Hydro-Québec–TransÉnergie's Lévis Substation De-Icing Project

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***Abstract* — In January 1998, Hydro-Québec's network was subjected to an ice storm of exceptional scope and magnitude. During the storm, the transmission system was severely damaged, thus exposing the network's vulnerability to severe climatic events of this type. In an effort to improve the supply of electricity to its customers, Hydro-Québec decided from then on to supply each 735-kV station with at least one 735-kV line that is secure with respect to ice accretion.**

This paper first presents the 735-kV lines on Hydro-Québec's transmission system that are considered to be strategic and shows how direct current can be used to make transmission lines secure and what the technology's advantages are. Lastly, the paper presents the system reinforcement program currently in use on the bulk transmission system for dealing with ice storms.

The second part of the paper presents in greater detail the project involving the implementation of additional de-icing equipment at Lévis substation, which is currently approved and scheduled to be put into operation in 2006. This section presents the lengths of lines to be de-iced from Lévis substation and the mechanical reinforcement that will be done on these lines.

I. INTRODUCTION

This paper only pertains to projects related to the 735-kV transmission system. Other de-icing and reinforcement projects will be carried out on the secondary transmission system and distribution system to ensure a secure supply of electricity over the entire network.

II. PROBLEM AREA

Historically, the province of Quebec was developed through waterways such that the electricity consumption centres in Quebec are largely found along the St. Lawrence River. To supply electricity to these centres, Hydro-Québec mainly counts on two major hydroelectric generating sites located more than 1000 km away and relatively far from each other. The main transmission system, as shown on Figure 1, is thus made up of two transmission corridors, one running north-west and the other north-east. Note that the northeastern corridor is found almost entirely in an area prone to ice accretion.

Hydro-Québec's transmission system has always been exposed to ice accretion resulting from atmospheric icing or freezing rain. In fact, since 1966, ice has been causing recurring problems on the Manic-Churchill 735-kV lines. More specifically, in 1969, major damage led to the destruction of 30 transmission towers in the Charlevoix area, while another storm led to the collapse of 32 towers near Rivière-Pentecôtes in 1973. Following these climatic events, major sections of line on the Churchill network, which was being built at the time, were modified in keeping with a higher design criterion.

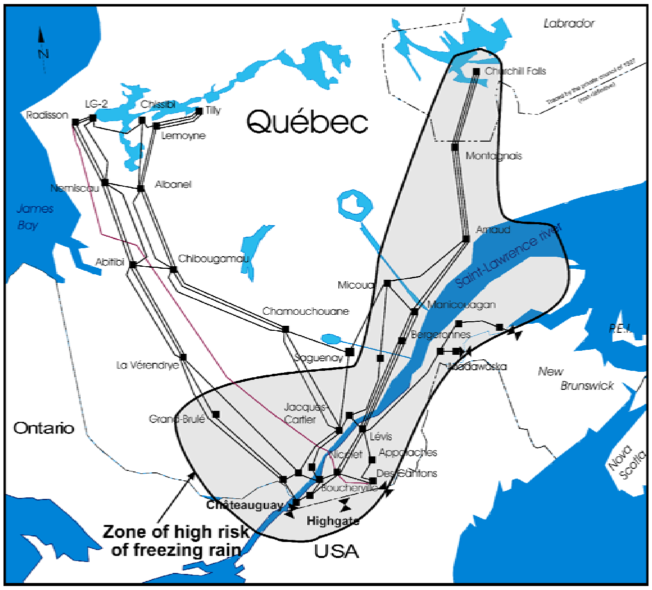

Fig. 1 – 735-kV transmission system located in areas at high risk of freezing rain

With the development of the James Bay network in the mid 1970s, detailed climatological studies, combined with optimized line costs, resulted in a substantial increase in the lines' capacity to withstand icing loads. This capacity was increased in the St. Lawrence Valley, from an equivalent radial ice capacity of 35 mm to 45 mm. New practices were also implemented, such as the use of anti-cascading towers, siting lines in areas less prone to ice conditions, and limiting the number of lines per corridor.

A. January 1998 ice storm

The January 1998 ice storm exposed the network's vulnerability to stationary weather systems. For five days from January 5 to 9, 1998, three consecutive freezing-rain events subjected Quebec's entire south-western network to exceptional climatic conditions never-before experienced in this area, leaving an equivalent radial ice accumulation of 75 mm in some places. The storm was also exceptional in terms of the size of the service area affected.

