Borehole inspection system

At the request of the Manicouagan Region, the robotics team has developed a highly sophisticated borehole inspection system consisting essentially of two color cameras coupled to a gyroscope. The new system was used intensively last fall for a series of inspections at Daniel-Johnson dam. The data collected during these tests bear witness to the many advantages of this instrument: quality color images, accurate probe positioning data, measurement of the crack width, user-friendly interface, automatic data storage, full view of the drilling area by juxtaposing several consecutive images, printouts of profiles, etc. In particular, the new inspection system makes it possible to locate cracks that utilities could never detect before, for lack of suitable instrumentation.

Michel Nadeau (standing) and Jean Lavallée check the borehole inspection system with its gyroscopic camera.

Further work on this project is now under way in an aim to develop computer tools that will allow the display of a fissure plane to be superposed on a 3-D image of the dam. The development will include modeling rules and a database to facilitate interpretation and diagnosis. (See also the section Awards and Distinctions.)

ROBOTIQUE, INFORMATIQUE ET ÉTALONNAGE
(ROBOTICS, DATA PROCESSING AND CALIBRATION)

Magnetic flux measurement in generators

Our research into ways of improving our diagnosis of turbine-generator units has led us to develop a new device for dynamic measurement of the magnetic flux in air gaps. The data collected are then used to assess the magnetic uniformity of the machine in order to better determine the cause of stator or rotor vibrations. Analysis of these magnetic "signatures" also provides a means of monitoring and detecting short circuits that occur between turns on the rotor poles.

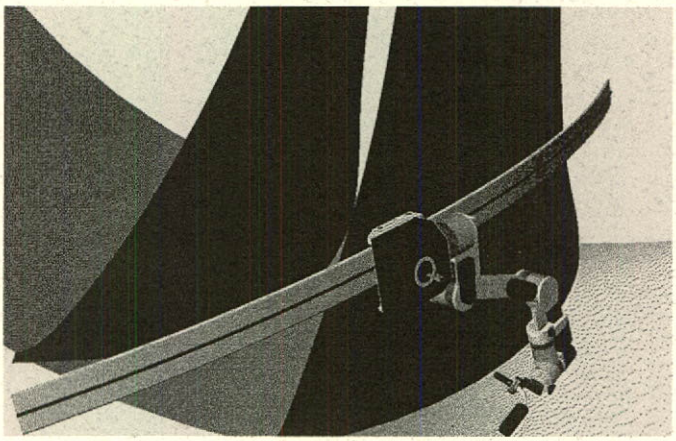
The last 12 months have seen tests on the commercial version of the probe as well as on a pre-prototype of the signal conditioner. The results of these tests were conclusive and the product will soon be marketed under licence by Vibro-Meter, a subsidiary of Nouveler. This project is but one of several similar undertakings involving the development of sensors for the dynamic measurement of various mechanical parameters of generators such as the air gap, stator bar vibration and shaft elongation.

SYSTÈMES DE MESURE
(MEASUREMENT SYSTEMS)

Progress in the Scompi technology

The past year saw several new developments of the Scompi technology in 1993. Designed for in situ repair of the blades of hydraulic turbines damaged by cavitation, at the request of the utility's Generation Maintenance Department, the Scompi technology has been used mainly at La Grande-3 generating station where the operators successfully employed two of these robots to do all the repair work, including the grinding of the deposit. The only exception was the initial gouging, which was done by hand.

The welding team has now produced another sample of this robot and sent it to Ontario Hydro Technologies for use in research and development projects aimed at adding new functions and thus extending Scompi's range of applications. This brings to four the number of Scompi robots made so far.



Robcad software is used to simulate the Scompi robot installed in the runner of a Francis turbine for welding a joint.

GE Canada and GEC Alsthom Électromécanique are now co-funding a feasibility study to assess the possibility of using Scompi to robotize the multipass welding of joints in the martensitic stainless steel blades of Francis turbines. This steel calls for very careful handling when it is welded. In particular, it has to be preheated to over 100°C, which makes for harsh working conditions and the robot could definitely improve productivity in this area.

GEC Alsthom Électromecanique continues to use Scompi at its plant in Tracy, Québec, for robotized weld overlay with Hydroloy HQ913 on the blades of turbine runners for La Grande-1 generating station. So far, 14 of the 20 blades now being manufactured in Tracy have been welded, which represents 2 tonnes of metal applied by the robot. Scompi's reliability needs no further proof.

TECHNOLOGIE DES MATÉRIAUX
(MATERIALS TECHNOLOGY)

Assessment of surface repair mortars for concrete

In the framework of a contract between the Maisonneuve Region and the Canadian Electrical Association (CEA), we have carried out a project involving the field assessment of surface repair mortars for concrete damaged by erosion. Erosion is caused by the abrasive action of particles, sand, silt, gravel and other solids carried by water and is one of the main causes of degradation of hydraulic structures.

Initiated in 1989, this project covers the assessment, selection and testing of different surface repair products and the formulation of recommendations as to the best materials to use at different dams. Forty mortars from 13 manufacturers were studied including cementitious grouts, epoxy-mortars and polymer-modified cement-based mortars containing styrene-butadiene rubber (SBR) and acrylic.

Each product was subjected to physico-mechanical and durability tests in the laboratory, then in the field at two dams. After analyzing the laboratory test data and inspecting the 21 mortars installed in the field, we selected the six best products and applied them on a large scale on the two spillways and adjacent piers of Chaudière-Ring dam in Hull, Québec.

The results obtained after 12 months confirmed the good performance of the six products and, on the basis of this study, Hydro-Québec's specialists can now select the most cost-effective materials not only for the repair of existing concrete structures but also for the design of future generating, transmission and distribution facilities.

Technologie des matériaux
(Materials Technology)

Study of metallurgical degradation at Tracy thermal generating station

One of the aspects of a refurbishing program under way at Tracy thermal generating station was to assess the major components to determine their stage of metallurgical degradation. We therefore studied the characteristics of the steel composing the disks of low-pressure turbines and evaluated the model currently used to determine the useful life of turbines. We also established the causes for the degradation of condenser tubes and checked the inspection method employed. Lastly, we estimated the degree of damage by creep to the interconnection tubing of a medium-pressure turbine.

As far as the disks are concerned, we discovered that the steel from one unit differed slightly from the others. Tests based on the fracture appearance transition temperature (FATT) criterion and tensile strength tests under static and dynamic loading (K_{Ic} and K_{Id}, respectively) were conducted to identify the type of fractures involved. The steel used at Tracy is generally of good quality except for one unit where the risk of fracture is consequently higher, especially with cold start-up. It should be pointed out that the model currently used for assessing the useful life of turbines appears somewhat deficient and is in need of revision.

Many cracks were discovered in the admiralty brass condenser tubes, mainly at the ends and at interfaces with the support structures. These cracks were attributed to a stress corrosion mechanism. The eddy current inspection method used detects only cracks that penetrate the entire thickness of the tube wall, whereas later we found cracks that reached only halfway through the walls, on tubes that had cleared inspection!

Lastly, we assessed the degree of creep damage from observations of replicas of the microstructure of the piping. On the whole, we did not find any significant damage. However, in all the parts exposed to heat, we discovered small cavities indicating that the steel is on the threshold of a creep damage process. We therefore proposed various ways to assess the residual creep life of the steels used to build condenser pipes and to plan inspection schedules accordingly.

This work was carried out jointly with Hydro-Québec engineers involved in the Bécancour and Tracy projects and specialists in generating-station upgrades and refurbishing. The technical personnel of Bechtel, Parsons Turbine and SNC-Lavalin also collaborated in this project.

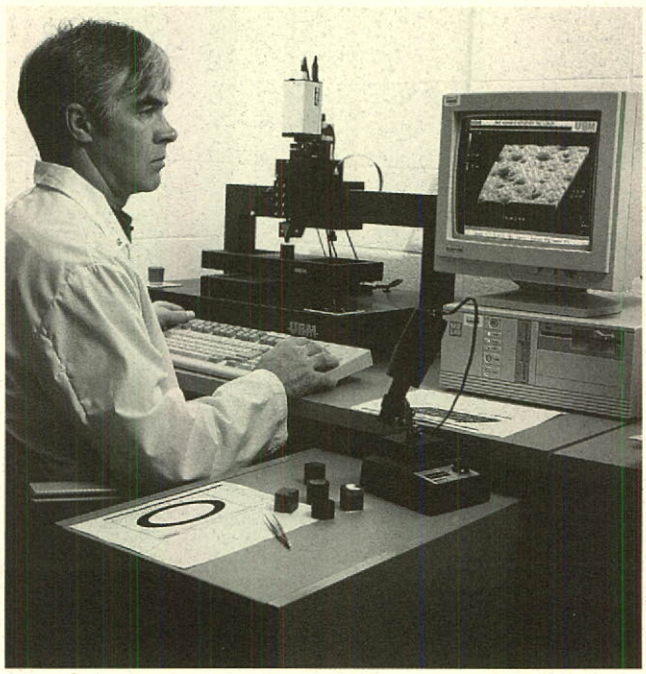
TECHNOLOGIE DES MATÉRIAUX
(MATERIALS TECHNOLOGY)

PREDICTING CAVITATION EROSION

Cavitation erosion in hydraulic turbines represents a crucial problem not only for the dimensioning of these machines but also for their operation. However, current knowledge and techniques do not allow the utility to combat the phenomenon, despite the availability of more resistant materials such as IRECA steel (Hydroloy) and better adapted repair techniques including sophisticated devices such as the Scompi robot. Thus, despite the very stringent guarantee clauses imposed on manufacturers, several of the turbines installed on the Hydro-Québec power system in recent years already show a substantial degree of erosion.

The aim of our research, therefore, is to keep turbines free of cavitation (and the associated noise) in normal operating conditions. This would result in markedly lower maintenance costs for the utility, increased productivity and improved working conditions at the generating station.

Major progress has been made in this area of research over the last few years. For example, Hydro-Québec, École polytechnique fédérale de Lausanne (EPFL) and Électricité de France (EDF) have developed new tools and original methods that should lead to the emergence of a suitable means of forecasting erosion of a prototype, based on the vibratory detection of cavitation during tests on a small-scale model. To that end, the three partners have pooled their resources in a research project aimed at developing the know-how and equipment needed to be able to accurately and reliably assess the erosive potential of cavitation on a model of a Francis turbine.



Jacques Larouche analyzes cavitation pitting on polished samples by means of a 3D laser profile meter.

In 1993, accelerometers were used to take vibratory measurements of acceleration and inferred forces and the measurements were calibrated with three other types of measurement: weight loss, electrochemical activation current on titanium samples based on the DECER technique, and pit counting of the impacts of cavitation on polished samples that varied in hardness. The calibration was done on four different test facilities offering a wide range of the intensity of cavitation impacts to be investigated: IREQ's vibratory cavitation device and high-speed cavitation jet, and EPFL's vortex generator and cavitation tunnel.

The crucial phase of this project comes when the vibratory signatures and cavitation erosion of a prototype and the Francis turbine model are compared. The blade geometry of a Francis turbine belonging to Hydro-Québec was measured by three different techniques based respectively on laser interferometry, templates and an articulated mechanical arm. These measurements will provide the input for building a model of the selected prototype and performing cavitation tests on this model.

In order to determine the influence of the operating parameters on the cavitation erosion of this blade, in June we carried out a series of measurements of the cavitation pits and vibratory detection of cavitation on the selected unit under service conditions. These measurements have already furnished promising results. However, it is the tests on the model that will be determining, since they will allow the research team to confirm whether the method they propose possesses the advantages claimed. This project is being carried out jointly with the client, Hydro-Québec's Generating Station Installations Department.

TECHNOLOGIE DES MATÉRIAUX
(MATERIALS TECHNOLOGY)

WIND TURBINE-DIESEL GENERATOR COMBINATION

This past year saw the demonstration of a wind turbine-diesel generator combination at the Atlantic Wind Test Site in Prince Edward Island. The purpose of the project is to demonstrate the effectiveness and reliability of a wind turbine-diesel generator combination with a high penetration level and no storage to be used for supplying electricity to an isolated load. The work was undertaken for Hydro-Québec's Power System and Equipment Planning Department.

The installation is designed to meet the energy requirements of a typical village. It comprises four wind turbines with a total capacity of 220 kW, two diesel generating units (50 kW each) and two synchronous compensators of a total capacity of 130 kVA, which provide the required reactive power. The system also includes a smoothing load of 190 kW and a 120-kW load simulating a village power demand.

The focus of the last 12 months' activities was on developing the various components of a system simulating the case of a village supplied only by wind power, with all the diesel generators shut down. The installation is now operational in manual mode and the next stage is to make it automatic.

MÉCANIQUE
(MECHANICAL ENGINEERING)

ANALYSIS OF A PHOTOVOLTAIC SYSTEM

An analysis of the technical and economic feasibility of a photovoltaic system as an alternative means of generating electricity was initiated in 1993. Undertaken jointly with CANMET's Energy Diversification Research Laboratory (EDRL) and the Boucherville firm TN-Conseil, this analysis concerns two generating systems, one of 100 kW, the other 200 kW.

The goal of this project, which is co-sponsored by the EDRL, Hydro-Québec and Québec's Ministry of Natural Resources, is to assess the generating capacity of each system in terms of its installation (panels, auxiliaries and infrastructure) and operating costs. The first is intended to serve remote regions not connected to Hydro-Québec's power system, as may be found mainly in Northern Québec and the Lower North Shore of the St. Lawrence. The analysis will focus particularly on a northern site exposed to a harsh climate. Also to be assessed, as a second scenario, is a more accessible location where the electricity generated could be injected directly into the Hydro-Québec system. Once the analysis is complete by the end of June, the partners will decide whether to proceed with a detailed engineering study for a selected location.

CHIMIE DES MATÉRIAUX
(MATERIALS CHEMISTRY)

Parallel algorithm for environmental applications at Hydro-Québec

In view of the excessively long resolution time of hydraulic simulation software used for environmental management, we have developed a parallel computation method based on the use of transputers with distributed memory. Developed by the utility's environmental health group, this software is designed to run on a microcomputer or a workstation and uses the finite-element method to perform the simulation. The advantage of this method is that it is very accurate but unfortunately this is offset by the long CPU time. For example, the study of some large rivers can take anywhere from 12 to 24 hours.

To overcome this problem, two stages of the finite-element method have parallel implementation, assembly and resolution of the system of linear equations. The parallel algorithm we have developed has proven particularly effective in the case of long, narrow rivers, when speed-up (acceleration over number of processors) is almost linear.

We decided to use the OCCAM 2 language to implement our algorithm, which allows us to make parallel applications by sending and receiving messages between concurrent processes; furthermore, it is well adapted to the transputer technology. The CPU times obtained for a machine with ten T805 processors were four times shorter than those obtained on a microcomputer equipped with an i486 processor, even though the T805 is less powerful than an i486.

LOGICIELS ET ALGORITHMES DE RÉSEAUX
(POWER SYSTEM SOFTWARE AND ALGORITHMS)

Long-term generation planning

Work on the development of PERESE, software designed for long-term generation planning, has now been completed and the package implemented at Hydro-Québec's Generation and Energy Exchanges Department. Software applications include validation of the commissioning dates of new facilities; estimation of excess-energy sales to neighboring provinces or states without jeopardizing system reliability; determination of the marginal value of the energy produced and of the water stored in large reservoirs; support for yearly generation planning, etc.

PERESE is a four-level hierarchy model. At the first level, it performs the aggregation of all the utility's hydroelectric plants, then determines the management policy for the resulting installation on a half-yearly basis, taking account of the random nature of water flow. This yields the hydroelectric production for each half-year in terms of the volume of energy stored in the reservoirs at the beginning of the half-year and the inflow expected during that period.

At the second level, the software performs a monthly distribution of the hydroelectric production determined in the previous level. Then, at level 3, this monthly production is distributed among the existing river basins. Lastly, at level 4, the production assigned to a given river is distributed among the various plants built along it.

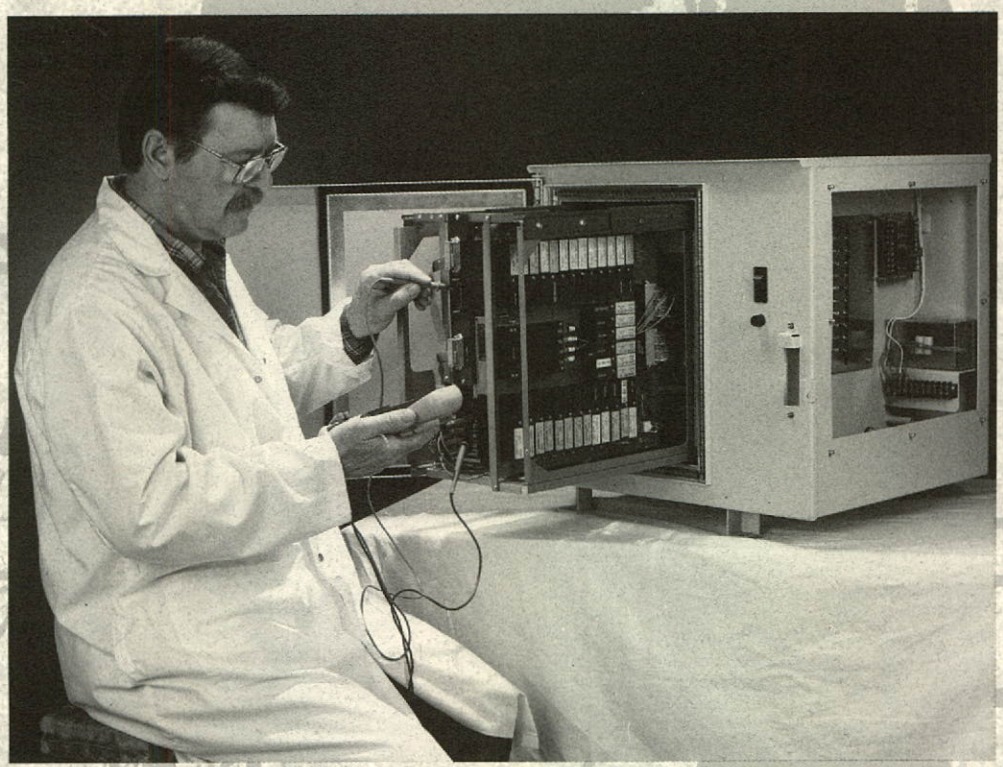
Depending on the requirements of the study concerned, the user may choose to stop at any level. It is also possible to distribute the half-yearly hydroelectric production by month, by valley or by generating station for any six-month period.

The software was originally programmed in FORTRAN for implementation on the computers at the processing centre of the utility's Finance and Administration group but a new version in C language has now been developed for workstation applications.

LOGICIELS ET ALGORITHMES DE RÉSEAUX
(POWER SYSTEM SOFTWARE AND ALGORITHMS)

Once again this year, many major research and development projects were carried out in the area of power transmission. A new monitoring system for HV circuit breakers was developed, for example, as well as a system for testing protection relays, and data acquisition units were installed in Hydro-Québec substations for the purpose of analyzing load behavior. In addition, field tests were conducted on a control device used by HV circuit breakers to switch shunt reactors. We also evaluated a number of new technologies such as fibre-optic current transformers and researched the discharge propagation mechanism in transformer oil.

During the course of the year, we investigated the phenomenon of geomagnetic storms and designed systems to measure their effects on transformers and static compensators in northern regions. We continued to take part in studies on the effects of electric and magnetic fields, completed demonstration tests on a 800-kV AC cable for under-river crossings, and developed an instrument to measure guy wire tension. In addition, we conducted a prospecting study on SF_6 technologies, while work on the effects of connections on substation equipment under earthquake conditions entered its second phase.



Robert Giraldeau verifies the local controller of the HV circuit breaker monitoring system.

An ambitious series of tests was carried out on portable temporary grounding sets, hot sticks, and series compensation equipment at IREQ's high-power and high-voltage laboratories. Several simulation studies were carried out at the request of external clients. We also developed or upgraded our power system software related to harmonic analysis, short-circuit-current calculations, power system restoration and alarm analysis in regional operating centres. Lastly, we developed various types of punctured-insulator detectors as well as a snow-removal system for photovoltaic panels used for powering local telecommunications stations.

HV CIRCUIT BREAKER MONITORING SYSTEM

A new monitoring system for HV circuit breakers has been developed. Its function is to detect warning signs that circuit breaker failure is imminent. In this way, routine maintenance can be eliminated and replaced by spot checks, depending on the actual condition of the equipment. The monitoring system is designed in such a way that its presence in no way affects the physical integrity of the switching device.

Three monitoring systems were installed in 1993 in cooperation with New York Power Authority, Consolidated Edison Company of New York, Empire State Electric Energy Research Corporation and Hydro-Québec's Operations and Maintenance Department. Two were installed on double-pressure SF_6 circuit breakers in the United States, at New York and Massena substations respectively, and the third in Québec, on an air-blast circuit breaker in the 400-kV busbar at IREQ's high-power laboratory.

The monitoring system consists of sensors, a local controller and a central controller. The local controller is a shielded enclosure placed at the base of the circuit breaker which contains a microprocessor and electronic cards for data acquisition. Forty sensors are used to measure the travel of the operating rods, the temperature in the cabinets, the gas moisture level and pressure, and, lastly, the load and short-circuit currents. All this data is transmitted by optical fibre to the central controller – a PC type computer – where it is stored.