The storm damaged about 900 km of transmission lines to a greater or lesser extent over the 3200 km of lines subjected to inclement weather. The extent of the damage was so considerable that in many cases some line sections had to be completely rebuilt, which led to delays in restoring service of several weeks. In fact, the ice storm caused the collapse of 150 735-kV structures, for a total of 10 damaged lines. The dimensions of the 735-kV structures and the emergency supply of the components of this type of line do not allow a fast restoration of service to be envisaged for a highly damaged line.

At the height of the ice storm, three of the five 735-kV substations that formed the Montreal loop were down, just like five of the seven 735-kV lines that supply the loop. The security of the supply had been exposed to an extreme level of risk on January 9 when the supply of electricity to the Montreal area was reduced to a single high-voltage line. Temporary outages to the water supply system and the resulting impacts on the drinking water supply and firefighting services showed the essential nature of these services that are highly dependent on electricity. There is also the importance of transportation, telecommunications, heating, lighting and access to high-rise buildings for a large city.

B. Observations for the 735-kV network

It was noted that the continuity of the supply of the load is highly dependent on the 735-kV network, and that the latter is affected by the remoteness of the generating sites, the hostile environment crossed by the lines, and the lead times involved in repairing the damaged structures.

C. Strategy

The strategy retained for the 735-kV network consists in ensuring that a minimal network backbone is maintained during severe and large-scale climatic events. Hence, each 735-kV substation must be supplied by at least one 735-kV line that is more robust and considered to be strategic. In short, this type of line must be capable of withstanding greater mechanical loads and, in the event of damage, the latter must be minor to ensure that service is restored more quickly.

III. CREATING A STRATEGIC LINE

The mechanical reinforcement of a line is not without limits, such that the line may have to be completely rebuilt to achieve the desired level of robustness. This is where de-icing techniques may prove to be a competitive solution by limiting the weight of the ice on the conductors, which allows the other line components to handle a greater load.

A. Review of potential solutions

In the fall of 1998, a task force made up of a group of engineers specialized in power system studies and substation equipment reviewed the methods designed to increase the capacity of transmission lines to withstand ice storms of the magnitude of the one experienced in January 1998. In all, 25 methods were studied and ranked: 16 “network” methods, applicable to the entire line route, and 9 “span-based” methods, which are applicable to only one or a few spans at a time.

The following criteria, presented in decreasing order of importance, were used to rank the methods:

- Implementation cost;
- Design reliability;
- Risk related to research and development;
- Lead times for initial implementation;
- Complexity of use;
- Impact on customers;
- Maintenance costs;
- Research and development costs.

The task force’s findings revealed that only two methods can be applied over the short term for the 735-kV network: mechanical line reinforcement and de-icing using direct current. The conversion of an existing line into a strategic one will thus require the use of these two methods.

B. Advantages of direct current

The series impedance of a given line is represented by:

$$Z = R + jX$$

When direct current is involved, the value of X is nil, while the value of X is about 29 times greater than the value of R in the case of a 735-kV line operated at 60 Hz. Hence, the network must provide 29 times more reactive power than the active power that would be required for de-icing purposes. In addition, since 735-kV lines have bundles of four large-size conductors and that de-icing currents are high, it would be virtually impossible for the network to supply reactive power, which justifies the use of a direct-current solution.

Figure 2 schematically represents how de-icing is achieved using direct current.

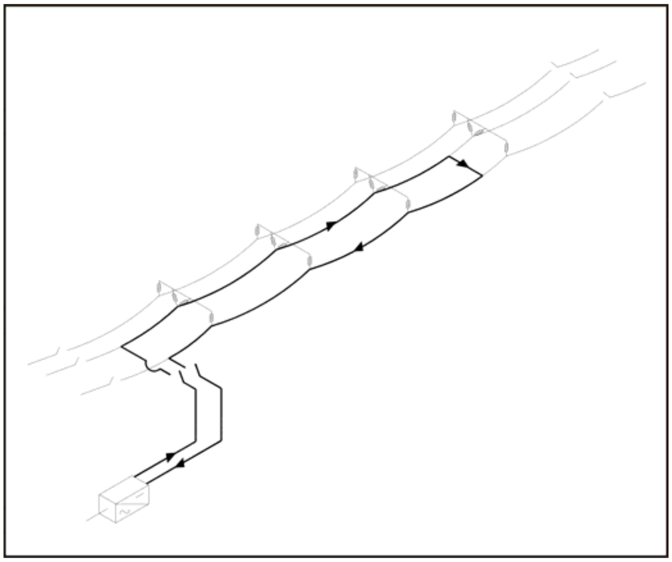

Fig. 2 – Schematic diagram of direct-current de-icing

Direct current can thus be used to de-ice lines over long distances by minimizing power requirements. In addition, the technology has the possibility of controlling the de-icing power, which is more complex when dealing with alternating current.