A modem provides access to this database, allowing the user to obtain a wide variety of written or graphic information on the condition of the circuit breakers, past events, and trends in measured and calculated values.

The monitoring system has been adapted to PK and PKV type air-blast HV circuit breakers, which are both commonly used on Hydro-Québec's transmission network. It is also planned to install one unit of the system for field testing at Hydro-Québec's Chénier substation as part of a pilot project.

This type of installation offers yet another attractive feature in that it allows the utility to better plan its maintenance practices not only for circuit breakers but also for other strategic components such as power and instrument transformers, disconnecting switches and surge arresters.

APPAREILLAGE ÉLECTRIQUE
(ELECTRICAL APPARATUS)

Roger Jutras tests the operating characteristics of one of the load behavior measurement systems installed in Hydro-Québec substations.

MEASUREMENT OF SYSTEM LOAD BEHAVIOR

Despite its strong influence on the power system, the behavior of the electrical load, a complex combination of randomly varying phenomena, remains one of its least known elements. Yet adequate modeling of the load is crucial both for system planning, because of its direct bearing on the required equipment, and for operation, because it also has an effect on the maximum permissible loading. Load behavior during voltage and frequency changes therefore have a profound effect on the system's capacity to withstand and recover from large disturbances.

At the present time, simulation software involves static models for loads, which do not take account of this phenomenon appropriately and this led Hydro-Québec to launch a major project several years ago to measure the effects of voltage variations on loads. Rather than resorting to the costly manual test disturbances and measuring equipment as it had previously done to gather similar data, the utility installed a prototype measuring system, TECC-I, at Boucherville, Bécancour and Québec-2 substations in May 1989. The measured values yielded by TECC-I allow a much better load representation in system design studies, especially in the simulation of major disturbances (of 10% or over), which are difficult to stage manually but which occur fairly often in the field.

The project under way focuses on load behavior during voltage and frequency variations. The relevant data are collected by intelligent acquisition units installed at critical substations which can also capture and store disturbances in electrical variables. All the criteria are set from a remote location. The central computer, also at a remote location, retrieves the data via nondedicated telephone lines and estimates load behavior model parameters.

This work was conducted for Hydro-Québec's task force on load modeling at the request of the Main Power System and Power System Expertise departments.

SYSTÈMES DE MESURE
(MEASUREMENT SYSTEMS)

AUTOMATIC TEST EQUIPMENT FOR PROTECTION AND CONTROL DEVICES (SERA)

SERA is a microcomputer-based system used for testing protection relays, regulation systems and sequential automatic-control devices. Designed for use both in the laboratory and in the field, SERA has three major components: a 386 or 486 PC, an acquisition/generation interface, and one or more three-phase amplification modules. The programs, all compatible with MS Windows, are adapted to the SERA test bench as well as the Doble F2000 and MultiAmp Epoch test benches currently in use at Hydro-Québec.

Significant progress was made in 1993 in both the hardware and the software aspects. For example, six pre-prototype units of the acquisition/generation interface are under construction and are scheduled for delivery in the latter part of 1994. It will then be possible to install the last programs of the system so that they can be handed over to our clients at Hydro-Québec.

SERA will allow acceptance, commissioning, maintenance and troubleshooting tests to be performed in addition to many others. These tests are conceived in "creator" mode and performed in "user" mode in a multi-task, multi-window type of user-friendly environment. Among the many attractive features of this system, mention should be made of the fact that it is easy to use, flexible and adaptable to changing requirements.

SYSTÈMES DE MESURE
(MEASUREMENT SYSTEMS)

FIELD TESTS ON A CONTROL DEVICE FOR 735-kV CIRCUIT BREAKERS USED TO SWITCH SHUNT REACTORS

The 735-kV air-blast circuit breakers used to switch shunt reactors are often equipped with auxiliary opening chambers with insertion resistors intended to limit switching surges. However, these auxiliary chambers require extensive maintenance and are frequently the cause of failure and synchronization problems. If these components could be eliminated, maintenance costs would be lower, while the reliability and availability of the equipment would be greatly enhanced.

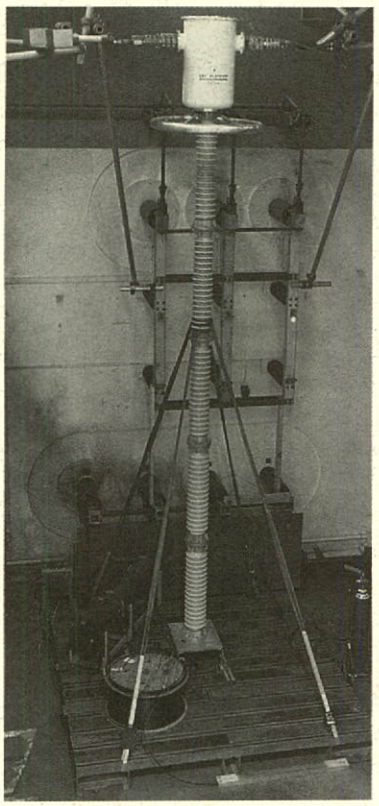
It appeared that this would be possible if the opening of each pole of the breaker could be controlled in order to avoid very short arcing times, which could cause reignition. The latter can result in large voltage variations of such rapidity that the insulation of the shunt reactor is severely stressed.

At the request of Hydro-Québec's power system planners, we worked jointly with the Studies and Standardization Department and the manufacturer, Snemo, on the development of a prototype known as ICOS for controlling the opening and closing points of circuit breakers used to switch shunt reactors. This prototype is equipped with a reignition detection system on all three phases of the circuit breaker which serves to record and store the day and time of the last 30 operations together with the possible alarms they may have triggered. IBM PCs equipped with a modem can access this data remotely.

In September 1993, ICOS was subjected to field tests at Duvernay substation where it successfully detected every reignition that occurred. It has been in service ever since and has functioned to the utility's entire satisfaction. (See section on Technology Promotion.)

ICOS is destined to play just as important a role for SF_6 as for air-blast HV circuit breakers. Since SF_6 breakers are not equipped with opening resistors, it is essential in their case also to control contact opening in order to avoid reignition.

APPAREILLAGE ÉLECTRIQUE
(ELECTRICAL APPARATUS)



Tests on an optical current transformer.

Optical current transformers

A series of full-scale tests has been performed in our laboratories as part of a project aimed at exploring the technological potential of unconventional current and voltage transformers. These tests have allowed us to assess two prototype current transformers built respectively by GEC Alsthom (Balteau) in France and Square D in the U.S.

Undertaken for the Substation Equipment Department, the project consists mainly in familiarizing ourselves with the technology of fibre optic instrument transformers. Members of several Hydro-Québec departments have met to discuss the criteria for assessing the performance of this new, very promising, technology. The assessment focuses on such aspects as protection, operation and maintenance of the transformers as well as the reliability, accuracy and stability criteria.

As with all emerging technologies, it is important to master the new sensing techniques put forward by equipment manufacturers before they reach full maturity so that the new test, commissioning and operating criteria are specified in full knowledge of the facts.

The tests performed so far have allowed us to establish the present performance level of fibre optic current transformers and to pinpoint areas that call for improvement. Among these were a number of full-scale tests never performed before which consisted in subjecting the units to high short-circuit currents while maintaining the temperature at -50°C. Also, a test technique using mixed currents representative of reclosing faults allowed us to simulate real system constraints.

The new technology can be applied at transmission system voltages of up to 735 kV and offers a number of outstanding advantages over conventional approaches. For example, because of the compact, lightweight sensors used, fibre optic current transformers do not need oil-filled insulating supports and are therefore safer to use. Our studies have shown that it is quite plausible that in the years to come fibre optic current and voltage transformers will be incorporated directly into the line hardware, supported only by suspension insulators containing fibre optic channels.

LIGNES AÉRIENNES
(OVERHEAD LINES)

Technological assessment of HV dead-tank switching devices

Apart from its metalclad substations, Hydro-Québec does not have any high-voltage SF_6 circuit breakers using the so-called dead-tank technology installed on its transmission system. The term "dead tank" is used to denote switching devices in which a vessel at ground potential contains the interrupters and the insulating medium.

The aim of the project undertaken in 1993 for the Studies and Standardization Department consisted in studying the possibility of applying the technology to the utility's high-voltage SF_6 circuit breakers. Dead tanks are already in widespread use in the United States where 60% of circuit breakers sold are of this type. Several electrical utilities in Canada also make use of the technology.

We therefore made visits to different manufacturers around the world – mainly in Japan, the United States and Switzerland – to learn more about the characteristics of this technology and its availability. These visits gave us an opportunity to examine different aspects, in particular costs, maintenance requirements, mechanical and electrical characteristics and problems that could occur at low temperature. We then visited utilities already using dead-tank switching devices to learn more about their advantages and drawbacks.

Hydro-Québec's needs for this technology will be assessed by its standardization specialists, to whom we have submitted a comprehensive report on our findings.

APPAREILLAGE ÉLECTRIQUE
(ELECTRICAL APPARATUS)

Failure of Auxiliary Chambers of 735-kV Circuit Breakers

The failure of auxiliary chambers of high-voltage circuit breakers poses a complex problem for utilities because of the many parameters involved. One of the first difficulties stems from the combined use of very different materials. Auxiliary chambers consist of a hollow porcelain body fitted with an aluminum collar at each end which is held in place by a Portland-cement-based mortar joint. Failures systematically occur a few millimetres below this collar. Another difficulty is the small number of such failures compared to the number of chambers installed. From the beginning of the 1970s to 1992, only 42 failures had been reported at Hydro-Québec substations for a total of 12,400 chambers. In an attempt to understand the phenomena involved in these failures, a research program was set up which included an experimental part as well as numerical modeling. The work was requested by the Equipment Maintenance and Dam Safety Department.

A study of all the failures was first undertaken in order to determine the particular circumstances surrounding each incident. The findings revealed that the failures were largely due to the intense cold and, also, that the average age of the failed chambers dropped at higher latitudes. Finite-element analysis on a three-dimensional model showed that under normal operating conditions thermal contractions of the entire unit at temperatures down to -50°C did not produce sufficient stress to cause cracking at the point where the failures were observed, even at the lowest level of mechanical resistance of porcelain as established in the laboratory. From these results, it was clear that another source of stress must exist. The fact that a certain link exists between the breakage damage observed and the aging of the apparatus suggests that a degradation phenomenon must also be at work.

The only material in the assembly that is likely to suffer degradation is the mortar, which can expand under the effect of freeze-thaw cycles and as a result of chemical reactions with the environment. Numerical analysis showed that the expansion was enough to crack the porcelain and, by varying the expansion profile, it was possible to recreate a high stress zone at the section where the failures occur. The existence of this expansion was revealed by measuring the residual stresses released when cutting new and old collars in half and by measuring the stresses using strain gauges during freeze-thaw cycling tests in IREQ's environmentally controlled chamber.

The failures that occurred in February 1993 provided further input for our database. Cracks had appeared during one of the coldest periods of the year but after a rainy month of January. Cooling tests showed that the stresses produced when the temperature drops to -50°C on a collar where the mortar was saturated with water prior to testing are much higher than when the mortar is dry. Below -30°C, stresses increase more rapidly because of the solidification of water absorbed by the mortar, in full agreement with the failure statistics.

Technologie des matériaux
(Materials Technology)

Research into Discharges in HV Transformer Oil

An agreement has been signed with the French company Jeumont-Schneider Transformateurs and the Laboratoire d'électrostatique et des matériaux diélectriques (LEMD) of the Centre national de la recherche scientifique (CNRS) in Grenoble to conduct research on the discharge propagation mechanism in transformer oil. This work was requested by Hydro-Québec's power system planning specialists.

Normal operation of HV transformers results in the formation of particles of cellulose, paint and metal whose effect on the insulating properties of oil are still poorly known. However, they are suspected to cause a number of faults that occur during operation with the inherent risk of fire or tank explosion.

Although the discharge propagation mechanism in air is well understood for different atmospheric conditions, the same cannot be said about large oil volumes. The phenomenon needs to be studied in relation to the applied voltage, the electrode configuration, the impedance in series with the streamers, and the quality of the insulating material.

The aim of the first stage of this project, which is now under way at the LEMD laboratory in Grenoble, is to develop a test method and an optical diagnostic. A test setup will shortly be installed at IREQ's high-voltage laboratory for accurate simulation of the high-stress conditions existing in 735-kV transformers.

APPAREILLAGE ÉLECTRIQUE
(ELECTRICAL APPARATUS)
CÂBLES ET ISOLANTS
(CABLES AND INSULATION)
LIGNES AÉRIENNES
(OVERHEAD LINES)

PARTICIPATION IN RESEARCH INTO MERLIN-GÉRIN CIRCUIT BREAKERS

An eight-member team representing different sectors of Hydro-Québec, including one researcher from IREQ, has been formed to study and resolve various problems related to 215-kV and 315-kV air-blast circuit breakers built by Merlin-Gérin. Some 80 such units are installed in Hydro-Québec substations and have been registering faults at a frequency up to three times higher than the average for other circuit breakers with the same rating.

The team set to work by first establishing itself an objective: to reduce the number of faults to the average for this type of equipment and to prolong the useful life of the circuit breakers concerned by 20 years. Naturally, the solutions they proposed had to cost less than the unit replacement cost. The next step was to analyze the fault reports and interview circuit breaker operators on a utility-wide basis. This inquiry allowed them to classify the problems according to three main sources of trouble: mechanical, the materials used, and circuit-breaker design.

Created in the context of Hydro-Québec's Performance Challenge Program, the team adopted a recommended systematic approach along with the appropriate tools and techniques to define the causes, determine the corrective measures, then assess and test the proposed solutions. They estimate that about 80% of the difficulties the utility has been having with its Merlin-Gérin circuit breakers will be overcome in the very near future.

APPAREILLAGE ÉLECTRIQUE
(ELECTRICAL APPARATUS)

ANALYSIS OF GROUND POTENTIAL AND EARTH CURRENTS DURING GEOMAGNETIC STORMS

The province-wide power failure on March 13, 1989 revealed the need to determine the maximum ground voltages to which the power system is exposed during geomagnetic storms. It appears, in fact, that disturbances induce not only ground voltages but also direct currents which may affect the operation of electrical equipment. This increased the urgency to find out more about this phenomenon.

André Lapointe (foreground) and Clément Vaillancourt examine one of the earth current measurement systems installed at Hydro-Québec substations in northern regions.

Two studies of geomagnetic storms are under way at the present time. In Abitibi, in northwestern Québec, a first set of five systems designed and built at IREQ have been in place since June 1992 measuring the magnetic fields and ground voltages over a 300-km distance. An analysis based on data collected during some 20 major magnetic storms that occurred between mid-July 1992 and mid-July 1993 showed that DC voltages can reach 1.7 V/km and that the mean voltage oscillates around 1 V/km. It was also observed that the magnetic activity reaches a peak at equinox

and that the duration of the storms varies between 1 and 3 h, although a storm period may comprise several individual storms. The measuring instruments will remain in place until the end of 1994.

The second project involves an evaluation of the impact of magnetic storms on power system operation, in particular the behavior of 735-kV transformers and static compensators. DC current is known to generate harmonics via transformers and thereby disturb the operation of the entire system to the point of total failure. We have therefore designed and built DC current measurement systems which will be installed at Chibougamau, Chamouchouane and Albanel in the northern part of the province, in spring 1994.

These digital processor-based systems will simultaneously collect 2000 items of data every 5 s at each of the 36 measurement points on the transformers and then calculate the harmonic content up to the tenth harmonic and transfer the results automatically to a master station in Montréal. The collection of data during magnetic storms over a period of ten years, the planned duration of the project, will contribute valuable information to Hydro-Québec and a dozen transmission specialists will be analyzing this data in the coming months.

These projects are being conducted jointly with power system planners at Hydro-Québec and a number of outside partners.

ROBOTIQUE, INFORMATIQUE ET ÉTALONNAGE
(ROBOTICS, DATA PROCESSING AND CALIBRATION)
APPAREILLAGE ÉLECTRIQUE
(ELECTRICAL APPARATUS)

EFFECTS OF CONNECTIONS ON SUBSTATION EQUIPMENT UNDER EARTHQUAKE CONDITIONS

Earthquakes are much less common on the eastern side of North America than in the west, especially California, but they can be quite strong and wreak considerable damage. The last major earthquakes to hit the province of Québec occurred in 1925 and 1988. The former, which reached a level of 7 on the Richter scale, was located in the Charlevoix region of the province, north of Québec City. The second, with a magnitude of 6.2, in the Saguenay area, provided a rare opportunity to study the effects of intraplate earthquakes on modern constructions and a power system such as Hydro-Québec's. By contrast with quakes in the west, which occur near plate boundaries, the earthquakes in Eastern Canada are felt over a much wider area; the Saguenay earthquake, for example, was felt as far away as Washington, 500 km to the south.

The 1988 quake cost Hydro-Québec an estimated $7 million in damages, which affected three substations in particular. The units of equipment that proved most susceptible were those comprising porcelain components and connected by electrical conductors. It was suspected at the time that the presence of these conductors had a determining influence on the transmission of seismic forces to the hardware.

The first phase of a research project initiated in an attempt to verify this hypothesis was completed in 1993. The findings have allowed us to identify the various mechanisms by which significant tensile forces can be developed by the conductors at the equipment terminals. The dynamic behavior of the conductor seems to be determining in this regard: under resonance conditions, in particular, far greater stresses may be generated than those considered at the design stage. Our preliminary findings have also allowed us to determine that an increase in sag in any one span will modify the conductor's dynamic behavior and may reduce its dynamic effects on the equipment.

Work has already begun on the next phase of the project in an aim to test new connection configurations or devices that would reduce the forces transmitted to the vulnerable units. The project was requested by the utility's studies and standardization specialists.

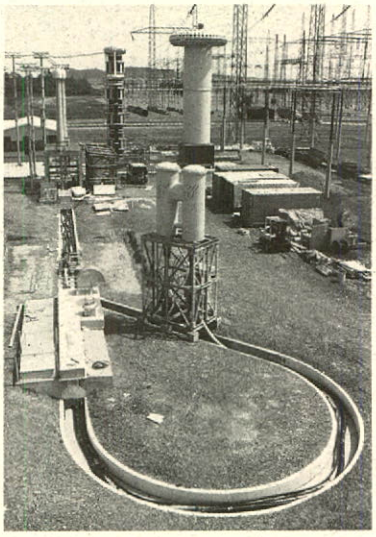
MÉCANIQUE
(MECHANICAL ENGINEERING)

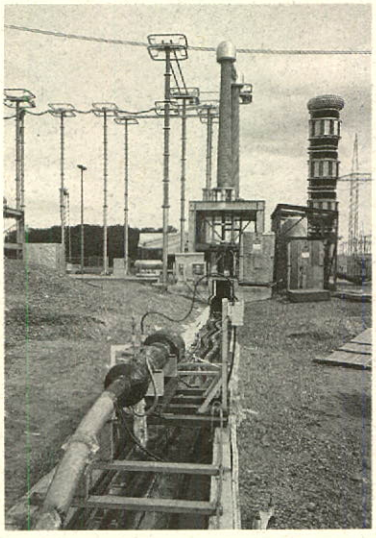
Demonstration of an 800-kV PPLP-insulated AC cable

A few years ago, at the request of the Transmission Facilities Department, we initiated a qualification program for oil-filled cable intended for under-river crossings. For the Radisson-Nicolet-Des-Cantons line, Hydro-Québec selected a Hitachi 500-kV DC cable, but for future river crossings at voltage levels as high as 735 kV it decided to test a PPLP-insulated 800-kV AC cable made by the Japanese company Sumitomo Electric. This choice was preceded by a thorough study of the responses received to an international call for tenders. The tests involved the construction of a cable prototype about 200 m long and five accessories: two outdoor sealing ends, two oil/SF_6 switchgear sealing ends, and one insulated straight joint. This cable, complete with its insulation of PPLP, a paper-polypropylene laminated material, underwent a series of preliminary tests at the plant before it left Japan.

The cable went on to pass all the type tests performed at IREQ's high-voltage laboratory and was then installed at the outdoor cable testing facility for a long-term test of 10 months under conditions simulating a normal aging process of 30 years. These tests were completed in fall 1993 and the results were most conclusive: the cable not only withstood all the tests without a fault but resisted all attempts to induce breakdown. Dissecting the cable after the tests, we had further proof that no major degradation had occurred during the entire test period. It is worth pointing out that this demonstration of cable reliability at such a high voltage level was a world first. However, the technology could also be used at other voltage levels. (See also the section Awards and Distinctions.)

Câbles et Isolants
(Cables and Insulation)
Laboratoire Haute tension
(High-Voltage Laboratory)





General view of 800-kV AC cable loop from Sumitomo Electric (top), the straight cable joint and the duct installation (right) at our cable testing facility.

Biological effects of electric and magnetic fields

Among the various projects involved in Hydro-Québec's plan of action on the biological effects of electric and magnetic fields, we contributed to several that aim specifically at assessing the environmental impact of electrical installations. This work was performed for the Environment Department.