IV. SECURING THE BULK TRANSMISSION SYSTEM

Following the January 1998 ice storm, Hydro-Quebec used digital simulations to determine the minimum network backbone needed to ensure the supply of a minimum load to guarantee electricity for essential services. The 735-kV lines represented by solid lines on Figure 3 are the strategic lines that require greater robustness to ensure a minimum network backbone.

On the basis of this backbone, Hydro-Québec conducted a cost-benefit study to determine the optimal solution, which led to the selection of a reinforcement program consisting of four projects. Carrying out these projects allows 90% of the reinforcement objective to be attained and only represents 40% of the cost of a solution aimed at securing all of the strategic lines.

Figure 3 shows the four projects that were retained as part of the bulk transmission system reinforcement program. The projects are listed below in order of how well they meet the reinforcement objective:

- The first project consists in installing a direct-current converter at Lévis substation designed to alternately de-ice four 735-kV lines, one of which is 242 km long, and a 315-kV line, with two circuits, each 183 km long. In addition, the lines to be de-iced are mechanically reinforced.
- The second project involves installing a direct-current converter at Boucherville substation that allows three 735-kV lines to be de-iced, with the longest one extending over 52 km. Once again, the lines to be de-iced are mechanically reinforced.
- The third project aims at reinforcing only a portion of the Duvernay–La Vérendrye line by replacing the phase conductors and reinforcing the structures.
- The fourth project consists in mechanically reinforcing the section between the Bergeronnes and Manicouagan substations, which is the other line section that will be de-iced using direct current from Lévis substation. This project also involves mechanically reinforcing the tie line between Manicouagan and Micoua substations.

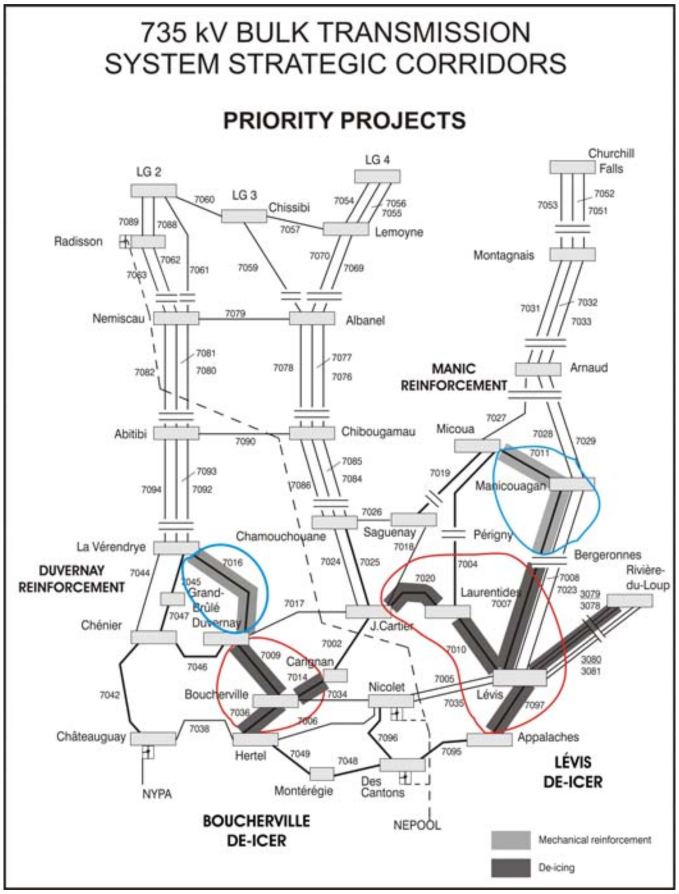

Fig. 3 – 735-kV bulk transmission system reinforcement program

V. LÉVIS SUBSTATION PROJECT

The 735-kV transmission lines in the Quebec City area were built early on in the 735-kV network. These lines are able to withstand icing loads corresponding to an equivalent weight of 30 to 35 mm of ice distributed evenly on line components. To make these lines strategic, it became necessary to increase their capacity to about 50 mm. However, structural studies showed that the scope of the work required to meet this objective, essentially consisting of mechanical reinforcement, was so substantial that it was preferable to rebuild several lines. De-icing the line conductors thus reduces the load on the structures, which allows, through the use of reasonable reinforcement, to withstand 50 mm of ice on the line components that have not been de-iced.