Two studies were conducted, for example, to determine the salient characteristics of the environment. The first consisted in evaluating the magnetic-field exposure of people living near or frequenting rights-of-way used for many other purposes than providing a corridor for power lines. The second was related to sites where Hydro-Québec workers risk being exposed to high electric and magnetic fields. These studies were initiated at the recommendation of the utility's Expert Committee on Environmental Safety. Work began also on a study of the characterization of magnetic fields in homes located in the proximity of transmission lines.

The study of the effect of electric and magnetic fields on the milk production of dairy cattle in conjunction with McGill University's Macdonald College has been completed and a final report presented. Another study under way on human perception of electric fields and ion currents by DC lines also drew to a close during the year and the results have already been presented at various international conferences.

A new research project was launched on the measurement of in vitro and in vivo induced currents. Sponsored by the Canadian Electrical Association, this study has as its objective to assess the intensity and orientation of currents induced by electric and magnetic fields in various organs of the human body.

Lignes aériennes (Overhead Lines)

SF_6 equipment in transmission substations

In response to a mandate from Hydro-Québec's studies and standardization specialists, we have spent the last two years prospecting for technologies related to certain types of apparatus used at substations with sulphur-hexafluoride (SF_6) insulation.

Hydro-Québec uses SF_6 technology in its gas-insulated substations (GIS), circuit breakers and some current transformers. The question now envisaged is whether to extend this technology to other substation equipment, in particular transformers and power capacitors.

A multidisciplinary team of researchers from three departments at IREQ tabled the results of an exhaustive bibliographic study of these different technologies at the beginning of 1993. On the basis of this study, Hydro-Québec has decided that, in view of its future needs, it must put the SF_6 capacitor option aside for the present in order to concentrate on SF_6 transformers (120/25 kV, 47 MVA). A series of technical discussions will be held next year with manufacturers and Asian electrical utilities currently using this technology.

Câbles et Isolants (Cables and Insulation)
Appareillage électrique (Electrical Apparatus)
Chimie des matériaux (Materials Chemistry)

Measuring guy wire tension

The tension of guy wires used to support telecommunications and transmission line towers has to be checked periodically to ensure they still meet the design criteria. To facilitate this task, we have developed a specific measuring instrument for the Equipment Maintenance and Dam Safety Department.

The measuring instruments in current use impose a lateral pressure on the guy wire which is supposed to result in a predetermined deformation of a few millimetres and the tension is calculated from the amount of force required to produce the deformation. In other cases, a manual method is adopted to determine the tension: a mechanical impulse is applied manually to the cable and the tension is deduced from the impulse propagation time.

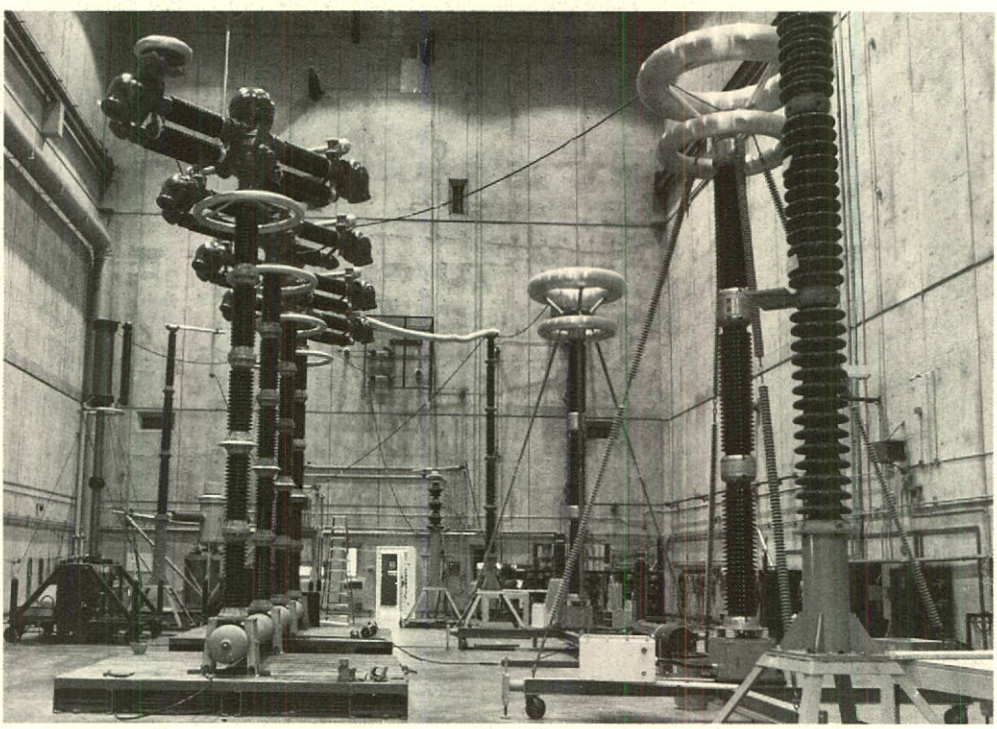
The new device is based on this same principle of the more or less rapid propagation of the impulse wave according to the cable tension but the measuring method has been honed. The impulse is no longer applied by hand but electrically by means of a solenoid so that the impulse is calibrated. The instrument then measures the wave propagation time between two points one metre apart, not along the entire length of the wire as before. It is therefore unnecessary to know the total length of the guy wire in order to determine its tension. The device is precalibrated for the type of wire to be tested and will deduce the tension from the measured propagation time. The components include an impact generator and two detectors; the impact generator and the first detector are placed near the ground, the second detector is located one metre higher.

The outstanding advantages of the new measuring device are its light weight, its measuring rapidity and the fact that is easily adapted to all guy wire diameters. The development work was completed in December 1993 and will be followed by the production of a number of industrial prototypes for testing by the departments interested in adopting this device for their activities.

LIGNES AÉRIENNES (OVERHEAD LINES)

MAIN HIGH-POWER LABORATORY TESTS

- Tests to compare the dielectric characteristics of a new 3.5-mH saturable reactor and three reactors damaged by overheating from Châteauguay converter station. Carried out at the request of Hydro-Québec's Equipment Maintenance and Dam Safety Department, the tests consisted in measuring the partial discharges present before and after discharge tests of capacitors precharged at 30 kV.
- 2.5-kA line charging interruption test and out-of-phase breaking currents (5 kA with a recovery voltage of 3.33 p.u.) on one quarter and on one half of a pole of a 735-kV air-blast circuit breaker to be used on Hydro-Québec's 12th line (at the request of Hydro-Québec's Installations Department).
- Short-line fault-current breaking tests on the chambers of GFX and HGF circuit breakers rated 31.5 to 50 kA and 145 to 330 kV), with or without subtransmission phase-to-ground capacitors and with or without capacitors between breaker terminals (at the request of Hydro-Québec's Studies and Standardization Department).



Line charging interruption test on one quarter or one half of a pole of an 735-kV air-blast circuit breaker to be used for Hydro-Québec's 12th line.

- Tests to verify the operation of a capacitive substation of 161 kV/$\sqrt{3}$ 25 kV/$\sqrt{3}$ using a capacitive voltage divider equipped with a transient damping circuit, which also prevents ferroresonance. This SDC-3 system was developed for the 600-kVA Mont Ste-Anne substation (Matapedia Region). At the request of the firm B.G. Checo, we conducted tests to verify the protection system as well as no-load tests,steady-state and transient load tests, and short-circuit tests.
- Accelerated-aging tests on 2-V, 625-Ah valve-regulated lead-acid batteries at 25, 40, 50, 60 and 70°C. Constant current discharge cycles and constant voltage charging cycles were periodically carried out in order to obtain data on battery aging. We also conducted high-current discharge cycles and overcharge tests at a higher constant voltage after the batteries were exposed to various temperatures. These tests were performed at the request of Hydro-Québec's Studies and Standardization Department.

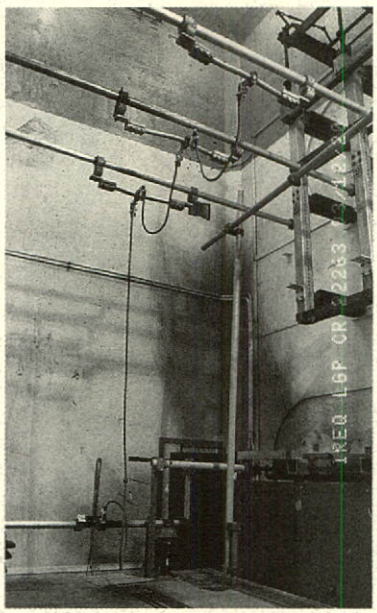
LABORATOIRE GRANDE PUISSANCE
(HIGH-POWER LABORATORY)

CERTIFICATION OF TEMPORARY GROUNDING SETS

An ambitious series of tests on portable temporary grounding sets was successfully carried out in 1993. This unprecedented program at IREQ's high-power laboratory, which involved some 650 tests, came about as a result of a decision by the Québec health and safety board (CSST). The Board had held an inquiry and found that temporary grounding devices did not offer adequate guarantees that they would withstand the currents generated by accidental restoration of the power system. As a result, it issued a decree calling a halt to all work that entailed installation of this type of equipment.

The first series of tests, in 1992, was conducted in an aim to identify requirements in an area where standards had never existed. Representatives of Hydro-Québec, the Canadian Union of Public Employees and the CSST eventually came to an agreement that paved the way for a test and certification protocol to be developed for temporary grounding sets and subsequent adoption of this protocol resulted in the drafting of a certification program.

As for the testing itself, which drew to a close in December, various technical difficulties had to be overcome. Not the least of these was that no practice had ever been established for qualifying grounding sets in terms of the currents that can be generated by accidental circuit restoration, i.e. currents of between 10 and 35 kA. Although the use of two disconnecting switches in series had allowed work to be performed wherever the grounding sets were unsuitable, the successful results of the tests convinced the authorities to remove most of the constraints and prohibitions, with the result that maintenance workers on the utility's generation, transmission and distribution systems have now been able to resume their normal activities.



Certification tests on temporary grounding sets.

LABORATOIRE GRANDE PUISSANCE
(HIGH-POWER LABORATORY)

TESTS ON 735-KV TRANSMISSION LINE SERIES COMPENSATION

- Fault-current breaking tests on a 1000-A compensated line with delayed zero crossing. These tests, requested by 735-kV circuit breaker manufacturers, were carried out on 1/4, 1/5 and 1/6 of the poles of SF_6, SF_6/N_2 and SF_6/CF_4 insulated circuit breakers.
- Pressure relief tests on varistors used to protect the capacitor banks on Hydro-Québec's series-compensated 735-kV transmission lines. The tests were carried out for General Electric and consisted of a capacitor current discharge at 340 kA peak at 2500 Hz, superimposed on a 31.5-kA_{rms}, 60-Hz symmetrical short-circuit current, for a duration of 12 cycles.
- Arcing tests on an electronically triggered air gap used for the protection of series-compensated capacitor banks (commissioned by General Electric).

- Tests to verify the 4.5-kA rated capacitive breaking current and performance tests on 18-kV_{rms}, 60-Hz high-voltage fuses used for the external protection of capacitors, at a capacitive current causing pre-arcing for 5 to 7 min, at 110 A, in accordance with IEC Publication 549, (at the request of General Electric).
- Tests to verify capacitor unit internal fuse operation at a lower voltage limit of 0.9 U_n (60 Hz) and at a higher voltage limit of of 2.2 $\sqrt{2}$ U_n (DC) with perforation of the capacitor through injection of a nail, followed by a voltage withstand test of 3.5 U_n (DC) during 10 s on 500-kvar, 8-kV capacitors (at the request of ABB).

LABORATOIRE GRANDE PUISSANCE
(HIGH-POWER LABORATORY)

MAJOR TESTS AT THE HIGH-VOLTAGE LABORATORY

Over 200 tests were performed in 1993 at IREQ's high-voltage laboratory either for Hydro-Québec or for external clients such as ABB, GEC Alsthom Énergie, Jeumont-Schneider, Northern Telecom, Sumitomo Electric, Trench Electric, Hitachi, GE Canada, Electrical Equipment, Ohio Brass, ALESA Alusuisse, Canadian Electrical Association and CITEQ (Centre d'innovation en transport d'électricité du Québec, a joint venture of ABB and Hydro-Québec).

- Tests on 95 current transformers
- Tests on 37 power transformers
- Tests on 35 shunt reactors
- Tests on 25-kV composite insulators
- Tests on SF6-insulated circuit breakers rated 300 kV AC
- Tests on porcelain insulators rated 120 kV, 230 kV, 330 kV and 765 kV
- Tests on 25-kV reclosers
- Tests on distribution surge arresters
- Tests on series compensation platforms
- Tests on air-core reactors
- Tests on 765-kV disconnecting switches
- Pollution tests on cable terminations
- Rain and fog tests on grounding equipment (straps, belts, hot sticks, ropes) and simulation with a dummy lineman
- Tests on new and used safety boots
- Tests on a 600-kW motor
- Pollution tests on the behavior of HVDC wall bushings under nonuniform rain
- Pollution tests on cutouts
- Pollution tests on epoxy bushings
- Pollution tests on smoke-polluted insulators
- Pollution tests on distribution surge arresters
- Leakage-current measurements on insulating mats and ropes
- Partial-discharge measurements on 735-kV bushings
- Measurements of 735-kV capacitive voltage transformer characteristics
- Temperature-rise and dielectric tests on distribution cables
- Temperature-rise tests on air-core reactors rated 600 A and 1200 A

LABORATOIRE HAUTE TENSION
(HIGH-VOLTAGE LABORATORY)

Effects of pollution on hot sticks

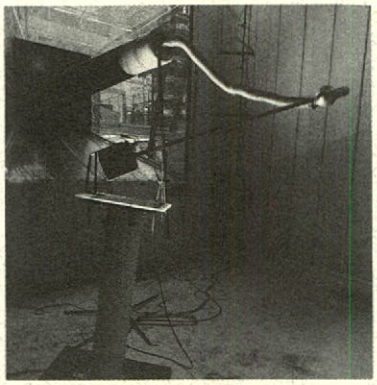
A series of tests have been performed on hot sticks to assess the effect of pollution when they are exposed to the atmosphere for long periods of time. The use of these tools under different climatic conditions raises questions about their performance, especially with regard to the leakage current.

After exposing the sticks to the environment prevalent at typical Hydro-Québec substations, we tested them in the laboratory under various atmospheric conditions, namely dry weather, rain and fog. The test results were compared to those obtained on new sticks and sticks whose surface had been treated with solvents or silicone applied with a wiping cloth. From our analysis of the findings of this comparison, we were able to draw the following conclusions about the long-term exposure of hot sticks to pollution:

- In dry conditions, the leakage current is hardly affected by the amount of pollution buildup on the surface.
- The leakage current is very high on polluted untreated sticks in the presence of rain or salt fog.
- The leakage current is quite low in salt fog in the case of hot sticks cleaned with a solvent and treated with silicone or wax.
- Under heavy rain, the leakage current is very high, even for hot sticks treated with silicone.

The test program revealed the importance of treating hot sticks with silicone before use. In moderately polluted environments and in fog, the presence of silicone substantially reduces the leakage current. In fact, cleaning with a silicone-treated wiping cloth is already a recommended maintenance practice for hot sticks used at Hydro-Québec.

The test program was conducted in cooperation with representatives of the Equipment Maintenance and Dam Safety Department.



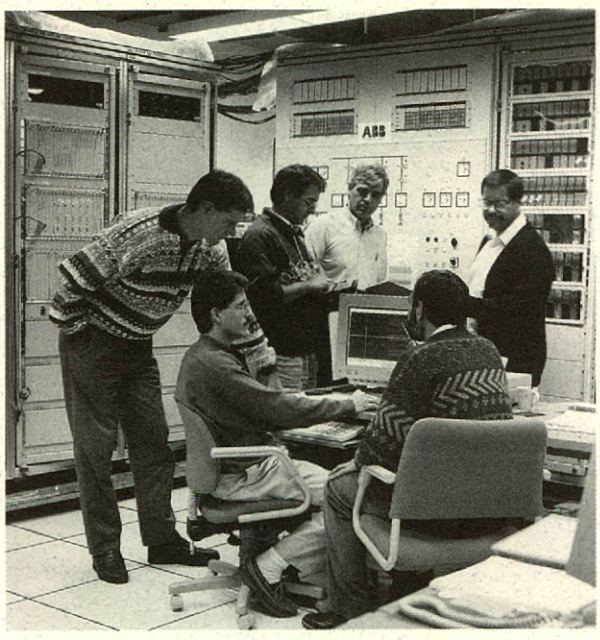
Pollution tests on hot sticks.

Laboratoire Haute tension
(High-Voltage Laboratory)

Simulator tests on static compensators at Dunsmuir and Forbes substations

Two studies each of four months were performed over the past year on static compensators, one for BC Hydro in British Columbia at its 132-kV Dunsmuir substation on Vancouver Island, the second for Minnesota's Northern States Power (NSP) in on its static compensator at the 500-kV Forbes substation.

ABB, the manufacturers of these two static compensators, shipped us the control cabinets to be installed at the two substations and our laboratory engineers immediately set to work to design and install the power system equipment and necessary interfaces between the ABB system and the IREQ simulator (valve models, sensors, etc.). They also modeled part of BC Hydro's 132-kV system to which the Dunsmuir compensator is connected, as well as the 500-kV system of Manitoba Hydro, NSP and Minnesota Power which feeds the Forbes static compensator.



Simulator study of the static-compensator controls for Northern States Power in the United States.

The Dunsmuir static compensator, which went into service in October 1993, consists of one branch of thyristor-switched capacitors (TSC) and three branches of TSC reactors, also switched by thyristors (TSR). Its dynamic range runs from -135 Mvar inductive to 165 Mvar capacitive, in steps of about 20 Mvar. The short-circuit level at Dunsmuir varies from 1300 to 4200 MVA at the 132-kV bus. Among other features characterizing

this substation, mention might be made of the presence of a large number of transformers and a system resonance at 76 Hz capable of producing harmful interactions with the control system.

The Forbes static compensator, for its part, will go into service in May 1994 on a 760-km stretch of 500-kV line series-compensated line linking Manitoba to Minnesota. This line will be used to increase energy exports from Dorsey substation near Winnipeg. The compensator comprises not only three branches of TSCs and two branches of TSRs but also two mechanically switched capacitors (MSC) of 300 Mvar each. With the TSC and TSR branches, the dynamic range of the compensator in steady state is -149 Mvar (reactive) to +110 Mvar in steps of approximately 55 Mvar; its overload capacity for a period of 10 s is -450 to +400 Mvar at 500 kV.

In both cases, the aim of the simulation tests was to verify and optimize the control system parameters, assess its performance as well as conformity with the technical specifications, and check the interactions between the power system and the controls.

Several thousand switching operations were performed on the simulator to test the behavior of the control systems in steady and non-steady state. During the course of the testing, we suggested a number of improvements to the controls. An ABB engineer was present throughout the test period and carried out the necessary modifications. Both studies were conducted in close cooperation with the engineers of the companies concerned, i.e. BC Hydro for the Dunsmuir static compensator, and Manitoba Hydro, NSP and Minnesota Power for the Forbes unit.

SIMULATION DE RÉSEAUX
(POWER SYSTEM SIMULATION)

STUDY OF THE BEHAVIOR OF SPARK GAPS PROTECTING SERIES COMPENSATION CAPACITORS

A revision of its transmission system design criteria in 1989 led Hydro-Québec to introduce the principle of series compensation on 37 of its 735-kV transmission lines to increase their capacity and efficiency. This principle consists in incorporating series capacitors protected by a spark gap and a bypass circuit breaker.

After the first capacitor banks had been installed by ABB, unexpected firing of the spark gaps occurred at Bergeronnes and Kamouraska substations during power system switching operations or disturbances. Inadequate immunization of the firing modules against ambient electromagnetic noise seemed the most likely cause and two modules were accordingly removed for assessment and modification by ABB.

This study performed on the IREQ simulator for the Power System and Equipment Planning Department consisted in comparing the operation of the two modified electronic modules with the two originals. All four modules were therefore connected to a model of the series capacitor of the MAN7-LEV7 line of Hydro-Québec's northeast network and then exposed to various types of disturbances.

Analysis of the results of this study showed that, depending on the type and origin of the disturbance, the original modules do indeed generate undesirable spark gap firing orders, unlike the modified units, which remained insensitive to the same disturbances. Thus the findings confirmed that ABB's modifications meet Hydro-Québec's quality criteria in every respect.

SIMULATION DE RÉSEAUX
(POWER SYSTEM SIMULATION)

Study of series capacitor protection at Chibougamau substation

The series capacitors used on Hydro-Québec's transmission system are protected against current surges by means of metal oxide arresters, designed to absorb excess energy, and spark gaps, which take the capacitors and arresters out of service in the event of extra-high surges.

The purpose of the study was to test the GE capacitor bank protection at Chibougamau 735-kV transmission substation. The parameters of interest were essentially the response time and accuracy of the energy monitor, the spark gap firing time, the reading and transmission of signals, and reproduction of the signals at ground level.

The control cabinets used to protect the series capacitor banks at Chibougamau were investigated on the IREQ power system simulator in a study that involved the simulation of the utility's entire series-compensated power system. With the help of current and voltage amplifiers, signals representative of real conditions were fed to the protection system and its operation was then verified for different internal and external faults on the compensated line.