A. *Solution retained*

The solution that was retained consists in installing a direct-current converter at Lévis substation capable of producing a 7200-A current. The flow of the current through the conductors of a 735-kV line produces sufficient heat to melt and dislodge the ice on the conductors. Each of the lines connected to Lévis substation and shown by the thick line in Figure 4 can thus be de-iced in sequence.

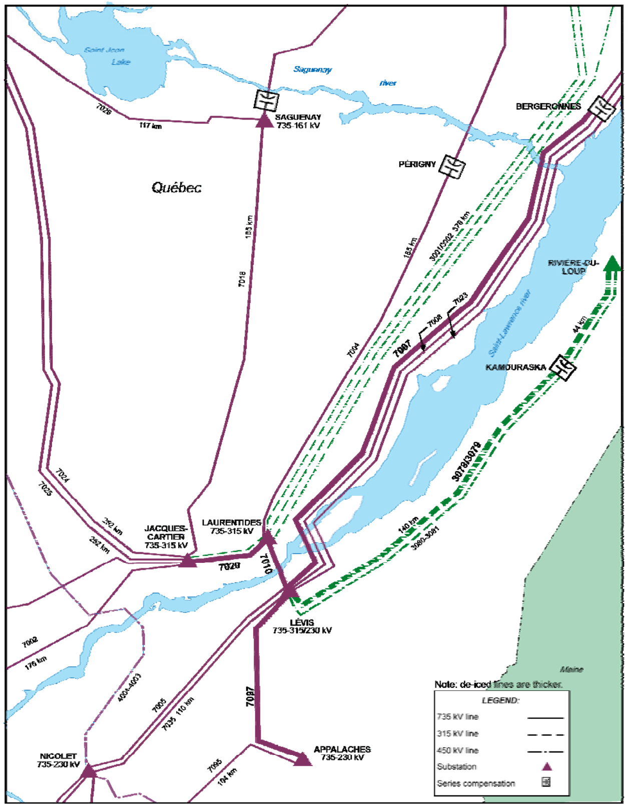

Fig. 4 – Sequential de-icing of lines at Lévis substation

Table 1 shows the length of the lines that can be de-iced. Note that line 7020 will be de-iced at the same time as line 7010, which will be done by bypassing the line at Laurentides substation during de-icing.

TABLE I
LINES DE-ICED FROM LÉVIS SUBSTATION

	Voltage (kV)	Circuit no.	Length (km)
Appalaches - Lévis	735	7097	78
Jacques-Cartier - Laurentides	735	7020	34
Laurentides - Lévis	735	7010	27
Lévis - Bergeronnes	735	7007	242
Lévis - Rivière-du-Loup	315	3078-3079	183-183

B. Line work

Despite the de-icing of the conductors, some work has to be done on the lines, in particular to ensure that the line can withstand the unbalanced loads that occur during ice shedding. Other work is done to meet other objectives, such as to increase the robustness of the line, protect the telecommunications system, limit the impacts of any damage, and add the measuring equipment needed for the de-icing operations.

1) Increased robustness

To meet the desired level of robustness, 11.1-mm steel overhead ground wire will be replaced with wire 16.2 mm in diameter made of better quality steel. The ground-wire peak will be mechanically reinforced by adding steel flanges.

Some line sections considered to be vulnerable will be reinforced. The reinforcement work will mainly involve adding new steel flanges to reinforce flanges that are not rigid enough.

2) Protection of telecommunications system

Three of the five lines that will be de-iced will be equipped with overhead ground wire with a core made up of fiber-optic cable for telecommunications needs. Considering the importance of communications, the Lévis substation direct-current converter will be used to de-ice the overhead ground wires. The project thus involves placing electrical insulators between the cable and the tower structure to allow the de-icing current to be injected.

3) Limiting the scope of the damage

The project will include additional protection to limit the scope of the damage in the event that the towers' mechanical design capacity is exceeded. When required, new terminal structures will be added to the line to limit the number of towers involved in a collapse to about 15.

4) Acquisition of information for de-icing operations

The project includes adding new weather stations to the existing network. In addition, in some locations devices will be added that measure the weight of the ice-covered conductors. The data obtained using the measurement stations will be transmitted through a standalone telecommunications network made up of repeaters installed at the top of the towers.

C. Work at the substations

Work at the substations consists of adding a converter at Lévis substation and the busbars required to route the direct current to the different lines to be de-iced.