The tests allowed us to detect a few minor problems with the programming logic. In addition, we found that the energy monitor was not set properly, preventing the spark gap from firing when major external faults occurred. The setting was consequently corrected.

With equipment design testing being done by simulation, the need for modifications in the field was reduced to a bare minimum if not totally eliminated. The tests provided an opportunity to ensure the equipment will in fact operate correctly in the field and thus avoid commissioning delays.

Simulation de réseaux
(Power System Simulation)

Harmonic analysis software

The development work on the harmonic analysis software initiated at the request of the utility's power system planning specialists some years ago drew to a close in 1993.

Harmonics represent one of the most serious threats to the proper operation of electric power systems and furthermore can lead to degradation of telephone communications, failures in control and protection devices as well as equipment overloading. It is therefore of the utmost importance to achieve high-precision models of the transmission system in order to be able to predict the propagation of these harmonics correctly.

The new software offers a set of features tailored to meet the specific needs of Hydro-Québec. It is designed to calculate the harmonic impedances of a multiphase transmission system of arbitrary configuration from a frequency scan of the mathematical representation of the power system in the steady state. In addition to the various impedance calculation options, the software can perform power flow analysis and supply a voltage sensitivity analysis at the harmonic source injection frequency. It will also compute telephone interference and distortion factors.

One of the striking features of this software is its ability to represent nonlinear elements in the calculation of a harmonic steady state. It is therefore a highly efficient tool for the study of low-damping phenomena. Modeling the nonlinear magnetization branch of a transformer allows us to analyze the effects on the AC system due to DC currents of geomagnetic origin or to a potential rise caused by ground electrodes in HVDC substations.

Currently available on SUN workstations, the harmonic analysis software has an integrated graphics processing feature and high-level syntax for input files and steady-state models. It is also compatible with the ElectroMagnetic Transients Program (EMTP) and can be used to initialize transient studies with EMTP.

Logiciels et Algorithmes de réseaux
(Power System Software and Algorithms)

SHORT-CIRCUIT SOFTWARE ADAPTED TO SERIES COMPENSATION

One of the activities planned in Hydro-Québec's transmission system reliability enhancement program launched in 1989 was to implement series compensation on its 735-kV transmission system to improve service quality and reliability.

This technology consists in installing series capacitors on the transmission lines in order, first, to reduce the problems inherent in carrying electric power over long distances and, second, to make the system more robust and increase its capacity. Lines equipped with series capacitors behave as if they were much shorter, which means that they can carry far greater amounts of energy and offer better withstand to incidents, so that they are less susceptible to major failure.

Series compensation equipment comprises banks of capacitors connected in series. Varistors are provided at the capacitor terminals to protect the compensators against ground potential rises and curtail the amplitude of short-circuit currents occurring on the 735-kV lines.

In view of the influence of varistors on the performance of the entire system, it is important to be able to represent these devices in short-circuit-current calculations in order to assess the protections correctly. By relating each impedance value to the short-circuit current, the model developed in this project allows the dynamic behavior of the current-voltage characteristic of the capacitor-varistor equipment to be converted into a static relation.

An iterative process is used to adjust the short-circuit currents taking into account the nonlinear characteristic of the series compensators until a point of convergence is reached which corresponds physically to the point of equilibrium of the system under symmetrical three-phase or unbalanced (single-phase, two-phase or two-phase-to-ground) fault conditions.

LOGICIELS ET ALGORITHMES DE RÉSEAUX
(POWER SYSTEM SOFTWARE AND ALGORITHMS)

POWER SYSTEM RESTORATION SOFTWARE

Considering all the social and economic issues at stake, power system restoration after a shutdown is one of the most crucial operations that a utility has to perform. However, it is also a complex and very delicate operation, which calls for scrupulous planning if losses attributable to delays are to be minimized and the risks of equipment failure reduced.

At Hydro-Québec, power system restoration follows detailed emergency instructions drawn up for each generating station and substation affected. These instructions are prepared after studying the restoration plans, each plan comprising an equipment connection scenario for a given subnetwork and a set of control variables (generator voltage levels, shunt reactor values and connected loads) subjected to the operating constraints (voltage profile and reactive output from generators). The study focuses on the steady state and takes account of harmonic analyses and simulations of transient phenomena.

The new system restoration software was developed as a tool for steady-state studies. Based on the connection scenario entered by the user, the control variable limits and the operating constraints, the software formulates the restoration process as a nonlinear program which takes account of an additional constraint related to the number of readjustments to the control variables. Thus, in a single execution of its optimization module, the software generates a solution which fulfills all the constraints while minimizing the readjustments, thereby simultaneously reducing the number of operator interventions.

Created for the Power System Expertise Department, the new software with its man-machine interface is easy to use and is compatible with Hydro-Québec's power flow program RP600, which means that validated data files can be used and results verified instantly.

LOGICIELS ET ALGORITHMES DE RÉSEAUX
(POWER SYSTEM SOFTWARE AND ALGORITHMS)

EXPERT SYSTEM FOR ALARMS ANALYSIS AT REGIONAL CONTROL CENTRES

The operators at Hydro-Québec's nine regional control centres share the responsibility for over 400 facilities. When a failure occurs at any one of these facilities, the operators have to promptly analyze the alarm messages they receive from the centre's real-time data acquisition system in order to determine the origin of the failure and its possible consequences. With a diagnostic in hand, they can alter the system configuration to mitigate the effects of the failure. However, interpretation of alarm messages is not always straightforward because of the increasing complexity of the power system and the huge volume of data to be processed.

To assist the regional control centre operators in their task of analyzing alarm messages, we have been working with specialists in control centre automation and operating personnel from the Maisonneuve and Manicouagan regions to develop a new expert system. LANGAGE, as it is known, is one of the few expert systems to function in real time. Its function is to monitor alarm messages continuously to determine whether the protections and automatic load pick-up control devices have operated. It then issues concise diagnostics giving the origin of the disturbance and its consequences. These diagnostics are of great help to operators and dispatchers at the control centres, allowing swift analysis of disturbances.

The pilot system was successfully validated by technicians at the Laurentides and Manicouagan regional control centres and is now undergoing the same process at Maisonneuve. Improvements and new functions will be added to the software in 1994 to meet the real-time needs of the Maisonneuve operators. LANGAGE will subsequently be implemented at other regional control centres forming part of the Hydro-Québec power system.

LOGICIELS ET ALGORITHMES DE RÉSEAUX
(POWER SYSTEM SOFTWARE AND ALGORITHMS)

SOFTWARE FOR CALCULATING CURRENT IN SUBSTATION GROUNDING SYSTEMS

In order to guarantee worker safety and ensure the integrity of communication circuits in substations, grounding systems must be designed to take into account the current injected into the grounding system of a substation under fault conditions as well as the impedance of the lines entering and leaving the station. A new version of EPMALTEL, the program developed to meet these requirements, came out this year, at the request of the Power System Studies Department.

The computation module uses new algorithms which improve the accuracy and provide new options to users. The new version of EPMALTEL is available on personal computers and SUN workstations. On a PC, the input/output module uses the Premier Pas software created by IREQ's mechanical engineering experts; a database created by the Power System Studies group is used for archiving the studies. On the SUN workstations, the input/output module is designed to run with the Open Windows windowing system and was created by the IREQ's Robotics, Data Processing and Calibration group.

Initiated in 1990, the project came to a close in December 1993 with the publication of a guide describing the I/O module and explaining the new algorithms.

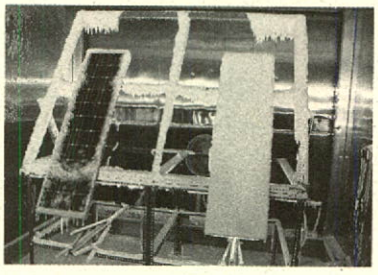
APPAREILLAGE ÉLECTRIQUE
(ELECTRICAL APPARATUS)

Development of a snow-removal system for photovoltaic panels

In many remote areas of the province of Québec, a combination of solar panels and a diesel generating unit are used to power local telecommunications stations. In winter, of course, the accumulation of snow and ice makes the panels impossible to use and we have therefore developed a fast snow removal system for this equipment.

The research conducted at the request of Hydro-Québec's Telecommunications Department has produced a technology that will keep the surface of the photovoltaic panel free of snow. Developed by a Boucherville (Québec) company, TN Conseil, this is a passive process that uses the reflection of the sun's rays to heat the back of the panels. Tests were performed at IREQ's high-power laboratory where we had reproduced wintry conditions to prove the effectiveness of this process. By simulating the sun, we were able to see how quickly the action of the solar rays melted the snow on the modified panel compared to the conventional panel placed in the same conditions.

Testing in a remote region is now planned in an aim to assess the effectiveness of the process in real conditions. The photovoltaic panels will be monitored by a data acquisition system for a complete winter season in 1994-95.



Tests on a snow removal system for photovoltaic panels.

Chimie des matériaux
(Materials Chemistry)

Punctured-insulator detectors

Installation of the punctured-insulator detector developed at IREQ on Hydro-Québec transmission lines continued over the year. Tests have been conducted at several points on the system and the utility's Equipment Maintenance and Dam Safety Department has begun to draft a standard on how to use the new device. The next stage in this project will be to create a database for gathering statistics on the reliability of the different types of porcelain insulator used on transmission and subtransmission lines.

A second device, operating on the same principle as the first, has been developed this year following a feasibility study at the end of 1992. This is a tester for composite insulators known by its French acronym, VIC. Construction of the prototype, by the Montréal firm Positron, was completed in June. After successfully passing all the tests performed in the high-voltage laboratory, the device was subjected to field tests in September on line 7010, which is equipped with several hundred composite insulators. Here again, the results have been most conclusive.

As work proceeded on the development of the VIC, an application for a patent was filed in the United States and negotiations began with a view to marketing this equipment. There could be a strong demand for it, in fact, because at the present time this test represents the simplest way to check composite insulators and could therefore be of interest to many utilities faced with reliability problems attributable to the first generation of composite insulators.

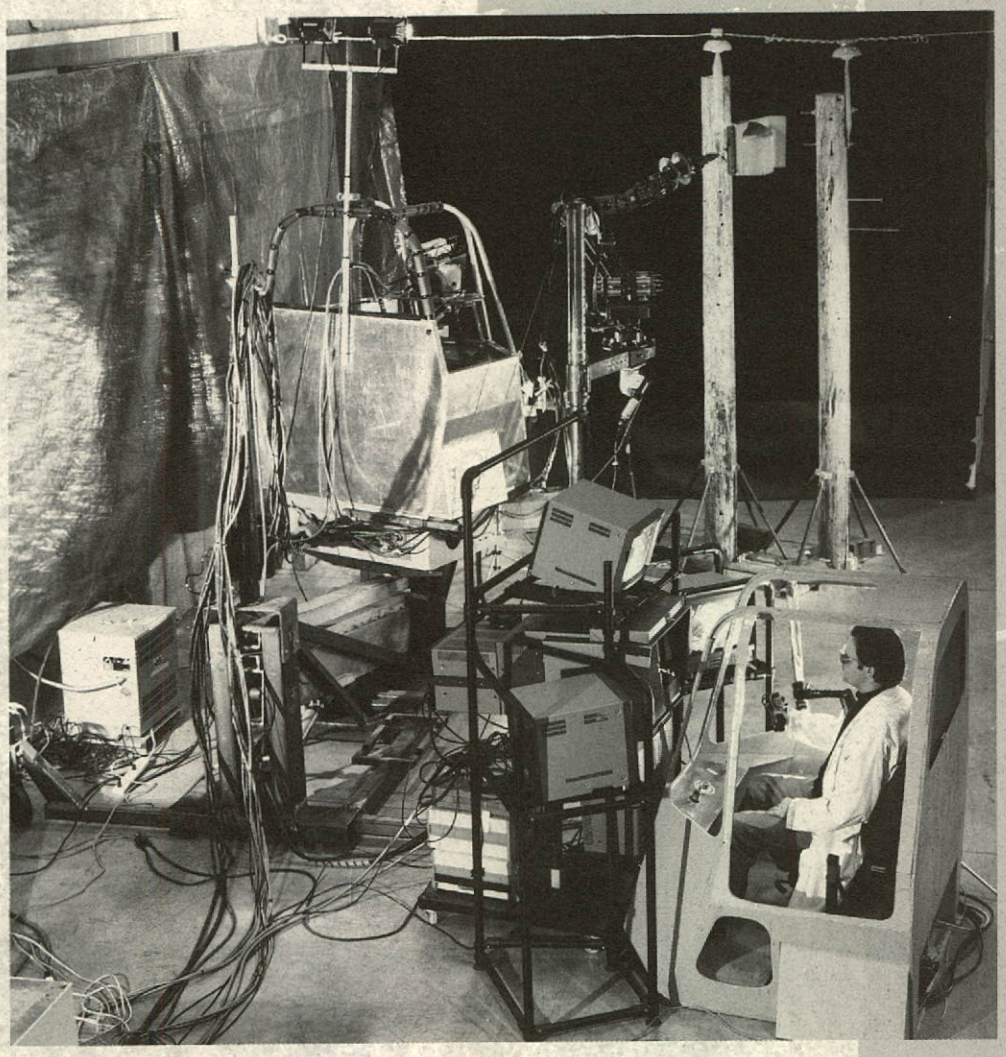
This year has also seen the development of two devices designed to meet a specific need that had arisen at Hydro-Québec. The problem was to find a means of swiftly identifying an insulator string that has flashed over. In two specific cases, a fault does not lead to destruction of the insulator, which makes it difficult to see the exact location of the fault. The insulators in question are porcelain units on the overhead ground wires feeding repeater stations on Hydro-Québec's telecommunications system and composite units on high-voltage transmission lines.

We have produced some original and inexpensive solutions which will help maintenance workers to spot the faulted insulator strings. Prototypes are now being tested and mass production should start as soon as the tests prove conclusive. These devices will be most useful to Hydro-Québec, since they promise to reduce transmission line downtime and speed up restoration of supply to microwave repeater sites.

Systèmes de mesure
(Measurement Systems)

Numerous projects were carried out this past year in robotics and telerobotic systems. We were asked to set up a test facility to study the possibility of operating a remote unit for live-line maintenance tasks from a control cab on the ground. We also continued to develop and test related technologies in conjunction with numerous outside firms. A new version of the MASSIF computer program, used to calculated the permissible temperature rise carried by the underground distribution cables, was developed, and our LORD software for distribution system planning was implemented throughout the province.

The new capacitive divider system for feeding small isolated loads successfully completed laboratory tests and a first prototype was installed in Québec's Gaspé region. We continued to study wood pole preservatives and developed a chemical process for removing the residual PCP-oil mixture from poles. As part of our project on the measurement of lightning current on the distribution system, we installed 20 data and measurement acquisition systems at the most critical locations. We also studied various new technologies for oil-free distribution transformers. Lastly, we conducted an assessment of pipe-cable pulling forces and developed a new computer program for calculating these forces and comparing them with the permissible values.



Work is under way on a remote operating unit with a ground-level operator for distribution system maintenance.

Remote operation with ground-level operator

Hydro-Québec is working jointly with a number of industrial partners on the development of a remote operating unit to be used for live-line maintenance tasks on overhead 25-kV distribution lines. A prototype was completed in 1992 but, in an aim to broaden the field of application for this type of work and maximize efficiency, the Distribution Department asked us to set up a testing facility to study the possibility of operating the unit from a control cab on the ground.

We began by creating a first prototype of a remote display interface which was then incorporated into a preliminary version of the test bench. The latter was set up in a large enough test chamber to accommodate a conventional bucket truck.

The findings of our first study provided an opportunity to compare the way common distribution system tasks are done using three different techniques: with a hot stick, remote operation from an elevated position with or without force feedback, and remote operation from the ground. Three linemen took part in the study, the aim of which was to analyze the different operating modes, assess their respective complexity, and compare both the performance of each method and the linemen's satisfaction with it. The results confirmed the potential of the new system.

ROBOTIQUE, INFORMATIQUE ET ÉTALONNAGE
(ROBOTICS, DATA PROCESSING AND CALIBRATION)

Telerobotics

Telerobotics-related activities at IREQ are focused on the development and experimentation of control algorithms and applications for robots and telemanipulators. The overall aim of the research team is to produce hybrid systems for equipment maintenance.

The TDS project, for example, which was initiated in 1992, involves a consortium comprising MPB Technologies (leading contractor), Hydro-Québec, McGill University and CAE Electronics. The primary objective of the project is to develop and operate a telerobotics test bench. The past 12 months have been dedicated largely to strengthening the links between the partners and, in November, a technical workshop was organized which brought together some 60 researchers and managers from across Canada. We took advantage of this event to present our results on the application of a Puma robot equipped with a laser-based range sensor and a force transducer and controlled by two joysticks and an automatic trajectory controller. This system, in laboratory, can perform several manipulations on a distribution structure.

We also proceeded to install and calibrate the Beaupré robot, a high-performance master-slave manipulator to be used to assess the importance of various criteria related to the performance of teleoperation systems. We renewed our commitment to support technology transfer from the academic community by funding the NSERC Industrial Research Chair in Telerobotics at McGill University. We also awarded a number of research contracts and collaborated in two IRIS2 project proposals.

In addition to orienting some technological choices for short-term projects, some of the expertise we have developed in longer-term avenues of research found applications in work performed in 1993: cartesian control of an auxiliary hydraulic arm for Hydro-Québec's teleoperation system, and the analysis and use of cylindrical images for borehole inspections.

ROBOTIQUE, INFORMATIQUE ET ÉTALONNAGE
(ROBOTICS, DATA PROCESSING AND CALIBRATION)

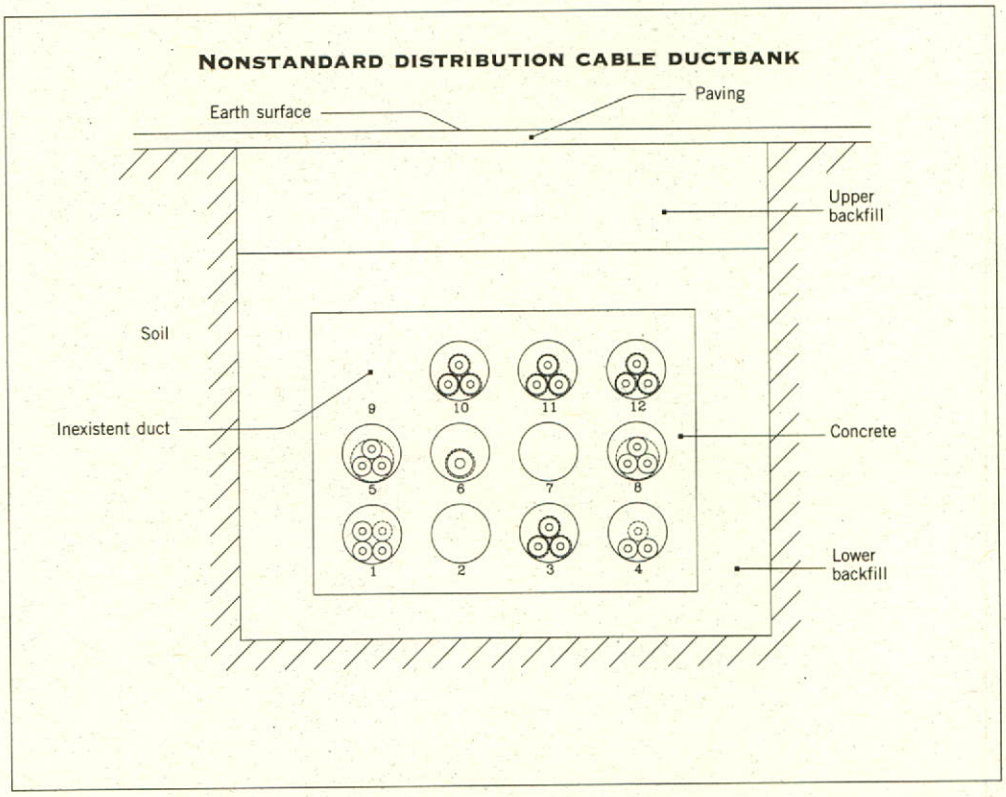
CALCULATION OF TEMPERATURE RISE IN UNDERGROUND DUCTS

Hydro-Québec has been using the MASSIF computer program to calculate the permissible load carried by its underground distribution cables for about ten years now. This software is designed to calculate the cable temperature in the steady state as well as under quasi steady-state conditions (cyclical). Recently, however, we were asked by the Distribution Department to develop a transient version of MASSIF for analyzing specialized and integrated spare cables. Circuits of low-voltage cables have also been incorporated. This new version has made it possible to analyze the thermal behavior of duct banks containing medium-voltage (three-phase and single-phase) and low-voltage (120/124 V and 347/600 V) cables. The main differences between the two versions can be summarized as follows:

- account taken for low-voltage 120/124-V and 347/600-V cables
- transient calculation of specialized and integrated spares
- new libraries of cables and daily load cycles
- option of no-load ducts
- extension of the finite-element mesh up to the cable conductors
- vector calculation of neutral current.

These recent modifications have resulted in an increased flexibility and wider application of the software. They have also enhanced the computation accuracy by extending the finite-element mesh up to the cable conductors. However, the improved version requires more memory space and a longer CPU time than the original, but these minor drawbacks should be resolved in the near future.

CÂBLES ET ISOLANTS
(CABLES AND INSULATION)



Distribution system planning with the LORD software

Optimal use of the distribution system is of capital importance to Hydro-Québec, which every year is required to spend several hundred millions of dollars on commissioning and operating new equipment. Efficient planning of this activity involves complex problems for the forty or more planners assigned to it.

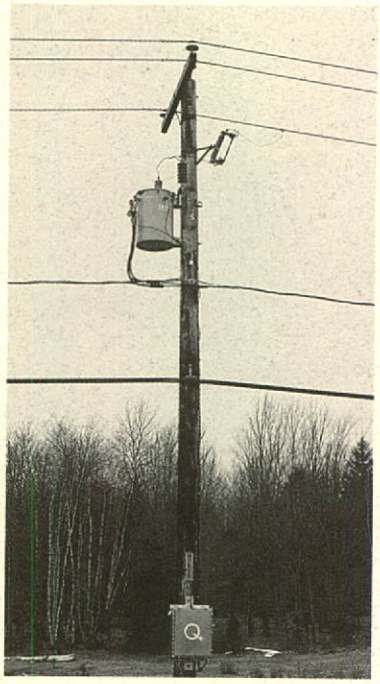
The LORD (French acronym for the distribution system optimization software developed at IREQ) computer program represents a useful tool for long-term planning which allows a utility to better plan its major investments in the distribution system. It determines the modifications that the utility will have to make to its system over the next 15 to 20 years in order to meet future demand. For example, it might propose the construction of new substations or the installation of underground cables rather than overhead lines. The solutions it presents to the planner not only minimize investments and losses (power and energy) but also take account of technical constraints inherent in system operation and service reliability. It should also be mentioned that sophisticated scientific-display techniques and man-machine interfaces have been incorporated into the software for easy implementation throughout the utility.

The LORD software was developed by IREQ's operations research group in cooperation with an experienced planner at Hydro-Québec. Work originally began in 1989 following a request from the Distribution Department and has now reached a crucial stage: implementation on a province-wide scale. Some fifteen planners who were given a training course in 1993 are now using the computer program to maximum capacity. The variety of studies that can be performed with this tool – minimization of losses in rural areas, simulation of the loss of a transmission substation, evaluation of costs ensuing from modifications to design criteria, and planning or postponing the construction of new distribution substations – are an eloquent illustration of its enormous potential.

All studies performed so far confirm LORD's ability to help the utility realize substantial savings both at the investment level and with respect to power and energy losses. Considering the entire distribution system, yearly savings are estimated to be of the order of $60 million.

One highlight this year: the team responsible for this project won first prize in the annual competition organized by the Canadian Operational Research Society (CORS) which has chosen this way to acknowledge the best OR applications in Canada. This is the first time Hydro-Québec has won this prize.

A marketing study carried out in the U.S. has revealed that LORD could meet the needs of many utilities specialized in electrical distribution and steps have accordingly been taken to commercialize the software.



One of the lightning-current measurement systems installed on the Hydro-Québec power system.

Logiciels et Algorithmes de réseaux
(Power System Software and Algorithms)

Lightning current measurement

The project involving the measurement of lightning current on the distribution system gathered momentum in 1993 when 20 data and measurement acquisition systems were installed at as many electrical installations on Hydro-Québec's 25-kV system. Each of these systems comprises an acquisition unit and current sensors and is scheduled to remain in place for three years. The Richelieu and Laurentides regions, which are particularly affected by lightning storms, were our primary target and were carefully examined to identify the meteorological "hot spots."

It turned out that 1993 was one of the worst years for the utility in terms of lightning damage to transformers. Our recording systems correctly detected and stored almost 90 lightning-related events, i.e. four or five per system. A cellular telephone built into the acquisition unit transmits the recorded signals to our laboratories for analysis.

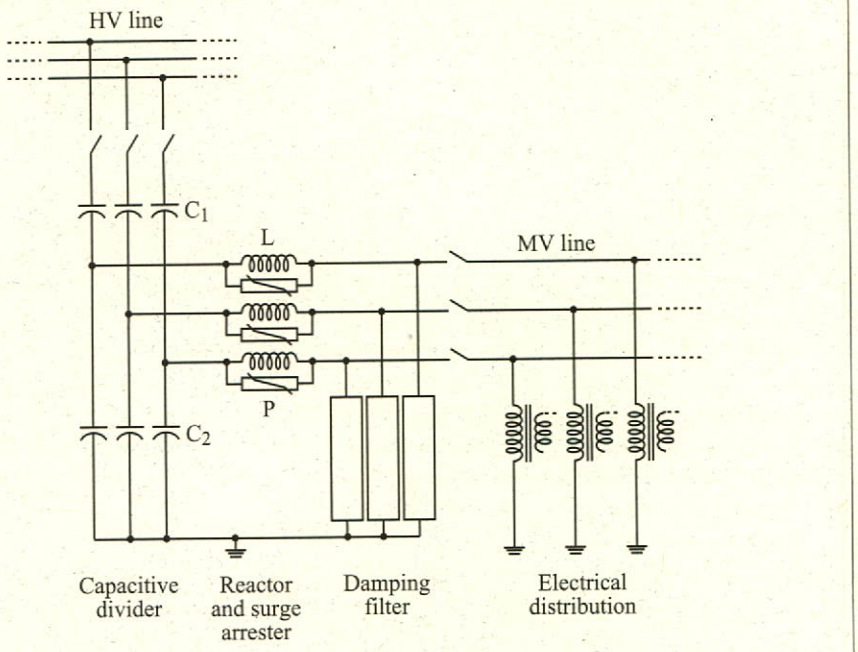
Apart from lightning events, the same systems record a large number of cases of neutral current due to transients. A classical example is that of the transient magnetizing current that accompanies transformer load pick-up.

The team carrying out this work for the Distribution Department is feverishly preparing for the next storm season. To cover the provincial-wide power system even more efficiently, they plan to install another 25 stations in 1994. The data collected there will be used to validate real stresses imposed by lightning and supply additional parameters for the simulation of suitable protection equipment.

Lignes aériennes
(Overhead Lines)

NEW TYPE OF TRANSFORMER SUBSTATION FOR FEEDING SMALL ISOLATED LOADS

It is not always economically feasible for a utility to build a conventional substation or extend the nearest distribution line over dozens of kilometres in order to supply electricity to a small isolated load of ≤2 MW. When there is a high-voltage line running close by, a viable substitute might be the new capacitive divider system, SDC-3.



Apart from the interrupter switches, this system comprises exclusively passive elements: capacitors, reactors, resistors and surge arresters. The capacitive divider consists of two capacitors which allow the voltage to be held at a medium voltage level while a reactor tuned to the capacitors ensures that the voltage remains in phase and in a constant ratio with that of the HV line for distribution purposes. The same reactor also blocks the propagation of harmonics produced by the HV line toward the load. Meanwhile, a filter damper designed at IREQ and produced by Federal Pioneer has the double function of filtering harmonics on the distribution side and damping oscillations, resonances and ferroresonances that can occur when the system is hooked up to the HV line, when loads are switched in or out, or in the event of disturbances.

On the distribution side, conventional transformers are used at their rated voltage and current. A surge arrester enters into operation parallel with the reactor if a short circuit occurs on the distribution system so that excessive overvoltages can be avoided at the reactor or the capacitors while the fault is being cleared. Moreover the fault current is limited to twice the rated current value.

Designed to supply loads of up to 1.5 MW, this system has been tested in IREQ's high-power laboratory and is now being installed at Rivière-Sainte-Anne substation, in the Matapedia region. This substation is located in one of the parks in the Gaspé Peninsula in eastern Québec, where it is used mainly to power the Mont-Albert tourist complex. The SDC-3 will be connected to the 161-kV line there and the distribution voltage will be 25 kV. Acceptance tests on this new type of substation will begin early in 1994, following which the new system will take over from the obsolete equipment at the substation. When the voltage on this line is raised to 230 kV, the only modifications required will be to add a few capacitors and change the tap on the reactor.

The SDC-3 was designed jointly with BG Checo, to which Hydro-Québec has awarded an exclusive worldwide marketing licence. BG Checo also has a licence for two other types of capacitive coupling systems designed for reliable and economical supply of small loads, either from high-voltage lines or from overhead ground wires.

APPAREILLAGE ÉLECTRIQUE
(ELECTRICAL APPARATUS)

Jean-François Labrecque takes a sample from one of the poles used in the study of wood preservatives.

Work on wood pole preservatives

Several studies were carried out in 1993 on pentachlorophenol (PCP) and other products used to preserve wood poles. In one, six substitutes for PCP were assessed under real service conditions after they had been applied to 60 poles set up at an outdoor test area at IREQ. Another involves a joint investigation with the Centre de recherche industrielle du Québec (CRIQ) in an aim to determine the mechanical resistance of the fibres in wood poles that had been treated against rot with chemical agents such as CCA-PEG (mixture of polyethylene glycol and copper, chromium and arsenic oxides).

The test results proved that, at -35°C, poles treated with CCA-PEG that had been in service six to eight years had a much higher spur penetration resistance. The force required to dig a lineman's spur into the wood at the top of a pole proved to be twice the value found on a pole treated with the PCP-oil mixture. The cause of the substantial hardening of the fibres at the pole surface seems to be the gradual disappearance of the polyethylene glycol over the years. This work was performed for the Distribution Department.

We also conducted various studies for the Environment Department. Among others, one project involves the development of a chemical process for removing the residual PCP-oil mixture from poles set aside for scrap. This process has since been patented. Further work was completed on joint studies with the Armand-Frappier Institute and the firm Biogénie on the biological degradation of PCP. The thrust of our studies of PCP in an environmentally controlled chamber over the past year was largely on the role of temperature on the loss and migration of this additive in utility poles. Meanwhile, work continues on the development of new analytical techniques in cooperation with the Université de Montréal.

Chimie des matériaux (Materials Chemistry)

New types of oil-free distribution transformers

Hydro-Québec is anxious to develop technologies that will lay the groundwork for introducing oil-free transformers on its power system. It is hoping to see this type of transformer used not only on its overhead and underground systems but also in transformer vaults found in large buildings. These new technologies have a twofold objective: to reduce electrical losses and to eliminate the inconvenient aspects of oil such as spills that can affect the environment and, in the event of an internal fault, the risks associated with combustion, which can cause injury to both operating personnel and the public at large. Obviously, any replacement technology must be able to offer an equivalent reliability to that offered by oil insulation and the space requirements must be substantially the same. All the work described below was carried out at the request of the Distribution Department.

Gas-insulated transformers

A project was conducted in collaboration with Ferranti-Packard/Rolls-Royce and the Université du Québec à Trois-Rivières to study the feasibility of developing a gas-insulated transformer. A pre-prototype was built and subjected to various temperature-rise tests by the university's electroheat group which then went on to develop a model of the thermal behavior from the point of view of its conduction and convection.

This first phase of the study allowed us to assess the thermal behavior of a 167-kVA single-phase transformer. The findings suggest that a high-temperature insulating material should be used to protect the transformer against cold-load pick-up stresses but without increasing the unit's dimensions. Future tasks will concentrate on the insulation design, tank seals and optimization of the cooling system.

Epoxy-insulated transformers

This past year saw the initiation of research into the use of epoxy resins for insulating transformer windings. This technology, which consists in encapsulating the windings in epoxy, is promising but it calls for a thorough knowledge of the thermal decomposition by-products of the insulating materials in order to avoid problems such as those that led to the banning of PCBs. We therefore investigated the properties of the Resibloc resin produced by ABB in a series of tests conducted under various pyrolitic and combustion conditions. The by-products were analyzed by gas-phase chromatography and mass spectrometry. Almost 100 by-products were identified although their toxicity has not yet been determined. Concurrently with this study, thermal calculations were performed with a view to simulating heat transfer in solid insulation.

Amorphous steel-core transformers

Over the year, another research team was engaged in making final improvements to the design of a toroidal magnetic circuit made of amorphous steel. This design is now protected by a patent. The first design was used to build five 100-kVA oil-insulated transformer prototypes, now installed for validation on Hydro-Québec's distribution system until spring 1994. The last 12 months' work dealt with the use of new amorphous steels and other new materials in the design of a dry-type transformer in which the heat transfer medium is incorporated into the electrical circuit.

APPAREILLAGE ÉLECTRIQUE
(ELECTRICAL APPARATUS)
CÂBLES ET ISOLANTS
(CABLES AND INSULATION)
TECHNOLOGIE DES MATÉRIAUX
(MATERIALS TECHNOLOGY)

TESTS AT THE HIGH-POWER LABORATORY

- Breaking tests of mainly active current at 600 A, 300 A and 75 A, magnetizing current at 25 A and no-load cable current at 40 A; short-circuit withstand and closing tests at 20 kA, in accordance with ANSI C37.71, on an SF_6-insulated 38-kV three-phase overhead interrupting switch.
- Current making and breaking tests at 12.5 kA, 7.5 kA and 3.75 kA in an operating sequence of O-2 s-CO-10 s-CO-20 s-CO, at 26.4 kV on an SF_6-insulated three-phase circuit breaker. The transient recovery voltage had to have a first crest of 48.5 kV and a slope of 3.7 kV/µs, which was achieved by inserting a 3.5-mH series reactor on the source side of the circuit breaker.
- Breaking tests on both symmetrical and asymmetrical 40-kA current in operating sequences of O-15 s-O, CO-15 s-CO and CO-15 s-CO-4 min-CO on a 27-kV no-load three-phase circuit breaker.
- Breaking tests at 7 kA, 3 kA, 100 A, 90 A, 80 A and 70 A on submersible and encapsulated 15-kV current-limiting fuses.
- Breaking tests at 11 kA, 3 kA, 450 A and 15 A on 23-kV expulsion-type fuse cutouts.
- Breaking tests at a load of 8 kA or 3 kA with 12.5 kA source and at 3 kA load and 8 kA source on 15.5-kV current-deviation type fuse cutouts.

Major clients:
Joslyn, Merlin-Gérin, Protelec, Siemens, Hydro-Québec

LABORATOIRE GRANDE PUISSANCE
(HIGH-POWER LABORATORY)

Shape-memory materials for electrical engineering applications

Shape-memory alloys (SMA), materials which are able to take on a new shape and resume their initial form by simple variations in temperature, could have a major impact in the field of electrical engineering and Hydro-Québec is anxious to take full advantage of this new technology. To that end, it has joined forces with a number of industrial partners and set up a company, AMHIX, for the express purpose of developing power system components that could derive benefit from the different features of SMAs. Several projects have already been defined and initiated. They include a study of the behavior and reliability of SMAs in an electromagnetic environment and the development of devices that could be incorporated into the distribution system.

AMHIX's program of activities covers the following aspects:

- technological risk of SMA behavior in the presence of electric current
- modeling SMA fatigue
- SMA product acceptance criteria
- mechanical devices for electrical connections
- design of a 25-kV reclosing circuit breaker
- electrical actuator
- temperature rise detector for disconnecting switches and electrical connectors
- self-protected fuse for cutouts.

Technologie des matériaux (Materials Technology)

Assessment of pipe cable pulling forces

The conventional Rifenburg-Smith model is the only one available for analytical estimation of the forces to which an electrical cable is subjected when it is pulled in an underground duct. However, it reduces the cable, from the point of view of its mechanical behavior, to a rope without any bending stiffness. For some convoluted cable route pulling profiles, this model thus yields pulling forces and lateral pressures that grossly underestimate the real values measured during pulling operations in the field.

A study conducted in 1993 has produced a number of original alternative models that take account of the effects related to the cable's bending stiffness during pulling. These models therefore yield much higher values for the pulling forces than the Rifenburg-Smith model. Two bending effects were studied in particular. The first is the increase in longitudinal force of friction due to additional lateral contact forces between the stiff cable and the extrados of the duct. The other is the internal mechanical energy losses due to hysteresis effects of the load/no-load bending cycles as the cable passes through successive curves in the duct, with relaxation of the cable in segments of constant curvature. We also examined a third effect, somewhat different from the others in that it increases the friction in composite curves formed from a series of small circular segments with sharp-edged interfaces.

Existing analytical models take account of the geometrical and physical nonlinearity of cable behavior but they are all somewhat approximate, because they are based on simplifying assumptions adopted in order to obtain conservative results for the pulling forces.

On the basis of the models proposed, we have developed a new computer program, PULLFLEX, for calculating the pulling forces imposed on pipe cable and compared them with the permissible values. The software will be validated in the coming year by comparing our calculation results with values measured during real pulling operations at Hydro-Québec's test centre in Vanier, near Québec City, and in the field.

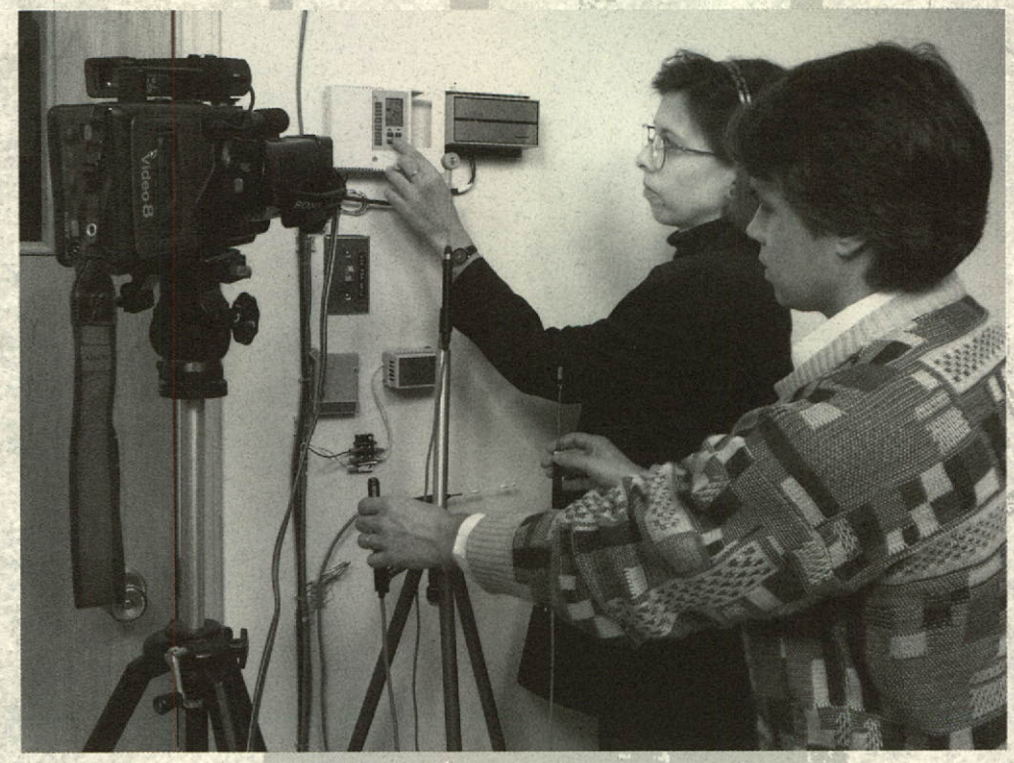
Concurrently with the analytical study, we performed a number of mechanical characterization tests at IREQ's high-power laboratory in an aim to identify the basic data related to the bending of a 25-kV three-phase cable to use as input for PULLFLEX. This work was initiated at the request of the Distribution Department as part of its review of the underground distribution system design.

Lignes aériennes (Overhead Lines)

This past year saw a flurry of activity in energy efficiency and in the industrial and commercial applications of electricity at our LTEE laboratories. For one of our projects, we evaluated, in the laboratory and in customer homes, the energy savings potential of using wall-mounted line voltage thermostats to heat customers' residences. Two new facilities were set up: a test bench for measuring the electrical performance of lighting accessories and a test facility for gas and electric infrared sources. We also developed two computer programs which allow us to determine the interaction between internal gains and thermal load in homes.

In the area of organic electrosynthesis, we completed a program involving the design and development of an electrochemical process for manufacturing anthraquinone. The process, which was commercialized in 1993, was tested for two anthraquinone derivatives in our pilot plant. We also continued with our research activities on the optimization of the electrochemical process of oxidation by means of cerium for the production of chemical and pharmaceutical products. Work progressed on LTEE's membrane separation program, an area with a wide range of industrial applications. One of the activities worthy of note included the waste acid recycling project. A number of partnership agreements were also conducted during the year.

In the area of industrial plasmas, we designed and tested a 650-kW furnace for the recovery of aluminum dross. We also carried out tests to demonstrate the atomization characteristics of a process of producing powders from advanced materials as well as on the forming of ceramics using a central-injection plasma torch.



Célyn Le Bel and Robert Caron verify an electronic thermostat in the dual-climate test chamber at LTEE.

WALL-MOUNTED LINE VOLTAGE THERMOSTATS

In April 1994, Hydro-Québec will be launching its Direct Installation Program, which involves installing a new kind of thermostat in the homes of its residential customers. By substituting more efficient electronic thermostats for the currently used bimetallic thermostats, the utility expects to reduce the amount of electrical energy used for baseboard heating by up to 12%. Our group has been an active participant in this program ever since it was first initiated by the utility's Commercial and Techological Development Department.