1) Work at Lévis substation

A 250-MW direct-current converter will be installed at Lévis substation. The converter will be capable of supplying a 7200-A current at a voltage level of +/-22 kV. The converter's power rating was determined based on its capacity to de-ice a 242-km-long 735-kV line consisting of 1354-MCM quad bundles and while taking into account the line's other two phases being placed in parallel for the current return. Based on estimates, this current level would be sufficient to melt 12 mm of ice in 30 minutes at -10°C and wind speeds of 11 km/h. In the absence of any ice or wind, the conductor temperature should be about 95°C, which is the maximum operating temperature.

To ensure the proper operation of the converter for de-icing purposes, it became necessary to find an additional function for the equipment so that it could operate continuously. The converter will thus be operated as a static compensator and when required for de-icing, it will be converted into a DC converter. The conversion time specified for design purposes is one hour.

As shown in the single-line diagram in Figure 5, the converter will be supplied directly from the 315-kV busbars. The 7200-A direct current will be transported to the lines to be de-iced through a double-pole overhead busbar installed in the substation. The direct-current busbar will be connected to the lines through disconnectors isolated at the line's voltage and installed on the line side in the substation. As these disconnectors can be operated during an ice storm, a specific operating capacity under ice conditions is required. Note that the line disconnectors will not be operated and the lines will be de-energized by opening the circuit breakers. The circuit breaker protective relays will thus be modified to prevent the circuit breaker from closing automatically.

There will be also a connection between the direct-current busbar and the optical ground wire to allow for de-icing.

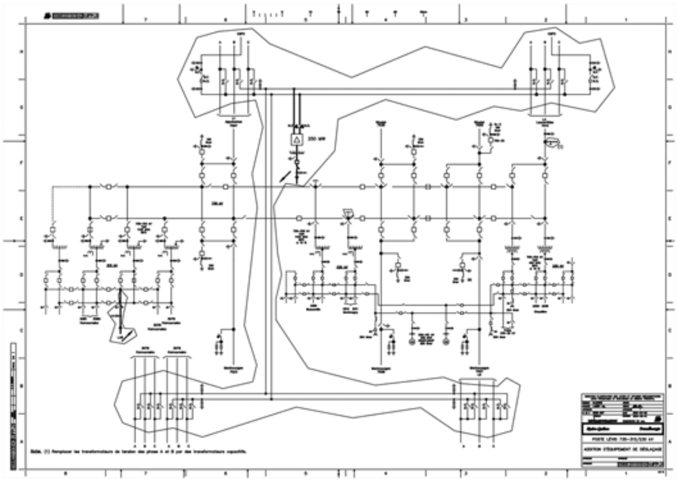

Fig. 5 – Single-line diagram of Lévis substation

2) *Work at the terminal substations*

In most cases, the work at the terminal substations consisted of installing a direct-current busbar and disconnectors in order to connect the line's phase conductors to be de-iced and thus close the circuit toward the de-icer. The work also included modifying the protective relays in order to prevent the line circuits breakers from closing automatically.

D. Operation

Three different types of de-icing arrangements will be used. The longest 735-kV line will be de-iced one phase at a time, with the other two phases being operated in parallel in order to minimize the converter's power use. The other 735-kV lines will be de-iced two phases at a time so that the line will be de-iced in two steps. For the 315-kV double-circuit line that is 183 km long, the two circuits will be de-iced simultaneously in a single step since this line has only two small bundled conductors. Each de-icing step takes about an hour to complete.

Given that transmission lines require different operating sequences and that this type of equipment will be very seldom used, it was preferable to automate the de-icer operating and control sequences. Thus, an operator at the Québec control centre (or Lévis substation control room) will be in charge of de-icer control; the operator will be responsible for starting up the automatic procedure, identifying the line to be de-iced, and in constantly authorizing subsequent automatic operations.

E. Operating procedure

The startup of the de-icing process will be based on a decision of a team of specialists who study weather conditions and forecasting. The analysis will incorporate weather conditions near the line as well as the weight of the ice actually measured on the line to be de-iced.

VI. CONCLUSION

Given the cost of increasing the mechanical strength of existing lines and the advantage of concentrating strategic lines connected to Lévis substation, the use of direct-current de-icing is a cost-effective solution. Using the de-icer as a static compensator during normal operation will increase the network's capacity and flexibility. Mechanically reinforcing the de-iced lines will provide a robustness that will benefit the network's strategic backbone. The telecommunications network by Optical Ground Wire will thus also be protected since the overhead ground wire will be de-iced.

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