Following tests in our dual-climate chamber, we were already able in 1992 to confirm that electronic thermostats had a non-negligible energy potential and, over the last 12 months, we have therefore subjected the electronic thermosats to validation tests in both the dual-climate chamber and real climatic conditions as well as tests in customer homes in Québec's Mauricie and Montérégie regions. The test results unanimously confirm the possibility of saving up to 12% of space heating energy.

We also conducted tests in our photometry laboratory to study the effects of flicker on incandescent lighting and submitted a series of recommendations to our Hydro-Québec client.

Lastly, we helped to define the technical criteria that the thermostats must fulfill if they are to maintain power quality at the the distribution level and meet the utility's reliability and performance requirements. This task involved cooperation with the group responsible at Hydro-Québec, leading manufacturers of electronic products, as well as the Centre de recherche industrielle du Québec (CRIQ).

ÉLECTROTECHNOLOGIES INDUSTRIELLES
(INDUSTRIAL ELECTROTECHNOLOGIES)

TEST FACILITY FOR LIGHTING ACCESSORIES

In order to contribute to Hydro-Québec's energy efficiency program, LTEE has equipped itself with a test bench for measuring and assessing the photometric and electrical performance of lighting accessories. The equipment includes an Ulbricht sphere photometer, 1.93 m in diameter, for measuring the total luminous flux. The spectroradiometer used for this purpose determines the spectral distribution of the sources under test and assesses their colorimetry (color temperature, chromaticity based on the trichromatic theory, color rendition index). The test bench also comprises reference ballasts used to evaluate the photometric and electrical performance in accordance with ANSI standards. The sphere photometer and spectroradiometer, for their part, are calibrated according to Canadian standards.

The test bench accommodates various light sources: incandescent, fluorescent and discharge type (mercury vapor, high-pressure and low-pressure sodium) light bulbs. It is also equipped with an arbitrary function generator for simulating electrical disturbances on the power system and assessing their impact on the photometric and electrical performance of lighting accessories. An auxiliary lamp is used to correct such disturbances in the case of particularly large light sources.

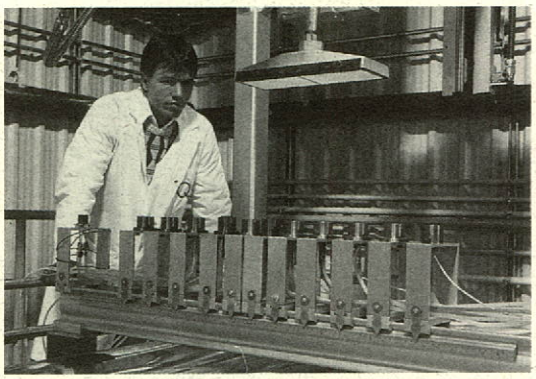
We thus possess a fully equipped testing facility for measuring the efficiency of lighting accessories at the level of the source, the commercial ballast and reference ballast (lumens/watt) as well as their respective impact on power quality. So far, the test bench has been used mainly to verify the efficiency of lighting accessories as part of its contribution to Hydro-Québec's energy efficiency program.

ÉLECTROTECHNOLOGIES INDUSTRIELLES
(INDUSTRIAL ELECTROTECHNOLOGIES)

THE IREG TEST BENCH FOR GAS AND ELECTRIC INFRARED SOURCES

Infrared technology is gaining wider and wider use in industry, especially in the pulp and paper sector where radiant gas burners and electric infrared emitters are used for boosting the drying capacity of cylinder drying sections, for equalizing the humidity profile across the web or for coating applications. One of the most valuable performance criteria for any infrared source it its radiation efficiency, i.e. the ratio of the radiant output over the power consumption of gas or electricity.

In order to assess this efficiency, we have developed – and just completed this year – a test bench specifically designed to measure the radiant output flux and power consumption. The IREG (infrared electric and gas) test bench comprises a central emitter support system, gas and electrical supplies, gas and electricity meters, a set of radiometers and a precision positioning system. In addition, a flue gas analyzing system is provided for assessing the combustion quality of the radiant gas burner.



Normand Bédard works at the IREG (infrared – electricity and gas) test bench.

With this test facility, we will be able to compare the performance of different infrared gas and electrical sources, as our contribution to Hydro-Québec's new energy approach. This work will probably be conducted in 1994 in a project for the Canadian Electrical Association.

The IREG test bench can also be used as a tool for developing new types of infrared emitters. In view of the very different advantages of electricity and gas as energy sources, it is not unreasonable to believe that equipment using both these forms of energy could also offer interesting characteristics. The IREG facility will allow us to test and assess innovative concepts.

ÉLECTROTECHNOLOGIES INDUSTRIELLES
(INDUSTRIAL ELECTROTECHNOLOGIES)

INTERACTION BETWEEN INTERNAL GAINS AND THERMAL LOAD IN HOMES

The recent awareness of energy-savings possibilities has led to several changes in the residential sector. Not only have efforts been made to improve the thermal insulation of new and existing homes but various energy-efficiency programs have been introduced by electrical utilities in an attempt to promote the use of energy-efficient equipment such as compact fluorescent lighting, efficient water-heaters and low-energy consumption appliances.

As a general rule, using more energy-efficient equipment corresponds to a reduction in the amount of heat generated inside the home. Naturally, heat gains influence the energy requirements in terms of heating and air-conditioning. In winter, for example, a reduction in internal gains creates greater heating requirements, which runs counter to the purpose of the energy-saving measure. Inversely, in summer, a lower internal gain reduces the air-conditioning load and associated energy requirements. This interaction between internal gains and heating/air-conditioning needs is affected by a wide range of parameters – climate, physical and thermal characteristics of the home, type of heating system, etc. – with the result that it is difficult to assess the real impact of the energy-saving measure on the internal gain.

To overcome this obstacle, we have developed two computer programs. The first, IMPACT, applies to a single home and is used to determine parametrically the climatic and thermal factors affecting the interaction between the internal gain and the total energy consumption. The second, IMPACT-PARK, is a modified version of the first and is used to assess the overall total energy impact of an energy-saving measure implemented throughout a selected residential area.

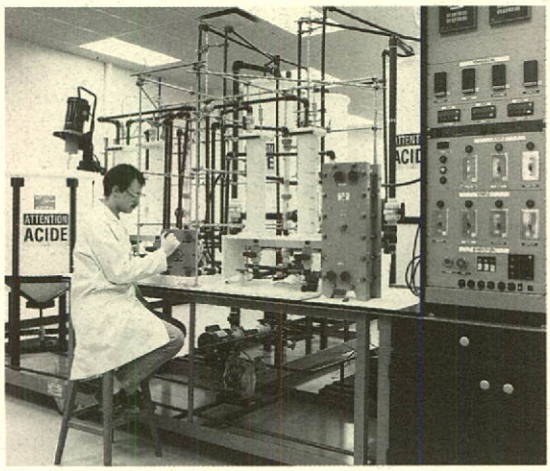
These two computer programs were designed to be user-friendly and are therefore readily accessible tools for all utilities involved in planning energy-efficiency programs for domestic appliances and home insulation.

ÉLECTROTECHNOLOGIES INDUSTRIELLES
(INDUSTRIAL ELECTROTECHNOLOGIES)

Anthraquinone derivatives

Anthraquinone is one of the basic feedstocks used to make dyes. It is also used in the paper industry to improve the performance and energy efficiency of chemical pulp manufacture and reduce its impact on the environment in order to meet the ever more stringent standards.

At the request of Hydro-Québec's Major Customer Accounts Branch, we carried out a three-year program with the American firm W.R. Grace & Co. to design and develop an electrochemical process for manufacturing anthraquinone. As a result of this project, Hydro-Québec has filed patent applications which add to the five existing patents obtained by the U.S. company.



Alain Couture performs tests on membrane separation at the Centre national en électrochimie et en technologies environnementales (CNETE) in Shawinigan with which LTEE has several joint projects under way.

In 1993, the process was put to the test for two anthraquinone derivatives. These demonstration tests were conducted at LTEE's electrosynthesis pilot plant, which has an annual capacity of 100 tonnes. This plant was built at a cost of $5 million and benefits from a grant of $2.8 million under the Canada-Québec agreement on technology development.

As far as the marketing of these products is concerned, Hydro-Québec has awarded the Taiwanese company Taysung an exclusive world licence for the manufacture of an anthraquinone dye. The licence provides for the construction of a first manufacturing plant in Québec by 1996. Negotiations are also under way to transfer the technology to several other companies (see the section Technology Promotion).

Oxidation by cerium

The electrochemical process of oxidation by means of cerium is a generic technology allowing a wide range of high-added-value chemical and pharmaceutical products to be synthesized. Developed in conjunction with the American multinational, W.R. Grace & Co., this process was recently the subject of a market survey conducted by the British company Synprotech which analyzed the products of commercial interest as well as the organizations likely to appropriate this technology. Many companies have in fact shown an interest and negotiations are now under way with a view to awarding licences.

On the basis of the positive outcome of previous studies carried out by W.R. Grace & Co., we have pooled our resources with the CNETE (Centre national en électrochimie et en technologies environnementales) to draw up an optimization program for the manufacture of these products. The program focuses chiefly on four products considered to have the most promising applications, namely anisaldehyde, p-t-butylbenzaldehyde, and para- and ortho-chlorobenzaldehyde. These fine chemicals are used in the pharmaceutical, cosmetic and electroplating industries. A significant improvement has been achieved in the synthesis of these aromatic aldehydes, thus enhancing the marketable advantages of the technology. Grants were provided by the Québec Ministry of Higher Education and Science for these programs.

Titanium reduction technology

We have also developed an electrochemical reduction technology for the synthesis of aromatic amines, which are most useful in the chemical and pharmaceutical industries. We are now seeking an industrial partner in order to scale up this technology.

CHIMIE ET ÉLECTROCHIMIE INDUSTRIELLES
(INDUSTRIAL ELECTROCHEMISTRY AND CHEMISTRY)

Membrane separation

LTEE's membrane separation program is aimed specifically at fostering the use of innovative technologies in the field of chemical separation so that Québec companies, whatever their size, have a chance to increase their competitive edge. Outside sources of support have added weight to Hydro-Québec's efforts in this direction in the last three years.

Among the projects financed by the utility's Major Customer Accounts Branch, the waste acid recycling by ionic membrane project was awarded a grant by the Québec Ministry of Higher Education and Science (MHES) and selected for sponsorship by the Ministry of International Affairs as one of three international cooperation projects. These obvious indications of approval encouraged us to contact renowned research organizations that share our concerns regarding this major environmental problem. Under a mandate from Hydro-Québec and in close partnership with the multinational Eka Nobel, we have also pursued our development work on the selective purification of the electrolyte used in the Eka Nobel process using a membrane technology. In addition to its advantages from the point of view of energy, the technology under development offers far more operating flexibility and lower investment costs for the sodium chlorate production process.

In the meantime, a market survey conducted in 1993 for the utility's Energy Efficiency Branch has revealed a vast, highly diversified potential market for membrane technologies. Consequently, we have decided to expand our field of activity to cover other such technologies that could be used in a liquid medium, i.e. microfiltration, ultrafiltration, nanofiltration and inverse osmosis. There are many potential applications, especially in the agro-food and environment sectors and, with this objective in mind, we have conducted several exploratory studies for electrotechnology engineers.

Our activities related to membrane technologies are largely inspired by the networking principle promoted by Hydro-Québec in its performance commitment plan. Thus the LTEE/Shawinigan college partnership has culminated in the creation of an electrochemistry centre recognized by the MHES. A non-profit organization has also been established, the Centre national en electrochimie et en technologies environmentales (CNETE), a technology transfer centre already boasting a dozen employees and working in close collaboration with LTEE to promote the use of electrochemistry and environmental technologies in industry.

Chimie et électrochimie industrielles
(Industrial Chemistry and Electrochemistry)

Advanced materials powder production

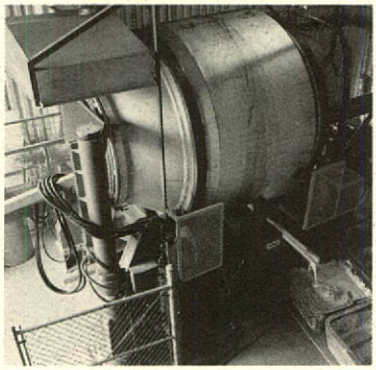
Testing began this year to demonstrate the atomization characteristics of a process of producing advanced materials powders, in particular titanium- and aluminum-based intermetallic powders. The test setup is composed mainly of a liquid-cooled double-wall reactor with a water tank to collect the powders.

The atomization process consists in focusing the jets of very-high-temperature gasses on a central point, which produces a sufficiently strong turbulence for the injected materials to be atomized. A first series of tests using a reel of aluminum wire to feed the reactor demonstrated the feasibility of the process. Other tests, this time feeding the reactor with liquid aluminum, produced even better results.

Preliminary tests show that it is possible to obtain adequately shaped particles this way but further testing is required to better identify the characteristics of this system.

A final point to note is that negotiations have recently led to an agreement between Hydro-Québec and the firm Pegasus Refractory Materials Inc. (PERMA) to work jointly on the research, development and commercialization of products that emerge from their respective work on the production of advanced materials.

Plasmas industriels
(Industrial Plasmas)



A 650-kW rotary furnace for the recovery of aluminum from dross.

Aluminum recovery from dross

The Droscar process was designed to recover aluminum contained in the dross produced at smelting plants. The unit comprises a rotary furnace revolving a full 360° round two horizontal graphite electrodes. A constant-current electric arc is held between the electrodes to heat the charge to 800°C. The rotation provides the necessary mechanical agitation for the aluminum droplets dispersed in the oxide matrix to agglomerate and, upon completion of the process, the metal is poured out through a specially designed tap hole.

A 650-kW pilot unit has been designed and installed in our laboratories to develop operating procedures. It will also be used in the task of optimizing and characterizing the overall process. The furnace has a capacity of 1.3 tonnes of aluminum dross and the full tap-to-tap cycle takes 90 min. The furnace can thus process over 3500 tonnes of aluminum dross annually under steady-state conditions.

Recently we installed a regulated 1.5-MW DC power supply which allows us to sustain an arc of over 50 cm to ensure a uniform temperature in the furnace. The arc voltage is kept at 300 V by automatically adjusting the arc length, which means that we can sustain the desired power level, optimize the arc length, and reduce electrode erosion.

The process optimization work is oriented specifically toward reducing dust emission, increasing the efficiency in terms of the amount of aluminum recovered, and reducing the energy consumption.

The demonstration unit is now in operation and has proved that it can process dross to the client's specifications. Industrial implementation of a 2-MW unit is being planned for the beginning of 1995. Lastly, we should mention that this process has been patented by Hydro-Québec.

PLASMAS INDUSTRIELS
(INDUSTRIAL PLASMAS)

Forming and synthesis of ceramics

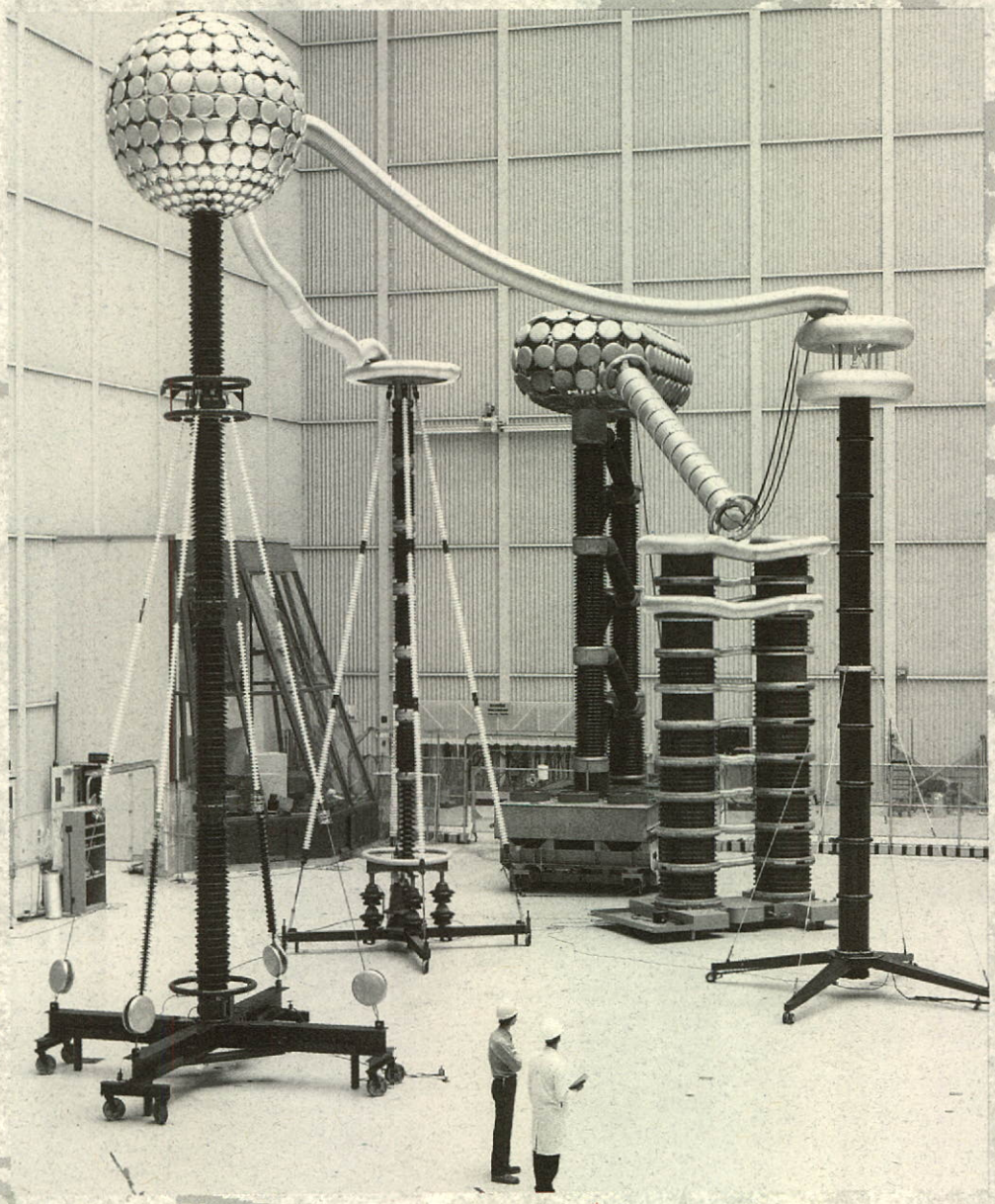
Work continued this year on our study of a prototype central-injection plasma torch which has all the appearances of being a promising tool for the forming of ceramics. Tests have shown in fact that it is possible to obtain thick deposits and small dense particles using alumina. The characteristics of these deposits compare favorably with those obtained with the conventional plasma projection method and are only slightly inferior to those yielded by hot isostatic pressing. The Canadian Electrical Association co-funded the work.

Another project, initiated in September, involves the development and demonstration of a torch for the deposition and synthesis of ceramic powders. This work will consist essentially in developing a second-generation torch from the existing prototype with a view to obtaining an even better performance. The new design will be easier to use and to market. The performance tests should start in 1994 with the formation of alumina deposits and geometrically simple parts.

PLASMAS INDUSTRIELS
(INDUSTRIAL PLASMAS)

During the past year, various test facilities and measurement systems have been set up to help us carry out R&D and testing. A new DC calibrator went into service at the high-voltage laboratory to verify the accuracy of DC voltage dividers up to a voltage of ±1 MV, and a facility was commissioned for three-phase reactor testing. At the high-power laboratory, we installed a new fibre-optic measurement and data acquisition system offering high speed and accuracy. We also developed a mechanical phenomena measurement and control system. The high-power laboratory has set to work on restoring the transformer bank damaged by fire last March.

The projects carried out in real-time digital simulation in 1993 yielded promising results. Lastly, we have applied to the Standards Council of Canada for accreditation of our calibration laboratory.



The high-precision 1000-kV DC calibrator (on the right, in the foreground) put into service at the high-voltage laboratory for verifying the accuracy of voltage dividers.

DWINA 1000

In 1993, a new 1000-kV DC calibrator went into service for verifying the accuracy of DC voltage dividers up to a voltage of ±1 MV with a margin of error of only 0.03%. It also allows us to verify the voltage dividers used to measure switching surges up to ±600 kV crest with a margin of error of ±0.2%.

This calibrator, known as DWINA 1000, named after the Russian river, was developed by researchers at the Russian Institute of Metrology and built by the firm Rostet-Moscow. The Institute already had a first-generation device rated 800 kV but decided to expand the boundaries of technology by developing the more advanced DWINA 1000. This device, the only one of its kind in the world, allows utilities to measure the ratio of voltage dividers at 1 MV rather than 3000 V and thus determine the effect of temperature rise and ion currents on this ratio.

Three-phase test facility

Work has begun on upgrading our facilities to make them more suitable for three-phase tests on three-phase reactors. The decision follows an agreement between the firm ABB and IREQ. The ABB plant in Varennes, which manufactures power reactors among other things, thus hopes to be in a position to conqueror the North American market.

We have been conducting single-phase tests on reactors for several years now but three-phase testing calls for a transformer that is also three-phase as well as certain modifications to our facilities. We began by determining the characteristics of the required transformer to ensure it matched existing equipment and then designed new busbars to make the capacitors more flexible and enhance their efficiency. The transformer, to be built by ABB Varennes, is scheduled for delivery in July 1994. The busbars will be installed two months earlier, in May.

Test automation

The project undertaken to automate the 60-Hz test area has a long-term objective, to refine the high-voltage laboratory's measurement techniques. The target testing activities are partial-discharge, loss, resistance, temperature, vibration and audible-noise measurement.

The partial-discharge measurement acquisition system, which has been in use for almost ten years, is now being redesigned in light of new technologies. Since last year, the laboratory has a new acquisition system which records partial-discharge measurements continuously during the tests.

The resistance and temperature measurement system has reached the testing stage and work is now under way on the loss measurement system. Standard capacitors and zero-flux current transformers will be used for all types of loss measurement.

Automation of the safety system in the main test hall

To improve the safety system in the main test hall and make it make easier to use, we have designed and put into operation a new means of handling the control and supervision of all the different test areas. The components include a programmable logic control connected to three computers. This control is extremely flexible; for example, it can be used, among other things, to check and display the condition of the test areas from each control room. The infrastructure installed will allow for future expansion.

LABORATOIRE HAUTE TENSION
(HIGH-VOLTAGE LABORATORY)

THE HIGH-POWER LABORATORY EQUIPPED WITH A NEW MEASUREMENT SYSTEM

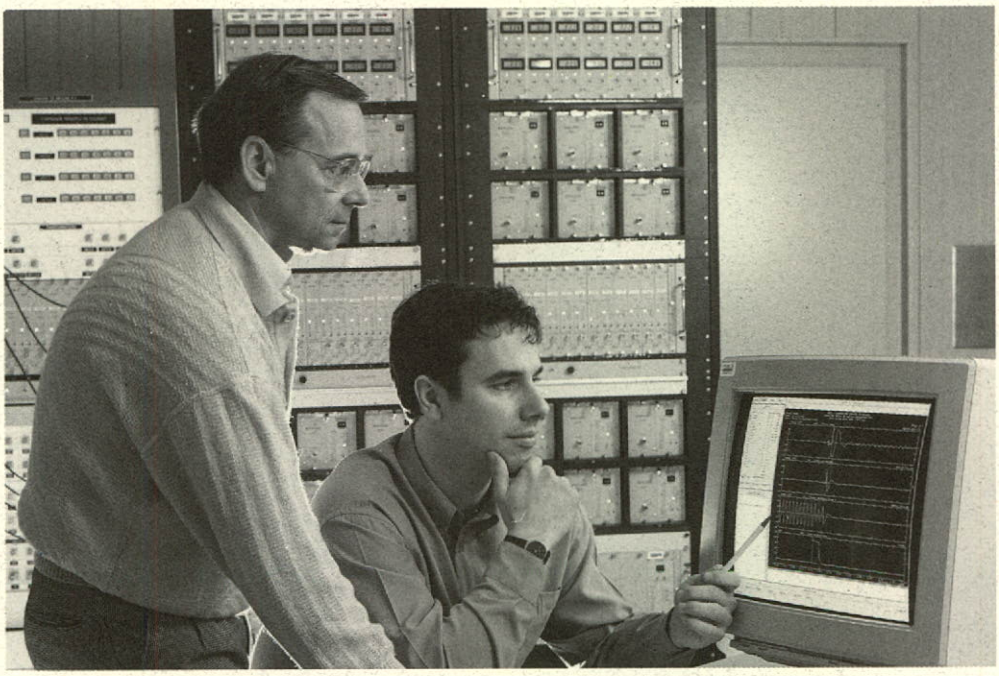
The three main test chambers at the high-power laboratory – the two high-voltage chambers and the medium-voltage chamber – have recently been equipped with an entirely new measurement system. This work involved many participants both in the definition of the laboratory's needs and, later, in the designing of the system and its implementation.

Ever-increasing requirements convinced us to develop a modular measurement system, which offers two main advantages, accuracy and speed. The equipment installed in the two high-voltage chambers comprises 24 channels, while there are 32 channels in the medium-voltage chamber. The data acquisition rate can reach one million samples/second, simultaneously on all channels. The overall precision is ±2% in the range 0 to 500 kHz and the 3 dB point is at 1.3 MHz.

Each channel has a two-port 16-MB random-access memory operating under the standard VME architecture. One interface provides direct access to the samples from a SUN 690 workstation while a second interface controls the acquisition process, allowing the memory to be separated into rotating buffers. This second interface also allows several independent events to be recorded and stored simultaneously.

Communication between the different cabinets is by optical fibre, connecting the test cells with the control room and the latter with the computer room. With fibre optics technology, the system benefits from optimum protection against electromagnetic disturbances.

This real-time measurement system offers graphic display of part or all the recorded data as soon as a test is completed and, depending on the type of phenomenon to be analyzed, the pertinent subset of data can be archived onto a disk.



André Chénier (standing) and André Godin use the new fibre optic measuring system at the high-power laboratory.

Its sophisticated man-machine interface offers a software environment that is easy to use, dependable and highly efficient, while the Ethernet network affords great flexibility in data communications. The software is designed to run under the UNIX operating system in an X (OPENWIN, in this case) environment and comprises all the required functions from test preparation, hardware calibration and execution of the tests to postprocessing and archiving on 8-mm tapes. Incidentally, postprocessing is done with the help of an original scientific language, TRAS, which allows mathematical and graphical processing on test signals.

SYSTÈMES DE MESURE
(MEASUREMENT SYSTEMS)
LABORATOIRE GRANDE PUISSANCE
(HIGH-POWER LABORATORY)
ROBOTIQUE, INFORMATIQUE ET ÉTALONNAGE
(ROBOTICS, DATA PROCESSING AND CALIBRATION)

MECHANICAL PHENOMENA MEASUREMENT AND CONTROL SYSTEM

Khaméléon is a measurement system designed for fast or slow data acquisition, operation control, and data display and processing as tests are in progress. The system is mobile and readily adaptable to the many different test configurations used in the high-power laboratory.

The Khaméléon system comprises a workstation, an instrument cabinet and a computer program. The workstation has a 53-cm video screen, a printer, a working surface for the keyboard, mouse and documents, and a mobile support equipped with a handle and sound-absorbent wheels for transportation. The screen has double-protection against electrostatic and magnetic interference.

The instrument cabinet contains all the equipment for 60 slow-acquisition channels, 16 fast-acquisition channels, eight relays for controlling slow phenomena, two relays and two generators of arbitrary functions for programming specific sequences. The cabinet was designed in terms of minimizing the assembly time.

The software, scheduled for completion by the end of 1994, comprises a core containing all the basic functions and 14 modules dedicated to specific tasks such as cable temperature control, slow acquisition by thermocouple, the relay sequencer, etc., which all form part of the high-power laboratory's routine mechanical testing activities. One original feature of Khaméléon is that it allows the user to configure, associate and synchronize the execution of these various tasks in the event that an unscheduled test has to be performed. Incidentally, Khaméléon is programmed in Labview 3 on a Macintosh platform for greater user-friendliness. In short, the high-power laboratory has clearly equipped itself with an evolutionary modular tool which can be easily adapted to the user's needs.

Work began on designing the instrumentation in January 1992 at the request of the high-power laboratory personnel. The hardware stage was completed in 1993 with the delivery of five mobile workstations. Development of the software also reached a major milestone in 1993 when a report on the analytical procedures and monitoring screen operations was submitted to the client. Programming of the Khaméléon computer program will continue in 1994.

SYSTÈMES DE MESURE
(MEASUREMENT SYSTEMS)

NEW MEASUREMENT SYSTEM FOR TEMPERATURE-RISE TESTS AT THE HIGH-VOLTAGE LABORATORY

The temperature-rise tests performed on transformers serve a threefold purpose: to determine the unit's thermal characteristics in order to assess its behavior for different overload conditions; to prove that it can withstand the prescribed overload conditions without exceeding the permissible temperatures; and to demonstrate that the ancillary equipment allows the transformer to withstand the same high overloads.

To make it easier to perform these essential tests, we have designed a new measurement and data acquisition system, with the result that the entire test procedure is now fully automatic. With the Labview software installed on a workstation, all the required data is recorded and saved by means of a multiplexer able to read up to 80 thermocouples, a digital voltmeter, a DC source and measuring shunts. The results are output in the form of a readily usable report.

As far as the processing of this data is concerned, the system calculates the temperature curve by regression and extrapolates up to stability. It also records the temperature level at the moment of interruption of the voltage supply to the transformer under test.

The next stage in this project will be to incorporate loss, audible-noise and vibration measurement into the system and, possibly, AC and DC source control in addition.

SYSTÈMES DE MESURE
(MEASUREMENT SYSTEMS)

REFURBISHING THE HIGH-POWER LABORATORY'S TRANSFORMER TEST BENCH

On March 11, 1993, a dielectric failure in a short-circuit test transformer at IREQ's high-power laboratory resulted in a fire that destroyed both the transformers in question as well as an adjacent one. The two units were part of a bank of six 735-kV, 1200-MVA short-circuit transformers serving as a power source for high-power testing.

The following days were spent recovering the oil that had been spilled, making safe the fire-ravaged areas, and planning repair work on the test installations. After certain verifications were done and corrective measures applied, some of the test facilities were put back in service, namely the medium-voltage test cells, where tests resumed fairly rapidly through the use of other transformers. The following step consisted in removing the two transformers and disconnecting the damaged circuits. We were able to resume high-voltage testing by the end of April by relying on three of the remaining transformers.

Once the $14.5-million repair project was approved by Hydro-Québec's board of directors, two new transformers were ordered from ABB. The first was delivered for acceptance tests at the end of December, barely two weeks after the civil engineering work (supports, fire-retardant walls, tanks and recovery basins) was completed. The second transformer is expected to be ready for dielectric tests by the beginning of February 1994. It should be noted that the engineering work and construction project as well as the manufacturing of test transformers proved to be a considerable challenge because of their size and the very short lead times.

Further work on the project in 1994 involves finalizing the acceptance tests, repairing the supply circuits (SF_6 busbar, disconnecting switches, surge arresters, etc.), while commissioning is expected to take place next June. The laboratory will then once again have six 735-kV, 1200-MVA short-circuit transformers to be used for the most critical tests (735-kV sacrificial surge arresters, 55- and 110-mvar, 735-kV shunt reactors, 735-kV varistors, etc.).

The Measurement Systems Department was also asked to carry out partial-discharge measurements on three of the four remaining transformers in order to assess their condition. Various detection devices such as partial-discharge measurement instrumentation and ultrasonic detection were used for this purpose. In addition to the equipment available at the high-power and high-voltage laboratories, we also requested the services of the New Jersey firm Physical Acoustics Corporation, to whom we leased an ultrasonic detection system. The Power System and Substation Testing Division also lent us one of its mobile data acquisition units as well as the personnel needed to operate it.

The tests revealed that there were no partial discharges in two of the transformers; however, problems such as ultrasonic signals coming from inside the equipment were detected on the third transformer. We also recorded electrical signals indicating partial discharges on the capacitive taps of bushings. These signals were first thought to be interrelated but an in-depth investigation revealed that this was not the case. We were then able to determine that the signals emanated from a defective insulating column mounted on one end of the transformer. The ultrasonic signals, for their part, were purely mechanical in origin; in fact, they originated from two of the transformer's eight tap changers.

Following these tests, the defective transformer was sent to our maintenance and repair centre in Varennes where we checked the tap changers and tightened certain loose parts. The final stage involves reinstalling the transformer in the high-power laboratory.

LABORATOIRE GRANDE PUISSANCE
(HIGH-POWER LABORATORY)
SYSTÈMES DE MESURE
(MEASUREMENT SYSTEMS)

Recent developments in real-time digital simulation

Real-time digital simulation of electrical transmission systems is increasingly becoming a reality. For the past four years, we have been adding models to the digital simulator that have been programmed in small high-speed computers called digital signal processors (DSPs). This has increased the accuracy of the new hybrid simulator and decreased the time required to set up studies. Recent studies carried out jointly with various universities have shown that it is possible to develop a real-time digital simulator that is on par with other system software analysis tools.

In a joint project with École de technologie supérieure, École polytechnique, and Université du Québec à Montréal, we created a reduced-system model called dynamic equivalent which uses the same equations found in software stability programs such as Hydro-Québec's ST600 program. The network, which includes 8 machines and 50 busbars, is simulated in real time in two DSPs. These equivalents are useful for representing in real time parts of the system that are located at a distance from the busbars near which disturbances are being simulated. Since the same algorithms are used as for the ST600, we thus hope to reduce the validation time required for a simulator setup.

In moving from analog to digital simulation, a major step must be successfully completed, namely the simulation of transmission lines that connect the main network components. Thanks to two research contracts awarded to Université Laval, it is now possible to use a DSP to simulate a model of a line that is more accurate than what is currently being used. In fact, this model is just as accurate as the one used in the EMTP software, which serves as reference for network simulation throughout the world. This model constitutes the core of our real-time digital simulation prototype.

In real-time simulation, it is beneficial to use mathematical models that power systems analysts are familiar with. In fact, it is reassuring for outside clients to know that in carrying out their studies we are using proven methods similar to those used in their own firm. The same holds true for our joint ventures with universities, since professors, by virtue of their pedagogical expertise and their research in electrical engineering, offer a unique perspective in the development of real-time digital methods.

Simulation de réseaux
(Power System Simulation)

Accreditation soon for the calibration laboratory

The calibration laboratory has two major clients, the high-voltage laboratory and the high-power laboratory, whose stringent requirements with regard to their measuring and testing equipment have led us to a major decision: to take the necessary steps to guarantee conformity of our tests with official standards.

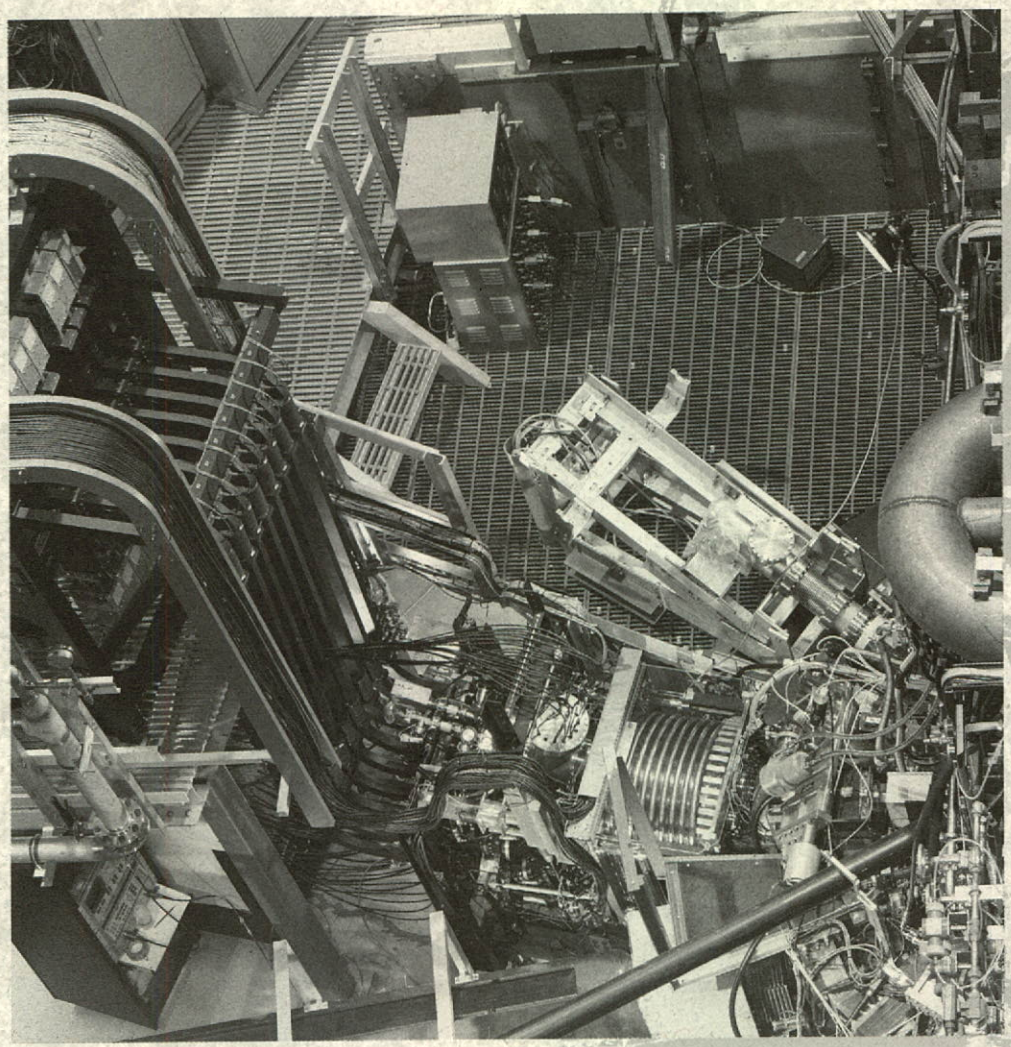
Our first step was to draft a quality assurance manual and submit it to the Standards Council of Canada (SCC) in order to have our laboratory accredited. The program we have set in motion meets the Council's criteria as set forth in the document "Accreditation criteria and methods for testing laboratories" (SCC CAN-P-4C-1991) and also complies with the international standard ISO/IEC Guide 25 (1990).

Our application will be examined by two organizations, the Standards Council of Canada and the Calibration Laboratory Assessment Service (CLAS), which is affiliated with the National Research Council (NRC). Since accreditation usually takes 18 to 24 months, we should receive our certificate during the course of 1994.

Robotique, Informatique et Étalonnage
(Robotics, Data Processing and Calibration)

Hydro-Québec has been working jointly with the Centre canadien de fusion magnétique (CCFM) on nuclear fusion projects for the past eight years. In 1993, the experimental tokamak device, the TdeV, was equipped with a current drive and lower hybrid frequency drive system with a rated power of 1 MW at a frequency of 3.7 GHz, as well as with several new diagnostics. CCMF also continued its joint thermonuclear fusion projects with organizations in Canada, the United States and Europe.

In the area of superconductivity, we worked on developing and manufacturing superconducting wires. Our researchers also sought to increase the nominal power rating of the superconducting fault-current limiter, one of the first applications considered for power equipment. This year's research into new materials covered a wide range of fields such as the development of new alloys for hydrogen storage, the use of nanocristalline alloys in transformers, the study of new permanent magnets for use in high-performance motors, and the development of high-energy efficiency electrodes.



New lower hybrid frequency heating and current drive system installed in the Tokamak de Varennes (TdeV).

MAGNETIC FUSION ACTIVITIES AT THE CCFM

Now in its eighth year, Canada's centre for magnetic fusion conducts research into nuclear fusion, a source of energy that is environmentally safe and, for all intents and purposes, inexhaustible. The CCFM is a joint undertaking of Hydro-Québec, Atomic Energy of Canada Limited (AECL) and the Institut national de la recherche scientifique (INRS). Its personnel comprises some 100 employees, from Hydro-Québec and INRS as well as from private companies such as MPB Technologies and Canatom.

The experimental research at the Centre is conducted on a tokamak device, the TdeV. The focus here at Varennes is on magnetic divertors, a key component in future fusion reactors but found in very few of today's tokamaks. Among other distinctive features of our tokamak that have led to original contributions to the theories of divertors, mention should be made of the ability to electrically bias the divertor plates and of the cryogenic high-flow pumping capacity in the divertor region.

The addition of new diagnostics in the edge plasma region in 1993 gave us an opportunity to broaden our understanding of the physical behavior of the plasma as well as of the interactions between the divertor and biasing. In particular, the measurements allowed us to validate new models of the interactions, while our results won further international recognition for CCFM scientists and their research programs.

The most important addition to the TdeV experimental research facilities in 1993 was the lower hybrid frequency heating and current drive system. A large proportion of the CCFM personnel participated in this project. With a rated power of 1 MW at a frequency of 3.7 GHz, this system comprises two klystrons for wave generation, a transmission line with many multiple power dividers, and a high-performance multi-junction antenna, not to mention the electrical power and control system requirements.

Tests performed in France early in the year revealed that the prototype antenna module offered a better performance than other modules built to date elsewhere in the world, largely due to the choice of materials and construction methods. Following the successful completion of these tests, work began on the production of 32 modules and the complete antenna was finally installed on the TdeV in November. During the first series of tests in December, a power of 200 kW, i.e. 20% of the rated power, was coupled to the plasma, which confirmed the antenna design and the quality of its fabrication. This represents an outstanding success for a new system of such scope and complexity.

Injecting this amount of power means that the pulse length of the TdeV can be substantially increased, while the combination of HF power and a pumped biased divertor will allow the CCFM scientists to make unique contributions to our understanding of this key element of future fusion reactors.

Two new diagnostics are now under development in joint projects funded by the U.S. Department of Energy. InterScience of Schenectady (NY), for example, has developed a thallium beam and installed it on the TdeV where it will be used to measure the plasma edge characteristics. First results are expected soon. In 1994, a team from the University of Maryland will install a microwave diagnostic to measure the properties of superthermal electrons created by injecting lower hybrid waves.

The first tests for the injection of compact toroids for tokamak plasma fueling were performed in 1993 as part of a joint program with the Ontario fusion research program (CFFTP), the University of Saskatchewan and the University of California at Davis. The preliminary results of this technically difficult project prove that compact toroids do in fact penetrate the plasma, resulting in an increase in the electron density. These studies will continue in 1994 to assess the advantages of this method of depositing fuel at the very centre of a tokamak plasma.

The last 12 months also saw a major effort dedicated to extending the CCFM's scientific program to the year 2000 and planning the experimental facilities required. Key to this plan is a major modification to the tokamak, to be known as TdeV-M, incorporating a divertor design that reflects the knowledge built up over the last ten years. Moreover, many new design tools have been developed for magnetic configurations and power supply requirements. This program is part of the overall plan approved by the International Advisory Committee and the CCFM's Board of Directors toward the end of 1993. In addition to modifications to the tokamak itself, additional power supplies and increased RF power injection are planned.

Theoretical interpretation and simulation work continued in collaboration with scientists at Massachusetts Institute of Technology and Princeton Plasma Physics Laboratory in the United States, the University of Nancy in France and the Culham Laboratory in England. The experimental and theoretical work on biased plasmas has led to a very promising new partnership between the CCFM and the Royal Institute of Technology in Sweden as well as the Technical University of St. Petersburg in Russia.

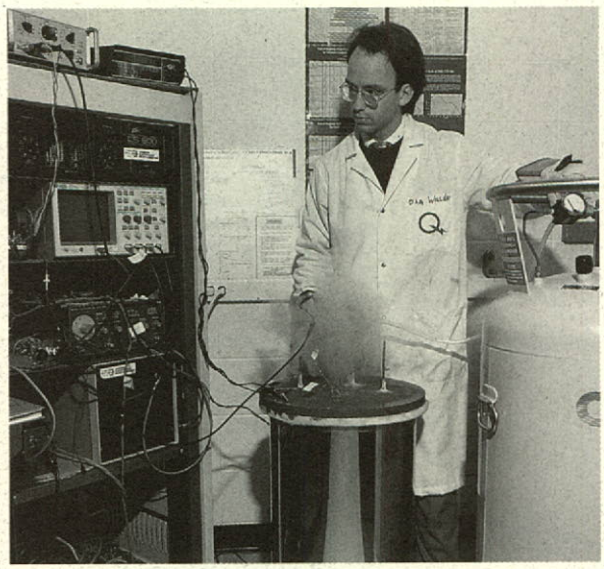
The participation of two senior research scientists from the CCFM in the European team working on the international fusion program, ITER, is now in its fifth year. Among the specific tasks in which the CCFM representatives are engaged, mention should be made of the divertor physics, the operating scenarios, and studies of the safety of the installations.

ADMINISTRATION DE PROJET – FUSION
(PROJECT MANAGEMENT – FUSION)

SUPERCONDUCTIVITY

In the course of 1993, our work focused mainly on superconducting materials and the superconducting fault-current limiter (SFCL). The project involving the superconducting magnetic energy storage system for network regulation has been postponed until a cost/benefit evaluation has been performed.

In the area of superconducting materials, techniques have been developed to fabricate wires several metres in length based on the BSCCO-type superconductor. The critical current densities of these wires are in the range of 10 – 20 kA/cm^2 at liquid nitrogen temperatures. A new process that accelerates the formation of the superconducting phase in the core of these wires produced 10 kA/cm^2 after only 30 h of treatment. Melt-textured yttrium-based superconductors were also fabricated, and a current density of 10 kA/cm^2 in a magnetic field of 1 T was measured. A new high-precision vibrating sample magnetometer (VSM) was successfully used for this purpose.



Dag Willen tests a superconducting current limiter.

A test rig capable of measuring critical current densities and critical temperatures of eight samples simultaneously was constructed to accommodate the large number of samples analyzed. Also, a programmable gas mixer was added to the furnace processing facilities for these materials so that the effects of any sequence of temperature and atmospheric composition can be explored.

Several laboratory-scale inductive fault-current limiters have been built using a bismuth-based high-temperature commercial superconductor. This device benefits from the rapid transition of a superconductor from the superconducting state to the normal resistive state.

The resulting nonlinear impedance is extremely effective in limiting the first few cycles of overcurrent during a short-circuit fault. Now that the nominal power rating of these prototypes has progressed from a few hundred volt-amperes to almost 10 kVA, the SFCL promises to be one of the first real applications of high-temperature superconducting materials for power utilities. An international agreement to collaborate in the development of a commercial device toward the year 2000 is now being negotiated.

TECHNOLOGIE DES MATÉRIAUX
(MATERIALS TECHNOLOGY)

RESEARCH INTO NEW MATERIALS

Several research projects on the use of new materials were undertaken this year. In the field of hydrogen storage and transportation, for example, we worked jointly with a team from McGill University on the development of new alloys for hydrogen storage. Their performance has proven superior to that of conventional storage materials and we have already taken steps to patent this technology.

We also studied new nanocristalline alloys with lower losses at 60 cycles than commercial amorphous alloys. In the long term, it could be envisaged that these grain-oriented steel alloys be used in transformers. Other work on magnetic materials over the past 12 months included an investigation into new permanent magnet materials which could possibly outrank the Fe-Nd-B alloy currently used in high-performance motors.

Lastly, we pursued a study on new electrodes known for their high energy efficiency, which could be used for synthesizing chlorate, a bleaching agent employed by the paper industry. The project is being carried out for the utility's Major Client Accounts Group.

TECHNOLOGIE DES MATÉRIAUX
(MATERIALS TECHNOLOGY)

Our research and development activities yielded interesting spinoffs during the past year both with respect to investments and future prospects. For example, we signed a $33-million R&D contract with U.S. firms for the development of prototypes of lithium batteries for electric vehicles. We also set up partnerships with an R&D firm in the area of shape-memory alloys. As part of our Hydro-Hydrogen project – a joint project with European and Canadian firms – investments of some $60 million were announced in 1993 for 20 projects to demonstrate the potential of hydrogen applications. Lastly, various licensing agreements have been signed regarding the production of anthraquinone, the production of digitized maps of the utility's meter-reading routes, and the manufacture of a new synchronous control interface for circuit breakers.

A major R&D agreement was signed with American manufacturers and organizations for the development of lithium polymer batteries intended for powering electric vehicles.

R&D AGREEMENT WITH THE AMERICAN AUTOMOBILE INDUSTRY ON ACEP BATTERIES

A major research and development contract was signed in December 1993 between Hydro-Québec, 3M of Minnesota and Argonne National Laboratories of Chicago to develop prototypes of lithium polymer (ACEP) batteries for electric vehicles. The two-year project will be carried out for United States Advanced Batteries Consortium (USABC) which umbrellas General Motors, Ford and Chrysler. The American Electric Power Research Institute (EPRI) is also associated with this consortium. USABC and the Department of Energy (DOE) will contribute as much as 70% of a total budget of US$33 million, which makes this the largest R&D contract Hydro-Québec has ever been awarded by a foreign country.

Lithium polymer batteries have been a major avenue of research at Hydro-Québec since the early 1980s and the teams of researchers and technicians involved in the ACEP development work have many achievements to their credit: microbatteries for plastic cards (credit cards, Medicare cards, etc.), batteries of just a few milliwatts for microelectronic applications, 10-Wh batteries, and coils of 100 Wh. The present focus is on the production of a more powerful battery which could eventually be used to supply electric vehicles. In 1993, our activities consisted mainly in optimization of the components, development of new concepts for polymers and additives, cycling of prototypes, and the development of manufacturing processes, in particular for thin-film lithium.

In the course of development of a high-energy-density battery, which is key to the breakthrough of electric vehicles into the market, the technology we have developed in our laboratories represents a significant stepping stone. The lithium polymer cell, already protected by some 40 patents, offers many interesting advantages. It is an all-solid battery based on the use of polymer electrolytes separating reactive materials such as lithium and other compounds such as vanadium or manganese oxide. It has a high energy density, excellent cyclability, almost zero self-discharge, and a configuration that lends itself to all the different applications envisaged. From the point of view of environmental pollution, it contains no cadmium, mercury, lead or other toxic materials.

The recent agreement opens up fascinating perspectives. If the cell development stage is is successful, we can confidently set to work on the next phase, which is to develop a battery with a capacity of about 40 kWh for vehicles.

ADMINISTRATION DE PROJET ACEP
(PROJECT MANAGEMENT – ACEP)
CHIMIE DES MATÉRIAUX
(MATERIALS CHEMISTRY)
CHIMIE ET ÉLECTROCHIMIE INDUSTRIELLES
(INDUSTRIAL CHEMISTRY AND ELECTROCHEMISTRY)

LICENCE AWARDED TO SNEMO FOR THE ICOS SYSTEM

Snemo has signed a licence agreement with Hydro-Québec to manufacture and market the ICOS system, a combination of hardware and software designed to control the opening and closing times of circuit breakers. The "synchronous" circuit breakers in question are those used to switch shunt reactors, and the effect of the new synchronous control interface is to reduce the transient stresses inherent in the switching operations. Using ICOS, the utility no longer has to install protection devices that are costly to purchase and maintain. Following a series of successful tests on a first prototype at Duvernay substation in the Laurentides Region in 1991, a new prototype with a remote monitoring device was sent for tests to the same substation. It passed all the tests with flying colors.

According to a study of the commercial potential of ICOS, the system appears likely to interest not only electrical utilities but also circuit-breaker manufacturers because its functions meet the market requirements better than any other product commercially available at the present time. Snemo, located in the Montréal suburb of Brossard, specializes in control and protection systems used in electrical substations.

CREATION OF A COMPANY TO CARRY OUT R&D ON SHAPE-MEMORY ALLOYS

Hydro-Québec has joined forces with Imago AMF Canada and X-Per-X to set up a company, AMHIX, that will carry out shape-memory alloy research and development, and design applications for these alloys in the electrical engineering industry.

The three-year agreement provides for the sum of $4 million to be invested in the development of equipment, components, prototypes and mechanical devices in the areas of power generation, power transmission and distribution. The research work planned will focus mainly on the mechanical devices to be used for underground cable connections as well as temperature sensing equipment and torque controllers for the detection of disconnecting-switch failures. Other aspects to be explored are 25-kV circuit breakers and low-voltage electrical actuators.

Shape-memory alloys represent a promising technology in electrical engineering at the present time. It involves "smart" materials which, under the effect of a variation in temperature, execute an action programmed at the manufacturing stage. Their operating range is -200°C to 200°C. For example, they will expand when the temperature drops, change their shape at another temperature, and recover their initial shape after being heated a few degrees or produce a mechanical action at the time they are heated.

Imago AMF Canada is a subsidiary of Imago France, while the Québec firm X-Per-X is a laboratory specializing in quality assurance, fractography and nondestructive testing. Based in Montréal, the new company is financed by a technology development fund set up by the Québec government. The project is being conducted at IREQ by a team of materials technology and electrical apparatus specialists.

INTERCONTINENTAL HYDROGEN PROJECT

Hydro-Québec has an active role in the Hydro-Hydrogen project which was created to promote hydrogen technologies for energy purposes. This joint project with Europe brings together the Québec government, the Commission of European Communities and some 50 organizations on both sides of the Atlantic. In October 1993, the Commission and three Québec ministries announced investments worth about $60 million covering a three-year period, to be divided among a score of projects. Of this sum, $12 million are earmarked for investment in Québec.

The goal of this large-scale undertaking is to develop products such as buses running on a mixture of hydrogen and natural gas, fuel tanks for automobiles, storage tanks, airplane engines, and transportation technologies. These products are scheduled for demonstration in 1995 to increase public awareness of the role of hydrogen as a clean, safe fuel.

In addition to managing the R&D projects carried out in Québec, Hydro-Québec will be responsible for management of the intellectual property generated by the activities of the entire group, on a worldwide basis. The Québec utility will also handle the management of all commercial consortiums during their fledgling phase.

Licence agreement on organic electrosynthesis technology

Hydro-Québec and the firm Taysung Enterprises (Canada), a subsidiary of a Taiwanese company, have signed an agreement to exploit an organic electrosynthesis technology developed at LTEE. The new process will be used to synthesize a chemical compound of the quinone family commonly employed to manufacture dyes.

This world first gives Québec an even more competitive edge in a sector of applied chemistry now in full expansion. Anthraquinone-based dyes are used mainly in the textile industry, where they are highly appreciated for their resistance and brilliance, and Taysung is one of the world's leading manufacturers. The technology in question, cerium oxidation, has been under study at LTEE since 1989. It has distinctive competitive advantages: high selectivity rate, low capital and operating costs, process safety and no environmental pollution.

Taysung is planning to build a new plant by the year 1996, at a cost of around $30 million, and the decision has been made to locate it in Québec.

Agreement with Systèmes M3i to replan Hydro-Québec's meter-reading routes

Hydro-Québec is currently replanning its meter-reading routes in accordance with a program drawn up by its Customer Services Department. In this connection, it has signed an agreement with the company Systèmes M3i which will undertake the digitization of the provincial highway network. Hydro-Québec will therefore make available to Systèmes M3i some of the data in its customer management system so that, by the end of the contract, we will be in possession of a digitized map of the entire road network, including the addresses of all our customers.

Systèmes M3i, in which Hydro-Québec holds 43% of the capital stock, was created five years ago for the design and development of advanced technological solutions in computer applications. The company is now in full expansion.

The route replanning program will increase meter-reader productivity, reduce the number of overtime hours spent on this activity, and trim at least 60% off the cost of route replanning. It is also estimated that the product has a market potential well worth exploring.

CORS PRIZE FOR THE LORD TEAM

The team responsible for developing the LORD (Logiciel d'Optimisation des Réseaux de Distribution) long-term distribution system planning software took first prize in the annual competition organized by the Canadian Operational Research Society (CORS), which in this way recognizes the best applications in the field in Canada. Developed at the request of the Distribution Directorate, LORD is easy-to-use, microprocessor-based software designed for rapidly comparing a large number of distribution equipment planning configurations covering periods of up to 15 years. With its sophisticated database and graphical interfaces, LORD is an invaluable tool for increasing productivity and realizing substantial savings on investments in future distribution systems.

In the foreground, l. to r.: Louis Delorme, team leader; behind him, l. to r.: Jean-François Mondoux, Nicole Jacques, Claude Paradis, David Kennedy, Christiane Simard, Marie Blanchard and Guy Leblanc.

A MERITAS PRIZE FOR THE SCOMPI ROBOT TEAM

The team that developed the Scompi robot at IREQ has earned one of the Meritas prizes awarded by the local branch of the Québec Order of Engineers every year to an engineer or a group of engineers whose achievements show outstanding merit for their initiative and high-quality end product. The Scompi robot is used for in situ repairs to turbine blades damaged by cavitation.

In the foreground, l. to r.: Bruce Hazel and Antonio di Vincenzo; behind, Marie-Claude Pétrin and Jean-Luc Fihey; in the background, Serge Turcotte, Martin Beaudoin and Yvan Laroche.

R&D TEAM OF THE YEAR

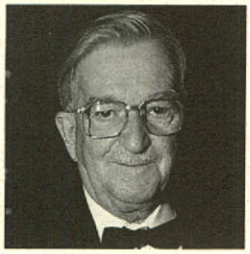
The Gyrocam team, comprising specialists in robotics, computer science and calibration, was chosen as R&D team of the year for its development of a borehole inspection system based on the use of a gyroscopic camera. Designed in conjunction with personnel in Hydro-Québec's Manicouagan Region, this new inspection system makes it possible to locate cracks in concrete, accurately assess their size and monitor their development over time.

From front to rear, on the left: Stéphane Gagnon, Jean Lavallée, Jean-Claude Besnard; in the middle, Stéphane Gendron; right: Pierre Girard, Léon Véronneau, Michel Nadeau, Louis Laroche and Régis Houde.

TEST TEAM OF THE YEAR

The team involved in work on 800-kV under-river cables was chosen as the team of the year in the area of testing. Its members, comprising representatives of the cables and insulation team and the high-voltage laboratory staff, have conducted a large-scale test program for the future installation of 735-kV AC under-river crossings.

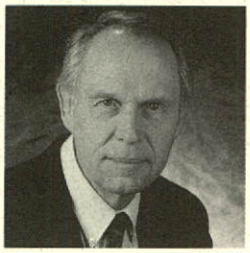
First row, from l. to r.: Alain Ricard, Mario Bélec and Jean Leduc. Second row: Normand Fleurent, Louis-Marie Daigneault, Robert Saint-Arnaud, Bruno Duguay, Gaston Guertin. Third row: Jean Choquette, Pierre Faucher, Jean-Claude Côté, Pierre Morrier, Gaston Bouffard, Mohamed Chaaban and Daniel Couderc. Not appearing on this photo: Daniel Jean and Marc Lafrenière.



Lionel Boulet wins the Armand-Frappier Prize

Lionel Boulet, founding director of Hydro-Québec's research institute, IREQ, has been awarded one of the highest distinctions in Québec, the Armand-Frappier Prize. This prize is awarded by the Québec government to acknowledge outstanding contributions to the management or promotion of research, science and technology, especially for the purpose of creating or developing research establishments.

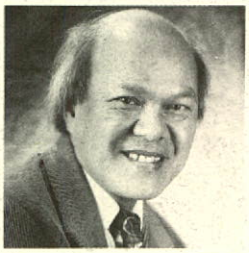
It was as Director of the Engineering Department at Université Laval that Mr. Boulet undertook an ambitious study in 1964 aimed at setting up an electricity research centre at Hydro-Québec. When the institute was finally founded in February 1967, he became its first director and remained at the helm of IREQ until 1982.



Two distinctions for Raymond Bartnikas

Raymond Bartnikas, distinguished senior scientist, has received the highest distinction awarded by IEEE Canada, the McNaughton Gold Medal. Presented at the Canadian Power and Computer Conference in the fall, this prize pays tribute to Dr. Bartnikas's outstanding contributions in the field of electrical insulation and measuring techniques.

Dr. Bartnikas was also awarded the Archambault Prize at the 61st Congress of the Association canadienne-française pour l'avancement des sciences (ACFAS) held last May in Rimouski, Québec. This prize is bestowed on researchers for their noteworthy achievements in the physical sciences, mathematics or engineering fields.

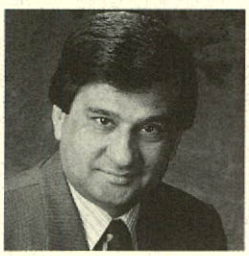


IEEE prize for Ngoc-Giao Trinh

Ngoc-Giao Trinh, a specialist in internal insulation, was awarded a prize by the IEEE (Institute of Electrical and Electronics Engineers) for his paper of the year in the area of switchgear. Entitled "Risk of burnthrough – A quantitative assessment of the capability of gas-insulated equipment to withstand internal arcs," this paper appeared in the January 1992 issue of IEEE Transactions on Power Delivery. It caught the jury's attention for the completely new statistical approach proposed.

Best paper award to Jahangir Mirza

Jahangir Mirza, a research scientist specialized in materials technology, was recognized as having submitted the best paper at the 5th International Conference on Structural Faults and Repair 93 held in Edinburgh, Scotland, last summer. The prize-winning paper in question, co-authored by Benoît Durand, a researcher from the same department, is titled "Evaluation, Selection and Installation of Surface Repair Mortars at a Dam Site."



Two awards for Ashok Kumar Vijh

Ashok Kumar Vijh, distinguished senior scientist, has been elected a founding member of the first college of the Académie francophone des ingénieurs. This academy, whose headquarters are in Paris, was set up by UNESCO to act as consultants and carry out on its behalf prospective studies designed to promote the smooth expansion of technology in French-speaking countries.

In addition, he has been made a Doctor of Science (*honoris causa*) by the Faculty of Engineering, Waterloo University in Ontario.

ORGANIZATION CHART

Technology and IREQ
(Institut de recherche d'Hydro-Québec)
Louis Masson

Centre d'innovation en transport d'énergie du Québec (CITEQ)
Centre canadien de fusion magnétique (CCFM)

Equipment Technology and Testing
Clément Ouellet

Cables and Insulation
Electrical Apparatus
High-Power Laboratory
High-Voltage Laboratory
Overhead Lines

Generation Technology and Materials
Camille Gaudreault

Materials Chemistry
Materials Technology
Mechanical Engineering
Project Management – Fusion

Power System Technology
Marc Hung

Measurement Systems
Power System Software and Algorithms
Power System Simulation
Robotics, Data Processing and Calibration

Application Technology and LTEE
(Electrochemical and Electrical Technologies)
Louis-F. Monier

Industrial Chemistry and Electrochemistry
Industrial Electrotechnologies
Industrial Plasmas

Technology Planning and Promotion
Michel De Broux

Hydrogen Project
Project Management – ACEP
Project Management – Motors
Technology Planning
Technology Promotion

Resources and Services
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MAY 1994

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Legal deposit – 2nd quarter 1994
Bibliothèque nationale du Québec
National Library of Canada
ISSN 1188-8059
ISBN 2-550-29407-6

Ce rapport est également publié en français.